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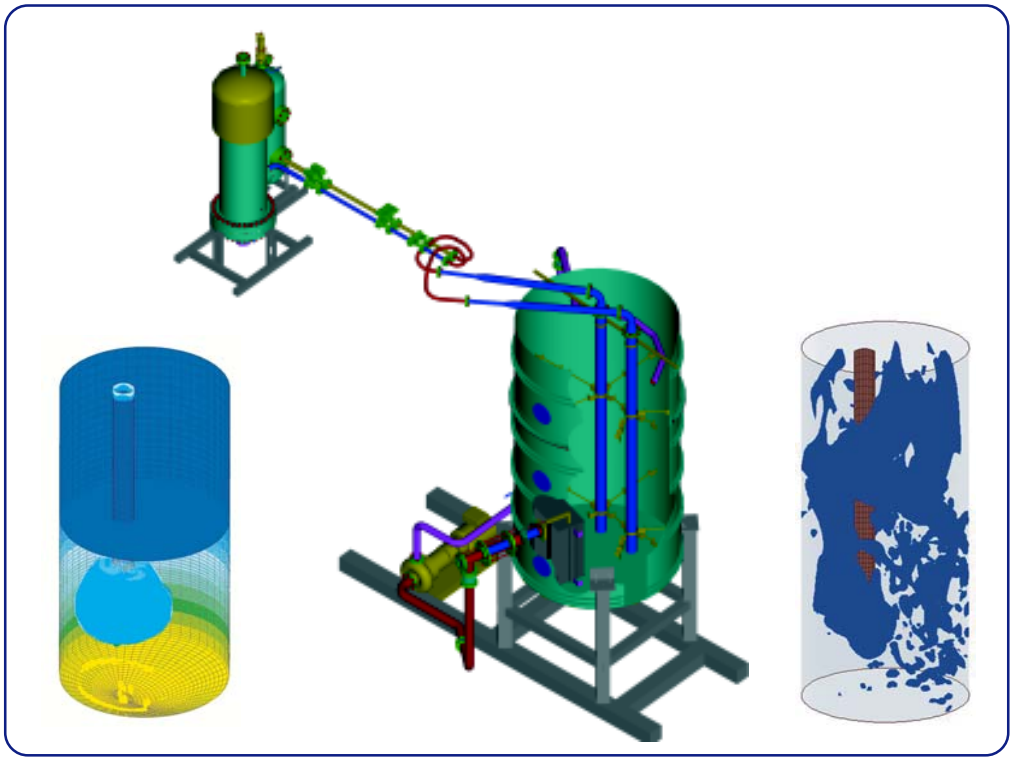

FINNUS
The Finnish Research Programme on Nuclear Power Plant Safety 1999–2002
Executive Summary

VTT TIEDOTTEITA – RESEARCH NOTES 2165

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Abstract

FINNUS (1999–2002) is the Finnish public research programme on nuclear power plant safety, launched and administrated by the Ministry of Trade and Industry (KTM). The programme has concentrated on the themes of ageing, accidents and risks. The general objectives of the programme have been to develop tools and practices for safety authorities and utilities, to provide a basis for safety-related decisions, to educate new nuclear energy experts, and to promote technology and information transfer. The technical objectives of the programme have been prepared under the guidance of the Radiation and Nuclear Safety Authority (STUK), but the views of the Finnish power companies have been taken into consideration. Funding of the programme has been mainly from public sources. The annual volume of the programme has been about Euro 3.6 million and 30 person-years. The research has been co-ordinated and mainly conducted by the Technical Research Centre of Finland (VTT) with a significant contribution from Lappeenranta University of Technology (LTKK).

The effects of **ageing** on nuclear power plants have been studied intensively in order to evaluate the safe remaining lifetime of the components and the efficiency of the corrective measures. The programme has mainly concentrated on studies in ageing effects on material properties and degradation mechanisms of metallic structures, structural integrity and in-service inspection as well as monitoring methods including reinforced concrete structures as a new area. The **accident** theme has concentrated on operational aspects of nuclear power plant safety. The issues of nuclear fuel behaviour, reactor physics and dynamics modelling, thermal hydraulics and severe accidents were addressed under the theme by conducting both computational and experimental studies. In the **risk** field, attention has been paid to advanced risk analysis methods and their applicability, and to the evaluation of fire risks, safety critical applications of software-based technology, as well as human and organisational performance.

