SAFIR2010 Annual Report 2010

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Summary

SAFIR2010 research programme was strongly based on chapter 7a, "Ensuring expertise", of the Finnish Nuclear Energy Act. The steering group of SAFIR2010 consisted of representatives from Radiation and Nuclear Safety Authority (STUK), Ministry of Employment and the Economy (MEE), Technical Research Centre of Finland (VTT), Teollisuuden Voima Oyj (TVO), Fortum Power and Heat Oy, Fortum Nuclear Services Oy (Fortum), Finnish Funding Agency for Technology and Innovation (Tekes), Helsinki University of Technology (TKK) and Lappeenranta University of Technology (LUT). In addition to representatives of these organisations, the Steering Group has permanent experts from the Swedish Radiation Safety Authority (SSM) and Fennovoima Oy (Fennovoima).

The realised volume of the SAFIR2010-programme was 7.2 M€ and 51.5 person years in 2010. Main funding organisations in 2010 were State Waste Management Fund VYR with 2.947 M€, and VTT with 2.776 M€. The programme was divided into eight research areas and in 2010 research was carried out in 33 projects.

In the following, a short summary on the results of individual projects (Chapter 2) and overall financial (Chapter 3) and administrative (Chapter 4) matters is given. Detailed information on project content and results is given in the Appendixes.

This report has been prepared by the programme leader in cooperation with project co-ordinator, the project leaders and staff.

Confidentiality	Public

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1 Introduction

The Finnish Ministry of Trade and Industry (KTM), currently Ministry of Employment and the Economy (MEE), launched in 2007 a new national four-year research programme on nuclear power plant safety from 2007 to 2010, SAFIR2010. The research programme is strongly based on the chapter 7a, “Ensuring expertise”, of the Finnish Nuclear Energy Act. The research needs and challenges, as well as the organisation of the programme have been presented in the Framework Plan of SAFIR2010 [1]. The programme is a link in the chain of public research programmes on nuclear safety that have proved to excel in order to maintain and develop know-how. The programme covered essentially the themes of the preceding SAFIR-programme [2,3].

In addition to the State Nuclear Waste Management Fund (VYR), also other key organisations operating in the area of nuclear safety were funding the programme. The ‘VYR-funding’ is collected from the Finnish utilities Fortum Power& Heat Oy and Teollisuuden Voima Oyj with respect of their MWth shares in Finnish nuclear power plants according to their operating or, in case of Olkiluoto 3, construction license power ratings.

The planned [4] and realised volumes of the SAFIR2010-programme in 2010 were 7.2 M€ and 7.2 M€ and 47.5 and 51.5 person years, respectively, representing a stable situation compared to the year 2009 [5]. The programme has been divided into eight research areas and in 2010 research was carried out in 33 projects. Final seminar of SAFIR2010 was arranged in March 2011 with some 200 participants, approximately 10 % of them from abroad [6].

Know-how developed in publicly funded research programmes can be applied in licensing processes. Simultaneously, challenges in the sufficiency of expert resources for different kinds of tasks are to be met. The construction of the new plant unit has increased international interest in nuclear safety work and research done in this area in Finland. The construction has also increased the attractiveness of the field as an employer, which is visible as well in the growing number of students of the field as in the number of applicants in recruiting.

Research on nuclear safety requires profound training and commitment. The research programme serves as an important environment providing long-term activity that is especially important now, when also the research community is facing a change of generation: A new generation of researchers has to be recruited and engaged. The international evaluation of the preceding SAFIR research programme stated that the high quality of results is partly due to long-term commitment in research by Technical Research Centre in Finland (VTT) and Lappeenranta University of Technology (LUT). Maintaining this kind of activity in different organisations in the hectic, modern world is a demanding challenge.

Globalisation and networking highlight the importance of national safety research. This also creates pressure to unify nuclear safety requirements and oversight procedures. Currently there are many projects related to national rules and international safety requirements and safety guides.

The steering group of SAFIR2010 consisted in 2010 of representatives from Radiation and Nuclear Safety Authority (STUK), Ministry of Employment and the Economy (MEE), Technical Research Centre of Finland (VTT), Teollisuuden Voima Oyj (TVO), Fortum Power and Heat Oy, Fortum Nuclear Services Oy (Fortum), Finnish Funding Agency for Technology and Innovation (Tekes), Helsinki University of Technology/Aalto University (TKK/Aalto) and Lappeenranta University of Technology (LUT). In addition to representatives of these organisations, the Steering Group had permanent experts from the Swedish Radiation Safety Authority (SSM) and Fennovoima Oy (Fennovoima).

Figure 1.1. All Finnish 'key player' organisations and Swedish SSM are represented in the SAFIR2010 Steering group.

In the following, a short summary on the results of the individual projects (Chapter 2) and overall financial (Chapter 3) and administrative (Chapter 4) matters is given. Detailed project progress reports are given in Appendix 1, publication lists in Appendix 2, information on international co-operation in Appendix 3, list of Academic degrees obtained in Appendix 4, list of international travels in the projects in Appendix 5 and Appendix 6 contains list of the persons involved in the programme in Steering Group, Reference Groups, Ad hoc Groups and in the Projects.

2 Main results of the research projects in 2010

SAFIR2010 was the Finnish National Research Programme on Reactor Safety for the period 2007 – 2010. SAFIR2010 research programme was strongly based on the chapter 7a, “Ensuring expertise”, of the Finnish Nuclear Energy Act. The objective was “to ensure that, should such new factors concerning safe operation of nuclear facilities emerge that could not be foreseen, the authorities have such sufficient and comprehensive nuclear engineering expertise and other facilities at their disposal that can be used, when necessary, to analyse without delay the significance of such factors.” High scientific quality was required from the research projects in the programme and their results have been distributed to the organisations involved in the Steering Group. As a condition in the programme was that the usability of the results must not be restricted to power plants of only one licence holder.

SAFIR2010 research programme was divided in eight research areas, which are:

1. Organisation and human factors
2. Automation and control room
3. Fuel and reactor physics
4. Thermal hydraulics
5. Severe accidents
6. Structural safety of reactor circuit
7. Construction safety
8. Probabilistic safety analysis (PSA)

These research areas include both research projects of the named topic and interdisciplinary co-operation projects.

The research areas with their challenges and research needs for the period 2007-2010 have been described in detail in the Framework Plan [1]. In 2010 there were altogether 33 research projects going on. The total volume of the programme for 2010 was 7.2 M€ and 51.5 person years. The research projects in the various areas with their planned and realised volumes are given in Table 2.1.

Table 2.1. SAFIR2010 projects in 2010.

Research area	Project	Acronym	Organisation(s)	Funding k€ (plan)	Funding k€ (realised)	Volume person months (plan)	Volume person months (realised)
1.							
	Safety management and organisatorial learning	MANOR	VTT	213,3	213,5	13	13
	Expert work in safety critical environment	SAFEX	HUT, TLL	153,5	146,3	13,0	13,9
2.							
	Model-based safety evaluation of automation systems	MODSAFE	VTT, HUT	178	178	15,5	16,4
	Certification facilities for software	CERFAS	VTT, TUT	106,3	106,3	9,8	9,6
	Operator practices and human-system interfaces in computer-based control stations	OPRACTICE	VTT	217,3	219,3	15,5	15,5
	Requirements engineering in nuclear power plant automation	VAHAYA	HUT	73,2	74	5,5	5
3.							
	Development and validation of fuel performance codes	POKEVA	VTT	331,6	340,5	26	29,4
	Tridimensional core transient analysis methods	TRICOT	VTT	319,2	374,4	25,2	27,3
	Total reactor physics analysis system	TOPAS	VTT	303,3	303,4	24,3	23,3
4.							
	Numerical modelling of condensation pool	NUMPOOL	VTT	101,9	101,9	6,8	6,7
	Improved thermal hydraulic analyses of nuclear reactor and containment	THARE	VTT	321,9	322,3	18,5	22,1
	CFD modelling of NPP steam generators	SGEN	VTT	121,2	121,4	8,7	9,7
	Improvement of PACTEL facility simulation	PACSIM	LUT	83	91,3	10,1	10,4
	Condensation experiments with PPOOLEX facility	CONDEX	LUT	268,7	324,7	20	30,5
	Passive safety system simulation	PASSIMU	LUT	43,3	42,9	4,1	4,1
	Open FOAM CFD-solver for nuclear safety related flow simulations	NUFOAM	Fortum	84,5	83,7	7,6	7,1
5.							
	Release of radioactive materials from a degrading core	RADECO	VTT	115,9	99,7	9	7,9
	Primary circuit chemistry of fission	CHEMPC	VTT	281	306,8	17,5	17,5

	products						
	Core melt stabilization	COMESTA	VTT	194,5	194,6	11,6	13,4
	Hydrogen combustion risk and core debris coolability	HYBCIS2	VTT	175,3	181,9	11	12,1
6.							
	Risk-Informed Inspections of Piping	PURISTA	VTT	178,6	158,4	11,3	10,3
	Fatigue endurance of critical equipment	FATE	VTT	233,4	203,4	13,3	16,8
	Water chemistry and oxidation in the primary circuit	WATCHEM	VTT	141,2	146,3	8,5	8,5
	Monitoring of the structural integrity of reactor circuit	RAKEMON	VTT	228,2	226,6	16	16
	Fracture assessment of reactor circuit	FRAS	VTT	392,1	392,3	28,8	28,8
	Influence of material, environment and strain rate on environmentally assisted cracking of austenitic nuclear materials	DEFSPEED	VTT	413,7	417,7	26	33,1
	Renewal of active materials research infrastructure	AKTUS	VTT	104	104,3	6,5	6,5
7.							
	Service life management system of concrete structures in nuclear power plants	SERVICEM AN	VTT	215,3	215,3	14,3	14,3
	IMPACT2010	IMPACT	VTT, partners	570	470,5	36,8	36,8
	Structures under soft impact	SUSI	VTT	184,1	184,2	12	13,7
8.							
	Challenges in risk-informed safety management	CHARISMA	VTT	281,6	279,5	21,5	21,5
	Implementation of quantitative fire risk assessment in PSA	FIRAS	VTT	205	205	9,3	11,6
	Extreme weather and nuclear power plants	EXWE	FMI	96,2	162,5	12	17,9
0.							
	Programme administration and information	SAHA2010	VTT	236,7*	248,2	10*	10
	Total			**7241,301**	**7165,000**	**499**	**540,7**

*for period 1.4.2010–31.3.2011 with VAT 22% included

2.1 Organisation and human factors research area

There were two projects in this research area in 2010: Safety management and organizational learning (MANOR) and Expert Work in Safety Critical Environment (SAFEX).

2.1.1 Safety management and organizational learning (MANOR)

The main objective of the research project is to study the facilitators and hindrances to organizational learning and development of safety culture in the nuclear power industry. The aim is to help the power companies and the regulator to create safety management practices that support the evaluation and management of the working practices and organizational performance based on a sound safety culture. The project contributes to the utilisation of operating experience, development of working practices and safety culture, development of job motivation and awareness of risks among the contractors as well as plants' own personnel, and identification of risky habits and conceptions in the organizations.

Specific goals in 2010

The goals of 2010 work focused on clarifying and publishing a framework which helps the stakeholders to work with the concepts of safety culture, safety management and organizational culture. The case study results gained between 2007-2010 were integrated with state-of-the-art on safety science and recommendations for utilising the integrated safety culture model in developing safety management practices and supporting organisational learning were given.

Figure 1. The DISC-model depicts the six safety culture criteria (in the middle) and the organisational functions which are necessary to in any safety critical organisation to fulfil the criteria.

Deliverables in 2010

- A two day seminar was arranged for the power companies and the regulator on safety culture with together with STUK. The seminar attracted around 80 participants.

- The DISC-model (Design for Integrated Safety Culture) and methods associated to it were finalised. DISC is a model that can be used as a basis for safety culture assessment and development work as well as for organisational learning e.g. when analysing operating experience

- The recommendations of the operating experience study have been put to use e.g. by starting the planning of training on event analysis training courses to Finland.
- Report on the history and present of the Nordic nuclear safety culture has been supplemented with results of 2010 work which tackle the role of subcontractors in the nuclear industry. The report is published at the NKS series.
- A final report on Manor project was written and is published in VTT publication series.
- The safety culture model has been presented to IAEA safety culture experts and Manor results are taken into consideration in IAEA's forthcoming safety culture work.
- Two scientific papers have been submitted to international journals and one has been published. In addition to that one paper was published in ALARA magazine.

2.1.2 Expert Work in Safety Critical Environment (SafeExpertNet)

The SafeExpertNet project focuses on studying the nuclear experts' work, work processes and how the organisation can support maintenance and development of expertise.

The SafeExpertNet research project aims at:

1. Providing new scientific knowledge and understanding about expert work in nuclear power plants and nuclear power sector, work processes of the experts in nuclear power plants, and knowledge and competences of the experts in nuclear power plants. The aim is also in defining and developing practices for preserving and developing expertise in nuclear power plants. These include HR-practices such as recruiting, competence development and employee turnover.

2. Providing new knowledge on nuclear power expertise community, and the roles of its different parties (including nuclear power plants, regulators, research and educational organisations, and authorities). Describing expertise in nuclear power network. Defining and developing sharing of knowledge and expertise, and utilization of them in the entire nuclear power community.

The results of the project can be immediately used in nuclear power community. The knowledge on nuclear experts' work, work processes and competences enables organisations and experts themselves to better understand the work environment and respond to changes in it. The improved knowledge on HR practices further contributes to continuous improvement and a more holistic view on nuclear experts' work, knowledge and career. The modelling of the nuclear power community, its actors and their expertise builds a strong basis for collaboration, utilization of expertise and development of knowledge needed in the future.

Specific goals in 2010

The SafeExpertNet project is a four year research and development program whose tasks and subtasks during different years are closely related to each other. The research plan for 2010 continues and deepens the work carried out in previous years.

The first main project was to carry out follow-up survey on *"Expert Work in Safety Critical Environment"*. The goal was to follow the development of organisation of work and well-being, motivation and competence development of the experts. Also quantitative data about motives, content, and opportunities of collaboration and knowledge sharing in the national nuclear power expertise community was provided. Another goal was to develop a tool for safety critical organisations to evaluate their actions which are reflecting safety culture in the organisation and the needs of the collaboration.

The second main task focuses on publishing the results of the study widely in the national field as well as in the academic field. The goal is to provide new practical and scientific knowledge for the nuclear power sector.

Deliverables in 2010

Reports:

1. Avaimia asiantuntijuuteen - opaskirja ydinvoima-alan organisaatioissa työskenteleville asiantuntijoille ja heidän esimiehilleen. (The good practice handbook on ways to support development of expertise.) Työterveyslaitos and Aalto-yliopisto 2010.
2. Kuronen-Mattila T. (2010): Tacit knowledge in nuclear power plants: The content, characteristics, and prerequisites for sharing. Licenciate's Thesis. Espoo: Aalto University.
3. Pahkin K., Kuronen-Mattila T., Mäki E., Leppänen A, ja Järvenpää E. (2011): Asiantuntijatyö turvallisuuskriittisessä ympäristössä SafeExpertnet 2007-2010. Työympäristötutkimuksen raporttisarja 57, Työterveyslaitos, Helsinki 2011. (myös PDF)
4. Työ ja Ihminen:
   - Leppänen A. Pahkin K, et al.: Asiantuntemus ja sen kehittyminen ydinvoimaympäristössä. (korjattavana)
   - Mäki E., Kuronen-Mattila T. & Järvenpää E.: Asiantuntijaverkostot: tutkimus Suomen ydinvoima-alalta. (korjattavana)
   - Pahkin K, Leppänen A, ja Järvenpää E.: Osaamisen kehittämisen käytännöt ja haasteet ydinvoima-alan asiantuntijaorganisaatiossa. (hyväksytty)
5. Kuronen-Mattila T., Mäki E. & Järvenpää E. (2011): Collaboration between experts –- Case Finnish Nuclear Power Industry. To be submitted to International Journal of Nuclear Knowledge Management at the end of January 2011.

Dissemination of the results (International conference presentation)*:*

1. Pahkin K, et al: "*Supporting expertise in nuclear organizations.* Presentation in the IAEA International Conference on Human Resource Development for Introducing and Expanding Nuclear Power Programmes 14-18 March 2010, Abu Dhabi, UAE
2. Pahkin K et al: "*Development of a survey for expert work in safety critical environment* ". Presentation at the European Academy of Occupational Health Psychology (EA-OHP) 29-31 March 2010, Rome, Italy
3. Kuronen-Mattila, T. (2010): *Tacit knowledge in nuclear power plants: content, characteristics and sharing*. International conference on Intellectual Capital, Knowledge Management & Organizational Learning, 11-12 November, Hong Kong.
4. Mäki, E., Kuronen-Mattila, T., Pahkin, K., Järvenpää, E., and Leppänen, A.: *Project summary reports* (a report on the SafeExpertNet project). Lähetetty SAFIR2010 -loppuseminaariin.
5. Pahkin, K., Leppänen, A., Mäki, E., Kuronen-Mattila, T. and Järvenpää, E.: *Supervisor's role in knowledge management and expertise development*. Lähetetty SAFIR2010 -loppuseminaariin.
6. Pahkin, K., Leppänen, A., Kuronen-Mattila, T, Mäki, E., Järvenpää, E.: *The practices and challenges of developing knowledge in nuclear industry organizations*. Abstrakti lähetetty NESTet 2011 education and training NUCLEAR ENGINEERING SCIENCE AND TECHNOLOGY Prague, Czech Republic 15 -18 May 2011 kongressiin.
7. Mäki, E., Kuronen-Mattila, T., Pahkin, K., Järvenpää, E., Leppänen, A. *Expertise development in the nuclear power industry – beyond formal training and education.*

Abstrakti lähetetty NESTet 2011 education and training NUCLEAR ENGINEERING SCIENCE AND TECHNOLOGY Prague, Czech Republic 15 -18 May 2011 kongressiin.

Others:

1. Five organizational level reports based on the results of the questionnaire survey (+18 department level results)
2. Mäki E. Hiljaa hyvä tulee, hiljaisella tiedolla vielä parempi. HETKY 5/2010.
3. Pahkin K, Kuronen-Mattila T ja Mäki E. Avoimuus auttaa toimimaan turvallisemmin. ALARA 4/2010.
4. Mäki E., Kuronen-Mattila T. & Pahkin K.: Tieto kasvaa jakamalla. ATS Ydintekniikka 2010.

International co-operation:

1. Tanja Kuronen-Mattila has participated to the IAEA Meeting of Technical Working Group on Managing Human Resources in the Field of Nuclear Energy (TWG-MHR), held in Vienna on 15-17.6.2010.
2. Krista Pahkin has participated to the IAEA Technical Meeting on the Considerations of Human Factors in New NPP Projects held in Vienna on 9-12.11.2010.

2.2 Automation and control room research area

There were four projects in this research area in 2010: Model-based safety evaluation of automation systems (MODSAFE), Certification facilities for software (CERFAS), Operator practices and human-system interfaces in computer-based control stations (O'PRACTICE) and Requirements engineering in nuclear power plant automation (VAHAYA).

2.2.1 Model-based safety evaluation of automation systems (MODSAFE)

Modern digitalized I&C systems are employed in critical applications creating new challenges for safety evaluation. However, such work still relies heavily on subjective evaluation which covers only a limited part of the possible behaviours and therefore more rigorous formal methods are needed. Model checking is a formal method that can be used for verifying the correctness of system designs. Before MODSAFE project, model checking had not previously been applied in a large scale to safety evaluation of nuclear power plant automation. However, there are good experiences in many other areas, such as verifying the correct behaviour of hardware and microprocessor designs, data communications protocols, operating system device drivers and flight control systems.
The objective of the MODSAFE project was to evaluate and develop methods based on formal model checking and apply them to the safety analysis of NPP safety automation. The aim was to develop and find a group of methods and tools that support utilities, regulators, vendors and support organizations in their practical safety evaluation efforts.

Specific goals in 2010

The work of the previous project years was continued in 2010 by modelling and analysing a new case study. The first goal was to utilize the selected case for developing a compositional technique for analysing large system designs with model checking. The compositional technique can be used to find a suitable configuration of modules that is computationally feasible but at the same time describes the system to be analysed with enough details to enable verification of the selected properties. Another main goal for 2010 was to develop a modular model checking approach for modelling function block diagrams with the UPPAAL model checker. The third goal was to investigate the scalability and coverage of model checking techniques for asynchronous systems.

Deliverables in 2010

An example case concerning Emergency Diesel Generator control system was identified, defined, and modelled with NuSMV and UPPAAL model checking tools. Some of the system's key requirements were analyzed with model checking.

In order to be able to model larger systems using UPPAAL, a module library for modelling systems given as function block diagrams was developed. Two versions of the library enabling a modular and systematic modelling approach were devised: one for modelling systems working synchronously and another for the asynchronous setting. The two modelling approaches were evaluated by developing UPPAAL models for the Emergency Diesel Generator control system and then comparing the scalability of the UPPAAL model checker for both of the models.
A new modelling approach for NuSMV was developed for checking larger systems. With the new approach it is possible to create different configurations of the model with little effort. In a configuration, a part of the system is left outside the model, and the model is defined so that it always has more behaviours than the real system. This enables efficient model checking of safety properties because NuSMV manages over-approximated models faster than plain models. This approach has also been experimented with the modular UPPAAL modelling method developed in the project.

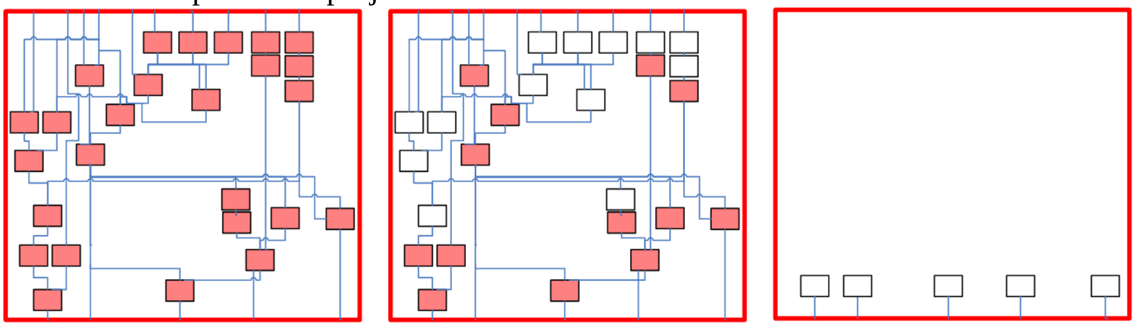

Figure 1. The principle of the compositional modelling approach developed for NuSMV model checker. Abstraction of function block diagrams on different levels. A red box indicates that the function block is a non-abstracted version. A white box indicates that an abstracted interface function block is used instead. The image on the left represents a non-abstracted module (function block diagram). The image on the right is a full-interface module without inner functionality. The middle image represents a semi-interface module, in which some function blocks are left intact, and some are over-approximated by interface function blocks. (For further details, see VTT Working Papers 156: Lahtinen, J., Björkman, K., Valkonen, J., Frits, J., and Niemelä, I., Analysis of an emergency diesel generator control system by compositional model checking.)

Also the performance of the NuSMV and UPPAAL model checkers was analysed and compared. Model checking function block diagrams with Uppaal is possible but currently inefficient. NuSMV suits better for that. However, UPPAAL is capable of depicting asynchronous systems with more detail than NuSMV. It would be beneficial if both tools could be used in the compositional verification of a single property. Developing systematic methodology for this is an interesting topic of further research.

2.2.2 Certification facilities for software (CERFAS)

As a part of the Finnish nuclear research program SAFIR2010 a project called CERFAS aimed to define necessary software certification services for nuclear industry needs. Main areas of the service development activities are process assessment and product evaluation. The software under certification is in most cases basic software (for example platform or COTS module), but also application software in those cases where it is independent of application projects. The certification is aimed in supporting qualification of applications (software and system) that for their part supports the licensing issues.

Specific goals in 2010

One of the main results of CERFAS was a guideline to producing a safety case. The guideline consists of a collection of safety case templates that includes claims, arguing methods, set of evidence and procedures for the safety evaluation processes. The argumentation in a safety case concerns I&C software of the highest safety category used in a nuclear power plant. Safety case templates, guidelines for argumentation and procedures for producing of safety cases are given in three reports [5, 6 and 7].

The report [5] includes guidelines for arguing direct and credibility evidence of testing, analysing and field experience. It gives an overview of the initial point in beginning of the evaluation: required artefacts, introduction to safety cases with safety properties and claims, testing, analysing and field experiment evidence as part of acceptable argumentation.

Evaluation in the software certification service is based on safety case templates which are given in the report [6]. Extracts of main claims and argumentations of safety case template are presented in the following two Tables 1 and 2, respectively.

Table 1. An extract of the main claims for self-supervision design [6].

4. Self-supervision design meets the software requirements
4.1 Plausibility checks are performed for minimizing potential residual faults
4.1.1 Potential residual faults are minimized by defensive programming
4.1.2 Diagnostic of potential residual faults is extensive
4.2 The system produces safe output in case of failures
4.2.1 Fail safe behaviour
4.2.2 System is in correct operation due to minor failures
4.2.3 Faults are not accumulated
4.3 Memory contents are protected or monitored
4.3.1 Potential residual faults are minimized
4.3.2 There is not any unauthorized change
4.3.3 Propagation of addressing faults or hardware faults, including intermittent faults are prevented
4.3.4 The software is maintained in its licensed form
4.4 Failure propagation is prevented by high covered error checking
4.4.1 Counters and reasonableness traps ensure that the program structure has been run through correctly
4.4.2 Any kind of parameter transfers are checked,

4. Self-supervision design meets the software requirements
including parameters type verification.
4.4.3 When addressing an array its bounds are checked
4.4.4 The run time of critical parts are monitored
4.4.5 Assertions are used

Table 2. An extract of the main claims and argumentation guides for the protection and monitoring of memory contents [6].

4.3 Memory contents are protected or monitored
Confirm for every appropriate argument: Examination and testing are properly performed
4.3.1 Potential residual faults are minimized
Confirm for every argument: Examination and testing processes are properly performed
Argue by code analysis and testing that the memory contents are protected or monitored
4.3.2 There is not any unauthorized change
Argue by examining and testing the security protection system
4.3.3 Propagation of addressing faults or hardware faults, including intermittent faults are prevented
Argue by examining and testing that the memory space for constants and instructions are write protected or supervised against changes
Argue by examining and testing that unauthorised reading and writing is prevented
4.3.4 The software is maintained in its licensed form
Argue by examining and testing that the system is secure against code or unauthorised data changes by the plant operator

CERFAS project created a set of procedures to support certification of safety-critical software [7]. Each certification body may have their own procedure to satisfy accreditation requirements of each service. Additional guidance is needed for software certification, because such service does not exist in Finland. Procedures are written in Finnish, to make them more usable for certification bodies. List of procedures is in Table 3.

Table 3. List of Software Certification Service procedures.

SCS01 Evaluation process model	SCS12 Accepting of current certifications
SCS02 Entering into a contract	SCS13 Rigour degrees of evaluation
SCS03 Specifying evaluation	SCS14 Supplementing and re-evaluating
SCS04 Planning evaluation	SCS15 Assessment Report Format
SCS05 Performing evaluation	SCS16 Certificate format
SCS06 Concluding evaluation	SCS17 Auditing development processes
SCS07 Mapping client's documentation	SCS18 Examining product artifacts
SCS08 Reviewing evaluation reports	SCS19 Witnessing testing and analyses
SCS09 Reporting preliminary evaluation	SCS20 Limiting liability and managing risks
SCS10 Reporting final evaluation	SCS21 Using SPICE model in product

SCS11 Highlighting deviations	certification

The claims provided by safety case templates are mainly originated from IEC 60880 and arguing techniques from IEC 61508-3. Claims are permanent, but more detailed criteria are needed depending on the case, for example making risk informed analyses to software artefacts. Guidelines for making templates are given in a CERFAS-report [5]. Results of argumentation are written in safety case templates, summaries in the assessment report and individual testing reports.

Deliverables in 2010

1. Harju, H., Lahtinen, J., Ranta, J,. Johansson, M., Nevalainen, R. Software safety standards for the basis of certification in the nuclear domain. In 7th International Conference on the Quality of Information and Communications Technology QUATIC 2010. Porto, Oct. 27 – 29, 2010.
2. Lahtinen, J., Ranta, J., Harju, H., Johansson, M., Nevalainen, R. Comparison between IEC 60880 and IEC 61508 for Certification Purposes in the Nuclear Domain. VTT and TUCS, SAFECOMP'2010, Vienna, Sep. 14 – 17, 2010.

3. Nevalainen, R., Halminen, J., Harju, H., Johansson, M. 2010. Certification of software in safety-critical I&C systems of nuclear power plants. VTT, TVO and TUCS. In book: "Nuclear Power", ISBN 978-953-307-110-7 published by Sciyo.
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2.2.3 Operator practices and human-system interfaces in computer-based control stations (O'PRACTICE)

The project aims at developing practices of Human Factors Engineering for the design, operation and evaluation of human-system interfaces (HSIs) at nuclear power plant control rooms (NPP CRs). The purpose is to gather knowledge of changing operator practices and new HSI solutions in order to promote safety use of digital technologies and develop new methods and practices for the evaluation of the safety of HSIs. As results of the project, a realistic concept of operations (ConOps) for digitalized control rooms can be developed, new innovative concepts for presentation of process information can be designed, and more reliable and valid methods for the evaluation of CRs and HSIs can be presented.

During the first three years of the project, studies have been conducted in which large screen displays (LSDs) and operating procedures have been investigated as collaborative tools, and the requirements for integrated use of different types of HSI elements have been outlined. One of the specific aims has been to develop a concept of operations for partly digitalized, hybrid CRs from the perspective of enhancing situation awareness and collaboration and coordination of activities between operators. It has been studied usage practices of operating procedures and different HSI components, and specifically their role in the development of an accurate situation model of the process state and in the collaboration between members of the operating team and between different personnel groups. This research is mainly based on the reference tests that have been conducted at the Loviisa and Olkiluoto training simulator. The second aim has been to develop new tools and methods for studying the adequacy, effectiveness and safety of hybrid HSIs. The aim has been to improve the reliability and validity of existing human factors engineering (HFE) evaluation methods and develop new cross-sectional and longitudinal tools and methods.

The O'PRACTICE project collaborates with, and is partly funded by Halden Reactor Project (HRP). The project collaborates with Electricité de France (EdF), and via the EU-funded MMOTION-project (including in FP7-EURATOM-FISSION-program) also with other European stakeholders at the nuclear field.

Main achievements in 2010

<u>1. Analysis and implications of the reference test results</u>

Firstly, the subtask focuses on the analysis and reporting of the TVO Olkiluoto reference test results. Conclusions have been drawn with regard of the integrated system validation (ISV) of the hybrid CR and HSIs, and the results have been presented in a format of an integrated system validation document. Secondly, a theoretical study has been conducted to describe the concept of ConOps (Concept of Operations) as a boundary object in the Human Factors Engineering (HFE) process, which becomes more detailed and elaborated as the design proceeds. Thirdly, based on the Loviisa and Olkiluoto reference test results, guidelines and recommendations have been prepared for the design of HSIs and for the development of operating procedures and simulator training activities for hybrid CRs and digital HSIs.

<u>2. Development of methods for the design and evaluation of CRs and HSIs</u>

The task aims at developing new HFE tools and methods for the specification of usability requirements for HSIs based on core-task modelling and for the analysis, documentation and validation of usability requirements. The second aim is to prepare a guide that would contain guidance on the use of the CASU (Contextual Assessment of Systems Usability) methodology, compare it to other relevant ISV methods and develop a new agile method for the evaluation of systems usability of HSIs at the earlier phases of the design process. First, the Usability Case method providing an accumulated documented body of longitudinal evidence of the degree of usability of a system has been further developed, and a theoretical paper has been prepared discussing, e.g., the application of the method to the evaluation of computer systems in the nuclear field. Second, the CASU method has been critically evaluated and compared to other ISV methods, and a practical guide has been prepared to support the use of the method. Thirdly, a pre-validation test method for a preliminary evaluation of the systems usability of design products has been further developed by applying it to a concrete case, and a paper on method development is in preparation.

3. O'PRACTICE final report

The final report presenting an overview of the findings of the project has been completed.

4. WGHOF participation

The Finnish delegates have participated in two WG-meetings during 2010.

Deliverables in 2010

- Two research reports were prepared and published of Loviisa and Olkiluoto reference test results.
- Two PowerPoint slide sets (one presenting design guidelines and recommendations, the other one the CASU methodology) were completed
- The O'PRACTICE final report was prepared and published
- Two papers (on CR design and ISV methodology) were prepared for the Enlarged Halden Project Meeting 2010
- Two presentations were given at the Enlarged Halden Project Meeting 2010 in March
- Two presentations on procedure usage and evaluation methodology were given at international workshops
- Three drafts of scientific papers (on ConOPs development, Usability Case methodology and pre-validation methodology) have been prepared
- Two ad hoc –seminars (one on the ConOps for digitalized CRs and the other one discussing the results of the project) were held
- Active participation at OECD/NEA Working Group in Human and Organizational Factors
- Collaboration with OECD HRP HAMLAB on several topics
- Participation in the EURATOM MMOTION project

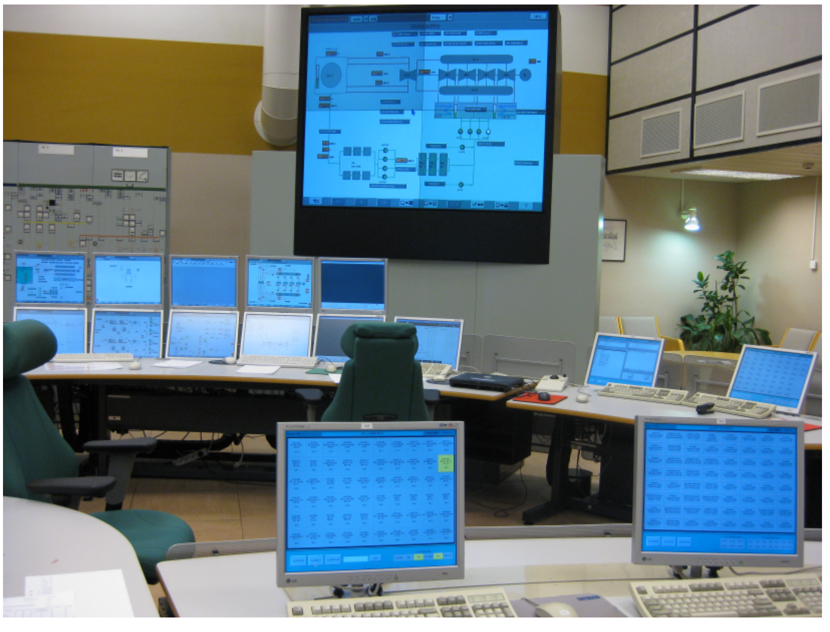


Figure 1. New user interfaces at the TVO Olkiluoto training simulator.

2.2.4 Requirements Engineering in Nuclear Power Plant Automation (VAHAYA)

The aim of the project was to review current practices and development needs in requirements engineering applied to instrumentation and control systems at nuclear power plants. The project was carried out in 2010 in close co-operation by researchers of Aalto University and VTT. The product requirements and architecture group (Preago) at Software Business and Engineering Institute (SoberIT) of Aalto University contributed to the project with its experiences on case study research and the knowledge based on requirements engineering and architecture research in software engineering. The Systems research knowledge centre of VTT, in turn, has a long research tradition in the safety aspects of nuclear power plants and NPP automation. Furthermore, VTT has studied systematic design of process automation, including requirements specification, in many other industrial domains.

Specific goals in 2010

The overview of the project is outlined in Figure 1. The aim of the project was to foster best practices of requirements engineering in nuclear power plant automation. The project started with eliciting a shared understanding of the core concepts of requirements engineering that, on the one hand served as a basis for the project, and on the other hand can in the future be used as a reference in nuclear power plant investments and renewals. Against this background, the project studied the state-of-the-art of requirements engineering in NPP automation in Finland. In addition, requirements engineering practices were studied in a few other safety critical application areas, such as military applications, and medical technology. The aim was to identify areas where existing requirements engineering practices could provide benefits to different stakeholders in the Finnish nuclear industry.

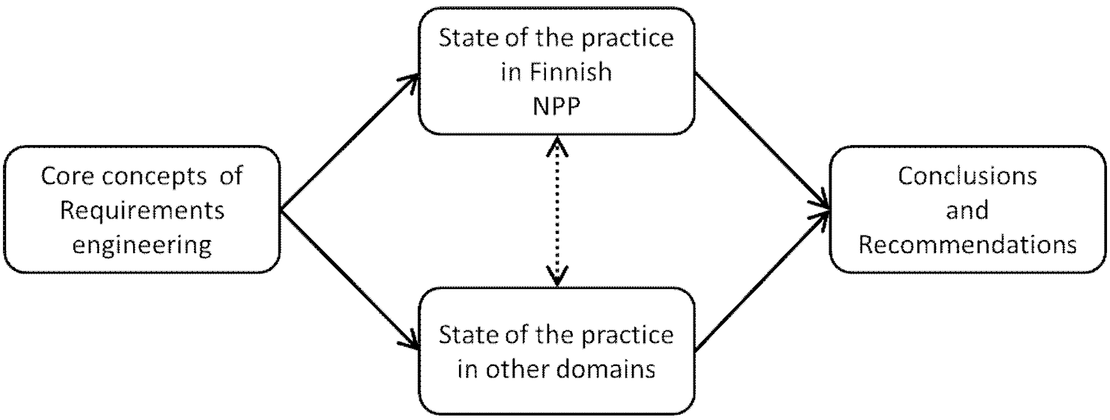


Figure 2 Summary of the VAHAYA project.

Deliverables in 2010
An overview of core concepts and processes of requirements engineering was captured. Seven NPP experts were interviewed in order to depict the state of the art in requirements engineering in Finnish NPPs. In addition, five other domains were surveyed and literature was reviewed. A cross-domain workshop was arranged in the beginning of September 2010. The

work was partly carried out in co-operation with an on-going ITEA 2 project Productivity in Collaborative Systems Development (PRISMA). Project results were summarised in a final report discussing the basic terminology of requirements engineering, the observations from the interviews and suggestions for future research directions.

2.3 Fuel and reactor physics

In the fuel and reactor physics research area there were three projects going on in 2010: Development and Validation of Fuel Performance Codes (POKEVA), Tridimensional core transient analysis methods (TRICOT) and Total reactor Physics Analysis System (TOPAS).

2.3.1 Development and Validation of Fuel Performance Codes (POKEVA)

In the project, development has been carried out to meet the demands on availability of methods for nuclear fuel performance assessments. A permanent goal is to create and maintain calculation tools, i.e. systems of computer codes for steady-state and accident conditions, which can be utilized independently of those in the possession of the power plant designers and fuel vendors. Systematic validation and maintenance as well as continuous feed of experimental data are inseparable elements of code development. Some of the existing codes base on obsolete modelling and architecture, and renewal of the system consisting of new parts or entirely new codes should be one of the long term objectives. Education and training of next generation experts is has been continued.

Specific goals in 2010

The three main goals for 2010 were: (1) development of a statistical procedure to estimate the number of failing rods in an accident, (2) completing a “state-of-the-art” review of the VTT version of the steady-state ENIGMA code, and (3) issuing a thorough evaluation of the OECD Halden Reactor Project’s overpressure, or lift-off test series IFA-610. The goal to extend the validation of the fuel - thermal hydraulic FRAPTRAN-GENFLO code was partially replaced by one to issue an improved and rectified version of the FRAPCON-3.4 steady-state code. Testing and validation of another version of the SCANAIR transient code was foreseen. Plans also included taking part in the IAEA FUMEX III and the OECE/CSNI/WGFS LOCA benchmark exercises to support code validation. In education, taking a master’s degree was expected.

Deliverables in 2010

- Development of a probabilistic transient code, particularly one for prediction of nuclear fuel failure rate in an accident was completed by a suggested two-stage approach one of which features an innovative use of neural networks methodology. The latter is an option to suppress the otherwise intolerably high number of calculations required. The method utilizes the theoretical basis of nonparametric statistics (i.e. order statistics, tolerance interval theory), and the so-called Wilks’ formula, in particular. Statistical parameters are identified as being either global or local, the former varying over the whole core, the latter over single rods. The core of calculations is based on the application of the combined fuel - thermal hydraulic FRAPTRAN-GENFLO code.

- Use of the coupled thermal-hydraulic fuel code FRAPTRAN-GENFLO was established as a versatile tool to simulate integral loss-of-coolant test arrangements and as the core tool in the probabilistic transient analyses.

- An extensive study on the VTT-amended ENIGMA steady-state code and its several sub-models was compiled. The report includes a description of the fuel rod and the phenomena affecting it on a theoretical level. The ENIGMA interface is described and the ENIGMA simulation models are examined. The performance of the code was assessed versus several fuel experiments. In addition to a host of practical improvements and corrections, significant alterations made to ENIGMA over the years include addition of cladding material data and correlations for VVER and M5 alloys, several subroutines to control the pellet radial power distribution, several instants of re-calibration and other attempts to improve the fission gas release and thermal conductivity models, models to describe the so-called high-burnup structure, several changes to relax limitations on input parameters, attaching an automated management system to run probabilistic analyses, and a generator to produce a burnup-dependent file to initialise the SCANAIR accident code. Areas calling for future attention include fuel-to-clad-gap heat transfer and cladding creep model validation. Further review of factors that contribute to the rod elongation behaviour is suggested (Figure 1).

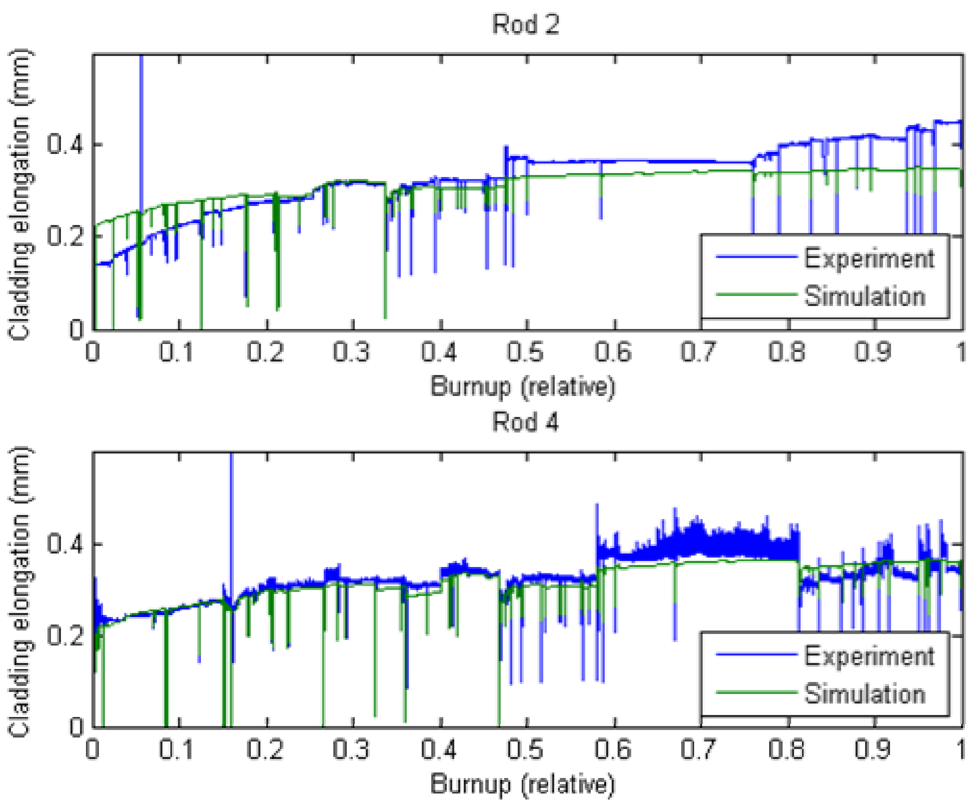


Figure 1. ENIGMA simulation of rod elongation behaviour in a Halden Project experiment.

- A comprehensive interpretation of the outcome of the in-pile measurements from the OECD Halden Project rod overpressure tests was issued. Internal rod pressure grows with burnup as a result of fission gas release and reduction of the free volume. If the rod internal pressure exceeds a certain level, the gap may re-open and increase (the lift-off phenomenon), potentially leading to a positive thermal feedback. The overpressure or cladding lift-off experiments at Halden, the IFA-610 series, have provided direct data on maximum tolerable rod overpressure so as to allow assessing the maximum pressure difference over the system pressure to which fuel rods of different designs (PWR, BWR, VVER) and fuel types (UO2, MOX) can be operated without causing a lasting fuel temperature increase and thus a potential threat to rod integrity. In the report, a summary was given over the trends in fuel behaviour observed from seven IFA-610 experiments. The analysis is extended by comparison with results of calculations made using the VTT version of the ENIGMA steady state fuel performance code. The overpressure threshold for the lift-off phenomenon was evaluated based on achieved normalized fuel temperature increase rates. Depending on the test, this rate starts to show up when an overpressure of no lower than 130 had been applied. No significant thermal feedback was seen from the last experiment with a VVER fuel segment, even under very high applied overpressures of up 300 bar. The fuel temperature modelling with the ENIGMA code is generally in good agreement with the experimental data below the lift-off threshold, when the gap between fuel and cladding is closed (Figure 2). Generally, the observed lift-off is weaker that what a code calculation would suggest.

- A coupling to the ENIGMA code input from a lattice physics code that was recently created to realistically account for the effect of gadolinium or other additives on power distribution in the pellet was validated in a benchmark exercise as well as applied work under a contract.

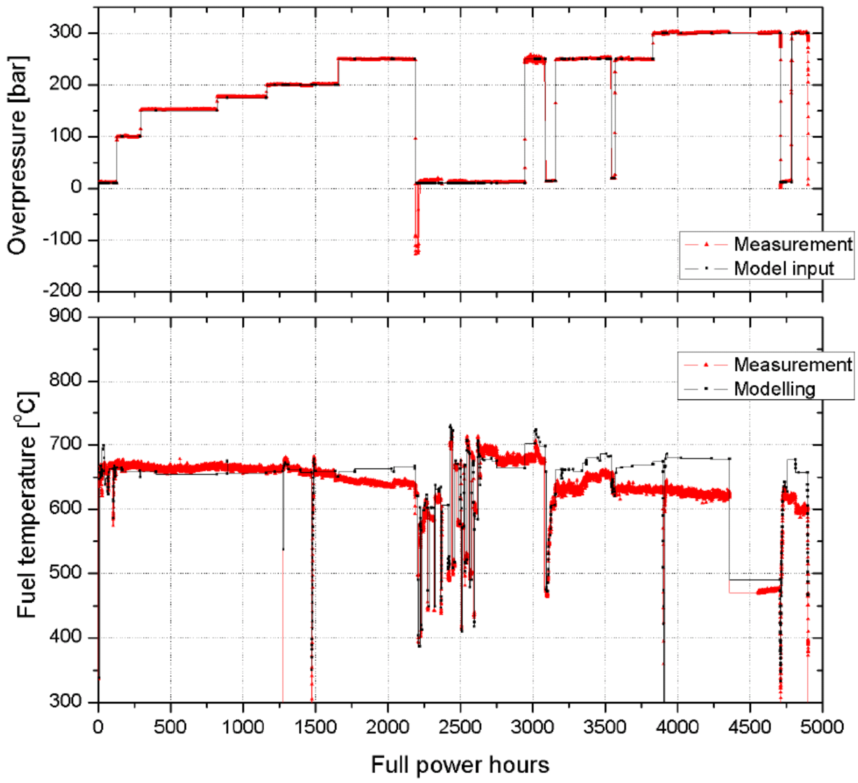


Figure 2. ENIGMA simulation of a Halden overpressure test showing some discrepancy at the instants of clad "lift-off"

- A version of FRAPCON 3.4 consolidating previous practical amendments and cleared of intractable parts of obsolete coding was issued. Under a collaboration effort with the USNRC and its Pacific Northwest National Laboratory (PNNL), VTT is regularly receiving successive versions of the PNNL-developed fuel performance codes FRAPCON and FRAPTRAN for steady-state and transient conditions, respectively. VTT is applying the codes in Finland for tasks that involve independent fuel safety research and assessment. VTT has further taken an active role in the development of the codes, both in collaboration with the NRC and PNNL and in-house. Not unlike its predecessors, the version 3.4 of the steady state performance model FRAPCON fails to conform to current standards as regards its coding and architecture. One of the obsolete features is maintaining a huge dynamically addressed array containing sub-arrays of different variables specified by pointers, and equivalence statements that together make the coding difficult to modify and the variables next to impossible to track down. Moreover, the recent FORTRAN compilers are more demanding than the formerly used, and too often attempts to compile parts that are not up to today's standards end up with serious difficulties. VTT has taken steps to 'modernize' the code and cure some of the above demerits, most notably by removing the packed huge arrays and the equivalence statements and substituting separate new arrays, one of its own for each variable. A number of other features have also been added to earlier versions during the years. The modifications and new features are mainly based on encountered actual inconveniences related to: difficulties in compiling, large power histories given as nodal values for a big number of axial segments and power steps, rod or channel geometries different from standard, need to describe test rodlets rebuilt from power reactor rods, and many others. The modified code can now be compiled mainly using standard options. In the report, the modifications and additions are described, and a complete list of the new input variables is given.

- Recent version of the IRSN SCANAIR code for reactivity accident analyses was installed and used in power reactor applications (Figure 3)

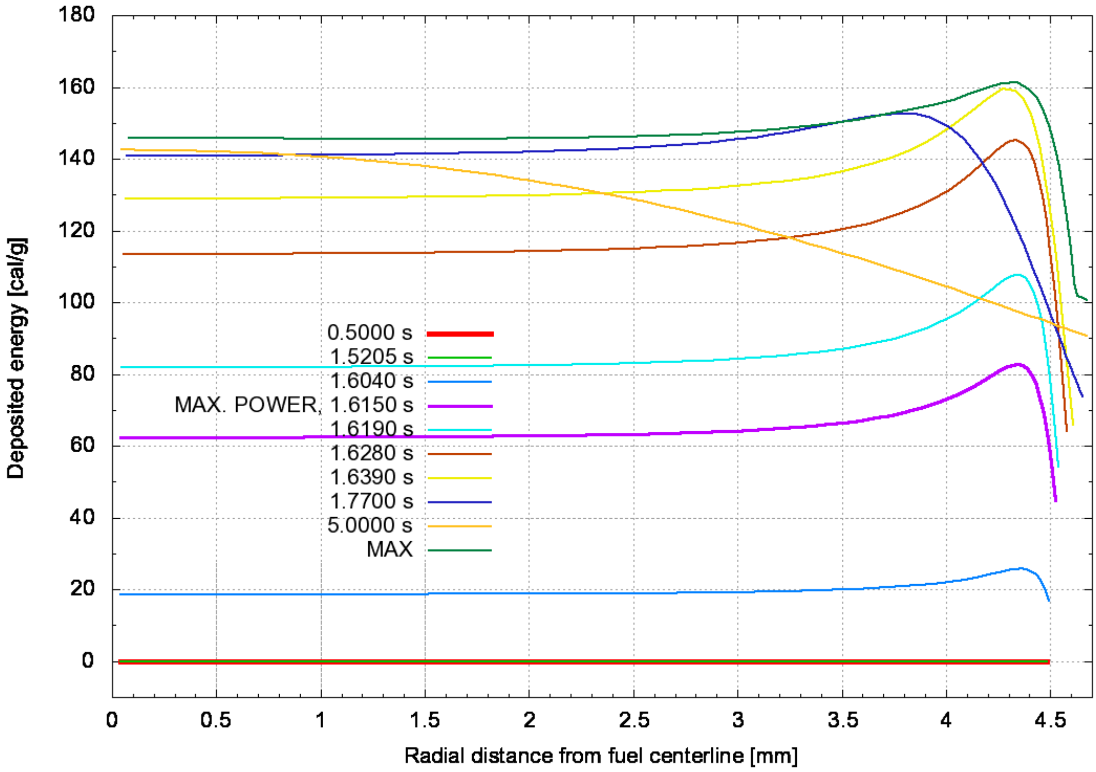


Figure 3 Radial distribution of maximal values of deposited energy in fuel in a reactivity accident.

- Part was taken in systematic IAEA (FUMEX III CRP) and OECD (WGFS/LOCA) international benchmark exercises that directly support the code validation. The VTT-amended ENIGMA and FRAPCON-3.3 codes for steady states and the coupled fuel - thermal hydraulics FRAPTRAN-GENFLO code were the models applied.

- A master's diploma thesis was issued on the SCANAIR code development and application. Several short courses and seminars were attended.

2.3.2 Total reactor physics analysis system (TOPAS)

The main objective has been to accomplish a unified, complete, up-to-date, easy-to-use and flexible entirety consisting of both programs acquired from elsewhere and programs that are the results of own development. Together with the reactor dynamics codes, the stationary reactor physics code system has to cover the whole range of calculations, from handling of basic nuclear data, i.e. cross section libraries, over fuel and core analyses in normal operating conditions to transient and accident studies using coherent models and methods. It should be possible to follow the whole life cycle of the nuclear fuel from a reactor physics point of view until its final disposal. The same or similar models can often be used in both the static and the dynamic calculations. Additionally, it is of utmost importance in today's situation, when the use of nuclear power is increased at the same time as the present generation of nuclear experts is gradually retiring from work, to maintain competence and train new personnel. Co-operation with the technical and other universities is necessary to make new students interested in this branch of science and thus ensure that the nuclear plants in Finland will be in the hands of competent people in the future, too. The tasks of the project also provide excellent possibilities for university students to perform work for their academic degrees.

Specific goals in 2010

Specific goals in 2010 included the following items:
Participation in the activities of the NEA-organised JEFF project, in order to maintain a reasonably accurate cross section library and knowledge about it. A new person will familiarise himself with NJOY code and the possibility to use NJOY to extract covariance data of cross sections is to be studied. Development of the Serpent code will be continued. Fixed-source mode will be implemented to Serpent. European Working Group on Reactor Dosimetry (EWGRD) will be participated. A new person will get acquainted to the use of CASMO and SIMULATE. Comparisons between combinations of Serpent/CASMO and ARES/SIMULATE for the EPR will be extended. Improved versions of Serpent and MultiTrans will be made. New person will be trained to use MCNP. In addition, new person will also be trained to criticality safety issues and BUC criteria. The UAM benchmark will be participated and CASMO calculations repeated with SCALE 6. Licentiate’s thesis is to be written on the sensitivity analysis methods implemented to CASMO. Convergence and accuracy of the Chebyshev Rational Approximation Method (CRAM) will be studied further. Reports on code development and testing and on the practical use of different codes will be written. Taking care of Finland's obligations in NEA, as well as other international research co-operation and information exchange in the field of reactor physics, have also been important goals, as well as reporting research results and educating new experts through international courses.

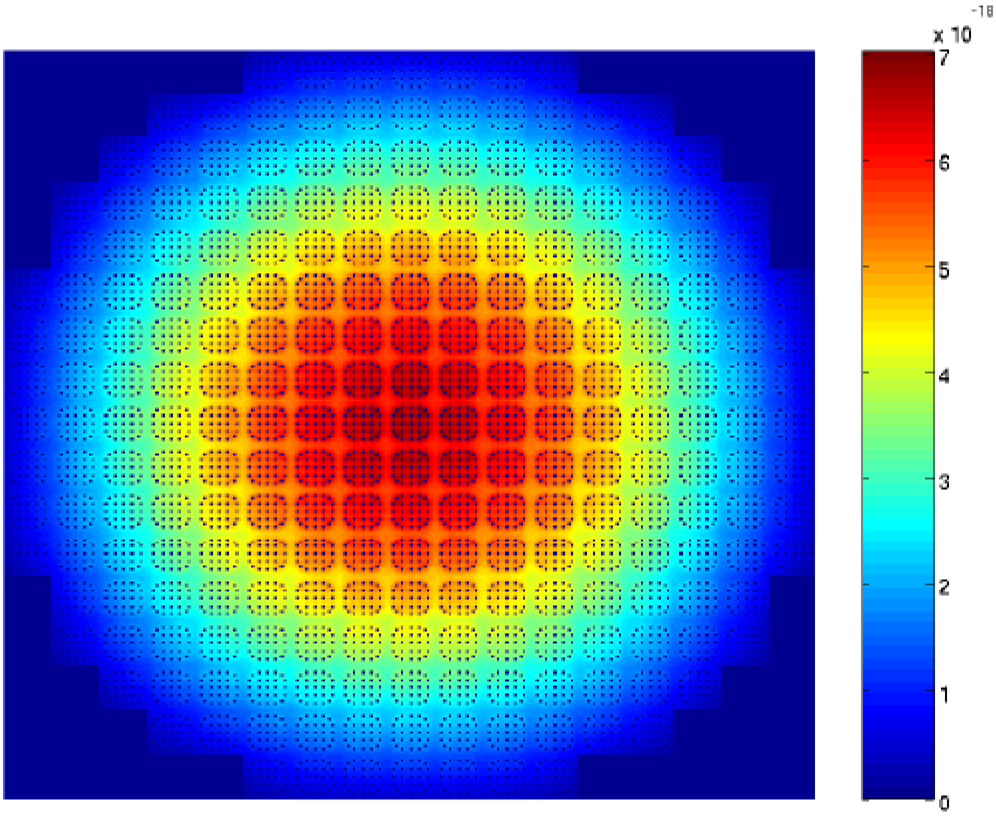


Figure 1. Reactor power distribution simulated with Serpent at core mid-plane of the Hoogenboom-Martin simplified PWR full-core benchmark (picture taken from "Joint International Conference on Supercomputing in Nuclear Applications and Monte Carlo 2010" proceedings article by Leppänen).

Deliverables in 2010

- The use of NJOY to extract covariance data has been studied and a research report has been written on the subject (VTT-R-04160-10). The work for implementing fixed-source mode to Serpent is ongoing. The meeting of the European Working Group on Reactor Dosimetry (EWGRD) has been attended.

- The use of ARES has not been studied further in 2010. New person has been trained to use CASMO and SIMULATE and she has also attended Studsvik Scandpowers CMS training course. The EPR calculations have not yet been extended.

- Several improvements were made to Serpent code. RSICC release of Serpent was issued in March 2010, in addition to the NEA distribution package. Work on MultiTrans has not continued in 2010. Two new persons were trained to use MCNP and they have both attended the MCNP5/MCNPX training course.

- New person has familiarized himself with criticality safety issues, but this has been done mainly outside of the TOPAS project.

- The participation to the UAM benchmark has continued and the CASMO calculations have been repeated with SCALE 6.0. The results from TSUNAMI-1D and CASMO were in excellent agreement. Licentiate's thesis has not been written: the current plan is to primarily write a report and a publication on the UAM benchmark activities, and reconsider the meaningfulness and appropriateness of the thesis later on. Convergence and accuracy of the Chebyshev Rational Approximation Method (CRAM) has been studied further and a new article has been written on subject, submitted to the journal of Nuclear Science and Engineering.

- Several scientific journal articles as well as conference papers have been written. Status report has been written on Serpent development (VTT-R-01296-10). Research reports have been written also concerning the use of NJOY to extract covariance data (VTT-R-04160-10) and on the MAMBO script package that facilitates the calculation of an equilibrium load in SIMULATE-3 (VTT-R-02358-10). NEA NSC meeting has been attended. Participation to the LWR uncertainty analysis of modelling (UAM) benchmark was continued. Also meeting of the European Working Group on Reactor Dosimetry (EWGRD) was attended. CASMO/SIMULATE and MCNP5/MCNPX training courses were participated.

2.3.3 Tridimensional core transient analysis methods (TRICOT)

The fundamental objective of the project is to continue the development of reactor dynamics computer codes (TRAB-3D and HEXTRAN) at VTT, especially in the area of thermal hydraulics. The goal is to have a truly independent transient calculation system, which can be utilized by the safety authority and other end-users for safety analyses that are independent from those of power plant designers and fuel vendors. To achieve this, the codes must be constantly developed in order to be on the same level as other codes used for similar purposes internationally.

In addition to the development work itself, it is essential that the new models are validated against measurements and the results of other codes. Much of this work can be done as international co-operation in the form of calculating benchmark problems. Another objective is to educate new experts to this field.

Specific goals in 2010

The project has two main areas. The first area is reactor dynamics, which contained further development and testing of the internally coupled TRAB-3D/SMABRE against the production version of TRAB-3D and the parallelly coupled TRAB-3D/SMABRE. Other tasks in the reactor dynamics area aimed at calculating international OECD/NEA benchmark cases with TRAB-3D/HEXTRAN and US NRC’s coupled neutronics/thermal hydraulics code TRACE/PARCS and analyzing differences between the results by performing variation calculations with both codes. The third task concerning reactor dynamics was to study uncertainties of VTT’s hot channel methodology.

The goal of the second main area was to develop tools for three-dimensional thermal hydraulics calculation in the nuclear reactor core using the porous medium approach. Main applications were
COOLOCE and pressure vessel of EPR.

Deliverables in 2010

- Possibility to use two-sided heat structures was added to the internal coupling of TRAB-3D/SMABRE and tested with the HPLWR pressure vessel. Capability of calculating reversed assembly-wise core flow was demonstrated with LOCA case of EPR. After several changes made into the code, the necessary options, where PWR and BWR needs deviation in model, have taken as a part of input deck. Several procedures and help routines for latest versions of internally coupled codes with separation of assemblies and flow channels were updated. For the validation, with BWR-model test cases of four transients have been recalculated. Report has been written.

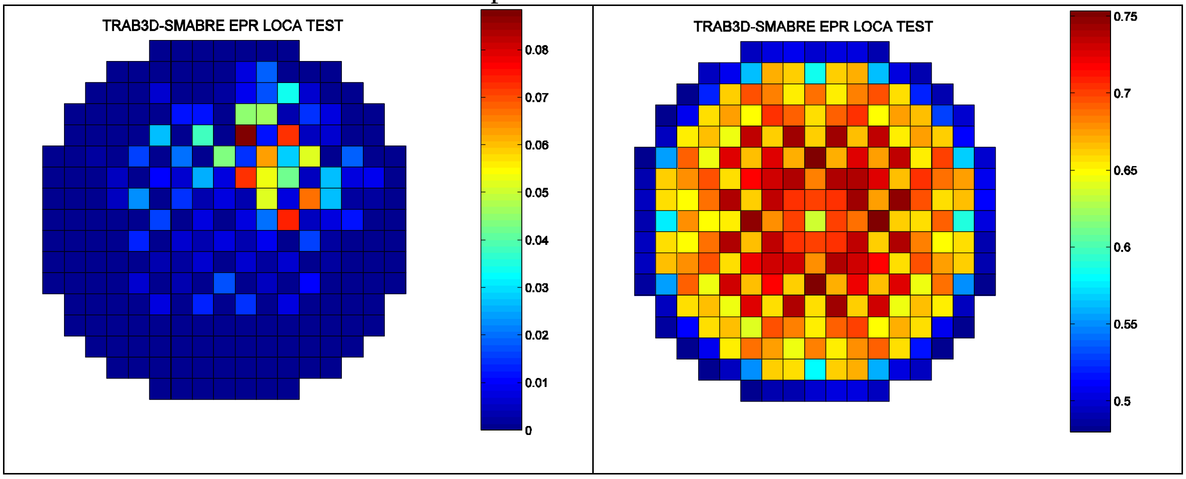


Figure: Assembly-wise core outlet void fraction about at time of flow reversal and with totally reversed flow in the LOCA test case for EPR with TRAB-3D / SMABRE.

- A TRACE/PARCS simulation model for Kozloduy-6, which can be modified for Kalinin-3, was received from Penn State, USA. The GenPMAXS code has been applied for generating PMAXS type PARCS cross section files from CASMO outputs. Report on PARCS user's experiences has been written.
- The COBRA-EN code was installed and modified so that it can be used for similar transients and similar fuel assemblies as VTT's TRAB-CORE model. Sensitivity calculations for a square-lattice PWR assembly were performed. Report has been written.
- The PORFLO code has been rewritten in 2010, mainly to simplify adaptation to the new applications. The code has been tested by recalculating Loviisa steam generator calculations. In 2010 new applications have been core debris coolability in the COOLOCE test facility and EPR pressure vessel. Report has been written. Conference paper has been written and presented in the AER symposium.
- Project has included the participation in the NEA Working party on Scientific Issues of Reactor Systems (WPRS). Project has included the participation to meeting of AER scientific council, AER working group D and to AER symposium and arrangement of AER symposium, which was held in Hanasaari in September. Number of registrated participants was 54 from abroad and 26 from Finland. Conference papers on PORFLO development and on validation of APROS nodal model were presented. Proceedings of the symposium have been delivered to the participants and AER members.
- User's manual for TRAB-3Dand HEXTRAN has been updated and revised. Paper on the application of sensitivity and uncertainty analysis tool has been written and presented in PHYSOR2010 conference. Compilation of the systematic validation matrix for the reactor dynamic codes has been started.

2.4 Thermal hydraulics research area

In the thermal hydraulics research area there were seven projects going on in 2010: Numerical modeling of condensation pool (NUMPOOL), Improved Thermal Hydraulic Analysis of Nuclear Reactor and Containment (THARE), CFD modelling of NPP horizontal and vertical steam generators (SGEN), Improvement of PACTEL Facility Simulation Environment (PACSIM), Condensation experiments with PPOOLEX facility (CONDEX), Passive safety system simulation (PASSIMU) and Open FOAM CFD-solver for nuclear safety related flow simulations (NUFOAM).

2.4.1 Numerical modeling of condensation pool (NUMPOOL)

Numerical methods for analyzing pressure suppression pools in boiling water reactors are developed. The numerical modelling work has three objectives. First, supporting the CONDEX project at Lappeenranta University of Technology (LUT), where experiments with new pressurized test facility are performed. Second, improving understanding of the thermal hydraulic phenomena in the dry well and in the wet well compartments of the containment. Third, developing methods for estimating pressure loads originating from the condensation pool.

Experiments are performed at LUT with pressurized test facility including an adequate model of the upper dry well compartment and withstanding prototypical system pressure (0.5 MPa). In the CONDEX project, condensation in the dry well and direct-contact condensation (DCC) in the wet well are examined and scenarios threatening the integrity of pool structures are studied.

In 2009, the CFD models for wall and bulk condensation and direct-contact condensation were further tested and developed. A 100 second long simulation for testing the present implementations of the condensation models was performed. In the beginning of the simulation, the bulk condensation and wall condensation in the dry well are the dominating effects, and the gas blown into the wet well is almost pure non-condensable air. In the end of the simulation, the gas consists mainly of steam and direct-contact condensation in the water pool becomes important.

Validation of the FSI calculations against the experiments and against numerical data was continued. Modeling of a realistic containment of a BWR was also started. In 2009, the initial phase of blowdown was modelled, where the pipes were cleared from non-condensable gas. Effect of FSI in the realistic containment was investigated.

Specific Goals in 2010

In 2010, the CFD model is revised following the ideas obtained from comparison of numerical results to the experiment during previous year. In particular, the direct-contact condensation model is improved based on the comparisons with the experimental results. Modelling the area between the phases in Euler-Euler modelling is studied. The effect of the number of the blowdown pipes on the pressure loads is investigated. In particular, the stochastic correlation of the loads originating form different pipes is investigated in the beginning of the discharge.

Order-of-accuracy of the coupled CFD-FEM and acoustic FEM calculations is first studied in simplified test cases. Propagation of a pressure transient in compressible fluid and a single degree-of-freedom oscillator are first considered separately. For the pressure wave propagation, the effect of the sound wave Courant number on the solution accuracy is studied in particular. Accuracy of the coupled calculations is then studied for the piston FSI problem.

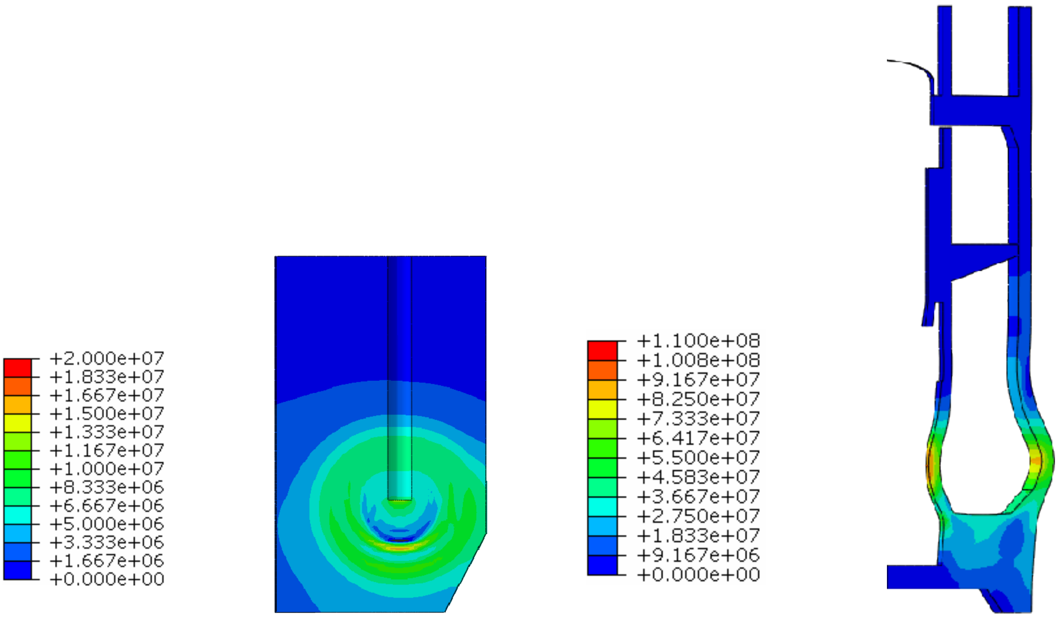
FSI calculations of the experiments and realistic BWR containment are also continued. Calculation of the experiment SLR-05-02 is re-run by using measured drywell pressure as boundary condition instead of the mass flow rate. The timing and shape of bubbles obtained in the calculation are compared with the high-speed recordings and previous calculations. For the BWR containment, the effects of the rapid collapse of a large steam bubble are studied with one-way and two-way coupled acoustic FEM calculations. The pressure source due to the bubble collapse is determined analytically and numerically.

20 s 20.0 s

Figure 1. A gas bubble in water pool in an experiment performed in the CONDEX project. On the right, iso-surfaces of void fraction in CFD simulation are shown.

In Figure 1, a photograph of a bubble is shown which was obtained in an experiment performed in the CONDEX project. On the right, an iso-surface of void fraction ($\alpha = 0.1$) obtained in a CFD simulation with the FLUENT code is shown. The CFD results are in reasonable agreement with the experiments. The wall condensation in the dry well compartment is, however, somewhat stronger in the experiment than in the simulation. Similarly, the direct-contact condensation in the water pool is also underestimated in calculations.

For studying FSI in a realistic BWR containment, a 22.5° sector model including one vent pipe was used. The collapse of a large spherical bubble with diameter 2.4 m was considered. The acoustic pressure as well as deformations and stresses are shown for the BWR containment in Fig. 2. As the pressure source obtains its peak value, a spherical high-amplitude pressure wave starts to propagate towards the walls. The pressure wave reaches the walls in about 2 ms, after which reflections of the wave occur. Also the wall motion of the containment affects the pressure field due to the FSI coupling. The pressure wave makes the lower part of the containment walls to bulge which causes high tensile stresses in the outer wall and high compressive stresses in the inner wall.



t = 18 ms *t* = 24 ms

Figure 2. Acoustic pressure and von Mises stress [Pa] in the BWR containment. The deformations have been scaled up by 100.

Deliverables in 2010

- CFD simulations of chosen experiment where direct-contact condensation is important.
- CFD simulation of chosen PPOOLEX experiment with parallel blowdown pipes.
- Repeating the FSI calculation of the experiment SLR-05-02.
- FSI calculation with a model of a BWR sector.
- Report on the CFD and FEM calculations.

2.4.2 Improved Thermal Hydraulic Analysis of Nuclear Reactor and Containment (THARE)

The main objectives of the project were to develop and validate calculation methods for safety evaluation of nuclear power plants. Both thermal hydraulic system analysis codes and CFD calculations were used in the analysis and their usability was studied and enhanced. An important objective was also to train new thermal hydraulic code users and educate young experts.

Validation of system analysis codes

The thermal hydraulic system analysis codes APROS and TRACE were validated with experimental data from Lappeenranta University and OECD research programs. Thermal hydraulic system analysis codes, like APROS and TRACE, rely largely on experimental correlations. When the codes are used in conditions beyond experimental data or applied in new problems the usability of the correlations and models has to be studied. Furthermore new features in the codes and increased computer performance allow more detailed modelling. Therefore continuous validation of codes is needed. In addition code validation gives an excellent opportunity for young scientist to international co-operation.

The ISP-12 test in ROSA-III was modelled with APROS (Figure 3). The test simulated 5% split break at the pump inlet in the recirculation line of a BWR with the condition that the off-site power and the high pressure core spray system are lost. The main phenomena were reproduced quit well with APROS although there is still small over prediction in reactor water inventory and probably hence under prediction in cladding temperatures. Figure 4 shows measured (red line) and calculated (blue) water inventory in the pressure vessel and hot rod maximum cladding temperatures. In the calculation the minimum water inventory was slightly higher than measured and low pressure safety injection (LPCI) started earlier than in the experiment. Therefore the pressure vessel started to fill up earlier and maximum cladding temperatures did not reach as high values as in the experiment. Measured data was somewhat contradictory and final checking of modelling was still going on when this report went in press.

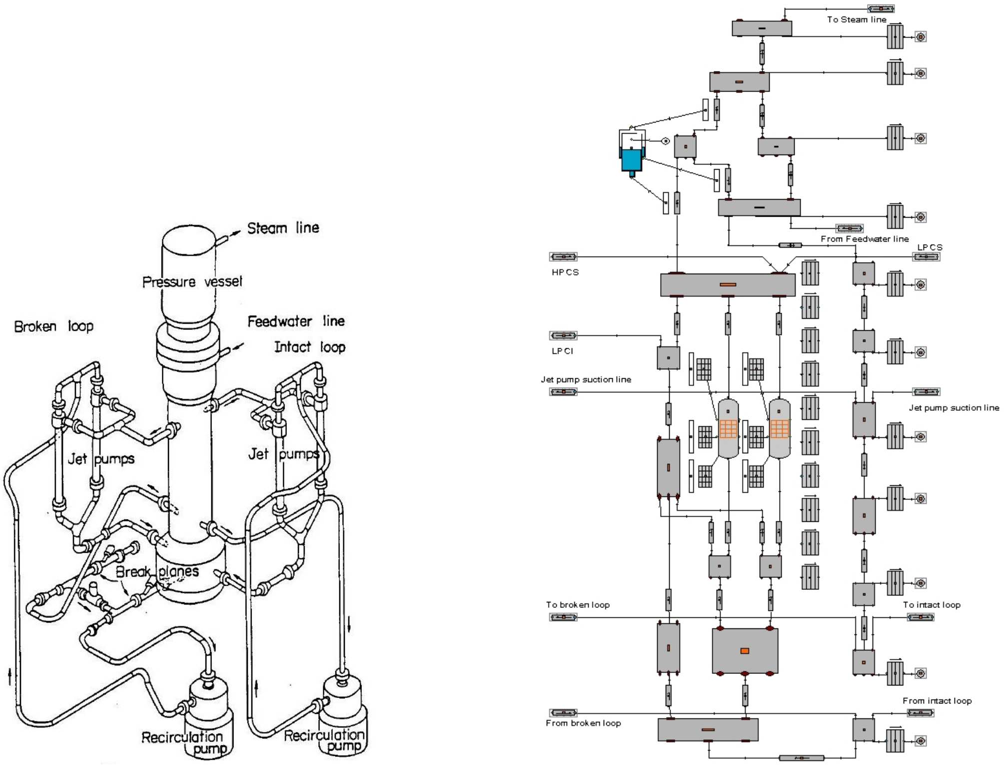


Figure 3 ROSA-III test facility and APROS model of the pressure vessel.

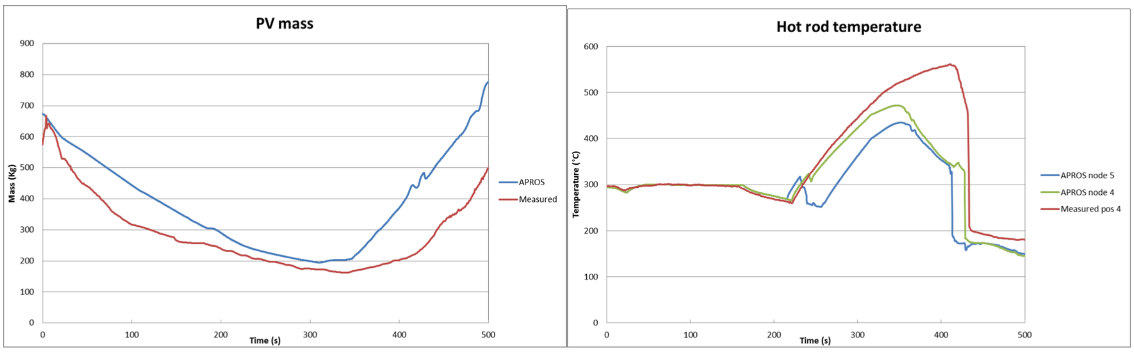


Figure 4 Measured (red line) and calculated water inventory and cladding temperatures.

The PWR-PACTEL benchmark was calculated with the model of the test facility using APROS code (Figure 5). The test consists of stepwise water inventory reductions and monitoring of natural circulation and heat transfer in the core and in the steam generators. The results of the benchmark are not yet available.

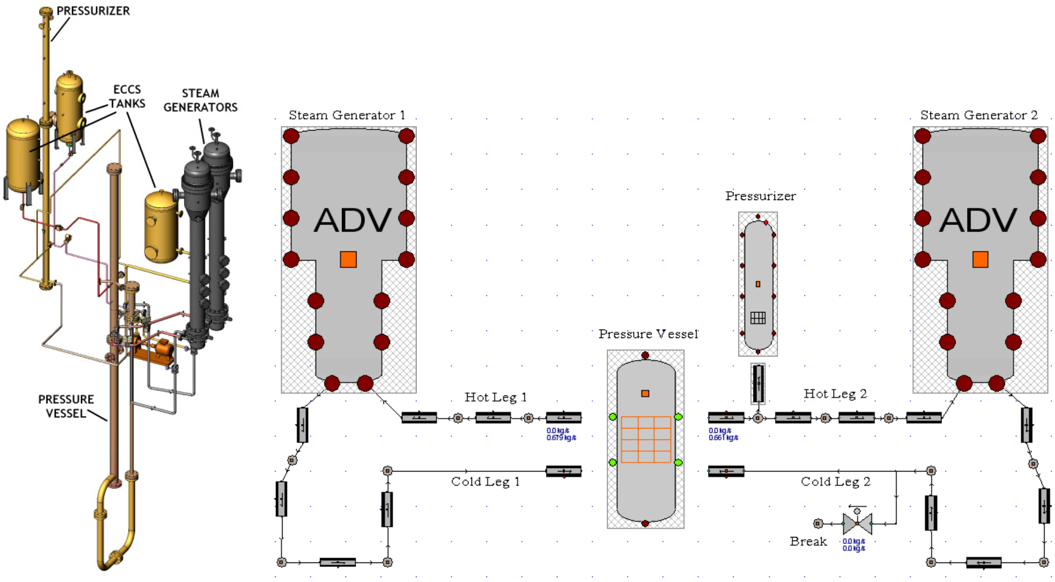


Figure 5 PWR-PACTEL test facility and APROS model

ROCOM is a test facility simulating a KONVOI type PWR. The test 1 simulates a pseudo-steady-state of test PKL III G 3.1 at 609 s, when cold water from the loop with broken steam line flows to downcomer (minimum temperature at 609 s.). From safety point of view, the most important aspect of the test is to observe the mixing of the injected water before it enters the core region. Most of the mixing presumably occurs in the downcomer region, therefore the temperature distribution in downcomer is analyzed in more detail. Even though CFD codes are usually utilized for this kind of analysis, limited 3D simulation capabilities are included in system codes making it viable to study mixing with a full system model. However the validity of system codes for such simulations has to be assessed.

The APROS model was created using APROS 3D flow model. The model consists of homogeneous fluid model complemented with a k-epsilon turbulence model. The TRACE model was created using TRACE VESSEL component. The most important difference to APROS 3D flow model is that the VESSEL component has no model for turbulence simulation.

ROCOM test 1 was calculated using both APROS and TRACE. Different nodalisation schemes were tested with both codes to obtain data on the required level of detail for simulating the downcomer temperature distribution properly. Overall, the test was adequately reproduced by both codes. Measured data and example simulation runs with both codes are presented in Figure 6. As seen in the figure, mixing was observed in the downcomer region up to almost homogeneous distribution in the lower downcomer, as in the experiment. However, the rate of mixing was somewhat different from the experiment. More specifically, the rapid temperature homogenization in upper downcomer as observed in the experiment was not reproduced precisely. In both APROS and TRACE calculations, the mixing began higher in the downcomer and occurred more gradually than in the measured data.

Further testing should be performed to obtain more information on the suitability of both APROS and TRACE for analysing coolant mixing in the pressure vessel downcomer region. Especially a test with less mixing in the downcomer would yield more knowledge of the accuracy of APROS and TRACE 3D fluid simulation models.

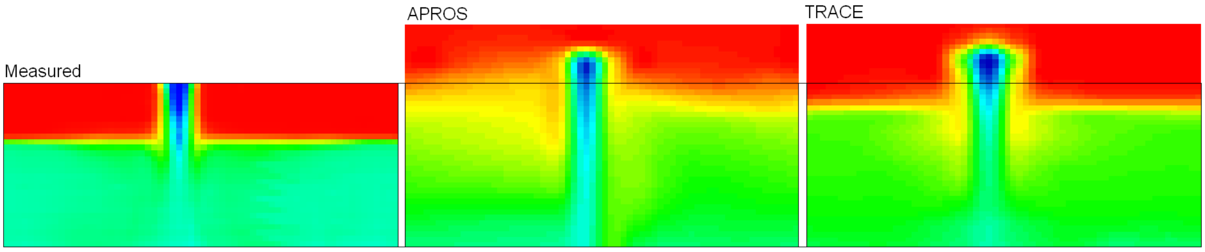


Figure 6 Experimental and measured temperature distribution in ROCOM test.

International standard problems (ISP) are important code and code users benchmarking exercises were participants has to model an accident scenario without a prior information of the results (blind) or even without previous experience of modelling the test facility (double blind). The ISP-50 was organized in a new ATLAS test facility, which is a scaled model of Korean APR1400 reactor. The ISP was for us as for most other participant a double blind exercise. The APROS model is presented in Figure 7. The test results and all calculations will be published in an OECD report.

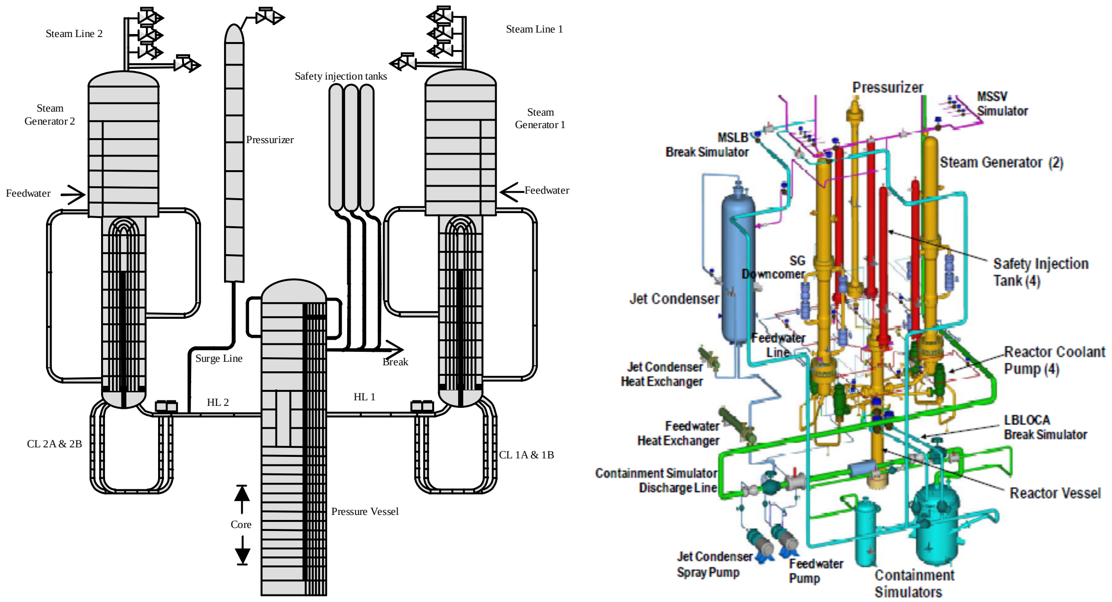


Figure 7 APROS nodalisation and ATLAS test facility.

Containment thermal hydraulics

A Generic Containment code-to-code comparison benchmark was organized in the frame of SARNET-2 WP7. VTT participated in the first step of the benchmark calculation (both in blind and open phase) with the APROS Containment. A basic version of a rather simple generic containment model based on a German PWR with 1300 MW_{el} was developed by FZJ and delivered to participants i.e. all participant used a similar lumped parameter nodalisation. This approach facilitates verification of the codes with minimized user effects. Various ISP calculations have shown that modelling choices, which the code user makes, has often a strong impact on the results. Therefore this kind of benchmark with fixed nodalisation allows “clean” code-to-code comparison. In order to provide a clear basis for comparison, a simple scenario, namely the in-vessel phase (0…12890s) of a SB-LOCA with loss of secondary heat

sink was defined. In order to simplify the case only the containment thermal hydraulics had to be modelled.
The rooms and compartments of the reactor and auxiliary building were grouped into 16 control volumes (zones) including merged heat structures in order to generate a simple generic nodalisation (Figure 8).

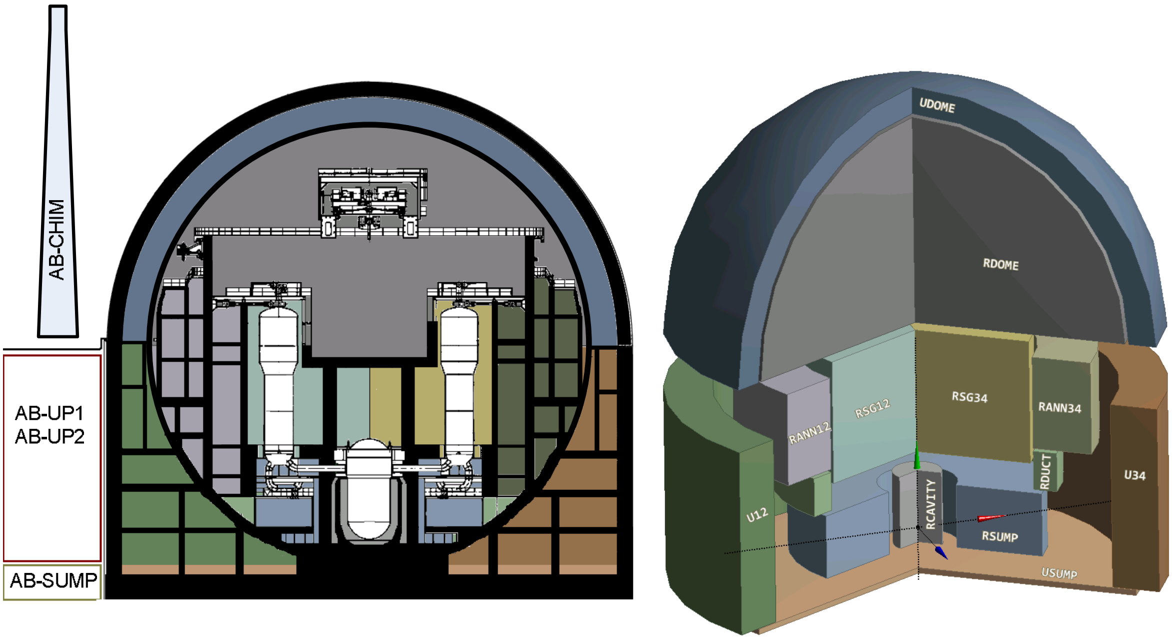


Figure 8. Control volumes within the reactor building [**Error! Bookmark not defined.**].

In total, calculation results from 14 different organizations applying 9 different codes were submitted. Because there were no experimental reference, average histories of all 22 contributions was calculated in order to allow comparison. The deviations between the different results are demonstrated qualitatively by means of a single standard deviation band. APROS calculation result on pressure history is compared to the standard deviation band and mean value of all other calculations in Figure 9. The APROS result is well within the standard deviation band, and in general, similar trend was observed in other target variables compared.

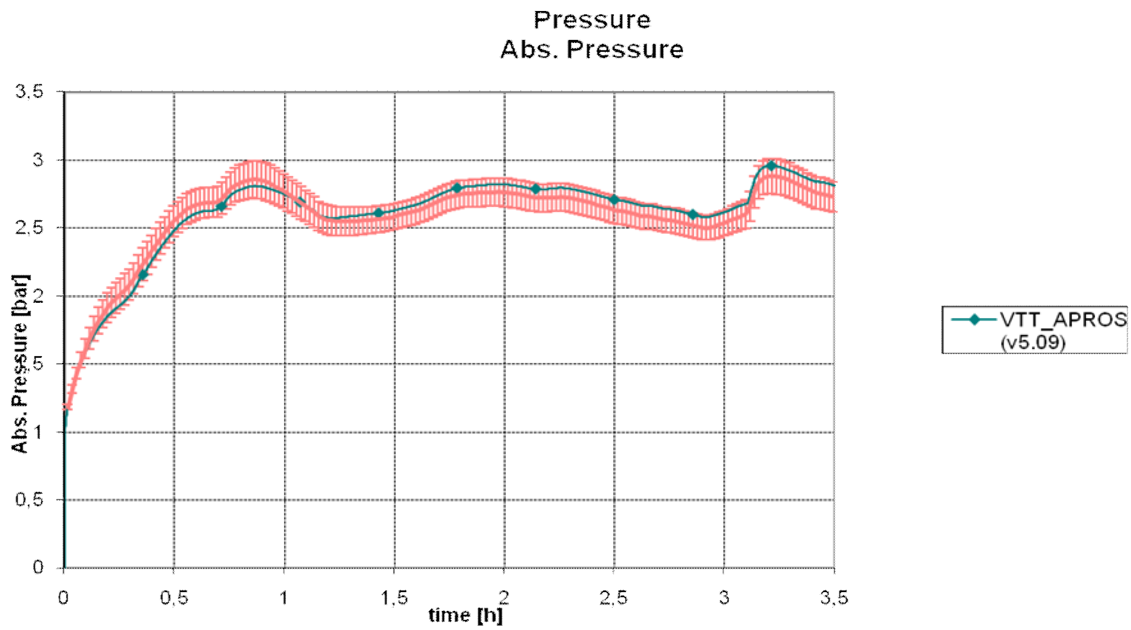
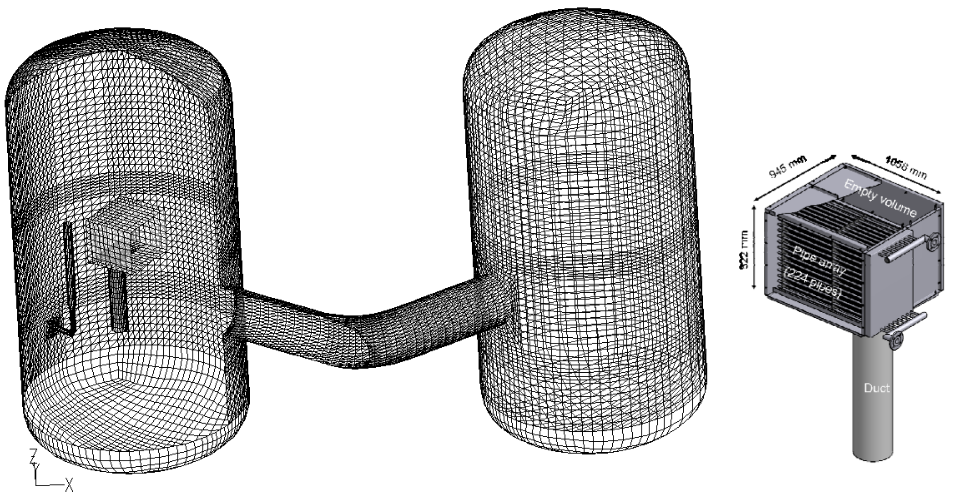


Figure 9. Calculated containment pressure compared to the mean value in SARNET Generic Containment benchmark.

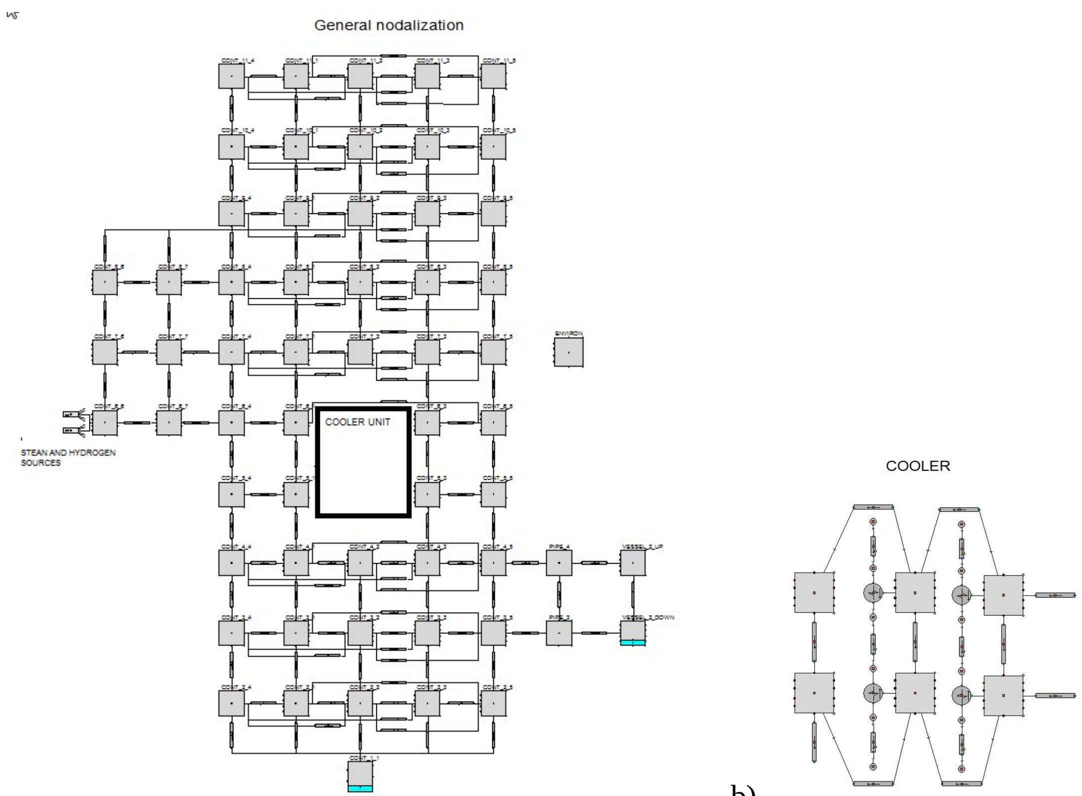
An OECD/SETH2 experiment of steam and helium injection and mixing, stratification and helium enrichment due to condensation of steam in a tube bundle cooler was simulated with a CFD-code Fluent and with a lumped parameter code APROS Containment. The experimental facility PANDA simulates a two part compartment connected with a corridor. Figure 10 shows the Fluent grid of the PANDA test facility and Figure 11 shows the most detailed nodalisation used with APROS Containment.

General trend for pressure (Figure 12) and concentrations were predicted rather well in the last CFD-simulation with refined model for the cooling water temperature distribution. Cooling rate drop due to helium enrichment inside the cooler tube bundle was not captured. The duct flow stagnation was properly predicted, but helium concentration inside the cooler stayed lower than in the experiments. The detailed APROS model reproduced the pressure behaviour very well. Some drop in the cooling rate due to helium enrichment during the helium injection phase could be captured, but generally, the cooling rate was over predicted. The general conclusion of the APROS simulations is that a lumped parameter code is able to simulate the most important phenomena inside the containment including the tube bundle cooler, if the nodalisation is built up properly. A very simple nodalisation does not give necessarily accurate or conservative results, and rather complicated multi-cell nodalization is needed to model satisfactory the stratification/mixing phenomena inside the cooler box and other parts of the test facility.



a) b)

Figure 10. a) Surface grid with some parts cut are shown. All cells are hexahedral, the triangular surface features are from post processing. b) Close view of the cooler unit.



a) b)

Figure 11. a) A 64-cell APROS nodalisation for vessels with a connecting pipe. b) A 6-cell nodalisation for the cooler.

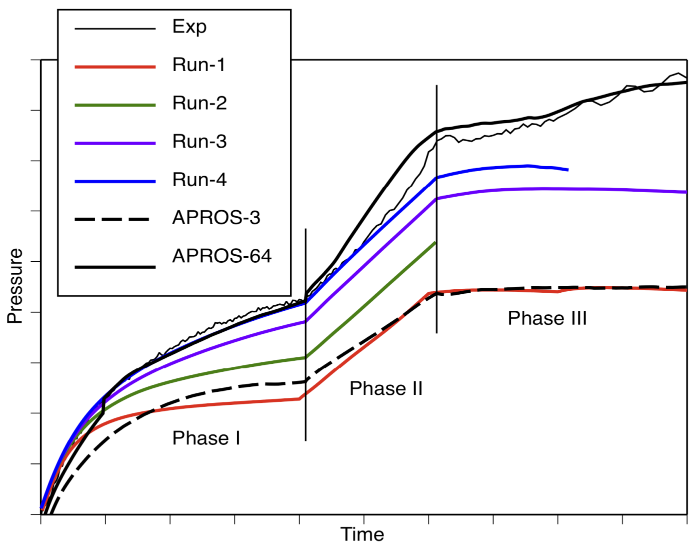


Figure 12. Messured and calculated pressures in Fluent runs with increasing modelling detailnes and with two APROS nodalisations.

APROS Containment capabilities to model suppression pool containment were tested by calculating PPOOLEX experiments. The PPOOLEX STR09 and PPOOLEX STR-11 experiments studied temperature stratification and mixing in the wet well. In the experiment steam was blown to the water pool through a blowdown pipe. Small steam flowrate resulted in stratified pool and higher flow rate mixed the pool. The POOLEX STB-21 experiment was earlier modelled with a very simple nodalisation, only one node for the water pool and two for the environment. Simple user definable steam velocity criteria for stratification and mixing were added in the code to predict stratification. In some experiments this approach gave good results and it was possible to reproduce the stratification and mixing measured in the experiment. Interpretation of the latest experiments is still going on, but it looks like the steam velocity in the blowdown pipe cannot alone define stratification and mixing in all the experiments and further model development is foreseen in co-operation with KTH/Stockholm in NORTHNET framework.

2.4.3 CFD modelling of NPP horizontal and vertical steam generators (SGEN)

The objective of the project is to develop a simulation methodology and tool for the modelling of horizontal and vertical steam generators of NPPs, where the multidimensional effects and the two-phase flow phenomena are taken into account. The model developed in the project includes the essential physical phenomena occurring in steam generators, such as heat transfer from the primary to the secondary side and the pressure loss of the two-phase flow in the tube banks of the secondary side.

Three-dimensional simplified model is made for a horizontal steam generator of VVER-440 NPP and for the vertical steam generator of the PWR PACTEL test. The models of the secondary sides are implemented in the commercial Fluent CFD code. The primary circuit is modelled with Apros.

Specific goals in 2010

The model for vertical steam generators is improved based on the simulation results. The model of the vertical steam generator is tested by comparing the simulation results to the available results of PWR-PACTEL experiments, which were performed by Riikonen et al. at the Lappeenranta University of Technology.

In Figure 1, the calculated stationary state of the secondary side of the PWR-PACTEL steam generator is shown for the experiment NC-10. The hot side of the steam generator is on the left-hand side, where the vapor generation is largest. The cold side is on the right, where cold feedwater is flowing from the downcomer. The temperature on the cold side is so low that bulk condensation of vapor occurs.

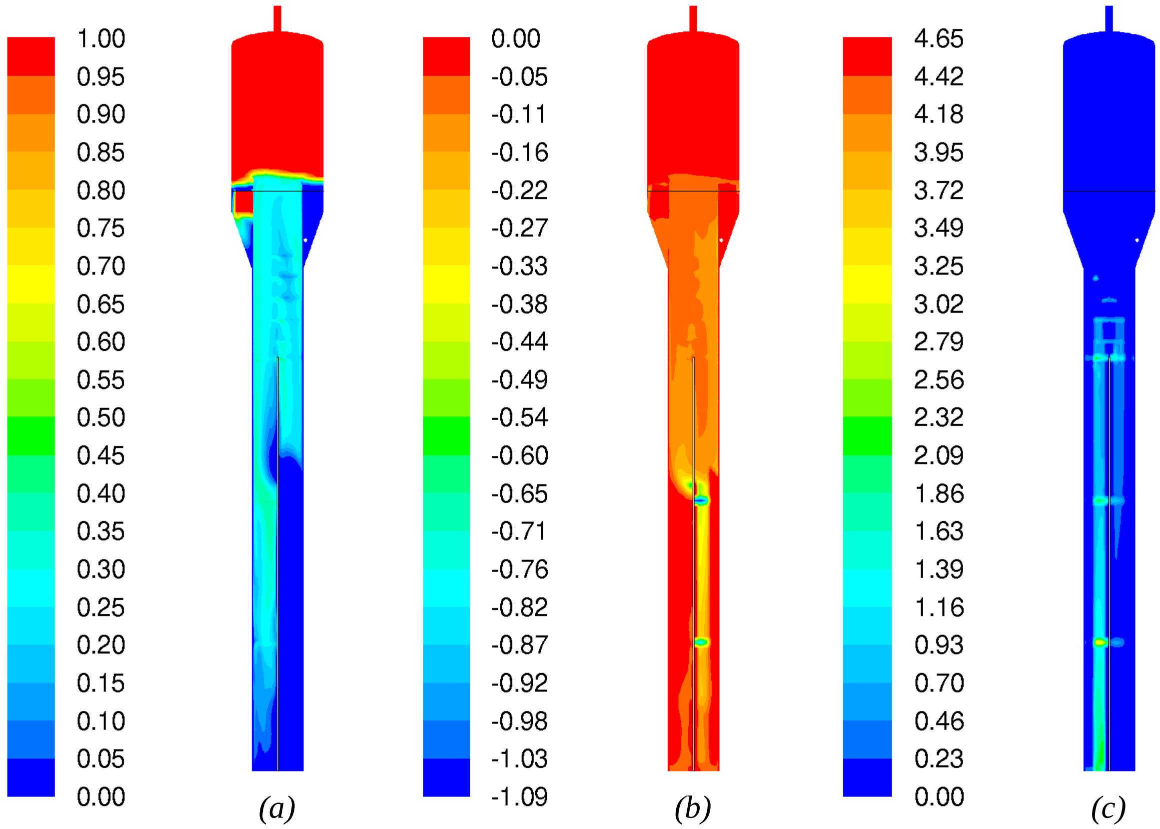


Figure 1. CFD modeling of the PWR-PACTEL steam generator: (a) Void fraction [-], (b) bulk condensation rate [kg/m^{3}s], and (c) vapor generation rate [kg/m^{3}s] in the middle plane of the steam generator.

In 2010, sensitivity analysis simulations are performed for horizontal steam generators. The Fluent-Apros coupling tool is improved for performing transient calculations. A short transient simulation, where the temperature of the feedwater decreases suddenly, is performed for the horizontal steam generator. Transient is first calculated with Apros, and the calculated temperature of the primary circuit is transferred to the numerical mesh of the Fluent model. Then, the CFD calculation of the secondary side is performed with Fluent by using the transient primary tube temperatures as a boundary condition.

In the transient, the temperature of the feedwater decreased suddenly by approximately 60° C. In Figure 2, the behavior of the iso-surface of the 70% void fraction during the transient is illustrated. Before the temperature drop, the surface is between 2.5 and 2.8 meters. Later, the surface has dropped to the level of about 2.3...2.5 meters.

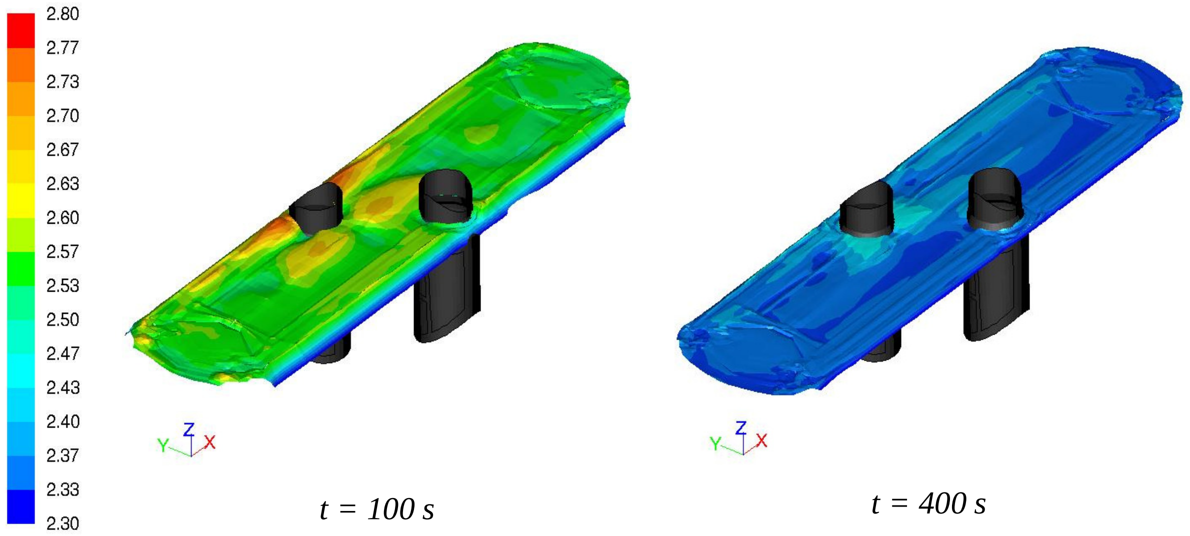


Figure 2. Iso-surface of 70% void fraction of steam on the secondary side of a horizontal steam generator. The iso-surface is colored with the vertical coordinate [m].

Deliverables in 2010

- Report: CFD modeling of the PWR-PACTEL steam generator
- Report: CFD modeling of the behavior of the VVER-440 steam generator

Acknowledgement: The authors are grateful to Mr. Vesa Riikonen and project PAOLA for providing the information on the PWR-PACTEL steam generator and the data on experiment NC-10. The data was only made available to two of the authors (T.P. and V.H.) because an international blind benchmark calculation on the PWR-PACTEL facility was simultaneously in progress.

2.4.4 Improvement of PACTEL Facility Simulation Environment (PACSIM)

The main objectives of the PACSIM project is to enhance the utilization of the TRACE simulation environment of the PACTEL facility with TRACE thermal hydraulic code. The Finnish Radiation and Nuclear Safety Authority, STUK, has required an independent tool to support safety and licensing analysis and decided to use the TRACE code. The use of TRACE enhances the preparedness to give analysis support and improves education in computational thermal hydraulics. During the year 2010 in the PACSIM project the earlier prepared TRACE models have been used for simulations of experiments carried out with VVER PACTEL facility containing horizontal steam generators. The project has given important validation knowledge for achieving the final goal of the full-scale VVER-440 model preparation, which will be carried out outside the SAFIR2010 programme. Another objective in the project has been preparation of a new TRACE-model with vertical steam generators, simulating the new PWR PACTEL facility set-up. The TRACE-code calculations have given valuable analysis and comparison support for the APROS calculations and the PWR PACTEL experiments.

Specific goals in 2010

Specific goals in 2010 calculations chosen experiments with complete TRACE input decks of the PACTEL facility both for VVER and PWR PACTEL facilities. Also, increased practical experience in the using the TRACE code was achieved. The functionality of the both model was tested and first calculations were carried out in order to validate the model of the VVER

PACTEL facility. The model of VVER PACTEL was validated against small break LOCA experiments SBL-31, SBL-33 and IMPAM VVER T2.3 (IMP06). The calculated results agreed well with the experiment data in most cases.

Another main goal during 2010 was to calculate new experiments carried out with PWR PACTEL with vertical steam generators. The chosen calculations for validation the tests were loss-of-feedwater experiment LOF-20, small break LOCA experiment SBL-50 and stepwise inventory reduction test SIR-31. The calculating results were agreeable with the experiment.

Deliverables in 2010

- Validation report: Calculation of PACTEL experiments SBL-31, SBL-33 and IMPAM VVER T2.3 (IMP06) with the TRACE code.
- Validation report: Simulations of the LOF-20, SBL-50 and SIR-31 PWR PACTEL experiments with the TRACE code

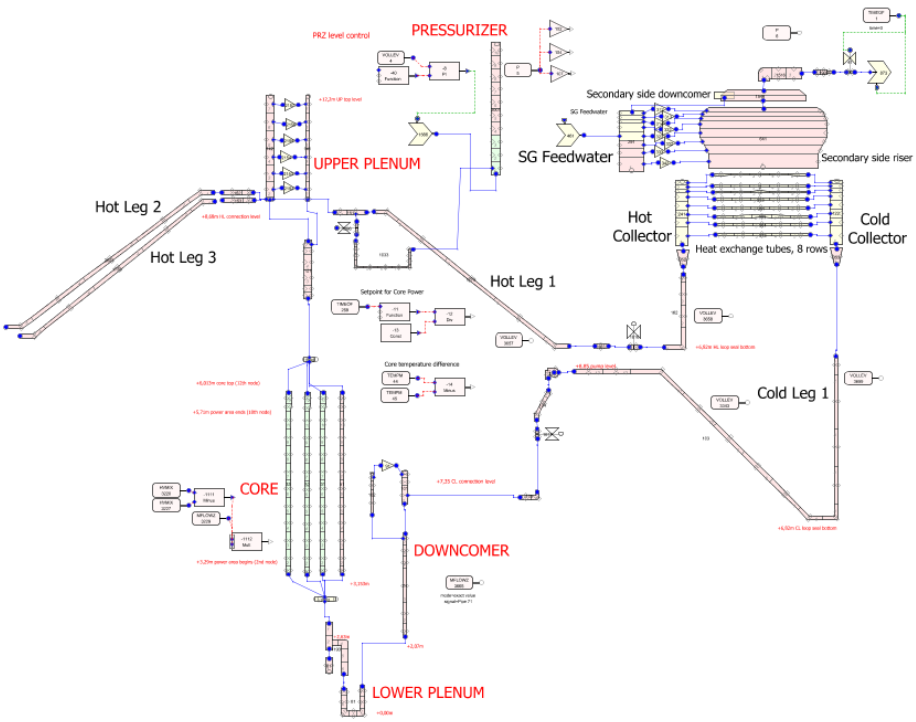


Figure 1. Main view of the VVER PACTEL facility model by SNAP editor.

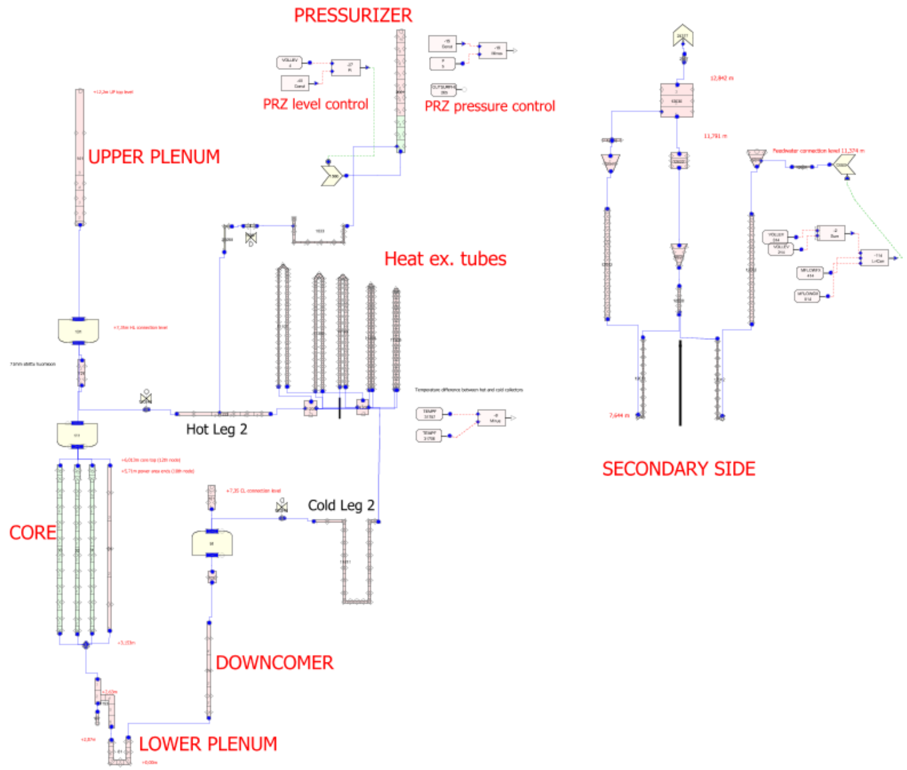


Figure 2. Main view of the PWR-PACTEL facility model by SNAP editor.

2.4.5 Condensation experiments with PPOOLEX facility (CONDEX)

The objective of the project is to improve understanding and increase fidelity in quantification of different phenomena in boiling water reactor (BWR) containment during steam discharge. These phenomena could be connected, for example, to bubble dynamics, direct-contact condensation (DCC), pressure oscillations, thermal stratification and global circulation and mixing in the pool. To achieve the project objectives, a combined experimental/analytical/computational study programme is being carried out. Experimental part (LUT: CONDEX) of the project is responsible for the development of a database on condensation pool dynamics and heat transfer at well controlled conditions. Analytical/computational part (VTT: NUMPOOL and THARE, KTH: NORTHNET RM3, LUT: CONDEX) use the developed experimental database for the improvement and validation of models and numerical methods including CFD and system codes. Also analytical support is provided for the experimental part by pre- and post-calculations of the experiments. The PPOOLEX test facility, modelling dry and wet well compartments of BWR containment and withstanding prototypical system pressure, is utilized in the experimental part of the project.

Specific goals in 2010

Specific goals in 2010 included two experiment series with the PPOOLEX test facility and simulation of several previous experiments with NEPTUNE_CFD and TransAT codes.
In the experiments with two parallel blowdown pipes, the objective was to study chugging phenomena (rapid condensation) while steam is discharged into the condensation pool filled with sub-cooled water. Particularly, the aim was to study if the pipe material (polycarbonate)

used in the earlier experiment series in 2009 with two blowdown pipes has had an effect on the general chugging behaviour and measured loads. Structural loads due to pressure oscillations were also compared to a single pipe situation. The aim was also to produce data for evaluating the capability of CFD and lumped parameter computer codes to predict pressure behaviour in a pool with more than one blowdown pipe. Two blowdown pipes made of steel were installed and equipped with temperature and pressure measurements (Figure 1).

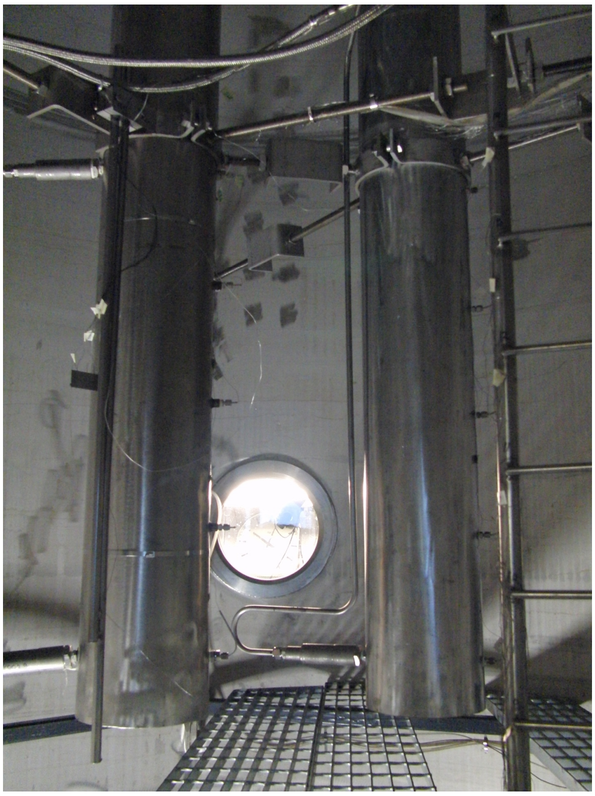


Figure 1. Parallel blowdown pipes in the PPOOLEX facility.

The formation and collapse of steam bubbles and the movement of the steam/water interface inside the pipes seemed to be synchronous on the basis of visual observations during the experiments and temperature measurements inside the pipes. A more detailed analysis with the help of the high speed video and high frequency pressure measurements revealed however, that there can be up to a 70 ms time difference between the occurrence of steam bubble collapses at the outlets of the two pipes (Figure 2). There was no clear pattern in which pipe the steam bubble first starts to collapse. Several successive bubbles can collapse first, for example, in pipe 1 but then the order can change for a single or several cycles.

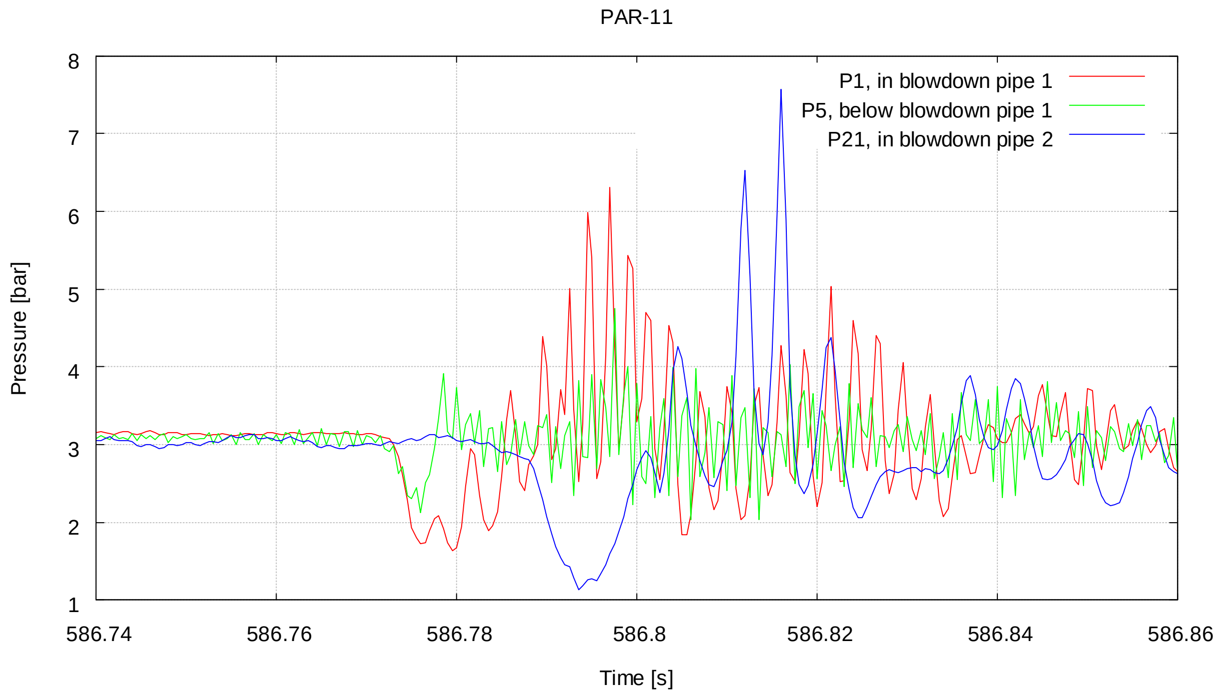


Figure 2. Pressure pulses caused by the non-synchronous collapse of parallel steam bubbles at the outlets of the two blowdown pipes.

The pipe material has an effect on the condensation phenomena inside the blowdown pipes. When the experiments done in 2009 with the polycarbonate blowdown pipes are compared with the steel pipe experiments a huge difference between the measured pressure curves inside the pipes can be observed. With the same test conditions the amplitude of the pressure pulses caused by water hammer is considerably larger in the steel pipe experiments. It seems like the flow mode is different with the polycarbonate pipes from that with the steel pipes. Due to minimal heat conduction through the polycarbonate pipe wall condensation tends to happen at the pipe outlet and therefore no high pressure loads due to water hammer are experienced inside the pipe.

Five thermal stratification and mixing experiments were carried out in August–November 2010. The main objective was to study thermohydraulic loading of the wet well structures due to thermal stratification as well as to get comparison data for evaluating the capability of GOTHIC and APROS codes to predict stratification and mixing phenomena. Furthermore, the sound velocity measurement system was tested in the wet well pool. The experiments consisted of a small flow rate stratification period and of a mixing period with continuously or stepwise increasing flow rate. The dry well structures were preheated before the actual experiments.

When the steam flow rate was low enough (typically ~100–150 g/s) temperatures below the blowdown pipe outlet remained constant while increasing heat-up occurred towards the pool surface layers indicating strong thermal stratification of the wet well pool water. During the stratification period the highest measured temperature difference between the pool bottom and surface was approximately 40 °C. During the mixing period total mixing of the pool volume was not achieved in any of the experiments (Figure 3). The bottom layers heated up significantly but never reached the same temperature as the topmost layers. The lowest measured temperature difference between the pool bottom and surface was 7–8 °C.

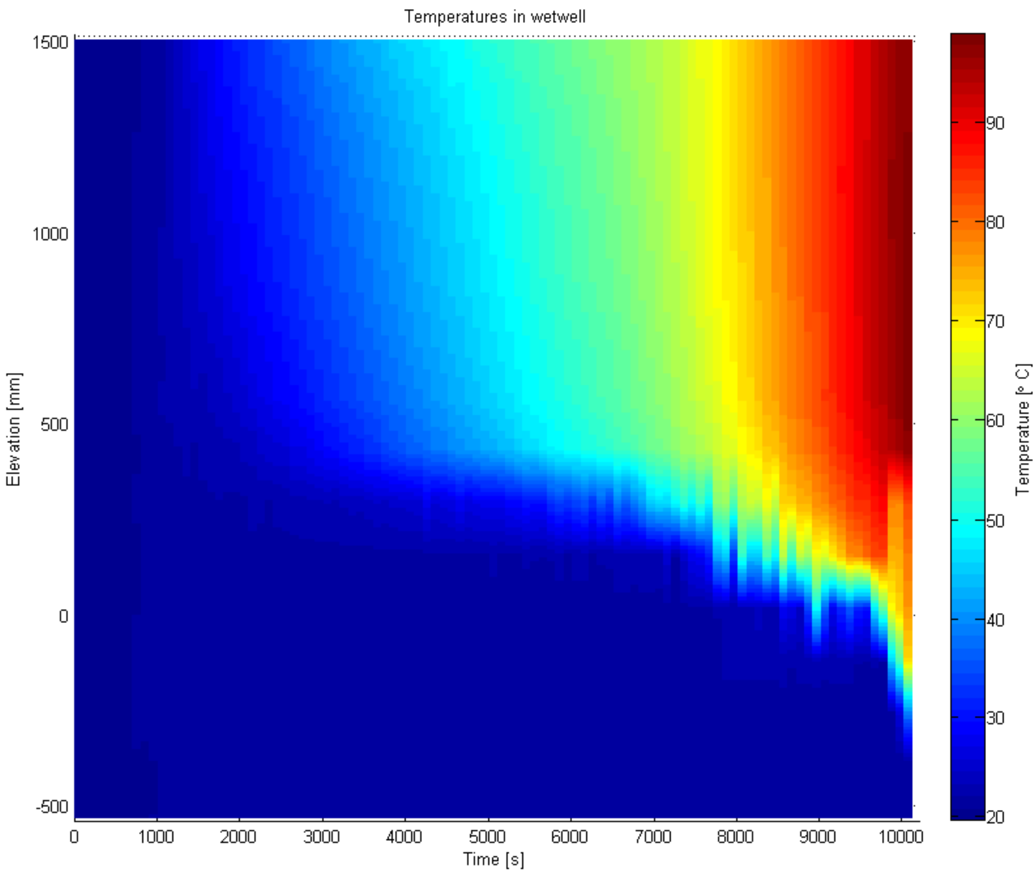


Figure 3. Vertical temperature distribution in wet well water in a stratification and mixing experiment.

According to the test results, it seems that a small void fraction doesn't have an effect on the speed of sound in the wet well water pool and that the acquired sound velocity measurement system cannot be used for the estimation of void fraction. However, more tests on this issue have to be executed before a final conclusion can be made.

The work with NEPTUNE_CFD code, being developed in the EU/NURISP project, continued with the simulation of selected POOLEX experiments. 2D and 3D simulations of a chugging related experiment STB-28 and 3D simulations of a quasi-steady steam-water interface experiment STB-31 were done. The STB-31 experiment was also calculated with TransAT CFD code by using several different grid resolutions.

The qualitative behaviour of bubble formation seems to be promising but outstanding sensitivity to the initial location of the steam/water interface has been observed. The initial turbulence level seems to be the most crucial parameter. To invoke mixing and thus developed turbulence field, few vigorous chugging cycles may be needed in the simulation. Regarding the bubble size and collapse time, e.g. the Hughes-Duffey condensation model seems to be capable of providing realistic condensation rates during the chugging mode, if the initial condition of simulation leads to mixing strong enough (Figure 4).

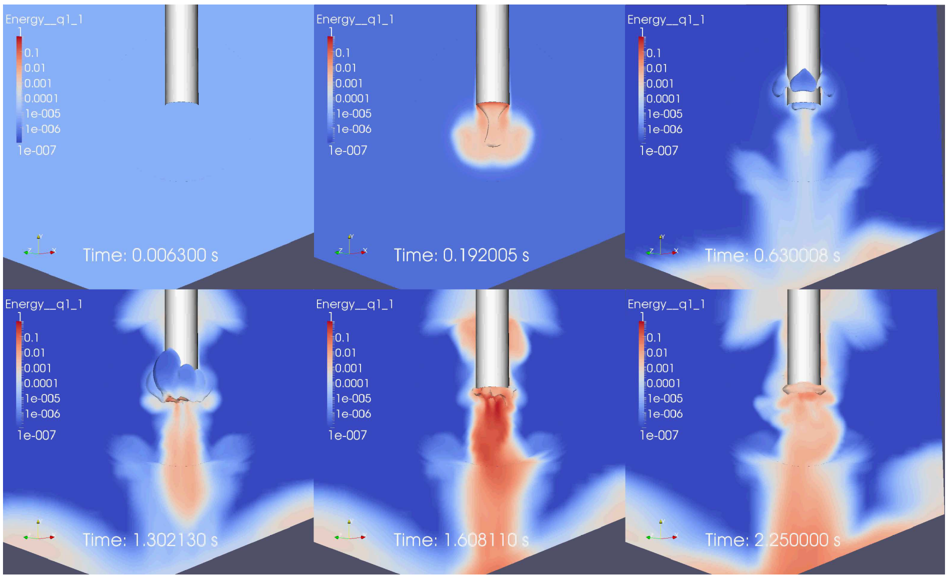


Figure 4. Turbulence kinetic energy in NEPTUNE_CFD simulation of the STB-28 experiment. Hughes-Duffey (1991) DCC model with initial surface set inside the pipe.

Deliverables in 2010

- A series of steam discharge experiments was carried out in the PPOOLEX test facility with two parallel blowdown pipes made of stainless steel. The aim was to study chugging phenomenon in a two blowdown pipe system while steam is discharged into the condensation pool filled with sub-cooled water. Particularly, the aim was to study if the pipe material (polycarbonate) used in the earlier experiment series in 2009 with two pipes has had an effect on the general chugging behaviour and measured loads. Pressure loads inside the blowdown pipes and in the condensation pool were registered with the help of several pressure transducers. Seven experiments were conducted. The steam mass flow rate into the test vessel ranged from 220 g/s to over 2350 g/s and the temperature of incoming steam from 148 °C to 207 °C. The behavior of the pipes was non-synchronous. Up to a 70 ms time difference between the occurrence of steam bubble collapses at the outlets of the two pipes was observed. There was no clear pattern in which pipe the steam bubble first starts to collapse.

- Five experiments consisting of a small flow rate stratification period and of a mixing period with continuously or stepwise increasing flow rate were carried out. One stainless steel blowdown pipe, submerged by 1.05 m, was used. During the stratification period the highest measured temperature difference between the pool bottom and surface was approximately 40 ºC. During the mixing period total mixing of the pool volume was not achieved in any of the experiments. The bottom layers heated up significantly but never reached the same temperature as the topmost layers.

- POOLEX experiments STB-28 and STB-31 were simulated with NEPTUNE_CFD_1.0.7 code. 3D simulations with a light “merged” mesh gave better convergence than earlier 2D-axisymmetric and 3D simulations. Regarding the bubble size and collapse time the Hughes-Duffey condensation model seems to be capable of providing realistic condensation rates during the chugging mode, if the initial condition of simulation leads to mixing strong enough. The fourth NURISP SP2-TH meeting in Stockholm on June 9-11 was participated. The periodic report of the work of LUT in the EU/NURISP SP2 was written.

- NORTHNET Roadmap 3 meetings were participated in Olkiluoto, Stockholm and Espoo. Status of condensation pool research in participating organisations (LUT, VTT, KTH) was presented and Roadmap 3 plan updated for the coming years. A combined POOL-NKS funding application for 2011 by LUT, VTT and KTH was written.

2.4.6 Passive safety system simulation (PASSIMU)

The objective of the project is to study the present situation in Finland and internationally in modeling passive safety systems, in respect of both the computational preparedness and the possible needs of new experiments. The nuclear power plant concepts proposed as options for the next nuclear power plant unit(s) in Finland introduce several variations of passive safety functions. The focus in this project is set on these seven Generation III nuclear power plant concepts and the passive features in those. The first goal of the project was to prepare a review on validation status of the passive safety systems related aspects. The second and the third goal of the project were set to study applicability of certain experimental facilities in passive safety system related studies and to test computer code(s) in conditions specific for the passive features. The evaluation and validation of the passive safety systems are mainly based on the experiments and computer code analyses. The operational conditions when passive features are present, such as driving force, pressure and flow rate, are typically beyond the original design conditions of the codes. The computer codes and experimental facilities will be reviewed in order to ensure the availability of analytical tools in the specific low pressure, low driving force and low flow conditions. As the code validation depends on the available experimental data, the experimental evaluation situation is reviewed. The project deliverables, the three reports, provide background material for further planning in future projects. The project orients to activate ideas for experimental and analytical modelling.

Specific goals in 2010

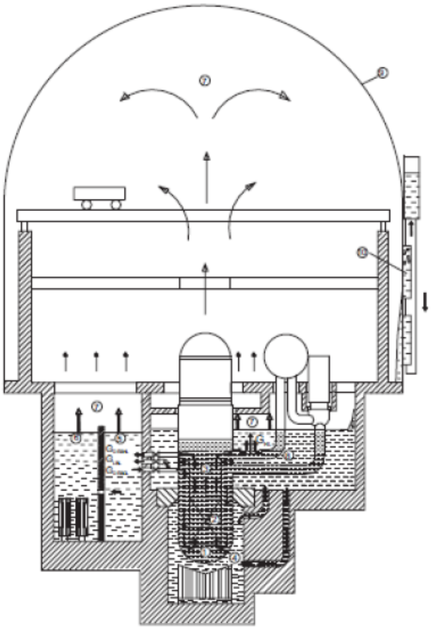
Specific goals in 2010 included system code testing in conditions typical for passive safety system operation and study on applicability of experimental resources at Lappeenranta University of Technology on passive safety system evaluation processes. Two PACTEL experiments on VVER-640 studies were chosen for simulation test cases, and utilization of the latest APROS version in simulations resulted to be fairly satisfactory. A review was prepared on the applicability of experimental facilities, resources and already gained experiences in passive safety system related experimental studies. Lappeenranta University of Technology has a wide experience on thermal-hydraulic experimental research, planning, constructing and operating test facilities, and this know-how and available hardware could be utilized in future studies on passive features. Additional laboratory premises, modern measurement equipments and data acquisition systems provide also new sophisticated possibilities. The results of these two goals are presented in a form of reports, intended to be as background material for future needs.

Deliverables in 2010

- One task of the PASSIMU project was to test thermal-hydraulic system code(s) in a low pressure, flow and driving force situation, typical conditions for passive safety systems. Two older PACTEL experiments were chosen to be the test cases in this sub-task, as these experiments were set to study features of the passive safety systems in suitable matching conditions, i.e. studies of VVER-640 concept focusing on designed passive safety system operation. The modified PACTEL set-up included original pressure vessel parts connected to additional tanks with connecting pipelines. The

APROS code 5.09 –version was utilized to re-produce the post-test calculations the two tests. These calculations were performed with two simulation models, simple and modified models. The simulation calculations were able to reproduce the main three events of the transients, i.e. first one-phase heating period, second oscillating transition period, and third steady two-phase natural circulation period. These calculation cases produced satisfactory quantitative and qualitative results compared with the measured data.

- The other sub-task in 2010 was to study the applicability of experimental facilities, other resources and gained experiences in passive safety system related experimental studies. Lappeenranta University of Technology has quite a wide experience on thermal-hydraulic experimental research, including database of about 900 experiments. The facilities include separate effect as well as large integral test facilities, such as PACTEL (PWR PACTEL) and PPOOLEX. These facilities could be available for future studies, either as side facility such as steam or other convenient environment provider, or as part of a modified set-up system with additional passive features attached to them, such as elevated tanks, pools or condensers. The operative unit at the university in this field of research, i.e. the Nuclear Safety Research Unit, has well established preparedness to plan and construct also new separate effect test facilities and rigs. The new additional laboratory premises could provide surroundings for example systems simulating operation of passive systems utilizing gravity forces. Also, modern measurement equipments and data acquisition systems would provide more sophisticated possibilities, as the enhancement of the infrastructure is on-going.



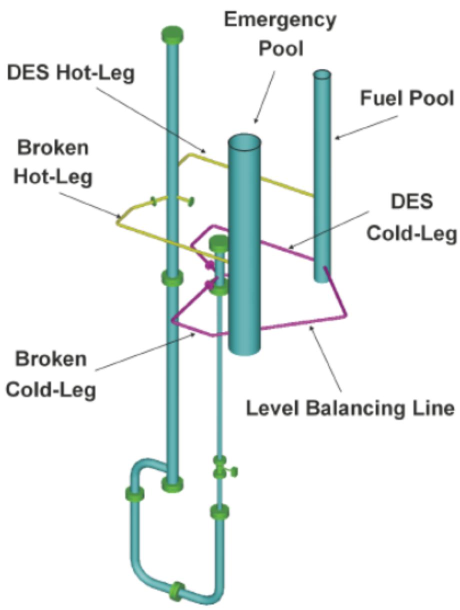


Figure 1. VVER-640 hot leg break situation (left) and modified PACTEL set-up (right).

2.4.7 OpenFOAM CFD-solver for nuclear safety related flow simulations (NuFOAM)

In commercial CFD software, the source code and the implementation of the numerical methods are not openly available. Thus, the possibilities to modify the solver or to include new models are limited. In addition, the license policy prevents the effective utilization of parallel computer resources. More effective utilization of parallel computing would allow the use of developed physical modelling and detailed computational grids. This would improve the accuracy and reliability of analysis and increase the number of situations where CFD methods can be utilized.
The main aim of the project is to validate the open source CFD code OpenFOAM as a tool for nuclear safety related simulations. The Finnish OpenFOAM community in the field of nuclear safety is formed. In single-phase flow simulations, the aim is to simulate flow and heat transfer in a T-junction of pipes by using accurate computational models and to utilize effectively parallel computing. As a result a more detailed understanding of coolant mixing is achieved.

An existing Euler-Euler two-phase model of OpenFOAM is taken into use. The solver is modified for calculations of water-air and water-steam mixtures. The longer term goal is to be able to simulate subcooled nucleate boiling in fuel rod bundles. The code is validated against experimental data obtained from literature.

Specific goals in 2010

In 2010, a validation plan for the OpenFOAM CFD solver in nuclear safety analysis is written. The form of the necessary documentation is described and the set for first validation calculations is outlined.

An international OECD/NEA benchmark is participated. In the benchmark, thermal mixing is simulated in a T-junction of pipes in an experiment performed at Vattenfall R&D. Different turbulence models of the single phase solvers of OpenFOAM are tested and validated for solving thermal mixing. In addition to the SST k-ω turbulence model, the turbulence effects were simulated by using the time-dependent LES and DES approaches.

A new two-phase solver is implemented by modifying one of the existing two-phase solvers of OpenFOAM. The models needed for simulations of two-phase flows of gas and water are added in the solver. The modified solver is validated against data found in literature.

In Figure 1, calculation of the mixing in the T-junction by using the detached-eddy simulation (DES) is illustrated. Hot water is flowing from the vertical pipe into horizontal pipe, where it is mixing with cold water. On the left, the calculated time-averaged velocity field is shown. On the right, an instantaneous temperature on the pipe surface is illustrated. Oscillations in the surface temperature occur, which potentially can cause thermal fatigue and affect the integrity of the pipe.

In two-phase modeling, the twoPhaseEulerFoam solver from the OpenFOAM library is chosen for further development. Models for the interphasial drag, lift force and wall lubrication force have been added in the solver. The modified solver has been tested against the experiments on bubbly flow performed by Hosokawa and Tomiyama (2009) and by Prasser et al. (2003). In the experiments, detailed measurements have been performed on the flow of air-bubbles and water in vertical pipes. In addition to the flow velocities of gas and water, the radial distribution of gas and the turbulent fluctuations of the flow have been measured.

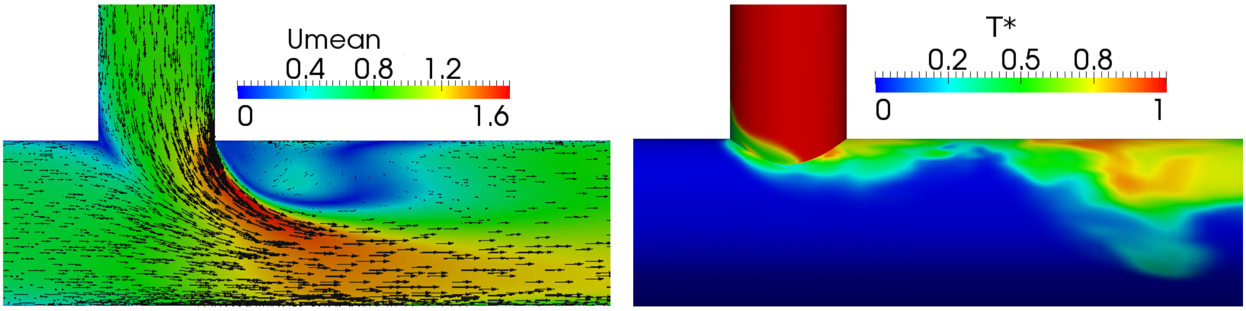


Figure 1. CFD simulation of mixing of hot and cold water in a T-junction of pipes with a detached-eddy turbulence model. i) Time-averaged velocity field in the intersection plane. ii) Instantaneous temperature on the surfaces of the pipes.

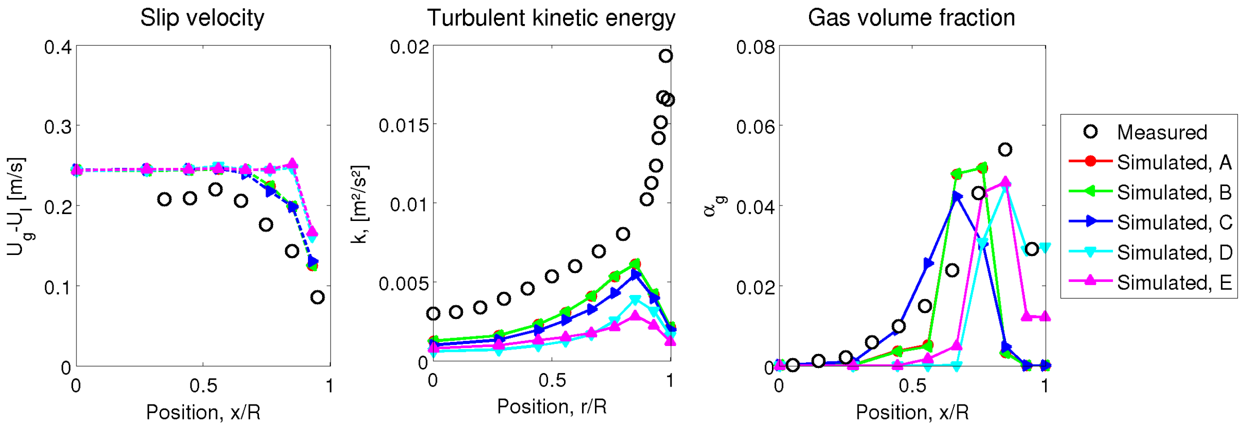


Figure 2. Comparison of experimental and simulated axial velocities, turbulent kinetic energy and gas volume fraction in Hosokawa and Tomiyama (2009).

In Figure 2, the results calculated with the modified OpenFOAM solver are compared to the experiments. On the left frame is shown the slip velocity between the phases, i.e., the difference between the gas and liquid phases. In the middle, the turbulent fluctuations calculated with different modeling techniques are compared to the measurements. On the right, the radial distribution of gas is shown. It is seen that in this case the maximum void fraction occurs near the pipe wall. In the pipe center, the void fraction is very small. This behavior is a result of the lift and wall lubrication forces affecting the bubbles.

A reasonable agreement with the experiments was achieved in both single-phase and two-phase calculations. Further improvement in the two-phase results could be obtained by improving the turbulence model and the near-wall treatment of the solver.

Deliverables in 2010

- Report: Validation plan of OpenFOAM for nuclear safety simulations
- Reports concerning single-phase flows: CFD study on thermal mixing in a T-junction, documentation of selected compressible turbulence models, documentation and validation of single-region buoyantPimpleFoam solver and conjugated heat transfer solver chtMultiRegionFoam, validation reports

on conjugated heat transfer and turbulence model near wall treatment in fully developed turbulent pipe flow.

- Reports concerning two-phase flows: Documentation of physical modeling and numerical implementation of the modified two-phase solver, two validation reports.

2.5 Severe accidents research area

There were four projects going on in 2010 in the severe accidents research area: Release of radioactive materials from a degrading core (RADECO), Primary circuit chemistry of fission products (CHEMPC), Core Melt Stabilization (COMESTA) and hydrogen combustion risk and core debris coolability (HYBCIS2).

2.5.1 Release of Radioactive Materials from a Degrading Core (RADECO)

The main objective of iodine behavior studies was to assess if the paints applied in Finnish nuclear power plants will contribute in formation of organic iodides under the chemical containment conditions prevailing in Finnish nuclear power plants during a severe accident. Organic iodides are highly volatile compounds which are difficult to remove from atmosphere with the existing filter technology.

Nitric acid is a principal radiolytic compound produced in large, and its production is another important problem concerning pH of solutions, owing to its chemical properties of being a strong acid and a strong oxidizing agent.

Specific goals in 2010

No iodine test was planned to do year 2010. The plan was to make summary report of all tests done and compare and fulfil these results with iodine data from international programs (PHEBUS-FP, EPICUR, OECD/BIP). It will be done together with CHEMPC project. Also the new results of the OECD/BIP project were closely followed.

There is a large scatter in the results from all of the programmes, so it is difficult to make comparisons between the different studies. The behaviour of iodine in water is dependent on the pH. High pH prevents the formation of elemental iodine and decreases the formation of volatile organic iodides. Chemical and radiolytic interactions with surfaces lead to evolution of gaseous iodine in the form of molecular iodine (I_2) and volatile organic iodides such as methyl iodide (CH_3I). These gaseous species are susceptible to radiolytic and chemical destruction in the atmosphere or deposition on surfaces. The balance between these removal mechanisms and the mechanisms for gaseous iodine production leads to the observed steady-state concentration of gaseous iodine.

The absorption of molecular iodine on painted surfaces depends on the ambient humidity or the amount of water absorbed by the paint. Only a small portion of the total amount of the iodine released is detected in the gas phase at the end of the irradiation. The results from RADECO project was the same level, mostly under detection limits.

The formation of nitric acid during high dose rates was tested. It is known that gamma irradiation of air/water will lower the pH. The high dose is achievable using Gammacell 220 ^{60}Co gamma source in Otaniemi. The formation of nitric acid in water/air system was measured by irradiating the known mixture with a gamma source and determining the amount of nitric ions formed in the irradiation after chemical treatment by spectrophotometry. The formation of radiolytic products can be commonly characterized by the so-called G-values, i.e., the number of molecules formed per 100 eV of radiation energy absorbed.

First series of tests were done with a small amount of distilled water and air irradiated in a closed vessel, so called moist air test. In addition some tests only with pure water phase were done. These test give more information on the formation of nitric acid in the water phase where the concentration of nitrogen is very low compared to the gas phase. The last preliminary tests were done using moisture air and painted concrete block to see the effect of painted surfaces, Figure 1.

Figure 1. The position of concrete block sample in Gammacell 220 ready for irradiation.

G-value calculated of these moist air results is 2.42 parallel experiments gave G-value 2.32. The G values found in literature for nitric acid formation from air range $G_{(HNO3)}$ = 2.3 -2.7 molecules/100 eV [1,2]. Compared to literature values measurements yield were exact the same. The determination of G-value for NO_3 formation of water in radiation gave G-value 0.024. This is three times that given in literature. The G values found in literature for nitric acid formation from water is $G_{(HNO3)}$ = 0.007 molecules/100 eV [3]. Our experiment was made in room temperature. Increasing the temperature decreases the amount of nitrogen dissolved in water and decreases the G-value for nitric acid formation in water. A preliminary experiment to study the influence of painted surface in the nitrate concentration was made by irradiating water with and without painted concrete block. The results with the 2.6 kGy dose gave 4 times more nitrate into the water than blank case.

Deliverables in 2010

- Zilliacus, R., Kekki, T., Formation of nitric acid during high gamma dose, VTT-R-00774-11, VTT, Espoo, 2011, 8 p.

- Lipponen, M., Kekki, T., Zilliacus, R., Comparison of experimental studies of organic iodide formation on painted surfaces, VTT-R-00775-11, VTT, Espoo, 2011, 19 p.

- Travel report of 6th Meeting of the BIP (Behaviour of Iodine) Project Programme Review Group and experts meeting on the proposed OECD/STEM project on source term evaluation and migitation has been sent to the reference group.

- Information related to the progress of the OECD/BIP Programme was distributed.

2.5.2 Primary circuit chemistry of fission products (CHEMPC)

The objective of the project is to study the behaviour of iodine in a 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 is a joint project with IRSN Cadarache research centre (2006-2010) for the determination of iodine chemistry in the primary circuit. The objective of the 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 focus in the gas phase chemistry of iodine in similar experimental conditions. In this study, novel analysis techniques for quantification of chemical reaction kinetics are developed. Such measurements provide information on high temperature chemistry and enable validation of for example iodine chemistry codes.

Radiolytic oxidation of elemental iodine in containment conditions is studied together with Chalmers University of Technology. The objective is to verify the possible iodine oxide aerosol particle formation. Another aim is to identify the reaction product species. The facility built at VTT is applied in this study. Desorption of gaseous iodine from deposited iodine oxide aerosols on different surfaces in containment conditions is studied in co-operation with RADECO project. Another objective is to study the retention of aerosol particles in heat exchanger under condensing conditions.

The last objective of the project is to continue to follow up Phebus FP and International Source Term Programmes (ISTP). A study of applying analysis techniques developed at VTT in ISTP is continued. VTT participates also in follow up meetings of ARTIST2 project.

Specific goals in 2010

The main goals in 2010 were to study the behaviour of iodine in primary circuit and containment conditions. In primary circuit experiments was studied the effect of reactions on primary circuit surfaces on the release and transport of iodine. Another goal was to study the oxidation of organic iodine – methyl iodide (CH_3I) - in conditions similar to the containment of a nuclear power plant during a severe accident. As a result a wide database for modelling was achieved. Next these experiments are explained more exactly.

The first objective in primary circuit experiments was to update the facility. Updates of the facility include new automated sampling system, new primary diluter and improved data logging capability. The second objective was to study the effect of reactions on primary circuit surfaces on the release and transport of iodine. In primary circuit studies the source of iodine was CsI powder which was evaporated at 400°C and 650°C on ceramic surface under

$Ar/H_2/H_2O$ atmosphere. Molybdenum oxide additive was also used. These experiments showed that as CsI precursor was used in alumina evaporation crucible, the results coincided mostly with the old experimental data. The surface of the reaction furnace tube will be pre-oxidized in the coming experiments.

The objective in containment experiments was to determine the influence of ozone and methyl iodide concentration as well as that of radiation intensity on the possible formation of iodine oxide aerosols from methyl iodide gas. The studied radiation types were UV (c-type) and gamma radiation. Another task was to study whether iodine transports as gaseous molecules or as attached to aerosol particles. The experiments were conducted at 50°C, 90°C or 120°C. The atmosphere was dry air or low amount of humidity (~2 vol-%) was added in some experiments. The volume fraction of oxygen in a gas flow was 21%. There were also revaporisation studies, in which the only source of iodine was the one deposited on the surface in the previous experiment. In these experiments, the aim was to study the effect of ozone and radiation on possible desorption of iodine from the surfaces. Possible gaseous reaction products and formation of particles were also measured. The total gas flow through the facility ranged from 2 l/min to 6 l/min (NTP).

In these experiments, the formation of ozone in air was significantly lower by gamma radiation than by UV radiation. The main gaseous reaction products from radiolytical oxidation of methyl iodide by UV radiation were formaldehyde and methanol. The formation of iodine oxide aerosol particles was also very efficient. As a result from decomposition of methyl iodide by gamma radiation, the main gaseous reaction products seemed to be iodoform (CHI_3) and formaldehyde. There was no formation of particles, because the ozone concentration produced by gamma radiation was very low. Ozone would be needed to oxidize gaseous iodine to iodine oxide particles. However, methyl iodide was not detected at the outlet of the facility. The reason for this is not known and the results are therefore uncertain.

A copper diffusion denuder was built and tested with gaseous iodine as well as with IO_x particles. The denuder trapped more than 99% of gaseous iodine and less than 2% of IO_x particles. This technique will be utilized in future experiments to separate gaseous iodine from iodine containing aerosol particles.

The third goal was to participate in international experimental program meetings. It included interpretation circle meetings of Phebus FP and ISTP programmes and participation in working group reviewing the progress of ARTIST2 project. As a result, data on severe accident phenomena is available. VTT participated also in reviewing the Phébus FPT-3 final report, which was issued at the end of 2010.

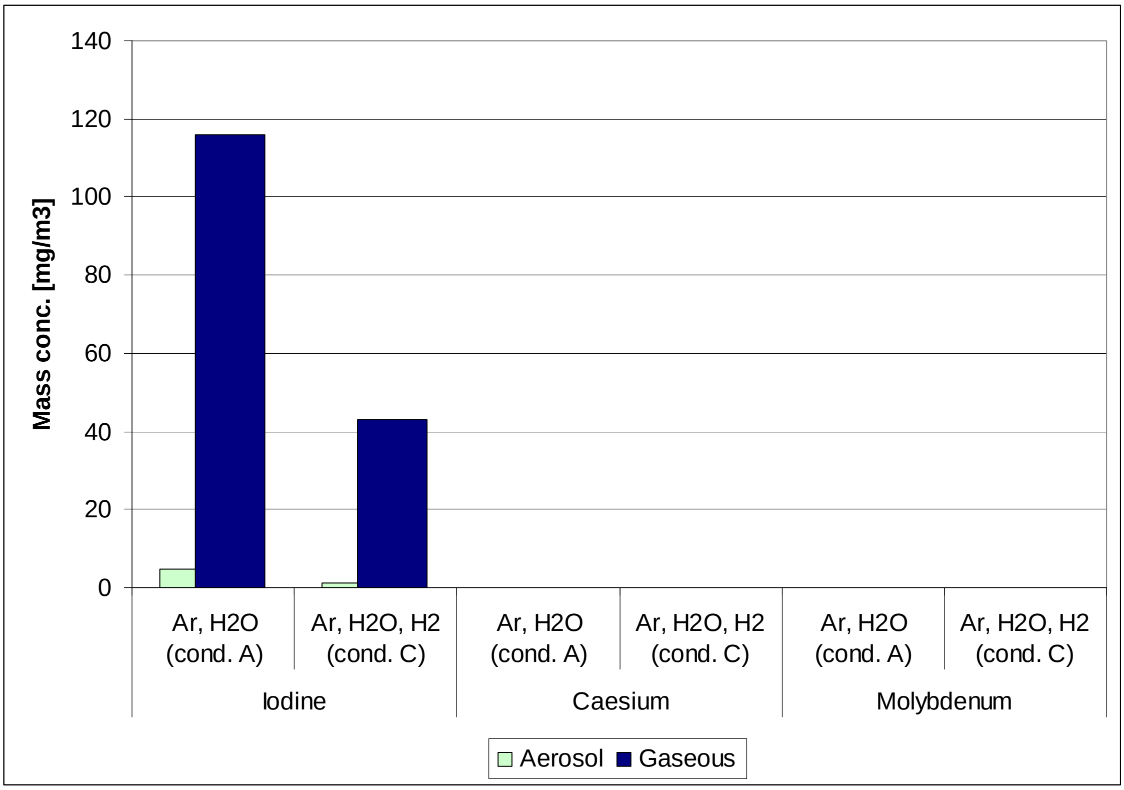


Figure 1. The transported mass concentrations of iodine, caesium and molybdenum in experiment on primary circuit chemistry of iodine are presented in figure. The results are calculated from aerosol filter and bubbling bottle ICP-MS data. It can be seen that when CsI and MoO_3 were used as precursor materials, gaseous iodine was only released at 400 °C temperature, which was already predicted in the light of previous experiments conducted with the old facility. The release of iodine seemed to decrease when hydrogen was added in flow. Some amount of gaseous iodine reacted also with Mitex^{TM} aerosol filter.

Deliverables in 2010

- A scientific paper "Influence of corium oxidation on fission product release from molten pool" was published in Nuclear Engineering and Design Vol. 240, No:5, pp. 1229-1241, 2010.

- A conference paper "Gas phase reaction of organic iodine in containment conditions" was published in Proceedings of the International Congress on Advances in Nuclear Power Plants 2010 (ICAPP 2010), 13–17.6.2010.

- A conference paper "Ongoing investigation of oxidising impact on source term" was published in Proceedings of the 4th European Review Meeting on Severe Accident Research (ERMSAR-2010), 11–12.5.2010.

- An abstract "Formation of particles from organic iodine species in the gas phase of NPP containment" was published in Proceedings of International Aerosol Conference 2010 (IAC2010), 29.8–3.9.2010.

- An abstract "The effect of chemical reactions on primary circuit surfaces on iodine" was published in Proceedings of American Nuclear Society: 2010 Winter Meeting and Nuclear Technology Expo, 7–11.11.2010.

- A report “EXSI facility - Primary circuit chemistry of iodine” was published in January 2011.
- A report “Experimental study on iodine chemistry (EXSI) – Containment experiments with methyl iodide” was published in January 2011.
- A report “EXSI facility – Experiments on radiolytical oxidation of CH_3I by gamma radiation” was published in January 2011.
- A report “Trapping of iodine with diffusion denuder” was published in January 2011.
- A Master´s Thesis “Chemical reactions on primary circuit surfaces and their effect on fission product transport in a severe nuclear accident” was published in June 2010.

2.5.3 Core Melt Stabilization (COMESTA2010)

The objective of the project is to develop competence for computational modeling of severe accidents and to investigate phenomena related to steam explosions and molten core – concrete interactions. Via the CSARP agreement, the latest versions of the severe accident simulation program MELCOR are got into use. MELCOR modeling expertise is developed further by simulating experiments related to two-phase flows. The international OECD SERENA-2 project generates new knowledge of steam explosions with real reactor materials. In addition, the steam explosion phenomenon is analyzed with computational methods. Results of the FESICO experiment, conducted in 2009, are further analyzed. Experiments conducted within the OECD MCCI-2 project are analyzed, and the last meeting and the final seminar are attended.