This executive summary gives a brief description of the goals and results of the programme. The programme has published 57 scientific articles, 233 mainly international conference papers, and 274 other reports. Six doctoral theses, two licentiate and 18 master's theses were completed. The total volume of the programme during the four years was about 130 person-years and Euro 14.4 million.

Preface

Public nuclear energy research in Finland as national programmes was started in 1989, launched by the Ministry of Trade and Industry (KTM). Since then, these programmes have been carried out in the fields of operational aspects of safety, structural integrity and nuclear waste management. In parallel, there have been technology programmes on nuclear fusion, advanced light water reactor concepts and plant life management, funded partly by the National Technology Agency (Tekes).

In 1998, KTM decided to continue the national research efforts on fission reactor safety in a single research programme after completion of the programmes on Reactor Safety (RETU 1995–1998) and Structural Integrity of Nuclear Power Plants (RATU2 1995–1998). The national advisory committee on nuclear energy, commissioned by KTM, made a general plan for the combined programme and for its organisation. The programme, *The Finnish Research Programme on Nuclear Power Plant Safety (1999–2002) FINNUS (Kansallinen ydinvoimalaitosten turvallisuustutkimusohjelma),* was to concentrate on the themes of ageing, accidents and risks. The concept of national research programmes will also continue after FINNUS: KTM has commissioned a long-term-plan for the next programme for the years 2003–2006, called preliminary SAFIR (Safety of nuclear power plants – Finnish national Research programme).

The Technical Research Centre of Finland (VTT) has co-ordinated the FINNUS programme and performed most of the research with a significant contribution from Lappeenranta University of Technology (LTKK). The main funding sources have been KTM, VTT, the Radiation and Nuclear Safety Authority (STUK), the Finnish power companies Teollisuuden Voima Oy (TVO) and Fortum Oyj. LTKK has offered a research laboratory for the use of the programme. These parties have also been represented in the steering group of the programme.

The execution of the programme was based on the general plan and annual plans prepared for KTM in co-operation with the regulatory body, the power companies and the research bodies. This report summarises the FINNUS programme. Highlights of the results are shown in Appendix A.

This report was prepared by the programme leader in co-operation with the project leaders and members of the programme staff. Several persons from various institutions have actively contributed to the steering, strategy and reference group activities of the FINNUS programme. This support is greatly appreciated by the programme staff.

Contents

1. Introduction

A continuous high level of safety is a prerequisite for the use of nuclear energy. About 27 % of electricity generated in Finland is nuclear, and in 2002 the Government made a positive decision-in-principle, approved by Parliament, concerning the construction of a new nuclear power plant (NPP) unit. High operational reliability and careful upgrading have maintained competitive production costs also in the open electricity market. Confidence in nuclear safety calls for continuous investment in plant operation and supervision. These activities are effectively supported by well directed research in various fields of technology and human behaviour in order to take into account modernisation and upgrading of plant processes, implementation of new techniques, changing production goals and renewal of safety requirements. Research also deepens the understanding of new technology needed in the construction and operating licensing phases of new units.

In the planning of the research period of FINNUS, 1999–2002, it was recognised that a focused and result-oriented research programme is necessary, where various fields of nuclear safety research are pooled and where strategic planning of resources is facilitated [1]. Thus, the previously separated fields of structural and operational safety research were combined into the Finnish Research Programme on Nuclear Power Plant Safety FINNUS. The Ministry of Trade and Industry (KTM) launched the programme and has administrated it. In order to guarantee independent know-how and research resources for the public sector, the needs of the Radiation and Nuclear Safety Authority (STUK) were dominant in the planning of the programme. This aspect has also been reflected in the funding and steering structure of the programme. In order to combine the limited national resources, the Finnish power companies have also contributed to the national programme by offering resources for specific tasks and by participating in the steering and reference groups.

The general objectives of the FINNUS programme in the long term were to

- develop tools and practices for safety authorities and utilities
- provide a basis for safety-related decisions
- educate new nuclear energy experts
- promote technology and information transfer.