Specific goals in 2010

MELCOR is an integral severe accident analysis code, developed in the USA. In the frame of the COMESTA project, Finland participates in CSARP (Co-operative Severe Accident Research Program). This gives us a license for latest versions of MELCOR and the right to participate in the annual CSARP meeting. Modeling expertise was developed by simulating counter-current flow experiments with MELCOR.

OECD SERENA-2 (Steam Explosion Resolution for Nuclear Applications) is an international experimental research project on steam explosions. In the frame of COMESTA, Finland participates in the SERENA-2 project. The experiments are conducted in France and in Korea. In 2009, the VULCANO VB-U7 experiment was conducted in Cadarache, France, in co-operation with CEA. It investigated interaction between corium and EPR sacrificial concrete. The experiment employed oxidic corium, which included UO_2 and ZrO_2. In 2010, the experiment results were analyzed (Figure 1).

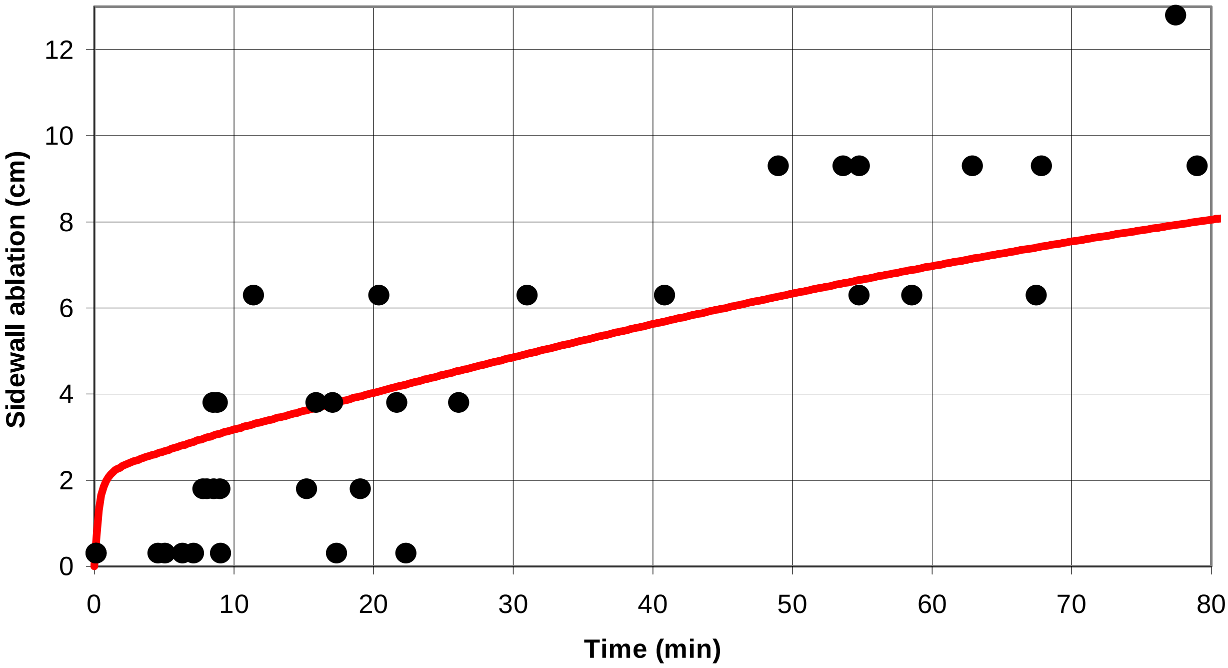


Figure 1. Sidewall ablation in VULCANO VB-U7 experiment. The dots mark the measured ablation, and the line is calculated with the FinCCI code, which was developed in the COMESTA project.

OECD MCCI-2 (Melt Coolability and Concrete Interaction) was an international experimental research program, investigating corium coolability and molten core – concrete interactions. In the three years long research program, experiments on corium coolability and molten core – concrete interactions were performed in two-dimensional geometries with real nuclear reactor materials. The investigated issues included large differences between concrete basemat and sidewall ablation with different concrete types, the effect of gases released from the concrete on the water ingression phenomenon, and melt pool coolability from below. The project ended in 2010. Within the COMESTA project, Finland participated in the MCCI-2 program. In addition, analysis and modeling work of the CCI experiments was continued.

Deliverables in 2010

- Counter-current flow experiments were simulated with MELCOR. It was found out that MELCOR significantly underestimates vertical counter-current flow rates. A research report was written and a presentation was given in the CSARP meeting.

- The MELCOR annual license fee was paid, giving the license to use MELCOR for all Finnish nuclear energy organizations.

- Two OECD SERENA-2 program meetings were attended.

- An OECD MCCI-2 program meeting and MCCI seminar were attended.

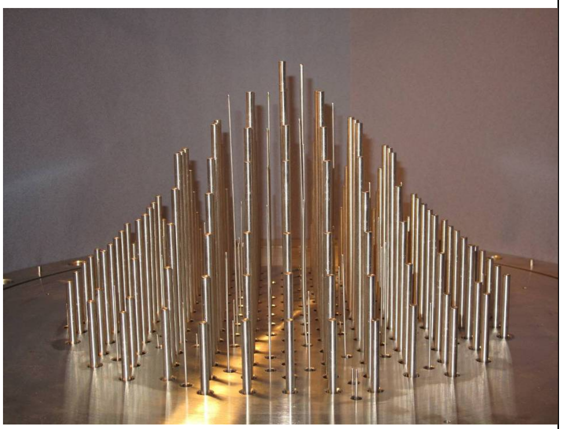
- Five CCI experiments were analyzed, and FinCCI code for simulating dry MCCI with oxidic corium was updated on the basis of the analysis. The CCI tests and VULCANO VB-U7 test were simulated with the FinCCI code, and a research report was written.

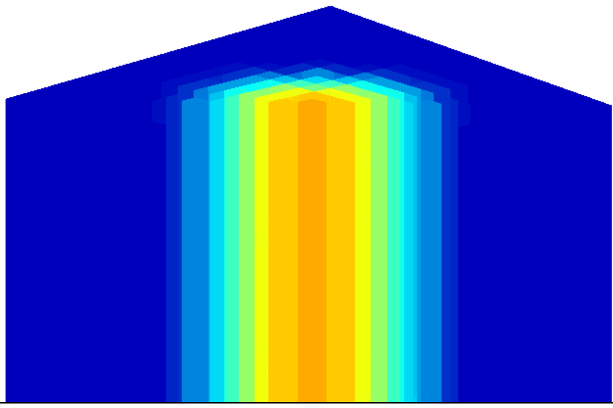
2.5.4 Hydrogen Combustion Risk and Core Debris Coolability (HYBCIS2)

The project focuses on two different topics in the area of severe accident research: the coolability of porous core debris beds and hydrogen behavior within the nuclear power plant containment. The COOLOCE test facility is used to measure dryout power in particle beds of different geometries. In addition to obtaining new experimental data important e.g. for the Finnish BWRs, the tests are used for validation and improvement of porous media codes applied for modeling of particle bed coolability. Hydrogen behavior (mixing and combustion) in the containment is analyzed by CFD tools such as the FLUENT code. Large-scale experimental data of hydrogen and recombiner issues as well as fission product behavior is obtained by participation to the international OECD projects THAI and THAI2.

Specific goals in 2010

The objectives in 2010 were to finalize the assembly of the COOLOCE (Coolability of Cone) experimental facility, to conduct experiments with the new experimental set-up and to continue the modelling of hydrogen behavior using FLUENT. First, a series of experiments is performed with the conical (heap-like) particle bed. Then, the conical particle bed set-up is replaced by a cylindrical one for comparison experiments. The experimental data is used to determine the effect of the heap-like geometry on the particle bed coolability and to validate simulation codes. A PORFLO model of the conical particle bed is generated, and the possibilities to utilize a full 3D approach for modelling of the particle bed dryout behavior are investigated. Also, the MEWA (WABE) code is applied to model the COOLOCE experiments. The participation to the ISP-49 standard problem on hydrogen combustion is continued as well as the follow-up of the OECD THAI and THAI 2 projects.





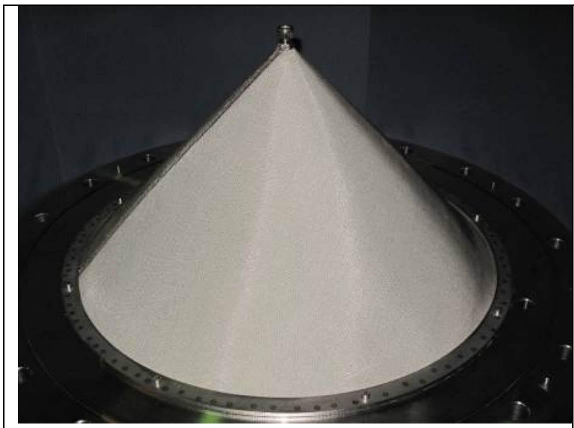


Figure 13. Heating arrangement of the COOLOCE test facility (top left), the test particle bed (∅ 50 cm) held in the conical shape by a wire net (bottom left) and a void fraction prediction within the conical particle bed by PORFLO (right).

Deliverables in 2010

- The preparation of the new COOLOCE test facility used to study dryout in particle beds of different geometries was continued. The installation of the heaters and temperature sensors was the main task in the assembly of the test facility. Prior to the experiments aiming for dryout, preliminary testing of the heating arrangement was done. A description of the facility was written.

- A sequence of tests at two ambient pressure levels was performed with the conical particle bed. Dryouts were seen at relatively high values of heating power. The intial dryouts in the experiments occurred near the top of the cone. This was an expected observation resulting from the multi-dimensional nature of the flows in the particle bed. Due to maintenance and modification work following the experiments, the test series with cylindrical particle bed were transferred to 2011.

- The in-house 3D code PORFLO was applied to the modelling of porous particle beds with the focus being on the conical COOLOCE particle bed and a cylindrical bed used as a reference for the conical configuration. Friction and heat transfer models suitable for porous beds were incorporated into the code. Test simulations with the updated code versions were run.

- MEWA simulations were performed as reference cases for the PORFLO simulations. Also, the first COOLOCE experiments were modelled using the MEWA code. The experimental and numerical results were presented in research reports.

- A journal paper (extension of a conference paper) was written of the STYX donwcomer experiments and their analysis which were conducted in 2008-2009.

- The last meeting of the ISP-49 standard problem on hydrogen combustion was attended. The results of the FLUENT calculations of the THAI deflagration tests were presented in the meeting. The calculation results suggest that FLUENT is capable of modelling the main phenomena of slow combustion processes even though some of the details are not captured by the applied model.

- The final seminar of the OECD THAI project (THAI Seminar 2010) was participated to, and a short summary paper of the modelling work conducted at VTT during the THAI project was presented. The final material produced by the THAI project as well as the seminar presentations were distributed to the Finnish nuclear energy partners.

2.6 Structural safety of reactor circuit research area

There were seven projects going on in 2010 in the structural safety of reactor circuit research area: Risk-Informed Inspections of Piping (PURISTA), Fatigue endurance of critical equipment (FATE), Water chemistry and oxidation in the primary circuit (WATCHEM), Monitoring of the structural integrity of reactor circuit (RAKEMON), Fracture assessment for reactor circuit (FRAS), Influence of material, environment and strain rate on environmentally assisted cracking of austenitic nuclear materials (DEF SPEED) and Renewal of active materials research infrastructure (AKTUS).

2.6.1 Risk informed inspections of piping (PURISTA)

Risk-informed in-service inspections (RI-ISI) aim at rational in-service inspection management by taking into account the results of plant-specific risk analyses in defining the inspection programme. The fundamental idea is to identify risk-significant locations where the inspection efforts should be concentrated. Even if RI-ISI has been widely applied in US, European utilities and safety authorities feel that several issues need further research, and the US approaches cannot be adopted as such. The overall objective of the project is to support the implementation of risk-informed ISI at Finnish nuclear power plants by studying relevant issues related to RI-ISI. Main objectives are the development of structural reliability methods for quantification of piping leak and break probabilities, the development of methods for evaluating inspection capability and the link between inspection qualification, detection probability and RI-ISI, and studying issues related to risk-ranking, selection of inspection sites and acceptance criteria of a RI-ISI programme.

Specific goals in 2010

In 2010 the work conducted in 2007-2009 was continued, and some new activities were initiated. The project was organised in four subprojects, and the specific goals of each subproject are described below.

In the first subproject, the goals were related to the estimation of piping failure potential. One goal was to expand the probabilistic capabilities of an existing probabilistic fracture mechanics (PFM) analysis tool, and finalise a licentiate thesis on structural lifetime, reliability and risk analysis approaches. A second goal was to conduct a pilot application of the OECD Piping Data Exchange Database (OPDE) to investigate its usability to improve initial crack estimates needed in the PFM crack growth simulations. A third goal was to finalise the work related to estimation of vibration induced stress variation and document it in a licentiate thesis.

The goals of the second subproject were related to the reliability of inspections. First, the new advanced features of the CIVA simulation program were to be tested. These features allow defining some of the ultrasonic inspection parameters as distributions, which can be used to compute probability of detection (POD) functions. Further, the aim was to contribute to the work within ENIQ TGR to develop a document on how to produce POD's for e.g. RI-ISI applications.
The third subproject focuses on participation in the activities of the European Network for Inspection and Qualification (ENIQ) Task Group on Risk. ENIQ TGR develops recommended practices and discussion documents related to RI-ISI. Further, one goal was finalise the report of the OECD/NEA-JRC co-ordinated benchmark on RI-ISI methodologies, RISMET. The RISMET benchmark is a unique comparative study of various approaches to set up an ISI programme, and its results are expected to improve the knowledge on differences in approaches and their impact on plant safety.

Deliverables in 2010

- The main result concerning research work on structural reliability analysis methods was a licentiate thesis on structural lifetime, reliability and risk analysis approaches for power plant components and systems. The main part of the thesis consists of an extensive literature study and review on the covered topics. The thesis includes also a computational part, presenting application of probabilistic failure and lifetime analyses to a representative set of NPP piping components with probabilistic fracture mechanics (PFM) based codes VTTBESIT (developed by VTT and IWM, Germany) and PIFRAP (developed by DNV, Sweden). VTTBESIT was also developed further here to allow more versatile Monte Carlo sampling based computations.

- A review of the OPDE database applications was made, and the applicability of the database for estimating nucleation frequency and sizes of initial cracks was evaluated.

- The work done during the programme period on estimation of vibration induced stress variation in piping systems was summarised in a research report.

- In the study of the performance and reliability of NDT techniques using simulations of the ultrasonic testing method, a new version of the simulation program was installed and the new features studied. The new version (Civa 10) includes comprehensive modifications and improvements especially concerning result data presentation and visualization. This program version now includes also tools to compute POD curves. For this computation inspection and/or defect variables can be given as distributions. The reporting summarizes all the work of the task performed during four year period of the research program.

- A journal article was published together with JRC on derivation and use of probability detection curves in the nuclear industry.

- A journal article was published on the application of a Bayesian model for the quantification of the European methodology for qualification of non-destructive testing. The article describes the results of a pilot study in which such a Bayesian model was applied to two realistic Qualification Dossiers by experienced NDT qualification specialists. At the end of the study, recommendations were made and a set of guidelines was developed for the application of the Bayesian model.

- The final reporting of the RISMET benchmark project was concluded, and a journal paper was published on the project. The final report has been endorsed by the NEA/CSNI Programme Review Group, and is in the publication process.

- The participation in and coordination of international work in the area of RI-ISI included the participation in the work of the Task Group Risk of the European Network for Inspection and Qualification working towards best practices for RI-ISI methodologies.

In addition to the aforementioned results, the project deliverables included several conference papers on research activities completed in 2009.

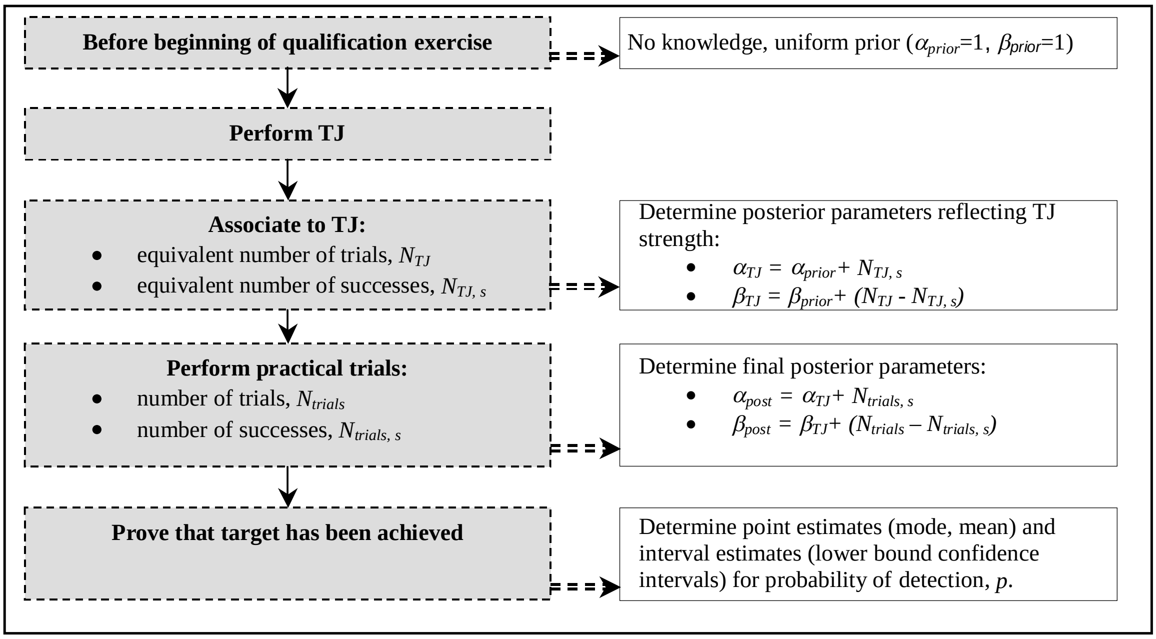


Figure 1. Principles of the Bayesian model for the quantification of the European NDT qualification methodology. The model combines expert opinion based on the Technical Justification (TJ) with results of practical trials.

2.6.2 Fatigue endurance of critical equipment (FATE)

The project aims to improve and verify models used for assessment of fatigue endurance and failure probability of nuclear reactor pressure boundaries and critical components. Quantitative, mechanism based and risk informed probabilistic evaluation of fatigue crack initiation and short crack growth due to thermal and/or mechanical loads is aimed. Applicability of design and evaluation practices will be assessed and discussed aiming to global enhancements.

Specific goals in 2010

Specific goals in 2010 included completion of development and verification of FABELLO fatigue bellows units to be applied for simulations of loading transients occurring in NPP primary circuits in artificial LWR coolant waters.

Metallographic and cyclic response characterisation of commercial 304L, 316L and 321 material batches were also performed. But these hot rolled plates were found questionable for studying performance of NPP primary circuit materials, for which the manufacturing process is different. However, cyclic deformation mechanisms were studied by transmission electron microscopy of samples fatigue loaded to selected conditions and interrupted before cracking.

The solution for direct strain measurement and control for valid LCF tests in hot water was a major challenge. A successful solution for the instrumentation was finally achieved and proven to work. The difficulty rises from the fact that the sensors need to be safely secured to a polished specimen without scratching and inside a closed equipment frame. Only small holes in the frame are available for this operation, see Fig. 1.

The general performance of the equipment can be evaluated by studying the measured hysteresis loops. Excellent hysteresis loops were obtained at an intermediate strain rate, Fig. 2. The bellows loading strategy eliminates friction in the load train and stress strain response can be accurately measured. For simple endurance testing, accurate measurement of stress response would not be critical as long as the desired strain history could be introduced, but the case is different, when mechanisms of environment assisted fatigue is to be studied.

The FABELLO equipment was found suitable both for ASTM E-606 valid standard tests and mechanism studies in simulated LWR coolant water environments.

Deliverables in 2010

- Development of the test facility for LWR water was successfully completed.
- Commercial candidate test materials were characterised through fatigue testing, cyclic response measurements and transmission electron microscopy. Furthermore, cold working and recrystallisation treatments were introduced aiming to learn on conditions for grain growth and manipulation of grain size for test materials.
- Revision of the fatigue design curve in ASME code was assessed and critically discussed.

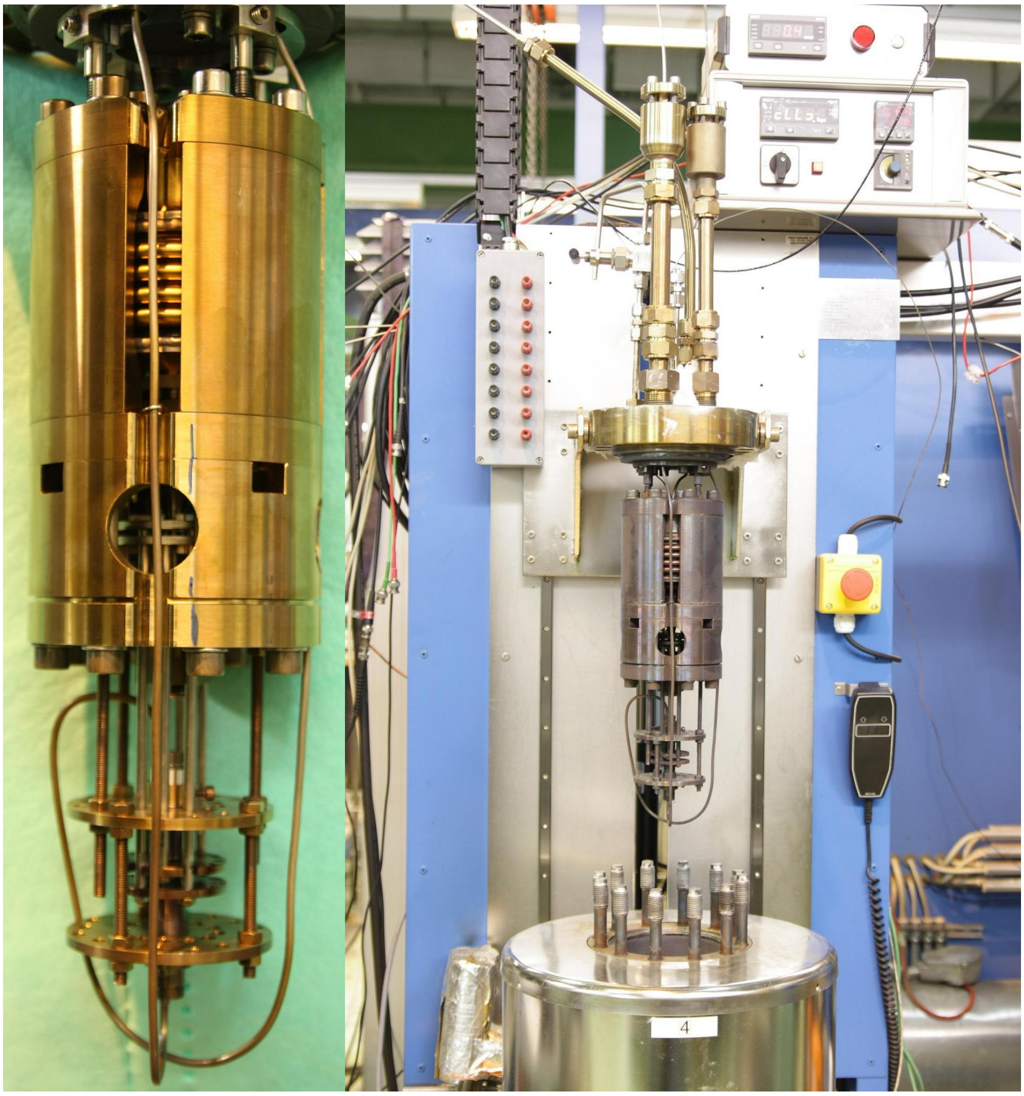


Figure 1. FABELLO unit before and after three months in 300 ºC pressurized water.

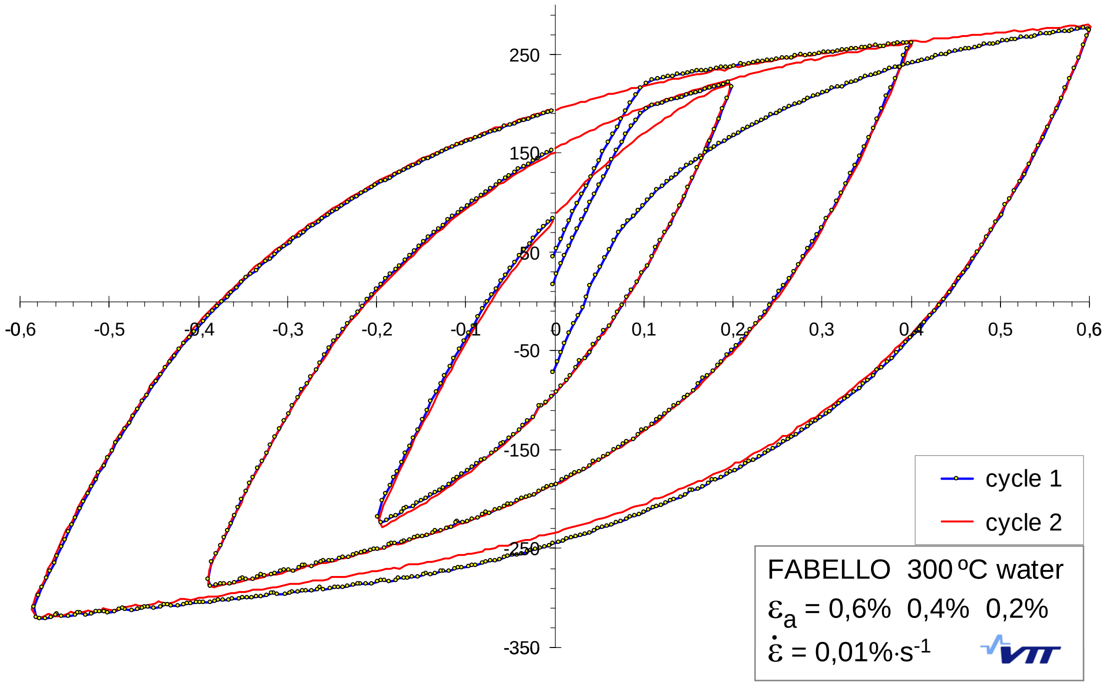


Figure 2. Hysteresis loops measured in 300 ºC pressurised water by the FABELLO. Two first cycles after each change of strain amplitude are shown.

2.6.3 Water chemistry and oxidation in the primary circuit (WATCHEM)

The objectives of the project were as follows:
The project aims at increasing the knowledge on material – water chemistry interactions so that potentially safety related effects arising from changes in plant water chemistry operation policies can be evaluated in before hand.

The first objective (Task 1) is to study how different water chemistry conditions (e.g. normal vs elevated alkaline concentration and optional water chemistries) affect the integrity and oxidation rate of different fuel cladding materials. This information is obtained with experimental tests in relevant conditions. The results will be used in modelling in order to get estimates for the relevant parameters of the oxidation processes. *Through this modelling approach the risks involved in application of new water chemistries can be estimated.*

The second objective (Task 2) is to study the formation mechanism and sources of the deposited corrosion product layers (crud) affecting the activity build-up, decontamination procedures available at the moment and effect of and options for chemistry conditions in these processes. This task consists of literature surveys of the subjects together with development of experimental methods to study the effect of flow rate on corrosion processes in relevant conditions. *Within this task knowledge and experimental facilities are developed for better understanding of the effects of flow rate on corrosion processes (FAC) and related activity build-up. In addition, a high enough competence level can be reached to enable selection of the best plant specific commercial decontamination practise.*

The third objective (Task 3) is pre-oxidation of component and system surfaces, which can have a crucial effect on the corrosion rate and activity incorporation onto the surfaces. Knowledge on optimisation of pre-oxidation techniques is needed both when decontaminated components and/or system parts are taken back into use and when new systems are taken into use for the first time. *This will be especially important when the Hot Functional Test (HFT) procedure of new plants is evaluated.*

Specific goals in 2010

<u>Task 1 Fuel cladding oxidation</u>
In this subproject the effect of different water chemistries on fuel cladding material corrosion will be studied in relevant PWR conditions in order to verify the applicability of the developed characterisation method. This subproject was finalised in 2009 with a comprehensive publication of the results in Corrosion Science Journal.

- 1.1 ZrNb-OXIDATION: In 2010 an additional joint publication with BARC, India and UCTM, Bulgaria will be published on the effect of oxygen from sub-cooled nucleate boiling on oxidation of Zr-Nb –cladding alloys.

<u>Task 2</u> Deposited corrosion product layers and Decontamination
This subproject includes the following tasks:

- 2.1 VISITING SCIENTIST: A scientist from VTT will work at BARC, India for one month in January –February 2010, concentrating on FAC-studies on carbon steel.
- 2.2 LITERATURE STUDY: A literature study will be made on flow assisted corrosion models.
- 2.3 FLOW ASSISTED CORROSION: Techniques and modelling approaches will be developed enabling study of corrosion processes of NPP construction materials under relevant hydrodynamic conditions. The first practical application will be the study on the effect of hydrazine injection on the corrosion rate of carbon steel under conditions similar to feed line in a

PWR plant.
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.**Task 3 Preoxidation**

This subproject includes the following tasks:

- 3.1 LITERATURE SURVEY: Literature survey will be made on start-up and shut-down water chemistries in PWR's.
- 3.2 HFT OPTIMISATION: Experimental investigation on the optimal length of the passivation period and on the possible positive effect of boric acid addition. Experimental measurements with Inconel 690 material will be carried out in water with 1 ppm Li and dissolved H_2 (30 cm^3/kg-H_2O) with and without boric acid addition using the CDE technique at 292°C.

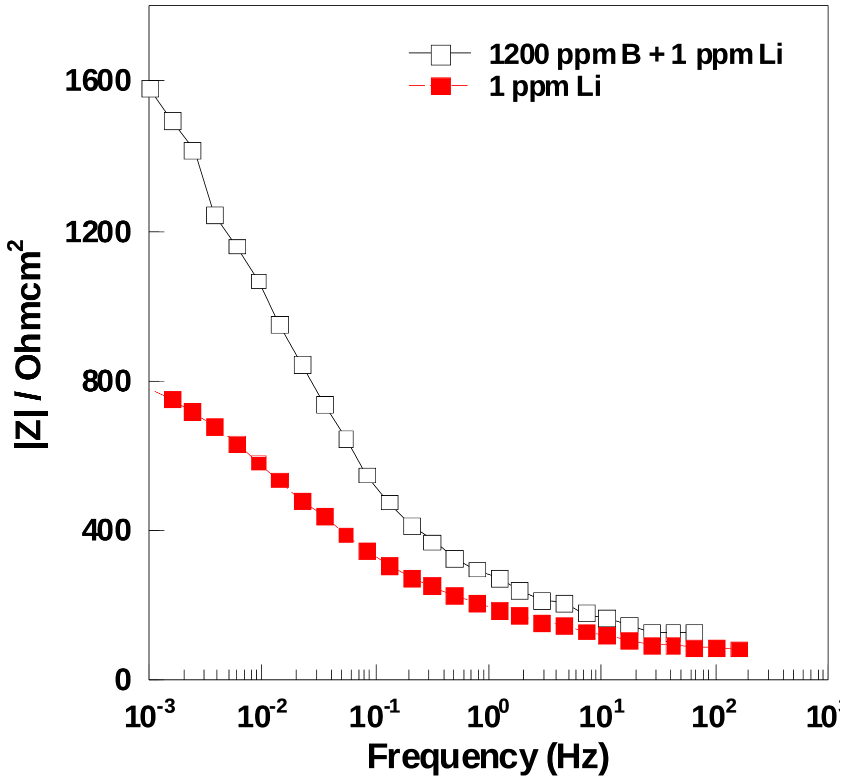

Figure 1. Boron (boric acid) has a positive effect on the impedance and thus on the oxidation resistance of Alloy 690 in simulated Hot Conditioning water chemistry conditions. Exposure time 70 hrs, T = 292°C.

Deliverables in 2010

- Two scientific articles were published together with BARC, India and UCTM, Bulgaria finalizing the results of experimental and modeling work on oxidation of Zr-Nb –cladding alloys.

- The main results from co-operation with BARC, India and UCTM, Bulgaria on development of in situ methods for optimisation of HFT water chemistry of a PWR plant were communicated in the form of a scientific journal article. Application of the methods in case of Alloy 690 was reported as a VTT Research Report. Boron (in the form of boric acid) was found to have a major positive effect on oxidation resistance of Alloy 690 under Hot Conditioning water chemistry conditions.

- A literature study on FAC models was performed and published as a VTT Research Report. The equipment for studies of flow assisted corrosion has been received and trial runs are on.

2.6.4 Monitoring of the structural integrity of reactor circuit (RAKEMON)

Non-destructive testing techniques are used to monitor the condition of the structures of reactor circuit during the operation of nuclear power plants. The in-service inspections (ISI) are normally performed during the shutdown period but there is also increasing need to monitor the condition of components during service by on-line methods. The tendency worldwide and also in Finnish nuclear power plants is to improve the efficiency of in-service inspections by applying risk-informed methods to the selection of inspection items, methods and timing of in-service inspections. This kind of ISI-programme is supported by on-line monitoring techniques that are used to focus the inspections to areas where failures are most probable and/or consequences are most severe.

There is a specific need to improve the reliability of NDE-techniques used for the ISI of bimetallic welds and inspection items where access is limited. Ultrasonic simulation can be used to optimize the inspection techniques for these problematic inspection areas.

The aim of this project is to develop techniques and monitoring systems that can be used to monitor the structural integrity of the primary circuit components. The aim is to develop measurement systems both for detection and analysis of macroscopic flaws and microscopic changes in the material that are often preceding the macroscopic failure. In 2007 and 2008 the basics for the design of monitoring system have been studied and first prototype was constructed. First version of the pilot monitoring system was constructed in 2008 and second version in 2009. Second version was seriously damaged during tests and was reconstructed later in 2009.

It is also necessary to develop inspection techniques that can be applied to reactor circuit components where the access is restricted and decreasing the reliability of inspection. This kind of inspection items are e.g. welds with coarse grain size and nozzle welds where the difficult geometry is restricting the performance of inspection.

Specific goals in 2010

Specific goals in 2010 included four main areas. The first was the pilot monitoring for on-line monitoring purposes. The second area was the simulation of Full Matrix Capture ultrasonic method. The third area was linear and nonlinear ultrasonic inspection and the fourth area was steam generator lifetime monitoring which was divided in two subcategories; new approach to use EC data and secondary water chemistry.

The different techniques of non-destructive evaluation that can be applied to on-line monitoring of piping and components have been thoroughly reviewed in early stage in a wide scope literature review in 2007. Special emphasis was put on techniques that can be used to monitor the whole through-thickness volume and large areas of the component and on the techniques that can be used without contact to the inspection item. The restrictions caused by the high temperature of primary circuit during operation and the effects of radiation dose on the transducer materials have been studied. Evaluation of thermal fatigue cracks versus EDM notches in SS pipe was started after reconstruction in 2009 and was continued during 2010. Simulations comparing EDM notches and fatigue cracks were made in 2010.

The geometry and the material properties of the component to be inspected must always be considered when an ultrasonic test is planned. In many cases these factors can be challenging and careful examination of the case is needed to ensure reliability of the inspection. Simulation of the ultrasonic inspection using computer program (CIVA 9) can be one part of necessary work providing tools to study how the ultrasonic beam is propagating in structure and what kind of signals can be expected to be received from the reflectors in the inspection area. In this area the difficult inspection geometries (nozzles) and anisotropic weld metals have been modelled with simulation program CIVA version 9. Phased array technique is relatively new inspection technique and very rapidly developing area. In 2009 phased array simulations were made with CIVA 9. In 2010 the focus was on full matrix capture method and its simulations (Fig 1.).

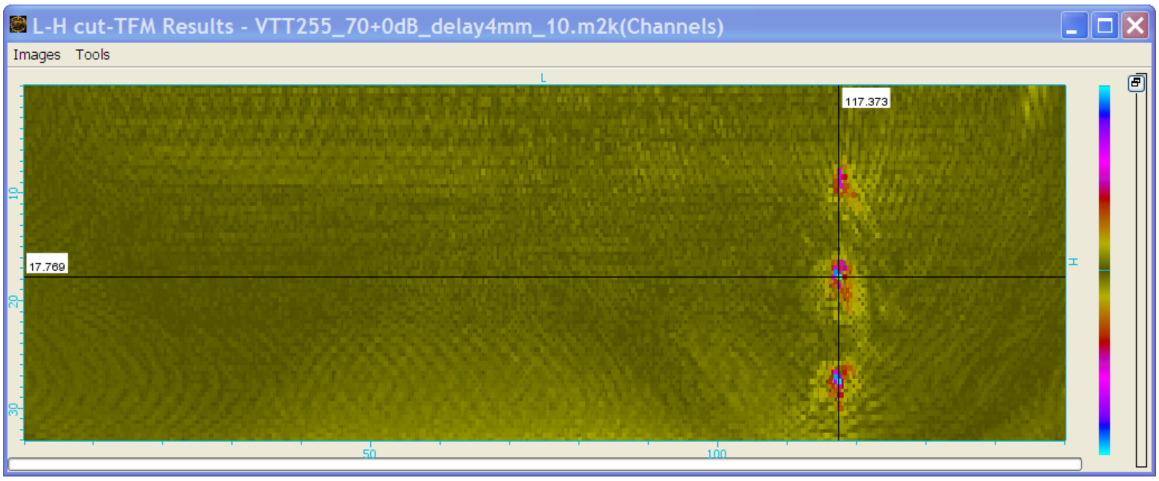

Figure 1. Example of Full Matrix Capture (FMC) simulation.

The new ultrasonic method for imaging closed cracks based on subharmonic ultrasound has been developed at Tohoku University in Japan. Reliability and applicability to inspection of real NPP components with this method was studied in literature review. Reliable inspection would be an important progress in the detection of dangerous closed cracks. Close cooperation with the involved scientists in Japan and also elsewhere was continued during 2010 and more contacts to international research institutes was made.

The eddy current inspection data of steam generators contain also additional information than flaw indications. Recently eddy current data has been applied to show locations of magnetite deposition on tubing. Improvement of eddy current analysis, e.g., concerning magnetite deposition on tubing or between tubes and flaw sizing was started by doing a literature review in 2009. In 2010 more studies on applicability of eddy current and small scale experimental tests were made.

Water chemistry plays an important role in nuclear power plants and understanding the variations in the local environmental condition facilitating iron deposition in SG's should be improved. Pertinence of water chemistry based predictions, NDE monitoring results concerning iron deposition and plant observations and experience should be discussed and documented. Magnetite dissolution and deposition in NPP secondary circuit was studied and documented in 2010.

Deliverables in 2010

- Education of three new research scientists and one new research engineer continued, including also National nuclear safety -course and courses of specific non destructive evaluation methods (EC, UT, etc.).

- Two research institute reports, two presentations in international conferences and also active participation in conferences (chairman of a session, etc.) and IAEA coordinated research program.

2.6.5 Fracture assessment for reactor circuit (FRAS)

The objectives of the project for fracture risk assessment comprise (i) calculation of design and unforeseeable loads and their effects on a structure by applying numerical modelling; (ii) development of advanced fracture mechanics assessment tools and analysis methods based on material characterisation, damage mechanisms models and structural performance, in order to control structural failure both in cases of postulated initial flaw and environmentally assisted (internal) material damage; (iii) determination of degradation in material properties during service.
During recent years several structural analysis assessment methods have been established.

Nonetheless, need for more accurate methods in load definition, true 3D flaw assessment, as well as irradiation embrittlement evolution assessment, still remains. Traditionally, numerical simulation of loads has treated different components more or less as separate even though they belong to the same aggregate, thereby disregarding the interaction of support loads on the entire system. Applicability and limits of sub-modelling techniques in numerical simulation of crack growth need to be investigated further. Feasible 'engineering assessment tools' cannot be reliably applied, unless they have been tailored and verified for the particular plant and component in question. Traditionally, material's fracture toughness estimates have been determined applying deep-notched 'high-constraint' specimens enabling conservative estimates to be derived. Sophisticated constraint corrections are required for shallow surface cracks with lower constraint, particularly in the case of asymmetric crack fronts during crack growth. Present limitations for specimen's measuring capacity in fracture resistance testing and under ductile crack growth are presumably unrealistic and hence need revision. Unified model for irradiation embrittlement is still lacking, despite of intensive previous research.

Recently, advanced multi-scale modelling techniques of material damage micro-mechanism have allowed micro-scale investigation of relevant damage mechanisms, without a necessity to postulate a pre-existing flaw. This provides means for more realistic material damage assessment for environmentally assisted failure, such as stress corrosion cracking, irradiation embrittlement, ageing embrittlement and hydrogen embrittlement that do not require the existence of pre-existing flaw. In conjunction with modern FEM structural analysis methods, the application of these advanced modelling techniques enables structural integrity assessment of a component, or structure, over an entire 'chain' from micro- to macro-scale on a more realistic basis than previously.

Specific goals in 2010

The project was realised in three sub-projects: 1) Definition of loads, 2) Advanced fracture mechanical assessment methods and 3) Advanced surveillance techniques.

The external loads transferred to the reactor circuit components by supports were studied. A pipe guillotine break with whipping was chosen as a dynamic analysis case for a short pipe section structure. Another dynamic case, earthquake was preliminarily studied. Typical nuclear power plant pipeline geometry and materials were chosen. The chosen basic elbow element model is the most improved one based on the previous studies within the same project.

The other type of structure examined here was a boiler feedwater pipe, which is a longer but thinner pipeline compared to the short section mentioned above. A certain experimental snap-back test was simulated and the simulation results were compared with the test results. The earthquake load was also preliminarily investigated with this model. The model behaved reasonably well and relatively close to the test situation. The elbow elements and nonlinear

spring elements were thus successfully used in a larger model based on real nuclear power plant.
All the analyses were conducted with the newest version of Abaqus Finite Element code. It is functioning in identical manner to previous versions and can be reliably used in similar studies. New features in this version that could be useful in this field of study have been briefly considered.

For Computational Fluid Dynamics (CFD) calculations, in order to predict the time dependent thermal fluctuations due to turbulent mixing, Large-Eddy Simulation (LES) or similar models are usually required which is computationally very expensive. Development of a more feasible approach was started, in which the spectrum of the fluctuations is estimated from a formula obtained from turbulence theory and the total power of the fluctuations is obtained from an inexpensive RANS calculation. From the spectrum, a realistic temperature load is generated by superposition of harmonic components with random phase-differences. Lifetime calculations for the Vattenfall thermal mixing experiment showed clearly more realistic results when compared with the traditional sinusoidal method.

As concerning research on weld residual stresses (WRSs), firstly was carried out a literature study on numerical simulations concerning the effect of both static and growing cracks to locally confined WRS distributions in NPP component welds. Also included was further development of fracture mechanics based analysis code VTTBESIT, originally developed by IWM (Germany). Earlier this analysis code was limited to such crack growth analyses where the aspect ratio (i.e. crack depth divided by its length) stays constant and growth increment computation is based on crack tip stress intensity factor (SIF) values only. Here the scope of VTTBESIT was expanded so that it allows the aspect ratio to alter during computed crack growth realisations while taking into account all SIF values over the crack front. The earlier/existing and new versions of VTTBESIT were compared against each other with several stress corrosion cracking (SCC) induced crack growth analyses performed for a representative set of NPP pipe component welds and taking into account the WRSs.

According to the results obtained with the new program version the crack growth was notably slower than obtained with the earlier/existing version. Then a set of computational analyses including WRSs was carried out for the same set of NPP pipe component welds. Firstly the WRSs as computed with selected five WRS relaxation procedures were compared to the as-welded state WRSs according to SINTAP procedure assumptions. Then using these results as part of input data a set of computational SCC induced crack growth analyses were carried out with the earlier/existing version of VTTBESIT. According to these results most of the WRS decrease occurs during the first five to ten load transients/cycles. Whereas according to the SCC computation results in the cases including the decrease in WRSs also the crack growth rates were to varying extent slower as compared to the cases with WRSs remaining in their initial values. One international conference paper was written and presented.

Engineering tools for fracture analyses were studied with focus on Zencrack fracture analysis software that implements a crack block methodology to introduce flaws into uncracked FE-meshes. Several reference cases were studied with different loading types applied. The most notable of these cases was a combined thermal Zencrack submodelling analysis where a crack was introduced in a submodel of the postulated crack region of a feedwater nozzle. Thermal and mechanical loading was defined in the model. To overcome limitations imposed by the crack block methodology a separate puncture analysis where a surface flaw transforms into a through-wall crack was studied. The calculated results corresponded well with the reference results obtained using traditional numerical fracture mechanics.

The research of engineering tools also included studying the applicability of XFEM implementation in commercial FE-software Abaqus. Carrying out XFEM crack growth analyses with Abaqus cohesive zone modelling of material failure must be applied. In 2010 the main goal was to combine experimental data on ductile fracture resistance (J-R) with cohesive zone modelling calculations in order to define realistic criteria for specimen's true measuring capacity and development of related material characterisation standardisation. The material parameters of the cohesive model were determined from experimental fracture toughness tests for high strength steel conducted previously in the project. Reasonable match between the calculated load - crack opening curve was obtained but the predicted fracture resistance curves deviated from the measurements. It was determined that more experimental testing should be carried out to provide more data for the calibration of parameters for cohesive zone modelling.

Transferability of fracture mechanics test data associated with different levels of specimen's constraint was to be investigated by performing fracture mechanics tests using specimens with both deep and shallow surface notches. In 2010 experimental work, an international round robin on applying low constraint testing practice was launched. The recommended practice describes a method to measure the J-integral fracture toughness and the extent of crack growth in a single-edge-cracked tension SE(T) specimen. The specimen geometry and loading mode is designed to produce a level of crack-tip constraint in the test that is similar to the constraint experienced in service for a surface circumferential flaw in a pipe under tension or bending load. The procedure is intended to be used for structural steels. VTT determines fracture toughness / resistance also using deep crack single edged bend SEB specimen for a comparison. Test specimens were notched, precracked and side-grooved. First fracture resistance curves with SEB specimens were determined.

Micromechanical modelling continued during 2010 with crystal plasticity and dislocation dynamics modelling of cleavage and embrittlement to develop further the Master Curve formalism for cleavage fracture, in close co-operation with the PERFORM60 project. In brittle fracture modelling work Beremin and Bordet loacal approach methods were critically reviewed. Modelling brittle fracture is challenging due to large scatter of the fracture toughness. Also, the fracture toughness has shown to depend on the position of the individual particles relative to the crack tip. Therefore, the critical stress level incurring the failure is impossible to determine exactly. The statistical fracture mechanics is a means to treat statistical phenomenon such as cleavage. The Beremin model is based on the probability of finding microcracks which cause the cleavage initiation and failure. Bordet et al. developed a more advanced local approach method that takes account of the probability of the initiation and the propagation. Both of these models contain material parameters that need calibration.

The Bordet statistical model for cleavage was implemented in Matlab and the parameters of the model were calibrated for the temperature of -155 ºC using the Master Curve. The Master Curve was also used to verify the implementation. The implementation was compared to the Beremin model maintaining the specimen size and geometry constant. The results indicate that the Bordet model produces failure probabilities similar to the Master Curve being more stable than the Beremin model.

Results of fracture resistance measurements (JR curves) on different materials using various specimen types (e.g., CT, SENB) were thoroughly analysed in order to define the measuring capacity of specimen. Results show that although measuring capacity according to ASTM E1820 – 08 standard is double compared to the previous -05 version it is still very conservative. Crack growth seems not to be limiting factor for using small specimens but J-integral, see Fig below. Research report on the results was finalized.

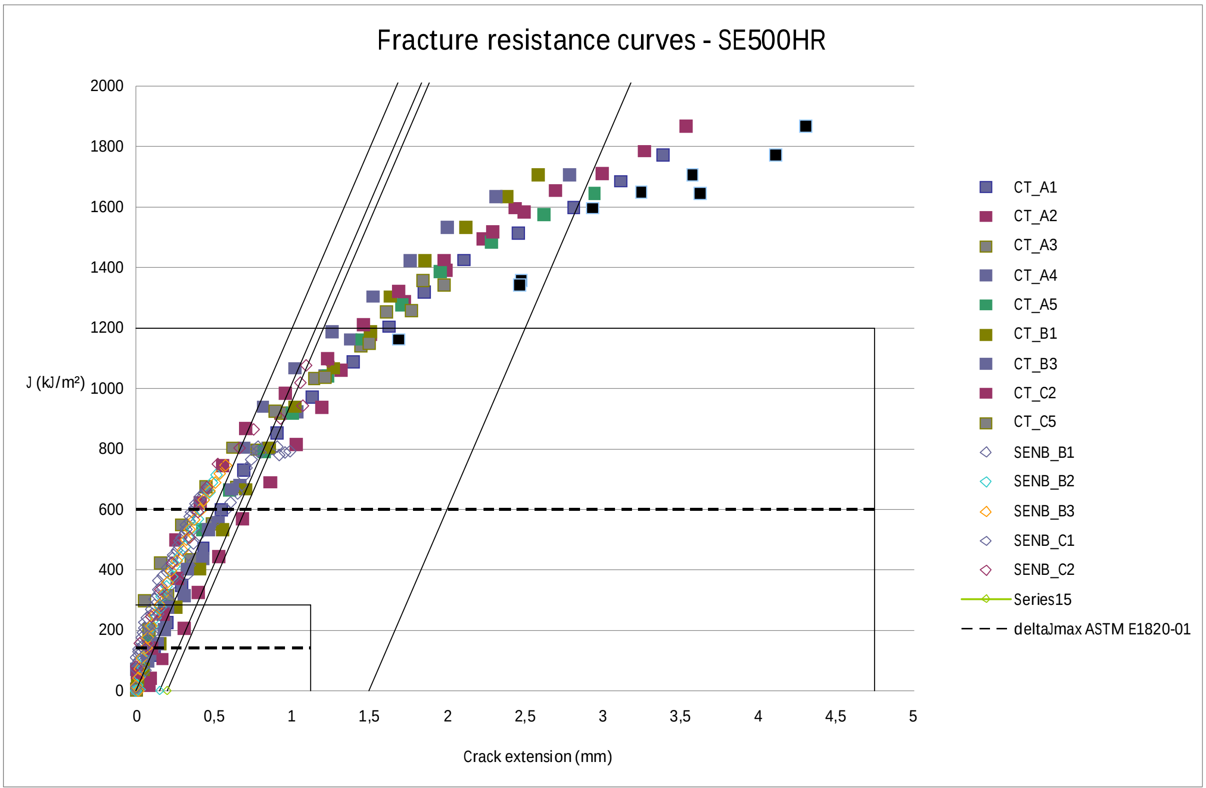

Fig. Fracture resistance curves and standard specimen size limitations showing the conservatism of standard requirements.

In 2009, joint research with Tohoku University (prof. Nagai) and VTT was concretized. VTT prepared and delivered relatively large number of ATOM probe and positron annihilation samples covering VVER-440 weld 501 and model alloys in various irradiation conditions (ref, I, IA, IAI). In 2010 the analyses were not completed and the report is dealyed. The microstructural data will be coupled to existing mechanical test data in order to create a microstructurally based model for mechanical behaviour. Further development on methods for characterisation of the irradiated materials was performed in 2010. Resistivity and Seebek measurement facilities were designed and realised. First measurements on pure copper and aluminium showed that the measurement system worked well. The results were inline with theoretical values. Resistivity measurements of VVER-440 weld in I- IA- and IAI conditions will be performed. Resistivity is shown to correlate well with the inclusion structure. The new data will be correlated with existing mechanical test data.

Deliverables in 2010

- The external loads transferred to the reactor circuit components by supports were studied. A pipe guillotine break with whipping was chosen as a dynamic analysis case for a short pipe section structure. Also, another dynamic case, earthquake was preliminarily studied. An certain experimental snap-back test was simulated and the results were compared with the test results. The model behaved reasonably well and relatively close to the test situation. The elbow elements and nonlinear spring elements were thus successfully used in a larger model based on real nuclear power plant. All the analyses were conducted with the newest version of Abaqus Finite Element code. It is functioning in identical manner to previous versions and can be reliably used in similar studies. New features in this version that could be useful in this field of study have been briefly considered. A research report of the work has been published.

- Numerical modeling of thermal loads due to turbulent mixing has been performed and comparison with experimental data has been made. Fatigue calculations with the newly developed method and with the traditional sinusoidal method have been performed in co-operation with the Nuclear Research and Consultancy Group (NRG). A research report and a conference publication of the work have been written.

- One conference paper and four research reports have been prepared on weld residual stresses (WRSs). Two of these reports concern results of work performed in 2009, but which were published during early spring of 2010. Of the two reports concerning results of work performed in 2010, one presents a computational study on WRS relaxation and crack growth in NPP pipe component welds, whereas the other one concerns interaction of cracks and WRSs in NPP component welds as well as further development and application of fracture mechanics based analysis tool VTTBESIT. The subject of the conference paper is WRSs in structural integrity analyses of NPP components.

- In low constraint fracture part, an international round robin was launched on recommended practice that describes a method to measure the J-integral fracture toughness and the extent of crack growth in a single-edge-cracked tension SE(T) specimen. The specimen geometry and loading mode is designed to produce a level of crack-tip constraint in the test that is similar to the constraint experienced in service for a surface circumferential flaw in a pipe under tension or bending load. The round robin specimens were notched, precracked and side-grooved. First comparison tests with deep crack SEB specimens were finished.

- Master of Thesis on two brittle fracture local approach models, Beremin and Bordet was published. Beremin local approach method is based on the probability of finding microcracks which cause the cleavage initiation and failure. Bordet et al. more advanced local approach method takes account of the probability of the initiation and the propagation. The results indicate that the Bordet model produces failure probabilities similar to the Master Curve while being more stable than the Beremin model.

- Two research reports - one on numerical cohesive zone modelling calculations using experimental data, in order to define specimen’s true measuring capacity in ductile crack growth and another research report on detailed fracture resistance curve data defining the specimen size requirements in ductile tearing.

- Research report on evelopment in utilizing Zencrack code in fracture mechanics analyses.

- Resistivity measurement system was designed, built up and tested for characterisation of irradiated materials. This work is supporting international co-operation with Tohoku University, Japan where ATOM Probe and PA characterisation of irradiated samples representing weld 501 material in eight different IAIA-conditions and ten different model alloys in irradiated conditions will be performed. First resistivity measurements showed that the sensitivity of the measuring system is adequate and the obtained results were well inline with the theoretical values.

- Research report on (non-linear neural network analyses) mechanical properties response to I-, IA- and IAI conditions, joint analysis including a broad data base. To be published.

2.6.6 Influence of material, environment and strain rate on environmentally assisted cracking of austenitic nuclear materials (DEF SPEED)

The DEF SPEED project aims to increase the understanding of environmentally assisted cracking (EAC) and irradiation assisted cracking (IASCC) mechanisms in austenitic nuclear materials. Localisation of plastic deformation and the interaction between strain localisation and oxide film formation/reduction are most probably playing a key role in EAC. Several mechanisms, such as dynamic strain ageing, recovery, environmentally enhanced creep and relaxation can affect localisation of deformation. Understanding of these phenomena is important, e.g., in order to be able to predict and quantify the risk for environmentally assisted cracking in non-sensitised stainless steels. These predictions can be used for selection of reliable criteria for Risk Informed In-Service Inspection RI-ISI programs. Better mechanistic understanding of EAC mechanisms is particularly important in the context of an ageing fleet of existing NPPs and of long lifetimes planned for new NPPs.

To increase the understanding of EAC and IASCC the following is done during the four year project: initiation studies using Super Slow Strain Rate Testing technique (SSSRT) in LWR environments on austenitic nuclear materials, in-depth investigations on deformation mechanisms and localisation of deformation in EAC, characterisation of the microstructure of irradiated stainless steels from plant internals and investigations on the effect of environment on fracture toughness properties in austenitic materials. The latest international knowledge is brought to Finland by participating in international co-operation within the field of EAC and irradiation assisted stress corrosion cracking (IASCC). New experts in the field of nuclear materials are also educated within the project. An additional task building a digital report archive on material reports was started in 2008.

Specific goals in 2010

1. The role of deformation in the initiation of environmentally assisted cracking (EAC) in austenitic materials is investigated using super slow strain rate testing of austenitic nuclear material in LWR environments. In 2010 the work was comprised of interrupted SSSRT of nickel-based weld metals, i.e. Alloy 152 and 182 in simulated PWR environment and development of new test equipment for SSSR testing.
2. Characterisation of deformation mechanisms and their influence on EAC in austenitic nuclear materials, where the work in 2010 focussed on TEM-investigations on deformation structures in austenitic stainless steel specimens before and after SSSRT and utilisation of different specimen preparation techniques, e.g. FIB. The research on the influence of dynamic strain ageing on austenitic nuclear materials culminated in the dissertation by Mykola Ivanchenko in November 2010.
3. Characterisation of irradiated stainless steel, where the work in 2010 consisted of reporting of characterisation work on non-irradiated reference samples, corresponding to materials characterised earlier in irradiated condition.
4. Influence of the strain rate and environment on fracture toughness properties of austenitic materials, where the work in 2010 consisted of presentation of the results at conferences and expert meetings and evaluation of the implication of the fracture toughness results on structural integrity.
5. International co-operation is an important part of the DEF SPEED project, both for bringing the latest knowledge to Finland, and to educate experts, and was continued in 2010 with active participation in selected meetings and conferences.

6. The report archiving task, started in 2008, was completed in 2010 and the data base was opened for the end users.

Deliverables in 2010

1. Super slow strain rate testing of austenitic nuclear materials in LWR environments

Due to overlapping need for the autoclaves used for SSSRT, new test equipment for SSSRT was designed and taken into use. Focus was put on good specimen alignment with easy installation. The elongation is, as earlier, measured from the specimen using LVDT sensors. Super slow strain testing to 5% in simulated PWR environment was performed during 2010 in the bellow loading testing equipment using polished tensile type specimens from nickel based weld metals Alloy 182 and 152. Several cracks were observed on the surface of the Alloy 152 specimen using SEM.

2. Characterisation of deformation

Electron back-scattered diffraction, EBSD, was utilised in 2010 for characterisation of SSSRT specimens made from non-sensitised Type 316L stainless steel pre-strained to 5, 8, 15, 20 and 28%, and further strained to a maximum of 9% in simulated BWR environment. The results show non-homogeneous deformation in all specimens. The residual strains are localised at the grain boundaries and neighbouring grains show marked differences in the amount of residual strain.

The TEM, SEM, and FIB -investigations were performed in 2010 on the same specimens as were characterised by using EBSD. Upon SSSRT the samples were examined by SEM and all the test bars showed cracks. The bar with smallest degree of CW (8 %) showed the smallest amount cracks, while CW of 28 % induced the largest amount cracks. FIB examination of the small cracks of 8 % CW bar showed that they tended to stop at the metal-oxide interface, Figure 14. TEM investigations most distinctly showed that upon applied deformation, the microstructures showed an increasing planarization. A blooming of strain was observed at the intersection of shear bands and a grain boundary of 20 % CW test bar, as shown in Figure 15. The observation is in line with the EBSD observations of uneven strain at the neighbouring grains.

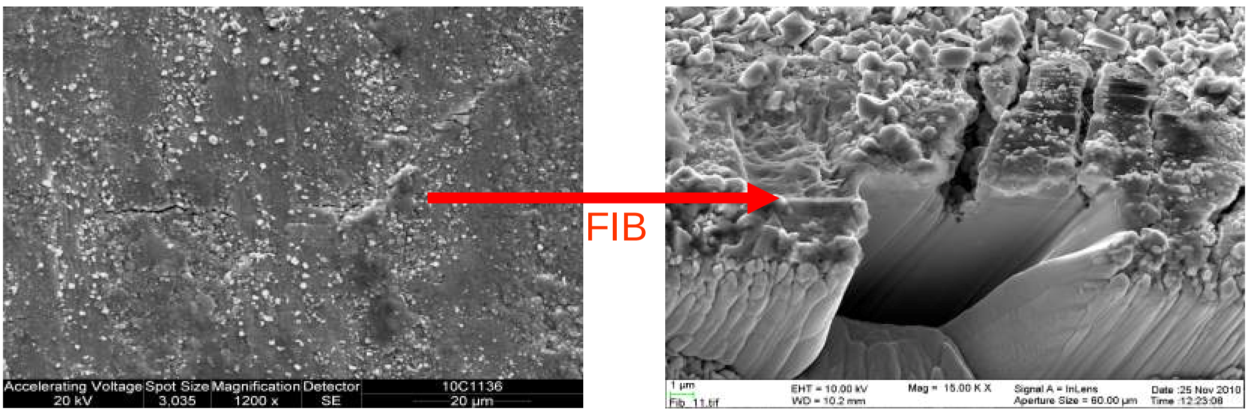

Figure 14. Focused ion beam technique can be used for characterization of near surface structures and small details. Cracking of the oxide, as seen in (left) is considered to be a

prerequisite for stress corrosion cracking, but cracks do not always penetrate into the substrate (right).

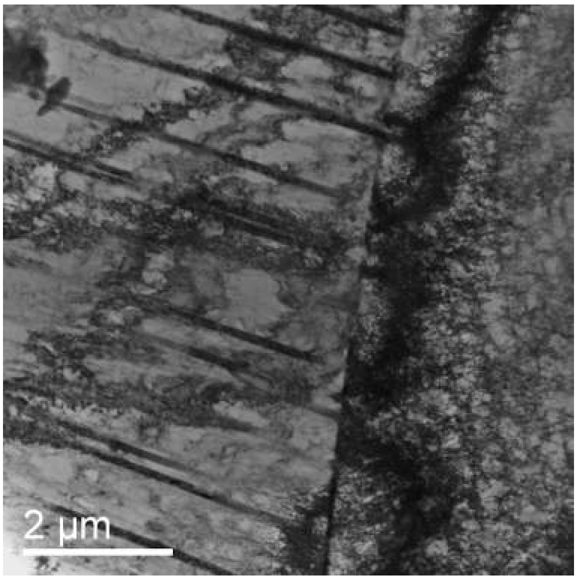

Figure 15 Strain blooming at the intersection of strain bands and a grain boundary of 20 % CW test bar.

The role of deformation in EAC has also been investigated by continued studies on dynamic strain ageing properties of austenitic nuclear materials using internal friction and tensile tests. The doctoral thesis work on the subject at Aalto University, partly funded by the DEF SPEED-project, was successfully defended in public in November 2010. Dynamic strain ageing behaviour as manifested by serrated yielding is observed at LWR-relevant temperatures in the studied materials, austenitic stainless steels of Type 304 and 316 and nickel-based materials Alloy 600 and 690, at strain rates below 10^{-4} s^{-1}. The activation enthalpies for DSA onset (120 kJ/mol for the stainless steels and 159 kJ/mol for the Ni-base materials) correspond to the diffusion of interstitials, i.e., nitrogen (in AISI 316NG) and carbon (in Alloy 600), determined using internal friction measurements. From the TEM-studies it was concluded that the diffusive redistribution of interstitial atoms in the DSA regime most likely affected the deformation behaviour of the material by promoting planar slip, which in turn promotes strain localisation.

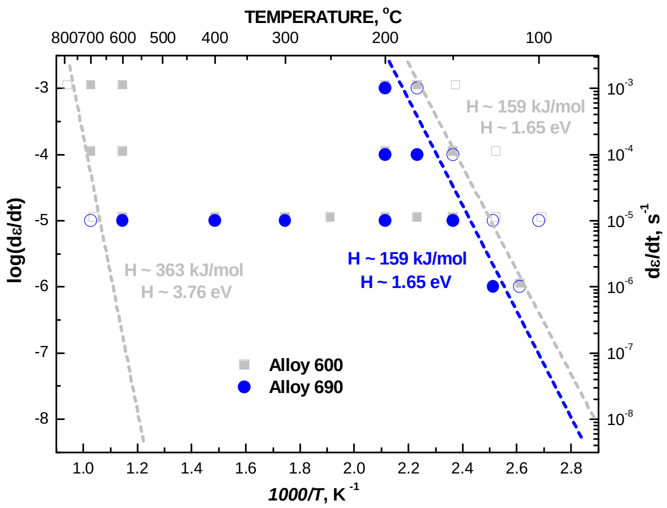

Figure 16. DSA-map for Alloys 600 and 690, where serrated yielding is observed at temperature between 150 and 600℃ at strain rates <10^{-4} s^{-1}.

3. Characterisation of irradiated stainless steels

VTT has been characterising irradiated materials for the OECD Halden project for some years. In 2010, the results from the characterisation work performed in 2009 on three non-irradiated, cold-worked stainless steels materials, from the same material as characterised in 2008 in irradiated condition, were reported. In mid-2010 VTT received several more materials slated for investigation, including three 30 dpa Type 304 stainless steel specimens in different post-irradiation annealed (PIA) conditions (for 2010 work), a 7 dpa Type 304L material in irradiated and in PIA condition (for 2011 work) and a slice from an irradiated barrel bolt (for 2012 work). Of particular interest in the PIA materials, is the grain boundary segregation. Depending upon the particular temperature and time of exposures, post-irradiation annealing can remove irradiation-induced loops, but may not necessarily total remove the grain boundary segregation. Due to the discrepancy in project calendars between Halden and Safir2010, the results of the 2010 investigations will be reported in Safir 2014 in the early part of 2011.

4.Influence of the strain rate and environment on fracture toughness properties of austenitic materials

The effect of hydrogenated PWR primary water on the Low Temperature Crack Propagation (LTCP) susceptibility of nickel based weld metals Alloy 182, 82, 152 and 52 has been studied in the DEF SPEED project by performing J-R –tests at a slow displacement rate in low temperature hydrogenated water. A remarkable reduction of the fracture toughness values was observed. The implication of the results for the structural integrity of a safe-end was evaluated in 2010. The calculation was performed for a nozzle/safe-end joint made of Alloy 182 with a postulated axial half-elliptic crack on the inner surface. Two cases were considered, i.e., shut-down and emergency cool-down situations. The transient heat transfer and stress/strain distributions through the DMW wall were calculated, also taking into account the weld residual stress distributions. The crack sensitivity analyses were then performed using both analytical equations and a fracture mechanics based analysis code VTTBESIT. The limiting criterion considered was the crack tip value of mode I J –integral, J_I, reaching the corresponding fracture toughness, J_{IC}. For all of the analysis cases studied, the critical crack sizes were relatively large, e.g. in the depth direction from 52 to 98 % of the wall thickness, which was assumed as 40 mm.

5. International co-operation and education

International co-operation in 2010 consisted of participation with presentations in the Fontevraud 7 conference, the Baltica VIII conference, the Halden IASCC meeting, the EPRI 690 expert group (together with the Tekes PERDI-project) and in the ICG-EAC meeting in Korea, the latter which included a visit to Doosan Heavy Industry. During to additional travel days from the ash incident, visits were also made to KAIST, SNU and KAERI. The SCAP project was finalised and a final report issued. The knowledge data base and the SCC data base were also finalised.

6. Report archiving

A task on materials report archiving was started in 2008. All screened reports have been scanned and selected meta-information fed into the archive data base. The digital archive was finalised during 2010 and opened to the end-users. New reports are added to the digital archive as they become available.

2.6.7 Renewal of active materials research infrastructure (AKTUS)

The objectives of this study is to carry out a survey on present and future technical needs of active materials research and testing facilities at VTT. This survey will be the basis for the engineering design for the infrastructure and technical testing facilities.
The study is urgent due to the renovation work and needs in the present location at VTT. The present infrastructure and main part of the facilities have been built in the 1970's and are, thus not technically up to date and the infrastructure is not fully serving all the requirements needed to enable fulfilment of today's tasks. Further the needs of operating nuclear power plants today have changed from the start of the nuclear technology in Finland and the construction of new plants will also generate new needs to assure long term demand for nuclear specific infrastructure.

The nuclear specific infrastructure is essential in the nuclear safety research and in providing support for the nuclear power plants and for the authority as well. The possibility to handle activated materials, mainly structural materials, will also promote efficiently education and training of new experts in the field.

Specific goals in 2010

Specific goals in 2010 include further identification of experimental needs and facilities for the existing and future research needs in the area of nuclear research in VTT. This work includes detailed description of technical facilities of today and corresponding specific needs for the infrastructure and the needs of space. The work also includes reviewing on modern or modernised European research facilities for active materials: technical capabilities, technical solutions, laboratory layout and networking possibilities. Conceptual engineering design will be subcontracted and continues exchange of information between VTT project team and engineering design team will be provided.

During past decades several hot cell facilities in EU have been closed, renovated or completely rebuild. These rearrangements have often been connected with shutdowns of the nuclear research reactors as in the case of CEA Grenoble, Forschungszentrum Julich (FZJ), Karlsruhe Technology Institute (KIT) and Risø National Laboratory. These major rearrangements of nuclear research activities particularly in France and Germany have also resulted in more focused responsibilities between different laboratories particularly when it concerns material or fuel research. In France new hot cell facilities at CEA Saclay and EdF Chinon concentrates only on material research and research on fuel is concentrated in CEA Cadarache and Marcoule. Fuel and waste research in Germany concentrates in Joint Research Centre Institute for Transuranium Elements (JRC ITU) whereas safety related material research is carried out at Forscshungzentrum Rossendorf (FZR) and fusion material research at renovated hot cells at FZJ and KIT. It is also noted that in United Kingdom all nuclear services has been concentrated into the National Nuclear Laboratory (NNL) which have build a new nuclear research facility at Sellafield where also existing material hot cells have been renovated.

The FP6 HOTLAB project in 2006 has made an inventory of the present research capabilities of several European hot laboratories available within Europe. Following an agreement with the IAEA, the HOTLAB PIE and transport casks catalogue, were integrated in the IAEA PIE Database in 2008. The merged data are kept at the iNFCIS website http://www-nfcis.iaea.org and are jointly managed by the IAEA and the HOTLAB working group.

Main results in 2010

The survey on the present infrastructure and research facilities at VTT identified following basic functions and research topics. Mechanical, microstructural and fracture mechanical characterisation of active structural materials (e.g., hot cells); radiochemistry; nuclear waste studies; dosimetry and other experimental work linked to nuclear technology; first wall material research for Fusion technology programmes; iodide filter measurements and also support functions for FiR1 test reactor. Additionally there are a substantial number of people carrying out modelling work on reactor physics, fuel performance, nuclear waste, fusion technology both at VTT and Aalto University. The number of persons working in the nuclear field at VTT is about 130 – 140 persons and the estimated turnover is about 18 M€ per year.

It is foreseen that in the near future the demand for national nuclear research services will increase or at least remain at the present level. This assumption is based on the following points, e.g., aging of present nuclear power plants, construction of OL3 plant, decisions on new nuclear power plants, building of nuclear waste repository plant, implementation of EU SET plan, participation in Jules Horowitch Reactor project and in several international R&D programmes, i.e., OECD Halden project, Gen4 and fusion projects.

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VTT have subcontracted conceptual engineering design for new building where all nuclear research activities at VTT are concentrated. The boundary value for conceptual engineering design was chosen as the large concept, i.e., 9 hot cells with 150 persons, which was based on the results of the previous survey on requirements. Special emphasis was taken on radiation safety, e.g., material handling, waste disposal and laboratory design and constructions. The result of the conceptual engineering design is a new building where office, laboratory and hot cells facilities form separate sections. The builder and owner of the new building will be Senaatti-kiinteistöt Oy and VTT will rent the facilities.

The present status of the project of the renewal of the nuclear infrastructure at VTT is in the decision making process concerning all parties in question.

2.7 Construction safety research area

There were three projects going on in 2010 in the construction safety research area: Service Life Management System of Concrete Structures in Nuclear Power Plants (SERVICEMAN), IMPACT 2010 and Structures Under Soft Impact (SUSI).

2.7.1 Service Life Management System of Concrete Structures in Nuclear Power Plants (SERVICEMAN)

The objective of the project has been to develop a predictive service life management system (SLMS) for concrete structures in nuclear power plants. The management system includes prediction of service life, guarding of safety and serviceability limits, prediction of maintenance and repair actions, calculation of life cycle costs and environmental impacts, evaluation of risks and inspection of structures. By the SLMS the safety, accepted structural performance and uninterrupted service of concrete structures are ensured during the planned service life of a nuclear power plant.

The SLMS is connected to the in-service inspection system of NPP. Thus the observed condition of structures is brought to the process of service life prediction and decision making on maintenance and repair actions. The system is provided also with qualitative and quantitative risk analyses, financial and ecological life cycle analyses and detailed structural condition analyses. The methodological ground of the service life management system was developed during the EU project LIFECON (2001-2003) (GIRD-CT-2000-00378).

The actual service life management system is supplemented by structural analyses and risk analyses as the consequences of degradation cannot be treated only as a problem of repair. The safety aspect must be considered too. That is why special risk analyses for corrosion of steel liner and prestressing tendons were conducted. Structural analyses were done for evaluating the structural consequences of possible tendon breaks.

The cracking behaviour of concrete structures in nuclear power pants was studied by a special design program (IVODIM) for serviceability limit state design. The programme was utilised in the cracking analyses of the project.

Specific goals in 2010

1 Development and programming of the service life management system
The main software for the management system and the databases has been accomplished. The degradation models for 5 degradation types have been integrated to the system. The timing of MR&R actions and special inspections is working. The project planning and annual resources planning have been programmed. The special goals for 2010 were the following:

- The outputs of the ServiceMan program were still subject to critical review. Minor changes or corrections to the software were to be done. At the end of the year the program ServiceMan was to be submitted to power companies. Final adjustments were planned to ensure the proper working of the program, printouts etc. Schooling was to be arranged in the autumn. A user manual was to be written both in Finnish and in English.

- The first special inspection was to be performed during 2010. It was addressed to one or two modules in the cooling water channelling system in Olkiluoto 1 and Loviisa 1 plants. The inspection was planned to be a “model” for later special inspections performed for other modules. The plan contained sample taking from 1) above the water level 2) tidal zone 3) under water level. The samples were to be analysed according to the testing plan made in 2007.

2 Structural degradation analyses

The structural risk analyses were planned to be a continuation to the material and component level analyses performed in 2009 (Task 3). The risk analyses of the containment building were designed to be a supplementing part of the service life management system as it is considered that the corrosion risks (included with other long-term hazards) in the containment building are more serious than in other structures of the plant.

The FEM grid and the material models for the Olkiluoto 2 containment was developed in 2009 and some preliminary stress analyses were performed. The special goals for 2010 were the following:

- FE analysis of Olkiluoto 2 containment was to be performed in VTT taking into account the relaxation of pre-stressing tendons and the time-dependent nonlinear behaviour of concrete as well as the interaction between steel and concrete (slip of tendons). Hypothetical breaks of tendons are assumed fir studying the distribution of stresses in the case of possible breaks as a result of corrosion. As a result of these studies an answer will be obtained how many tendon breaks would possibly be tolerable and in which kind of combinations they could be without jeopardising the safety of the containment. By combining this data to the results of the component level risk analyses (probability of a tendon break) the level of structural risk as a result of corrosion in tendons was to be evaluated.

- Using the stress analyses conducted by VTT cracking analyses of the containment were to be performed by ÅF-Consult. The calculation model and results of the stress analyses are transformed into a suitable format for the IVODIM program used in the cracking analysis. The analysis gives an estimation about the crack widths corresponding to stresses. The calculated crack widths give one additional method to evaluate the durability of the concrete structures and the calculated crack widths can be compared to the recommended values presented in design codes. Both service and accident loads can be used in the analyses. The results help also to estimate the safe test pressure for the containment leakage tests.

3 Risk analyses for the service life management system

(no goals for the year 2010)

4 Participation in national research cooperation with other owners of infrastructure

Partners in the BTS-research cooperation are The Finnish Transport Agency (the Finnish Transport Agency was formed on 1 January 2010 as the waterways functions of the Finnish Maritime Administration, the Finnish Rail Administration and the central administration of the Finnish Road Administration), Radiation and Nuclear Safety Authority, City of Helsinki, City of Tampere, City of Espoo, City of Turku. The research in BTS has been focused around durability and aging management of concrete structures.

In 2007 a field study DURAFIELD on durability of concrete materials and structures was started. In 2008 this project was expanded to an international project and the project name was changed to DURAINT. The results of this research can be utilised in the degradation models of NPP structures.

The share of VYR financing is about 15% of the whole budget BTS and about 3 % of BTS and DURAINT together. The specific goals in 2010 were the following:

- Consulting on concrete technological topics
- The effect of permeability properties of concrete repair materials on service life
- Acceptance of form liners
- SILKO tests of concrete repair materials (excluding restrained shrinkage)
- SILKO tests of protective agents of concrete
- Correlation between CEN/TS 12390-9 slab test and EN13687-3

- Correlation between CEN/TS 12390-9 slab test and the combination of EN13687-1 and EN13687-2
- The applicability of heating surface instrument for heating and drying of concrete substrate for water proofing

5 International cooperation

Participation in OECD/NEA/CSNI/IAGE (Integrity and Aging) work group. IAGE work group is divided into three subgroups: IAGE Seismic, IAGE Metal and IAGE Concrete. The IAGE Concrete group deals with aging phenomenon and aging management of concrete structures in nuclear power plants. Traditionally VTT has participated in the work of this group by SAFIR financing (in 2003 – 2010).

Participating in COST C25 "Sustainability of Constructions: Integrated Approach to Life-time Structural Engineering" in years 2007-2010. COST C25 is a European network with EC financing for travels. Cooperation in COST C25 is useful for the implementation of the service life management system of NPP structures. The specific goals for 2010 were the following:

- Participation in OECD/NEA/CSNI/IAGE (Integrity and Aging) work group.
- Active participating in COST C25 "Sustainability of Constructions: Integrated Approach to Life-time Structural Engineering".

Deliverables in 2010

1 Development and programming of the service life management system

- Finalizing the service life management system software. The programming language has been changed completely to English. Some smaller additions and corrections have been made.

- Program Manual describing all displays, planning phases and printouts of the program ServiceMan is ready. It is available both in English and in Finnish.

- Paper and presentation in the international workshop AMP 2010:"Service Life Management System of Concrete Structures in Nuclear Power Plants", 8th-10th Nov 2010, Toronto.

- A special ServiceMan schooling day was arranged. During the day all functions and displays of the Serviceman program were carefully examined and they were generally approved. The ways how to use the program in the year 2011 were preliminarily agreed.

- Mentoring of another VTT's researcher on the program ServiceMan has been started and a lot of tutorial material has been prepared.

- A special inspection was done during the revisions of Olkiluoto 1 and Loviisa 1. The specimens were taken from two modules/plant at three heights: above the water level, tidal zone, and under water level. The carbonation depth and the chloride profiles were determined and the micro-structural thin-section studies were performed from the samples. The chloride profiles were modeled and the remaining activation time of corrosion was evaluated based on the models.

- The report "Condition Assessment of Cooling Water Channels in Finnish Nuclear Power Plants" has been made.

2. Structural degradation analyses

- A model of OL2 containment using shell elements for the containment and truss elements for the post-tensioned tendons was developed. The interaction between container and tendons was modeled by using different contact analysis options available in the ABAQUS finite element code. The possible breaks of tendons were modeled as deactivation of the contacts in the extent of anchoring distance given by Finnish standards and by discarding the tendons completely (the lower and upper solutions). Their effect on the stress distribution was evaluated. This model was deployed for the cracking analyses with IVODIM programme. For comparative cracking analyses with ABAQUS, so called unlinear “concrete damaged plasticity” material model was used, but this model still needs improvements. The normal bending reinforcement layers have been re-checked and for zone under evaluation, the reinforcement is accurate enough and in coherence with the IVODIM model.

- For the whole wall thickness, a 3D solid model with the steel liner was used. Analyses with that model, giving stresses for the liner, were conducted.

- The report “Structural failure analyses of post-tensioned containment building of Olkiluoto 2 nuclear power plant” is ready.

- The cylindrical, prestressed concrete wall with the thickness of 800 mm was considered in the cracking analyses made using IVODIM design tool by ÅF-Consult Oy. The stress resultants of the shell element model of OL2 containment were transformed from ABAQUS program (VTT) into IVODIM system (ÅF). The crack widths were calculated for the whole containment and the results of a control area were analysed more precisely. The control area, its cross-section and the broken tendons are shown in Figure 1 below. Six different loading cases were studied. The basic loads taken into account are the dead load of structures, the prestressing forces of tendons and the test pressure load.

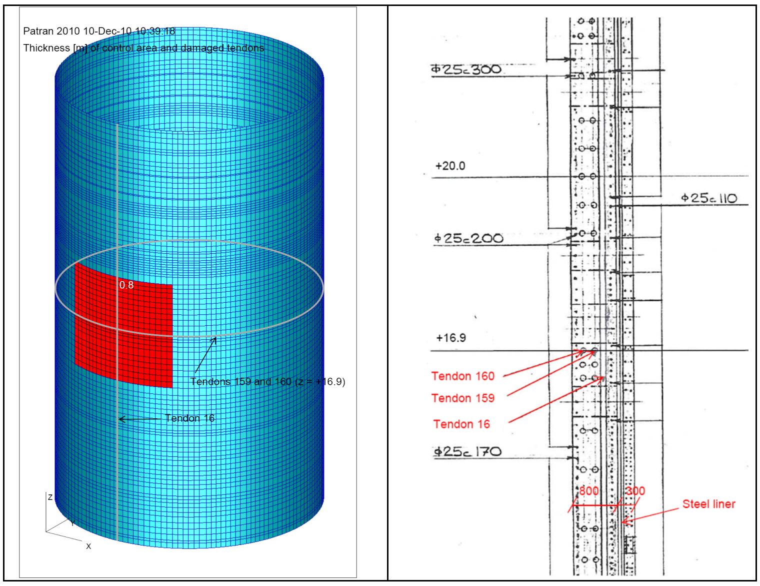


Figure 1. Cracking analysis model of Olkiluoto 2 containment.

- The report “Crack Width Analysis for Containment Building of Olkiluoto 2 Nuclear Power Plant”is ready.

4 Participation in national research cooperation with other owners of infrastructure

- Participation in preparation of the following guidelines of bridge repair:
  Under preparation:
  - Protection of concrete

- Coating of concrete
- Coating agents
- Anti graffiti agents
- Repair using ejector

Published:

- Replacement of reinforcement. Betonirakenteet - Raudoituksen uusiminen - Työkohtaiset laatuvaatimukset (Concrete structures - renewal of reinforcement). SILKO - guidelines 2.262. 7 p. (In Finnish)
- Cleaning of concrete surface. Betonirakenteet - Betonipinnan puhdistus - Työkohtaiset laatuvaatimukset (Concrete structures – cleaning of concrete surface). SILKO - guidelines 2.251. 8 p. (In Finnish)
- Repair of concrete structures have been published (Being printed)

- Carbonation and chloride penetration tests as well as chloride analyses are completed.
- A proposal of which form liners in Finnish market may be accepted for Finnish Transport Agency is reported. Muottikankaita koskevan tutkimusaineiston analysointi (Analysis of research material related to form textiles). VTT Research Report VTT-R-02854-10. 25 p. (In Finnish)
- Research report on the SILKO tests of repair materials is completed. SILKO test results of concrete repair materials 2010. VTT Research Report VTT-R-07436-10. 40 p.
- The SILKO tests on coating materials are ongoing (continued in 2011)
- The comparative tests between different test standards are ongoing
- Research report has been written about the theoretical calculations of parameters for heating and drying of concrete bridge decks for waterproofing works. The site study is finished.

DuraInt – The results of the field and laboratory tests until the end of year 2010 have been reported. The field tests and some laboratory tests are still going on, however. Degradation and service-life modeling is still ongoing (continued in 2011).

5 International cooperation (OECD/ NEA/IAGE and COST C25)

- The annual meeting of OECD/NEA IAGE Concrete WG was held on 14th April 2010 in Paris. Erkki Vesikari participated the meeting.
- The meeting of COST Action C25 was held in May 24 – 25 in Izmir.
- International workshop AMP 2010 was held in November 8 - 10 in Toronto. Erkki Vesikari, Aki Mattila and Vesa Hiltunen participated the workshop. Program ServiceMan was introduced.

2.7.2 Impact of an aircraft against a structure (IMPACT 2010)

A general objective of this project is to obtain experimental information on the physical phenomena involved in a condition where an airplane impacts against a nuclear facility. The missiles used in impact tests are describing wings, engines and carriages of aeroplane and also model of fuselage. Four specific aims of the project include firstly new data on the time-varying forces that arise during such an impact. Secondly, it is believed that high hydrodynamic shock pressures can arise while the fuel tanks impact against a fixed structure. Data on this phenomenon are requested. Thirdly, data on the shedding of the debris and spreading of liquid (fuel) from the disintegrated tanks by the impact are also requested. Fourth, response of reinforced and/or pre-stressed concrete wall (deflection, penetration) to aircraft-like impact loads will also be tested

The first phase of Impact project with foreign partners has ended in December in 2008, but the continuation project has been started in March 2009 with the same partners. Also the discussion of the next phase 3 (Impact 3) has already started.

Specific goals in 2010

1 Test apparatus

The test apparatus has been changed to be suitable to shoot missiles without carriage, which is a heavy piece under the pipe and may have an effect on results. Most of the force plate tests in the year of 2010 have been done using stainless steel pipes, which are not sensitive to break by tearing mechanism as Al pipes were in some tests in 2008. The stainless steel pipes are flattened by folding mechanism during shooting and therefore the test and the measured force-time function can be repeated reliable. The Impact apparatus has been changed and a corner profile has been attached by bolts on top of the acceleration tube (see *Figure 1, left*). The stainless steel pipe situated between the acceleration tube and corner profile can be accelerated without heavy carriage and the measuring results do not include disturbing results of heavy particles hits. The corner profile can be removed and an aeroplane model including wings can be tested.

The project of Impact Phase 2 also includes some tests with steel liners, installed on one or on both sides of the concrete walls. The preliminary fixing system for liners has been designed in 2010 and the first tests will be performed in 2011. Also the Tag meeting (Technical Advisory Group) of project has decided the impact tests with floor-wall structures will be designed and built later on in 2011 or 2012.

After 100 tests the apparatus has been strengthened by replacing the beginning part of the acceleration tube with the new steel tube thickness of 7 mm and also welding corner profiles to the lower corners of the tube. The acceleration tube can now withstand the maximum design pressure of 20 bars.

The object of the task 1 was to improve the test apparatus to be suitable to test stainless steel pipes without heavy carriage under the missile using maximum pressure of 20 bars.

2 Preliminary design of missiles and walls

New type of missiles and concrete walls have been calculated and designed in order to achieve the desired failure mode. All test mentioned in chapter 4 has been predesigned and calculated to have successful tests and to minimize the amount of unsuccessful test. The TAG meeting has decided the structure, dimensions of missiles, structure of concrete walls and also the schedule of testing.

The object of the preliminary design and calculation was to ensure the tests have been succeed in a desired way and also the number of unsuccessful test has been minimized.

3 Improvement of measuring system

The data acquisition system consists of 32 channels and the data has been collected with the frequency of 100 kHz. The noise of the measuring signals has been decreased by UPS (Uninterruptible Power Supply) and all the measuring cables have been renewed by screened cables also to reduce electrical noise.

Two plywood walls at the back of the concrete wall have been instrumented to measure the post-velocity of the missile. The final length of the reinforcement has been measured manually using marks on the surface of the bars. The laser sensor to measure the speed of the missile has been renewed.

New measuring card (8 channels) has been bought to measure extra channels and for backup.

The object of the task 3 was to improve the data acquisition system and to reduce noise of sensors to get more accurate and reliable test results. The object was also to be able to measure the post velocity of the missile after perforating the wall.

4 Testing of missiles and concrete walls

The main purpose of test campaign in 2010 was to test stainless steel missiles and pre-stressed concrete walls using different impact velocities. The tests have been performed either by using force plate or concrete walls. The schedule of tests has been decided in TAG meeting in March and December in 2010. Six specimens of stainless steel and Al missiles have been tested. Ten specimens of concrete walls, thickness of 150 mm have been manufactured and tested. Four specimens of pre stressed concrete walls thickness of 250 mm have been manufactured and tested. Liner design has been decided, but the tests will begin in 2011.

The curved walls and floor-wall structures will be tested at the end of the project
The object of the task 4 in 2010 was to test stainless steel missiles and concrete walls with different velocities.

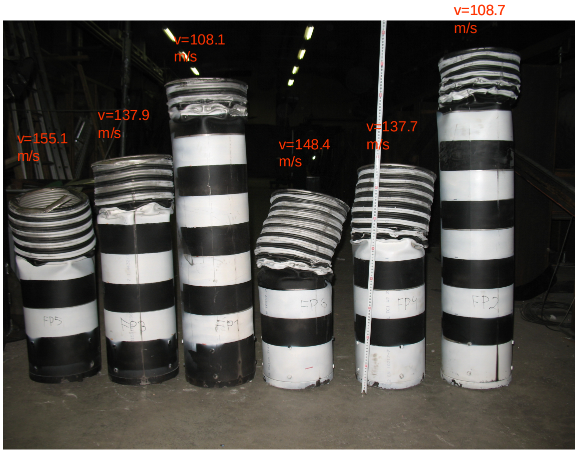


Fig. 1. Corner profile installed on top of acceleration tube (left). Stainless steel missiles after shooting (right).

Deliverables in 2010

Test apparatus

- The impact apparatus has been modified by installing a corner profile on top of acceleration tube. The missiles can be shot without a heavy carriage, which could cause defects on force-time function. The beginning part of the acceleration tube has been strengthened to withstand the maximum pressure of 20 bars. The supporting frame will be modified for liner and floor-wall structures later on in 2011.

Preliminary design of missiles and walls

- All the force plate and concrete wall tests have been designed and pre-calculated in order to have successful tests.

Improvement of measuring system

- The measuring system has been improved to reduce noise of sensors in order to get more accurate and reliable test results. New measuring system has been designed to measure the post velocity of the missile after perforation.

Testing of missiles and concrete walls

- In 2010 six type of stainless steel missiles have been tested successfully. The missiles have been either dry or filled with water. Ten concrete walls thickness of 150 mm and four concrete walls thickness of 250 mm have been tested successfully. The tests campaign will continue according to schedule made by TAG meeting.

2.7.3 Structures under soft impact (SUSI)

The aim is to develop and take in use numerical methods for predicting response of reinforced concrete structures to impacts of deformable projectiles that may contain combustible liquid ("fuel"). Structural behaviour, in terms of collapse mechanism type and the damage grade, will be predicted both by simple analytical methods and by involved non-linear FE-models. The applicability of softening factors introduced in adopting classical perforation and scabbing formulae, developed for hard missiles, will be studied further. Experimental data is needed in order to verify the accuracy of numerical models.

The aim of the liquid study is to assist the IMPACT 2010 project in planning the tests with water filled missiles besides assessing and analysing the test results. An other essential objective is the development and calibration of suitable analytical and numerical methods, which can be applied in real scale analyses of fuel spreading and fire risk. Primarily, the suitability of Fire Dynamics Simulator code (FDS) for the current issue will be further studied, and the testing and validation of the sub-models will be continued. New aim is the full-scale simulation of fuel spread and combustion following an aircraft crash by utilizing the data gained from the VTT IMPACT tests and from GRS.

Specific goals in 2010

Simplified methods will be developed further: Post analyses for the impact tests will be carried out as the test program proceeds. When experimental data is gathered the role of damping will be studied in more detail.

Bending and shear failure of a reinforced concrete slab subjected to a projectile impact can be simply modelled with a two mass system. The two mass system is, however, sensitive to the assumed angle of shear cone. Nonlinear analyses of reinforced concrete structures are quite sensitive for material parameters. Assumed tensile cracking properties of concrete dominate the calculated maximum deflection value. Tensile damage assumptions affect the dynamic vibration behaviour of the damaged wall. Also the assumption of the compression recovery after tensile cracking seems to affect remarkable the bending vibration frequency and the permanent displacement of the wall.

In the hard missile studies there is a good correlation between the main measurement and simulation results even though the impact velocity, reinforcement, material properties and the realized damage mechanisms varied in different tests. However, the finite element model was developed in such an artificial way that it is able to describe the assumed behaviour, and it is thus not universally applicable to all types of cases, especially if they are beforehand unknown. The used complex analysis method is able to predict the mechanical behaviour of reinforced concrete structures subjected to hard missile impact, such as tunneling, perforation, scabbing and global slab oscillation, but it is very sensitive to certain parameters which may not necessarily have any physical relevance. The methods, codes and computational capacity allow very sophisticated and detailed simulations, but more experience, stronger command of these varying methods and deeper understanding of the physical phenomena is still needed.

Liquid dispersal study has given new qualitative and quantitative experimental information on the phenomena affecting liquid spread, and on important input parameters such as spray speed, propagation direction and drop size needed for numerical simulation. The Fire Dynamics Simulator (FDS) program has been applied both in liquid spreading and fuel burning analyses in impact.

Deliverables in 2010
Examples on the numerical simulations are given in Figs 1-3.

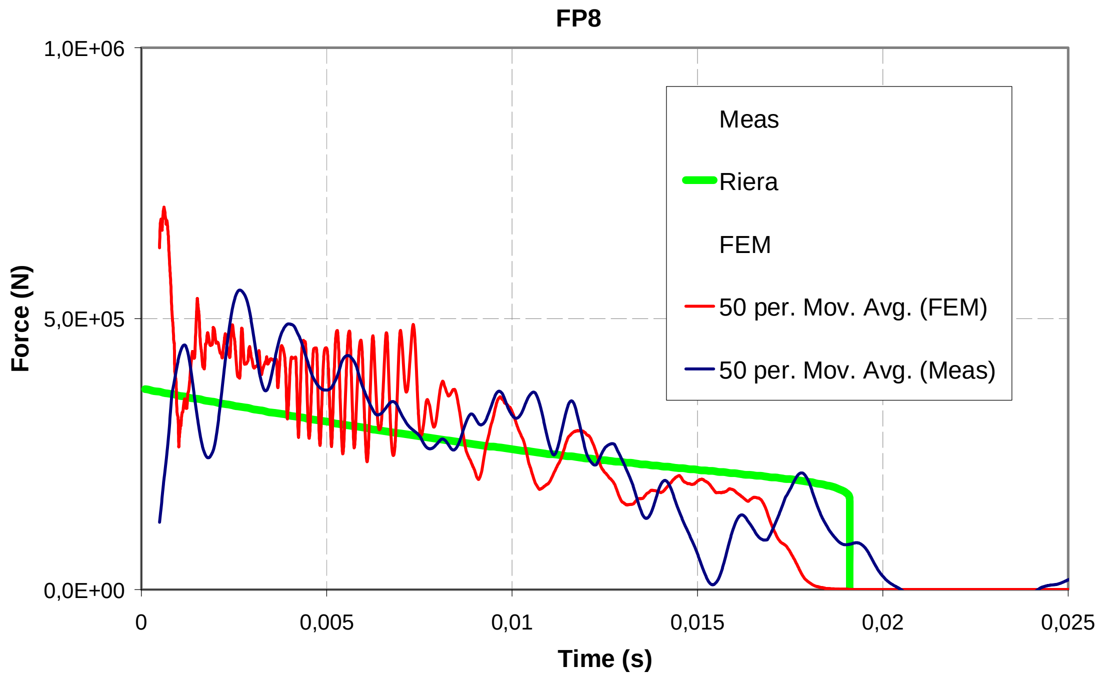


Fig.1. Calculated load functions vs. measured values.

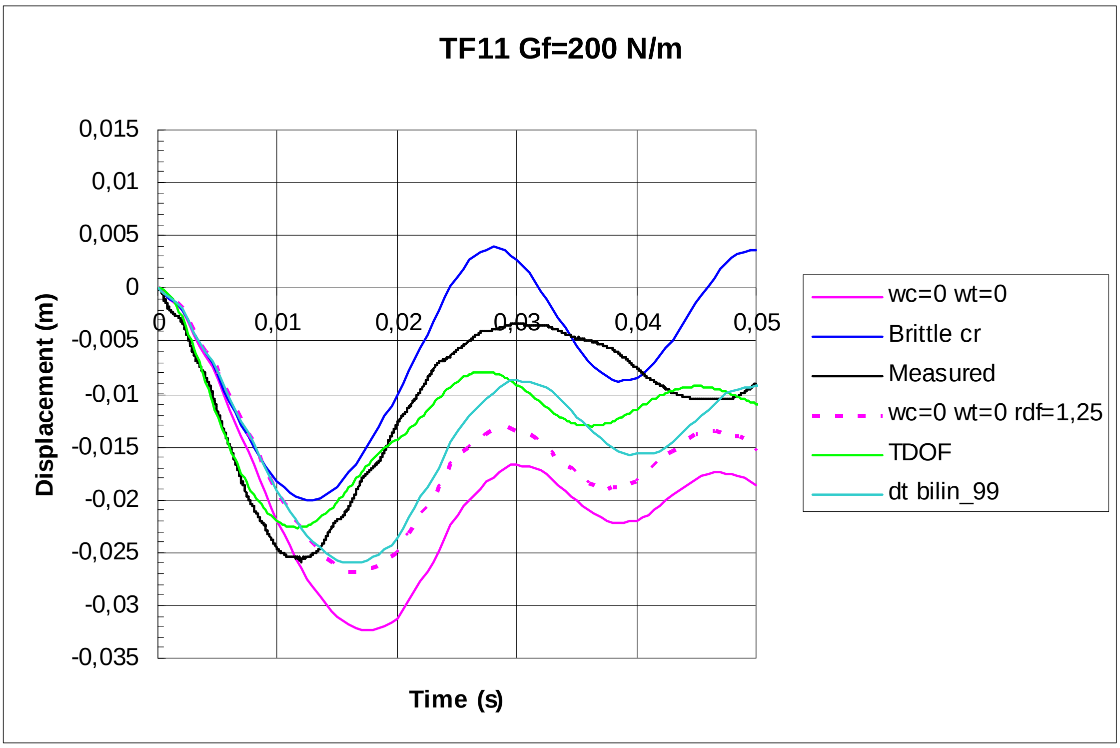


Fig. 2. Central deflection of a two way supported wall as a function of time.

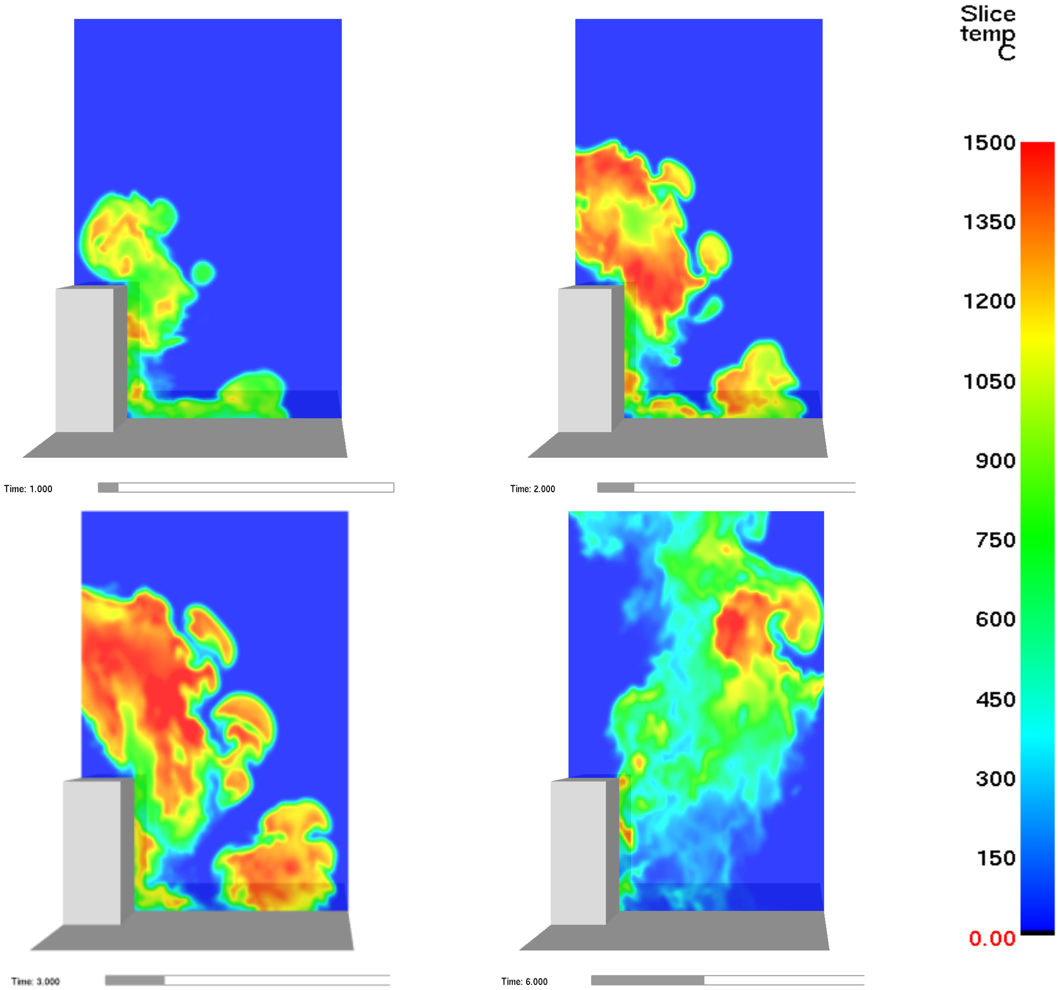


Fig. 3. Simulation of Fires from Aircraft Impacts. Prediction of fuel distribution (fire ball / pool fire), and the corresponding heat exposures.

2.8 Probabilistic safety analysis (PSA) research area

There were three projects going on in 2010 in the Probabilistic safety analysis (PSA) research area: CHAllenges in Risk-Informed Safety MAnagement (CHARISMA), Implementation of Quantitative Fire Risk Assessment in PSA (FIRAS) and Extreme weather and nuclear power plants (EXWE).

2.8.1 CHAllenges in Risk-Informed Safety MAnagement (CHARISMA)

Challenges in risk-informed safety management are related to use of probabilistic safety assessment (PSA) to support decision making and to intrinsic as well as practical problems in PSA techniques. Generally, the project deals with the whole scope of risk-informed methods and application areas related to safety of nuclear power plants. The main objectives are:
• to develop risk-informed decision making methods that integrate results from risk and reliability analyses with other expertise in the problem domain,
• to develop assessment methods for nuclear power plants operation and maintenance in order to enhance risk-informed ways of planning of activities and acting in safety-critical situations,
• to develop methodologies in the problem areas of PSA,
to advance skills in nuclear risk analysis, assure the competence transfer to the new generation and to participate in international co-operation.

Specific goals in 2010

- Preparing the final report of the NKS project as well as the report of the WGRISK task on PSA criteria. Develop guidance to the definition of valid subsidiary criteria, i.e., lower level criteria that are indirectly related to the societal and individual risk criteria but that are directly applicable with present PSAs.
- Reporting the results of development of a contextual and systemic approach to analysis of performance shaping factors (PSF) of fire situations from the controllability of the situation point of view. Modelling of operational actions for fire PSA in collaboration with FIRAS project.
- Reporting the results from the international comparison study of HRA methods organised by the OECD/NEA Halden Reactor Project. Participation in the Swedish-German-Finnish project EXAM-HRA whose overall objective is to provide guidance for a ”state of the art” HRA for purposes of PSA to ensure that plant specific properties are properly taken into consideration in the analysis.
- Examination of theoretical properties of dynamic flowgraph methodology (DFM) in comparison to the conventional fault tree modelling.
- Pre-study on the preparation of guidelines for reliability analysis of digital systems in PSA context.
- Summarizing issues and results considered at level 3 PSA during 2007-2008.
- Participation in the EU-project ASAMPSA2 aiming to develop best practice guidelines for the performance of Level-2 PSA methodologies with a view to harmonization at EU level and allowing a meaningful and practical uncertainty evaluation in a Level-2 PSA. Finalisation of the guidelines.

Deliverables in 2010

- Three conference papers on risk criteria for nuclear power plants. Report summarising the four-year project on safety goals for nuclear power plants. Guidance report for the definition and application of probabilistic safety criteria.

- A conference paper on the developed approach to the analysis of the controllability of fire situations. Collaboration with FIRAS project on modelling of operational actions for fire PSA.

- Three conference papers on the use of the Bayesian approach for human reliability analysis in the international comparison study of HRA methods. NPSAG summary report on Phase 1 of the EXAM-HRA Nordic-German co-operative project. Halden work report on LOFW scenario of the International HRA Empirical Study (draft early 2011).

- The applicability of various existing reliability importance measures to dynamic flowgraph methodology models was analyzed and a report was written.

- Student research project on the comparison of fault tree analysis and the dynamic flowgraph methodology with test cases.

- Report on the state-of-the-art of reliability analysis of digital I&C systems including comparison of Nordic experiences and plan for an international activity to develop guidelines for reliability analysis of digital systems in PSA context.

- Summary report on the studies carried out in 2007-2008 at level 3 PSA.

- Draft guidelines for the performance of Level 2 PSA submitted world-wide for the final review of the end users.

2.8.2 Implementation of Quantitative Fire Risk Assessment in PSA (FIRAS)

The project aims at development and application of modelling techniques for fire spread on cables and other fire loads found at NPPs, integration of the quantitative fire risk assessment methods into the NPP fire PRA, and carrying out fire simulations related to but outside OECD PRISME-project aiming to (i) guidance for the design of experiments and (ii) validation of the developed fire models. New experimental techniques have been developed to study the vertical flame spread, and analysis methods have been developed to estimate pyrolysis model parameters from the small scale experiments.

Specific goals in 2010

The specific goals in 2010 included

- Vertical flame spread experiments in the new 2-m test rig, continuing the test series performed during 2008 and 2009, and writing a scientific publication reporting the experimental methods and results.

- Validation of flame spread simulations on cable materials (See Figure 18).

- Probabilistic fire simulations of complicated rooms enabling comprehensive testing of the models, development of modelling technique for the specification of random initial fire within a complicated cable room, writing a scientific article, and related development and maintenance of Probabilistic Fire Simulator software.

- Further development and application of fire-HRA (stochastic operation time) model in cable room scenario.

- Simulations of the PRISME experiments to (i) guide the design of experiments and (ii) to validate the models developed and used in the FIRAS project.

Deliverables in 2010

- The influence of aging on the fire performance properties of cables was studied by measuring the flame spread rates on “old” samples, delivered to VTT by TVO in 1995. The results, shown in Figure 17, gave no clear indications of changes in fire performance during this period of ageing.

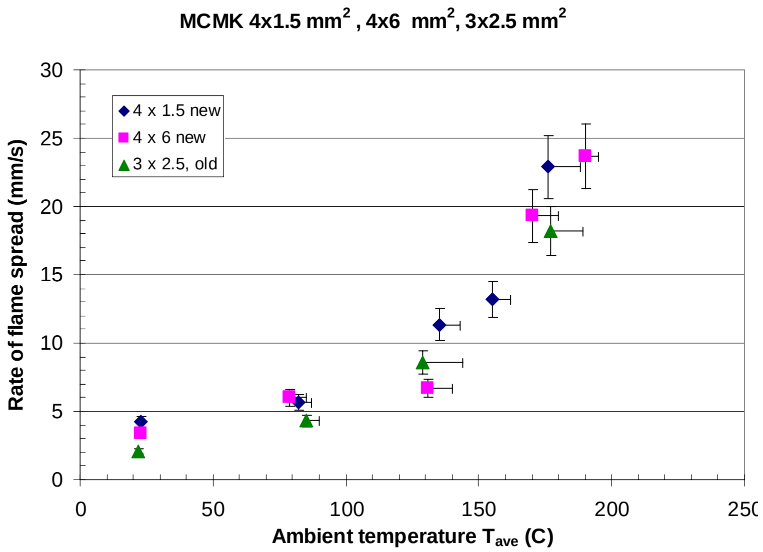


Figure 17. Steady-state flame spread rate on “old” and “new” PVC cables at different ambient temperatures.

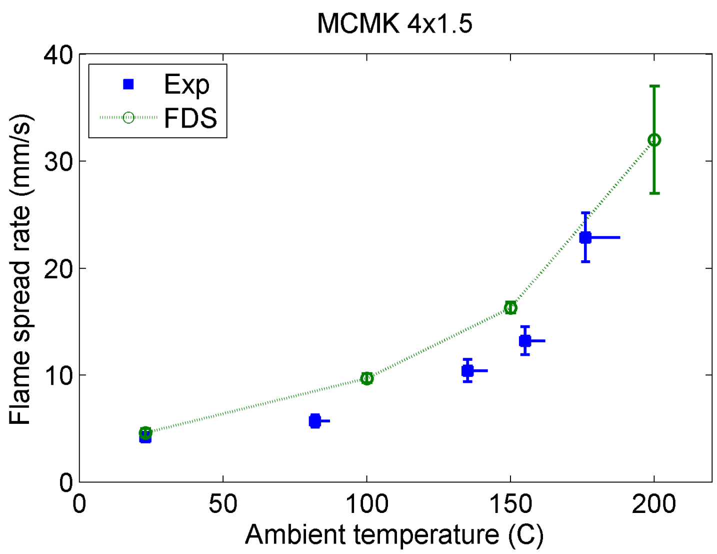


Figure 18. Comparison of measured and simulated steady-state flame spread rate on PVC-cable at different ambient temperatures.

- The additives (presumably mainly softeners) in PVC materials were found to have an important role on the flame spread characteristics. A new set of pyrolysis model parameters was estimated for MCMK cables, and the validation simulations that were unsuccessful in 2009, were repeated. The results, shown in Figure 18, were satisfactory.

- The probabilistic simulations of the cable tunnels were reported in a scientific journal article (submitted). The probabilistic simulations of the more challenging target, big cable room, were performed but the fire spreading results were found to be unreliable for making conclusions about the failure probabilities.

- The computational tool for the fire-HRA of fire suppression and management situation improved and site-specific data was collected using expert workshop. The tool was applied for a simple scenario.

- The results of a joint benchmarking exercise within the OECD/PRISME project were published.

2.8.3 Extreme weather and nuclear power plants (EXWE)

The overall objective of the project is to comprehensively analyse extreme weather events and sea level rise that are relevant for nuclear power plant safety in Finland. The design basis of new nuclear power plants is affected by risks caused by harsh weather conditions and extreme sea level. Some exceptional weather phenomena may also prevent normal power operation of a functioning plant and concurrently endanger its safe shutdown. Extreme weather events could affect, for example, the external power grid connection, emergency diesel generators (blockage of air intakes), ventilation and cooling of electric and electronics equipment rooms and the seawater intake. The nuclear power plant units now in use, under construction or in design are planned to be operational several decades, up to the 2070's. The risks caused by weather or climate are very often related to rare situations, e.g. those occurring once in 20 or 50 years, or once in 100 years or even less frequently. Climate change caused by increasing greenhouse gas concentrations in the atmosphere may alter the occurrence of relevant extreme weather and sea level events and also influence on the most effective ways to operate the power plants.

Specific goals in 2010

In 2010 the study concentrated in three main topics: a) to aggregate the weather and climate extremes studies results into a single publication, b) to examine the return levels of climate extremes utilizing millennium long climate model simulations and c) to present scenarios for the mean sea level on the Finnish coast up to year 2100 and probabilities for extremely high sea levels in the future.

Deliverables in 2010

- A summary publication about the weather extremes in Finland. The aggregation report sums up the central findings from the extreme climate and weather studies conducted during the years 2007-2010 under the EXWE project. It comprises results of return periods of extreme air temperature, enthalpy, precipitation, snow cover and length of dry, hot and cold spells. Studies of danger-causing weather phenomena such as hail, snowstorms, freezing precipitation, tornadoes and downbursts are included in this report as well. Human induced climate warming might trigger abrupt and nonlinear climate changes, which might have fatal consequences in continental to global scale. These issues related to the melting of the Arctic sea-ice cover and the continental ice sheets, and changes in the Atlantic thermohaline circulation are also discussed in this report. The latest results concerning sea level height along the Finnish coastline has been included in this report as well.

- A report on weather extremes based on millennium long climate simulations. In order to extend the extreme event analysis to very rare events (occurring a few times per millennium) and to get better understanding of the natural climate variability, model output from a 1200-year preindustrial control climate simulation was utilized. The simulation was run with a coupled atmosphere-ocean climate model ECHAM5/MPIOM at the FMI within the COmmunity earths System MOdelS (COSMOS) co-operation (http://cosmos.enes.org). After corrections for systematic biases, these millennium-long time series allowed estimation of probabilities for extreme weather events in the current climate in a statistical material much wider than the observed data. To give an example, it was found that the 500-year return level estimate for an extreme 7-day average temperature was 24.0°C (with 95%-confidence interval of 23.6…24.6°C) in July and -30.2°C (-31.1…-29.3°C) in February over a grid box (300 km x 300 km) covering much of southern Finland. Based on Fig. 1, the probability for the occurrence of a day with a mean temperature of at least 25ºC in July is about 0.2% in our country.

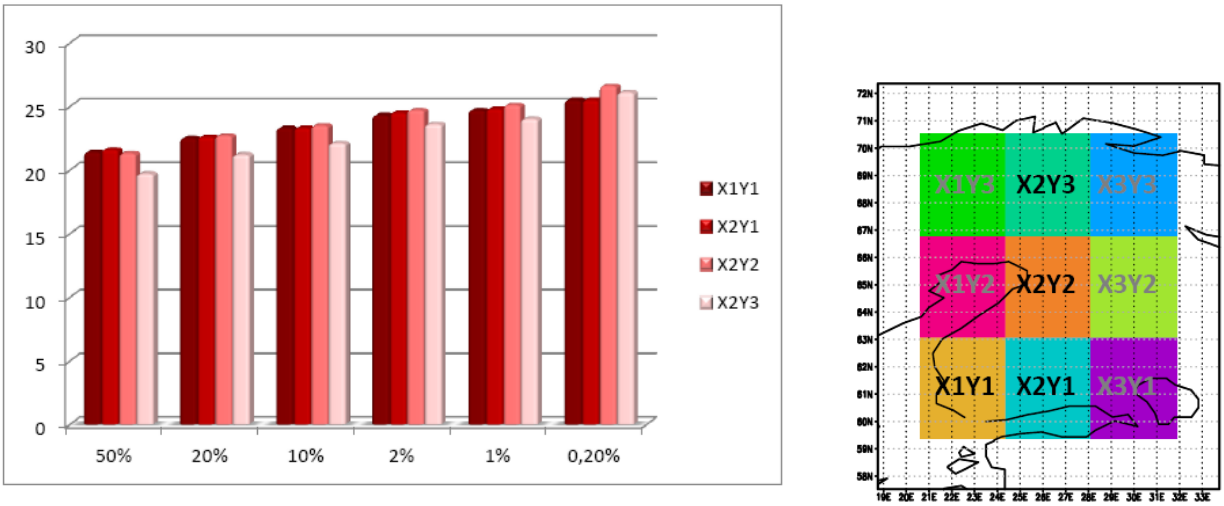


Figure 1. Probabilities of the occurrence of at least one day in July with mean temperature higher than that given in the vertical axis, based on millennium control climate simulation adjusted to present the period 1961-2009. The corresponding model grid boxes are shown on the right.

- A report on the effect of climate change on mean and extreme sea level events on the Finnish coast. In the Gulf of Finland, the past declining trend of the mean sea level will probably not continue in the future, because the accelerating rise in the sea level will exceed the land uplift. In the Gulf of Bothnia, the land uplift will dominate over the sea level rise most probably in the near future. According to the average scenario for the year 2100, the mean water level will rise about 45 cm in Helsinki and about 15 cm at Rauma

(Fig. 2), relative to the current situation. The uncertainty ranges are wide, however. Regarding extreme sea level events, observed probability distributions that are based on century-long time series were extrapolated in Fig. 3 to assess probabilities of very extreme sea level events, up to those 10^{-8} occurrences/year.

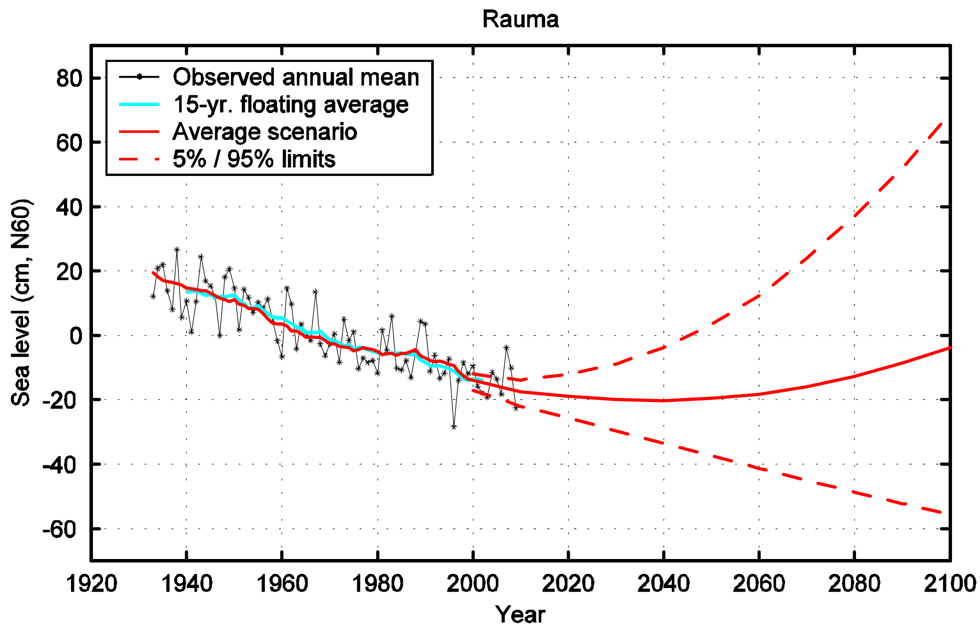


Figure 2. Observed annual mean sea levels in the 20th century and scenarios (conservative estimate) up to 2100 at Rauma.

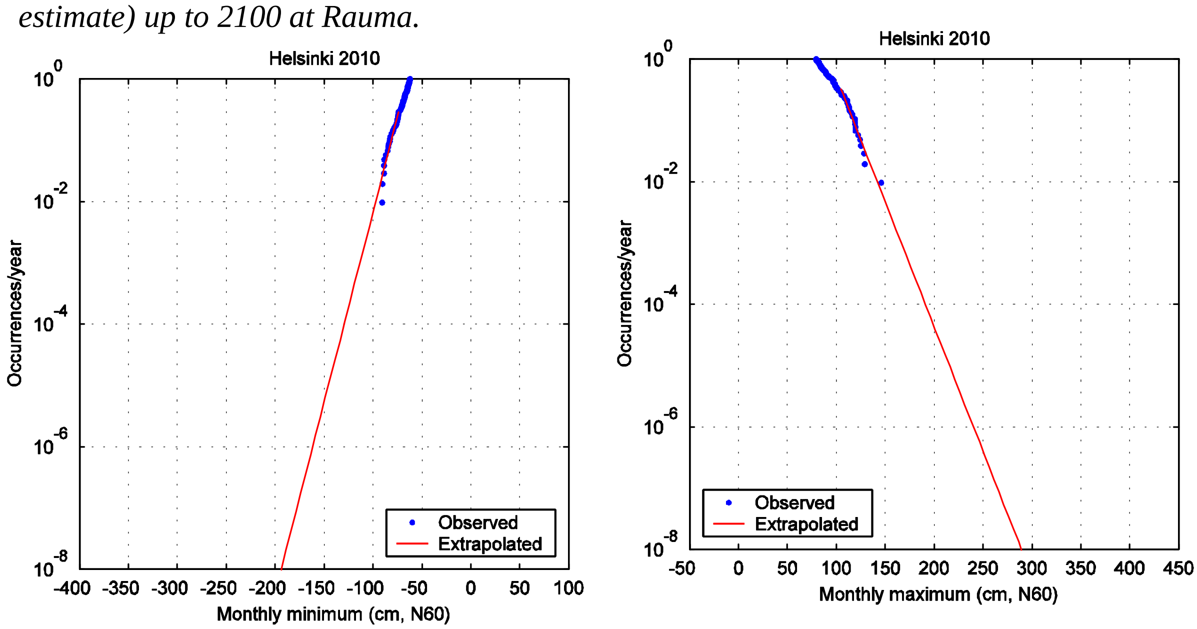


Figure 3. Probability distributions for monthly maximum and minimum sea levels in Helsinki in the present conditions.

3 Financial and statistical information

The planned and realised volumes of the SAFIR2010-programme in 2010 were 7.165 M€ and 7.241 M€ and 47.5 and 51.5 person years, respectively. The major funding partners were VYR with 2.947 M€, VTT with 2.776 M€, Fortum with 0.218 M€, TVO with 0.110 M€, NKS with 0.148 M€, EU with 0.028 Me and other partners with 1.014 M€. The planned and realised volume, funding and costs of SAFIR2010 projects in 2010 have been illustrated in Table 3.1. The planned and realised funding by the major funding partners has been illustrated in Figure 3.1. The planned and realised costs by cost category have been presented in Figure 3.2. Personnel costs form the major share of the yearly costs.

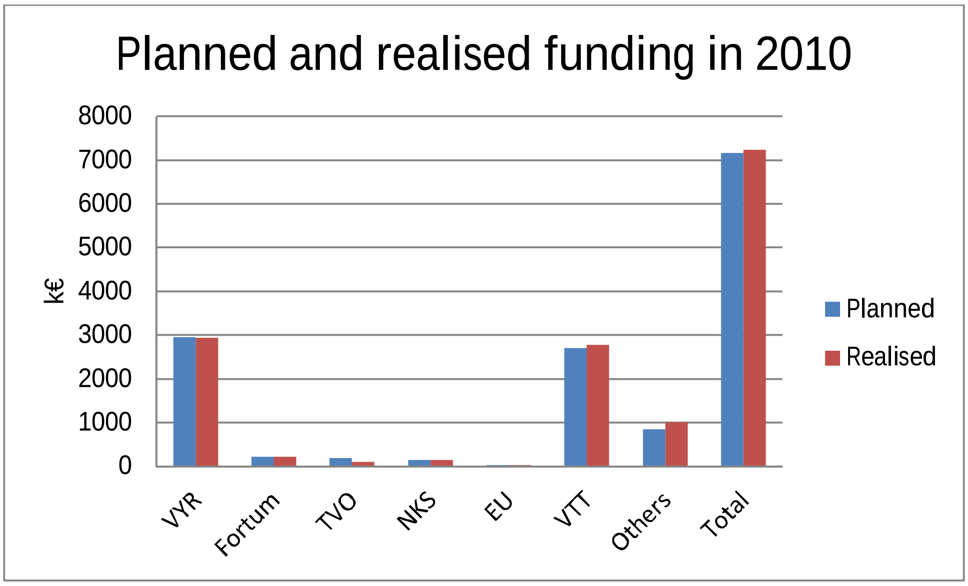


Figure 3.1. Planned and realised financing of the SAFIR2010 programme in 2010.

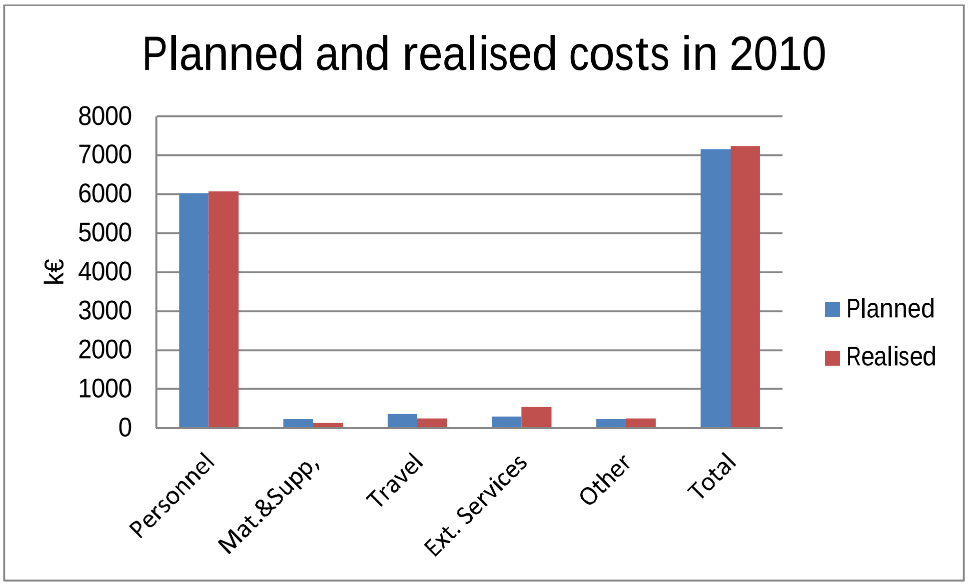


Figure 3.2. Planned and realised costs of the SAFIR2010 programme in 2010.

The Finnish Research Programme on Nuclear Power Plant Safety (SAFIR2010) 2007-2010

5.8.2011
E.K. Puska

Resource Summary 2010

		Expenses						Funding										Päivitys
	Volume	Personnel	Mat&supp	Travel	Ext serv	Other	Total 2010	VYR funding %	VYR2010	Fortum	TVO	NKS	EU	VTT	Other	tarkistus	Muu rah.	
Research area, Organisation, Project, Acronym	pers months	k €	k €	k €	k €	k €	k €		k€	k €	k €	k €	k €	k €	k €	check sum	Other	
1. VTT																		
Safety management and organisatorial learning	13	185,946	0,848	22,403	4,053	0,227	**213,477**	**38,6**	**82,300**	0	0	35	0	75,034	21,143	213,477	OKG	OK
MANOR	13	192,3	2	17	0	2	**213,3**	**38,6**	**82,300**	0	0	35	0	76	20	213,300		
1. TKK&TTL																		
Expert work in safety critical environment	13,9	130,806	0	8,206	7,337	0	**146,349**	**46,2**	**67,580**	0	0	0	0	0	78,769	146,349		OK
(SafeExpertNet) (SAFEX)	12,95	137,982	0	5,515	10	0	**153,497**	**45,4**	**69,700**	0	0	0	0	0	83,797	153,497		
2. VTT&TKK&other																		
Model-based safety evaluation of automation systems	16,4	167,248	0,23	7,146	3,328		**177,952**	***70,8***	**126,000**	0	0	0	0	51,952	0	177,952		OK
MODSAFE	15,5	160,3	0,7	15	2	0	**178**	***70,8***	**126,000**	0	0	0	0	52	0	178		
2. VTT&TTY																		
Certification facilities for software	9,6	100,156	0	5,111	0	1,033	**106,3**	**67,1**	**71,300**	10	10	0	0	10	5	106,300	Fennovoim	OK
CERFAS	9,8	87,8	1	14	0	3,5	**106,3**	**67,1**	**71,300**	10	10	0	0	10	5	106,300		
2. VTT																		
Operator practoces and human-system interfaces in																		
computer-basd control stations	15,5	211,611	0,91	5,901	0,904	0	**219,326**	**29,3**	**64,300**	40	10	0	0	62,203	42,823	219,326	Halden	OK
OPRACTICE	15,5	209,3	1	7	0	0	**217,3**	**29,6**	**64,300**	40	10	0	0	63	40	217,300		
2. TKK																		
Requirements engineering in nuclear power plant	5	73,575	0	0,222	0,247	0	**74,044**	***52,9***	**39,200**	0	0	0	0	16,934	17,91	74,044	TKK	OK
automation (VAHAYA)	5,5	69,25		2,5	1,05	0,4	**73,2**	***53,6***	**39,200**	0	0	0	0	17	17	73,2		
3. VTT																		
Development and validation of Fuel performance	29,4	307,399	0,016	15,611	4,302	13,167	**340,495**	**50,2**	**170,800**	0	0	0	0	110,419	59,276	340,495	Halden	OK
codes, POKEVA	26	302,8	0	27	0	2	**331,8**	**51,5**	**170,800**	0	0	0	0	110	51	331,800		
3. VTT																		
Tridimensional core transient analysis methods	27,3	332,477	0,145	7,152	22,863	11,745	**374,382**	**29,2**	**109,200**	0	0	0	0	254,47	10,712	374,382		OK
TRICOT	25,2	303,2	0	11	0	5	**319,2**	**34,2**	**109,200**	0	0	0	0	210	0	319,200		
3. VTT																		
Total reactor physics analysis system	23,3	250,285	0,152	34,24	8,395	10,299	**303,371**	**34,7**	**105,300**	0	0	0	0	198,071	0	303,371		OK
TOPAS	24,3	271,5	0	15	3	13,8	**303,3**	**34,7**	**105,300**	0	0	0	0	198	0	303,300		
4. VTT																		
Numerical modelling of condensation pool	6,7	88,689	0	3,562	0	9,649	**101,9**	**36,6**	**37,300**	0	0	24,6	0	40	0	101,900		OK
NUMPOOL	6,8	83,9	0	6	0	12	**101,9**	**36,6**	**37,300**	0	0	24,6	0	40	0	101,900		
4. VTT																		
Improved thermal hydraulic analyses of nuclear	22,1	260,114	0	15,126	45,005	2,042	**322,287**	**43,7**	**140,900**	9	0	0	0	164,387	8	322,287	TEM	OK
reactor and containment, THARE	18,5	245	0	20	55	1,9	**321,9**	**43,8**	**140,900**	9	0	0	0	164	8	321,900		
4. VTT																		
CFD modelling of NPP Steam Generators	9,7	111,965	0,122	4,172	0	5,179	**121,438**	**32,3**	**39,200**	40	0	0	0	42,238	0	121,438		OK
SGEN	8,7	105,2		6		10	**121,2**	**32,3**	**39,200**	40	0	0	0	42	0	121,200		
4. LTY																		
Improvement of PACTEL Facility Simulation	10,4	91,25052	0	0	0	0	**91,25052**	**61,4**	**56,000**	0	0	0	0	0	35,25052	91,251	LUT	OK
Environment PACSIM	10,1	83	0	0	0	0	**83**	**67,5**	**56,000**	0	0	0	0	0	27	83,000		
4. LTY																		
Condensation experiments with PPOOLEX facility	30,5	310,114	0	4,20039	10,33881	0	**324,6532**	**59,8**	**194,076**	0	0	24,624	0	0	105,9532	324,653	Northnet	OK
CONDEX	20	221,676	16	15	16	0	**268,676**	**72,2**	**194,076**	0	0	24,6	0	0	50	268,676	LUT	

4. LTY																		
Passive safety system simulation	4,1	42,3635	0	0,48884	0	0	42,85234	53,3	22,852	0	10	0	0	0	10	42,852	Fennovoim	OK?
PASSIMU	4,1	41,3	0	1	1	0	43,3	53,8	23,300	0	10	0	0	0	10	43,300		
4. Fortum Nuclear Services																		
OpenFOAM CFD-solver for nuclear safety related	7,1	83,67	0	0	0	0	83,67	46,9	39,200	36,1	0	0	0	0	8,37	83,67	Aalto	OK
flow simulations (NUFOAM)	7,6	79,5	0	5	0	0	84,5	46,4	39,200	45,3	0	0	0	0	0	84,5		
5. VTT																		
Release of radioactive materials from a degrading cor	7,9	98,175	0,209	1,348	0	0	99,732	33,0	32,912	0	0	0	0	66,82	0	99,732		OK
RADECO	9	111	1	3,9	0	0	115,9	32,7	37,900	0	0	0	0	78	0	115,900		
5. VTT																		
Primary circuit chemistry of fission products	17,5	231,432	11,049	18,38	4,201	41,762	306,824	31,0	95,000	30	0	37	0	137,824	7	306,824	IRSN	OK
CHEMPC	17,5	227	8	16	0	30	281	33,8	95,000	30	0	37	0	112	7	281,000		
5. VTT																		
Core melt stabilization	13,4	146,211	0,005	11,058	37,315	0	194,589	43,9	85,500	0	0	0	0	94,089	15	194,589	TEM	OK
COMESTA2010	11,6	143	0	16,5	0	35	194,5	44,0	85,500	0	0	0	0	94	15	194,500		
5. VTT																		
Hydrogen combustion risk and core debris	12,1	149,761	16,829	2,183	7,96	5,186	181,919	37,5	68,300	0	0	0	0	113,619	0	181,919	TEM	OK
coolability (HYBCIS2)	11	135,5	18	5	2	14,8	175,3	39,0	68,300	0	0	0	0	97	10	175,300		
6. VTT																		
Risk-informed inspections of piping	10,3	141,06	0	5,731	11,658	0	158,449	47,0	74,471	0	0	0	0	83,978	0	158,449	JRC	OK
PURISTA	11,3	161	10	7,6	0	0	178,6	46,2	82,600	0	0	0	0	84	12	178,600		
6. VTT																		
Fatigue endurance of critical equipment	16,8	170,813	12,854	3,168	16,589	0	203,424	24,8	50,400	13	20	0	0	120,024	0	203,424		OK
FATE	13,3	167	45,4	5	16	0	233,4	21,6	50,400	13	50	0	0	120	0	233,400		
6.VTT																		
Water chemistry and oxidation in the primary circuit	8,5	120,951	0,031	6,993	9,036	9,3	146,311	41,1	60,200	0	0	0	0	86,111	0	146,311		OK
WATCHEM	8,5	124,2	5	4	8	0	141,2	42,6	60,200	0	0	0	0	81	0	141,200		
6. VTT																		
Monitoriing of the structural integrity of reactor circuit	16	179,612	1,605	10,248	21,394	13,748	226,607	33,6	76,200	15	0	0	0	135,407	0	226,607		OK
RAKEMON	16	198	3	20,2	2	3	226,2	33,7	76,200	15	0	0	0	135	0	226,200		
6.VTT																		
Fracture assessment of reactor circuit	28,8	332,316	3,194	7,448	14,188	35,188	392,334	33,2	130,100	10	45	0	0	189,254	17,98	392,334	BG	OK
FRAS	28,8	335,1	5	18	8	26	392,1	33,2	130,100	10	45	0	0	189	18	392,100		
6. VTT																		
Influence of material, environment and strain rate on	33,10	321,272	8,562	16,48	43,605	27,821	417,74	30,1	125,700	0	0	0	0	194,937	97,103	417,740	SWE 58	OK
environmentally asssisted cracking.. DEFSPEED	26,00	251,5	32,7	36	62,5	31	413,7	30,4	125,700	0	0	0	0	195	93	413,700	Halden 35	
6. VTT																		
Renewal of active materials research	6,5	99,466	0	0,019	0	4,811	104,296	57,5	60,000	0	0	0	0	44,296	0	104,296		OK
infrastructure AKTUS	6,5	98	0	6	0	0	104	57,7	60,000	0	0	0	0	44	0	104		
7.VTT																		
Service life management system of concrete																		
structures in nuclear power plants	14,30	164,649	0	5,868	43,394	1,389	215,3	43,8	94,300	15	15	0	0	86	5	215,300	Fennovoim	OK
SERVICEMAN	14,30	192,3	5	18	0	0	215,3	43,8	94,300	15	15	0	0	86	5	215,300		
7. VTT																		
IMPACT2010	36,8	275,196	72,093	0,06	121,111	2,05	470,51	8,5	40,000	0	0	0	0	116,553	313,957	470,510	Partners	OK
	36,8	467	73	10	15	5	570	7,0	40,000	50	50	0	0	130	300	570,000		
7. VTT																		
Structures under soft impact	13,7	151	3	0	26	4	184,245	56,0	103,100	0	0	0	0	81,145	0	184,245		OK
SUSI	12,0	148	5	4	27	0	184,1	56,0	103,100	0	0	0	0	81	0	184,100		
8, VTT																		
Challenges in risk-informed safety management	21,5	247,452	0	16,607	15,49	0	279,549	37,8	105,700	0	0	26,9	27,6	90,593	28,756	279,549	Halden	OK
CHARISMA	21,5	244,8	2	9,6	25,2	0	281,6	37,5	105,700	0	0	26,9	27,6	88	33,4	281,600	Ringhals	
8. VTT																		
Implementation of quantitative fire risk assesssment	11,60	166,009	0,119	4,18	34,733	0	205,041	46,3	95,000	0	0	0	0	110,041	0	205,041		OK
in PSA, FIRAS	9,30	160	5	5	35	0	205	46,3	95,000	0	0	0	0	110	0	205,000		

8. IL																			
Extreme weather and nuclear power plants	17,90	162,4975	0	0	0	0	**162,4975**	**29,2**	**47,500**	0	0	0	0	0	114,9975	162,498	FMI 106,9975		OK
EXWE	12,00	96,171	0	0	0	0	**96,171**	**49,4**	**47,500**	0	0	0	0	0	48,671	96,171	Fennovoima 8		
Administration. VTT																			
Programme administration and information	10	171,305	0,03	3,812	29,252	43,78775	**248,1868**	**95,4**	**236,700**	0	0	0	0	0	11,487	248,187		OK	
SAHA2010	10	172	0	6	16	42,7	**236,7**	**100,0**	**236,700**	0	0	0	0	0	0	236,7			
Total	**540,7**	**6077**	**132,349**	**247,1242**	**543,0098**	**242,0068**	**7241,301**	**40,7**	**2946,591**	**218,1**	**110**	**148,124**	**27,6**	**2776,399**	**1014,487**	**7241,302**			
Plan	*498,95*	*6026*	*238,9*	*357,815*	*304,75*	*238*	*7165*	*41,34287*	*2962,276*	*277,3*	*190*	*148,1*	*27,6*	*2706*	*853,868*	*7165,144*			
								back	15,685										

Figures 3.3-3.6 contain presentations of cost and volume distribution by research area. In these Figures, the following short acronyms are used instead of the official name of the research area:

1. Organisation and human factors – “Human”
2. Automation and control room – “Automation”
3. Fuel and reactor physics – “Core”
4. Thermal hydraulics – “Thermal”
5. Severe accidents – “Severe”
6. Structural safety of reactor circuit – “Materials”
7. Construction safety – “Concrete”
8. Probabilistic safety analysis (PSA) – “PSA”

Figures 3.3 and 3.4 show the distribution of planned and realised costs and volumes in the eight research areas in 2010, respectively. In the areas of fuel and reactor physics, thermal hydraulics and probabilistic safety analysis the cost increase versus the planned cost was the largest due to intensive training of young personnel. This is also reflected in the planned and realised volumes for these areas in Figure 3.4. In most research areas more work was done than planned with a fairly small increase in the planned costs, as can be seen from Figures 3.3 and 3.4. Main reason for this was that young researchers and research trainees were involved in the projects in a somewhat larger extent than planned.

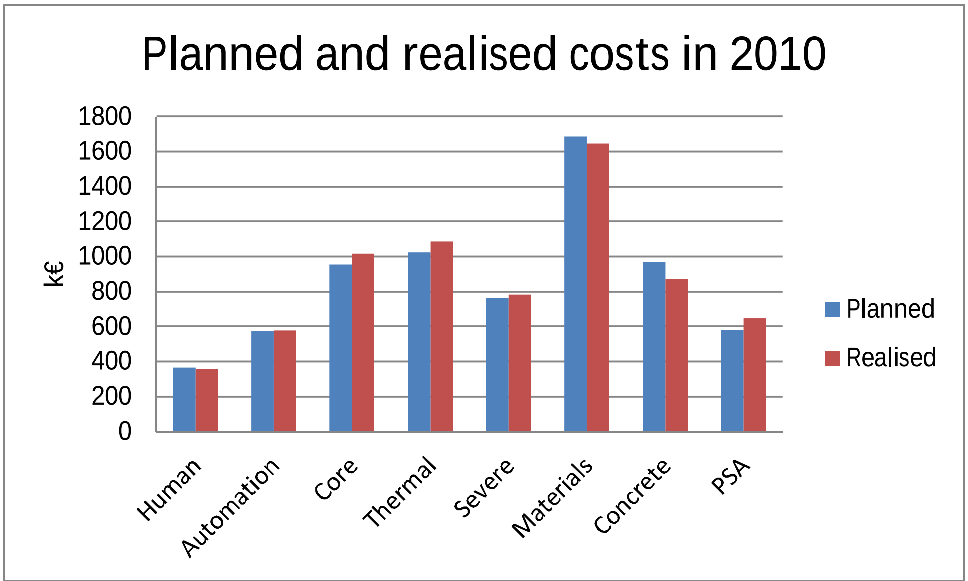


Figure 3.3. Planned and realised costs in the SAFIR2010 research areas in 2010.

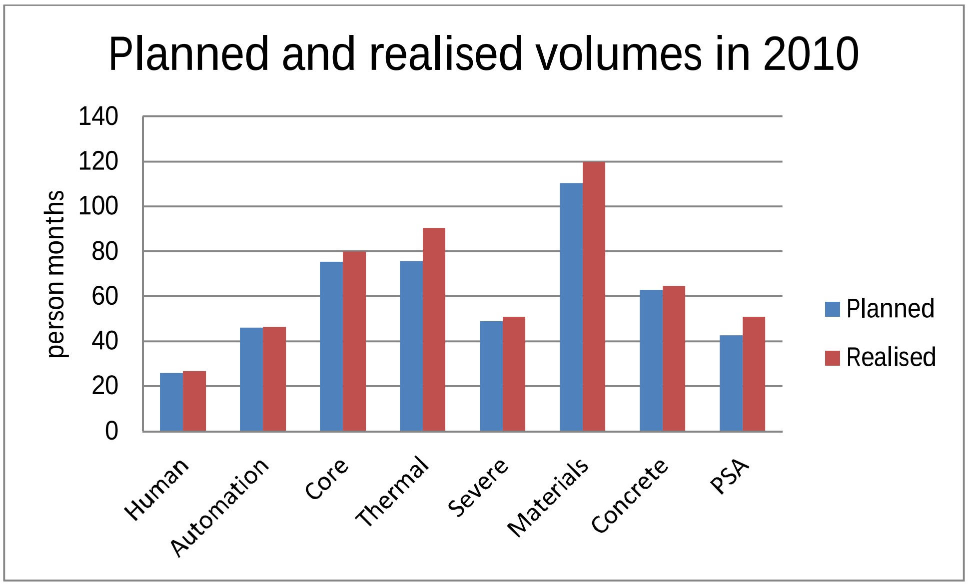


Figure 3.4. Planned and realised volumes in the SAFIR2010 research areas in 2010.

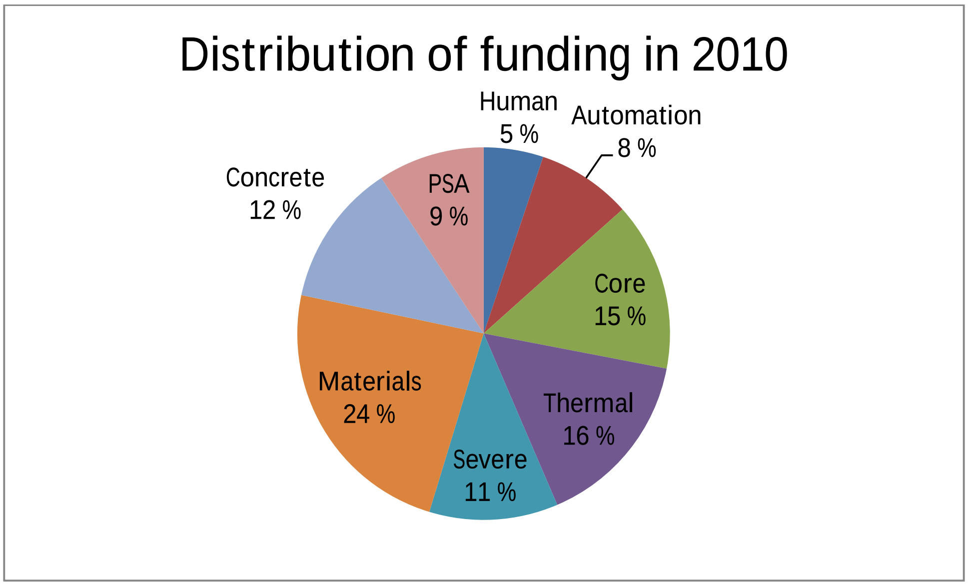


Figure 3.5. Distribution of total funding in SAFIR2010 research areas in 2010.

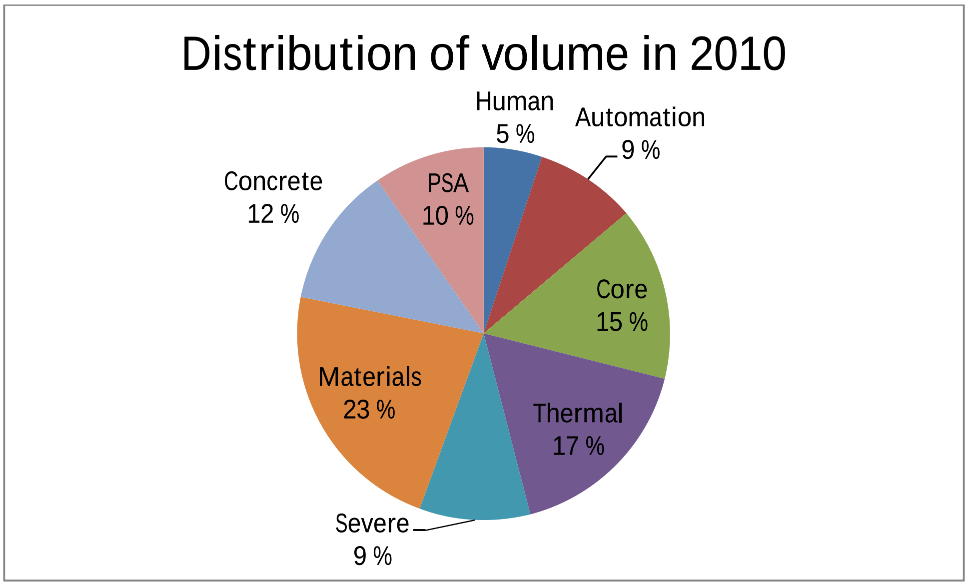


Figure 3.6. Distribution of person years in SAFIR2010 research areas in 2010.

The programme produced 248 publications in 2010. Major part of the publications consisted of conference papers and extensive research institute reports. The number of scientific publications as well as the total number of publications varied greatly between the projects, as indicated in Table 3.2. The average number of publications was 5.3 per person year, and the average number of scientific publications was 0.8 per person year. Many of the projects have deliberately aimed at publication of the results as extensive research institute reports, since the full reports are found to be more useful for the end-users than scientific articles or conference presentations. Thus, the number of scientific publications in the research programme is fairly low despite the continuous increase during the span of the research programme.

Table 3.2. Publications in the SAFIR2010 projects in 2010.

Project	Volume pers. year	Scientific	Conference papers	Res. inst. reports	Others	Total
MANOR	1.24	2	2	1	2	7
SAFEX	1.24	4	7	3	4	18
MODSAFE	1.48	0	3	2	2	7
CERFAS	0.93	2	2	3	0	7
OPRACTICE	1.48	0	3	4	4	11
VAHAYA	0.52	0	0	0	1	1
POKEVA	2.48	0	1	8	0	9
TRICOT	2.16	0	3	7	1	11
TOPAS	2.31	5	3	3	0	11
NUMPOOL	0.65	0	1	1	0	2
THARE	1.76	0	0	5	2	7
SGEN	0.83	0	2	2	0	4
PACSIM	0.96	1	2	2	1	6
CONDEX	1.9	0	1	3	1	5
PASSIMU	0.39	0	0	2	0	2
NUFOAM	0.72	0	0	11	0	11
RADECO	0.86	0	0	2	0	2
CHEMPC	1.67	1	4	4	1	10
COMESTA	1.1	1	4	3	0	8
HYBCIS2	1.05	1	0	2	1	4
PURISTA	1.08	3	6	4	1	14
FATE	1.27	0	1	1	0	2
WATCHEM	0.8	3	0	3	0	6
RAKEMON	1.52	0	2	2	0	4
FRAS	2.74	1	1	8	1	11
DEFSPEED	1.8	1	2	4	1	8
AKTUS	0.62	0	0	0	1	1
SERVICEMAN	1.38	0	1	5	0	6
IMPACT2010	3.52	0	0	1	0	1
SUSI	1.14	3	1	1	0	5
CHARISMA	2	0	7	9	2	18
FIRAS	0.89	4	4	1	0	9
EXWE	1.14	4	3	5	5	17
SAHA2009	0.95	0	0	3	0	3
TOTAL	**46.58**	**36**	**66**	**115**	**31**	**248**

Altogether seven academic degrees were obtained in the research projects in 2010, one Doctoral degree, one Licentiate and five Masters degrees. This information is collected in Table 3.3 and in Appendix 4.

Table 3.3. Academic degrees obtained in the projects in 2010.

Project	Doctor	Licentiate	Master
SAFEX		1	
POKEVA			1
CHEMPC			1
FRAS			1
DEFSPEED	1		
EXWE			2
TOTAL	**1**	**1**	**5**

4 Organisation and information

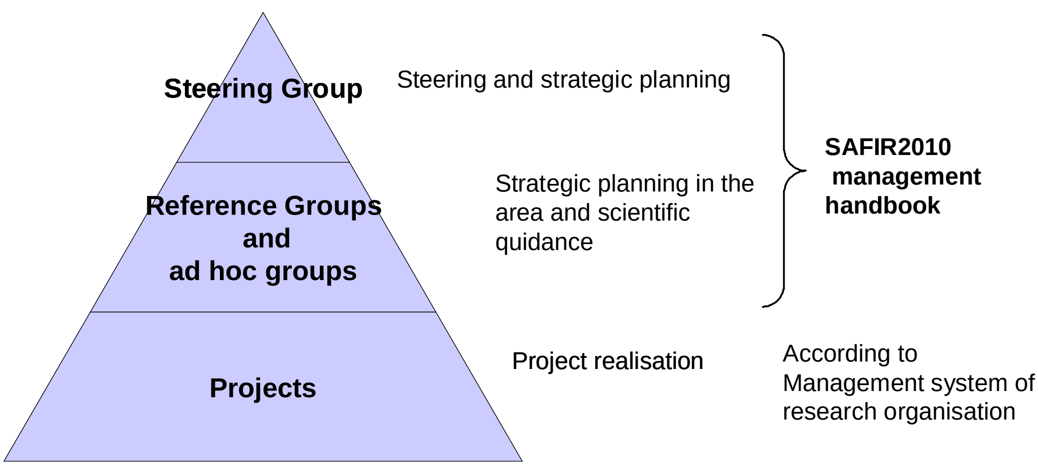
The SAFIR2010 steering group had three meetings and the eight reference groups had three meetings during the administration period (April 2010-March 2011). The formal approval of the final products of the projects in February 2011 was carried out with a two-stage procedure including first the approvals by the separate Reference Groups and then the approval by the Steering Group. In 2010 the work in the ad hoc groups continued vividly and at the end of 2010 there were nine ad hoc groups in SAFIR2010. In certain areas these ad hoc groups had a very important role. The ad hoc groups met upon the needs of the specific project. All the interest groups have regularly been informed using standard progress reports. The list of persons involved in the steering and reference groups, as well as programme staff and their main duties have been presented in Appendix 6. Figure 4.1 illustrates the organisation and quality management in the SAFIR2010 programme.

The information on the research performed in SAFIR2010 was communicated formally via the quarterly progress reports yearly, the annual report of the programme and the www-pages of the programme. The detailed scientific results were published as articles in scientific journals, conference papers, and separate reports.

Final Seminar of SAFIR2010 was arranged on March 10-11,2011 at Hanasaari, Espoo. The seminar was attended by some 200 participants, 10 % from abroad. The Final Report of SAFIR2010 [7] concentrated on the presentation of the results achieved during the latter half of the research programme. The results from the years 2007 and 2008 are found in the Interim Report of SAFIR2010 [6].

In addition to conducting the actual research according to the yearly plans, SAFIR2010 functioned as an efficient conveyor of information to all organisations operating in the nuclear energy sector in Finland and as an open discussion forum for participation in international projects, allocation of resources and planning of new projects.

Figure 4.1 Organisation and quality management in the SAFIR2010 programme.



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[4] Puska, E.K. & Suolanen, V., SAFIR2010 Annual Plan 2010, VTT Research Report VTT-R-03666-10. 37 p + app. 203 p.

[5] Puska, Eija Karita; Suolanen, Vesa, SAFIR2010 Annual Report 2009, VTT Research Report VTT-R-03922-10. 122 p + app. 222 p.

[6] Puska, Eija Karita. 2009. SAFIR2010.The Finnish Research Programme on Nuclear Power Plant Safety 2007-2010.Interim Report. Espoo, VTT. 535 p. VTT Tiedotteita - Research Notes; 2466. ISBN 978-951-38-7266-3; 978-951-38-7267-0. http://www.vtt.fi/inf/pdf/tiedotteet/2009/T2466.pdf

[7] Puska, E.K. & Suolanen, V., SAFIR2010, The Finnish Research Programme on Nuclear Power Plant Safety 2007-2010, Final Report. VTT Research Notes 2571. Espoo, Technical Research Centre of Finland (VTT), 578 p. ISBN 978-951-38-7689-0; ISSN 1235-0605

Appendix 1
PROJECT PROGRESS REPORTS

4/10

Safety management and organizational learning (Manor)

Turvallisuuden johtaminen ja organisatorinen oppiminen

Duration	2007 – 2010	
Project manager	Pia Oedewald, VTT	
Volume in 2010 (person y.)	Plan: 1.3	Realised 31.1. 2011 1.3
Cost in 2010(k€)	Plan: 213,3	Realised 31.1.2011 213,5

Main Objectives

The main objective of the research project is to study the facilitators and hindrances to organizational learning and development of safety culture in the nuclear power industry. The aim is to help the power companies and the regulator to create safety management practices that support the evaluation and management of the working practices and organizational performance based on a sound safety culture. The project contributes to the utilisation of operating experience, development of working practices and safety culture, development of job motivation and awareness of risks among the contractors' as well as plants' own personnel, and identification of risky habits and conceptions in the organizations.

Objectives in 2010	Realised
1) Safety management and organizational learning (4 person months; VYR 50k€, VTT 15k€)	
MANOR Final Report "Safety management and organizational learning in the nuclear industry" - designing the outline and content of the report - writing the chapters - publication process	- The target group of the report and the contents of the 9 chapters have been agreed in the project group. Writing responsibilities have been allocated -Writing of the chapters finalised - Publication process in progress
2) Safety culture in subcontracting (3 person months; NKS 35, VTT 15)	
Report "Subcontractors' role in the Nordic nuclear safety culture" - Analysis of the existing data (35 interviews collected in the MOSACA project in 2009 from the power companies and regulators) - project group miniseminars - writing of the report	-The analysis is completed - Three miniseminars has been held. A scientific article was drafted. -The task is finalised.
3) MTO initiatives in improving safety culture (2,5 person months; OKG 20k€, VYR 10€, VTT 15€)	
An evaluation of the effectiveness of the MTO activities of the OKG's HO department - analysis of interviews and e-	- interviews and e-mail survey has been carried out. Analysis

mail survey for HO personnel and their stakeholders at OKG - Looking at OKG's safety performance indicator data for evidence of HO's effects on safety culture - Internal report for OKG - Chapter on MTO initiatives in improving nuclear safety as part of the MANOR final report	is done - document analysis has been done -the task is completed, preliminary results have been reported to the plant -the task is in progress
4) Integration of theoretical findings on safety management and organizational learning (3,5 person months; VTT 31, VYR 22,3)	
- Writing of two scientific articles on Manor's themes - Writing of two conference papers on Manor's themes - Presentation of the results of Manor 2007-2010 at a joint seminar for the power companies and STUK - MANOR-project administration	Two papers have been published and one is submitted in a scientific journal: - Reiman, T. (2010): Understanding maintenance work in safety-critical organizations – managing the performance variability. *Theoretical Issues in Ergonomics Science* - Pietikäinen, E., Oedewald, P., Haavisto, M-L., Reiman, T., Ruuhilehto, K. & Heikkilä, J.(2010). Pyrkivätkö turvallisuuskriittiset organisaatiot oppimaan kokemuksistaan? Kokemustiedon käsittelyä ohjaavat oletukset ydinvoimateollisuudessa ja terveydenhuollossa. *Työelämän tutkimus*. - Reiman T. & Rollenhagen C. (submitted). Review of potential human performance biases in safety management approaches One conference paper has been written and one article for ALARA journal: - Reiman, T., Rollenhagen, C. (2010). Identifying the typical biases and their significance in the current safety management approaches. Presented at the 10th International Probabilistic Safety Assessment & Management Conference, Seattle, USA - Oedewald, P, Reiman, T., Pietikäinen E. (2010): Turvallisuuskulttuuria voi arvioida ja kehittää. Alara. - The seminar was arranged with 80 participants from power companies, STUK, and outside nuclear industry.

Comments

none.

Education of experts

An important aim of the MANOR-project is the development and maintenance of behavioural scientific expertise in the domain of nuclear industry. To promote this aim, the research results are utilised in e.g. dissertation work.

Expert Work in Safety Critical Environment (SafeExpertNet)
Asiantuntijatyö turvallisuuskriittisessä ympäristössä

Duration	2007 – 2010	
Project manager	YTM Krista Pahkin (TTL)	
Volume in 2010	1,09 person years (13 person months)	Realised 31.1.2011: 1,32 person years
Cost in 2010 (k€)	VYR 69,7 k€, TTL 39,9 k€, Aalto-yliopisto 43,9 k€ yht. 153,5 k€	Realised 31.1.2011: 144,9 k€ 94,4 %

Main Objectives

The SafeExpertNet research project aims at 1) providing new scientific knowledge and understanding about a) expert work in nuclear power plants and nuclear power sector, b) work processes of the experts in nuclear power plants, and c) knowledge and competences of the experts in nuclear power plants; 2) Defining and developing practices for preserving and creating expertise in nuclear power plants. These include HR-practices such as recruiting, competence development and employee turnover; 3) Providing new knowledge on nuclear power expertise network and the roles of different parties (including nuclear power plants, regulators, research and educational organizations); 4) Describing expertise in nuclear power network; and 5) Defining and developing collaboration and communication in the nuclear power network.

	1	2	3	4	5	6	7	8	9	10	11	12	htkk
Tutkimustehtävä 1													
1.2. Uusintakysely													**2,0**
Tutkimustehtävä 2													
2.1. Kyselylomaketutkimus													**1,0**
2.2. Teemahaastattelut													**1,0**
Tutkimustehtävä 3													
3.1. Artikkelit ym.													**4,0**
3.2. Opaskirja													**5,0**
yhteensä													**13,0**

Objectives in 2010	**Realised**
Task 1: HR Practices (19,5 k€, 2 person months. Funding: VYR, TTL)	
Subtask 1.1 Good practices on initiation of experts	No activities in 2010
Subtask 1.2 Survey on "Expert Work in Safety Critical Environment": Follow-up survey	Survey has been done between 14.2.-5.3.2010. Altogether 279 persons from five companies have participated to the survey (response rate 68.2 %). Testing of the new scales has been done. Task completion: 100 %
Task 2: Developing collaboration and knowledge sharing in nuclear expert community (23,6 k€, 2 person months. Funding: VYR, Aalto University)	
Subtask 2.1 Survey on "Expert Work in Safety Critical Environment": Provides quantitative data about motives, content, and opportunities of collaboration and knowledge sharing in the national nuclear power expertise community.	See above task 1.2. Task completion: 100 %
Subtask 2.2 Thematic interviews: Provides qualitative data about motives, content, and opportunities of collaboration and knowledge sharing in the national nuclear power expertise community	Due to difficulties in identifying the informants in two remaining organizations, the interviews were cancelled. Resources we re-allocated for Task 3. Task completion: 100 %
Subtask 2.3 Workshop	No activities in 2010.
Task: 3 Publishing and dissemination of results (110,5 k€, 9 person months. Funding: VYR, Aalto University, TTL)	
Task 3 Publishing and dissemination of results This task focuses on publishing the results of the study in the academic field as well as the national industrial field.	*Reports:* 1. *Avaimia asiantuntijuuteen - opaskirja ydinvoima-alan organisaatioissa työskenteleville asiantuntijoille ja heidän esimiehilleen*. (The good practice handbook on ways to support development of expertise.) Published. 2. Report of the SAFEX-project: *Asiantuntijatyö turvallisuuskriittisessä ympäristössä - SafeExpertNet 2007-2010.* Työympäristötutkimuksen raporttisarja 57, Työterveyslaitos 2011. Kirja: ISBN 978-952-261-058- PDF: ISBN 978-952-261-060-7 3. Työ ja Ihminen tutkimusraportti: Asiantuntijana turvallisuuskriittisellä toimialalla (Knowledge management on safety critical organizations): Articles are at the moment in finalizing process. - Leppänen A. Pahkin K et al.: *Asiantuntemus ja sen kehittyminen ydinvoimaympäristössä*. (korjattavana) - Mäki E., Kuronen-Mattila T. & Järvenpää E.: *Asiantuntijaverkostot: tutkimus Suomen ydinvoima-alalta*. (korjattavana) - Pahkin K, Leppänen A, & Järvenpää E.: *Osaamisen kehittämisen käytännöt ja haasteet ydinvoima-alan asiantuntijaorganisaatiossa*. (hyväksytty) 4. Licentiate Thesis: Tanja Kuronen-Mattila: *Tacit Knowledge in Nuclear Power Plants: The Content, Characteristics and Prerequisites for Tacit Knowledge Sharing.* Työn esitystilaisuus oli 10.9.2010.

	Dissemination of the results (International conference presentation)*:* 1. Pahkin K, et al: "*Supporting expertise in nuclear organizations.* Presentation in the IAEA International Conference on Human Resource Development for Introducing and Expanding Nuclear Power Programmes 14-18 March 2010, Abu Dhabi, UAE 2. Pahkin K et al: "*Development of a survey for expert work in safety critical environment* ". Presentation at the European Academy of Occupational Health Psychology (EA-OHP) 29-31 March 2010, Rome, Italy 3. Two abstracts has been send to ICICKM –kongrenssiin (International conference on Intellectual Capital, Knowledge Management & Organizational Learning) 11/2010. Both have been accepted, but only one has been presented. - Kuronen-Mattila, T. *Tacit knowledge in nuclear power plants: content, characteristics and sharing* - Kuronen-Mattila, T., Mäki, E. & Järvenpää, E.: *Collaboration between experts -– Case Finnish Nuclear Power Industry.* To be submitted to IJNKM (International Journal of Nuclear Knowledge Management) by the end of January 2011. 4. Two abstracts has been send to SAFIR2010 final seminar: - Mäki, E., Kuronen-Mattila, T., Pahkin, K., Järvenpää, E., and Leppänen, A.: *Project summary reports* (a report on the SafeExpertNet project). - Pahkin, K., Leppänen, A., Mäki, E., Kuronen-Mattila, T. and Järvenpää, E.: *Supervisor's role in knowledge management and expertise development*. 5. Two abstracts has been send to NESTet 2011 education and training NUCLEAR ENGINEERING SCIENCE AND TECHNOLOGY Prague, Czech Republic 15 -18 May 2011: - Pahkin, K., Leppänen, A., Kuronen-Mattila, T, Mäki, E., Järvenpää, E.: *The practices and challenges of developing knowledge in nuclear industry organizations*. - Mäki, E., Kuronen-Mattila, T., Pahkin, K., Järvenpää, E., Leppänen, A. *Expertise development in the nuclear power industry – beyond formal training and education.* *Others:* 1. Five organizational level reports based on the results of the questionnaire survey will be written (1/target organization/not made public): 5 company level reports (+18 department level results) delivered and feedback given. 2. Mäki E. *Hiljaa hyvä tulee, hiljaisella tiedolla vielä parempi*.

	HETKY 5/2010. 3. Mäki E., Kuronen-Mattila T. & Pahkin K.: *Tieto kasvaa jakamalla.* ATS Ydintekniikka 2010. 4. Pahkin K, Kuronen-Mattila T ja Mäki E. *Avoimuus auttaa toimimaan turvallisemmin*. ALARA 4/2010. *International co-operation:* 1. Tanja Kuronen-Mattila has participated to the IAEA Meeting of Technical Working Group on Managing Human Resources in the Field of Nuclear Energy (TWG-MHR), held in Vienna on 15-17.6.2010. 2. Krista Pahkin has participated to the IAEA Technical Meeting on the Considerations of Human Factors in New NPP Projects held in Vienna on 9-12.11.2010.
	Task completion: 100 %

Comments: -

Education of experts: -

SAFIR2010 31.1.2011 PROGRESS REPORT 4

Model-based safety evaluation of automation systems (MODSAFE)
Malleihin perustuva automaation turvallisuuden arviointi

Duration	2007 – 2010	
Project manager	Research Scientist Janne Valkonen	
Volume in 2010 (person months)	Plan: 15,5	Realised 31.1.2011: 16,4
Cost in 2010 (k€)	Plan: 178	Realised 31.1.2011: 178

Main Objectives

Methods based on formal model checking are developed and applied in the safety analysis of NPP safety automation. The general objectives of the project are:

1. development of methods for model based safety evaluation of NPP automation
2. application of the methods in selected case studies
3. evaluation of the suitability of formal model checking methods for NPP automation analysis
4. operationalisation of model based safety evaluation to a part of safety case of safety automation systems
5. development of recommendations for the practical application of the methods.

Objectives in 2010	Realised
1 Selection and modelling of cases (49 k€, 4 person months)	
The objective of the task is to get, prepare and model the case studies to be utilised in the other tasks. The plan is to model a new case concerning the emergency diesel generator control system (Fortum). The other tasks of this research plan will utilise the models created.	A case study concerning Emergency Diesel Generator control system has been identified. The structure of the model has been defined. The system has been modelled with NuSMV and Uppaal model checking tools. Models finished. Task completion: 100 %
2 Model checking of asynchronous processes (40,3k€, 3,5 person months)	
The objective is to investigate the scalability and coverage of model checking techniques for asynchronous systems. The focus is on developing a systematic approach and techniques to utilize special features and strengths of given model checkers to enhance coverage and scalability of model-based system analysis.	In order to be able to model larger systems using Uppaal, a module library for modelling systems given as function block diagrams has been developed. Two versions of the library enabling a modular and systematic modelling approach have been devised: one for modelling systems working synchronously and another for the asynchronous setting. The two modelling approaches have been evaluated by developing Uppaal models for the Emergency Diesel Generator control system and then comparing the scalability of the Uppaal model checker for both of the models. Reporting finished. Task completion: 100 %
3 Development of modular approach to model checking larger systems (65,5k€, 6 person months)	
The objective is to develop an approach to model checking systems containing several sub-systems and to combine model checking results of sub-systems for verifying a larger system. If the selected case study allows, the plan is also to investigate whether such a methodology can be extended to the case where sub-systems are analysed using model checkers	A new modelling approach for NuSMV has been developed for checking larger systems. With the new approach it is possible to create different configurations of the model with little effort. In a configuration, a part of the system is left outside the model, and the model is defined so that it always has more behaviours than the real system. This enables efficient model checking of safety properties since NuSMV manages over-approximated models faster than plain models. This approach has also been experimented with the modular Uppaal modelling method developed in Task 2.

based on different modelling languages (such as UPPAAL and NuSMV).	Performance of the model checkers analysed and compared. Reporting finished. Task completion: 100 %
4 Reporting and publishing (23,2k€, 2 person months)	
The most important achievements and results of the whole four-year project will be reported in an article to be submitted to a suitable scientific journal. The article will summarize the results and draw conclusions on applicability of model checking methods for verifying I&C systems. Additionally, some articles will be submitted to selected conferences.	Scientific article written to *IEEE Transactions on Reliability*. The article summarizes the results of MODSAFE. The title off the article is *Catching Time-Related Errors in NPP Safety I&C Designs through Model Checking*. A conference article in ESREL 2010. *Model checking methodology for supporting safety critical software development and verification.* A conference article in SIAS 2010. *Model checking methodology for verification of safety logics.* A conference article in NPIC 2010. *Verification of automated changeover switching unit by model checking.* Model checking article in Automaatioväylä. Model checking article in ATS Ydintekniikka. Travel report of NPIC&HMIT conference. Task completion: 100 %

Comments

Excess travel budget used for working.

Education of experts

Jonatan Ropponen worked as a summer trainee in project in Aalto University on modular modelling techniques for function block diagrams using UPPAAL.

The Master's Thesis of Juho Frits (Model checking embedded control software) was accepted in Aalto University in March 2010. The technical report based on the Thesis has been delivered to the reference group 2.

Certification facilities for software (CERFAS)
Ohjelmistojen sertifiointivalmiuksien kehittäminen

Duration	2007 – 2010	
Project manager	Hannu Harju, VTT	
Volume in 2010 (person m.)	Plan: 9,8	Realised 30.11.2010 9,6 person m.
Cost in 2010 (k€)	Plan: 106,3	Realised 30.11.2010 106,3 k€

Main Objectives

The strategic objective of CERFAS is to develop facilities for flexible, supported, commercially exploitable, high quality Software Certification Service able to certificate safety critical and safety related software. The main other features to support the Service are the following:

- advanced methods for evaluation of software process and artefacts, that is, documents, code, test plans, etc.
- competence development to provide facilities for Software Certification Service.

Objectives in 2010	**Realised**
1 Dissemination (23,2 k€; 2,0 person months)	
Dissemination of project results and experiences • Results, feedback and conclusions of the previous case studies. • Ad hoc meetings in March and in September 2010. • Cooperation with domestic software manufacturers and potential evaluators. • Workshop with Swedish utilities. • Workshop with international research partners (e.g. ISTI).	Project results were presented in the following meetings, conferences or journals: • Ad hoc-group meeting was in April 2010. • Workshop with TVO and Swedish utilities 15. March 2010 • Workshop with ISTI and other partners 1.9.2010 in EuroSPI conference • Conference SafeComp 2010 in September • Conference QUATIC 2010 in September *Task completion: 105 %*
2 Finalising the Internal Software Certification Service (38,6 k€; 3,5 person months)	
The subproject aims to develop facilities of SCS on the view from clients. 2.1 Technical certification of safety critical software (Handbook of SCS) • Certification risk management • Assessment criteria • Assessment techniques • Technical product assessment procedures • Software safety justifiction • Etc. (3 methods, 14 topics) 2.2 Quality of SCS certification project	2.1 Handbook • 3 methods and 16 separate guides are identified • Assessment techniques and guides are specified. Half of them were presented shortly in Ad hoc April 2010. Rest were presented in October 2010. • Versions of Handbook were presented in Ad hoc group meetings in April and October 2010. • Handbook is ready in 20.th December. • The handbook is divided into three parts: o Part 1 (in Finnish) ▪ Software safety properties ▪ Client's documentation and evidence ▪ Safety Case as a part of certification ▪ Claims for assessment of Category A software ▪ Direct and credible evidence ▪ Format of the Safety Case report o Part 2 (in English) ▪ Safety Case Templates for Category A software o Part 3 (in Finnish) ▪ A procedure "Certification risk management added". ▪ 21 Assessment procedures

Objectives in 2010	Realised
	2.2 Quality of SCS certification project • A procedure added to the handbook Task completion: 105 %
3 Finalising the external SCS service (18 k€; 1,5 person months)	
The subproject aims to develop facilities of SCS on the view from clients. 3.1 (Facilities for domestic software manufacturers – deleted) 3.2 (Facilities for external evaluators- deleted) 3.3 Cooperation with stakeholders	3.3 Cooperation with stakeholders • Workshop with TVO and Swedish utilities (see item 1) • Ad hoc group meetings at April and October 2010 *Task completion: 81 %*
4 Publishing the results (24,7 k€; 2,5 person months)	
4.1 Handbook of Software Certification Service 4.2 Scientific paper or article	4.1 Handbook of Software Certification Service • The first version of the handbook is done and will be presented in ad hoc October 20. 4.2 Scientific paper or article • Articles are prepared in SafeComp 2010 and QUATIC 2010 conferences and in SCIYO book • All of these were presented at Ad hoc April 2010 and also in October meeting. *Task completion: 110*

Other results

One conference paper which was presented by Risto Nevalainen and Mika Johansson in EuroSPI 2009 conference Madrid 2-4.9.2009, "Additional requirements for process assessment in safety-critical domain", was published also in Software Process Improvement and Practice Journal in Summer 2010. Article was selected from app 50 conference articles with 11 others to be republished in this scientific journal.

Risto Nevalainen has updated ISO/IEC 15504 Part 5: Exemplar Assessment Model for Software Engineering Lifecycle Processes, due to new release of standard ISO/IEC 12207 Software Engineering Lifecycle Processes. This work will update significantly the ISO-based assessment model and method in CERFAS during 2010.

Operator practices and human-system interfaces in computer-based control stations (O'PRACTICE)
Operointikäytännöt ja käyttöliittymät digitaalisissa valvomoissa

Duration	2007 – 2010	
Project manager	Dr. Jari Laarni / Dr. Leena Norros VTT Systems Research	
Volume in 2010 (person y.)	Plan: 15.5 person-months	Realised 31.01.2011 15.5 pms
Cost in 2010 (k€)	Plan: 217.0 k€	Realised 31.01.2011 217.0 k€

Main Objectives

The project aims at developing practices of Human Factors Engineering (HFE) for the design, operation and evaluation of human-system interfaces at nuclear power plant (NPP) control rooms. In the project we will gather knowledge of changing operator practices and new human-system interface (HSI) solutions in order to promote safety use of digital technologies and develop new methods and practices for the management of design process and evaluation of the safety of HSIs. The aim is also to develop expertise on user-centred design of complex industrial systems in Finland, further promote international collaboration with research and expert organizations, and institutions and strengthen delivery of expertise in the field of user-centred design.

The project is divided into four tasks and two of these tasks are further divided into subtasks. Most of the tasks continue the work carried out during 2007-2009.

Objectives in 2010	Realised
1 Analysis and implications of the reference test results (94 k€, 7.0 person months)	
1.1 Analysis and reporting of Olkiluoto reference test results (5.0 pms) The subtask focuses on the analysis and reporting of the Olkiluoto reference test results. (VYR, TVO, HRP-In-kind, VTT)	Task completion: 100 % The Olkiluoto reference test data has been analysed, and a report on the reference test results has been completed. The final test results have been presented on December 8 at TVO. Preliminary test results have been presented earlier at three meetings held with the representatives of the company. A manuscript on the role of ConOps in the CR design (based in part on the chapter 6 “Tavoitteena hyvä valvomo” of the book “Valvomo. Suunnittelun periaatteet ja käytännöt”) has been completed.
Deliverables: - Report on the Olkiluoto reference test results - Conference talk and paper on ConOps development	Deliverable completion: 100 % Laarni, J. et al.: O'PRACTICE: TVO:n Olkiluodon voimalaitoksen päävalvomon systeemikäytettävyys. (Final report). VTT-R-10653-10. Savioja, P, Norros, L. & Tommila, T.: An integrative tool for joint system design: Concept of Operations revisited. (Draft) Norros, L., Savioja, P. & Laarni, J.: Concept of Operations as a boundary object for HFE in control room design. An abstract submitted to ICI 2011 (South Korea). Laarni, J., Norros, L., Liinasuo, M. & Savioja, P.: Muuttuva operointikonsepti ja ammattikuva – mitä muuttuu operaattorityössä käyttöliittymien digitalisoinnin myötä? ATS Ydintekniikka, 1/2010.
1.2 Conclusions and guidelines based on the reference test results	Task completion: 100 % The PowerPoint slide set “Suuntaviivoja

(2.0 pms) Based on the reference test results, guidelines and recommendations for the design of HSIs and for the development of operating procedures and simulator training activities for hybrid CRs will be developed. (VYR, Fortum, HRP-In-kind, VTT)	valvomosuunnitteluun" has been completed. Ad hoc workshop presenting the guidelines and recommendations has been arranged on January 11 2011 at VTT.
Deliverables: - Report on the guidelines and recommendations - Arrangement of a workshop on the topic	Deliverable completion: 100 % Laarni, J. et al.: Suuntaviivoja valvomosuunnitteluun. VTT-R-00807-11. Koskinen, H. & Norros, L. (2010). Towards a design concept for new control spaces. In: Proceedings of the EHPG Enlarged Halden Programme Group Meeting, March 14-19, 2010, Storefjell, Norway. Norros, L., Savioja, P. & Salo, L. 2010. Using emergency operating procedures in NPP process control. Post-ISSNP2010 International Workshop on Advanced Methodologies and Practices for Nuclear Safety & Simulation. August 26-27, 2010. NCST/HEU (abstract).
2 HFE-based design and validation method development: method evaluation and guidance for use (81 k€, 6.0 person months)	
2.1 Systemic requirements development from the human factors standpoint (2.0 pms) The subtask includes the application of the core task modelling for the generation of human factors requirements and evaluation of its suitability for these purposes. (HRP-In-kind, VTT)	Task completion: 100 % A manuscript on the claim-based evaluation of NPP human-system interaction concepts has been completed. It presents the application of the Usability Case -methodology in a practical case.
Deliverable: - Conference talk and paper on human factors requirements development	Deliverable completion: 100 % Norros, L., Savioja, P. & Salo, L. (2010). Activity analysis in the evaluation of the usability of complex systems. Presentation at the Nordic Conference on Activity Theory and the Fourth Finnish Conference on Cultural and Activity Research, May 23-25, Helsinki. Norros, L., Liinasuo, M., Koskinen, H. & Savioja, P.: Usability Case – integrating usability evaluations in design. (First draft for an article to be submitted to Design Studies).
2.2 Validation method development, evaluation and guidance for use (4.0 pms) The subtask includes i) a development of a practical guide providing guidance for the use of the CASU method, ii) its evaluation and iii) development of a pre-validation test measure package. (Fortum, HRP-In-kind, VTT)	Task completion: 100 % A paper on the integrated system validation has been prepared and presented at the EHPG Enlarged Halden Programme Group Meeting. The pre-validation method package (in a PowerPoint slide format) has been prepared and presented at the O'PRACTICE ad hoc workshop on January 11 2011. A conference paper on pre-validation method development is under preparation and will be submitted by February 4 2011.
Deliverable: - Practical guide to support the use of the CASU method	Deliverable completion: 100 % Savioja, P. Norros, L, Salo, L., Laarni J. & Liinasuo, M.: Integrated system validation: The questions of

- Report on pre-validation method development	independence and reference. In Proceedings of the EHPG Enlarged Halden Programme Group Meeting, March 14-19, 2010, Storefjell, Norway. Norros, L. et al.: O'PRACTICE: Contextual Assessment of Systems Usability – Description of the method. VTT-R-00803-11. Laarni, J., Savioja, P., Karvonen, H. & Norros, L.: Pre-validation of nuclear power plant control room design. A paper accepted to HCI International 2011 (USA).
3 O'PRACTICE final report (33 k€, 2.0 person months)	
The subtask includes the preparation of the final report which will summarize the main findings from the project. (VYR, VTT)	Task completion: 100 % The final report of the project has been completed.
Deliverable: - O'PRACTICE final report	Deliverable completion: 100 % Laarni, J. et al.: Operator practices and human-system interfaces in computer-based control stations (O'PRACTICE): Final report. VTT-R-00679-11.
4 WGHOF (9.0 k€, 0.5 person months)	
Participation on WG-meetings in 2010 and some work within the work tasks adopted by the WGHOF. (VYR)	Task completion: 100 % Jari Laarni participated in the OECD/NEA workshop "Human performance and the operation of nuclear plant technology" and in the 8th WGHOF meeting, held in March in Washington, USA. Leena Norros participated in the WGHOF meeting held in September in Paris.
Deliverable: - Attending at meetings.	Deliverable completion: 100 %

Comments

The team has participated in a project called "Man-Machine-Organization Through Innovative Orientations for Nuclear" (MMOTION) co-ordinated by EdF to the 7th Framework Programme of the European Atomic Energy Community (Euratom) for nuclear research and training activities (2008 to 2011).

Education of experts

The project staff includes presently five post-graduate scientists.

Hanna Koskinen was working as a secondee in Halden till the end of 2010.

Requirements Engineering in Nuclear Power Plant Automation (VAHAYA)
Vaatimusten hallinta ydinvoimalaitosten automaatiossa

Duration	2010	
Project manager	Tomi Männistö, Aalto University	
Volume in 2010 (person months)	Plan: 5,5	Realised 31.1.2011: 5
Cost in 2010 (k€)	Plan: 73	Realised 31.1.2011: 73

Main Objectives

The aim of the project is to collect best practices of requirements engineering for the design of instrumentation and control systems at nuclear power plants. The project starts with eliciting a shared understanding of the core concepts of requirements engineering that, on the one hand serves as a basis for the project, and on the other hand can in the future be used as a reference in nuclear power plant investments and renewals. Against this background, the project studies the state-of-the-art of requirements engineering in NPP automation in Finland. In addition, requirements engineering practices are studied in a few other safety critical application areas, such as military applications, and medical technology. The aim is to identify areas where existing requirements engineering practices could provide benefits to different stakeholders in the Finnish nuclear industry.

Objectives in 2010	**Realized**
Task1 Core concepts of RE (1 person months)	
Core concepts of requirements engineering (1 person month)	Overview of core concepts and processes of requirements engineering has been reported in the VAHAYA final report. Task completion: 100 %
Task2 RE in NPP automation (1 person months)	
Requirements engineering in NPP automation in Finland, interviews of 3-5 industrial experts	7 interviews were carried out and results reported in the final report. Task completion: 100 %
Task3 Best practices in various domains (2,5 person months)	
Review of best practices in various application areas and in other countries; a cross-domain workshop on requirements engineering	Five other domains have been surveyed and literature has been reviewed and summarized (partly in the PRISMA project). A workshop was arranged in the beginning of September 2010. Summary of discussions is taken into account in the final report. Task completion: 100 %
Task4 Comments and further development needs (0,5 person months)	
Collecting comments and further development needs from NPP automation professionals	A workshop was organized on September 1 and comments for the report have been received. Identified topics for further research were summarised in the final report and used as a basis for planning continued research activities. Task completion: 100 %
Task5 Project management and reporting (0,5 person months)	
Project management	Task completion: 100 %

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Development and Validation of Fuel Performance Codes (POKEVA)
Polttoainemallien kehittäminen ja validointi

Duration	2007 - 2010	
Project manager	Seppo Kelppe, VTT	
Volume in 2010 (person y.)	Plan (1.1-31.12.10) 2.48	Realised 28.1.2011 2.80 (113%)
Cost in 2010 (k€)	Plan:(1.1-31.12.10): 340.0	Realised 28.1.2011 340.4 (100%)

Main Objectives

In the project, development will be carried out to meet the demands on availability of methods for nuclear fuel performance assessments. A permanent goal is to create and maintain calculation tools, i.e., systems of computer codes for steady-state and accident conditions, which can be utilized independently of those in the possession of the power plant designers and fuel vendors. Systematic validation and maintenance as well as continuous feed of experimental data are inseparable elements of code development. Some of the existing codes base on obsolete modelling and architecture, and renewal of the system partly is one of the objectives. Education of the next generation of experts is to be continued.

Objectives in 2010	**Realised**
<u>1 Transient codes</u>	
1.1 SCANAIR code and RIA analyses	
• Validation of V_6.6 reporting	A master's thesis and a research report completed.
• New SCANAIR V_7 installation	A new SCANAIR code version was received. Test runs were completed. V_7 Installation completed. Applications
• Elaboration of power-reactor related features, thermal hydraulic behaviour	Study on the effect of radial power distribution proposed. Included in contract work.
• IAEA CRP FUMEX III RIA Case calculation	Under reconsideration for 2011
• Further testing of the adequacy of accident initialisation	To be continued *100 % accomplished*
1.2 Probabilistic accident assessment • Verification of neural networks	Effort on the verification of neural networks completed. System was elaborated and description report issued. Conservative approach set as primary method; neural networks encouraging; experience will accumulate pending on core-wide applications. A number of small programs have been coded for data processing, writing inputs and steering the calculations. FRAPTRAN-GENFLO is applied for the stacked calculations. The method utilizes the theoretical basis of nonparametric statistics, and Wilks' formula, in particular. Fuel performance code results are then used in two different ways: to directly scale the number of rod failures in the worst global scenario to the whole reactor scale, and to perform a neural network analysis. The two methods are complementary, at this point neural networks lack comprehensive validation in this context.

• Users' Instructions report	Ad hoc group approval of progress and status. Users' Instructions report, report issued *100 % accomplished*
1.3 Thermal hydraulics with fuel performance codes • Validation and updating of documentation • Completion of a solid FRAPTRAN-GENFLO interface	Rectifying of PC compiler problems mainly solved; actions reported. Retesting performed with the probabilistic tool application. Adaptation of FRAPTRAN version 1.4 completed *Objective partly replaced by 2.3 below*
1.4 International collaboration with FRAPTRAN • Comparative analyses with two FRAPTRAN versions (VTT, SSM Sweden)	Exchange of more information on development of FRAPTRAN; *100 % accomplished*
<u>2. Steady State codes</u>	
2.1 Code development - PSI collaboration on fission gas release modelling • Validation and development of improvements in ENIGMA fission gas release modelling Comparison of FUMEX III cases BWR RIA common experience	Informal discussions to reactivate a collaboration plan Exchange of FUMEX III results under way Exchange of BWR RIA calculation results under way *Continuing under SAFIR2014/PALAMA project in 2011*
2.2 IAEA CRP FUMEX III (steady-state operation conditions) • general cases • PCI cases	Preparation of a presentation at the FUMEX III review meeting in June. Meeting attended, presentation given. Presentation at an internal seminar. RIA cases to be considered under 1.1 above postponed, 2011 Simulation of several Studsvik ramp cases. A report

• Possible more cases	completed. No more FUMEX III steady state cases in 2010 *100% accomplished*
2.3 Development and International collaboration on FRAPCON • Consolidated VTT version of FRAPCON 3.4 Additional deliverable (reference group approval)	A consolidated VTT version of FRAPCON 3.4 with a report issued. Modifications with many new features - nodal power input, axial node and time step refinements, added rod lower end gas plenum, provision of describing re-fabricated rods and more - were introduced. Moreover with modernization, the huge combined arrays with pointers indicating the variables and use of equivalence statements were abandoned so as to make the code more transparent, more easy to use and compile, and to facilitate future modifications. Several detected errors were corrected. The report includes users' information on the new features and input variables.
• New version of FRAPCON	Moving over to FRAPCON 3.4 even to be used with the probabilistic procedure. Completed
• FRAPCON experience feed-back to PNL	A copy of a consolidated VTT FRAPCON 3.4 being delivered to PNNL; a description given at the FRAPCON User's Group Meeting *100 % accomplished*
2.4 State-of-the-art review on fuel behaviour and ENIGMA models • Compilation of a comprehensive review and issuing a document	A review basing on several earlier VTT pieces of work and further studies. Topics covered include heat transfer, cladding creep, volume changes and fuel conductivity and other material property changes with burnup. Parameter studies largely rely on the calculated FUMEX III cases. Report issued *100 % accomplished*
<u>3. Halden Project collaboration</u> • EHPG Paper to be completed and presented	Paper completed, presentation prepared and given
• A review on Halden lift-off tests	Preparing a comprehensive summary agreed upon. Two reports issued covering summary and qualification of essential HP overpressure tests with supportive ENIGMA analyses.

• Other tasks	In concert with HP, other in-kind items were overruled. *100 % of 2010 goal accomplished*
<u>4. International collaboration and project management</u> Participating in selected working groups of the IAEA and NEA	WGFS Interim meeting attended; plenary with Jules Horowitz International Programme update in September 2010 Registration to WGFS Benchmark exercise
SAFIR2014 Planning	VYR application for a SAFIR2012 project *PALAMA* (2011-2014) left in due time
Participating in selected international conferences	JAEA FSRM attended; Topical Meeting in Orlando Fl. USA Domestic seminar on international fuel research collaboration arranged in June covering CABRI & SCIP Projects (Contract), Halden Project, IAEA FUMEX III benchmark, OEAC WGFS work, Jules Horowitz Reactor and related International project, and Japanese information exchange. Finnish-Russian-Hungarian VVER fuel seminar attended with a presentation on SCANAIR RIA calculations on VVER ANT International ZIRAT 14 Seminar (on cladding creep etc) attended. IZNA-1 to 10 packages ordered J Horowitz International Project reviewed and information distributed. CEA Post-Graduate Course on Metallurgy and Properties of Zr Alloys for Nuclear Applications attended
SAFIR2010 final reporting	Seminar in March 2011: general summary; topical report prepared *100% accomplished*

Comments

Personnel and education of experts

Asko Arffman has completed his diploma thesis on RIA behaviour and SCANAIR code applications

A licentiate’s thesis is under consideration on the ENIGMA code validation.

Tridimensional core transient analysis methods (TRICOT)
Kolmiulotteiset transienttianalyysimenetelmät

Duration	2007 – 2010	
Project manager	E. Syrjälahti, VTT	
Volume in 2010 (person y.)	Plan: 2.4 person y.	Realised 31.1.2011 2.6 person y.
Cost in 2010 (k€)	Plan: 373.9 k€	Realised 31.1.2011 373.9 k€

Main Objectives

The objective of the project is to continue development of reactor dynamics computer codes (TRAB-3D and HEXTRAN) at VTT, especially in the area of thermal hydraulics. The goal is to have a truly independent transient calculation system, which can be utilized by the safety authority and other end-users for safety analyses that are independent from those of power plant designers and fuel vendors, To achieve this, the codes must be constantly developed in order to be in a same level as other codes used for similar purpose internationally.

In addition to development work itself, it is essential that the new models are validated against measurements and the results of other codes. Much of this work can be done as international co-operation in the form of calculating benchmark problems. Another objective is to educate new experts to this field.

Objectives in 2010	**Realised**
1 Dynamics codes (156.2k€, 10.5 person months)	
1.1 TRAB-3D/SMABRE In 2010 this task will complete the modelling of planned PWR features. Modelling of cross flow between parallel core channels will be tested and studied, and the heavy reflector will be modelled. A possibility of modelling individual bypass channels of assemblies in the core island is modelled as a new feature. Testing and validation of the internally coupled model will continue with code comparisons against the production version of the TRAB-3D-SMABRE code using the EPR model. A first step towards 3D thermal hydraulics modelling will be taken by applying the porous media model PORFLO in reactor dynamics, with one-sided coupling of one circuit component modelled with PORFLO to the SMABRE circuit. (VYR, VTT)	After several changes made into the code for returning the calculation capabilities for PWR, the necessary options, where PWR and BWR needs deviation in model, have taken as a part of input deck. Several procedures and help routines for latest versions of internally coupled codes with separation of assemblies and flow channels are updated. For the validation, with BWR-model test cases of four transients have been recalculated. Better results have achieved compared to results at the end of former project at 2006 while comparing to standalone TRAB-3D or Simulate results**. Possibility to use two-sided heat structures, that enable modelling of EPR heavy reflector, was added to the internal coupling of TRAB-3D/SMABRE and tested with the HPLWR pressure vessel. Capability of calculating reversed assembly-wise core flow was demonstrated with LOCA case of EPR.** **Hämäläinen A., Räty H. The internally coupled TRAB-3D 3.0 and SMABRE 6.0 codes. Research report VTT-R-00523-11.** Task completion: 100 %

<u>1.2 TRAB-3D validation</u> In 2010 it is intended to calculate the OECD/NEA Kalinin-3 benchmark with both HEXTRAN/SMABRE and TRACE/PARCS, including the plant transient calculation involving a 3D core model. (VYR,VTT)	M. Seppälä attended Kalinin-3 benchmark's second workshop 12.-13.4.2010 in Pisa, Italy. A TRACE/PARCS simulation model for Kozloduy-6, which can be modified for Kalinin-3, was received from Penn State, USA. New versions of PARCS (v 3.0) and GenPMAXS (v5) have been received from USNRC. The GenPMAXS code has been applied for generating PMAXS type PARCS cross section files from CASMO outputs. **Seppälä M., PARCS user experiences at VTT in 2010. Research report VTT-R-00315-11** Task completion: 100 %.
<u>1.3 Uncertainty analysis</u> Sensitivity and uncertainty analysis tools and methods will be developed and tested towards practical application in safety analyses and capability to answer the requirements posed by safety authority. In 2010, the work will especially focus on hot channel analysis methodology and the uncertainties related to it. (VYR,VTT)	The sub-channel code COBRA-EN has been installed. Some additional coding was needed ia for time-dependent input data. Also new correlations and output options have been added to enable comparisons to TRAB calculations. Several calculations with PWR assembly have been made. Report: E. Syrjälahti. Sensitivity studies for the subchannel calculations of PWR fuel assembly. VTT-R-09072-10. Task completion: 100 %
2 Three dimensional core hydraulics (76k€, 6.9 person months)	
<u>2.1 PORFLO code development and applications</u> Two new applications are proposed for 2010: the open core of an EPR reactor, and a first step towards for the long term objective of using the PORFLO 3D flow solution and the TRAB-3D-SMABRE coupled neutronics-thermal-hydraulics code together. The starting point in coupling of PORFLO and TRAB-3D-SMABRE is a one-sided coupling of calculation of one circuit component by PORFLO to the circuit model of SMABRE. VTT participates in NEA's new PWR benchmark focusing on one fuel bundle (OECD/NEA Benchmark Based on NUPEC PWR Sub-channel and Bundle Tests (PSBT)). Additionally, the two earlier applications, OECD/NEA BWR full size fine mesh bundle test benchmark exercises (BFBT) and modeling of Loviisa steam generator will continue with a modest effort. (VYR, VTT)	An unplanned re-writing of the code was done, mainly to simplify the frequent adaptation to new applications. Now almost the whole code is in f90 and only very few traces of the original f77 code continue to co-exist. One of the most important new implementation techniques is the 'collapse' of six phase-specific and direction-specific momentum equation solutions into one. For the phase, an index is now used for the first time in PORFLO, instead of separate variables, which facilitates adding more than two phases. For the direction, a permutation-based indexing scheme was developed. The whole scheme facilitates e.g. the adding of correlations by touching one place of the code only. Boundary conditions in PORFLO used to be hard-wired in the source code. Now there is table of boundaries and their types, which must be filled properly in the initialization phase. Several new discretization schemes were coded, most importantly new high order schemes. Choice of the scheme will also imply the calculation of flow area between cells based on the porosities in the cells. Linear solutions were accelerated even two-fold by implementation of the so-called Eisenstat trick. Handling of friction terms was improved by the possibility of giving different friction correlations in three independent directions. This feature is useful e.g. with tube bundles, where the flow setting is significantly different in the direction of the tubes or in the lateral direction. Development of the k-epsilon turbulence model in PORFLO

	was started in 2009, but some checking and comparisons are still needed. There were some indications that a coding bug may be present in the model. At the moment, PORFLO is solving turbulence for the mixture of the two phases. Some testing and preparations for parallel PORFLO were done. Domain decomposition seems to be the most suitable, and most often used, method for the parallelization of CFD codes. A key part of this method is to be able to divide the solution of linear systems of equations between parallel processes. Therefore, to asses the feasibility of this approach in general, the parallelization of, or the first attempts at parallelizing, the linear iterative solvers was tackled first. The coefficient and preconditioning matrices have been divided into separate blocks (one for each process) and coupling matrices have been formed that define the communications between the processes. There are currently preliminary versions of two preconditioned solution algorithms in PORFLO (CG, or Conjugate Gradient, and BiCG, or Bi-Conjugate Gradient). Parallelizability was demonstrated and good rate of convergence was achieved, scalability may be further improved by fine tuning the communications between the processes. The checking and finalization of re-written code were performed with using the COOLOCE simulation application. The experiments and application of PORFLO to simulations are done in another Safir2010 project (HYBCIS-2). After the developments, preliminary PORFLO simulations indicate much better convergence and also realistic locations of highest void fraction. On the whole, the heat transfer section of the code was biggest coding task in order to accommodate COOLOCE simulations. Writing of application-specific closure laws has continued with putting some more MEWA-like terms in the PORFLO equations in order to facilitate comparison between the two codes. Some problems were encountered with the handling of void fractions in two adjacent pressure cells, and the forces resulting from the practical approach chosen. Another check after the big changes in the code was to re-run the previously performed simulations of the Loviisa horizontal steam generator. Now they seem to run without major problems. The application of PORFLO to fuel bundle flow will be continued on a subchannel basis, rather than with a CFD-like dense grid. **Demonstration calculations with the PORFLO-based model of the EPR reactor pressure vessel were performed. First simulations were performed with only the major RPV internal parts present; it is easily possible to add finer details even later. At the time of this writing, the model works in 'technical' sense, i.e. calculates without crashing, but not yet equipped with all realistic correlations, nor validated or coupled to other codes. Boundary conditions are given at the four inlets and four outlets.** The StarNode visualization software has also been developed further, e.g. for preparation of animations. Current developments include adding quantity names and units in an

	almost automatic fashion. Conference paper “Hovi V. & Ilvonen M. 3D PORFLO simulations of Loviisa steam generator.” AER Symposium, Espoo Hanasaari, September 20-24 , 2010 **Takasuo E., Hovi V., Ilvonen M.: PORFLO code development status and user instructions 2010. Espoo, Technical Research Centre of Finland (VTT), 2011. 25p.+2 app. (VTT Research Report VTT-R-00446-11.** **Hovi V. & Ilvonen M. The 3D two-phase porous medium flow solver PORFLO and its applications to VVER SG and EPR RPV. SAFIR2010 final seminar.** Task completion: 100%
3 Management and co-operation (87 k€, 5.35 person months)	
3.1 International co-operation Participation in the OECD Nuclear Energy Agency (NEA) working groups and benchmarks. This project will include the participation in the meetings of the NEA Working Party on the Scientific Issues of Reactor Systems (WPRS). The cooperation and information exchange on VVER safety within the AER framework together with other countries that use VVER reactors will also be continued. (VYR, VTT)	A. Daavittila participated in the OECD/NEA Working Party on Scientific Issues of Reactor Systems (WPRS) meeting in Paris, France, 28-29 January, 2010 M. Seppälä participated in the Kalinin-3 benchmark's second workshop 12-13 April and AER working group D meeting 15-16 April in Pisa, Italy. E. Syrjälahti attended PHYSOR conference in Pittsburgh, USA, 9-14 May, 2010. Paper “E. Syrjälahti & A. Hämäläinen: Sensitivity studies for main steam line break in Loviisa NPP with HEXTRAN-SMABRE“. All members of project group attended AER symposium in Hanasaari, Espoo, 20-24 September, 2010. Papers “Hovi V. & Ilvonen M. 3D PORFLO simulations of Loviisa steam generator” and “Rintala, J. Validation of new 3-D neutronics model in APROS for hexagonal geometry.” H. Räty participated in the 21st meeting of the Scientific Council of AER in Budapest, Hungary in November 29-20, 2010. Task completion: 100 %
3.2 Documentation and QA The subproject aims at reporting the research results of the project, improving the usability of the code system e.g. through proper documentation and auxiliary codes, as well as making it possible to perform some other necessary development work that cannot be foreseen. A systematic validation matrix for TRAB-3D, HEXTRAN and SMABRE will be compiled, assessing which features of e.g. benchmarks have been hard coded in the calculations and should be either taken into account or, included as hidden options in the codes to ease systematic re-calculation of the validation cases. The results of the work done during	Three reports on TRAB-3D have been written (on new neutronics data option, new output option and code status; RESEARCH REPORTS VTT-R-02176-10 … VTT-R-02178-10). The user’s manual for the 3D codes has been updated and revised: H. Räty. User’s manual for reactor dynamics codes TRAB-3D and HEXTRAN, Revision 1. Research Report VTT-R-04724-07 Rev. 1. 155 p. 24.3.2010. Work with the validation matrix started by recalculating old AER dynamic benchmarks with the Hextran version 3.3. New version of code demands remarkable changes especially in hydraulics part of the input file. Some post-processing scripts are written to ease comparisons between results calculated with different code versions. Task completion: 100%

the SAFIR2010 program and its predecessors are published as VTT project reports as well as in international journals and conferences. (VYR, VTT)	
3.3 Project management and information exchange (VYR, VTT)	**Syrjälahti E., Hämäläinen A. and Räty H., TRICOT Symmary report. SAFIR2010 final report.** Task completion: 100 %
4 AER Symposium (55 k€, 2.4 person months)	
4.1 AER Symposium The responsibility to organize AER's annual symposium on VVER reactor physics and reactor safety will fall on Finland in autumn 2010. (VTT, Fortum)	VTT and Fortum arranged the symposium in Hanasaari, Espoo on 20-24.9.2010. The web pages for the symposium were set up at: http://www.vtt.fi/sites/aer2010/?lang=en. Number of registrated participants was 54 from abroad and 26 from Finland. Also eight quests were participating to the social programme. The symposium was successful but financially person months were realized clearly higher than expected. The application to Tieteellisten Seurain Valtuuskunta has been submitted in order to cover the losses. Hanna Räty participated to AER Scientific Council meeting in Hungary in 29-30th of November, were the final proceedings as books were delivered. All the participants got electric version of proceedings already at symposium. Task completion: 100 %

Comments:

Education of experts:

The project staff includes presently five young persons (YG<35 y.)

Total reactor physics analysis system (TOPAS)
Kattava reaktorifysikaalinen laskentaohjelmisto

Duration	2007 - 2010	
Project manager	Dr Petri Kotiluoto, VTT	
Volume in 2010 (person y.)	Plan: 2.31	Realised 31.01.2011 2.22
Cost in 2010 (k€)	Plan: 303.3	Realised 31.01.2011 303.3

Main Objectives

The objective of the project is to further develop VTT's computer code system for reactor analysis into a unified, up-to-date and sufficiently complete entirety in order to make it possible to perform all analyses that are needed in Finland in the field of nuclear reactor physics. It should be possible to follow the whole life cycle of the nuclear fuel from a reactor physics point of view. Especially the demands of new nuclear fuel designs and the new Finnish nuclear power plant have to be taken into account. The project also includes international co-operation and the education of new experts in nuclear reactor technology.

Objectives in 2010	**Realised**
1 Cross sections Participation in the activities of the NEA-organised JEFF project is continued as one of the best ways to maintain a reasonably accurate cross section library and knowledge about it.	
A new person will make himself familiar with NJOY and the possibility to use NJOY to extract covariance data of cross sections will be studied.	Antti Räty has studied the use of NJOY to extract covariance data and has written a research report on the subject (VTT-R-04160-10).
Development of the Serpent code will be continued, partly in Oak Ridge where Jaakko Leppänen will continue to work the first four months in 2010 as a post doc. Fixed-source mode will be implemented to Serpent.	Jaakko Leppänen has been working in Oak Ridge for 14 months before coming back to Finland in the begin of May. This secondment has offered a good opportunity to develop Monte Carlo methods in international collaboration. The work for implementing fixed-source mode to Serpent is ongoing. Full-core Monte Carlo simulations have been performed for the Hoogenboom-Martin Monte Carlo performance benchmark with Serpent, in very high resolution, using over 6 million reaction rate tallies. Proceedings paper "Use of the Serpent Monte Carlo Reactor Physics Code for Full-Core Calculations" has been written by Leppänen for the Joint International Conference on Supercomputing in Nuclear Applications and Monte Carlo 2010, to be held in October 2010 in Japan. In addition, Leppänen has attended International Conference on Nuclear Data for Science and Technology, held in April 26-30, 2010, in Jeju Island, Korea, where a proceedings paper "New data processing features in the Serpent Monte Carlo code" was presented. Leppänen has also attended the International Youth Nuclear Congress (IYNC-2010) held in Cape Town, South Africa, July 12-18, 2010, where he presented a paper "HTGR Modelling Capabilities in the Serpent Monte Carlo Code" and gave a general presentation about the Monte Carlo method in the plenary session. In addition, a discussion forum for Serpent

	users has been initiated.
Cross sections are also highly relevant in reactor dosimetry. VTT will take part to the European Working Group on Reactor Dosimetry (EWGRD). The NSVA-3 spectrum adjustment code and its modification to different multigroup formats will be studied further, especially if a Master's thesis can be supervised on subject (requiring external funding or other arrangements). Keeping the CASMO codes up-to-date always involves the installation and testing of any new program or library versions as well as further validation of versions already in use. The latest version, CASMO-5, was released in 2007. If CASMO-5 (or HELIOS-2) code is purchased, installation, testing and validation work will be carried out.	ASTM International and the European Working Group on Reactor Dosimetry (EWGRD) are jointly organizing the 14th International Symposium on Reactor Dosimetry (ISRD-14), taking place in May 22-27, 2011, in Bretton Woods, New Hampshire, U.S.A. An abstract will be written to ISRD-14 by Tom Serén, Dean Thornton (Serco), and Martin Phillips (Babcock International Group), concerning the Sizewell B activation dosimetry measurements carried out in 2008 at VTT, with a comparison to earlier measurement campaigns. The study also included comparison to MCBEND simulation results and calibration measurements of earlier samples for quality assurance. Tom Serén has attended the EWGRD meeting organized in October 12-14, 2010, in Sofia, Bulgaria. *Task completion: 100 %*
<u>2 Development and validation of nodal methods</u> Here the knowledge on the calculation models and the correct use of the computer codes has badly diminished, due to retirement or resign of specialists. The feasibility of the presently available nodal codes, i.e. ARES and HEXBU-3D as well as Studsvik Scandpower's SIMULATE-3 to perform any analyses needed for the reactors presently in operation in Finland and the new one being constructed will be under surveillance. A new person will get acquainted to the use of CASMO and SIMULATE. Serpent-ARES calculations are an important parallel method for CASMO-SIMULATE calculations. A new person will familiarize himself with the ARES code. As a Serpent-ARES benchmark, reactor core power distribution calculations will be carried out for used nuclear fuel, using the new burnup capabilities of the Serpent code. Some other code combinations, such as Serpent-	A computation package for minor actinide management (MAMBO) has been written. This package combines scripts written previously at VTT with some new ones. The package facilitates the calculation of an equilibrium load in SIMULATE-3. In SIMULATE the loading is given as a map of assembly numbers. With the help of this script package the reloading pattern is given as moves from old position to new one and the script creates the loading map used in SIMULATE. The reloading pattern is repeated in consequent SIMULATE runs until an equilibrium is obtained. Some additional scripts help to do the analysis of minor actinides. Report on MAMBO package has been written. Silja Holopainen has attended the Studsvik Scandpowers CMS training course and get acquainted to the use of CASMO and SIMULATE.

SIMULATE, might also be tested. With the goal of improving accuracy in the calculation of in-core power distributions for light water reactors, a new "Variational Nodal Expansion Method" (VNEM) has been developed at IFE in Halden. If the VNEM code can be obtained for VTT, benchmark calculations will be carried out.	 Preliminary negotiations with IFE to obtain the VNEM executables for VTT have been carried out (obtaining source code at this stage is excluded). The proposal from IFE is to benchmark VNEM code against plant data of OL1/OL2-reactors, which has been preliminary discussed with TVO. *Task completion: 100 %*
<u>3 Development and validation of Monte Carlo and other transport methods</u> Monte Carlo calculations have been extensively used for cross section library comparisons, criticality safety and benchmark studies. The profound knowledge on Monte Carlo methods and codes will be further strengthened through a post doc exchange to Oak Ridge National Laboratory (ORNL), U.S.A. Work will include development of Serpent and other Monte Carlo codes at ORNL. Also, a new Monte Carlo code MORA has been developed at VTT, intended for full-core reactor physics calculations. MORA has the potential to run significantly faster than any continuous-energy code, such as Serpent or MCNP. Even though the new MORA code has raised some interest, the Monte Carlo code development work will mainly focus on Serpent. The newest version of the DOORS ("discrete-ordinates system for deep-penetration neutron and gamma transport") package, including the 1D ANISN, 2D DORT and 3D TORT codes, needs to be maintained. The latest versions of BOT3P need also to be maintained and tested. With the BOT3P pre- and post-processing tool combined with TORT, deterministic 3D discrete-ordinate calculations can be more easily performed. A new person might be introduced to this field also. The ability of the 3D in-house radiation transport code MultiTrans to perform fuel bundle calculations	 Jaakko Leppänen has been working in Oak Ridge for 14 months before coming back to Finland in the begin of May. This secondment has offered a good opportunity to develop Monte Carlo methods in international collaboration. New person Antti Räty has studied the use of BOT3P and TORT, and other related tools such as TOPICS-B (for generating cross section file for TORT calculations). As an application, the deterministic OL1/OL2 TORT model has been updated by including a fixed-source description (for cycle 10) and test runs have been performed. He has continued writing a report on these calculations. The current aim is to compare the three-dimensional fixed-source calculation system with previous two-dimensional activity inventory calculations. Also Pauli Juutilainen has studied the deterministic transport methods in general (diffusion and transport methods such as discrete ordinates and spherical harmonics approximation), related to his M.Sc. thesis to be written on fast reactor calculation methods (mainly funded outside of the TOPAS project).

should be enhanced. Especially the cubic cells of the current tree multigrid method are problematic, as the axial meshing becomes oversized for heterogeneous 3D fuel bundle geometry. It should be possible to use different axial length, and thus, to reduce the required number of geometry cells drastically. Also the possibility to perform simple 2D lattice calculations (using quadtree instead of octree) should be investigated. In addition, the coupling of MultiTrans to burnup calculations should be studied. Another objective is to build and deliver a distribution package of MultiTrans code to NEA. The Monte Carlo program MCNP developed in Los Alamos is used in a wide range of neutron and photon transport applications. The new versions of MCNP5 and MCNPX are now available at VTT also. In 2009, new persons have started to familiarize themselves with the use of MCNP. This work will be continued. In order to further improve the skills of MCNP usage and to certificate person's competence, MCNP training courses can be also attended. In order to maintain and to further improve the preparedness to perform complicated 3D calculations with both deterministic and Monte Carlo methods, suitable international benchmark problems, e.g. OECD/NEA benchmarks, will be attended.	Silja Holopainen and Karin Rantamäki have attended the MCNP5/MCNPX training course in France in the turn of March and April. *Task completion: 100 %*
<u>4 Criticality safety, isotopic concentrations</u> The criticality safety calculation system is further tested and developed through the work of the OECD/NEA Working Party on Nuclear Criticality Safety (WPNCS). The project is participating in an expert group within WPNCS working on "Isotopic composition data of spent nuclear fuel by post irradiation examinations (PIE)" for at least two years. Measured isotopic compositions are very important data in criticality analyses. If burnup credit is to be used for VVER fuel, experiments to	

validate the isotopic composition of irradiated VVER fuel are necessary. VTT will participate in an international consortium that will contract out radiochemical analyses of the irradiated VVER-440 fuel in Dimitrovgrad. An expert group on uncertainty analysis for criticality safety is also being established, cf. subproject 5. International criteria for the use of burnup credit (BUC), i.e. taking into account the reduced reactivity of the fuel in criticality safety analyses for spent fuel storage and transportation, have to be studied. At least one new person will continue to study this field. Swedish Strålsäkerhetsmyndighe-ten has proposed a Finnish-Swedish comparison of the methods used for criticality safety analysis and calculation of suitable benchmarks for different fuels in different storages. VTT will also have collaboration with Paul Scherrer Institute (PSI) related to criticality safety issues and the use of MCNPLINK ABURN script has been used to combine accurate Monte Carlo simulation with burnup calculation code ORIGEN2. However, the developer of ABURN has resigned VTT in 2008.	Karin Rantamäki has started to make herself familiar with the criticality safety analysis. *Task completion: 30 %*
5 Development of sensitivity analysis methodology Determination of the uncertainty of different parameters and their importance for the final results is necessary in order to understand the accuracy of computer programs. Such analysis is nowadays gradually extended to all essential reactor physics programs and parameters of various kinds. Also, a transition from conservative models to the use of best estimate models is in progress and the application of the best estimate methodology with the evaluation of uncertainty (BE+U) in the nuclear licensing process is studied in several countries. As an application, sensitivity analysis (perturbation theory) has	The project has taken actively part in the UAM bechmark. The benchmark workshop UAM-4 in Pisa was attended by Maria

been connected to the KRAM solver in CASMO. A Licentiate's thesis is planned to be written on the subject.

The project will take part in the activities of OECD/NEA's groups UAM and UACSA (Expert Group on Uncertainty Analysis in Modelling & Expert Group on Uncertainty Analyses for Criticality Safety Assessment). In a UAM meeting in 2010, reactor physics issues will still be treated. In the SCALE 6 program, uncertainty analysis methods should be better implemented. CASMO calculations are to be repeated with SCALE 6 for the next UAM meeting.

Pusa. The latest accomplishments were presented in the meeting and in addition Maria Pusa chaired a session there.

The developed sensitivity and uncertainty analysis methods for CASMO-4 have been further validated, and the treatment of fission spectrum uncertainties has been improved. A new covariance library 44GROUPCOV from SCALE 6.0 has been distributed to the participants of the benchmark. The updated library is based on both true evaluations and approximate covariance data, and it contains uncertainty information for 100 new materials and spans the full energy range of the multigroup cross-section libraries. The covariance library has been processed to become compatible with the cross-section libraries of CASMO-4, and can now be used together with the S/U version of CASMO-4.

The benchmark exercises 1.1 and 1.2 for the PWR case have been recomputed with CASMO after the alterations in the calculation system, and in addition a new set of results have been computed for the BWR case.

Scale 6.0 has been taken into use and comparison results for the pincell exercise for both PWR and BWR cases were computed with the new TSUNAMI-1D. The results from TSUNAMI-1D and CASMO were in excellent agreement. After receiving permission from ORNL, it was also attempted to compare results for the exercise 1.2 by using TSUNAMI-2D from the development version of SCALE 6.1. Unfortunately, the TSUNAMI calculations were terminated prematurely – presumably due to problems in the development version. However, the inputs for the benchmark exercise 1.2 for TSUNAMI-2D have been prepared and are ready for the release of SCALE 6.1.

The amount of participants in the benchmark exercises 1.1 and 1.2 had increased from the previous meetings, and some interesting methodologies and results were presented in the workshop. Excluding ORNL, all other participants are using statistical sampling methods for the computation of uncertainties. There was some initial discussion regarding the prospective of connecting the GRS statistical uncertainty code SUSA to Serpent.

PSI presented a comparison between the CASMO-4 results (presented by Pusa in the UAM-3 meeting) and direct perturbation results computed with CASMO-5 for the pincell exercise 1.1. The comparison showed a good agreement between the sensitivities, giving credence to the developed methodology in CASMO.

Based on the feedback from the participants, large parts of the definitions for the reactor physics related benchmark exercises 1.1 and 1.2 are going to be rewritten. Therefore the reactor physics phase will extend to the UAM-5 meeting that will take place in the spring of 2011.

The reporting on the activities pursued in the benchmark was initially planned to be carried out in the form of Maria Pusa's licentiate's thesis. The current plan is to primarily write a report and a publication on the activities, and reconsider the meaningfulness and appropriateness of the thesis later on.

The burnup calculation methods in Serpent will be further developed with the ultimate intention of enabling the propagation of an uncertainty estimate through the whole burnup calculation chain. Such uncertainty is related to both the basic nuclear data (cross sections) and the statistical uncertainty of the Monte Carlo simulation results. It is also necessary to estimate the numerical error related to the computational method that is used for solving the burnup equations. A method for estimating the total uncertainty in each calculation step would be highly valuable and improve the readiness of using the best estimate models. The goal is very challenging and has a high scientific significance. As a first step, the research will concentrate on the error related directly to the solving of the burnup equations. The Chebyshev Rational Approximation Method (CRAM) has proved succesful in this context and its convergence and accuracy will be further studied. The characteristics of the burnup matrix and some new solution methods will also be considered.	Research on the burnup calculation methods has been continued. New rational approximations have been considered, and the accuracy and convergence of the Chebyshev rational approximation method (CRAM) have been studied. The latest developments have been covered in a paper entitled "Rational Approximations to the Matrix Exponential in Burnup Calculations" written by Maria Pusa, and it has been submitted to the journal of Nuclear Science and Engineering. *Task completion: 100 %*
<u>6 Documentation, publications and results of code development</u> The subproject aims at reporting the research results of the project, improving the usability of the code system e.g. through proper documentation and auxiliary codes, as well as making it possible to perform some other necessary development work that cannot be foreseen. The results of the work done during the SAFIR2010 program are published as VTT project reports as well as in international journals and conferences. An essential part of the development of reactor physics analysis tools consists of the documentation of programs, their methods as well as user's guides including the scripts necessary for running the codes.	Status report written on Serpent development (VTT-R-01296-10). Research reports written also concerning the use of NJOY to extract covariance data (VTT-R-04160-10) and on the MAMBO script package that facilitates the calculation of an equilibrium load in SIMULATE-3 (VTT-R-02358-10).

During 2010, a Licentiate's thesis on sensitivity and uncertainty analysis methods related to the development of KRAM solver in CASMO is planned to be written.	The current plan is to primarily write a report and a publication concerning the sensitivity and uncertainty analysis, and reconsider the meaningfulness and appropriateness of the thesis later on. *Task completion: 100 %*
<u>7 International research co-operation and training courses</u> In 2010, international research co-operation will continue, for instance, through the staff mobility to the ORNL in U.S.A. In addition, new international collaboration might be established with a research group in Madrid related to Serpent code development. Also the collaboration with IFE Halden project through NKS might be strengthened related to VNEM. The subproject also aims at taking care of Finland's obligations in NEA as well as other international research co-operation and information exchange in the field of reactor physics, reporting research results and educating new experts through international courses. The Finnish representation in the OECD Nuclear Energy Agency's (NEA) Nuclear Science Committee (NSC) is at least partly included in the project. Committee has annual meetings in Paris and the participants are presupposed to examine a large amount of scientific material as well as distribute obtained information among Finnish specialists and provide NEA with the information it requests. Participation in the NEA working groups and benchmarks is one of the most important ways of validating the methods and codes used in reactor analysis. As mentioned above, project members intend to take part in the work on nuclear data libraries and criticality safety studies. The project is also represented in the NEA/NSC "Working Party on the Scientific Issues of Reactor Systems" (WPRS) and "Working Party on Nuclear Criticality Safety". A Finnish expert will also take part to	Staff mobility to Oak Ridge has been successfully fulfilled. Preliminary negotiations have been carried out with IFE related to the use of VNEM. Two persons have attended MCNP5/MCNPX training course. Also NEA course on analytical neutron transport benchmarks has been attended. Markku Anttila has participated a NEA meeting in Paris in June 2010. EWGRD meeting was attended in October 12-14, 2010, in

the European Working Group on Reactor Dosimetry (EWGRD), related to the determination of reactor pressure vessel neutron dose with experimental and computational methods. EWGRD meetings will be attended.	Sofia, Bulgaria.
Moreover, the results of the project research are presented at suitable international conferences, such as PHYSOR2010 conference in May 2010 in U.S.A. and combined SNA2010 + MC2010 conference in October 2010 in Japan.	PHYSOR2010 conference has been attended by Jaakko Leppänen (with a special invitation to the Monte Carlo workshop). Proceedings paper has also been written to SNA2010 + MC2010 conference by him, attended in October. Jaakko Leppänen has also attended the International Conference on Nuclear Data for Science and Technology 2010 as well as IYNC-2010 conference.
Education of new nuclear reactor and fuel experts and broadening the area of expertise of the current ones will be continued through international training courses related to certain computer programs, problems or techniques as well as summer schools in reactor analysis.	Leppänen and Pusa have also attended in October a workshop organised in MIT, Boston, related to Monte Carlo and burnup calculation methods.
The responsibility to organize AER's annual symposium on VVER reactor physics and reactor safety will probably fall on Finland in autumn 2010. Decisions on the next symposium will be made during autumn 2009. The TOPAS project workers will take part to the symposium arrangements, but the costs and work will be budgeted entirely on TRICOT project.	AER symposium arrangements were successfully carried out. *Task completion: 100 %*
<u>8 Project management and information exchange</u> The subproject includes making plans for and supervising the project, collecting progress reports, arranging meetings and information exchange for the project's reference group, possible ad hoc groups, etc.	Status reports, project meetings and project plans. *Task completion: 100 %*

Comments

In the volume numbers, person year means 10.5 person months.

Education of experts

Project staff has included five young persons (YG, ≤ 35 y). One person has been working as a research trainee in 2010.

About deliverables

The list of deliverables in the project plan contained items intended to be completed during the year but also such that are the result of two or several years' work. For example in the case of computer programs that are developed during the whole span of the TOPAS project or continued in future projects, only interim versions and reports can be available on a year-by-year basis.

SAFIR2010 31.1.2010 PROGRESS REPORT 4/10

Numerical modeling of condensation pool (NUMPOOL)
Lauhdutusaltaan numeerinen mallintaminen

Duration	2007 – 2010		
Project manager	Dr Timo Pättikangas, VTT		
Volume in 2010 (person y.)	Plan: 0.68	Realised 31.1.2010	0.67
Cost in 2010 (k€)	Plan: 101.9	Realised 31.1.2010	101.9

Main Objectives

The CFD model for condensation in the PPOOLEX experiments is further developed. The model is revised following the ideas obtained from comparison of numerical results to the experiment during previous year. In particular, the direct-contact condensation model is improved based on the comparisons with the experimental results. Different alternatives for modelling the area between the phases in Euler-Euler modelling are studied for improving the direct-contact condensation model. The effect of the number of the blowdown pipes on the pressure loads is investigated. Two CFD simulations are performed: (i) CFD simulation of an experiment where the direct-contact condensation dominates, (ii) CFD simulation of an experiment with two blowdown pipes.

Some of the numerical methods of the coupled CFD-FEM calculations are first reviewed. The issues considered are treatment of the fluid compressibility in the pressure-correction method as well as the explicit coupling algorithm and its stability. Simplified test cases are chosen and validation calculations are carried out. FSI calculations of the experiments and realistic BWR containment are also continued. Calculation of the experiment SLR-05-02 is re-run by using measured drywell pressure as boundary condition. The timing and shape of bubbles as well as pressures and displacements are compared with the experiments and previous calculations. For the BWR containment, two-way coupling of CFD and FEM is used instead of the Linear Perturbation Method (LPM). Effect of time step on the solution stability and accuracy is investigated.

Objectives in 2010	**Realised**
1 CFD modelling of the CONDEX facility (42.0 k€, 3.2 person months)	
1.1 Modelling of direct-contact condensation in the wetwell Different alternatives for modelling of direct-contact condensation in the water pool are tested and compared. (VYR, NKS, VTT).	Parameters of the direct-contact condensation model have been studied. The model has been modified based on previous simulations, where condensation of vapour in the air-vapour mixture was incomplete in the water pool. The condensation in the water pool was incomplete also in the latest test calculation performed in early summer. Effect of the model parameters have on the condensation have been tested. Task completion: 100 %
1.2 Simulation of an experiment with dcc of almost pure steam Experiment, where almost pure steam is flowing into the water pool is modelled with a revised direct-contact condensation model.	The first 100 s of the experiment WLL-05-02 has been calculated one more time with revised direct-contact condensation model. Paper written with the CONDEX team on the experiment and modelling was presented in the CFD4NRS-3 conference. In the modelled experiments, the highest molar fraction of vapour in the vent pipe previously been 70–80%. The effect of modifications of the condensation model has been tested with higher molar fractions of vapour.

(VYR, NKS, VTT).	Task completion: 80 %
1.3 Simulations of an experiment with two vent pipes An experiment with two vent pipes is modelled. An experiment performed with air is considered as a candidate. (VYR, NKS, VTT).	CFD mesh for the geometry with two vent pipes has been constructed. A 30 second long test simulation of steam discharge with the model has been performed by using the Euler-Euler model of Fluent. In the early part of the discharge, the vent pipes behave approximately in a synchronous manner. The diffusive nature of the Euler-Euler method makes it difficult to resolve small time differences between the vent pipes. Task completion: 80 %
2 ABAQUS modelling of the CONDEX facility (41.9 k€, 3.6 person months)	
2.1 Modelling of fluid-structure interaction Treatment of the fluid compressibility in the pressure-correction method as well as the explicit coupling algorithm and its stability are first reviewed. Simplified test cases are then chosen and validation calculations are carried out. (VYR, NKS, VTT)	Order of accuracy of the CFD, structural and FSI solutions has been examined in simple test cases. For CFD, the propagation of a 1D pressure pulse was considered by using different time steps and solution methods. For the structural solution, a single degree-of-freedom oscillator and an oscillating beam were used. For FSI, the 1D piston problem was considered. Task completion: 80 %
2.2 Repeating FSI calculation of experiment SLR-05-02 Calculation of the experiment is re-run by using measured drywell pressure as boundary condition instead of mass flow rate. The timing and shape of bubbles as well as pressures and displacements are compared with the experiments and previous calculations. (VYR, NKS, VTT)	CFD calculations without FSI have been performed and comparison with experiments and earlier simulations has been made. Effect of mesh density as well as turbulence and surface tension modelling on the bubble formation has been tested. Task completion: 90 %
2.3 Modeling of a sector of BWR containment Two-way coupling of CFD and FEM is used instead of the Linear Perturbation Method (LPM) used previously. Effect of time step on the solution stability and accuracy is investigated.	Analytical and numerical modelling of the pressure source due to a condensing steam bubble has been performed. Analytical solutions have been derived for the simplified case of constant bubble pressure and for the case where the bubble pressure is determined by the ideal gas law. The analytical solutions have been compared with numerical ones obtained with Abaqus FEM code. CFD calculations for modelling the bubble collapse have been performed with Star-CD. The VOF model and compressible water and air have been used. The calculations have been performed as 1D by assuming spherical symmetry and as 3D in the BWR geometry. FSI calculations with one- and two-way coupling have been performed for a bubble collapse in the BWR containment by using the acoustic FEM model and a pressure source obtained with a 1D model.

(VYR, NKS, VTT)	Task completion: 90 %

Comments

The report on the work done in 2010 is delayed and it will be finished by the end of February 2011.

In subtask 2.3, more work was done than initially planned: the dynamics of collapsing steam bubbles was studied in detail. In subtasks 2.1 and 2.2, somewhat less work was done than was initially planned.

Education of experts

The project staff includes presently one post-graduate student.

Publication

Pättikangas, T.J.H., Niemi, J., Laine, J., Puustinen, M. and Purhonen, H., CFD modelling of condensation of vapour in the pressurised PPOOLEX facility, CFD4NRS-3, Experimental Validation and Application of CFD and CMFD Codes to Nuclear Reactor Safety Issues, OECD/NEA & IAEA Workshop, Washington D.C., USA, 14–16 September 2010 (to be published).

Status of SAFIR report review

Pättikangas, T., Niemi, J. and Timperi A., Numerical modelling of pressure suppression pools with CFD and FEM codes. ***Reviewer: Juha Poikolainen, TVO.***

Improved thermal hydraulic analysis of nuclear reactors and containment (THARE)
Kehittyvät termohydrauliikka-analyysit

Duration	2007 – 2010	
Project manager	Ismo Karppinen, VTT Processes	
Volume in 2010 (person y.)	Plan: 1.7	Realised 31.1.2011 2.1
Cost in 2010 (k€)	Plan: 321.9	Realised 31.1.2011 322

Main Objectives

The main objectives of the project are to develop and validate calculation methods for safety evaluation of nuclear power plants. Both thermal hydraulic system analysis codes and CFD calculations are used in the analysis and their usability is studied and enhanced. An important objective is also to train new thermal hydraulic code users and educate young experts.

Objectives in 2010	**Realised**
1 APROS and TRACE validation (Plan: 9.5 person months, 106 k€)	
1.1 APROS validation with ISP-12 experiment. ISP-12 studied SBLOCA in BWR with ROSA-III experiments. ROSA-III is a 1/424 volumetric scale electrically heated (4 MW, 44% of full power) model of a BWR with external pumps. Break was located in the suction line of the recirculation pump resulting in core dry out and heat up. The ISP-12 will be modelled with APROS.	The ROSA-III is modelled with APROS 5.09. The core is modelled with two parallel fuel channels. One for high power bundle and the other for the remaining three fuel bundles. Each channel has three fuel rod groups with different powers. In the calculations the major events of ISP-12 was reproduced reasonably well. However there is still discrepancy in the break flow rate when water level drops below the suction line of the recirculation pump. In calculations break flow turns sharply to steam while more continuous liquid flow was measured. Pressure vessel water inventory is slightly higher than measured and LPI starts earlier. Consequently core maximum temperatures are lower than in the experiment. Modelling will be checked ones more and the report will be finalized. *Task completion 95%*
1.2 Pre-test calculations of PWR-PACTEL experiments with APROS. PWR-PACTEL experiment studying the behaviour of vertical steam generator (EPR design) will be analysed with APROS. The work includes pre-test calculations with the reference plant model to help in design and preparation of the tests. The test to be analysed will be chosen, when the tests have been defined.	According the reference group decision in meeting 3/2010 (7.9.) the task was devoted to participating in the PWR-PACTEL benchmark. Blind calculation of PWR-PACTEL benchmark experiment has been performed. The obtained results look realistic and consistent with the available experimental information. Deadline for submitting calculations is 28.2.2011. *Task completion:100%*
1.3 TRACE and APROS 3D model validation with ROCOM data. The task includes creation of 3D thermal hydraulic models for the ROCOM facility with both APROS and TRACE codes and validation of models with experimental data.	Calculations with TRACE have been done. Several nodalisations were tested. In the detailed model the vessel was divided in 16 sectors and 5 layers in the downcomer (>1000 nodes). The number of sectors affects more results than refining the mesh in axial or radial direction. Errors in APROS 3D module has been found and corrected. Similar nodalisation studies than with TRACA has been done also with APROS 3D. The results are consistent with TRACE calculations. Both codes somewhat failed to produce the very sharp mixing plane detected in the experiment. *Task completion:100 %*

1.4 ISP-50 post-test calculations with APROS ISP-50 studies a break of direct vessel injection line in ATLAS test facility, which models APR1400 plant. Blind calculation was performed in 2009. The work will continue with post-test calculations.	Test data and results of all participants have been received. Calculation results were discussed in the workshop 25-26.5. in Paris. Modelling of upper plenum has been refined and distribution of heat losses has been corrected. In addition, primary and secondary pressure behaviour has been improved by refining upper plenum volume and steam generator safety valve boundary conditions. More measured data was received 3.9. Downcomer liquid level has notable differences in both pre-test and post-test calculations. The number of sectors in the downcomer model was increased to possibly obtain better results, but no major improvement was observed in the liquid level behaviour. The post test calculation was submitted in December 2010. *Task completion:100 %*
2 containment (Plan: 4.5 person months, 73 k€)	
2.1 SARNET benchmarks. Generic containment benchmark in WP7 will be modelled with APROS containment. First calculations will be done with a fixed nodalization to compare codes against each other. .	The test case, SBLOCA with given base nodalisation, has been modelled and the results has been submitted. In preliminary comparison the main parameters of the APROS calculation agree well with the other calculations. *Task completion: 100 %*
2.2 Modelling of PANDA experiment with Fluent and APROS A PANDA experiment studying natural convection induced by containment cooler will be further studied with Fluent and APROS containment model. The task includes post test calculations with the Fluent CFD model and APROS containment model taking in account the possible deficiencies in the pre test calculations.	The FLUENT simulation of PANDA cooler experiment has been compared with test data. Modelling of the tube side of the cooler has been refined to better account the measurements. Calculation of steam diffusion in the condensation model has been improved. Pressure behaviour is quite well reproduced but all the affects of Helium on the gas flow through the cooler is still not captured. Measured Helium concentration inside the cooler was even 60% while calculated max. value was about 40 %. It looks like that the calculated flow field inside the cooler differs from the experiment. The calculation was discussed with the experimentalist in the SETH-2 meeting December 14-15. The PANDA cooler experiment has been calculated with APROS Containment starting from very simple one node/vessel model. The results show that with adequate nodalisation the pressure behaviour and condenser cooling rate can be modelled quite well. However the results are sensitive to nodalisation. An article to SAFIR2010 final report has been written. *Task completion: 95 %*
2.3 Validation of APROS containment with PPOOLEX experiments. Calculations of the experiments with APROS containment model will be continued. The new wall condensation experiments with insulated dry well will be calculated.	A new wet well stratification model of APROS has been qualitatively tested with POOLEX STB21 data. The stratification model based on steam velocity worked well also in PPOOLEX STR-11 experiment, but for STR-9 test the required threshold velocities for stratification and mixing were clearly higher. It looks like the simple velocity criterion is not sufficient to predict the stratification behaviour. The development of a model with predictive capabilities would require using additional criteria in addition to the gas velocity in the blowdown pipe. Finalization of the report is waiting experimental data and interpretation of the data (data report). *Task completion: 95 %*
3 International research programmes (Plan: 3.5 person months, 128 k€)	
3.1 OECD/GAMA Participation in the OECD/NEA/ CSNI Working Group on the Analysis and Management of	Ismo Karppinen participated in the annual GAMA meeting 21-24.9. in Paris.

Accidents (GAMA). *(Financing: VYR, VTT)*	*Task completion: 100 %*
3.2 USNRC/CAMP To participate USNRC/CAMP code assessment and maintenance programme. *(Financing: VYR, VTT)*	Participation fee has been paid. Seppo Hillberg and Pasi Inkinen participated in a TRACE User Workshop in Potomac, Maryland, USA, March 15-18, 2010. *Task completion: 100 %*
3.3 OECD/ROSA To follow the OECD/ROSA research programme. *(Financing: TEM, VYR, VTT)*	Pasi Inkinen participated in the OECD/ROSA-2 meeting 27-28.5. in Paris and Ismo Karppinen in the meeting in Tokai-mura 30.11-1.12. *Task completion: 100 %*
3.4 OECD/SETH2 To follow the OECD/SETH2 research programme. *(Financing: VYR, VTT)*	Participation fee has been paid. I. Karppinen participated in SETH-2 meeting 15-16.6. in Paris and Risto Huhtanen in the final meeting 14-15.12. in Villigen. *Task completion: 100 %*
3.5 OECD/PKL2 To follow the OECD/PKL2 research programme. *(Financing: VYR, VTT)*	Participation fee has been paid. I. Karppinen participated in the PRG meeting 26-27.4. in Pisa and Pasi Inkinen in the meeting 9-10.11. in Paris. *Task completion: 100 %*
3.6 Northnet The work plan of the Northnet was divided in three categories (roadmaps): 1) Thermal hydraulics and heat transfer in fuel assemblies (KTH) 2) TH and heat transfer in the reactor pressure vessel and the primary circuit (Vattenfall Utveckling) 3) Thermal hydraulics and heat transfer in the containment (VTT) The subtask covers coordination of the RoadMap 3. *(Financing: Fortum, VTT)*	RM3 meetings were held 28.1. in Olkiluoto, 27.8. in Stockholm and 10.1.2011 in Espoo. The latest PPOOLEX experiments and calculations of the experiments with FLUENT, GOTHIC and APROS were discussed in the meetings. *Task completion: 100 %*
4 Coordination and international co-operation (Plan: 1 person months, 15 k€)	
To coordinate THEA–project.	*Task completion: 100 %*

Education of experts

The project staff includes one trainee and two young experts.

Publications

Huhtanen R., Silde A. Steam and helium mixture with a containment cooler, simulation of Panda facility experiment ST4-1. SAFIR2010 Final Report.

Status of SAFIR report review

Task 1.1
Lauerma S. Validation of APROS with ISP-12, BWR SBLOCA in ROSA-III test facility, Espoo 2011, VTT-R-00837-11

To be finalized 2/2011. Reviewer: J. Poikolainen

Task 1.3
Inkinen P. Modelling of ROCOM facility with APROS and TRACE. Espoo 2011. VTT-R-00751-11

To be finalized 2/2011. Reviewer: E. Virtanen

Task 1.4

Inkinen P. Simulation of ISP-50 with APROS. Espoo 2011. VTT-R-00749-11

To be finalized 2/2011. Reviewer: T. Toppila

Task 2.2

Huhtanen R. Steam and helium mixture with a containment cooler, CFD simulation of Panda facility experiment ST4.1 VTT-R-00835-11

Silde A. Simulation of experiment ST4-1 at PANDA facility with tube-bundle cooler using the APROS containment code. VTT-R-00834-11

To be finalized 2/2011. Reviewer: E. Virtanen

Task 2.3

Luukka J. Modeling of water pool stratification in POOLEX and PPOOLEX experiments with APROS Containment, Espoo 2011, VTT-R-00810-11

To be finalized 2/2011. Reviewer: J. Poikolainen

SAFIR2010 31.1.2011 PROGRESS REPORT 4/10

CFD modelling of horizontal and vertical steam generators (SGEN)
Ydinvoimalaitosten vaaka- ja pystyhöyrystinten mallintaminen virtauslaskennalla

Duration	2008 – 2010	
Project manager	Dr Timo Pättikangas, VTT	
Volume in 2010 (person y.)	Plan: 0.87	Realised 31.1.2011 0.92
Cost in 2010 (k€)	Plan: 121.2	Realised 30.11.2010 116.2

Main Objectives

The objective of the project is to develop a simulation methodology and tool for the modelling of a horizontal and vertical steam generators of NPPs taking into account the multidimensional effects and the two-phase flow phenomena. The model developed in the project includes the essential physical phenomena occurring in the steam generator, such as heat transfer from the primary to the secondary side and the pressure loss of the two-phase flow in the tube bundles on the secondary side.

The models are implemented in the commercial Fluent CFD code. The model is tested with three-dimensional simulations of steam generator of a VVER-440 plant. PWR-PACTEL experiment is used as the test case for the model of the vertical steam generator. The primary circuit is modelled with Apros.

Objectives in 2010	**Realised**
1 Porosity model for the secondary side of a steam generator (20 k€, 1.5 person months)	
1.1 Improvement of the porosity model for vertical steam generators The interfacial and tube drag terms of the porosity model are modified for the vertical steam generator. The model is improved based comparison of the results to the PWR-Pactel experiments. (VYR, VTT)	Problems with mass conservation in Fluent were encountered. These affect seriously PWR-Pactel simulations were the feed water injection rate is small. The mass conservation problem was analyzed and practical solutions for circumventing the problem was chosen. The model for the tube configurations has been modified to suit also for triangular arrangements of the heat transfer tubes. The model for the friction caused by the tubes on the flow on the secondary side has been modified for the triangular tube arrangement. Task completion: 100 %
1.2 Improvement of the porosity model for horizontal steam generators The model is improved based on feedback obtained from the test simulations performed by FNS in subtask 2.1. (FNS)	The Fluent model for the secondary side has been modified for transient simulations. Transient temperatures of the primary tubes can now be used as a boundary condition, when the flow on the secondary side is calculated. Transient test simulations with the VVER-440 model have been performed. Task completion: 100 %
2 Testing the model for horizontal steam generator (23 k€, 2.4 person months)	
2.1 Simulations of VVER-440 steam generator Stationary state is calculated with a smaller steam production rate. The	Stationary state has been calculated with a smaller steam production rate. The effect of the anisotropic tube friction at

effect of the anisotropic tube friction at the ends of the steam generator is studied. Chosen short transient is calculated. Possibilities of calculating transport of magnetite with new drag coefficients is considered. (FNS)	the ends of the steam generator has been tested. Change in the temperature of the feedwater has been chosen as the test case of transient simulation. The transient has been simulated with Loviisa NPP Apros-model. The data obtained from the plant model has been used as a boundary condition for running the transient with the detailed Apros-model of the steam generator. As a result, the temperature of the steam generator primary circuit during the transient was obtained. CFD simulation of the transient on the secondary side has been performed. Task completion: 100 %
3 Testing model for vertical steam generator (40.2 k€, 3.1 person months)	
<u>3.1 Simulations of PWR-Pactel steam generator</u> Stationary states of PWR-Pactel steam generator are calculated at different power levels. The simulations are compared to experiments. Chosen short transient is calculated. (VYR, VTT)	Test simulations with the PWR-Pactel model have been performed. Three different test cases have been prepared for the secondary pressures 40 bar (105 kW), 20 bar (355 kW) and 10 bar (635 kW). Stationary state of the PWR-Pactel experiment NC-10 corresponding to the 20 bar case has been calculated. The flow on the primary side calculated with Apros was found to be sensitive to the initial state. The main features of the simulation result has been compared to the available data and observations from the experiment. Comparison of the CFD-simulation to the experiment suggest that some leakage of hot water from the hot side to the cold side occurs. Task completion: 80%
4 Apros modelling of the primary circuit (22 k€, 1.7 person months)	
<u>4.1 Apros model for the primary side</u> The Fluent-Apros coupling tool is used for calculating the boundary conditions needed in tasks 2 and 3. The coupling tool is modified for transient calculations. (VYR, FNS, VTT)	New boundary conditions for the VVER-simulations have been calculated to be used in subtask 2.1 The Apros-Fluent coupling tool has been modified, so that transient primary tube temperatures can be interpolated to the Fluent mesh. The coupling tool has been tested for the feedwater transient in VVER-440 steam generator. Task completion: 100 %

Comments

Mass imbalance problems of Fluent consume some of the resources originally planned to be used for model development in Task 1. More work than originally planned was needed for testing the transient modelling in subtask 1.2. Correspondingly, less resources than was originally planned were available for the subtask 3.1.

Transient calculations for the PWR-Pactel steam generator were not performed because more resources than was planned was used on the mass imbalance problem as is discussed above.

The preliminary realized costs in subtask 2.1 funded by FNS are 5 k€ lower than planned. The exact costs will be confirmed in February 2011.

Education of experts

The project staff includes one post-graduate student.

Publications

Pättikangas, T.J.H., Niemi, J. and Hovi V., Three-dimensional porous media model of a horizontal steam generator, CFD4NRS-3, Experimental Validation and Application of CFD and CMFD Codes to Nuclear Reactor Safety Issues, OECD/NEA & IAEA Workshop, Washington D.C., USA, 14–16 September 2010, 12 p.

Rämä, T., Toppila, T., Pättikangas, T.J.H., Niemi, J. and Hovi V., CFD-Simulation of the VVER-440 steam generator with porous media model. 8th International Seminar on Horizontal Steam Generators. OKB "Gidropress", Podolsk, Russia,. 19–21 May 2010.

Status of SAFIR report review

Pättikangas, T., Hovi, V. and Niemi, J., Three-dimensional porosity model for simulation of transients in steam generators. Research Report VTT-R-00724-11, 36 p. + app. 3 p., 2011. ***Reviewer: Virpi Kouhia, LUT, review in progress.***

Rämä, T. and Peltokorpi, L., Simulation of the high pressure feedwater preheaters isolation transient. Report FNS-TERMO-202, 22 p., 2011. ***Reviewer: Eero Virtanen, STUK, review in progress.***

Improvement of PACTEL Facility Simulation Environment (PACSIM)
PACTEL koelaitteiston simulointiympäristön kehittäminen

Duration	2008-2010	
Project manager	Juhani Vihavainen, Lappeenranta University of Technology (LUT)	
Volume in 2010 (person y.)	Plan: 0.96	Realised 31.12.2010: 0.99
Cost (k€) 2010	Plan: 83 k€	Realised 31.12.2010: 85 k€

Objectives

The main objectives of the PACSIM project are to enhance the utilization of the TRACE thermal hydraulic code and to improve the simulation environment of the PACTEL facility. The Finnish Radiation and Nuclear Safety Authority, STUK, has required an independent tool to support safety and licensing analysis and decided to use the TRACE code. The project enhances the preparedness to give analysis support, and improves education in computational thermal hydraulics. In 2008 the complete three-loop PACTEL facility model with horizontal steam generators, auxiliary systems and necessary control modules was created for TRACE in this project. The work will continue with validation calculations of earlier VVER type PACTEL experiments giving important validation knowledge for achieving the final goal of STUK of the full-scale VVER-440 model preparation with TRACE, which will be carried out outside the SAFIR2010 programme. In 2008 also a new TRACE model with vertical steam generators for the modified PWR-PACTEL facility was prepared. The TRACE code calculations with this model will give valuable analysis and comparison support for the APROS calculations of the future PWR PACTEL experiments.

Objectives in 2010	**Realised**
1 Calculations with the VVER-PACTEL model (56 k€, 5,1 person months)	
1 Validation calculations This subtask aims to validate the full TRACE-model, which has been prepared in this project during 2008. The calculated experiments in 2010 are small break LOCA situations including natural circulation with VVER-specific features like loop seal effect. Accumulator and other ECC systems are also included. Experiments chosen: SBL-31, SBL-33 and IMPAM-VVER T2.3 *(Financing: VYR)*	All calculations of the chosen experiments have been completed. Report is still under way but it will be completed for review on 11.2.2011. Task completion: 99 %
2 Calculations with the PWR PACTEL mode (27 k€, 5 person months)	
2.1 Calculation of the PWR-PACTEL experiments This subtask aims for calculation of the PWR-PACTEL tests, which are SIR-31, LOF-20 and SBL-50. *(Financing: LUT)*	The TRACE code has been used for modelling the PWR PACTEL with vertical steam generators. Calculations of experiments CHR-01, SIR-31, LOF-20 and SBL-50 have been finalized. Report has been delivered for review on 27.01 2011. Task completion:100 %

Comments

Education of experts

The project will increase the expertise level of thermal hydraulics calculation in LUT and the TRACE code and PACTEL model will be useful both for teaching and for research activities.

Publications

Journal article:
Vihavainen, Juhani & Riikonen, Vesa & Kyrki-Rajamäki, Riitta, TRACE code modeling of the horizontal steam generator of the PACTEL facility and calculation of a loss-of-feedwater experiment, Annals of Nuclear Energy, 2010, vol. 37, nro. 11, p. 1494-1501, ISSN 0306-4549 (IF 0.604), available also online: http://dx.doi.org/10.1016/j.anucene.2010.06.013

Conference papers:

V. Kouhia, R. Kyrki-Rajamäki, H. Purhonen, A. Rantakaulio, V. Riikonen, A. Räsänen, New possibilities to simulate vertical steam generators with integral facility PWR PACTEL, ENC2010, 31 May -03 June 2010, Barcelona, Spain, (paper in poster session).

Antti Rantakaulio, Virpi Kouhia, Vesa Riikonen, Antti Räsänen, Heikki Purhonen, Riitta Kyrki-Rajamäki, A New Integral Facility PWR PACTEL for Vertical Steam Generator Simulation, ICAPP'10, San Diego, CA, USA, June 13-17, 2010, Paper 10108.

Status of SAFIR2010 report review:

Vihavainen, J., Validation report: Calculation of PACTEL experiments SBL-31, SBL-33 and IMPAM VVER T2.3 (IMP06) with the TRACE code. Research report PACSIM 1/2010, Laboratory of Nuclear Engineering, LUT Energy, Lappeenranta University of Technology, Lappeenranta, 2011. **Reviewer Heikki Kantee. Will be sent for review by 11.02.2011**

Rantakaulio, A., Vihavainen, J., Validation report: Simulations of the LOF-20, SBL-50 and SIR-31 PWR PACTEL experiments with the TRACE code, Research report PACSIM 2/2010, Laboratory of Nuclear Engineering, LUT Energy, Lappeenranta University of Technology, Lappeenranta, 2011. **Reviewer Mikko Lemmetty. Has been sent for review on 27.01.2011.**

SAFIR2010 31.1.2011 PROGRESS REPORT 4/10

Condensation experiments with PPOOLEX facility (CONDEX)
Lauhdutuskokeet PPOOLEX laitteistolla

Duration	2007 – 2010	
Project manager	Mr Markku Puustinen, Lappeenranta University of Technology	
Volume in 2010 (person y.)	Plan: 1.9	Realised 31.12.2010 2.9
Cost in 2010 (k€)	Plan: 268.7	Realised 31.12.2010 318.8

Main Objectives

The main goal of the project is to improve understanding and increase fidelity in quantification of different phenomena in the dry well and wet well compartments of a boiling water reactor (BWR) containment during steam discharge. These phenomena are connected to bubble dynamics, direct-contact condensation (DCC), chugging, pressure oscillations, thermal stratification and global circulation and mixing in the pool. Sophisticated, high frequency instrumentation and high-speed video cameras or corresponding equipment has to be used due to the fast nature of the investigated phenomena. The final result of the project will be an experimental database on condensation dynamics and heat transfer, which can be used as such or for testing and developing computational methods used for nuclear safety analysis.

Objectives in 2010	**Realised**
1 STRATIFICATION AND MIXING IN THE WETWELL POOL (96.7 k€, 6.5 person months)	
1.1 Facility modifications and additional measurements The outer walls of the dry well compartment will be thermally insulated. An array of properly positioned thermocouples will be added to the pool volume in order to measure accurately the characteristics of thermal stratification and mixing. Adequate measuring techniques for the determination of the steam mass flow rate over a wide range will be added. For getting a more uniform initial temperature distribution of the dry well wall structures the pre-heating procedure will be developed further. (VYR, NORTHNET)	The dry well compartment (walls and vessel head) of the PPOOLEX test facility was thermally insulated with 50-100 mm thick mineral wool. A single steel blowdown pipe was installed to replace the two transparent pipes used in the last experiment series of 2009. A parallel thinner steam line with a small range flow meter was constructed to widen the usable range of possible steam flow rates. The system for sound velocity measurement in the pool was installed and tested. Some problems were encountered with the water transducer. Instrumentation to track the development of thermal stratification and to observe mixing was installed. According to the recommendations of the NORTHNET RM3 meeting extra temperature measurements were added into the blowdown pipe for tracking the movements of the steam/water interface. GOTHIC calculators will make an attempt to estimate the effective momentum term of the simulation model on the basis of the movement of the interface. Task completion: 100 %
1.2 Experiments on stratification and mixing A series of experiments on thermal stratification and mixing will be carried out. Steam mass flow rates needed to break down and mix the stratified water volume of the wetwell pool will be found out. Data for evaluating the capability of the GOTHIC code to predict stratification and mixing	Five experiments were carried out. The experiments consisted of a small flow rate stratification period and of a mixing period with continuously or stepwise increasing flow rate. The dry well structures were heated up before the actual experiments. Strong thermal stratification was easily achieved during the first half of the experiments. Temperatures below the blowdown pipe outlet remained close to the initial value while increasing heat-up occurred towards the pool surface. Total

phenomena will be produced. Pre-test analysis with GOTHIC code by KTH will support the selection of test parameters and procedure. (VYR, NORTHNET, NKS)	mixing of the pool volume was not achieved in any experiment with those flow rates available in the PPOOLEX facility. The bottom layers heated up significantly during the mixing period but never reached the same temperature as the topmost layers. Task completion: 100 %
2 MULTIPLE BLOWDOWN PIPES (112.0 k€, 9.0 person months)	
<u>2.1 Facility modifications and additional measurements</u> Parallel blowdown pipes from steel will be manufactured, installed and instrumented. Adequate measuring techniques for the determination of sound velocity and void fraction in the pool will be added. Additional pressure sensors will be installed to the pool volume to produce high resolution data that can be used in the code development work. The experiments will be carried out with a thermally insulated drywell compartment. (VYR, NORTHNET)	The importance of the sound velocity measurement in the parallel pipe experiments was discussed in the NORTHNET RM3 meeting in Stockholm. The participants emphasized that such measurements have been missing in the previous experiments on the issue and that they will give significant extra value to the experiments. The main measurement elevation should be on the level that is occupied by the cloud of small bubbles. The transmitter and receiver of the sound velocity measurement system was moved to a higher elevation (above the blowdown pipe outlet level). A parallel blowdown pipe made of steel was manufactured and installed. Pressure and temperature measurements were attached inside the lower half of the pipe. An automatic valve guide system was added to the steam line valve in order to be able to control steam flow during the experiments. Task completion: 100 %
<u>2.2 Experiments with multiple blowdown pipes</u> Experiments with two transparent blowdown pipes with the PPOOLEX facility in 2009 gave contradictory results to the earlier studies on the issue. A series of experiments with steel blowdown pipes will be carried out to exclude the possible effect of the pipe material (polycarbonate) used in 2009 on the results. Suggestions from the simulation partners (VTT and KTH) related to the improvement of test conditions and test procedures will be taken into account. Data for evaluating the capability of CFD and lumped parameter computer codes to predict pressure behaviour in a pool with more than one blowdown pipe will be produced. (VYR, NORTHNET, NKS)	A series of seven experiments with two parallel blowdown pipes was conducted. The capacity of the steam source (PACTEL steam generators) was adequate for the chugging mode to develop in two blowdown pipes. To maximize steam production the heat capacity of the steam generator structures was utilized in the experiments through increased steam generator pressure level and with the help of the automatic steam flow control system. High pressure pulses were measured in both blowdown pipes. Based on visual observations during the experiments it looked like the pipes behaved synchronously. However, a detailed examination of the high speed video recording and pressure measurements revealed that the formation, and particularly the collapse, of the parallel bubbles did not always happen synchronously. Up to 70 ms time difference could be observed between the two blowdown pipes. There was no clear pattern in which pipe the steam bubble first started to collapse. Some problems have been encountered with the sound velocity measurement system. Due to the high noise level associated with steam flow in the pipes and rapid condensation phenomenon the receiver has sometimes difficulties to hear the transmitted signal. Also some problems with the USB cable and with the recording computer have been encountered. Further interpretation of the sound velocity data will be tried. Task completion: 100 %
3 CFD CALCULATIONS AND EU/NURISP (35.0 k€, 3.0 person months)	
<u>3.1 NEPTUNE and TransAT calculations and EU/NURISP</u>	3D simulations of the POOLEX STB-28-4 experiment with NEPTUNE_CFD_1.0.7 by using a light “merged” mesh

NEPTUNE CFD code developed in the preceding EU/NURESIM project will be further improved by carrying out modelling exercises related to the steam discharge experiments with the POOLEX and PPOOLEX facility. Furthermore, a new CFD code called TransAT will also be used in the simulations. Calculation of selected steam discharge experiments will be continued with NEPTUNE and TransAT CFD codes. Work and model improvements done in the NURESIM and NURISP projects on steam condensation inside a vertical blowdown pipe will form the basis for the simulations. Information related to the EU/NURISP project will be distributed to the Finnish organizations. (VYR)	proved better convergence than earlier 2D-axisymmetric and 3D simulations. Concerning the simulation results, the qualitative behaviour of bubble formation seems to be promising but outstanding sensitivity to the initial location of the steam/water interface has been observed. The initial turbulence level seems to be the most crucial parameter. To invoke mixing and thus developed turbulence field, few vigorous chugging cycles may be needed in the simulation. Regarding the bubble size and collapse time, e.g. the Hughes-Duffey condensation model seems to be capable of providing realistic condensation rates during the chugging mode, if the initial condition of simulation leads to mixing strong enough. NEPTUNE_CFD has been updated to version 1.0.8 and the simulations continue now with that version. This version has some new NURESIM/NURISP models for phase change modelling. The next step is to improve the robustness of the simulation and test condensation models further. TransAT simulations (of STB-31 experiment) with different condensation models are ongoing with the new TransAT version 2.3.0. This version was published on week 34/2010, so results from it are too few to be reported in 2010. However, the initial results of these (RANS) calculations are promising. Task completion: 100 %
4 PROJECT MANAGEMENT (25.0 k€, 1.5 person months)	
<u>4.1 Project management</u> (VYR)	NORTHNET Roadmap 3 Meeting was participated in Olkiluoto on January 28th, 2010. Status of condensation pool research (LUT, VTT, KTH) was presented and research plans for 2010 were discussed. NORTHNET Roadmap 3 Meeting was participated in Stockholm on August 27th, 2010. Status of condensation pool research (LUT, VTT, KTH) was presented. NORTHNET Roadmap 3 Meeting was participated in Espoo on January 10th, 2011. Status of condensation pool research (LUT, VTT, KTH) was presented and updated research plans for 2011 and beyond were discussed. Task completion: 100 %

Comments

Education of experts

The project staff includes presently three young persons (YG).

Publications

Journal article:

Lucas, D., Bestion, D., Coste, P., Pouvreau, J., Morel, Ch., Martin, A., Boucker, M., Bodèle, E., Schmidtke, M., Scheuerer, M., Smith, B., Dhotre, M. T., Ničeno, B., Galassi, M. C., Mazzini, D., D'Auria, F., Bartosiewicz, Y., Seynhaeve, J.-M., Tiselj, I., Štrubelj, L., Ilvonen, M., Kyrki-Rajamäki, R., Tanskanen, V., Puustinen, M., Laine, J., Main results of the European project NURESIM on the CFD-modelling of two-phase Pressurized Thermal Shock (PTS). Kerntechnik 74 (2009) 5-6, Pp. 238-242.

Conference paper:

Pättikangas, T.J.H., Niemi, J., Laine, J., Puustinen, M., Purhonen, H., CFD Modelling of Condensation of Vapour in the Pressurized PPOOLEX Facility. CFD4NRS-3, 14-16 September 2010, Washington D.C., USA.

Research report:

Tanskanen, V., Jordan A., Validation of Condensation Models against POOLEX Condensation Pool Experiment, NURISP Document D2.3.4.15a, June 2010. NURISP, Nuclear Reactor Integrated Simulation Project of the 7th Framework Programme EURATOM.

Status of SAFIR report review (2010)

Laine, J., Puustinen, M., Räsänen, A., PPOOLEX Experiments on Stratification and Mixing in the Wet Well Pool, Research Report, CONDEX 1/2010. ***Reviewer: Mikko Lemmetty***

Puustinen, M., Laine, J., Räsänen, A., Multiple Blowdown Pipe Experiments with the PPOOLEX Facility, Research Report, CONDEX 2/2010. ***Reviewer: Eero Virtanen***

Tanskanen, V., Jordan, A., 3D CFD Simulation of STB-28 Steam Discharge Experiment, Research Report, CONDEX 3/2010. ***Reviewer: Timo Toppila***

SAFIR2010 31.1.2011 PROGRESS REPORT 4/10

Passive safety system simulation (PASSIMU)
Passiivisten turvallisuusjärjestelmien simulointi

Duration	2007 – 2010	
Project manager	Heikki Purhonen, Lappeenranta University of Technology	
Volume in 2010 (person y.)	Plan: 0.4	Realised 31.12.2010 0.4
Cost in 2010 (k€)	Plan: 43.3	Realised 31.12.2010 43.6

Main Objectives

The objective of the PASSIMU project is to study passive safety system in chosen nuclear power plant concepts. The objectives are to study the state-of-the-art situation in Finland and internationally in modelling passive safety systems, in respect of both the computational preparedness and the possible needs of new experiments.

The concepts proposed for the sixth NPP unit in Finland have safety systems including passive features. In this project first task was to gather information on chosen NPP concepts and specifically on passive safety systems in those. Further, brief summary on some international evaluation activities, both computational and experimental ones, have been reviewed for the project background purposes.

The aim of the project is to review the availability of analytical tools also in low pressure, low driving force and low flow conditions. These conditions are beyond the normal design conditions of the computer codes. Typically those conditions are difficult to handle numerically in these codes. The project is set to focus on LUT test facility resources in respect of passive safety system evaluation, i.e. in studying the possible availability of facilities on passive safety system evaluation processes. Keeping in mind possibilities of the available analytical tools, the computer code(s) are to be tested in one challenging test case.

Objectives in 2010	**Realised**
1 COMPUTER ANALYSES (13.3 k€, 1.3 person months)	
<u>1.1 Computer analyses with APROS/TRACE</u> Studying of capabilities of APROS and/or TRACE in typical passive safety system low pressure low flow conditions. Readily available data of the PACTEL tests for passive systems of VVER-640 can be utilized for TRACE. The calculated TRACE results can also be compared with previous analyses of the same test performed with APROS, CATHARE, RELAP and KORSAR codes. Other tests from the 2009 PASSIMU state-of-the-art report are considered as well for APROS analyses. (VYR, Fennovoima, TVO)	APROS code was tested in low flow conditions as planned. PACTEL VVER-640 experiments were chosen as a test case. The model of PACTEL in VVER-640 has been constructed. The test1 and test2 were chosen as calculation cases, following the earlier simulation cases with other codes. The simulation model has been modified, calculations are ready, and the report on calculation results has been prepared, namely as a publication mentioned below. Task completion: 100%
2 APPLICABILITY OF EXISTING TEST FACILITIES AT LUT (30 k€, 2.8 person months)	
<u>2.1 Applicability of PACTEL, PPOOLEX and transparent flow facility</u> The existing test facilities at LUT are reviewed in respect of their applicability to the studies of passive safety systems. (VYR, Fennovoima, TVO)	The review on facility possibilities and capabilities has been prepared in report form. The review concentrates on some facility set-ups and earlier performed experiments and experiences at LUT. The focus was set on passive safety systems used in core and containment cooling. A concise summary information on chosen cases and selected applications is provided in the report form. Hence, the final report presents some LUT facilities, equipments and systems possibly available for future studies. The report also includes

	short notes to the earlier research experiences of LUT on the project subject (The report is ready to be reviewed latest 4.2.2011) Task completion: 100%

Comments

The PASSIMU 1/2009 report was finished this year 2010. Year 2010 resources have been consumed also for report preparation including also the revision work. The PASSIMU 1/2009 report was distributed 1.6.2010.

Education of experts

One Bachelor's thesis at LUT is completed 2010 on PASSIMU related subject. This thesis will be publicly available in the electrical library Doria of the National Library of Finland, National Library Network Services; Doria is available at www-address <http://oa.doria.fi/>:

Telkkä, Joonas, Passiiviset turvallisuusjärjestelmät kolmannen sukupolven painevesireaktori-laitoksissa, Passive Safety Systems in Third Generation Pressurised Water Reactors. Kandidaatintutkielma, 26.11.2010. Lappeenrannan teknillinen yliopisto, Teknillinen tiedekunta, Energiatekniikan koulutusohjelma.

Publications

Status of SAFIR2010 report review (2009)

Kouhia, V., Review of Designs and Validation Aspects of Passive Safety Systems in Advanced Nuclear Power Plant Concepts. Research Report, Lappeenranta University of Technology, Nuclear Safety Research Unit, PASSIMU 1/2009. Ylöjärvi, 10.5.2010. ***Reviewed by Mikko Lemmetty, and distributed 1.6.2010 according to Distribution List.***

Reports 2010

Kouhia, V., Simulation of Experiments on Start of Natural Circulation and Long Term Cooling. Research Report, Lappeenranta University of Technology, Nuclear Safety Research Unit, PASSIMU 1/2010. Ylöjärvi, 28.1.2011. ***Reviewer: Anitta Hämäläinen, VTT (delivered for reviewing 28.1.2011).***

Kouhia, V., Possibilities in Experimental Research on Evaluation of Passive Safety Systems. Research Report, Lappeenranta University of Technology, Nuclear Safety Research Unit, PASSIMU 2/2010. Ylöjärvi, 31.1.2011. ***Reviewer: Juha Poikolainen, TVO (to be delivered latest 4.2.2011).***

SAFIR2010 31.1.2011 PROGRESS REPORT 4/10

OpenFOAM CFD-solver for nuclear safety related flow simulations (NuclearFOAM)
OpenFOAM CFD -ratkaisija ydinturvallisuuden virtaussimulointeihin

Duration	2010 – 2011	
Project manager	Dr. Tellervo Brandt, Fortum Power and Heat Oy	
Volume in 2010 (person y.)	Plan: 0.76	Realised 31.1.2011 0.68
Cost in 2010 (k€)	Plan: 84.5	Realised 31.1.2011 80,1

Main Objectives

The main aim of the project is to validate the open source CFD-software OpenFOAM as tool for nuclear safety related simulations.
In this project, we strengthen the Finnish OpenFOAM community in the field of nuclear safety and participate to Northnet and other international cooperation.
In the one-phase flow simulations, the aim is to be able to simulate flow and heat transfer in a complex geometry, especially in a fuel assembly, as a time dependent flow, with more accurate computational methods and models and effectively utilizing parallel computing. As a result we expect to have more detailed understanding of the coolant mixing and the results can be used in verifying safety issues when increasing the burn up of the fuel.
An existing Euler-Euler two-phase model of OpenFOAM is taken into use and validated. Model for convective two-phase heat transfer are added in the existing Euler-Euler solvers of OpenFOAM. Heat transfer model for subcooled nucleate boiling is tested in a geometry relevant for fuel bundles.

Objectives in 2010	**Realised**
1 Validation plan of OpenFOAM for nuclear safety analysis (14.3 k€, 1.5 person months)	
<u>1.1 Validation plan of OpenFOAM for nuclear safety analysis</u> We make a plan on how to validate the OpenFOAM CFD solver for nuclear safety analysis. (FNS)	The report will be finished in February 2011. Task completion: 75 %
2 Simulation of one-phase flows (47.6 k€, 4.6 person months)	
<u>2.1 OECD/NEA T-junction benchmark</u> We will participate to an international OECD/NEA benchmark where the aim is to simulate thermal mixing in the Vattenfall T-junction test case. This case is simulated using URANS (Unsteady Reynolds Averaged Navier-Stokes), LES (Large Eddy Simulation) and DES (Detached Eddy Simulation). (VYR, FNS)	The T-junction benchmark has been simulated as LES, and the results have been submitted to the benchmark organisers. Different turbulence models of the single phase solvers of OpenFOAM have been tested and validated for solving pipe flow. The tested turbulence models are the standard k-ε model, k-ω SST model, a LES model and a DES model. Pressure loss and heat transfer coefficient have been compared to correlations. Grid sensitivity of the results has been studied. Conjugate heat transfer has been tested by solving simultaneously the fluid flow and the heat conduction in solid. Five reports documenting the OpenFOAM solver and the calculated benchmarks have been written. Task completion: 100%
3 Simulation of two-phase flows (22.6 k€, 1.5 person months)	
<u>3.1 Testing of the existing two-phase</u>	

models The existing Euler-Euler multiphase solvers are reviewed and one of them is chosen for further development. A suitable validation case is chosen and validation calculations are performed. The scalability of the solver is tested in parallel computations. (VYR)	First version of a new two-phase solver has been implemented by modifying the existing solver twoPhaseEulerFoam. In the new twoPhaseNuFoam solver, models for interfacial drag, lift force and wall lubrication force have been added. The twoPhaseNuFoam solver has been tested against experiments on bubbly flow in a vertical pipe performed by Hosokawa and Tomiyama (2009) and by Prasser et al. (2003). A reasonable agreement with the experiments was achieved. Further improvement of the results could be obtained by improving the turbulence model and the near-wall treatment of the solver. Four reports documenting the solver and the calculated benchmarks have been written. Task completion: 100%

Comments

Education of experts

The project staff includes two post-graduate students.

Publications

No publications.

Status of SAFIR report review

T. Toppila, Validation plan of OpenFOAM for nuclear safety analysis. ***Reviewer: Eero Virtanen, STUK. Will be submitted to review by the end of February.***

Tomas Brockmann, Calculation of the OECD/NEA T-junction benchmark with OpenFOAM. ***Reviewer: Mikko Lemmetty (TVO). Will be submitted to review by 24.2.2011.***

J. Peltola, OpenFOAM 1.7.x: buoyantPimpleFoam and enhancements, VTT Technical Research Centre of Finland, Research Report (2010). ***Reviewer: Vesa Tanskanen, LUT, review in progress.***

J. Peltola, OpenFOAM 1.7.x: Compressible single-phase turbulence models and enhancements, VTT Technical Research Centre of Finland, Research Report (2010). ***Reviewer: Vesa Tanskanen, LUT, review in progress.***

J. Peltola, OpenFOAM 1.7.x: Single-phase heat transfer: Validation of near-wall treatment in standard k-ε, k-ω SST, k LES and Spalart-Allmaras DES turbulence models, VTT Technical Research Centre of Finland, Research Report (2010). ***Reviewer: Vesa Tanskanen, LUT, review in progress.***

J. Peltola, OpenFOAM 1.7.x: chtMultiRegionFoam, VTT Technical Research Centre of Finland, Research Report (2010). ***Reviewer: Vesa Tanskanen, LUT, review in progress.***

J. Peltola, Validation of conjugate heat transfer, VTT Technical Research Centre of Finland, Research Report (2010). ***Reviewer: Vesa Tanskanen, LUT, review in progress.***

J. Peltola and T. Pättikangas, twoPhaseNuFoam v0.1: Physical modelling, VTT Technical Research Centre of Finland, Research Report VTT-R-06313-10, 28 p. (2010). ***Reviewer: Timo Toppila, Fortum, review done.***

J. Peltola and T. Pättikangas, twoPhaseNuFoam v0.1: Implementation and numerics, VTT Technical Research Centre of Finland, Research Report VTT-R-06311-10, 47 p. (2010). ***Reviewer: Timo Toppila, Fortum, review done.***

J. Peltola and T. Pättikangas, twoPhaseNuFoam v0.1: Bubbly vertical pipe flow of Hosokawa & Tomiyama (2009), VTT Technical Research Centre of Finland, Research Report VTT-R-06517-10, 26 p. (2010). ***Reviewer: Timo Toppila, Fortum, review done.***

J. Peltola and T. Pättikangas, twoPhaseNuFoam v0.1: Bubbly vertical pipe flow in FZD MT-Loop 074, VTT Technical Research Centre of Finland, Research Report VTT-R-06601-10, 28 p. (2010). ***Reviewer: Timo Toppila, Fortum, review done.***

Release of radioactive materials from a degrading core (RADECO)
Radioaktiiviset päästöt vakavissa reaktorionnettomuuksissa

Duration	2007 – 2010	
Project manager	Tommi Kekki, VTT	
Volume in 2010 (person y.)	Plan: 0.86	Realised 31.1.2011 0.75
Cost in 2010 (k€)	Plan: 115.9	Realised 31.1.2011 97.4

Main Objectives

Iodine is one of the most important fission product released in a nuclear reactor accident. The main reason for this is that a significant fraction of iodine may exist in a volatile form. Organic iodide formation in post accident containment could result from gas or aqueous phase homogeneous processes, or from processes initiated at the painted surfaces in containment. There is some data available on the production of organic iodides from painted surfaces, but reactions of iodine with different types of paints may be different.

Nitric acid is a principal radiolytic compound produced in large, and its production is another important problem concerning pH of solutions, owing to its chemical properties of being a strong acid and a strong oxidizing agent.

The progress of severe accident phenomena during a severe accident have not been investigated in the same extent as the severe accident phenomena starting during operation. The oxidation of metals in oxygen-rich atmosphere and release of fission products may be different from those during normal operation

Objectives in 2010	**Realised**
1 Iodine (69,9 k€, 5 person months)	
<u>1.1 The production of organic iodides from painted surfaces</u> No iodine test are planned to do year 2010. We have capability to do iodine tests, if needed. The plan is to make summary report of all tests done and compare and fulfil these results with iodine data from international programs (like OECD/BIP, EPICUR, THAI). (VYR, VTT)	Maija Lipponen was finalised the summary report in the end of January 2011. Task completion: 100 %
<u>1.2 OECD/BIP</u> The information from the project is useful to compare our own experimental iodine test results, especially the modelling part could be helpful to understand the phenomena. (VYR, VTT).	The sixth meeting of the Programme Review Group (PGR) was organised 4.10.2010 in Paris. Travel report of the 6th meeting was sent to the reference group. AECL has prepared a draft agreement for a follow-up project OECD BIP2. Answers will be appreciated before the end of January 2011. Task completion: 100 %
<u>1.3 Formation of nitric acid</u> The formation of nitric acid during high dose rates will be tested. It is known that gamma irradiation of air/water will lower the pH. The high	The whole measurement procedure of nitric acid formation test is working. All planned nitric acid tests are done. The report was finished in the end of January 2011.

dose is achievable using FiR-1 research reactor or Gammacell device in Otaniemi. Using the FeSO4 dosimeters the dose can be measured.(VYR, VTT).	Task completion: 100 %
2 Shutdown conditions (33 k€, 3 person months)	
<u>2.1 Accident during shutdown conditions</u> Selected shutdown accident scenarios of Olkiluoto 1 and 2 will be performed with MELCOR 1.8.6 YT code. (VYR, VTT)	Atso Suopajärvi has started the work in the middle of October. The calculation cases were selected together with TVO. The calculations were not finished and the report was not written. Task completion: 35 %
3 Project management (13 k€, 1 person months)	
<u>3.1 Project management</u> RADECO project management, reference group meetings. (VYR, VTT)	The annual administrative reports were written as requested by the SAFIR2010 management. The third reference group meeting was organized and the minutes were written. Task completion: 100 %

Comments

Education of experts

Primary circuit chemistry of fission products (CHEMPC)
Fissiotuotteiden primääripiirin kemia

Duration	2007 – 2010	
Project manager	Mr Teemu Kärkelä, VTT	
Volume in 2010 (person y.)	Plan: 1.6	Realised 26.01.2011 1.6
Cost in 2010 (k€)	Plan: 281	Realised 26.01.2011 281

Main Objectives

The objective of the first subtask is to conduct iodine revaporisation experiments. VTT will also study possibilities to use various sampling instruments and online detection techniques in EPICUR and CHIP facilities. In the second subtask the aim is to help in the interpretation of results from Phebus FP and ISTP programs and participating in experiments conducted with CHIP facility. In the third subtask the objective is to study gaseous iodine chemistry at containment conditions in co-operation with Chalmers University of technology. The objective in the fourth task is to participate in the follow up meetings of ARTIST-2 project and model the deposition of aerosols in heat exchanger. The objective in the last subtask is to develop sampling technique to separate gaseous iodine from aerosol particles in sample flow.

Objectives in 2010	**Realised**
1 Primary circuit chemistry of iodine (108 k€, 8.4 person months)	
1.1 Experiments on chemistry of iodine in primary circuit Experiments on chemical revaporisation of iodine species will be carried out. (VYR, VTT)	The oxidation of stainless steel evaporation crucibles has been conducted. 2 experiments were conducted with EXSI facility, which automatic sampling was updated during autumn 2010. An abstract of the results was accepted and the results were presented in American Nuclear Society (ANS) Winter Meeting and Nuclear Technology Expo 2010 conference, 7-11.11.2010. Measurements were conducted during CHEMPC2009. A report on the updated test facility and the experiments has been written. A publication about the experiments is under preparation. It will be submitted by the end of March 2011. Task completion: 100 %
2 Phebus FP and ISTP follow up (25 k€, 1.5 person months)	
2.1 Participation in the Phebus FP and ISTP meetings VTT will participate in Phebus FP and ISTP interpretation circle meetings. VTT will review FPT-3 final report. (VYR, VTT)	The first and the second Phebus FP and ISTP interpretation meetings have been participated. Travel accounts will be submitted by mid-February. Phebus FPT-3 report review is completed and the final report has been issued at the end of 2010. Task completion: 100 %
2.2 Participation in the CHIP experiments M.Sc.Tech Teemu Kärkelä will participate in experiments using	Visit at Cadarache centre in autumn 2010 is cancelled. Anticipated experiments with the CHIP facility have not yet

CHIP facility at IRSN Cadarache research centre. (VYR, VTT)	been conducted at IRSN. Task completion: 0 %

3 Radiolytic oxidation of iodine (69 k€, 4.5 person months)	
<u>3.1 Complementary iodine oxidation experiments</u> Experiments on radiolytic oxidation of elemental and organic iodine will be carried out using facility built at VTT. The study is conducted together with Chalmers University of technology. (VYR, NKS, VTT)	Joachim Holm from Chalmers participated in conducting experiments at VTT 17.5 – 3.6.2010. All experiments have been conducted. Paper on radiolytical oxidation of organic iodine was accepted and results were presented in ICAPP 2010 conference, 13-17.6.2010. Measurements were conducted during CHEMPC2009. An abstract of the results was also accepted and the results were presented in International Aerosol Conference 2010 (IAC 2010), 29.8-3.9.2010. Measurements were conducted during CHEMPC2009. An abstract about CH3I experiments was accepted and the results will be presented in ICAPP2011 conference. A publication about the facility is under preparation. It will be submitted by the end of March 2011. Task completion: 100 %
<u>3.2 Scoping study: IOx particles behaviour on different surfaces</u> Aerosol particles formed due radiolytic oxidation of iodine will be deposited on various surfaces. Desorption of iodine from the samples under for example UV and gamma radiation will be measured in EXSI and RADECO facilities. (VYR, VTT)	A novel impactor for sampling of radioactive iodine oxide aerosols has been designed. Preliminary test on radioactive IOx particles deposition on painted concrete surface has been conducted. A test on radioactive IOx particles deposition on metal and copper surfaces and iodine desorption from surfaces was conducted in December 2010. Task completion: 100 %
<u>3.3 Experiments with gammaradiation at Chalmers</u> M.Sc.Tech. Teemu Kärkelä will participate in experiments on comparing the reaction products of iodine oxidation in air by UV and gammaradiation. (VYR, NKS, VTT)	Experiments were conducted in September 2010 at Chalmers. Teemu Kärkelä participated in measurements. A report on results has been written. Task completion: 100 %
4 ARTIST-2 (50 k€, 1.1 person months)	
<u>4.1 Participation in the ARTIST-2 meetings</u> VTT participates in the follow up meetings of ARTIST2 program. (VYR, FORTUM, VTT)	Participation in the 2nd meeting of ARTIS 2 Project Review Committee (PRC), 25-26.1.2010, PSI Villingen. Task completion: 100 **%**
<u>4.2 Follow-up: Modelling of aerosol</u>	Report on aerosol deposition in condensing heat exchanger

deposition in heat exchanger and aerosol deagglomeration experiments Aerosol deposition in heat exchanger under condensing conditions will be studied in experiments conducted in Hercules-facility. (VYR, FORTUM, VTT)	has been issued. Tutoring work on aerosol deagglomeration experiments has been started. Task completion: 100 **%**

5 Diffusion denuder (29 k€, 2.0 person months)	
5.1 Development of a diffusion denuder Sampling technique for gaseous iodine to be utilised at first in EXSI (VTT) and CHIP (IRSN) facilities. (VYR, VTT)	First experiment on IOx particles deposition in diffusion denuder has been conducted. The retention of gaseous iodine has been studied in December 2010. A report on results has been written. Task completion: 100 **%**
5.2 Parts for IRSN CHIP facility Manufacturing of special parts. (IRSN)	Parts for the CHIP facility have been manufactured. Task completion: 100 **%**

Comments

The visit of Teemu Kärkelä at Chalmers University of Technology (Göteborg) took place in September 2010. The visit included experiments on radiolytical oxidation of CH3I. Gammaradiation was used as a source of radiation and the reaction products were measured online. The experimental set-up is unique in a field of severe accident study.

Education of experts

The project personnel include presently three young persons (YG): three post-graduate scientists. The results published in the project will be part of thesis of Mr. Teemu Kärkelä, Mr. Jarmo Kalilainen and Mr. Joachim Holm. The project includes international co-operation within SARNET, Phebus FP, ISTP and NKS framework as well as with IRSN, PSI and CHALMERS.

Core Melt Stabilization (COMESTA2010)
Sydänsulan stabilointi

Duration	2010			
Project manager	Mr. Tuomo Sevón, VTT			
Volume in 2010 (person y.)	Plan:	1.10	Realised 31.1.2011	1.28
Cost in 2010 (k€)	Plan:	194.5	Realised 31.1.2011	194.6

Main Objectives

The objective of the project is to develop competence for computational modeling of severe accidents and to investigate phenomena related to steam explosions and molten core – concrete interactions. Via the CSARP agreement the latest versions of the severe accident simulation program MELCOR will be got into use. MELCOR modeling expertise is developed further by simulating experiments related to two-phase flows. The international OECD/SERENA project will generate new knowledge on steam explosions with real reactor materials. In addition, the steam explosion phenomenon is analyzed with computational methods. Results of the FESICO experiment, conducted in 2009, will be further analyzed and published. Experiments conducted within the OECD/MCCI-2 project will be analyzed, and the last meeting and the final seminar will be attended.

Objectives in 2010	Realised
1 MELCOR 2-phase Flow Simulations (22.5 k€, 2.0 person months)	
Experiments on two-phase flows are simulated with MELCOR. The accuracy of the MELCOR thermal-hydraulic models is studied and the effect of parameters and nodalization is investigated. (VTT, VYR)	No action since the previous meeting. Task completion: 100 %
2 CSARP (29.5 k€, 0.6 person months)	
Latest versions of MELCOR are obtained. CSARP/MCAP meeting is attended. (VYR, VTT)	No action since the previous meeting. Task completion: 100 %
3 OECD/SERENA (41.5 k€, 1.2 person months)	
The program review group meetings are attended. Experiment reports are distributed to the reference group. (TEM, VTT, VYR)	A travel report of the program review group meeting in Korea was sent to the reference group. Task completion: 100 %
4 Steam Explosion Analysis (48.5 k€, 3.8 person months)	
Steam explosion experiments are simulated with MC3D or Texas V codes. A reactor-scale benchmark exercise within the SERENA project is participated. (VTT, VYR)	Writing a report of the calculations is going on. Task completion: 95 %
5 FESICO Experiment (13.5 k€, 1.0 person months)	
Analysis of the experiment results is	The experiment results were analyzed with the FinCCI code.

continued and a publication is written. (VTT, VYR)	It was found out that ablation of the special hematite-containing concrete type can be quite well simulated with the siliceous concrete sidewall correlations. A combined report with task 6 was written and sent to the reference group. Task completion: 100 %
6 MCCI-2 (31 k€, 2.3 person months)	
The last meeting of the project and the MCCI seminar are attended. Analysis and modeling work of the CCI experiments is continued. (VTT, VYR)	CCI tests 4 and 5 were analyzed with the obtained concrete compositions. It was found out that the new tests fit well to the previous correlations that were developed on the basis of the CCI tests 1–3. Only small updates to the correlations were caused by the additional experiment data. The existing Excel macro for simulating MCCI was updated with the new versions of the correlations. The name FinCCI was given for the code. All the available 2-D dry MCCI experiments were simulated with the code. In LCS concrete tests the results were good. Siliceous concrete tests involve larger uncertainties. Also a reactor-scale case was calculated. A report, combined with task 5, was written and sent to the reference group. Task completion: 100 %
7 Project management (8 k€, 0.7 person months)	
COMESTA project management, reference group meetings. (VYR, VTT)	The fourth reference group meeting was attended. Articles for the final seminar were written. Annual administrative reports were written. Applications for the next year's project were updated to correspond to the reduced funding. Task completion: 100 %

Education of experts

The project staff includes two young persons (YG), the project manager and Mr. Atso Suopajärvi.

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Hydrogen Combustion Risk and Core Debris Coolability (HYBCIS2)
Vetypaloriski ja sydänromukasojen jäähdytettävyys

Duration	2010	
Project manager	Ms. Eveliina Takasuo , VTT	
Volume in 2010 (person y.)	Plan: 1.14	Realised 25.1.2011: 1.15
Cost in 2010 (k€)	Plan: 181.3	Realised 25.1.2011: 181.5

Main Objectives

The main objectives of the project are to conduct experiments investigating the coolability of porous particle beds and to model hydrogen behavior within the nuclear power plant containment for code validation purposes. The COOLOCE test facility is used to measure dry-out power within particle beds of different geometries. The porous beds represent core debris formed during a severe accident in the containment of a BWR. The dry-out power and coolability of a conical bed is compared to that of a cylindrical bed. In addition to obtaining new experimental data, the tests are used for validation and improvement of porous media codes applied for modeling particle bed coolability. Hydrogen behavior (mixing and combustion) in the containment is analyzed by CFD tools such as the FLUENT code. Large-scale experimental data of hydrogen and recombiner issues as well as fission product behavior is obtained by participation to the international OECD projects THAI and THAI2.

Objectives in 2010	**Realised**
1 Particle bed coolability (135.6 k€, 9.0 person months)	
<u>1.1 COOLOCE experiments</u> The installation of the COOLOCE facility is finalized (continued from 2009). A series of tests is performed in the conical test rig. A cylindrical test bed is built and installed into the test vessel. A test series is run with the cylindrical bed and the dry-out power is compared to that of the conical bed.	Experiments aiming for dryout at two ambient pressure levels have been performed with the conical particle bed (COOLOCE-1 and COOLOCE-2). Descriptions of the facility and the first test have been written. Preparations for continuing the experiments have been started. The possibility to use heaters with improved heat resistance has been investigated and a new offer for a separate pressure vessel bottom lid for the cylindrical particle bed has been received from the manufacturer. Task completion: 75 %
<u>1.2 MEWA analysis</u> Analysis of the particle bed experiments is conducted using the MEWA code, including reporting.	A journal article about the STYX downcomer experiments and their modeling is in press for Nuclear Engineering and Design. MEWA calculations have been done of the cylindrical and conical particle bed as a reference for the COOLOCE experiments and PORFLO simulations. Also, the first COOLOCE dryout experiment has been modelled by MEWA. Task completion: 40 % (note the dependency on task 1.1)
<u>1.3 PORFLO analysis</u> 3D analysis of the COOLOCE tests using the PORFLO porosity model is initiated. An input for the particle bed case is generated and test calculations are run.	Test simulations of the new models for the particle bed friction and heat transfer have been completed for the year 2010. The dryout process for the cylindrical particle bed can be reproduced by the code (void profile development). Realistic void profile distributions may also be produced for the conical case. Further simulations are needed in order to verify the predicted dryout powers. A report of the topic has

	been written. Task completion: 100 %
2 OECD/THAI and THAI2 programmes (34.7k€, 2.0 person months)	
2.1 Analytical work The modelling of the OECD ISP-49 deflagration tests is finalized in co-operation with the ISP participants, including participation to joint publications. Further, the modelling work is continued by simulation cases that will be decided later.	The modeling work concerning the HYBCIS project has been completed. The ISP-49 data analysis and reporting that will include the VTT results still continues by the ISP organizers. A joint publication of the HM-2 benchmark (of 2008) is being prepared by GRS (Nuclear Technology) and the benchmark participants. Task completion: 90 %
2.2 Programme follow-up Follow-up of the closure of the THAI programme and the initial stages of the THAI2 programme. Distribution of results to the Finnish nuclear energy partners.	The follow-up of the THAI project has been completed and the project material distributed. The start of the THAI2 project has been delayed due to discussions with potential participant countries (more information expected in early 2011). Task completion: 100 %
3 Project management and information exchange (11.0k€, 1 person month)	
Project management, administration and information exchange.	The management duties, project administration tasks and SAFIR2010 internal reporting have been done. Task completion: 100 %

Comments

The planned cost has been changed from the original budget because an additional person-month of VTT funding for a senior research scientist (16k€) was accepted based on the increased cost of the experimental research. The THAI2 participation fee has been removed from the project cost.

Education of experts

The project group includes two post-graduate students (E. Takasuo and V. Hovi). The project manager gains experience in experimental research, programming for CFD problems, international co-operation and project management. V. Hovi is the main programmer of the PORFLO code and develops his skills in several research areas in nuclear power plant thermal hydraulics.

Risk informed inspections of piping (PURISTA)
Putkistojen riskitietoiset tarkastukset

Duration	2007 – 2010	
Project manager	Dr Kaisa Simola, VTT	
Volume in 2010 (person y.)	Plan: (1.08) 1.00*	Realised 31.1.2011 0.98
Cost in 2010 (k€)	Plan: (178.6) 166.6*	Realised 31.1.2011 158.5

* updated plan: JRC funding will not be realised

Main Objectives

The overall objective of the project is to support the implementation of risk-informed in-service inspection (RI-ISI) at Finnish nuclear power plants by studying relevant issues related to RI-ISI. Main objectives are the development of structural reliability methods for quantification of piping leak and break probabilities, the development of methods for evaluating inspection capability and the link between inspection qualification, detection probability and RI-ISI, and studying issues related to risk-ranking, selection of inspection sites and acceptance criteria of a RI-ISI programme.

Objectives in 2010	**Realised**
1 Evaluation of piping failure potential (70 k€, 5.4 person months)	
<u>1.1 Probabilistic analysis methods for leak and break</u> Continue code development of the probabilistic fracture mechanics (PFM) analysis tool VTT BESIT by further development of sampling method for the simulation procedure and widening the scope of the tool to include e.g. water hammer to the selection of covered degradation mechanisms. A licentiate thesis concerning RI-ISI and other related probabilistic structural analysis methods and applications will be completed. Preparation of a conference paper and/or a scientific journal article is planned. (VYR, VTT)	The licentiate thesis concerning structural reliability and risk methods for power plant applications, including also PFM and quantitative RI-ISI, is on the publishing process. The emphasis of the thesis is on an extensive literature study. The computational part concerns the comparison of VTT PFM approach to Swedish PFM analysis tool NURBIT for a representative set of piping component analysis examples. Both the literature and computational parts of the work have been completed. Two presentations concerning the thesis have been given in ad-hoc meetings held at VTT, the first one at 26.4.2010 and the second at 5.10.2010, respectively. The thesis draft was sent for comments to Professor Juha Paavola (TKK of Aalto university) and Kaisa Simola at 29.11.2010, and comments received by the end of January have been taken into account. Task completion: 100 %
<u>1.2 Database applications</u> A pilot application of the OECD Piping Data Exchange Database (OPDE) will be conducted, including familiarisation with the database contents and evaluation of the applicability of the database for producing and creating practical piping component leak/break probability estimates will be reviewed. The possibilities to use the SCAP (Stress Corrosion Cracking and Cable Ageing), will also be investigated. The database application is planned to focus on investigating crack data to improve initial crack estimates needed in the PFM crack growth simulations.	Familiarisation with OPDE database contents, and earlier applications of the database, has been completed. The applicability of OPDE and SCAP databases to estimate piping degradation potential has been evaluated. The work has been reported in a technical report. Task completion: 100 %

(VYR, VTT)	

1.3 Vibrations The study on a method with which vibration induced stress variation in a piping system can be estimated without performing strain gage measurements will be finalised. The work will be published as a licentiate thesis. (VYR, VTT)	Development of the graphical user interface for the rain-flow analysis code has been carried out with reduced content Depart from the plans, validation of the investigated method was carried out using accelerations rather than the strains or stresses. A technical report which sums up the work done within the project during years 2007-2010 has been written. The plans of the task have been changed and the budget reduced due to the delay in writing the licentiate thesis. Task completion (with updated plan): 100 %
2 Reliability of inspection (51 k€, 2.8 person months) **(updated resources (see note in 2.2): 39 k€, 2.1 person months)**	
2.1 NDT simulation The new advanced features of the CIVA simulation program will be tested. These features allow defining some of the ultrasonic inspection parameters as a range inside which computations are made over the whole variation area. Using computed experimental data trials are made to define probability of detection (POD) in some example case. In the report ultrasonic modelling and simulation results over the whole research program period will be summarized. The applicability and usefulness of the ultrasonic inspection simulation will be assessed. (VYR, VTT)	Some study of literature examples including POD computations using simulated data is made. A paper on application of Civa simulation program for virtual ultrasonic testing is written and presented in Baltica VIII conference. The new version (Civa 10) of the Civa software is installed. It includes now tools for computation of simulation-supported POD-curves. Studies of the new features of the software version have been made. A report summarizing all the work of the task performed during four year period of the research programme has been completed. Task completion: 100 %
2.2 Ways to produce PODs for ISI The task focuses on contributing to the work within ENIQ TGR on how to produce probability of detection (POD) estimates for e.g. RI-ISI applications. A discussion document will be drafted together with JRC. (VYR,VTT, JRC)	The first and the second drafts of a technical document on POD curves prepared by JRC has been commented. A conference paper on the NKS-project (completed in 2009) has been written and presented at the ESREL2010 conference in September. An article “Derivation and use of probability detection curves in the nuclear industry” has been written together with JRC, and is being published in Insight-journal (December 2010). Task completion: 100 % *Note: the planned JRC funding (12 k€) will not be realised. This leads to a reduced contribution to the POD discussion document. Task completion refers to the updated plan.*

<table>
<tr><th colspan="2">3 Preparation, acceptance, follow-up and updating of RI inspection programme (30 k€, 1.9 person months)</th></tr>
<tr><td><u>3.1 ENIQ Task Group Risk</u>
Participation in the work of the ENIQ Task Group Risk in developing recommended practices and discussion documents related to RI-ISI. Following topics are under development within TGR: 1) RI-ISI for new plants; 2) What magnitude of risk is reasonable to achieve through ISI? 3) Guidance regarding how we set inspection targets following the selection of ISI sites; 4) PSA technical adequacy for RI-ISI applications.
Of primary interest is to follow the development in the first topic (RI-ISI for new plants). A conference paper on TGR work will be prepared and presented at the PSAM10 Conference. (VYR, VTT)</td><td>The final report of the RISMET benchmark has been completed. A journal article on RISMET project has been written, and published in the International Journal for Nuclear Power, Issue 7 (July 2010).

Conference papers on ENIQ TGR activities have been written for PSAM10 conference (June, Seattle) and for Baltica VIII conference (May, Helsinki). Presentations have been given at the respective conferences.

The ENIQ TGR meeting has been hosted in Espoo in May, and TGR and joint TGR/TGQ meeting have been attended in October. Participation on TGR task on “What magnitude of risk reduction is reasonable to achieve through ISI” is being conducted in co-operation with JRC. The Matlab tool developed at VTT for calculating piping weld failure probabilities using Markov process simulations is used for this task.

Task completion: 100 %</td></tr>
<tr><th colspan="2">4 International co-operation and project management (27.6 k€, 1.2 person months)</th></tr>
<tr><td>Project management and participation in international working groups and meetings: ENIQ Task Group on Risk, European Safety, Reliability and Data Association (ESReDA).
Planned international conferences: Probabilistic Safety Assessment and Management (PSAM10), Seattle, June 7.-11. European Safety and Reliability Conference (ESREL2010), Greece, September 5.-9.
(VYR, VTT)</td><td>Ad-hoc meetings (together with FRAS and RAKEMON projects) has been participated and presentations given on project results in April and October.

Following meetings/conferences have been attended:
RISMET meeting (Petten, March)
ENIQ TGR meeting (Espoo, May)
Baltica VIII (Helsinki, May)
PSAM10 (Seattle, June)
ESREL2010 (Rhodes, September)
ENIQ TGR and TGR/TGQ joint meeting (Schiphol, October)

Final administrative reporting of the project has been completed, and a summary paper to be presented at SAFIR2010 final seminar has been written.

Task completion: 100 %</td></tr>
</table>

Education of experts

The project staff includes presently four young post-graduate scientists.

Fatigue endurance of critical equipment (FATE)
Primääripiirin väsyminen

Duration	2007 – 2010			
Project manager	Mr. Jussi Solin, VTT			
Volume in 2010 (person y.)	Plan:	1,4	Realised 31.1.2011	1,6
Cost in 2010 (k€)	Plan:	233 → 203	Realised 31.1.2011	203

Main Objectives

The project aims to improve and verify models used for assessment of fatigue endurance and failure probability of nuclear reactor pressure boundaries subjected to hot coolant water. Quantitative, mechanism based and risk informed probabilistic evaluation of fatigue crack initiation (and crack growth) due to thermal and/or mechanical loads is aimed in long run, but the current project deals mostly with the applicability of the ASME and RCC-M design codes, YVL Guide 3.5 and experimental data available for existing and new plants. In 2010 the main focus is in fatigue assessment of typical transients in surge and spray lines in PWR's and experimental program including tests in PWR coolant water.

Objectives in 2010	**Realised**
1 Fatigue mechanisms in air and hot water (3,3 person months)	
<u>1.1 Cyclic tests for stress strain response and endurance</u> Cyclic straining (LCF & HCF) tests in air for Ti-stabilised stainless steel. Evaluation of fatigue mechanisms and design criteria. (Funding: VYR, VTT, TVO, Fortum)	A relevant VVER primary piping sample (08X18H12T) and three other materials (304L, 316L, 321 as 25 mm plates) have been fatigue tested in air. Monotonic and cyclic stress strain curves and apparent modulus trends are measured for all variants. LCF tests extended to HCF range for the pipe material indicated clearly higher HCF strength than assumed for the new ASME 2009b design curve. A conference paper discussing the NRC (Reg. Guide 1.207) and ASME (2009b) design curve modifications and their applicability to different stainless grades is prepared. Participation in a European "task force" meeting (25.10. Areva, Paris) concerning position to evolution of ASME code rules and fatigue code cases in process. Task completion: 100 %
<u>1.2 Cyclic straining experiments for DSA and microstructures</u> Interrupted cyclic straining and heat treatments to measure DSA and to produce samples to be used in TEM study in subtask 1.3. (Funding: VYR, VTT)	Good material availability and assumed homogeneity of plate were arguments for selecting AISI 321 alloy to this task. One specimen was interrupted after 5 million cycles at 0,2% strain amplitude. In addition, sequential loading and annealing experiments were performed up to initial hardening and softening stages with the same amplitude. Task completion: 100 %
<u>1.3 Microscopy</u> Electron microscopy (TEM) and research to reveal cyclic deformation and fatigue mechanisms. (Funding: VYR, VTT)	Electron microscopy study on development of dislocation microstructures as function of cumulative cyclic plastic strain with and without annealing (and potential DSA effect) for five interrupted samples from subtask 1.2 is ready. Report was revised and ready reviewed. Task completion: 100 %
<u>1.4 Test Material characterisation</u> Mapping of grain sizes and other characteristics of studied material batches.	A study of microstructure, grain sizes and other properties of different stainless steel samples was performed. Manipulation of grain size through deformation and recrystallisation was experimented. Reported in a VTT report.

(Funding: VYR, VTT)	Task completion: 100 %

2 Transient simulation in hot water (10 person months)	
2.1 New fatigue facility Tuning and testing of the new fatigue bellows system is continued to verify standard LCF procedure in hot water. (Funding: VYR, VTT)	Mounting of strain gauge to specimen is solved and functionally tested in FABELLO. Calibration tests and preparation for “real tests” are performed, except verification measurements on load train alignment. The specimen geometry has been verified applicable in LCF regime (0,3% ≤ ε_a ≤ 0,6%), which will be targeted in first autoclave tests. Fatigue lives in RT air are identical to those for standard LCF specimens. Task completion: 100 %
2.2 Fatigue tests in hot water Strain controlled constant amplitude tests in selected PWR water chemistry will be performed to compare with previous data and F_{en} models. (Funding: VYR, VTT, TVO, Fortum)	The water circulation loop was not available and real tests were replaced by 3 months of variable performance tests in 300C non-relevant water without aims to measure endurance, because the F_{en} values would be irrelevant. FABELLO works well and drift in strain instrumentation transducers was stabilised. Pneumatic control systems behave complex. Task completion: 80 %
2.3 Transient simulation A schematic laboratory transient to simulate some typical transients in plants will be selected and applied in strain controlled constant temperature transient simulation tests . (Funding: VYR, VTT, TVO, Fortum)	“EPR” transients were simulated in performance tests in 300C without aims to measure endurance (see 2.2). Task completion: 100 %

Comments

Water circulation loop was not available and a new one was ordered as part of VTT 2011 investment plan to be delivered in June 2011. In this perspective, it was impossible to target real tests. Instead, comprehensive long term performance testing was performed for three months in non-relevant stagnant water environment.

Education of experts

Notable part of manpower was allocated to an educationally oriented generic material science study aiming to learn of recrystallisation and grain growth behaviour of different stainless steel grades – and to see if manipulation of test material is a feasible target. In addition to education of experts, motivation for this activity grew from lack of NPP –relevant material batches in TR6 projects.

SAFIR2010 28.01.2011 PROGRESS REPORT 4/10

Project name in English: Water chemistry and oxidation in the primary circuit (WATCHEM)
Suomenkielinen nimi: Vesikemia ja hapettuminen reaktoripiirin olosuhteissa

Duration	2007 – 2010	
Project manager	Dr Timo Saario, VTT	
Volume in 2010 (person y.)	Plan: 0.8	Realised 28.01.2011 0.8
Cost in 2010 (k€)	Plan: 146	Realised 28.01.2011 146 (100%)

Main Objectives

To correlate lab results on cladding oxidation with plant results. To organise an IAEA FUWAC project meeting on fuel cladding oxidation. To perform a literature study on PWR crud formation. To design and acquire an experimental tool for studies on Flow Assisted Corrosion (FAC). To develop a method for determining the progress and efficiency of different possible pre-oxidation treatments. Verification of the method with Inconel 690 under PWR conditions especially in relation to Hot Functional Conditioning of a new plant.

Objectives in 2010	**Realised**
1 Fuel cladding oxidation. (1 k€, 0.1 person months)	
A scientific publication on the effect of oxygen on Zr-Nb -fuel cladding oxidation.	Scientific article ready and published. Task completion: 100 %
2 Deposited corrosion products. (87 k€, 5.5 person months)	
Visiting scientist period at BARC, India Designing and acquiring experimental facility for Flow Assisted Corrosion (FAC) studies. Literature study on FAC models	Visiting scientist period realised 23.1 – 28.2.2010. FAC equipment designed, purchased and received. Start of studies pending on the acceptance of the pressure bearing parts by TUKES. Manuscript sent for check-up to Ossi Hietanen/Fortum. Task completion: 100 %
3 Preoxidation (58 k€, 2.9 person months)	
Literature study on PWR start-up and shut-down procedures. Verification of methods for determining the efficiency of pre-oxidation during Hot Functional Testing. Verification of the method with Inconel 690 under PWR conditions.	Literature study will be performed in 2011 in WAPA-project (agreed within the TR6). Manuscript checked by Kirsti Tossavainen/STUK. Task completion: 100 %

Comments / international co-operation

A joint scientific publication on oxidation of fuel cladding under oxidising conditions has been prepared and published in co-operation with Bhabha Atomic Research Centre, India and University of Chemical Technology and Metallurgy, Sofia, Bulgaria.

SAFIR2010 31.1.2011 PROGRESS REPORT 4/10

Project name Monitoring of the structural integrity of reactor circuit (RAKEMON)
Rakenteiden eheyden monitorointi

Duration	2007 – 2010	
Project manager	Ari Koskinen, VTT	
Volume in 2010 (person y.)	Plan: 1.33	Realised 3.12.2010: 1.33
Cost in 2010 (k€)	Plan: 226.2	Realised 3.12.2010: 226.2

Main Objectives

The aim of this project is to develop techniques and monitoring systems that can be used to monitor the structural integrity of the primary circuit components. The aim is to develop measurement systems both for detection and analysis of macroscopic flaws and microscopic changes in the material that are often preceding the macroscopic failure.

Objectives in 2010	**Realised**
1 Task 1 Monitoring of the structural integrity of reactor circuit (103k€, 7 person months)	
1.3 Subtask 3 Selection of advanced techniques for development of the pilot monitoring system	Phased Array technique is suitable and sampling phased array technique is very promising. Sampling phased array method can not be tested due to lack of suitable equipment for that method. Nevertheless the method itself has shown very promising results in variety of applications worldwide. For example more precise sizing capabilities for different kind of flaws and smaller near field area are remarkable advantages that sampling phased array method fulfils. Task completion: 100%
1.4 Subtask 4 Pilot monitoring system and monitoring tests	In 2010 measurements were started with conventional TRL 2 MHz 45 degree ultrasonic probe used with Krautkrämer UMS 35 ultrasonic equipment. With 45 degree probe all the artificial cracks and EDM notches can be found but flaws produced with thermal fatigue (cracks) are relatively difficult to locate and the sizing of these realistic thermal fatigue cracks is not possible with conventional ultrasonic methods. Indications from EDM notch and thermal fatigue crack with similar dimensions are very different. The amplitude difference is in scale of about -8 dB. Also with TRL 2 MHz 60 degree probe all the flaws can be found but the difference between EDM notch indication and thermal fatigue crack indication is in the same scale as with 45 degree probe. Also TRL 4 MHz probes with 45 and 60 degree angles were tested but no significant improvement compared to 2 MHz probes was observed. The temperature of over 200 degrees Celsius with conventional probes is making measurement more difficult due to fact that probe itself can be used in that temperature only for very short time periods. Good contact between test piece and used probe seems to be difficult to obtain. Especially for high temperature use designed contact paste dries up on the test piece surface and therefore weakens the contact on the next

	measurement. More tests and some minor modifications were done during January 2011 but no significant improvements on contact issues were found. In ultrasonic simulations typical point of view is to simulate ultrasound, different wave modes, angles and different material behaviours. Different kind of flaw types give different kind of indications as has been shown with simulations during 2010. The CIVA program is not designed for simulating different kinds of indications but can be used for that purpose to some extent. More precise simulations of crack indications are needed and therefore more ultrasonic simulations of the test piece have been done with more realistic crack simulations. Task completion: 100%
2 Task 2 Inspection of items with limited access, difficult geometry or unfavourable grain structure (30k€, 2 person months)	
<u>2.1 Subtask 1</u> Experimental measurement and simulation of Phased Array - applications in demanding inspection areas	NDE simulation is a rapidly growing area and for example new version of simulation program CIVA with many new features is launched every year. In 2010 version new area was added to CIVA program. It consist features for POD (probability of detection) calculations and more precise possibilities for simulation of dissimilar metal welds and anisotropic materials. With more complex calculations calculating time of course increases and therefore it is a necessity to evaluate the needed accuracy for each simulation before doing the actual simulation. Simulations in 2010 have been focused on phased array probes and applying "Full Matrix Capture" (also called "Sampling Phased Array") technique. Simulations and experimental measurements with this sampling PA are ready and writing of research report is almost done. This report also reviews and summarize briefly all the work performed using ultrasonic simulation program during the SAFIR2010 research program. Report will be finalized during February 2011. Task completion: 100%
3 Task 3 Subharmonic ultrasonic inspection (16k€, 1 person month)	
<u>3.1 Subtask 1</u> Subharmonic ultrasonic inspection	Reliability and applicability to inspection of real NPP components with this method was studied in 2010. Reliable inspection with this new rising method will be an important progress in the detection of dangerous closed cracks in near future. There are studies that show some improvement on this reliable inspection issue, but at the moment it is yet to be confirmed by further studies. Nevertheless more studies on subharmonic ultrasonic method and its reliability have been done and collaboration with international contacts has been continued. Writing of research report was converted to writing an article which will be published in proceeding of the SAFIR 2010 final seminar due to better visibility of very important NDE research area. Presentation will also be given during the final seminar. Task completion: 100%
4 Task 4 SG lifetime monitoring (77.2k€, 6 person month)	
<u>4.1 Subtask 1</u> Development of data archiving	During the year 2010 the tests for steam generator tubes

system for results	have been started. First a state-of -the art review was conducted of the magnetite deposits, their behaviour and effect on steam generators tubes. Also some actual test results of inspections of a steam generator have been reviewed. Keeping in mind the gained information of the magnetite behaviour on and between the steam generator tubes, a mock-up for the laboratory scale studies was designed and built. This mock-up consists of four tubes that were set in a frame according to the measurements in a horizontal steam generator. Tests were done with several different set ups. First the initial tests were done for tubes that were in water for reference measurements. After these reference measurements the amount of magnetite was increased to see the point that the eddy current signal was disturbed and that alteration was visible in the data. During the test new eddy current equipment was taken in use and some valuable learning of the eddy current and the new equipment have been occurred. Also the future test results in future projects will be more accurate because of the new equipment. Initial test have been done in four different frequencies 100, 200, 300, 400 kHz. Also some lower frequencies (25 kHz) were tried. Work will be continued with new challenges in MAKOMON project. Task completion: 100%
<u>4.2 Subtask 2</u> Options of the secondary water chemistry in SG's	In early 2010 it was decided that the literature study will focus on magnetite dissolution and deposition. The title of the report is "Magnetite dissolution and deposition in NPP secondary circuit". The goal of this review was to gather information from various sources to gain understanding of the present situation of the research related to magnetite dissolution and deposition. Magnetite dissolution and deposition are major problems in many nuclear power plants (NPP). High removal rate of protecting oxide layer decreases the operating life of the equipment and causes dangerous situations, which can lead to casualties and major financial losses. Mechanism of flow accelerated corrosion (FAC) is generally well-understood and there are several models and software which predict FAC rate with good accuracy. FAC can be considered as an extension of a general corrosion process, where dissolution of the surface oxide is accelerated due to enhanced mass transfer of soluble species from the surface. The main parameters having influence on the magnetite dissolution rate are: concentrations of oxidants and reductants, electrochemical potential, temperature, pH, material properties (alloying elements) and hydrodynamic factors. The factors affecting magnetite deposition are basically less well understood. Theories of magnetite deposition can be divided into models describing the deposition of soluble iron and models describing the deposition of magnetite particles. Especially the factors affecting the attachment of the particles should be further studied. This literature study is ready and was sent to reviewer in December 2010. Task completion: 100%

Comments

Active participation in the US-NRC PARENT-project will be essential also in future (meeting held in Otaniemi in October). In that project an international round robin-exercise on inspection techniques will be organized as was in previous PINC-project. Participation in IAEA co-ordinated Research Programme started in March 2008 and is still ongoing. Round robin measurements were made in September 2010 and will be reported during 2011. The original plan was to finalize the project and reporting during 2010 but due to other international participants this could not be done in time. Last meeting was in Richland in June hosted by PNNL. Also an IAEA report is being written and will be published during 2011.

Education of experts

The project staff included five young persons (YG): Four post-graduate scientists that each except one have participated in training courses on NDE. Also one new research engineer who has also participated in training courses on NDE. Two scientific visits to Fraunhofer Institute for Nondestructive Testing (IzfP), Germany were made in autumn 2008 and 2009. Participation in BALTICA VIII conference in May (one presentation, chairman of one session).

SAFIR2010 3.12.2010 PROGRESS REPORT 3/10

“Fracture assessment for reactor circuit” (FRAS)
“Reaktoripiirin murtumisriskin arviointi”

Duration	2007 – 2010	
Project manager	Päivi Karjalainen-Roikonen, VTT	
Volume in 2010 (person months)	Plan: 24	Realised 3.12.2010
Cost in 2010 (k€)	Plan: 392	Realised 3.12.2010 350 (89 %)

Main Objectives

The objectives for fracture risk assessment comprise (1) calculation of design and unforeseeable loads and their effects on a structure by applying numerical modelling; (2) development of advanced fracture mechanics assessment tools and analysis methods based on material characterisation, damage mechanisms models and structural performance, in order to control structural failure both in cases of postulated initial flaw and environmentally assisted (internal) material damage; (3) determination of degradation in material properties during service.

Objectives in 2010	**Realised**
1 Definition of loads (102 k€, 7 person months)	
<u>1.1 Loads transferred by supports</u> The objective is to define the external loads transferred to the reactor circuit components by supports. In 2010 detailed modelling of the supports of a certain reactor circuit component (most probably RPV) will be conducted. Both the effect of the loads transferred to the vessel by a critical accident outside the vessel (such as an earthquake) and the effect of the loads transferred to the surrounding structures by a critical accident inside the vessel are to be analysed. The modelling of the earthquake load is preliminarily tried out with the pipe model created previously. (VYR, VTT)	Reporting of the 2009 work completed. The preliminary earthquake assessment was included in that report. The pipeline model studied in 2008 is analysed with more realistic materials. Next, the pipe break case will be analysed in a more detailed manner and the newest version of Abaqus finite element code will be used. A slightly more realistic earthquake assessment has been conducted with that model. Modelling of RPV and its supports was preliminarily started, but it was only preliminarily studied and will not be reported. In order to study a longer section of a pipeline, a finite element model of boiler feedwater pipe of Indian Point NPP (USA) fitted with modern supports has been built using the knowledge gathered earlier within this project. Some preliminary analyses have been conducted with that model and the results have been compared with some test results and corresponding results of more simplified models found in literature. Reporting is finished. Task completion: 100 %
<u>1.2 Fluid-structure interaction</u> Methods for realistic estimation of the amplitude and frequency of the fluid temperature fluctuations will be examined. One goal is to reduce the over-conservatism of the sinusoidal method used for assessing thermal fatigue due to turbulent mixing. Additionally, an artificial temperature signal is generated from estimated power spectrum of the fluctuations,	A method has been developed for generating an artificial temperature signal from the power spectrum of the fluctuations. An approximate formula describing the low-frequency range of the fluctuations is used for estimating the power spectrum. For calculating the total power of the fluctuations, a transport equation for the total power has been included into the Star-CD CFD code. The new method has been preliminarily found to produce clearly more realistic results than the sinusoidal method. Data on the ratio of the mechanical and thermal turbulence time scales has been searched from the literature. The calculations

after which the rainflow counting can be used for calculating the lifetime. The total power of the fluctuations is obtained from CFD calculations. The calculations will be compared with the Vattenfall thermal mixing experiment. The feedwater nozzle of a boiling water reactor, studied in 2009, is used as a realistic test case for the calculations. (VYR, TVO, VTT)	are being compared with the Vattenfall thermal mixing experiment. Modeling of the feedwater nozzle of a boiling water reactor has been started. Part of the work has been carried out in co-operation with Marieke Hannink, NRG, during her NULIFE early career expert visit at VTT. Task completion: 100 %
1.3 Residual stresses Numerical simulations concerning weld residual stress (WRS) distributions will be continued in 2010. The results from time dependent elastic-plastic analyses will be used as input data for crack growth FEM simulations, with initial crack postulates located in selected typical primary circuit component welds. Further development of fracture mechanics and weight function based analysis code VTTBESIT will be performed taking into account especially crack aspect ratio. Analysis of examples involving application to primary circuit component welds of various WRS relaxation assessment procedures as well as as-welded state WRS definitions from commonly used fitness-for-service procedure handbooks will be performed. Participation in international research project organised by U.S. NRC: NRC Weld Residual Stress FEA Model Validation Program, is planned. (VYR, TVO, BG, VTT)	Paper was presented in Baltica VIII conference held in spring 2010. It was about procedures to estimate longer time behaviour/decrease of WRSs as a function of transient loads, and numerical simulation of WRS distributions as applied to a feed water nozzle with connecting safe-end and pipe in a Finnish BWR. Crack growth analyses involving WRSs are in the final stage. The stress distributions needed as a part of input data in these analyses are taken from the results of the FEM simulations. Also further development of the used in-house fracture mechanics analysis tool VTTBESIT is under way. This mainly concerns improving accuracy of crack growth increment computation. Also, the above mentioned procedures for estimating decrease of WRSs as a function of transient loads are applied to a representative set of pipe welds. The domestic experimental WRS data to be made available to the project task group will be compared to the WRS distributions defined according to commonly used fitness-for-service procedures. For all these cases crack growth analyses are carried out with VTTBESIT to see how the decrease in WRSs as compared to time independent WRSs affects crack growth rates. Two reports have been finished. Task completion: 100 %.
2 Advanced fracture mechanical assessment methods (149 k€, 11 person months)	
2.1 Engineering assessment tools T-junctions among other components belong to the most important structural parts of reactor circuit. Due to the complexity of the case, no simple engineering methods are available. Thus the solution is sought by using finite element method and integrating its application to existing plant database. A commercial code (ZENCRACK) has been tested and found to be a suitable tool. In 2009 the developement of a process of automatically performing Zencrack analyses for pre-existing models e.g. from a plant database was started. In 2010 the developement of the automated	Zencrack analyses concerning three dimensional crack growth and incorporation of residual stresses have been performed. Also automated crack growth analysis procedure has been developed further. Reporting Zencrack related work is under way. The work related to numerical crack growth analyses such as extended finite element method (XFEM) and cohesive zone modelling is ongoing. Cohesive zone model parameters are calibrated based on experimental tests. XFEM crack growth modelling in Abaqus is being studied. Two reports have been finished. Task completion: 100 %

process is continued. Work on combining Zencrack analyses and submodelling technique is also carried out in this task. The inclusion of special phenomena as a three dimensional residual stress distribution in the Zencrack analysis is also studied. (VYR, VTT, TVO)	
2.2 Assessment of 3D flaws Transferability of fracture mechanics test data associated with different levels of specimen's constraint will be investigated by performing tests using specimens with both deep and shallow surface notches. Fracture resistance curve and T_0 reference temperature testing will be carried out for selected materials using surface cracked specimens at different degrees of tension and bending. This provides input for the development of FEM analysis methods taking account of constraint effects in structural analysis. Experimental work will continue along with numerical analyses of test data. These data are to be further applied for the development and verification of constraint corrections, e.g., the Master Curve T-stress correction. (VYR, VTT)	Experimental work for preparing and testing of semi-elliptical surface cracks in the ductile-to-brittle transition region has been started. Taking part in the international Round Robin has been agreed. In the round robin a method to measure the J-integral fracture toughness and the extent of crack growth in a single-edge-cracked tension SE(T) specimen will be used. The specimen geometry and loading mode is designed to produce a level of crack-tip constraint in the test that is similar to the constraint experienced in service for a surface circumferential flaw in a pipe under tension or bending load. The test is intended to be used for structural steels. Test specimens have arrived. SET and SEB specimens have been notched, prefatigued and side-grooved. Tests with deep crack SEB-specimen have been performed. Test for SET will follow. Task completion: 100 %
2.3 Micromechanical modelling This work will continue during 2010 with crystal plasticity and development of WST model. Dislocation dynamics modelling of cleavage and embrittlement to develop further the Master Curve formalism for cleavage fracture will be performed, in close co-operation with the PERFORM60 project. Modelling activities will be performed in co-operation with University of Illinois, IBM Research and Lawrence Livermore National Laboratories, USA. XFEM based techniques will be applied as a part of michromechanical modelling actions 2010. (VYR,VTT)	Master of Thesis on two brittle fracture local approach models, Beremin and Bordet was published. Beremin local approach method is based on the probability of finding microcracks which cause the cleavage initiation and failure. Bordet et al. more advanced local approach method takes account of the probability of the initiation and the propagation. The results indicate that the Bordet model produces failure probabilities similar to the Master Curve while being more stable than the Beremin model. Task completion: 100 %
3 Advanced surveillance techniques (129 k€, 8 person months)	
3.1 Ductile crack growth measuring capacity The aim is to produce ductile fracture re-sistance (J-R) data to be applied in later numerical calculations in order to define realistic criteria for spec-imen's measuring capacity and development of related material characterisation standardisation.	Thorough analysis of experiments CT, SENB and WOW specimen types were completed. Fracture mechanical analysis of all results have been performed. Numerical modelling has been performed.

During 2009, experimental work was mainly finished and numerical cohesive zone modelling calculations were started. In 2010 the main goal is to continue by combining experimental data on ductile fracture resistance (J-R) with cohesive zone modelling calculations in order to define realistic criteria for specimen's true measuring capacity and development of related material characterisation standardisation. (VYR, VTT)	Reporting is finished. Task completion: 100 %
<u>3.2 Irradiation embrittlement</u> Based on the analyses relevant radioactive material samples were chosen, prepared and sent to micro-structural characterisation to Tohoku University (Atom Probe and PA) with the aim at forming a link between the microstructure and material embrittlement. The test matrix was specified in detail in liaison with Tohoku University, followed by sample preparation at VTT and the subsequent transportation to Japan. Large number of model alloys and VVER-440 materials in varying conditions will undergo ATOM-PROBE and PA analyses in Tohoku University, Japan. In 2010 the analyses will be completed and reported. Co-operation with ORNL (atom probe studies) is delayed but planned to be initiated. A new method for characterisation of irradiated ferritic materials will be applied in 2010. Resistivity measurements of VVER-440 weld in I- IA- and IAI conditions will be performed. Resistivity is shown to correlate well with the inclusion structure. The new data will be correlated with existing mechanical test data.	Draft report of non-linear analyses of VVER-440 surveillance data was prepared. The report will be completed in 2010. A detailed test matrix on ATOM Probe and PA characterisation of irradiated materials was agreed with Tohoky University. Samples representing weld 501 material in eight different IAIA-conditions and ten different model alloys in irradiated conditions were prepared by VTT with EDM. The samples were transported to Japan in February 2009. First data was expected to be available in 2010 but is delayed due to Japan. Resistivity and Seebeck-coefficient measurements devices (jig, programs, etc.) are finished and the preliminary tests have been performed. Resistivity test measurements at room temperature and at liquid nitrogen have been made for aluminium. Results correlate well with literature values. Also for Seebeck-coefficient measurements the test system seems to work well. Pure reference material (Al, Fe, Ni, Cu) has been ordered for both tests. Pressure vessel steel specimens in I, IA, IAI –states have not been made yet. Annealing oven is finished. Task completion: 100 %

Comments

The project is proceeding according to the plans.

Education of experts

A MScTech –thesis work (Mr. Pasi Lindroth from Helsinki University of Technology) within Sub-Task 2.3 has been completed.

1.

Project name in English: Influence of material, environment and strain rate on environmentally assisted cracking of austenitic nuclear materials (DEF SPEED)

Suomenkielinen nimi: Materiaalin tilan, ympäristön ja muodonmuutosnopeuden vaikutus austeniittisten ydinvoimalaitosmateriaalien ympäristövaikutteiseen murtumiseen

Duration	2007 – 2010	
Project manager	MSc U. Ehrnstén, VTT Materials for Power Engineering	
Volume in 2010 (person y.)	Plan: 2.5 py (26 pm)	Realised 31.1.2011: 127 % in relation to planned pm volume, 33.1 pm (VTT 27.8, Aalto 5.3), 3.2 py.
Cost in 2010 (k€)	Plan: 413.7 417.6*	Realised 31.1.2011: 417.6 k€ (100%)

1 py = 10.5 pm
* actual final budget. The difference is due to the difference is exchange rate used for NKr in original budget and at invoice day.

Main Objectives

The project aims to increase the understanding of environmentally assisted cracking (EAC) mechanisms in austenitic nuclear materials by identification of precursor events for EAC. The role of deformation mechanisms and localisation of deformation in EAC of deformed, non-sensitised stainless steels, nickel-based materials and their weld metals as well as irradiated stainless steels are investigated in depth during the four year project. Investigations are performed on different types of materials as a function of cold work, environment (BWR and PWR) and strain rate. Crack initiation test technique evaluations were carried out on sensitised stainless steel during the first year (2007), and continued on non-sensitised stainless steel and then nickel-based materials and their weld metals. The role of dynamic strain ageing and localisation of plastic deformation on EAC of nickel-based materials is studied within a thesis work. Determination of the influence of strain rate and environment on the fracture toughness properties of austenitic nuclear materials were started during the first year within a diploma work and continued during the second and third year with a larger test matrix. The latest international knowledge is brought to Finland by participating in international co-operation within the field of EAC and irradiation assisted stress corrosion cracking (IASCC). An additional task concerning digitalisation and classification of existing reports was started in 2008 and continued in 2009

Objectives in 2010	**Realised***
Task 1.1 Crack initiation testing in simulated LWR environments budget 103 k€, 6.2 pm	
<u>1.1 Initiation tests in simulated LWR environments (VYR, VTT, SSM)</u> Initiation testing on deformed non-sensitised stainless steel and then Ni-base materials in simulated LWR environment(s) Deliverables in 2010: **D1. initiation test data on selected austenitic materials** D2 joined with D3 (TR6 meeting 11/2010)	• First set of SSSRT on specimens made from Inconel 182 and 152 weld metal in simulated PWR-environment finalised. No macroscopic cracks observed after 8% straining. SEM-investigations show small cracks in all investigated specimens. These specimens will be investigated using EBSD. • Design of new bellows performed, and adequate equipment performance verified at standard strain rate. • **First SSSRT in the new device in simulated PWR-environment terminated. Instability in load at super slow strain rate observed, and the test was used for optimisation of control parameters, but the issue was not yet solved.** • **SSSRT results summarised in special report for the final SAFIR2010 seminar** Task completion 100%

- New progress since last progress report written in **bold**. Numbers for task completion % are based on evaluated % of results in relation to set goals. Achieved deliverables will be indicated in bolded green. Inability to reach set deliverable would be indicated in bold plum.

Task 1.2 Characterisation of deformation budget 97 k€, 7.1 pm	
1.2 Characterisation of deformation (VYR, VTT, SSM) Detailed characterisation of deformation mechanisms and their influence on EAC using SEM/EBSD, TEM, etc. Deliverables in 2010: **D3: Research report on characterisation work on specimens from initiation tests**	• EBSD characterisation of cold deformed and super slowly strained non-sensitised Type 316L specimens performed. The four specimens, cold deformed to 8, 15, 20 and 28% and further strained 5% in simulated BWR environment showed transgranular cracking in the 20 and 28% cold deformed specimens and no macroscopic cracking in the 8 and 15% cold deformed specimens. *SEM showed cracks in all the test bars.* • TEM specimens from near surface area fabricated from a sensitised stainless steel SSSRT specimen by using two focused ion beam (FIB) methods as well as by electrolytic polishing approach. • A dislocation density gradient was observed next to the oxidised surface, which is in line with our mechanistic understanding of metal-environment interaction. • **TEM-investigations performed on the head and the deformed gauge regions of 8, 15, 20, and 28 % cold deformed stainless steel SSSRT bars to investigate basic deformation structures. Reported in D3.** • **FIB examination (“micro cross-section”) on a surface crack of 8 % cold deformed sample was investigated using FEG SEM** • **Report *Pakarinen, J. The effect of prior cold work on the deformation and crack initiation of SSSRT tested AISI 316 stainless steel. Report VTT-R-00321-11*, final draft issued. To be signed before February 10th, 2011.** Task completion: 100%

Task 1.3 Characterisation of irradiated stainless steels revised budget 35 k€,1.8 pm	
1.3 Characterisation of irradiated stainless steels (VTT, Halden) Characterisation of irradiated stainless steel using FEG-STEM as in-kind contribution for the Halden project. Participate in CIRII extension project. Deliverables in 2010: **D4: Research reports on characterisation work for Halden concerning irradiated stainless steels**	• The non-irradiated materials, which were characterised in irradiated condition in 2009, have been characterised • Report finalised and results presented at Halden IASCC meeting in Sept. 2010. • **Characterization of 30 dpa 304 Chooz A materials in three post-irradiation annealed conditions was begun, and in accordance with the Halden offer, will be reported in 2011 at Enlarged Halden Programme Group meeting.** Task completion: 100%

2 Influence of strain rate and environment on fracture toughness properties of austenitic nuclear materials Budget 53 k€, 2.7 pm	
2.1 J-R tests in environment Determination of the influence of environment and strain rate on the fracture properties of Ni-based weld materials Deliverables in 2010: D5: **Conference** and/or journal **publication**	• Paper presented at Baltica conference: *M. Ahonen, U. Ehrnstén and H- Hänninen: Effect of Hydrogenated Low Temperature Water on Fracture Toughness of Nickel-based Weld Metals* • Paper presented at the Fontevraud 7 conference: *Ahonen, M, Ehrnstén, U. Hänninen H. Low temperature crack propagation of nickel based weld metals in hydrogenated PWR primary water* • Preparation of cross-sections for detailed microscopic investigations in progress. • **Report issued*: Cronvall, Otso: Structural Integrity Study Concerning LTCP Phenomenon VTT Research report VTT-R-00055-11, 17.01.2011.*** • **An evaluation of the implication of the LTCP-results for the structural integrity of a safe-end made of Alloy 182 with a postulated axial half-elliptic crack on the inner surface was performed. Two cases were considered, i.e., shut-down and emergency cool-down situations. For all of the analysis cases studied, the critical crack sizes were relatively large, e.g. in the depth direction from 52 to 98 % of the wall thickness, which was assumed as 40 mm.** Task completion: 100%

3 Investigations of dynamic strain ageing behaviour Budget 27k€, 1.8 pm	
3. Investigations of dynamic strain ageing behaviour Determination of strain ageing behaviour of austenitic weld materials Deliverables in 2010: **D6: Doctoral thesis on DSA in austenitic materials**	▪ Mykola Ivanchenko defended his thesis: *Dynamic strain ageing of austenitic strainless steels in Ni-base alloys* on November 19th, 2010. ▪Available at http://lib.tkk.fi/Diss/**/** Task completion: 100 % / 100 % (€)

4 International co-operation Budget 79 k€, 2.8 pm	
3.1 International co-operation The latest knowledge in the field of EAC is brought to Finland by active participation in international co-operative projects and groups. Deliverables in 2010: D7: **Detailed travel reports** D8: **Presentations**	• DEFSPEED results presented by U. Ehrnstén to the Swedish Materialgruppen, who finances the project through SSM, 4.2.2010, Stockholm • SCAP final report issued • Familiarisation with the data base performed • ICG-EAC 2010 meeting in South Korea, Jeju Island attended by U. Ehrnstén and H. Hänninen. Two presentations were given at the meeting: 1. *Hänninen, H. et al. Effect of Hot Cracks on EAC Crack initiation and Growth of EAC initiation and crack growth in Nickel-based weld metals*" 2. *Ehrnstén, U. Hietanen, Ossi and Kytömäki, P.: Results from investigations on core basket bolts removed from a VVER plant.* Travel report issued. • A dissimilar metal weld specimen received from KAIST as agreed during the post technical tour after ICG-EAC • Travel report distributed to TR6 on general assembly meeting for the Perform60 project (W. Karlsen). • VTT-representatives attended the Fontevraud conference in September 2010. Detailed travel report issued. • **W. Karlsen reported on VTT research results at Halden IASCC meeting on 23-24.9.2010. Travel report issued.** • **U. Ehrnstén and H. Hänninen attended the EPRI 690 expert group meeting and the LTCP workshop in December 2010 in Tampa, USA. Travel report issued.** Task completion: 100%

5 Report archiving Budget 33.0 k€, 2.0 pm	
5. Report archiving Building of a digital data bank for nuclear materials reports Deliverables in 2010: **D9: Commissioned digital report archive comprising reports on nuclear materials**	▪ All identified material reports scanned ▪ One set will to remove empty pages re-scanned ▪ Metadata input finalised ▪ Structure of database finalised ▪ Distribution of the reports from the temporary location in the database into the final location for each customer finalised ▪ The database has been opened to STUK, Fortum and TVO. ▪ VTT continues to assists the companies in any technical problems to access the data base. ▪ Updating of the data base with new reports is the responsibility of VTT, and the system is adopted. Task completion: 100 %

Education of experts

The project staff comprises presently of experienced researchers and 5 young persons (<35 years). One young scientist performed SEM and TEM-work for the DEF SPEED project in 2007-08, and is now working for another employer within the nuclear field. One new materials scientist (Matias Ahonen) graduated in 2008 within the project and continues to perform research in the project. He will work for the OECD Halden project in Norway from the beginning of 2010 for a scheduled period of one year. Two young technicians participate in the demanding autoclave testing. A research scientist for TEM work was recruited in 2009 and has participated in the DEF SPEED work. He defended his doctoral thesis on September 25th, 2009 at the Tampere University. A doctoral thesis by Mykola Ivanchenko on DSA, partly funded by the DEF SPEED project, is finalised and defended in November 2010. A new researcher (Juha-Matti Autio) was recruited in August, and he participated in the SAFIR 2010 work.

Project name in English: Renewal of active materials research infrastructure (AKTUS)

Suomenkielinen nimi: Aktiivisten materiaalien tutkimusympäristön uudistaminen

Duration	2007 – 2010	
Project manager	MSc S. Tähtinen, VTT Materials in Power Engineering	
Volume in 2010 (person y.)	Plan: py (6.5 pm)	Realised 31.12.2010: 6,5 pm (100%)
Cost in 2010 (k€)	Plan: 104 k€	Realised 31.12.2010: 104 k€ (100%)

Main Objectives

The objectives of this study are to make a review on future and technical needs of active materials research and testing facilities in Finland. This study will be the basis for the engineering design (hankesuunnitelma) for the infrastructure and the first technical capability description of testing facilities. This engineering design will be started at VTT with VTT´s own finance in 2009, and the work will most probably be subcontracted from a special engineering team.

The study is urgent due to the renovation work and needs in the present location at VTT Espoo (Otakaari 3).The present infrastructure and main part of the facilities have been built in the 1970's and are, thus not technically up to date and the infrastructure is not fully serving all the requirements needed to enable fulfilment of todays tasks. Further the needs of operating nuclear power plants today have changed from the start of the nuclear technology in Finland and the construction of new plants will generate new needs to assure long term hot cell facilities in Finland.

Objectives in 2009	**Realised***
1 Task 1 Renewal of active materials research infrastructure budget 125,5 k€, 7 pm (VTT), realised 120,1 k€, 6,5 pm (VTT)	
<u>1.1 Experimental Needs (VYR, VTT)</u> Review on the present experimental facilities and needs for the future capabilities.	Following research areas have been identified and reviewed: - Mechanical and microstructural characterisation and fracture mechanics of active structural materials (Hot cells for specimen preparation, mechanical testing, metallography, environmental testing). - Radiochemistry (chemical analysis HR-ICP-MS) - Nuclear waste deposition (bentonite, iron/bentonite dissolution, low pH concrete) - Dosimetry - Other experimental work linked to nuclear technology (plasma burn, γ-spectroscopy, material test reactors JHR) - Support functions for FiR1 test reactor - First wall material research for Fusion technology (Beryllium and Tungsten studies by SIMS). Task completion: 100% / 100%

*Task completions are given as % of doing/ % of money. Some delay exists in the latter.

1.2 European capabilities and models (VYR, VTT) Review on modern or modernised European research facilities for active materials: technical capabilities, technical solutions, laboratory layout and networking possibilities.	European HOTLAB database has been established by the Hot Cell working group in FW6th HOTLAB project http://www.sckcen.be/hotlab/ and has been integrated with IAEA PIE data base http://www-nfcis.iaea.org. Task completion: 100% / 100 %
1.3 Description for the Engineering Design (VYR, VTT) To define technical requirements and needs for the Engineering design.	VTT has subcontracted the survey to ISS Proko Oy. Task completion: 100% / 100 %

Service Life Management System of Concrete Structures in Nuclear Power Plants (SERVICEMAN)
Ydinvoimaloiden betonirakenteiden käyttöiän hallintajärjestelmä

Duration	2007 – 2010	
Project manager	Erkki Vesikari, VTT	
Volume in 2010 (person y.)	Plan 14.3 person-months	Realised 31.1.2011 14.3 per-m
Cost in 2010 (k€)	Plan: 215,3 k€	Realised 31.1.2011 215,3 k€

Main Objectives

The main objective of the project is to develop a service life management system (SLMS) for concrete structures in nuclear power plants. The SLMS consists of a SLM Tool for maintenance, repair and renovation (MR&R), and supplementing risk and structural analyses. The SLM Tool includes prediction of degradation in structures, guarding of safety limits, specification and timing of MR&R actions, timing of special inspections, and evaluation of life cycle costs and environmental impacts. By the service life management system (SLMS) the safety, performance and serviceability are secured during the operational life of the plant.

Objectives in 2010	**Realised**
Task 1 Development and programming of service life management system (55 k€, 4.1 person months)	
<u>Task 1 Subtask 3</u> <u>Finalising of SLMS and transferring it into use</u> The outputs of the ServiceMan program are still subject to critical review. Minor changes or corrections can still be made in the first part of the year 2010. In the second half of the year the program ServiceMan is transferred to the power companies. Final adjustments are made to ensure the proper working, printouts etc. Schooling is arranged if necessary. A user manual is written both in Finnish and in English. (VTT)	The program ServiceMan is ready and submitted to the power companies TVO and Fortum. The user manuals both in Finnish and in English are ready. ServiceMan Schooling day was arranged on 25th of November for the power companies. A representative of STUK (Jari Louhivirta) was also present. During the day all functions and displays of the Serviceman program were carefully examined and they were generally approved. It was agreed that the errors which were observed will be corrected before the end of the project. It was also agreed that taking of the program into use would mean at this phase continuing the special inspections in accordance with the timings of Serviceman program. This is important for improving the degradation models. Also a module based life cycle plan will be done for the power plants and registering “damages” using the program will be started. However, the program will not be used for laying down annual work programs so far. Mentoring of another VTT’s researcher for the use and upkeep of the program ServiceMan has been started and a lot of tutorial material has been prepared. The programming language has been changed to English (for the user both languages Finnish/English are available). Task completion 100 %
<u>Task 1 Subtask 4</u> <u>Performing a special inspection and a condition analysis</u> The first special inspection is performed during 2010. It is addressed to one or two modules in the cooling water channelling system in Olkiluoto and Loviisa plants. The inspection is	Special inspections (sample taking) was done in Olkiluoto 1 at the end of May and in Loviisa 1 between 10-14 August. The specimens were taken from two modules/plant at three heights: above the water level, tidal zone, and under water level.

planned to be a "model" for later special inspections performed for other modules. Samples are taken from 1) above the water level 2) tidal zone 3) under water level. The samples are analysed according to the testing plan made in 2007. (VTT)	The carbonation depth and the chloride profiles were determined and the micro-structural thin-section studies were performed from the samples according to the plan. The chloride profiles were modelled and the remaining activation time of corrosion was evaluated based on the models. The report "Condition Assessment of Cooling Water Channels in Finnish Nuclear Power Plants" is ready. Task completion: 100 %
Task 2 Development and programming of structural degradation analyses and a system for serviceability limit state design (55 k€, 4.2 person months)	
Task 2 Subtask 1 2. Structural risk analyses Structural risk analyses are performed using the Finite Element Method (FEM). The FEM grid and the material models for the Olkiluoto I and II plants were developed in 2009 and some preliminary stress analyses were performed. In 2010 nonlinear FE analysis with relaxation of the pre-stressed tendons and the time-dependent nonlinear behaviour of concrete as well as the interaction between steel and concrete (slip of tendons) are performed. Hypothetical breaks of tendons are assumed to study the distribution of stresses in the case of possible breaks as a result of corrosion. As a result of these studies an answer will be obtained how many tendon breaks would possibly be tolerable and in which kind of combinations they could be without jeopardising the safety of the containment. By combining this data to the results of the component level risk analyses (probability of a tendon break) the level of structural risk as a result of corrosion in tendons can be evaluated (VTT).	. Finite Element models of post-tensioned concrete containment building of OL2 nuclear power have been done. In particular, a model using shell elements for the containment and truss elements for the post-tensioned tendons have been analyzed under real loads. The interaction between container and tendons has been studied using different contact analysis options available in the Abaqus finite element code. Finally, the possible breaks of tendons were modelled as deactivation of the contacts in the extent of an assumed anchoring distance and by discarding the tendons completely (the lower and upper solutions). Their effect on the stress distribution has been evaluated. For the cracking analyses with IVODIM programme, only linear material properties are deployed. For comparative cracking analyses with Abaqus, so called nonlinear "concrete damaged plasticity" material model is used for concrete, but this model still needs some improvements and these comparative cracking analyses are not reliable enough. The normal bending reinforcement layers have been re-checked, the untensioned post-cast part of the wall has been excluded, and for the relatively restricted area under evaluation, the model is accurate enough and in coherence with the corresponding IVODIM model. The model and calculated stress resultants have been transferred to Subtask 2. The stress distributions have been examined and evaluated. The effect of tendon breaks to the nearest other tendons has been evaluated. In the above mentioned shell model, only the post-tensioned part of the containment wall is simulated. For the whole containment building with the pools resting on the cylinder wall included, a more detailed, but otherwise corresponding 3D solid element model is used. It contains the same truss elements for the tendons, but also the liner is modelled explicitly. Analyses with that model are not yet realistic enough for estimating the structural integrity of the liner or for verifying the results of the shell element model. The final research report is completed. Task completion: 100 %
Task 2 Subtask 2. Cracking analyses. Cracking analyses of the containment will be performed for the selected cases of Task 2.1. The calculation model and	First a test model has been transformed from Abaqus program (VTT) into IVODIM system (ÅF). Then a conversion program for the results of Abaqus has been programmed and tested using the first version of the final model. The cracking

results of the analyses done in Task 2.1 will be transformed into a suitable format for the IVODIM program used in the cracking analysis. This task supplements the stress analyses by giving the estimation about the crack widths that correspond to the stresses calculated in Task 2.1. The calculated crack widths give one additional method to evaluate the durability of the concrete structures and the calculated crack widths can be compared to the recommended values presented in design codes. Both service and accident loads can be used in the analyses. These results help also to estimate the safe test pressure for the containment leakage tests. (ÅF-Consult)	analyses have been done using the shell element model of the containment building of Olkiluoto 2 nuclear power plant. The Abaqus model and stress resultants of studied loading cases have been transformed from Subtask 1. The calculation of crack width has been made using the IVODIM design tool. The results of the cracking analyses have been processed and documented in the final report of the cracking analyses. The final report is completed. Task completion:100 %.
4 Task 3 Participation in concrete technological research cooperation with other owners of infrastructure (financing by VYR 17 k€)	
(VYR, Finnish Transport Agency, City of Helsinki , City of Tampere, Industry, TEKES, VTT) 1. Consulting on concrete technological topics 2. The effect of permeability properties of concrete repair materials on service life 3. Acceptance of form liners 4. SILKO tests of concrete repair materials (excluding restrained shrinkage) 5. SILKO tests of protective agents of concrete 6. Correlation between CEN/TS 12390-9 slab test and EN13687-3 7. Correlation between CEN/TS 12390-9 slab test and the combination of EN13687-1 and EN13687-2 8. The applicability of heating surface instrument for heating and drying of concrete substrate for water proofing **DuraInt** = “Effect of interacted deterioration parameters on service life of concrete structures in cold environments”. Field study, theoretical study and degradation modelling. (VTT + HUT + International co-operation)	1 Directions for: - Protection of concrete - Coating of concrete - Coating agents - Anti graffiti agents - Repair using ejector are under preparation. - Replacement of reinforcement - Cleaning of concrete surface - Repair of concrete structures - Concrete spraying have been published Task completion 100 % 2. Carbonation and chloride penetration tests as well as chloride analyses are completed. Task completion 100 % (of year 2010) 3. A proposal of which form liners in Finnish market may be accepted for Finnish Transport Agency. Reported. Task completion 100 % 4. Research report is completed. Task completion 100 % (of year 2010) 5. The tests are ongoing Task completion 100 % (of year 2010) 6. The tests are ongoing Task completion 100 % (of year 2010) 7. The tests are ongoing Task completion 100 % (of year 2010) 8. Research report has been written about the theoretical calculations of parameters for heating and drying of concrete bridge decks for waterproofing works. The site study is finished. Preliminary results are available. Task completion 100 % (of year 2010) DuraInt – The results of the field and laboratory tests until the end of year 2010 have been reported. The field tests and some laboratory tests are still going on, however. Degradation and service-life modelling is still ongoing. Task completion 100 % (of year 2010)
5 Task 5 International cooperation (OECD/ NEA/IAGE and COST C25) (11 k€)	
<u>5.1 Subtask 1</u> Participation in the activity of OECD/NEA IAGE Concrete WG	 The annual meeting of OECD/NEA IAGE Concrete WG was held on 14th April 2010 in Paris. Erkki Vesikari participated the

(VTT) Participating in COST C25. "Sustainability of Constructions: Integrated Approach to Life-time Structural Engineering" (VTT)	meeting. Memo in Finnish has been written. The meeting of COST Action C25 was held in May 24 – 25 in Izmir. Training School in Malta 28.7.-1.8. 2010 The international workshop on Aging Management Program AMP 2010 was held in November 8 – 10 in Toronto. Erkki Vesikari, Aki Mattila and Vesa Hiltunen participated the workshop. Program ServiceMan was introduced. Task completion: 100 %

SAFIR2010 31.1.2011 PROGRESS REPORT 4/10

Project name in English (IMPACT2010, Impact phase 2)
Suomenkielinen nimi IMPACT2010

Duration	2007 – 2010 (duration to 2010)	
Project manager	Mr Ilkka Hakola, VTT TK201	
Volume in 2010 (person y.)	Plan: 3.5	Realised 31.1.2011 3.5
Cost in 2010 (k€)	Plan: 520[1)]	Realised 31.1.2010 470 (90 %)[1)][2)]

[1)] Original plan: VYR 40 k€, VTT 130 k€, 7 partners 150 k€/each and one giving results (value of 150 k€) for the years 2009-2011. Seven partners have signed the contracts of Impact 2, but TVO has decided not to join the project. In addition one partner will give his own impact results (value of 150 k€). The SAFIR/Impact 2010 project will end in January 2011, but the project with Finish and foreign partners will continue to the end of 2011. The discussion has already started to begin Impact phase 3.
[2)] SAFIR management group JR3/10 has decided to pay the total amount of VYR funding (100%).

Main Objectives

A general objective of this project is to obtain experimental information on the physical phenomena involved in a condition where an airplane impacts against a nuclear facility. The missiles used in impact tests are describing wings, engines and carriages of aeroplane and also model of fuselage. Four specific aims of the project include firstly new data on the time-varying forces that arise during such an impact. Secondly, it is believed that high hydrodynamic shock pressures can arise while the fuel tanks impact against a fixed structure. Data on this phenomenon are requested. Thirdly, data on the shedding of the debris and spreading of liquid (fuel) from the disintegrated tanks by the impact are also requested. Fourth, response of reinforced and/or pre-stressed concrete wall (deflection, penetration) to aircraft-like impact loads will also be tested.

The first IMPACT project with foreign partners has ended in December in 2008, but the continuation project has been started in March 2009 with the same partners. Also the discussion of the next phase 3 (Impact 3) has already started.

Objectives in 2010	**Realised**
1 Test apparatus (Total 27 k€, 1 person months)	
The test apparatus will be changed to be suitable for liner testing, curved structures and floor-wall structures.	The acceleration tube has been changed to be able to shoot without heavy carriages and the frame has been modified for 1 way slabs. Beams and plywood structure has been installed at the back of the frame to get information of the post-velocity of the missile. The back part of the apparatus (1/4 part) has been corrected and strengthened in December 2010 after 100 shots. In the Tag meeting in December 2010 was decided, the wall tests with liner will begin in 2011 and curved walls and floor-wall structures will be tested in the next project Impact 3.

	Task completion: 100 % of the work for 2010.
2 Preliminary design of missiles and walls (Total 54 k€, 4 person months)	
New type of stainless steel missiles, 3D missiles and target concrete curved walls has to be calculated and designed in order to achieve the desired failure mode.	Missiles made of stainless steel, carbon steel or aluminium have been designed and tested. Some tests have been performed using water in side. Concrete walls thickness of 150 mm have been designed and tested. Pre-stressed concrete walls thickness of 250 have been also designed and tested. Curved walls and floor-wall structures will be designed in the next project Impact 3. *Task completion: 100 % of the work for 2010*
3 Improvement of measuring system (Total 80 k€, 6 person months)	
The data acquisition system will be improved by increasing measuring system, which is capable to measure forces and stresses when floor-wall structure is used as target	New wide band isolation amplifier has been developed to decrease noise during impact. All the cables have been renewed. The noise using force plate has been decreased using plastic plates behind the transducers. Two plywood walls at the back of the concrete wall have been instrumented to measure the post-velocity of the missile. The final length of the reinforcement has been measured manually using marks on the surface of the bars. New measuring card (8 channels) has been bought to measure extra channels and for backup. The measuring system for the curved structure will be design also in the next project Impact 3. *Task completion: 100 % of the work for 2010*
4 Testing of missiles and concrete walls (Total 359 k€, 27 person moths)	
Testing of stainless steel missiles, Al missiles and 3D missiles	Stainless steel missiles and Al missiles have been tested (6).
Testing of concrete walls (150 mm)	Concrete walls, thickness of 150 mm have been manufactured and tested in 2010. (10)
Testing of pre stressed concrete walls (250 mm)	Pre stressed concrete walls thickness of 250 mm have been manufactured and tested in 2010 (4).
Testing of curved walls and/or wall-floor structures.	The curved walls and floor-wall structures will be tested at the end of the project
Reporting, documentation	Reporting has been started *Task completion: 100 % of the work for 2010*

Comments

The project, Impact 2 (Impact phase 2) with foreign partners has been started at the beginning of March 2009 and will be continue 3 years (to the end of 2011). Eight agreements for the Impact 2 project have been signed. The test matrix and the budget will be updated during each TAG meeting.

Ad Hoc and TAG meetings

Ad Hoc group has had 3 meetings in 2010 (25.1.2010, and 25.5.2010 and 25.10.2010). The next Ad Hoc meeting will be in February 2011 (4.2.2011). Impact project has had also TAG meetings and Workshops in March (9 - 11.3.2009), minTAG (unofficial) meeting in August (during SMIRT in 13.8.2009), TAG2 meeting and Workshop in December (3 - 5.12.2009), TAG3 in June (16 - 18.6.2010) and TAG4 in December (8.-10.12.2010). The Next TAG5 meeting and workshop will be in June (8.-10.6.2011).

Education of experts

Technical student Kalle Kunisto has written a thesis required for diploma with the subject of ‘Dynamical analysis of structure in impact tests’. The work is dealing with the dynamics of supporting frame used in impact tests. Surveyor of the work is Jouni Freund (TKK), tutor Ilkka Hakola. The test with heavy impact hammer has been done in December 2009. The work will be accepted in February 2011.

SAFIR2010 2.2.2011 PROGRESS REPORT 4/10

Structures Under Soft Impact (SUSI)

Duration	2007 – 2010	
Project manager	Arja Saarenheimo, VTT	
Volume in 2010 (person y.)	Plan: 1.14	Realised 1.2.2011: 1.3
Cost in 2010 (k€)	Plan: 184.1 k€	Realised 1.2.2011: 184.1 k€

Main Objectives

The aim is to develop and take in use numerical methods for predicting response of reinforced concrete structures to impacts of deformable projectiles that may contain combustible liquid ("fuel"). Structural behaviour, in terms of collapse mechanism type and the damage grade, will be predicted both by simple analytical methods and by involved non-linear FE-models. The applicability of softening factors introduced in adopting classical perforation and scabbing formulae, developed for hard missiles, will be studied further. Experimental data is needed in order to verify the accuracy of numerical models.

The aim of the liquid study is to assist the IMPACT 2010 project in planning the tests with water filled missiles besides assessing and analysing the test results. An other essential objective is the development and calibration of suitable analytical and numerical methods, which can be applied in real scale analyses of fuel spreading and fire risk. Primarily, the suitability of Fire Dynamics Simulator code (FDS) for the current issue will be further studied, and the testing and validation of the sub-models will be continued. New aim is the full-scale simulation of fuel spread and combustion following an aircraft crash by utilizing the data gained from the VTT IMPACT tests and from GRS.

Objectives in 2009	Realised
1 Task Loading function (25 k€, 2 person months)	
Existing loading function calculation procedures will be developed further. The available test data will be used for verification and testing of numerical methods. Methods for more accurate extraction of load pulses from the measured data of force transducers will be applied using the measured unit impulse results. Softening factors utilized in converting the perforation and scabbing thickness estimates from hard missile impact formulae for soft missiles impacts are studied further.	Existing load function calculation procedures were developed further. Work reported in the deliverables. Task completion: 100 %
2 Task Structural integrity (110 k€, 7,5 person months)	
Simplified methods, especially the Two Degree of Freedom model will be developed further: Rate dependency of the bending reinforcement steel will be taken into account. For FE plate models simplified stress resultant yield	TDOF method developed further. One dimensional penetration-perforation model was developed for hard missile studies. Comparative post studies were carried out with the simplified methods. Work reported in the deliverables.

condition will be studied and implemented in order to separate possible failure mechanisms more clearly. Simplified models and FE models will be used also in analyzing pre stressed concrete slabs impacted by solid missiles. The inclusion of the effect of pre-stress in the simplified models will be studied. FE analyses for some selected tests will be carried out with LS-DYNA explicit code. Firstly, the capability and accuracy of the code will be tested against experimental data. Furthermore, the effect of shear reinforcement and post-tensioning with Dywidag bars on the structural behaviour and integrity of the concrete wall will be studied. Post analyses for the impact tests will be carried out as the test program proceeds. When experimental data is gathered the role of damping will be studied in more detail.	ABAQUS analyses carried out instead of LSDYNA analyses. Post analyses are carried out, reported in a VTT Research report (R-00833). A conference paper prepared to EUROSAFE Forum 2010, in co-operation with GRS, IRSN, TUT and VTT. Two scientific papers submitted to the Journal of Disaster Research (JDR). They were reviewed, revised and published in Vol.5 No.4, 2010. Task completion: 100 %
3 Task Jet fuel dispersion outside the building (49 k€, 2,5 person months)	
The aim of the liquid study is to assist the IMPACT project in planning the tests with water filled missiles besides assessing and analyzing the test results. In 2010, the practical aspects concerning the use of Fire Dynamics Simulator code (FDS) for the evaporative high-speed sprays will be studied further. The high-speed spray validation will be continued using existing VTT data. Full-scale simulations of fuel spread and combustion following an aircraft crash in full scale will be continued in a generic power plant geometry.	Due to the observed difficulties with the stability of high-speed spray computations, an alternative route was explored – as agreed in the ad hoc –group. The thermal stress by 10 ton fuel release has been simulated using the prescribed gas-flow boundary conditions. The results are analyzed in the form of maximum survivable cable sheat thickness as a function of distance from the impact location. At the same time, the spray computations are continued to resolve the stability issues. Liquid dispersal in two new IMPACT tests no. FP16 and FP17 have been measured. Scientific article of liquid dispersal study have been submitted and accepted to Nuclear Engineering and Design. Spray computations were successfully carried out for 10 ton of kerosene. The thermal stresses and pool formation are reported. VTT Research report (R-00314) ready. Task completion: 100 %

3. Deliverables

Task	Deliverable
1.	Joint report on tasks 1 and 2
2.	Scientific article or conference paper
3.	Report on liquid dispersion studies or scientific article or conference paper

CHAllenges in Risk-Informed Safety MAnagement (CHARISMA)
Riskitietoisen turvallisuudenhallinnan haasteet

Duration	2007 – 2010	
Project manager	Lic.Tech. Ilkka Karanta, VTT	
Volume in 2010 (person y.)	Plan: 1.9 CHARISMA 1.6 ASAMPSA2 0.3	Realised 28.1.2011 1.9 CHARISMA 1.6, ASAMPSA2 0.3 (1.1.-31.12.10)
Cost in 2010 (k€)	Plan: 278.0 CHARISMA 227.6 ASAMPSA2 49.4	Realised 28.1.2011 280.9 CHARISMA 230.1 ASAMPSA2 51.8

Main Objectives

Challenges in risk-informed safety management are related to use of probabilistic safety assessment (PSA) to support decision making and to intrinsic as well as practical problems in PSA techniques. Generally, the project deals with the whole scope of risk-informed methods and application areas related to safety of nuclear power plants. The main objectives are:

- to develop risk-informed decision making methods that integrate results from risk and reliability analyses with other expertise in the problem domain
- to develop assessment methods for nuclear power plants operation and maintenance in order to enhance risk-informed ways of planning of activities and acting in safety-critical situations
- to develop methodologies in the problem areas of PSA
- to advance skills in nuclear risk analysis, assure the competence transfer to the new generation and to participate in international co-operation.

Objectives in 2010	**Realised**
1 Risk-informed decision making	
1.1 Validity of safety goals An NKS-project has been carried out in 2006–09 on risk criteria for PSA, covering both the history and experience aspects as well as development needs and guidance to define and apply risk criteria. In parallel to the Nordic project, a task of the OECD/NEA Working Group Risk (WGRISK) has been accomplished on the use of risk criteria in the member countries of OECD/NEA. In 2010, the results will be documented in a scientific journal article and will be also presented in three conference papers in PSAM10 conference. The project has been performed jointly by Scandpower AB and VTT. (VYR, VTT)	Three papers presented in PSAM10. Final draft of the final report and the Guidance document prepared. Manuscript on "Status and experience with the probabilistic risk criteria for nuclear power plants" prepared. Manuscript on "Justification of risk criteria for nuclear power plants" under preparation. *Task completion: 90 %*

2 Human reliability	
<u>2.1 Risk-informed ways of management of fire situations</u> The goal is to analyze a fire scenario in a risk relevant cable room from the human decision making and cooperation point of view. The analysis is made in collaboration with FIRAS project, by utilizing knowledge from quantitative fire research results. The long-term goal is to contribute to interdisciplinary development of a holistic fire-safety assessment at the plants. In 2010, a conference paper will be prepared on former results of the study. A scientific article will be written on the identification and analysis of Performance Shaping Factors (PSF) of fire situations. The development of modelling of operational actions for fire PSA will be continued in collaboration with the FIRAS project and the representatives of the plants. (VYR, VTT)	The paper presented in ESREL 2010. Collaboration with FIRAS project on modeling of operational actions for fire PSA completed. Manuscript of the article under preparation. *Task completion: 100 %*
<u>2.2 Emerging human reliability analysis</u> In 2010, the results from VTT's experience from the comparison study presented as a conference paper (PSAM10), and a scientific article will be prepared about the VTT's HRA approach. There is also a plan to continue the benchmark study with a new case, and VTT's aim is to participate in the continuation study. A study on usage of performance shaping factors in present HRA methods will be made, e.g., related to the quantification of human error probabilities. VTT will also participate in the Swedish-German-Finnish project EXAM-HRA whose overall objective is to provide guidance for a "state of the art" HRA for purposes of PSA to ensure that plant specific properties are properly taken into consideration in the analysis. (VYR, VTT, Halden in-kind)	Papers presented in PSAM10 and ESREL-2010. Participation in the EXAM-HRA meetings in February and March, June, October. *Task completion: 80 %*
3 Reliability of automation	

<u>3.1 Reliability of distributed control systems</u> Probabilistic risk analysis of digital control systems will be considered at the architecture level. In 2010, the theoretical properties of DFM will be explored, especially in comparison to the conventional fault tree modelling. Tentatively, a research trainee will be employed to this task.. This work will support and complement the ongoing development of a dynamic reliability analysis program at VTT (the development of the program itself is outside of CHARISMA). The computation of probabilities for top events will be analyzed both theoretically and at the implementation level. International research work in this field will be followed, e.g. the DIGREL task of OECD/NEA.	The applicability of commonly used importance measures to analyzing dynamic flowgraph methodology models has been analyzed. A short technical notice has been written and sent to referees. *Task completion: 95 %*
<u>3.2 Guidelines for reliability analysis of digital systems in PSA context</u> Work in 2010 includes a questionnaire on user needs, establishing international contacts via OECD/NEA WGRisk Digital I&C network, and vendors, meaning a preparation of a proposal for a Task within OECD/NEA WGRISK, short state-of-the art summarising Nordic experience and main international references on the subject, acquisition of demonstration/benchmark cases or existing PSA models that can be reviewed in a comparative manner during the actual project phase in 2011–12.	WGRISK activity proposal made and accepted by WGRISK, and CSNI. Activity started by contacting the task members and presenting the working plan. Tele/webmeeting arranged on December 3. Questionnaire made to WGRISK and Nordic partners. Literature collected. Working meeting held May 10 with Nordic partners. Proposal for 2011- made to Nordic PSA Group. NKS workshop organised September 14. Draft working report prepared and sent to the utilities for commenting. *Task completion: 80 %*

4 Level 2 and level 3 PSA	
4.1 Level 3 PSA In 2010, only a summary of research conducted in the research programme will be written. (VYR, VTT)	Summary Report done and sent for inspection. *Task completion: 100 %*
4.2 ASAMPSA2 (Advanced Safety Assessment Methodologies: Level 2 PSA) ASAMPSA2 is a 3-year EU-project aiming to develop best practice guidelines for the performance of Level-2 PSA methodologies with a view to harmonization at EU level and allowing a meaningful and practical uncertainty evaluation in a Level-2 PSA. In 2010, the guidance documents will be finalised. (EU, VTT)	User needs document finalised. The draft guidance document sent to end users for commenting . VTT's responsibilities are chapters on human reliability and consequences of in-vessel water injection, expert judgments. Participation in the working meetings in January 2010 and May 2010. Draft versions of VTT's chapters prepared for project group review. *Task completion: 100 % (year 2010 work)*
5 Project management, co-operation and information exchange	
5.1 Project management and information exchange (VYR, VTT)	Ad hoc meetings together with reference group 2, theme reliability of automation, held at 5.5.2010 and 31.8.10. Ad hoc meetings together with reference group 5, theme level 2 PSA, held at 22.1.2010 and 27.8.10. Participation in the planning of PSAM11 conference to be organised in Helsinki in 2012. VTT is member of the organisation committee. Proposal made to SNETP (Sustainable Nuclear Energy Technology Platform) of EU for a research plan on "safety margins and probabilistic assessment". *Task completion: 95 %*

Comments

Task 4.2 are not financed by VYR.

Education of experts

The project staff includes presently 3 post-graduate scientists and one research trainee.

SAFIR2010 31.1.2011 PROGRESS REPORT 4/10

Implementation of Quantitative Fire Risk Assessment in PSA (FIRAS)
Kvantitatiivisen paloriskiarvioinnin soveltaminen PSA-järjestelmissä

Duration	2007 – 2010	
Project manager	Simo Hostikka, VTT	
Volume in 2010 (person y.)	Plan: 0.8	Realised 13.12.2010 1.1 (137 %)
Cost in 2010 (k€)	Plan: 158	Realised 13.12.2010 207 (131 %)

NOTE: VTT provided additional funding for writing journal papers and for theimprovment of PFS-tool during the fall 2010. These tasks were originally not planned for FIRAS –project, but were managed under FIRAS for technical reasons. Therefore, both the volume and costs were clearly higher than planned.

Main Objectives

The main objectives of the project are:

1. Application of modelling of fire development and spread to fires involving cables and other fire loads found at NPPs
2. Integration of the quantitative fire risk assessment methods into the NPP PSA systems. As a novel development, the PFS on the fire scenario-development will be combined with systemic modelling of personnel actions in co-operation with the CHARISMA/SAFIR2010 project. A model for fire brigade operations will be developed and linked to PFS.
3. Carrying out fire simulations related to but outside OECD PRISME aiming to (i) guidance for the design of experiments and (ii) validation of the developed fire models.

Objectives in 2009	**Realised**
1. Fire spread modelling	
<u>1.1 Experiments providing input and validation data for fire spread simulations</u> Vertical flame spread experiments in the new 2-m test rig will be performed, focusing on NPP cables and continuing the test series performed during 2008 and 2009. A specific goal for 2010 is writing a scientific publication reporting the experimental methods and results. (VYR, VTT)	*20.5.2010* Experiments on old MCMK cable samples carried out: STA: 3 cable parts x 2 atmospheres x 2 heating rates = 12 tests Standard cone calorimeter :2 tests 2 m flame spread apparatus: 5 tests Report under preparation *10.9.2010* Report almost ready. IAFSS article on 2-m experiments and simulations under preparation. *13.12.2010* Report submitted. IAFSS article submitted for review. A journal article on flame spread tests under preparation. Task completion: 100 %
<u>1.2 Validation of the fire simulation</u> In 2010, the specific goals are solving the combustion and spreading rate problems in the cable simulations (observed in fall 2009), and the related development and maintenance of Fire Dynamics Simulator The results of the four year project will be published in the international literature. (VTT)	*20.5.2010* Modelling of the degradation reactions of PVC sheath studied in detail. Methods for the TGA estimation have been compared and the effects of different TGA parameters to the cone results were studied. *10.9.2010* PVC modelling has been studied further. IAFSS-article under preparation. (funding outside FIRAS) 2-m simulations of MCMK cables finished. Results demonstrated the importance of material model accuracy on flame spread, showing good agreement with the experimental

	results when new material model was used. *13.12.2010* Conference presentation on pyrolysis modelling of flame retardant electrical cables accepted and submitted to Fire and Materials conference 2011. Abstract submitted to Combustion Institute (Easter section) meeting 2011. Task completion: 100 %
2. Integration of quantitative fire risk assessment into NPP PSA systems	
2.1 Probabilistic fire simulation of fire risk-relevant rooms in NPPs A series of probabilistic fire simulation studies will be carried out in rooms with characteristics enabling comprehensive testing of the models. In 2010, the specific goals is the development of modelling technique for the specification of random initial fire within a complicated cable room, writing a scientific article, and related development and maintenance of Probabilistic Fire Simulator software (VYR, VTT)	*20.5.2010* Some of the 2009 cable tunnel simulations were repeated to ensure the reliability. The report for the year 2009 completed and delivered. The manuscript of a scientific article about cable tunnel fires is under preparation. The TMMC scaling method within PFS tool has been improved and tested in analytical test cases. *10.9.2010* Updated detailed model of the TVO-cable room has been created. Random burner model ready. Final details of the model are adjusted before the MC simulation. Journal article on tunnel simulations under preparation. (funding outside FIRAS) *13.12.2010* Monte Carlo –simulations of the TVO room are running. Results are expected in January 2011. *31.1.2011* Monte Carlo –simulations finished and reported. However, good results were not achieved due to the erroneous code behaviour in at least 20 % of the simulations. Task completion: 100 %
2.2 Combining simulation-based fire scenario development with systemic modelling of personnel actions The goal is a holistic fire-safety assessment methodology that combines the science-based fire characterisation to risk-informed management of fire situations. In 2009, one main control task will be analysed and the predictive model of the fire-brigade timings will be combined with the PFS tool. (VYR, VTT)	*20.5.2010* A specific ad hoc meeting concerning the fire-HRA was held at TVO 17.2.2010. The results of the meeting are being implemented in the PFS tool. *10.9.2010* Literature review on HRA methods. Updated model was used to compare with the fire-brigade's suppression probability curves (NUREG/CR-6850) in adhoc meeting 30.8.2010. *13.12.2010* Updated version of the fire-HRA method (stochastic operation time model) has been reported. Task completion: 100 %
3 International activities	
3.1 PRISME project utilisation Simulations of the PRISME experiments will be carried out. In 2010, the probabilistic fire simulation methods developed within subtask 2.1, are used to perform uncertainty analysis of PRISME experiments.	*20.5.2010* Journal article of BE#1 submitted to FSJ. Sensitivity study of PRS-SI-D1 test was performed and reported at PRISME meeting in April. A common publication will be written with IRSN and GRS participants. Samples of the cable used in PRISME INTEGRAL tests was

(VTT)	received and prepared for STA tests. *10.9.2010* PRISME article on BE#1 was submitted to NED, not FSJ. Reviewer comments received and article revised. PRISME poster on BE#2 submitted to EUROSAFE. PRISME simulations for BE#2 repeated and sent to IRSN. Presentation in Interflam conference on validation of THIEF-model using PRISME LEAK data. This attending to conference was *NOT planned* for FIRAS, but necessary because the NRC-representative could not attend. Cable STA results received and analyzed. Cable model for NYM-J cable created based on the cone tests performed at Lund University. *13.12.2010* BE#1 article in press. Travel reports submitted. *31.1.2011* BE#1 article published Task completion: 100 %
3.2 OECD PRISME project The Finnish participation fee of the OECD PRISME project (VYR)	Task completion: 100 %

Education of experts

One research trainee has worked part-time on FIRAS during the spring and fall 2010 and full-time during the summer 2010.

SAFIR2010 14.2.2011 PROGRESS REPORT 4/10

Project name in English (EXWE)
Suomenkielinen nimi Sään ääri-ilmiöt ja ydinvoimalaitokset

Duration	2007 – 2010	
Project manager	Dr Kirsti Jylhä, Finnish Meteorological Institute	
Volume in 2010 (person y.)	Plan: 1.0	Realised 1.2.2010-31.1.2011: 1,7
Cost in 2010 (k€)	Plan: 96	Realised 1.2.2010-31.1.2011: 162

Main Objectives
The primary objectives of the research were to produce a comprehensive study about the frequency, intensity, spatial and temporal variation and the impacts of the extreme weather events that are relevant from the point of safety of nuclear power plants. In the study both instrumental meteorological records, as well as, climate model simulations are utilized. The study aimed to clarify the influence of climate change on extreme weather. Sea level in the Baltic Sea were included into the study.

Objectives in 2009	**Realised**
1 Aggregation of results into a single publication	
1 Aggregation of the weather and climate extremes studies results into a single publication (4 months) (VYR, FMI)	Progress in short. The report is in preparation and addresses the following main topics: changing climate in Finland; the return levels of extreme temperature and extreme enthalpy; precipitation extremes (incl. droughts, snow cover); danger-causing weather phenomena (hail, snowstorms, freezing rain, tornadoes, down bursts); dangerous water levels in the Baltic Sea; abrupt and nonlinear climate change. About 30 papers or reports are summarized. Task completion: 100 %
2 Millenium simulations	
2 Estimation of climate extremes using millennium long climate simulations (4 months) (VYR, FMI)	Progress in short Model data analysis is almost completed, reporting under, with the focus on PDFs of 1-day and 7-day temperature extremes. Task completion: 100 %
3 Baltic Sea level	
3. Influence of climate change on Baltic Sea level (4 months) (VYR, FMI)	Progress in short. A literature review about the impacts of melting of the Greenland Ice Sheet on the spatial distribution of global sea level rise, with special emphasis on the Finnish coastline. Construction of scenarios for the mean sea level in Finland by 2100 Development of scenarios for probabilities of extreme sea level events. Task completion: 100 %

Comments

Education of experts

The project staff includes presently three PhD students (Hanna Tietäväinen, Hilppa Gregow and Milla Johansson) and three graduate students (Hilkka Pellikka, Aleksi Jokela, Miika Mäkelä).

SAFIR2010 4.3.20111 PROGRESS REPORT 4/10

Administration and information of the research programme (SAHA2010)
Tutkimusohjelman hallinto ja tiedotus

Duration	2007 – 2010 (31.3.2011)	
Project manager	Dr. Eija Karita Puska, VTT	
Volume in 2010* (person y.)	Plan: 0,95	Realised 4.3.2011 0,87
Cost in 2010* (k€)	Plan: 236,7**	Realised 4.3.2011** 195,1

* Periods: plan 1.4.2010-31.3.2011
* *with 22 % value added tax in the total VYR funding for the period 1.4.2010-31.3.2011.

Main Objectives

The programme manager, project co-ordinator and assisting staff supervise the programme by ensuring planning, follow-up, invoicing and necessary communication activities of the projects according to the instructions of the Ministry of Employment and the Economy and the decisions of the programme steering group. The administration project prepares the annual reports and plans of the programme and organises external information activities. 3-4 steering group meetings are arranged annually. The programme administration prepares the final seminar of SAFIR2010 and performs other tasks assigned by the steering group.

Objectives in 2010 (31.3.2011)	**Realised**
1 Programme administration and information (k€, person months)	
Preparation of 3-4 steering group meetings (for 2010)	1. Steering group meeting 4.6.2010 2. Steering group meeting 14.10.2010 3. Communication procedure with steering group in February 2011 for final acceptance routines created 4. Last steering group meeting 10.3.2011 prepared *Task completion:90 %*
Preparation of programme progress reports for the steering group and for the ministry	Progress report 1/10 prepared. Progress report 2/10 prepared. Progress report 3/10 prepared. Progress report 4/10 prepared *Task completion: 100 %*
Participation in the project reference group meetings and possible mini seminars	Participation in 8 out of the 8 meetings 1/10. Participation in 8 out of the 8 meetings 2/10. Participation in 8 out of the 8 meetings 3/10. Communication procedure with reference groups in February 2011 for final acceptance routines created and communications perfortmed. *Task completion: 100 %*
Participation in the ad hoc meetings (when desired by the group)	No ad hoc meetings participated. Invitations received for information. *Task completion: 0 %*
Maintenance of programme web pages	web pages being updated. *Task completion: 85 %*

Maintenance of administration, invoicing and information routines for SAFIR2010	Administration and invoicing routines maintained. Information via email and www-pages. Publication CD 2009&2010 *Task completion: 80 %*
Programme QA manual possible updates	At www-pages. No activities currently.
Programme brochure	Ready SAFIR2010-2014 brochure *Task completion: 100 %*
Preparation of annual plan 2010	Ready. At www-pages. *Task completion: 100 %*
Preparation of annual report 2009	Ready *Task completion: 100 %*
Preparation of annual report 2010	Material collected *Task completion: 80 %*
SAFIR2010 Final seminar	March 10-11, 2011 at Hanasaari, Espoo. Reservations & information & programme *Task completion 10: %*
SAFIR2010 Final seminar publications	Seminar proceedings ready *Task completion 100: %*
2 EU FP 7 activities (10,6 k€, 0,5 person months)	
Participation in the EU FP7 CCE-Fission Committee)	Participation in CCE-FI meeting on June 29, 2010 in Brussels *Task completion: 100%*
FP7 national support group	*Participation in 1st meeting 2010* *Task completion: 100 %*

Comments

Education of experts

Appendix 2

Publications of the projects in 2010

Expert Work in Safety Critical Environment (SafeExpertNet):

Scientific publications

Leppänen A. Pahkin K et al.: Asiantuntemus ja sen kehittyminen ydinvoimaympäristössä. (Työ ja Ihminen, 2010)

Mäki E., Kuronen-Mattila T. & Järvenpää E.: Asiantuntijaverkostot: tutkimus Suomen ydinvoima-alalta. (Työ ja Ihminen, 2010)

Pahkin K, Leppänen A, & Järvenpää E.: Osaamisen kehittämisen käytännöt ja haasteet ydinvoima-alan asiantuntijaorganisaatiossa. (Työ ja Ihminen, 2010)

Kuronen-Mattila T., Mäki E. & Järvenpää E. (2011): Collaboration between experts -– Case Finnish Nuclear Power Industry. To be submitted to International Journal of Nuclear Knowledge Management at the end of January 2011.

Conference papers

Pahkin K, et al: "*Supporting expertise in nuclear organizations.* Presentation in the IAEA International Conference on Human Resource Development for Introducing and Expanding Nuclear Power Programmes 14-18 March 2010, Abu Dhabi, UAE

Pahkin K et al: "*Development of a survey for expert work in safety critical environment* ". Presentation at the European Academy of Occupational Health Psychology (EA-OHP) 29-31 March 2010, Rome, Italy

Kuronen-Mattila, T. (2010): Tacit knowledge in nuclear power plants: content, characteristics and sharing International conference on Intellectual Capital, Knowledge Management & Organizational Learning, 11-12 November, Hong Kong

Mäki, E., Kuronen-Mattila, T., Pahkin, K., Järvenpää, E., and Leppänen, A.: Project summary reports (a report on the SafeExpertNet project). Lähetetty SAFIR2010 -loppuseminaariin.

Pahkin, K., Leppänen, A., Mäki, E., Kuronen-Mattila, T. and Järvenpää, E.: Supervisor's role in knowledge management and expertise development. Lähetetty SAFIR2010 -loppuseminaariin.

Pahkin, K., Leppänen, A., Kuronen-Mattila, T, Mäki, E., Järvenpää, E.: The practices and challenges of developing knowledge in nuclear industry organizations. Abstrakti lähetetty NESTet 2011 education and training Nuclear Engineering Science and Technology Prague, Czech Republic 15 -18 May 2011 kongressiin.

Mäki, E., Kuronen-Mattila, T., Pahkin, K., Järvenpää, E., Leppänen, A. Expertise development in the nuclear power industry – beyond formal training and education. Abstrakti lähetetty NESTet 2011 education and training Nuclear Engineering Science and Technology Prague, Czech Republic 15 -18 May 2011 kongressiin.

Research institute reports

Avaimia asiantuntijuuteen - opaskirja ydinvoima-alan organisaatioissa työskenteleville asiantuntijoille ja heidän esimiehilleen. (The good practice handbook on ways to support development of expertise.) Työterveyslaitos and Aalto-yliopisto 2010.

Kuronen-Mattila T. (2010): Tacit knowledge in nuclear power plants: The content, characteristics, and prerequisites for sharing. Licenciate's Thesis. Espoo: Aalto University.

Pahkin K., Kuronen-Mattila T., Mäki E., Leppänen A, ja Järvenpää E. (2011): Asiantuntijatyö turvallisuuskriittisessä ympäristössä SafeExpertnet 2007-2010. Työterveyslaitos, Helsinki 2011. (myös PDF)

Others

Five organizational level reports based on the results of the questionnaire survey (+18 department level results)

Mäki E. Hiljaa hyvä tulee, hiljaisella tiedolla vielä parempi. HETKY 5/2010.

Pahkin K, Kuronen-Mattila T ja Mäki E. Avoimuus auttaa toimimaan turvallisemmin. ALARA 4/2010.

Mäki E., Kuronen-Mattila T. & Pahkin K.: Tieto kasvaa jakamalla. ATS Ydintekniikka 2010.

Safety management and organizational learning (MANOR):

Scientific articles

Reiman, T. (In press). Understanding maintenance work in safety-critical organizations – managing the performance variability. *Theoretical Issues in Ergonomics Science*.

Pietikäinen, E., Oedewald, P., Haavisto, M-L-, Reiman, T., Ruuhilehto, K., Heikkilä, J. (2010). Pyrkivätkö turvallisuuskriittiset organisaatiot oppimaan kokemuksistaan ? Kokemustiedon käsittelyä ohjaavat oletukset ydinvoimateollisuudessa ja terveydenhuollossa. *Työelämän tutkimus – Arbetslivsforskning*, 8, 279-290.

Reiman, T. & Rollenhagen, C. (submitted). Human and organisational biases affecting the management of safety.

Conference papers

Reiman, T. & Rollenhagen, C. (2010). Identifying the typical biases and their significance in the current safety management approaches. 10th International Probabilistic Safety Assessment & Management Conference, 7-11 June 2010, Seattle, USA.

Reiman, T. & Pietikäinen, E. (2010). Leading indicators of system safety – monitoring and driving the organizational safety potential. The 5th International Conference Workingonsafety.net, 7-10 September 2010, Røros, Norway.

Research institute reports

Oedewald, P., Reiman, T., Pietikäinen, E., Macchi, L. & Gotcheva, N. (to be published in VTT publication series). Safety management, safety culture and organisational learning in the nuclear industry.

Reiman, T., Pietikäinen, E., Kahlbom, U. & Rollenhagen, C. (2010). Safety Culture in the Finnish and Swedish Nuclear Industries – History and Present. NKS-213. NKS, Roskilde, Denmark.

Others

Oedewald, P., Reiman, T. & Pietikäinen, E. (2010). Turvallisuuskulttuuria voi arvioida ja kehittää. Alara 4/2010.

Model-based safety evaluation of automation systems (MODSAFE):

Conference papers

K. Björkman, J. Valkonen, J. Ranta, Verification of Automated Changeover Switching Unit by Model Checking, Proceedings of the 7th International Topical Meeting on Nuclear Plant Instrumentation, Control and Human-Machine Interface Technologies (NPIC&HMIT 2010), November 7-11, 2010, Las Vegas, Nevada, 1719-1728

J. Lahtinen, J. Valkonen, K. Björkman, J. Frits, I. Niemelä, Model checking methodology for supporting safety critical software development and verification, European Safety and Reliability Conference, ESREL2010. Rhodes, Greece, 5 – 9 Sept. 2010. Reliability, Risk and Safety – Back to the Future. Ale, Papazoglou & Zio (Eds). European Safety and Reliability Association, ESRA. London (2010), 2056–2063

J. Valkonen, K. Björkman, J. Frits, I. Niemelä, Model checking methodology for verification of safety logics, SIAS 2010 - The 6th International Conference on Safety of Industrial Automated Systems. Tampere, 14.-15.6.2010, SIAS 2010 Proceedings. Suomen Automaatioseura (2010), 6 p.

Research institute reports

Lahtinen, J., Björkman, K., Valkonen, J., Frits, J., & Niemelä, I. Analysis of an emergency diesel generator control system by compositional model checking – MODSAFE 2010 work report, VTT Working Papers 156, VTT 2010, Espoo, 35 p. http://www.vtt.fi/inf/pdf/workingpapers/2010/W156.pdf.

Björkman, K., Valkonen, J. & Ranta, J., Model-based analysis of an automated changeover switching unit for a busbar – MODSAFE 2009 work report, VTT Working Papers, VTT Espoo, 25 p.

Others

Pakonen, Antti; Valkonen, Janne, Mallintarkistus löytää piilevät automaation suunnitteluvirheet
Automaatioväylä. Automaatioväylä Oy (2010) No: 7, 16 – 17

Valkonen, Janne; Niemelä, Ilkka, Turvallisuuskriittisten järjestelmien verifiointi mallintarkastuksella
ATS Ydintekniikka . Vol. 39 (2010) No: 1, 6 – 8

Certification facilities for software (CERFAS):

Scientific publications

Nevalainen, R., Halminen, J., Harju, H., Johansson, M. Certification of software in safety-critical I&C systems of nuclear power plants. VTT, TVO and TUCS. In book: "Nuclear Power", ISBN 978-953-307-110-7 published by Sciyo.

Johansson, M., Nevalainen, R. Additional Requirements for Process Assessment in Safety-Critical Software and System Domain. Journal of Software Maintenance and Evolution: Research and Practice, incorporating Software Process: Improvement and Practice. Special Issue Paper JSME-10-0051, 14.5.2010.

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Lahtinen, J., Ranta, J., Harju, H., Johansson, M., Nevalainen, R. Comparison between IEC 60880 and IEC 61508 for Certification Purposes in the Nuclear Domain. VTT and TUCS, SAFECOMP'2010, Vienna, Sep. 14 – 17, 2010.

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Harju, H., Lahtinen, J. Safety Case Templates. Category A Software. SAFIR 2010, CERFAS-project. VTT-R-10277-10, 2010, 47 p.

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Operator practices and human-system interfaces in computer-based control stations (O'PRACTICE):

Conference papers

Filippi, G., Norros, L. , Pirus, D., Dionis,F. & Henry, N. 2010. MMOTION project, the European Project for defining the EU research roadmap on HF, I&C and HSI for NPPs. 7th International Topical Meeting on Nuclear Plant Instrumentation, Control and Human Machine Interface Technologies (NPIC & HMIT 2010) Las Vegas, Nevada, USA – November 7-11, 2010.

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Research institute reports

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Laarni, J., Norros, L., Savioja, P., Aaltonen, I., Karvonen, H., Koskinen, H., Liinasuo, M. & Salo, L. (2011). Suuntaviivoja valvomosuunnitteluun. VTT-R-00807-11.

Norros, L., Savioja, P., Liinasuo, M., Karvonen, H., Laarni, J., Aaltonen, I., Koskinen, H. & Salo, L. (2011). O'PRACTICE: Contextual Assessment of Systems Usability – Description of the method. VTT-R-00803-11.

Others

Automaatioseura. 2010. Valvomo - Suunnittelun periaatteet ja käytännöt (The control room - principles and practices of design). Helsinki: Suomen Automaatioseura ry. (Chapters 5-6, s. 54-98, by Norros, L. & Savioja, P.).

Laarni, J. & Norros, L. Liinasuo M. & Savioja, P. 2010. Muuttuva operointikonsepti ja ammattikuva - mikä muuttuu operaattorityössä käyttöliittymien digitalisoinnin myötä? ATS Ydintekniikka, 1/2010, 9-11.

Norros, L., Savioja, P. & Salo, L. 2010. Activity analysis in the evaluation of the usability of complex systems. In: Nordic Conference on Activity Theory and the Fourth Finnish Conference on Cultural and Activity Research, May 23-25, 2010, Helsinki. (abstract).

Norros, L., Savioja, P. & Salo, L. 2010. Using emergency operating procedures in NPP process control. Post-ISSNP2010 International Workshop on Advanced Methodologies and Practices for Nuclear Safety & Simulation. August 26-27, 2010. NCST/HEU (abstract).

Requirements Engineering in Nuclear Power Plant Automation (VAHAYA):

Others

Raatikainen, M., Männistö, T., Tommila, T., Valkonen, J. Requirements Engineering in Nuclear Power Plant Automation. VAHAYA final report. (in Finnish), 2011

Development and Validation of Fuel Performance Codes (POKEVA):

Conference paper

Klecka, L. An Enhanced Radial Power Profile Model for the ENIGMA Code. Paper presented at the Enlarged Halden Project Programme Group Meeting. Storefjell Resort Hotel, Norway 14 to 19 March 2010. OECD NEA 2010. 11 p

Research institute reports

Tulkki, V. Simulations of FUMEX III Inter-Ramp cases. VTT Project Report VTT-R-01546-10. 7.5.2010 37 p.

Arffman, A. Applications of the SCANAIR code for the simulation and interpretation of reactivity initiated accidents. VTT Project Report VTT-R-03691-10, 24.5.2010. 85 p.

Arffman, A. Statistical Evaluation of Nuclear Fuel Failure Rate in Accident Conditions: System Description. VTT Project Report VTT-R-06753-10, 31.8.2010. 12 p + App. 4p.

Rintala, J. Statistical Evaluation of Nuclear Fuel Failure Rate in Accident Conditions: Users' Manual. VTT Project Report VTT-R-06817-10, 13.9.2010. 5 p.

Stengård, J-O. A modified version of the fuel performance code FRAPCON-3.4. VTT Project Report VTT-R-06825-10, 7.10.2010. 15 p.

Klecka, L. HRP Lift-off Experiment Summary and Modelling with ENIGMA Code Part 1. VTT Project Report VTT-R-09939-10, 31.12.2010. 54 p.

Klecka, L. ENIGMA Code Adjustment for the Overpressure Modelling. VTT Project Report VTT-R-10189-10, 31.12.2010.   p.

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Tridimensional core transient analysis methods (TRICOT):

Conference papers

Hovi V. & Ilvonen M. 3D PORFLO simulations of Loviisa steam generator. AER Symposium, Espoo Hanasaari, September 20-24 , 2010

Rintala, J. Validation of new 3-D neutronics model in APROS for hexagonal geometry. AER Symposium, Espoo Hanasaari, September 20-24, 2010.

Syrjälahti E. & Hämäläinen A. Sensitivity studies for the main steam line break in the Loviisa NPP with the HEXTRAN-SMABRE. PHYSOR 2010, Pittsburgh, Pennsylvania, USA, May 9-14, 2010. on CD-ROM, American Nuclear Society, LaGrange Park, IL (2010)

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Räty H. User's manual for reactor dynamics codes TRAB-3D and HEXTRAN, Revision 1. Research report VTT-R-04724-07 Rev.1. 155 p. 24.3.2010.

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Takasuo E., Hovi V., Ilvonen M.: PORFLO code development status and user instructions 2010. Research Report VTT-R-00446-11. 25 p./2 app. 24.1.2011.

Others

Proceedings of the twentieth Symposium of AER. Hanasaari, Espoo, September 20-24, 2010. ISBN 978-963-372-643-3.

Total reactor physics analysis system (TOPAS):

Scientific publications

Pusa, M. and Leppänen, J., Computing the Matrix Exponential in Burnup Calculations. Nuclear Science and Engineering 164 (2010), 140-150.

Leppänen, J., Performance of Woodcock delta-tracking in lattice physics applications using the Serpent Monte Carlo reactor physics burnup calculation code. Annals of Nuclear Energy 37 (2010), 715-722.

Rantamäki, K.M., Holopainen, S. and Anttila, M., Comparison of CASMO-4E to CASMO-4. In preparation (to be submitted to Annals of Nuclear Energy).

Pusa, M., Rational Approximations to the Matrix Exponential in Burnup Calculations. Submitted to Nuclear Science and Engineering.

Fridman, E. and Leppänen, J., On the use of the Serpent Monte Carlo code for few-group cross section generation. Submitted to Annals of Nuclear Energy.

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Viitanen, T. and Leppänen, J., New data processing features in the Serpent Monte Carlo code. International Conference on Nuclear Data for Science and Technology 2010. April 26-30, 2010, Jeju Island, Korea.

Leppänen, J., HTGR Modelling Capabilities in the Serpent Monte Carlo Code. International Youth Nuclear Congress (IYNC-2010). July 12-18, 2010, Cape Town, South Africa.

Leppänen, J., Use of serpent Monte Carlo Reactor Physics Code for Full-Core Calculations. Joint International Conference on Supercomputing in Nuclear Applications and Monte Carlo 2010 (SNA + MC2010). October 17-21, 2010, Tokyo, Japan.

Research institute reports

Leppänen, J., Serpent Progress Report 2009. VTT-R-01296-10. 12 p.

Räty, A., Covariance Data in NJOY. VTT-R-04160-10. 26 p.

Rantamäki, K., MAMBO: laskentapaketti tasapainolatauksen hakemiseen ja analysointiin. VTT-R-02358-10. 35 p.

Numerical modeling of condensation pool (NUMPOOL):

Conference papers

Pättikangas, T.J.H., Niemi, J., Laine, J., Puustinen, M. and Purhonen, H., CFD modelling of condensation of vapour in the pressurised PPOOLEX facility. CFD4NRS-3, Experimental Validation and Application of CFD and CMFD Codes to Nuclear Reactor Safety Issues, OECD/NEA & IAEA Workshop, Washington D.C., USA, 14–16 September 2010, 12 p. (2010).

Research institute reports

Pättikangas, T., Niemi, J. and Timperi A., Numerical modelling of pressure suppression pools with CFD and FEM codes. Research Report VTT-R-00927-11, VTT Technical Research Centre of Finland, Espoo (2011).

Improved Thermal Hydraulic Analysis of Nuclear Reactor and Containment (THARE):

Conference papers

Karppinen I., Hillberg S., Inkinen P., Lauerma S., Luukka J., Kurki J., Silde A., Huhtanen R. Improved thermal hydraulic analyses of nuclear reactor and containment, THARE summary report in “SAFIR2010 The Finnish Research Programme on Nuclear Power Plant Safety 2007-2010”, Final Report, Eija-Karita Puska (Ed.), Helsinki 2011, VTT Research Notes, to be published.

Huhtanen R., Silde A. Steam and helium mixture with a containment cooler, simulation of Panda facility experiment ST4-1. SAFIR2010, Final Report, Eija-Karita Puska (Ed.), Helsinki 2011, VTT Research Notes, to be published.

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Lauerma S. Validation of APROS with ISP-12, BWR SBLOCA in ROSA-III test facility, Espoo 2011, VTT-R-00837-11

Inkinen P. Modelling of ROCOM facility with APROS and TRACE. Espoo 2011. VTT-R-00751-11

Inkinen P. Simulation of ISP-50 with APROS. Espoo 2011. VTT-R-00749-11

Huhtanen R. Steam and helium mixture with a containment cooler, CFD simulation of Panda facility experiment ST4.1 VTT-R-00835-11

Silde A. Simulation of experiment ST4-1 at PANDA facility with tube-bundle cooler using the APROS containment code. VTT-R-00834-11

Luukka J. Modeling of water pool stratification in POOLEX and PPOOLEX experiments with APROS Containment, Espoo 2011, VTT-R-00810-11

Others

Karppinen I.: OECD/PKL-2 Programme review Group meeting, Pisa, Italy, 26-27.4.2010, travel report (*In Finnish*).

Karppinen I.: Annual meeting of the OECD/NEA/CSNI/GAMA (Working Group on Analysis and Management of Accidents), Paris, 21-24.9.2009, travel report (*In Finnish*).

CFD modelling of NPP horizontal and vertical steam generators (SGEN):

Conference papers

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Rämä, T. and Peltokorpi, L., Simulation of the high pressure feedwater preheaters isolation transient. Report FNS-TERMO-202, 22 p., 2011.

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Kouhia, V., Kyrki-Rajamäki, R., Purhonen, H. Rantakaulio, A., Riikonen, V., Räsänen, A., New possibilities to simulate vertical steam generators with integral facility PWR PACTEL, ENC2010, 31 May -03 June 2010, Barcelona, Spain, (paper in poster session).

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Others

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Others

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Kouhia, V., Simulation of Experiments on Start of Natural Circulation and Long Term Cooling. Research Report, Lappeenranta University of Technology, Nuclear Safety Research Unit, PASSIMU 1/2010. Ylöjärvi, 28.1.2010.

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OpenFOAM CFD-solver for nuclear safety related flow simulations (NuFOAM):

Research institute reports

Toppila, T., Validation plan of OpenFOAM for nuclear safety analysis.

Brockmann, Tomas, Calculation of the OECD/NEA T-junction benchmark with OpenFOAM.

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A. Matala, C. Lautenberger, S. Hostikka, A new method for estimation of pyrolysis kinetics and comparison to existing methods. 7th US National Meeting of Combustion Institute, March 20-23, 2011, Georgia Institute of Technology, USA.

Submitted scientific publications

Matala, A. & Hostikka, S. Probabilistic simulation of cable performance and water based protection in cable tunnel fires. Submitted to Nuclear ngineering and Design.

Extreme weather and nuclear power plants (EXWE):

Scientific publications

Jylhä, K., Tuomenvirta, H., Ruosteenoja, K., Niemi-Hugaerts, H., Keisu, K. and Karhu, J.A., 2010. Observed and projected future shifts of climatic zones in Europe, and their use to visualize climate change information. Weather, Climate, and Society, 2: 148-167
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Ruosteenoja, K., Räisänen, J. and Pirinen, P., 2010. Projected changes in thermal seasons and the growing season in Finland. International Journal of Climatology, n/a. doi: 10.1002/joc.2171

Spangenberg, J., Carter, T., Fronzek, S., Jaeger, J., Jylhä, K., Kühn, I., Omann, I., Paul, A., Reginster, I., Rounsevell, M., Schweiger, O., Stocker, A., Sykes, M., Settele, J. Scenarios for investigating risks to biodiversity. Global Ecology and Biogeography, accepted.

Ylhäisi, J.S., Tietäväinen, H., Peltonen-Sainio, P., Venäläinen, A., Eklund, J., Räisänen, J. and Jylhä, K., 2010. Growing season precipitation in Finland under recent and projected climate. Nat. Hazards Earth Syst. Sci., doi:10.5194/nhess-10-1563-2010.

Conference papers

Jylhä, K. and Jokinen, P., 2010. Climatic zones in Europe as a dissemination tool of climate change information. Conference on Future Climate and Renewable Energy: Impacts, Risks and Adaptation, 31 May - 2 June 2010; Conference proceedings, p. 102-103. poster PDF-tiedosto (6354 kt)

Rauhala J., Juga I., 2010: Wind and Snow Storm Impacts on Society. SIRWEC, International Road Weather Conference 5-7.2.2010, Canada, 8 pp.

Tietäväinen, H., Ylhäisi, J. and Jylhä, K., 2010. Summertime Precipitation in Finland under Recent and Projected Climate. Conference on Future Climate and Renewable Energy: Impacts, Risks and Adaptation, 31 May - 2 June 2010; Conference proceedings, p. 26-27.

Research institute reports

Molarius, R., Keränen, J., Jylhä, K., Sarlin, T. & Laitila, A., 2010. Suomen elintarviketuotannon turvallisuuden haasteita muuttuvissa ilmasto-olosuhteissa, VTT Tutkimusraportti: VTT-R-2672-10, 82 s. + liitt. 51 s. PDF-tiedosto (6613 kt)

Saku S., Solantie R., Jylhä K., Valta, H. & Venäläinen A., 2011: Äärilämpötilojen alueellinen vaihtelu Suomessa (Spatial variations of extreme temperatures in Finland). Ilmatieteen laitos, Reports 2011:1.

Salanne, I., Byring, B., Valli, R., Tikkanen, M., Peltonen, P., Haapala, J., Jylhä, K., Tolonen-Kivimäki, O. & Tuomenvirta, H., 2010. Ilmastonmuutos ja tavaraliikenne. Liikenne- ja viestintäministeriön julkaisuja 15/2010. ISBN 978-952-243-159-2 (verkkojulkaisu).

Perrels, A., Tuovinen, T., Veijalainen, N., Jylhä, K., Aaltonen, J. Molarius, R., Porthin, M., Silander, J. & Rosqvist, T., 2010: The implications of climate change for extreme weather events and their socio-economic consequences in Finland. VATT Research Reports 158/2010, 133 p.

Venäläinen A, Johansson M, Kersalo J, Gregow H, Jylhä K, Ruosteenoja K, Neitiniemi-Upola L, Tietäväinen H, Pimenoff N, 2010: Pääkaupunginseudun ilmastotietoja ja -skenaarioita. Teoksessa: Pääkaupunkiseudun ilmasto muuttuu. Sopeutumisstrategian taustaselvityksiä. HSY Helsingin seudun ympäristöpalvelut, HSY:n julkaisuja 3/2010, s. 12-35. ISBN (nid.) 978-952-6604-04-6, ISBN (pdf) 978-952-6604-05-3.

Others

Fronzek, S., Carter, T.R., and K. Jylhä, 2010: Scenarios of climate change for Europe. In Settele J., Penev L., Georgiev T., Grabaum R., Grobelnik V., Hammen V., Klotz S., Kotarac M. & Kuhn I., (eds): Atlas of Biodiversity Risk. Pensoft Publishers. ISBN 978-954-642-446-4. 68-71.

Johansson M., Kahma K., Pellikka H., 2010: Meriveden pinnankorkeuden skenaariot ja lyhytaikaisvaihtelut (in Finnish). Ilmatieteen laitos, 17 pp.

Johansson M., Kahma K., Pellikka H., 2011: Meriveden pinnankorkeuden ja lyhytaikaisvaihteluiden skenaariot Suomen rannikolla (in Finnish). Ilmatieteen laitos.

Jokela, A., 2011: Sään ääri-ilmiöt luonnollista vaihtelua kuvaavassa 1200-vuotisessa ilmastokokeessa. Pro Gradu -tutkielma (Master's Thesis). Helsingin yliopisto. (Valmisteilla)

Jylhä, K., Carter, T.R., and Carter, T.R., 2010: Current climatic conditions and observed trends in Europe. In Settele J., Penev L., Georgiev T., Grabaum R., Grobelnik V., Hammen V., Klotz S., Kotarac M. & Kuhn I., (eds): Atlas of Biodiversity Risk. Pensoft Publishers. ISBN 978-954-642-446-4. 66-67.

SAFIR2010 Administration and information (SAHA):

Puska, E.K. & Suolanen, V., SAFIR2010 Annual Plan 2010, VTT Research Report VTT-R-03666-10. 37 p + app. 203 p.

Puska, E.K. & Suolanen, V., SAFIR2010 Annual Report 2010, VTT Research Report VTT-R-00818-12. 108 p. + app.

Puska, E.K. & Suolanen, V., SAFIR2010, The Finnish Research Programme on Nuclear Power Plant Safety 2007-2010, Final Report. VTT Research Notes 2571. Espoo, Technical Research Centre of Finland (VTT), 578 p. ISBN 978-951-38-7689-0; ISSN 1235-0605.

Appendix 3

Finnish members in international committees and working groups in 2010

OECD/Nuclear Energy Agency

Committee on Nuclear Regulatory Activities (CNRA), J. Laaksonen STUK , P. Tiippana, STUK

* Working Group on Inspection Practices, J. Kupila, STUK
* (CNRA/CSNI) Task Group on Safety Performance Indicators, S. Suksi, STUK
* Task Group on Regulatory Effectiveness Indicators, K. Koskinen, STUK
* Working Group on Operating Experience (WGOE), J. Turpeinen, Loviisa NPP, S. Suksi, STUK

Committee on the Safety of Nuclear Installations (CSNI) T. Vanttola, VTT, K. Valtonen, STUK

* Working Group on Risk Assessment, Jan-Erik Holmberg, VTT, R. Virolainen, STUK
* Working Group on Analysis and Management of Accidents, I. Karppinen, VTT, N. Lahtinen, STUK
* Working Group on Integrity and Ageing of Components and Structures, P. Varpasuo, Fortum Nuclear Services, R. Keskinen, STUK
* Group on Integrity of Metal Components and Structures, J. Solin, VTT, R. Keskinen, STUK
* Subgroup Group on Ageing of Concrete Structures, E. Vesikari, VTT
* Subgroup Seismic Behaviour, P. Varpasuo, FNS
* Working Group on Human and Organisatorial Factors (WGHOF), L. Norros, VTT, K. Levä, STUK
* Working Group on Fuel Safety (WGFS), R. Sairanen, STUK, S. Kelppe, VTT

Committee on Radiation Protection and Public Health (CRPPH), O. Vilkamo, STUK

Nuclear Development Committee (NDC), J. Aurela, TEM, H. Tuomisto, Fortum

Nuclear Science Committee (NSC), A. Daavittila, VTT, R. Mattila, STUK

* Working Party on Scientific Issues of Reactor Systems (WPRS), A. Daavittila, VTT, J. Leppänen, VTT
* Working Party for Nuclear Criticality Safety, R. Mattila, STUK , A. Ranta-aho, TVO

* Working Party on Scientific Issues of Fuel Cycle (WPFC), A. Daavittila, VTT

* Working Party on Multi-scale Modeling of Fuels and Structural Materials for Nuclear Systems, WPMM, T. Planman, VTT

Information System on Occupational Exposure (ISOE), V. Riihiluoma, STUK

NEA Projects

CABRI Water Loop Project 2000–2010. Umbrella Agreement with OECD, bilateral Agreement with IRSN; jointly with Fortum Power and Heat Oy and Teollisuuden Voima Oy. K. Valtonen STUK (Steering Committee), S Kelppe VTT (Technical Advisory Group)

Halden Reactor Project, Management Board, K. Valtonen, STUK, Halden Programme Group, O. Ventä, T. Vanttola, VTT

* *Irradiation Assisted Stress Corrosion Cracking,* W. Karlsen, VTT
* *Fuel performance analysis,* S. Kelppe, VTT
* *Reliability of software based control systems,* J. Hämäläinen, VTT
* *Integrated system validation, Innovative Displays,* L. Norros & P. Savioja, VTT

SCIP Project on Fuel Integrity (ended 6/2010)

* Management Board, J. Halinen, Fortum Nuclear Services

* Programme Review Group, S. Kelppe, VTT

SCIP II Project on Fuel Integrity (2009-2014)

* Management Board, A. Knuutila, TVO, deputy J. Halinen, Fortum Nuclear Services

* Programme Review Group, L. Klecka, VTT, deputy S. Tähtinen VTT

ROSA-2 Project on Thermal Hydraulic Transients, I. Karppinen, VTT, E. Virtanen, STUK

PKL-2 Project on PWR Thermal Hydraulics, Boron Dilution, I. Karppinen, VTT, E. Virtanen, STUK

SETH-2 Project on Containment, Management Board, E. Virtanen, STUK, Programme Review Group I. Karppinen, VTT

MCCI-2 Project on Severe Accidents (ex-vessel), Management Board, Programme Review Group, T. Sevón, VTT

SERENA-2 Project on Steam Explosions, Management Board, T. Routamo, STUK, Programme Review Group, I. Lindholm, VTT

THAI Project on Thermal-hydraulics, Hydrogen, Aerosols, Iodine, E. Takasuo, VTT, M. Tuomainen, STUK

BIP Project on Behaviour of Iodine, T. Kekki, VTT, R. Sairanen, STUK

PRISME Project on Fire Propagation

* Management Board, S. Hostikka (Chairman), VTT, J. Marttila (member), STUK

* Programme Review Group, S. Hostikka, VTT

COMPSIS Project, Database on computerised system events, H. Takala, STUK

FIRE Project, Database on Fire Events

* Project Review Group, J. Marttila, STUK, M. Lehto, STUK, J. Pesonen, TVO, Tunturivuori, TVO, K. Jänkälä Fortum Nuclear Services, Siren, Fortum Nuclear Services

ICDE Project, Database on Common-Cause Failure Data Exchange, K. Jänkälä, Fortum Nuclear Services, J. Pesonen, TVO, R. Virolainen, STUK

OPDE Project, Database on Piping Failures, R. Keskinen, STUK, K. Simola, VTT

Stress Corrosion Cracking (SCC) and Cable Ageing Project (SCAP), K. Wahlström, STUK, R. Keskinen, STUK

Generation IV International Forum (GIF)

Risk and Safety Working Group (RSWG), A. Daavittila, VTT

Economic Modelling Working Group (EMWG), R. Tarjanne, LTY

Senior regulators' Working Group, J. Laaksonen, STUK

International Atomic Energy Agency

Nuclear Safety Standards Committee, L. Reiman, STUK

International Nuclear Event Scale (INES), K. Tossavainen, STUK

Incident Reporting System (IRS), T. Eurasto, STUK

Incident Reporting System for Research Reactors (IRSRR), K. Alm-Lytz, STUK

Technical Working Group on NPP Instrumentation and Control (TWG-NPPI&C), J. Valkonen, VTT

Co-ordinated Research Projects

- *International Working Group of Life Management of Nuclear Power Plants (IWG-LMNPP)*, T. Planman, VTT
- *Optimisation of Water Chemistry to ensure Reliable Water Reactor Fuel Performance at High Burnup and in Ageing Plant (FUWAC) 2006-2010*, P. Kinnunen, VTT
- *CRP Coordinated Research Programme "Assuring Structural Integrity of Reactor Pressure Vessels"*, T. Planman, VTT
- *CRP Coordinated Research Programme "Advanced, Surveillance, Diagnostics, and Prosnostics Techniques Used for Health Monitoring of Systems, Structures, and Components in Nuclear Power Plants", A. Koskinen, VTT*
- *CRP FUMEX II; Coordinated Research Programme on "Improvement of models used for fuel behaviour simulation"*, S. Kelppe VTT
- *International Working Group on Water Reactor Performance and Technology (IWGFPT)*, R. Teräsvirta, Fortum Nuclear Services, S. Kelppe, VTT

Commission of the European Communities

DG Research

- *JRC Board of Governers*, Erkki KM Leppävuori, VTT
- *Networks coordinated by JRC/IE*, R. Rintamaa, VTT
- *European Network for Ageing Materials Evaluation & Studies (AMES)*,
  T. Planman, VTT, J. Kohopää, Fortum Nuclear Services
- *European Network for Inspection Qualification (ENIQ) Steering committee*, K. Hukkanen, TVO
- *European Network for Inspection Qualification (ENIQ) TGR, ENIQ task group for Risks*, K. Simola VTT

Scientific and Technical Committee Euratom (STC), R. Salomaa, TKK

QA group of the ENEN-Association (European Nuclear Education Network), Chair, R. Salomaa

European Working Group on Reactor Dosimetry (EWGRD), T. Serén, VTT

Nuclear Fission Safety in the Seventh Framework Programme

Consultative Committee Euratom-Fission (CCE-Fission), J. Aurela and A. Väätäinen, TEM

Western European Nuclear Regulators Association (WENRA)

* *Task Force on Safety Critical Software – Licensing Issues,* P. Suvanto and M. Koskela, STUK

Group of Experts under Article 31 of the Euratom Treaty, O. Vilkamo, STUK

Group of Experts under Article 37 of the Euratom Treaty, O. Vilkamo, STUK, L. Pöllänen, STUK

JRC-Ispra-ISID, Reactor Safety Programme Users Advisory Board (RSPUAB), R. Virolainen, STUK

Phebus FP Project, A. Auvinen, T. Kärkelä VTT

* Scientific analysis working group (SAWG).
* Bundle interpretation circle (BIC).
* Circuit and containment interpretation circle (CACIC).
* Containment chemistry interpretation circle (CCIC).

SARNET-2, Governing Board, I. Lindholm, VTT

* Management: Severe Accident Research Priorities WP1.3, I. Lindholm VTT

* Corium and Debris Coolability WP5, I. Lindholm, E. Takasuo VTT

* Molten Coriun Concrete Interaction WP6, T. Sevón VTT

* Containment WP7, I. Lindholm, I. Karppinen VTT

* Source Term WP8 A. Auvinen, T. Kärkelä VTT

NURISP, Governing Board, E.K. Puska, VTT, R. Kyrki-Rajamäki, LUT

* SP2: Thermal Hydraulics, M. Ilvonen, VTT, V. Tanskanen, LUT

Euratom Fusion Programme in the 7th Framework Programme

Consultative Committee for the Euratom Specific Research and Training Programme in the Field of Nuclear Energy – Fusion (CCE-FU), S. Karttunen, VTT, R. Munther, Tekes, Juha Lindén, Tekes

European Fusion Development Agreement (EFDA) Steering Committee, S. Karttunen, VTT, J. Lindén, Tekes

Science and Technology Advisory Committee (STAC), R. Salomaa, Aalto/TKK

The European Joint Undertaking for ITER and the Development of Fusion Energy ("Fusion for Energy – F4E", Governing Board, S. Karttunen, VTT, Juha Lindén, Tekes

The European Joint Undertaking for ITER and the Development of Fusion Energy ("Fusion for Energy – F4E", Executive Committee, K. Törrönen, Energywave Ltd

IEA Fusion Power Co-ordinating Committee (FPCC), S. Karttunen, VTT, R. Munther, Tekes

Programme Committee of the ASDEX-Upgrade, Max Planck Gesellschaft, T. Kurki-Suonio, Aalto/TKK.

Steering Committee of the Association Euratom-Tekes, S. Karttunen, VTT, R. Munther, Tekes, H. Tuomisto, Fortum and (D. Bartlett, V. Marchese, M. Pipeleers, EU Commission)

Cooperation on VVER Reactor Physics and Dynamics (AER)

Scientific council, H. Räty, VTT, M. Antila, Fortum Nuclear Services

Nordic Nuclear Safety Research (NKS)

Steering group, A. Daavittila, VTT, J. Aurela, TEM, T. Ikäheimonen, STUK, N. Bergroth, Fortum Nuclear Services

TUD (Informationsystem för Tillförlitlighet, Underhåll och Drift), A. Helminen, TVO

NPSAG (Nordiska PSA gruppen), R. Himanen, J. Pesonen, TVO

Nordic Thermal-Hydraulic Network (NORTHNET)

Steering group, T. Toppila, Fortum Nuclear Services

RM 1 Fuel assembly T/H, T. Toppila, Fortum Nuclear Services

RM 2 Primary system T/H, T. Toppila, Fortum Nuclear Services

RM 3 Containment T/H, I. Karppinen, VTT

Scientific Communities

Probabilistic safety assessment and management (PSAM) conferences

* *Organising committ*ee, R. Virolainen, STUK

International Group for Radiation Damage Mechanisms in Pressure Vessel Steels (IGRDM), K. Wallin and M. Valo, VTT, J. Kohopää, Fortum Nuclear Services

International Co-operative group for environmentally assisted cracking (ICG-EAC), U. Ehrnstén

ASTM E-10, M. Valo, VTT

* *committee E-10 on Nuclear Technology and Applications* concentrates on monitoring of irradiation embrittlement using small specimens and developes related standards.

ASTM E-8, K. Wallin, VTT

* committee E-8, Fatigue and Fracture

ASME, R. Rintamaa, VTT

Cooperation with various institutes

Bhabha Atomic Research Institute, India

* Scientific co-operation on water chemistry and corrosion issues, T. Saario VTT

Leningrad NPP Sosnovyj Bor, Russia

* *The Finnish-Russian co-operation on integrity of pressurised components*, P. Kauppinen, VTT

Institute de Radioprotection et de Sûreté Nucléaire (IRSN), France

* *Behaviour of highly irradiated fuels in case of reactivity accident and the SCANAIR computer code,* S. Kelppe, VTT;
* Co-operation in use and validation of MC3D code, I. Lindholm VTT

Source term separate effect test program (IRSN, CEA, EDF), A. Auvinen VTT

* International source term scientific analysis working group (SAWG).
* International source term chemistry interpretation circle (CHEMIC).

Research Institute of Technology, NITI, Russia

* *Scientific cooperation on thermal-hydraulic experiments,* H. Purhonen, LUT

US Nuclear Regulatory Commission (USNRC)

* PIRT Panel (on fuel burnup), K. Valtonen, STUK
* *Code Application and Maintenance (CAMP),* S. Hillberg, VTT
* *Co-operative Severe Accident Research Programme (CSARP),*T. Sevón , VTT
* *FRAPCON-3/FRAPTRAN Code Users' Group*, S. Kelppe, VTT
* *FRAPTRAN/GENFLO Fuel Performance CodeDevelopment, S. Kelppe*, VTT
* *US NRC Program for the Inspection of Nickel Alloy Components (PINC), Pentti Kauppinen, VTT*

Electric Power Research Institute (EPRI)

* *Cooperative Irradiation Assisted Stress Corrosion Cracking (IASCC) Research Programme (CIR),* W. Karlsen, VTT

ASN (Authorité de Sûreté Nucléaire), Ranska

* *Groupe Permanent d'Experts pour les Réacteurs Nucléaires*, N. Lahtinen, STUK

Commissariat à l'Énergie Atomique (CEA), Saclay, France

*Co-operation in the use and validation of the TONUS code, E. Takasuo, VTT

* Jules Horowitz Materials Testing Reactor- Finnish in kind project, T. Vanttola, P. Kinnunen, VTT

Stuttgart University/IKE, Germany

*Application of the WABE/MEWA code to particle bed coolability, E. Takasuo, VTT

Swedish Nuclear Power Inspectorate (SKI), Sydkraft, OKG and Vattenfall Ab, Sweden

* *SKI Forskningnämnd*, U. Ehrnstén, VTT
* *SSM Reaktorsäkerhetsnämd*, L. Reiman, STUK, K. Wallin, VTT

Strålsäkerhetsmyndigheten (SSM), Sweden

* SSM-VTT collaboration on FRAPCON and FRAPTRAN code validation and development, S. Kelppe, VTT
* SSM BRITE – Barrier Review, Intergration and Tracking Experts group, T. Saario VTT

University of Illinois, USA

* *Computational fracture mechanics, assessment of damage*, K. Wallin, VTT

VGB SWR-Arbeitskreis, Germany

* N. Paaso, TVO

VGB DWR-Arbeitskreis, Germany

* K. Tompuri, TVO

ITU, Karlsruhe, A. Auvinen and J. Jokiniemi, VTT

* Revaporisation of fission products from Phebus FP samples

National Institute of Standards and Technology (NIST), USA

* *Development of Fire Dynamics Simulator*
* *Direct numerical simulation of flame spread on cylindrical wood rods.* S. Hostikka, VTT

London City University / Adelard LLP, J. Valkonen, VTT

ALARA Engineering , Sweden, P. Kinnunen, VTT

* *A deterministic model for corrosion and activity incorporation in nuclear power plants*

BGH_2 Society, Bulgaria, P. Kinnunen, VTT

* *A deterministic model for corrosion and activity incorporation in nuclear power plants*

IVF – Industriforskning och utveckling AB

* *No Lead in Nordic Electronics*, A. Turtola VTT

SINTEF – Stiftelsen for industriell og teknisk forskning ved Norges tekniske høgskole

* *No Lead in Nordic Electronics*, A. Turtola VTT

DELTA – Danish Electronics, Light and Acoustics

* *No Lead in Nordic Electronics*, A. Turtola VTT

UKAEA / JET Joint European Torus, Culham, UK

* *Transport and plasma-wall experiments and related code development*, T. Tala, J. Likonen, VTT and J. Lönnroth, TKK

Max-Planck-Institut für Plasmaphysik, Garching, Germany

* *ASDEX-Upgrade tokamak experiments and modelling*, T. Kurki-Suonio, TKK

SCK-CEN, Mol, Belgium

* *In-reactor mechanical testing of reactor materials*, S. Tähtinen, VTT

Other co-operation

EC/TC45/SC45A/Working Group A3, H. Heimbürger, STUK

IEC/TC45/SC45A/Working Group A10, H. Palmén, VTT

IEC/TC45/SC45A, Nuclear Instrumentation Committee (SESKO), P. Suvanto, STUK

ISO/IEC JTC1 SC7 (Software and Systems Engineering)/Working Group 10 (Process Assessment), R. Nevalainen, TTY

European Working Group on Reactor Dosimetry – Programme Committee (EWGRD-PC), T. Serén, VTT

Working Group on Reactor Dosimetry for VVER Reactors (WGRD-VVER), T. Serén, VTT

European Network of Testing Facilities for the Quality Checking of Radioactive Waste Packages (ENTRAP), T. Kekki, VTT

Nordic Reactor Physics Meetings “Reactor Physics Calculations in the Nordic Countries”, R. Höglund, TVO

European Association of Cognitive Ergonomics (EACE), L. Norros, VTT

New Technology and Work (NeTWork), L. Norros, VTT

Nordic ALEX-group on advanced alara-princip in chemistry and radiation (Westinghouse Atom, Alara-Engineering, WA-BWR-plants), N. Paaso, TVO

The human factors network for the process industries (PRISM), co-ordinated by the European Process Safety Centre (EPSC), K. Ruuhilehto, VTT

BWR OG PSA (BWR Owners Group, PSA task) J. Pesonen, TVO

ISTC Project #833 METCOR “Investigation of corium melt interaction with NPP reactor vessel steel”, NITI, Sosnovy Bor, Russia, Collaborator and Steering Committee Member, H. Tuomisto, Fortum

MSWI (Melt-Structure-Water Interaction) Project, KTH, Stockholm, Advisory Group, H. Tuomisto, Fortum Nuclear Services

VVER Forum’s WG on the use of PSA, R. Virolainen (Chairman) and I. Niemelä, STUK

EPRI Alloys 690/52/152 Expert Panel, U. Ehrnstén, VTT, H. Hänninen, HUT

Commission of the European Communities

Nuclear Fission Safety in the Sixth Framework Programme

Phebus FP Project, A. Auvinen, T. Kärkelä, VTT

* Scientific analysis working group (SAWG).
* Bundle interpretation circle (BIC).
* Circuit and containment interpretation circle (CACIC).
* Containment chemistry interpretation circle (CCIC).

SARNET2, A. Auvinen, T. Kärkelä, VTT

* Source Term work package (WP8).
* EC Collaboration with International Science and Technology Center (ISTC) project Ex-vessel Source Term Analysis (EVAN).

Cooperation with various institutes

Institute de Radioprotection et de Sûreté Nucléaire, Cadarache, France

Source term separate effect test program (IRSN, CEA, EDF), A. Auvinen, T. Kärkelä, VTT
* International source term scientific analysis working group (SAWG).
* International source term chemistry interpretation circle (CHEMIC).

Paul Scherrer Institut (PSI), Villingen, Switzerland

ARTIST II Programme, A. Auvinen, VTT

Appendix 4

Academic degrees obtained in the projects in 2010

Expert Work in Safety Critical Environment (SafeExpertNet)

Licentiate:

Tanja Kuronen-Mattila: *Tacit Knowledge in Nuclear Power Plants: The Content, Characteristics and Prerequisites for Tacit Knowledge Sharing.* 10.9.2010.

Development and Validation of Fuel Performance Codes (POKEVA)

Master of Science in Technology:

Arffmann, Asko. Applications of the SCANAIR code for the simulation and interpretation of reactivity initiated accidents. Aalto University, School of Science and Technology, Faculty of Information and Natural Sciences. May 2010.

Primary circuit chemistry of fission products (CHEMPC)

Master of Science in Technology:

Kalilainen, J., Chemical reactions on primary circuit surfaces and their effect on fission product transport in a severe nuclear accidents. Helsinki University of Technology, Master's Thesis, 9 June 2010. 60 p.

Influence of material, environment and strain rate on environmentally assisted cracking of austenitic nuclear materials (DEF SPEED)

Doctor of Technology:

Ivanchenko, M. Dynamic Strain Aging of Austenitic Stainless Steels and Ni-Base Alloys. TKK Dissertations 248. Engineering and Architecture., November 2010. 90 p. + app. 38 p.

Extreme weather and nuclear power plants (EXWE)

Master of Science in Meteorology:

Jokinen, P. Kesäkuukausien voimakkaat matalapaineet Suomessa ja tapaustutkimuksena vuoden 1890 myrsky. University of Helsinki, Department of Physics, Master's Thesis, 1 February 2010.

Master of Science in Geophysics:

Pellikka, H. Grönlannin mannerjäätikön tulevaisuus: merenpinnan nousu maailmanlaajuisesti ja Itämerellä. University of Helsinki, Department of Physics, Master’s Thesis, 10 January 2011.

Appendix 5

International travels in the projects in 2010

International travels in VAHAYA project in 2010

None

International travels in WATCHEM project in 2010

Saario, T., participation in the IAEA Technical Meeting on Water Chemistry and Clad Corrosion/Deposition including Fuel Failure, 22-24 Nov 2010, Kiev, Ukraine.

Saario, T., participation in the Nuclear Plant Chemistry 2010 –conference, Quebec, Canada, 3-7 Oct, 2010.

Saario, T., visiting scientist period at Bhabha Atomic Research Centre (BARC), India, 23.1.-27.2.2010.

International travels in Expert Work in Safety Critical Environment (SafeExpertNet) project in 2010

1. Pahkin K, et al: "*Supporting expertise in nuclear organizations*. Presentation in the IAEA International Conference on Human Resource Development for Introducing and Expanding Nuclear Power Programmes 14-18 March 2010, Abu Dhabi, UAE
2. Pahkin K et al: "*Development of a survey for expert work in safety critical environment* ". Presentation at the European Academy of Occupational Health Psychology (EA-OHP) 29-31 March 2010, Rome, Italy
3. Kuronen-Mattila, T. (2010): Tacit knowledge in nuclear power plants: content, characteristics and sharing International conference on Intellectual Capital, Knowledge Management & Organizational Learning, 11-12 November, Hong Kong.
4. Tanja Kuronen-Mattila has participated to the IAEA Meeting of Technical Working Group on Managing Human Resources in the Field of Nuclear Energy (TWG-MHR), held in Vienna on 15-17.6.2010.
5. Krista Pahkin has participated to the IAEA Technical Meeting on the Considerations of Human Factors in New NPP Projects held in Vienna on 9-12.11.2010.

International travels in CERFAS project in 2010

Harju, Hannu, VTT: QUATIC'2010, 7th International Conference on the Quality of Information and Communications Technology: QUATIC 2010, Porto, Sep. 27 – 29, 2010.

Lahtinen, Jussi, VTT: Cert – QSS Workshop, Pisa Italy, The 29th International Conference on Computer Safety, Reliability and Security: SAFECOMP'2010, Vienna, Sep. 14 – 17, 2010.

Nevalainen Risto, Tampere University of Technology, Pori Unit: 17^{th} EuroSPI Safety Conference: European Systems & Software Process Improvement and Innovation, Grenoble, Sep. 1 – 3, 2010.

International travels in CHEMPC project in 2010

Auvinen A., Kärkelä T., Phebus FP, ISTP and SARNET2 follow-up meetings, 22-25.3.2010, Petten, Netherlands.

Auvinen A., Kärkelä T., Phebus FP and ISTP follow-up meetings, 6-8.10.2010, Aix-en-Provence, France.

Auvinen A., Kärkelä T., SARNET2 follow-up meeting, 23-24.11.2010, Pisa, Italy.

Auvinen A., ARTIST-2 PRG meeting, 25-26.1.2010, Villingen, Switzerland.

Auvinen, A., Kärkelä, T., 4th European Review Meeting on Severe Accident Research (ERMSAR-2010), 11-12.5.2010, Bologna, Italy.

Kärkelä, T., International Congress on Advances in Nuclear Power Plants 2010 (ICAPP 2010), 13-17.6.2010, San Diego, CA, USA.

Auvinen, A., Kärkelä, T., Kalilainen, J., International Aerosol Conference 2010 (IAC2010), 29.8-3.9.2010, Helsinki, Finland.

Auvinen, A., Kalilainen, J., American Nuclear Society: 2010 Winter Meeting and Nuclear Technology Expo, 7-11.11.2010, Las Vegas, Nevada, USA.

Kärkelä, T., Visit at Chalmers University of Technology, 16.9-2.10.2010, Göteborg, Sweden.

International travels in COMESTA2010 project in 2010

Lindholm, I. & Suopajärvi, A., OECD SERENA-2 Programme Review Group and Management Board meetings. March 15–17, 2010, Paris, France.

Lindholm, I., OECD SERENA-2 Programme Review Group and Management Board meetings. October 18–20, 2010, Jeju Island, Korea.

Sevón, T., OECD MCCI-2 Programme Review Group and Management Board meetings. June 30 – July 1, 2010, Argonne National Laboratory, Illinois, USA.

Sevón, T., CSARP and MCAP meetings. September 13–17, 2010, Bethesda, Maryland, USA.

Sevón, T., PLINIUS–LACOMECO workshop on European severe accident research infrastructures. October 26, 2010, Aix-en-Provence, France.

Sevón, T., MCCI seminar. November 15–17, 2010, Cadarache, France.

International travels in DEF SPEED project in 2010

Ehrnstén, U. Meeting with project sponsor Karen Gott, SSM, 4.02.2010, Stockholm, Sweden

Ehrnstén U., Hänninen H., (Aalto). ICG-EAC (International Co-operative Group on Environmentally Assisted Cracking) meeting, 11.04 – 16 (22).04. 2010, Jeju Island, Korea.

Ehrnstén, U. Baltica VIII. Life Management and Maintenance for Power Plants. 18 - 20 May, 2010, Helsinki - Stockholm – Helsinki.

Karlsen W. Halden IASCC Review Meeting 2010, 23-24 September 2010, Halden, Norway.

Ahonen, M., Ehrnstén, U., Karlsen, W. Fontevraud 7, Contribution of materials investigations to improve the safety and performance of LWRs, 26-30 September, 2010, Avignon, France

Ehrnstén, U. EPRI 690 expert group meeting and workshop on environmental fracture. 30.11. – 3.12.2010, Tampa, USA.

International travels in EXWE project in 2010

Jylhä, K. FUME Project Meeting, 15-18 March 2010, Tunis.

Tietäväinen, H., Jokinen, P., Gregow, H., CES annual meeting, 31 May – 2 June 2010, Oslo, Norway.

Tietäväinen, H., European Geosciences Union General Assembly 2010, Vienna, Austria, 02 – 07 May 2010

Tietäväinen, H., International Meeting on Statistical Climatology, 12.-16.7.2010, Edinburgh, UK

International travels in FATE project in 2010

Solin, J. International Symposium, Fontevraud 7. Avignon, France 26-30. 9. 2010.

International travels in FIRAS project in 2010

Hostikka, S., OECD/PRISME benchmarking, programme review group and management board meetings. 27-28.4.2010, Aix-en-Provence, France

Hostikka, S., OECD/PRISME benchmarking, programme review group and management board meetings. 12-13.10.2010, Aix-en-Provence, France

Hostikka, S. Nottingham, UK. Oral presentation at Interflam 2010 conference. 5-7.7.2010.

International travels in FRAS project in 2010

Cronvall, O. International Conference on Life Management and Maintenance for Power Plants (Baltica VIII), Helsinki - Stockholm - Helsinki, 18-20 May, 2010.

Planman, T., CABINET-project kick-off meeting, Munich, 23 September 2010

Laukkanen, A., CABINET-project kick-off meeting, Munich, 23 September 2010

Cronvall, O. FONTEVRAUD 7, CONTRIBUTION OF MATERIALS INVESTIGATIONS TO IMPROVE THE SAFETY AND PERFORMANCE OF LWRs, 26 to 30 september 2010, Avignon, France.

Keinänen, H., Kärnteknik 2010. Stockholm, Sweden 1-2 December 2010

Kuutti, J., Kärnteknik 2010. Stockholm, Sweden 1-2 December 2010

International travels in HYBCIS2 project in 2010

Huhtanen, R., CSNI-ISP-49 on "Hydrogen deflagration" - Fourth meeting, 22-23 June 2010, NEA Headquarters, 12, Boulevard des Iles, 92130 Issy-les-Moulineaux, France.

Takasuo, E., THAI Seminar 2010, 6-7 October 2010, OECD/NEA Headquarters, Issy-les-Moulineaux, France.

International travels in MANOR project in 2010

Reiman, T. & Oedewald, P. 10th International Probabilistic Safety Assessment & Management Conference, 7-11 June 2010, Seattle, USA.

Reiman, T. The 5th International Conference Workingonsafety.net, 7-10 September 2010, Røros, Norway.

Pietikäinen, E. 1st Nordic Patient safety conference 19.-21.May 2010, Stockholm, Sweden.

Oedewald, P. IAEA Technical meeting on Safety culture in pre-operational phases, 1-4 June 2010, Vienna, Austria

Oedewald, P. IAEA Consultancy meeting on Safety culture in pre-operational phases, 14-17 September 2010, Vienna, Austria.

International travels in MODSAFE project in 2010

K. Björkman, J. Valkonen, J. Lahtinen, 7th International Topical Meeting on Nuclear Plant Instrumentation, Control and Human-Machine Interface Technologies (NPIC&HMIT 2010), November 7-11, 2010, Las Vegas, Nevada, USA

J. Valkonen, European Safety and Reliability Conference, ESREL2010. 5 – 9 Sept. 2010, Rhodes, Greece

International travels in NUMPOOL project in 2010

Pättikangas, T.J.H., Northnet Roadmap 3 Reference Group Meeting, 17 August 2010, Royal Institute of Technology, Stockholm, Sweden.

Pättikangas, T.J.H., CFD4NRS-3, Experimental Validation and Application of CFD and CMFD Codes to Nuclear Reactor Safety Issues, OECD/NEA & IAEA Workshop, 14–16 September 2010, Washington D.C., USA.

International travels in O'PRACTICE project in 2010

Laarni, J., OECD/NEA workshop "Human performance and the operation of nuclear plant technology"/ 8th WGHOF (Working Group on Human and Organisational Factors) meeting, Washington, USA, March 1-3, 2010.

Norros, L., EHPG Enlarged Halden Programme Group Meeting, Storefjell, Norway, March 14-19, 2010.

Norros, L., ISSNP Post workshop on Human-Technology Interaction systems Harbin on August 24 - 29, 2010. (ISSNP = The 3rd International Symposium on Symbiotic Nuclear Power Systems for 21st Century).

Norros, L., NEA/WGHOF (Working Group on Human and Organisational Factors) meeting, Paris, France, September, 2009.

International travels in PACSIM project in 2010

Rantakaulio, A., ICAPP'10, San Diego, CA, USA, June 13-17, 2010

International travels in PURISTA project in 2010

Simola, K., RISMET project meeting. March 25–25, 2010, Petten, the Netherlands.

Sarkimo, M., BALTICA VIII – International Conference on Life Management and Maintenance for Power Plants. May 18–20, 2010, Stockholm, Sweden.

Simola, K. The 10th International Probabilistic Safety Assessment and Management Conference, PSAM10. June 7–11, 2010, Seattle, USA.

Simola, K., European Safety and Reliability Conference , ESREL2010. September 5–9, 2010, Rhodes, Greece.

Simola, K., ENIQ Task Group on Risk and joint ENIQ Task Group on Risk and Task Group Qualification meeting. October 19–20, 2010, Schiphol, The Netherlands.

International travels in RADECO project in 2010

Kekki, T., OECD/BIP Programme Review Group 6th Meeting and experts meeting on the proposed OECD/STEM project on source term evaluation and migitation, October 4-5, 2010, Paris, France.

International travels in RAKEMON project in 2010

Sarkimo, M., Third Zetec European Customer Symposium, February 10 – 11, 2010, Paris, France.

Leskelä, E., NDT-päivät, March 17 – 18, 2010, Tallinn, Estonia.

Koskinen, A., Baltica VIII – 2010, International Conference on Life Management and Maintenance for Power Plants, 18 – 20 May, 2010, Helsinki – Stockholm – Helsinki.

Leskelä, E., US-NRC PARENT kick-off meeting, June 1 – 3, 2010, PNNL, Richland, USA.

Koskinen, A., Coordinated Research Programme (CRP) meeting on Advanced, Surveillance, Diagnostics and Prognostics Techniques Used for Health Monitoring of Systems, Structures and Components in Nuclear Power Plants June 6 – 12, 2010, PNNL, Richland, USA.

Kauppinen, P., the Eleventh International Conference "Material Issues in Design, Manufacturing and Operation of Nuclear Power Plants Equipment", June 14 – 18, 2010, St. Petersburg (Pushkin), Russia

Koskinen, A., 8th International Conference on NDE in Relation to Structural Integrity for Nuclear and Pressurised Components, September 29 – October 1, Berlin, Germany.

Jäppinen, T., 8th International Conference on NDE in Relation to Structural Integrity for Nuclear and Pressurised Components, September 29 – October 1, Berlin, Germany.

Sandlin, S., Nordic Symposium, Nuclear Technology 2011, December 7 – 8, Stockholm, Sweden

International travels in SERVICEMAN project in 2010

Vesikari, E., OECD/NEA/CSNI/IAGE annual Concrete work group meeting, 14th April, 2010, Paris, France.

Vesikari E., COST C25 Meeting, 24 – 25 April, 2010. Izmir, Turkey.

Vesikari E., Hiltunen V.& Mattila A., AMP2010 Int Workshop, 8 - 10 November, 2010. Toronto, Canada.

Calonius K., NULIFE Network meeting, 7-9 September 2010, Stockholm, Sweden.

Calonius K., NULIFE ACCEPT meeting. 22nd October 2010, Offenbach, Germany.

International travels in SGEN project in 2010

Hovi, V., CFD4NRS-3, Experimental Validation and Application of CFD and CMFD Codes to Nuclear Reactor Safety Issues, OECD/NEA & IAEA Workshop, 14–16 September 2010, Washington D.C., USA.

Rämä, T., 8th International Seminar on Horizontal Steam Generators. OKB "Gidropress", 19–21 May 2010. Podolsk, Russia.

International travels in THARE project in 2010

Hillberg Seppo, TRACE user workshop, Potomac, USA, 15-18.3.2010

Inkinen Pasi, TRACE user workshop, Potomac, USA, 15-18.3.2010

Karppinen Ismo, OECD/PKL2 Programme Review Group meeting, Pisa , Italy 26-27.4.2010

Inkinen Pasi, OECD/CSNI International Standard Problem ISP-50 meeting 25-26.5. and OECD/ROSA2 Programme Review Group meeting 27-28.5.2010 Paris, France

Hillberg Seppo, USNRC/CAMP (Code Application and Maintenance Program), Spring Meeting, Stockholm, Sweden, 09-11.6.2010

Inkinen Pasi, USNRC/CAMP (Code Application and Maintenance Program), spring meeting, Stockholm, Sweden, 09-11.6.2010

Karppinen Ismo, OECD/SETH2 Programme Review Group meeting 15-16.6.2010, Paris, France

Karppinen Ismo, Northnet RoadMap 3 meeting, 27.8.2010, Stockholm, Sweden

Karppinen Ismo, OECD/GAMA (Working Group on Analysis and Management of Accidents) annual meeting, 21-24.9.2010, Paris, France

Inkinen Pasi, OECD/PKL2 Programme Review Group meeting Paris, France 9-10.11.2010

Karppinen Ismo, OECD/ROSA2 Programme Review Group meeting, Tokai-mura, Japan 30.11-1.12.2010

Huhtanen Risto, OECD/SETH2 Programme Review Group meeting, Villigen, Switzerland 14-15.12.2010

International travels in TOPAS project in 2010

Holopainen, S., Basic CMS training course. April 19–23, 2010, Hamburg, Germany.

Holopainen, S., MCNP5/MCNPX Training Course. March 29 – April 2, 2010, Paris, France.

Rantamäki, K., MCNP5/MCNPX Training Course. March 29 – April 2, 2010, Paris, France.

Pusa, M., NEA course on Analytical Benchmarks: Case Studies in Neutron Transport Theory. April 6–9, 2010, Issy-les-Moulineaux, France.

Pusa, M., UAM-4 benchmark meeting. April 14–16, 2010, Pisa, Italy.

Leppänen, J., International Conference on Nuclear Data for Science and Technology 2010. April 26–30, 2010, Jeju Island, Korea.

Leppänen, J., PHYSOR 2010 conference. May 9–14, 2010, Pittsburgh, USA.

Anttila, M., NEA meeting. June 8, 2010, Paris, France.

Leppänen, J., IYNC-2010. July 12–18, 2010, Cape Town, South Africa.

Leppänen, J., Workshop at MIT. October 7, 2010, Boston, USA.

Pusa, M., Workshop at MIT. October 7, 2010, Boston, USA.

Serén, T., EWGRD meeting. October 12–14, 2010, Sofia, Bulgaria.

Leppänen, J., Monte Carlo & Super-Computing in Nuclear Applications. October 17–21, 2010, Tokyo, Japan.

Appendix 6

The steering group, the reference groups and the scientific staff of the projects in 2010

Steering Group of SAFIR2010 – SAFIR2010 Johtoryhmä

Person	**Organisation & Finnish abbreviation**
Marja-Leena Järvinen, Chairperson	Radiation and Nuclear Safety Authority (STUK)
Section Head Keijo Valtonen	Radiation and Nuclear Safety Authority (STUK)
Director Kari Hiltunen	Finnish Funding Agency for Technology and Innovation (Tekes)
Senior Technology Advisor Piia Moilanen	Finnish Funding Agency for Technology and Innovation (Tekes)
Technology Manager Timo Vanttola	Technical Research Centre of Finland (VTT)
Technology Manager Pentti Kauppinen	Technical Research Centre of Finland (VTT)
Senior Adviser Pekka Pyy	Teollisuuden Voima Oyj (TVO)
Technology Manager Liisa Heikinheimo	Teollisuuden Voima Oy (TVO)
Manager Sami Hautakangas	Fortum Power and Heat Oy (Fortum)
Senior Engineer Ritva Korhonen	Fortum Nuclear Services Oy
Professor Rainer Salomaa	Helsinki University of Technology (TKK)
Professor Riitta Kyrki-Rajamäki	Lappeenranta University of Technology (LUT)
Counsellor Jaana Avolahti	Ministry of Employment and the Economy (TEM)
Chief Engineer Jorma Aurela, TEM contact person	Ministry of Employment and the Economy (TEM)
Director Juhani Hyvärinen	Fennovoima Oy (Fennovoima)
Harri Heimbürger, Expert	Radiation and Nuclear Safety Authority of Finland (STUK)
Eija Karita Puska, Director of SAFIR2010, Secretary of the Steering Group	Technical Research Centre of Finland (VTT)

SAFIR2010 Reference Groups / Tukiryhmät

Chairpersons, members and *experts /* Puheenjohtajat, jäsenet ja *asiantuntijat* 19.2.2010

1. Organisation and human factors / Organisaatio ja ihminen

Person	Organisation
Matti Vartiainen, chairperson	**TKK**
Kirsi Levä	STUK
Milka Holopainen	STUK
Leena Norros	VTT
Maaria Nuutinen	VTT
Petri Koistinen, vice-chairperson	TVO
Jari Tauluvuori	TVO
Teuvo Tinell	Fortum Nuclear Services Oy
Magnus Halin	Fortum Power and Heat Oy
Nina Koivula	*Fennovoima Oy, Expert*

2. Automation and control room / Automaatio ja valvomo

Person	Organisation
Olli Hoikkala, chairperson	**TVO**
Mika Koskela	STUK
Heimo Takala	STUK
Jukka Kupila	STUK
Jari Hämäläinen	VTT
Olli Ventä	VTT
Mauri Viitasalo	TVO
Martti Välisuo, vice-chairperson	Fortum Nuclear Services Oy
Ville Nurmilaukas	Fortum Service
Matti Kattainen	Fortum Nuclear Services Oy
Ilkka Niemelä	TKK
Juha Sirola	*Fennovoima Oy, Expert*

3. Fuel and reactor physics / Polttoaine ja reaktorifysiikka

Person	Organisation
Riku Mattila, chairperson	**STUK**
Risto Sairanen, vice-chairperson	STUK
Risto Teräsvirta	Fortum Nuclear Services Oy
Markku Anttila	VTT
Seppo Tähtinen	VTT
Kari Ranta-Puska	TVO
Randolph Höglund	TVO
Martti Antila	Fortum Nuclear Services Oy
Pertti Aarnio	TKK

4. Thermal hydraulics / Termohydrauliikka

Person	Organisation
Eero Virtanen, chairperson	**STUK**
Nina Lahtinen	STUK
Antti Daavittila	VTT
Anitta Hämäläinen	VTT
Juha Poikolainen	TVO
Mikko Lemmetty	TVO
Timo Toppila, vice-chairperson	Fortum Nuclear Services Oy
Heikki Kantee	Fortum Nuclear Services Oy
Timo Siikonen	TKK
Virpi Kouhia	LUT
Pasi Junninen	*Platom Oy, Expert*

5. Severe accidents / Vakavat onnettomuudet

Person	Organisation
Risto Sairanen, chairperson	**STUK**
Lauri Pöllänen, vice-chairperson	STUK
Ilona Lindholm	VTT
Pekka Viitanen	TVO
Janne Vahero	TVO
Tommi Purho	Fortum Nuclear Services Oy
Eerikki Raiko	Fortum Nuclear Services Oy
Jarmo Ala-Heikkilä	TKK
Mika Pikkarainen	LUT

6. Structural safety of reactor circuit / Reaktoripiirin rakenteellinen turvallisuus

Person	Organisation
Martti Vilpas, chairperson	**STUK**
Rainer Rantala, vice-chairperson	STUK
Kim Wallin	Suomen Akatemia
Pertti Aaltonen	VTT
Erkki Muttilainen	TVO
Anneli Reinvall	TVO
Antti Kallio	TVO
Alpo Neuvonen	Fortum Nuclear Services Oy
Petri Kytömäki	Fortum Power and Heat Oy
Ossi Hietanen	Fortum Nuclear Services Oy
Hannu Hänninen	TKK

7. Construction safety / Rakennustekninen turvallisuus

Person	Organisation
Pekka Välikangas, chairperson	**STUK**
Jukka Myllymäki	STUK
Heli Koukkari	VTT
Eila Lehmus	VTT
Vesa Hiltunen	TVO
Timo Kukkola	TVO
Joonas Koskinen	Fortum Nuclear Services Oy
Tapani Kukkola	Fortum Nuclear Services Oy
Jari Puttonen	TKK
Juha Matikainen	*Fennovoima Oy, Expert*

8. Probabilistic safety analysis (PSA) / Todennäköisyyspohjainen turvallisuusanalyysi (PSA)

Person	Organisation
Reino Virolainen, chairperson	**STUK**
Jouko Marttila	STUK
Ilkka Niemelä	STUK
Esko Mikkola	VTT
Irina Aho-Mantila	VTT
Kaisa Simola	VTT
Risto Himanen	TVO
Jari Pesonen	TVO
Kalle Jänkälä, vice-chairperson	Fortum Nuclear Services Oy
Toivo Kivirinta	Fortum Power and Heat Oy
Ahti Salo	TKK

Monitoring of the structural integrity of reactotr circuit (RAKEMON)
Rakenteiden eheyden monitorointi

Research organisation: VTT
Project manager: Ari Koskinen, VTT
Deputy project manager: Tarja Jäppinen, VTT

Person	Org.	Tasks
Ari Koskinen, MScTech	VTT	Project manager, pilot monitoring system
Tarja Jäppinen, LicTech	VTT	Deputy project manager, eddy current applications
Matti Sarkimo, LicTech	VTT	Ultrasonic simulations
Esa Leskelä, MScTech	VTT	Ultrasonic simulations
Mikko Vepsäläinen, MSc	VTT	Water chemistry
Stefan Sandlin, MSc	VTT	Subharmonic ultrasonics
Antti Tuhti, BScTech	VTT	Pilot monitoring system

Service life management system of concrete structures in nuclear power plants (SERVICEMAN)
Ydinvoimaloiden betonirakenteiden käyttöiän hallintajärjestelmä

Research organisation: VTT
Project manager: Erkki Vesikari, VTT

Person	Org.	Task
Erkki Vesikari, LicTech	VTT	Project manager, Tasks 1.3, Finalising the management system (software). Task 1.4 Condition assessment of the NPP cooling water systems. Task 5. International co-operation.
Kim Calonius, MScTech	VTT	Task 2.1 Structural analyses
Stefania Fortino, Dr (Tech)	VTT	Task 2.1 Structural analyses
Esa Turunen, MScTech	VTT	Task 2.2 Cracking analyses
Liisa Salparanta, MScTech	VTT	Task 4. Experimental research (BTS)
Hannele Kuosa, MScTech	VTT	Task 4. Experimental research (DuraInt)

CFD modelling of NPP horizontal and vertical steam generators (SGEN)
Ydinvoimalaitosten vaaka- ja pystyhöyrystinten mallintaminen 3D virtauslaskennalla

Research organisations: VTT and Fortum Power and Heat Oy
Project manager: Timo Pättikangas, VTT
Deputy project manager: Tommi Rämä, Fortum Power and Heat Oy

Person	**Org.**	**Task**
Timo Pättikangas, DTech	VTT	Project manager, development of CFD models for steam generators
Ville Hovi, MScTech	VTT	CFD and APROS modelling of steam generators
Jarto Niemi, MScTech	VTT	Development of CFD models for steam generators, development of FLUENT–APROS coupling
Tommi Rämä, MScTech	Fortum	Deputy project manager, CFD modeling of VVER-440 horizontal steam generator
Lauri Peltokorpi, MScTech	Fortum	APROS modelling of Loviisa NPP
Timo Toppila, MScTech	Fortum	CFD modeling of VVER-440 horizontal steam generator

Structures under Soft Impact (SUSI)
Iskuormitetut rakenteet

Research organisations: VTT and TUT
Project manager: Arja Saarenheimo, VTT
Deputy project manager: Kim Calonius, VTT

Person	**Org.**	**Tasks**
Arja Saarenheimo, LicTech	VTT	Project manager, structural analyses
Kim Calonius, MScTech	VTT	Deputy project manager, structural analyses
Ari Silde, MScTech	VTT	Liquid dispersal studies
Simo Hostikka, DrTech	VTT	Fire dynamic simulations
Topi Sikanen, MScTech	VTT	Fire dynamic simulations
Markku Tuomala, Prof	TUT	Analytical methods

Improved Thermal Hydraulic Analysis of Nuclear Reactor and Containment (THARE)
Kehittyvät termohydrauliikka-analyysit

Research organisation: VTT
Project manager: Ismo Karppinen, VTT

Person	Org.	Task
Seppo Hillberg, MScTech	VTT	Deputy project manager , validation of APROS and TRACE codes, follow-up of USNRC/CAMP
Risto Huhtanen, MScTech	VTT	Development and validation of CFD calculation methods
Pasi Inkinen, MScTech	VTT	Validation of APROS and TRACE codes
Ismo Karppinen, MScTech	VTT	Project manager, follow-up of OECD/GAMA, OECD/ROSA2, OECD/SETH2, OECD/PKL2, co-ordination of Northnet RM3
Sampsa Lauerma, trainee	VTT	Validation of APROS
Juha Luukka, MScTech	VTT	Validation of APROS Containment
Jarto Niemi, MScTech	VTT	Development of Fluent condensation model and error corrections in APROS 3D solver
Ari Silde, MScTech	VTT	Validation of APROS Containment

Total reactor physics analysis system (TOPAS)
Kattava reaktorifysikaalinen laskentaohjelmisto

Research organisation: VTT
Project manager: Petri Kotiluoto, VTT

Person	Org.	Task
Markku Anttila, MScTech	VTT	Cross sections, criticality safety and isotopic concentrations, development of sensitivity analysis methodology
Silja Holopainen, DTech	VTT	Development and validation of nodal methods, Monte Carlo method
Pauli Juutilainen, Technical University Student	VTT	Criticality safety and isotopic concentrations, Monte Carlo burnup calculation
Petri Kotiluoto, PhD	VTT	Project manager, development and validation of Monte Carlo and other transport methods
Jaakko Leppänen, DTech	VTT	Cross sections, development and validation of Monte Carlo and other transport methods
Maria Pusa, MScTech	VTT	Development of sensitivity analysis methodology, Monte Carlo burnup calculation
Karin Rantamäki, DTech	VTT	Deputy project manager, cross sections, development and validation of nodal methods, Monte Carlo method
Antti Räty, MSc	VTT	Development and validation of nodal methods, 1D data condensation
Tom Serén, LicTech	VTT	Cross sections and reactor dosimetry

Tridimensional core transient analysis methods (TRICOT)
Kolmiulotteiset transienttianalyysimenetelmät

Research organisation: VTT
Project manager: Elina Syrjälahti

Person		**Task**
Syrjälahti Elina, MScTech	VTT	Project manager, Sensitivity and uncertainty analysis of reactor dynamic codes.
Daavittila Antti, MScTech	VTT	TRACE/PARCS
Hovi Ville, MScTech	VTT	PORFLO development and applications
Hämäläinen Anitta, DrTech	VTT	TRAB-3D/SMABRE, AER symposium arrangements
Ilvonen Mikko, MScTech	VTT	PORFLO development and applications
Inkinen Pasi, MScTech	VTT	3D visualization methods
Räty Hanna, MScTech	VTT	Deputy project manager, TRAB-3D/SMABRE, AER symposium arrangements
Seppälä Malla, MScTech	VTT	TRACE/PARCS
Takasuo Eveliina, MScTech	VTT	PORFLO applications
Leveinen Auli, Secretary	VTT	AER symposium arrangements
Rajasalmi Maria, Secretary	VTT	AER symposium arrangements
Rantamäki Karin, MScTech	VTT	AER symposium arrangements

Requirements Engineering in Nuclear Power Plant Automation (VAHAYA)
Vaatimusten hallinta ydinvoimalaitosten automaatiossa

Research organisation: Aalto University and VTT
Project manager: Tomi Männistö, Aalto University

Person	**Org.**	**Task**
Tomi Männistö, Professor	Aalto University	Project manager
Mikko Raatikainen, M.Sc. (Tech.)	Aalto University	Researcher
Teemu Tommila, M.Sc. (Eng.)	VTT	Researcher
Janne Valkonen, M.Sc. (Tech.)	VTT	Researcher

Water chemistry and oxidation in the primary circuit (WATCHEM)
Vesikemia ja hapettuminen reaktoripiirin olosuhteissa

Research organisations: VTT, University of Chemical Technology and Metallurgy (Bulgaria)
Project manager: Timo Saario, VTT

Person	Org.	Task
Timo Saario, Dr. Tech.	VTT	Project manager, Participation in IAEA FUWAC project, experiments, method development
Petri Kinnunen, Dr. Tech.	VTT	Deputy project manager, Participation in IAEA FUWAC project, EIS modelling
Mikko Vepsäläinen, MScTech	VTT	FAC –method development, preoxidation experiments
Martin Bojinov, Prof., DSc	UCTM, Bulgaria	Modelling of impedance spectra, literature study on FAC
Taru Lehtikuusi, technician	VTT	Chemistry control - experiments

Expert Work in Safety Critical Environment (SafeExpertNet)
Asiantuntijatyö turvallisuuskriittisessä ympäristössä

Research organisations:
Finnish Institute of Occupational Health (FIOH) and Aalto University (Aalto)

Project manager: Krista Pahkin, FIOH
Deputy project manager: Eerikki Mäki, Aalto

Person	Org.	Task
Krista Pahkin	FIOH	Project manager, Participation in tasks 1 and 3
Anneli Leppänen	FIOH	Participation in tasks 1 and 3
Mervi Hasu	FIOH	Participation in task 3
Eerikki Mäki	Aalto	Deputy project manager, Participation in tasks 2 and 3
Tanja Kuronen-Mattila	Aalto	Participation in tasks 2 and 3
Eila Järvenpää	Aalto	Participation in tasks 2 and 3

Task 1: HR Practices
Task 2: Developing collaboration and knowledge sharing in nuclear expert community
Task 3: Publishing and dissemination of results

Renewal of active materials research infrastructure (AKTUS)
Aktiivisten materiaalien tutkimusympäristön uudistaminen

Research organisation: VTT
Project manager: Seppo Tähtinen
Deputy project manager: Ulla Ehrnstén

Person	**Org.**	**Task**
Seppo Tähtinen, MScTech	VTT	Project manager Task 1-3
Ulla Ehrnstén, MScTech	VTT	Deputy project manager Task 1-3
Arto Kukkonen, Tech.	VTT	Task 1,3
Tommi Kekki, MSc Tech	VTT	Task 1, 3
Timo Vanttola, PhD Tech	VTT	Task 3
Ulla Vuorinen, MSc Tech	VTT	Task 1, 3
Maija Lipponen, MSc Tech	VTT	Task 1, 3
Pentti Kauppinen, PhD Tech	VTT	Task 1-3

Task 1 Experimental Needs

Task 2 European capabilities and models

Task 3 Description for the Engineering Design

Certification facilities for software (CERFAS)
Ohjelmistojen sertifiointivalmiuksien kehittäminen
Research organisation: VTT and TTY
Project manager: Hannu Harju, VTT
Deputy project manager: Risto Nevalainen, TTY

Person	**Org.**	**Task**
Hannu Harju, Tech.Lis	VTT	Project manager, product certification
Jussi Lahtinen, M.Sc.Tech	VTT	Formal methods
Jukka Ranta, Tech.Lis	VTT	Verification tools and methods.
Risto Nevalainen, Tech.Lis.	TTY	Deputy project manager, Software measurement
Mika Johansson, M.Sc.Tech	TTY	Process assessment

Primary circuit chemistry of fission products (CHEMPC)
Fissiotuotteiden primääripiirin kemia

Research organisation: VTT
Project manager: Teemu Kärkelä, VTT
Deputy project manager: Ari Auvinen, VTT

Person	Org.	Task
Teemu Kärkelä, MScTech	VTT	Project manager, Iodine experiments, Participation in Phebus and ISTP projects
Ari Auvinen, MScTech	VTT	Deputy project manager, Participation in Phebus, ISTP and ARTIST2 projects, Iodine experiments - interpretation of results
Unto Tapper, PhD	VTT	Electron microscopy - iodine experiments
Raoul Järvinen, Technician	VTT	Construction of experimental facility
Jouni Hokkinen, MScTech	VTT	Participation in ARTIST2 project
Riitta Zilliacus, MSc	VTT	Chemical analysis - iodine experiments
Tommi Kekki, MScTech	VTT	Radio tracer measurements - iodine experiments
Maija Lipponen, MSc	VTT	Chemical analysis - iodine experiments
Tuula Kajolinna, Engineer	VTT	Gas compound analysis - iodine experiments
Jarmo Kalilainen, MScTech student	VTT	Participation in conducting iodine experiments in primary circuit conditions
Pekka Rantanen, LicTech	VTT	Participation in conducting iodine experiments in primary circuit conditions

Core Melt Stabilization (COMESTA2010)
Sydänsulan stabilointi

Research organisation: VTT
Project manager: Tuomo Sevón, VTT
Deputy project manager: Eveliina Takasuo, VTT

Person	Org.	Task
Tuomo Sevón, MScTech	VTT	Project manager, MELCOR 2-phase flow simulations, CSARP, FESICO experiment, OECD MCCI-2
Eveliina Takasuo, MScTech	VTT	Deputy project manager
Ilona Lindholm, MScTech	VTT	OECD SERENA-2, Steam explosion analysis
Atso Suopajärvi, MScTech	VTT	Steam explosion analysis

Influence of material, environment and strain rate on environmentally assisted cracking of austenitic nuclear materials (DEF SPEED)

Materiaalin tilan, ympäristön ja muodonmuutosnopeuden vaikutus austeniittisten ydinvoimalaitosmateriaalien ympäristövaikutteiseen murtumiseen

Research organisation: VTT
Project manager: Ulla Ehrnstén, VTT
Deputy project manager: Wade Karlsen, VTT

Person	**Org.**	**Task**
Ulla Ehrnstén, MScTech	VTT	Project manager, responsible for SSSRT tests, ICG EAC board member, 15^{th} env. deg. conference scientific committee member
Wade Karlsen, PhD	VTT	Deputy project manager, TEM investigations, international co-operation
Janne Pakarinen, PhD (young person)	VTT	TEM-investigations
Pasi Kuivalainen, engineer (young person)	VTT	Autoclave tests, design of new equipment
Pasi Väisänen, engineer (young person)	VTT	Autoclave tests performance
Kristiina Kalliola, information assistant	VTT	Building of digital report archive
Juha-Matti Autio MScTech (young person)	VTT	SCAP data base
Otso Cronvall, MScTech (young person)	VTT	Structural integrity evaluation
Pirjo Koponen, archivist	VTT	Building of digital report archive
Marketta Mattila, technician	VTT	Autoclave tests, water chemistry
Pertti Aaltonen, M. Sc	VTT	SCAP-project, mentor
Tapio Saukkonen, MSc	Aalto U.	EBSD measurements
Mykola Ivanchenko, MSc	Aalto U	Dynamic strain ageing investigations, thesis
Hannu Hänninen, professor	Aalto U	Mentor

Extreme weather and nuclear power plants (EXWE)
Sään ääri-ilmiöt ja ydinvoimalaitokset

Research organisations: Finnish Meteteorological Institute (FMI)
Project manager: Kirsti Jylhä, Finnish Meteorological Institute

Person	Org.	Task
Kirsti Jylhä, PhD	FMI	Project manager Analyzing of extremes based on climate scenario data
Aleksi Jokela	FMI	Millennium simulations
Heikki Järvinen, Prof.	FMI	Millennium simulations
Kimmo Kahma, Prof.	FMI	Baltic Sea level
Miika Mäkelä	FMI	Aggregation of publications
Hilkka Pellikka, MSc	FMI	Baltic Sea level
Kimmo Ruosteenoja	FMI	Analyzing of extremes based on climate scenario data
Petri Räisänen, PhD	FMI	Millennium simulations
Seppo Saku, MSc	FMI	Analyzing extremes based on measured data
Hanna Tietäväinen, MSc	FMI	Aggregation of publications

Fatigue of primary circuit components (FATE)
Primääripiirin komponenttien väsyminen

Research organisation: VTT
Project manager: Jussi Solin
Deputy project manager: Jouni Alhainen

Person	Org.	Task
Jussi Solin, MScTech	VTT	Project manager, Participation in all subtasks
Jouni Alhainen, MScTech	VTT	Deputy project manager, Development of transient simulation, Fatigue experiments
Wade Karlsen, PhD	VTT	Transmission electron microscopy
Ville Rantanen, student	VTT	Trainee on materials characterisation
Esko Arilahti, Engineer	VTT	Assembly of bellows fatigue equipment, Fatigue experiments
Jukka Väinölä, MScTech	VTT	Design of Fabello equipment
Pieti Marjavaara, MScPhys	VTT	Instrumentation of Fabello equipment
Simo Ylitalo	Kelloseppä koulu	Prototyping of instrumentation for Fabello
Mikko Patalainen, MScTech	VTT	Detail design of Fabello equipment
Erkki Järvinen, MScTech	VTT	Instrumentation and software of fatigue test control system
Matti Halonen, MScTech	VTT	Instrumentation and software of fatigue test control system

Implementation of Quantitative Fire Risk Assessment in PSA (FIRAS)
Kvantatitatiivisen paloriskiarvioinnin soveltaminen PSA-järjestelmissä

Research organisation: VTT
Project manager: Simo Hostikka, VTT
Deputy project manager: Johan Mangs, VTT

Person	**Org**	**Task**
Simo Hostikka, DScTech	VTT	Project Manager, DNS flame spread simulations, OECD PRISME
Johan Mangs, PhD	VTT	Deputy Project Manager, vertical flame spread experiments
Anna Matala, MScTech	VTT	Pyrolysis model parameter estimation,
Antti Paajanen	VTT	Monte Carlo simulations for fire PRA, development and maintenance of Probabilistic Fire Simulator
Terhi Kling, MScTech	VTT	fire-HRA modelling
Topi Sikanan, MScTech	VTT	Sub-grid scale modelling of cable objects.

Fracture assessment for reactor circuit (FRAS)
Reaktoripiirin murtumisriskin arviointi

Research organisation: VTT
Project manager: Päivi Karjalainen-Roikonen, VTT

Person	Org.	Task
Kim Calonius, MScTech	VTT	Loads transferred by supports
Antti Timperi, MScTech	VTT	Fluid-structure interaction
Otso Cronvall, MScTech	VTT	Residual stresses
Heikki Keinänen, MscTech Kalle Kaunisto, Res. Trainee Juha Kuutti, MScTech	VTT	Engineering assessment tools
Anssi Laukkanen, MScTech Tapio Planman, MscTech Päivi Karjalainen-Roikonen, MscTech	VTT	Assessment of 3D flaws
Anssi Laukkanen, MScTech Tom Andersson, MScTech Pasi Lindroth, MScTech	VTT	Micromechanical modelling
Heikki Keinänen, MScTech Kalle Kaunisto, Res. Trainee Juha Kuutti, MScTech	VTT	Development of sub-modelling technique
Lauri Elers, MScTech Anssi Laukkanen, MScTech Tapio Planman, MScTech	VTT	Ductile crack growth measuring capacity
Matti Valo, MScTech, Petteri Lappalainen, MScTech, Tapio Planman, MScTech	VTT	Irradiation embrittlement

Hydrogen Combustion Risk and Core Debris Coolability (HYBCIS2)
Vetypaloriski ja sydänromukasojen jäähdytettävyys

Research organisation: VTT
Project manager: Eveliina Takasuo, VTT
Deputy project manager: Tuomo Sevón, VTT

Person	Org.	Task
Eveliina Takasuo, MScTech	VTT	Project manager, MEWA and PORFLO calculations, COOLOCE experiments, follow-up of the OECD THAI project
Tuomo Kinnunen, Engineer	VTT	COOLOCE experiments, technical design and construction of the test facility
Pekka H. Pankakoski, MscTech	VTT	COOLOCE experiments, technical design and construction of the test facility (part-time)
Stefan Holmströn, DrTech	VTT	COOLOCE experiments, technical design and management of the test facility
Seppo Peltonen, Engineer	VTT	COOLOCE test facility construction
Ville Hovi, MscTech	VTT	PORFLO code development and calculations
Mikko Ilvonen, LicTech	VTT	PORFLO code development and calculations
Risto Huhtanen, LicTech	VTT	FLUENT modeling of hydrogen behavior

Project full name IMPACT 2010
Projektin nimi suomeksi IMPACT 2010

Research organisation: VTT
Project manager: Ilkka Hakola VTT

Person	**Title**	**Org.**	**Task** Tasks: 1.1 Management; 1.2 Apparatus, 1.3 Pre-stressed walls, 1.4 Basic walls, 1.5 3D missile
Ilkka Hakola	MScTech	VTT	Project manager, 1.1, 1.2, 1.3, 1.4, 1.5
Vepsä Ari	MScTech	VTT	Assistant project manager, 1.1, 1.2, 1.3, 1.4, 1.5
Calonius Kim	MScTech	VTT	1.3, 1.4, 1.5
Halonen Matti	MScTech	VTT	1.2, 1.3, 1.4, 1.5
Halonen Pekka	Technican	VTT	1.2,1.3, 1.4, 1.5
Hietalahti Jouni	Research eng.	VTT	1.2, 1.3, 1.4, 1.5
Järvinen Erkki	MScTech	VTT	1.2, 1.3, 1.4, 1.5
Kukko Heikki	Research Prof.	VTT	1.1
Mäkinen Jukka Olavi	Research eng	VTT	1.2, 1.3, 1.4, 1.5
Patalainen Mikko	Student	VTT	1.1, 1.2, 1.3, 1.4
Saarenheimo Arja	LicScTech	VTT	1.3, 1.4, 1.5
Schlesier Erja	Assistant	VTT	1.1

Safety management and organizational learning (MANOR)
Turvallisuuden johtaminen ja organisatorinen oppiminen

Research organisation: VTT
Project manager: Pia Oedewald, VTT
Deputy project manager: Teemu Reiman, VTT

Person	Org.	Task
Pia Oedewald, M.A. (Psych)	VTT	Project manager
Teemu Reiman, PhD (Psych)	VTT	Deputy project manager
Elina Pietikäinen, M.A. (Psych)	VTT	Research scientist
Nadezhda Gotcheva, PhD (Psych)	VTT	Research scientist
Luigi Macchi, PhD (Psych)	VTT	Research scientist

Model-based safety evaluation of automation systems (MODSAFE)
Malleihin perustuva automaation turvallisuuden arviointi

Research organisations: VTT, Aalto
Project manager: Janne Valkonen, VTT

Person	Org.	Task
Janne Valkonen, M.Sc.(Tech.)	VTT	Project manager, Selection and modelling of cases, Model checking of asynchronous processes, Development of modular approach to model checking larger systems, Reporting and publishing
Kim Björkman, M.Sc. (Tech.)	VTT	Selection and modelling of cases, Model checking of asynchronous processes, Development of modular approach to model checking larger systems, Reporting and publishing
Jussi Lahtinen, M.Sc.(Tech.)	VTT	Selection and modelling of cases, Model checking of asynchronous processes, Development of modular approach to model checking larger systems, Reporting and publishing
Ilkka Niemelä, Professor	Aalto	Selection and modelling of cases, Model checking of asynchronous processes, Development of modular approach to model checking larger systems, Reporting and publishing
Juho Frits, M.Sc.(Tech.)	Aalto	Selection and modelling of cases, Model checking of asynchronous processes, Development of modular approach to model checking larger systems, Reporting and publishing
Jonatan Ropponen Summer intern	Aalto	Model checking of asynchronous processes

OpenFOAM CFD-solver for nuclear safety related flow simulations (NuFOAM)
OpenFOAM CFD -ratkaisija ydinturvallisuuden virtaussimulointeihin

Research organisation: Fortum Power and Heat Oy, VTT, Aalto
Project manager: Dr Tellervo Brandt, Fortum Power and Heat Oy
Deputy project manager: Dr Timo Pättikangas, VTT

Person	**Org.**	**Task**
Tellrvo Brandt, D.Sc.	Fortum	Project manager
Timo Toppila, M.Sc.	Fortum	Subproject 1
Timo Pättikangas, D.Sc.	VTT	Subprojects 1 and 3.1
Juho Peltola, M.Sc.	VTT	Subproject 1 and 3.1
Timo Siikonen, Prof.	Aalto	Subproject 2.1
Tomas Brockmann, M.Sc.	Aalto	Subproject 2.1

Numerical modeling of condensation pool (NUMPOOL)
Lauhdutusaltaan numeerinen mallintaminen

Research organisation: VTT
Project manager: Timo Pättikangas, VTT
Deputy project manager: Antti Timperi, VTT

Person	**Org.**	**Task**
Timo Pättikangas, DTech	VTT	Project manager, CFD modeling of condensation pool
Jarto Niemi, MScTech	VTT	CFD modeling of condensation pool
Antti Timperi, MScTech	VTT	Deputy project manager, modeling of fluid-structure interactions

Operator practices and human-system interfaces in computer-based control stations (O'PRACTICE)
Operointikäytännöt ja käyttöliittymät digitaalisissa valvomoissa

Research organisation: VTT
Project manager: Jari Laarni, VTT

Person	**Org.**	**Task**
Jari Laarni, PhD	VTT	Project manager, Development of the concept of operations for digitalized CRs, Management of HFE activities
Leena Norros, Res Prof, PhD	VTT	Deputy project manager, Development of the concept of operations for digitalized CRs, Management of HFE activities, Participation in WGHOF
Iina Aaltonen, MScTech	VTT	Development of the concept of operations for digitalized CRs
Hannu Karvonen, MA	VTT	Development of the concept of operations for digitalized CRs
Hanna Koskinen, MA	VTT	Development of the concept of operations for digitalized CRs, Secondee at OECD Halden Reactor Project
Marja Liinasuo, PhD	VTT	Development of the concept of operations for digitalized CRs, Management of HFE activities
Leena Salo, MScTech	VTT	Development of the concept of operations for digitalized CRs, Management of HFE activities
Paula Savioja, MScTech	VTT	Development of the concept of operations for digitalized CRs, Management of HFE activities

Improvement of PACTEL Facility Simulation Environment (PACSIM)
PACTEL koelaitteiston simulointiympäristön kehittäminen

Research organisation: LUT
Project manager: Juhani Vihavainen, LUT

Person	**Org.**	**Task**
Juhani Vihavainen, Lic.Tech	LUT	Project manager, PACSIM project, TRACE code modelling and calculations
Heikki Purhonen, DrTech	LUT	Deputy project manager
Antti Rantakaulio, MScTech	LUT	TRACE code modelling and calculations
Virpi Kouhia, MScTech	LUT	Modeling of experiments, Apros code
Vesa Riikonen, MScTech	LUT	Data management of experiments

Passive safety system simulation (PASSIMU)
Passiivisten turvallisuusjärjestelmien simulointi

Research organisation: LUT
Project manager: Heikki Purhonen, LUT
Deputy project manager: Vesa Riikonen, LUT

Person	**Org.**	**Task**
Heikki Purhonen, DTech	LUT	Project manager, Planning and report revision
Vesa Riikonen, MScTech	LUT	Deputy project manager, Report revision
Virpi Kouhia, MScTech	LUT	APROS simulation and analysis, material retrieval and analysis, construction of reports
Markku Puustinen, MScTech	LUT	Report revision

Development and Validation of Fuel Performance Codes (POKEVA)
Polttoainemallien kehittäminen ja validointi

Research organisation: VTT
Project manager: Seppo Kelppe, VTT
Deputy project manager: Jan-Olof Stengård, VTT

Person	**Org.**	**Task**
Seppo Kelppe, MScTech	VTT	Project management, fuel behaviour and performance, international collaboration
Jan-Olof Stengård	VTT	FRAPCON and FRAPTRAN-GENFLO applications
Ville Tulkki, MScTech	VTT	ENIGMA code validation, FUMEX III CRP
Libor Klecka, MScTech	VTT	ENIGMA code, reactor physics, Halden experiment qualification
Asko Arffman, MSc Tech	VTT	SCANAIR code validation; RIA simulations; probabilistic methods
Jukka Rintala, MScTech	VTT	Probabilistic transient analysis methodology
Anitta Hämäläinen, Dr Tech	VTT	Thermal Hydraulics

Risk informed inspections of piping (PURISTA)
Putkistojen riskitietoiset tarkastukset

Research organisation: VTT
Project manager: Kaisa Simola, VTT
Deputy project manager: Ari Vepsä, VTT

Person	Org.	Tasks
Kaisa Simola, PhD	VTT	Project manager, risk-informed in-service inspection methodology, probability of detection
Ari Vepsä, MScTech	VTT	Deputy project manager, vibrations and probabilistic fracture mechanics
Jouni Alhainen, MScTech	VTT	Probabilistic fracture mechanics software development
Otso Cronvall, MScTech	VTT	Probabilistic fracture mechanics, database analyses
Esa Leskelä, MScTech	VTT	NDT simulations
Ilkka Männistö, MScTech	VTT	Risk-informed in-service inspection methodology, database analyses
Matti Sarkimo, LicTech	VTT	NDT simulations

Release of radioactive materials from a degrading core (RADECO)
Radioaktiiviset päästöt vakavissa reaktorionnettomuuksissa

Research organisation: VTT
Project manager: Tommi Kekki, VTT
Deputy project manager: Riitta Zilliacus, VTT

Person	Org.	Task
Tommi Kekki, MSc	VTT	Project manager, Participation in OECD/BIP project, Iodine and nitric acid experiments
Riitta Zilliacus, MSc	VTT	Deputy project manager, iodine and nitric acid experiments
Maija Lipponen, MSc	VTT	Iodine literature study
Jaana Rantanen	VTT	Nitric acid experiments
Ilona Lindholm, MScTech	VTT	Shutdown conditions
Atso Suopajärvi, MScTech	VTT	Shutdown conditions