The research objectives of the FINNUS programme were classified under three themes, **ageing**, **accidents** and **risks** aiming at integrity, safety and reliability. The effects of ageing on nuclear power plants (NPP) have been studied intensively in order to evaluate the safe remaining lifetime of the components and the efficiency of possible corrective measures. The ageing field covered material sciences of the metallic structures in a nuclear power plant, structural integrity studies and in-service inspection and

monitoring methods including reinforced concrete structures as a new area. The accident theme covered operational aspects of nuclear power plant safety. Research has been conducted in the fields of basic reactor physics and dynamics, fuel studies, thermal hydraulics and special questions of severe accidents. In the field of risk studies, one of the goals has been to concentrate on advanced risk analysis methods and their applicability, and on the other hand, to pay attention to the risk or reliability evaluation of a certain process or technology. In the FINNUS programme, the latter group included studies on fire risks, safety critical applications of software-based technology, as well as human and organisational performance.

Until the publication of this report, the FINNUS programme has produced a total of 564 reports in various categories. A major publishing channel has been conference presentations but also 57 refereed scientific articles have been produced. Many detailed technical results were documented as working reports with limited distribution. Concurrently with this report, the Final Report of the programme has been published [2] giving information of the 11 research projects of the programme in more detail. The Final Report includes project summary reports of the main goals and achievements as well as a selection of more detailed research results in the form of presentations of the FINNUS Final seminar 14–15 November 2002 in Otaniemi, Espoo.

The research methods have formed a broad spectrum:

- development of theoretical models, from technical to psychological
- use of highly sophisticated mathematical methods
- development of computer codes
- calculations and simulations with international and in-house computer codes
- studies on chemical and physical phenomena
- planning and construction of novel experimental facilities
- carrying out and analysing experiments and tests
- collection of statistical data, as well as
- use of observation and interviews when applicable.

International co-operation has been vital in all the fields of the programme – which has traditionally been intensive in the nuclear energy research area. The most important contact organisations have been the OECD Nuclear Energy Agency (NEA), the International Atomic Energy Agency (IAEA), the Commission of European Communities (EU) and the Nordic Nuclear Safety Research (NKS). NKS and the OECD Halden project financed some tasks in the programme. As a main rule, the projects of the EU Framework Programmes were not financially included in FINNUS. However, there has been lively collaboration between FINNUS and EU projects, not least of all thanks to the research scientists taking part in both.

In addition to publishing activities in various international forums, the research staff have contributed to working groups and networks, as well as defined and solved international benchmarks and participated in round robin exercises. The programme has been presented to national and international technical communities and nuclear safety organisations. In 2000, a mid-term seminar of the whole programme was arranged and an interim report was published [3].

The research programme contributed to education of new experts in the field of nuclear safety in co-operation with the universities. Six doctoral theses, two licentiate and 18 master's theses were completed. In 2002, the programme employed a total of 25 young researchers and research trainees participating in the research projects as summer trainees or with a purpose of graduating. On-going studies for licentiate and doctoral degrees in the projects include both young researchers and senior experts.

FINNUS (1999–2002) briefly:	
Research fields: NPP ageing, accidents and risks **Research Partners**: VTT Processes VTT Industrial Systems VTT Building Technology Lappeenranta University of Technology (LTKK) **Co-ordination:** VTT Processes	**Number of research projects: 11** **Total volume (1999–2002)**: Euro 14.4 million 130 person-years **Funding in 2002** (million Euro): KTM: 1.40 VTT: 1.00 STUK: 0.65 Utilities: 0.23 Others: 0.26
http://www.vtt.fi/pro/tutkimus/finnus/ or seek at **http://www.vtt.fi**	

In FINNUS there have been 11 research projects. Chapter 2 gives brief information of these projects and their main results, describing their interdisciplinary co-operation and providing some statistical information. A summary is given in Chapter 3. The Appendix A contains highlights of the achievements of the programme.

2. FINNUS programme

2.1 Organisation

The research has mainly been performed by VTT with a significant contribution from Lappeenranta University of Technology (LTKK). VTT has also co-ordinated the execution of the programme. The general plans were prepared for the four-year period 1999–2002, and re-evaluated in the strategy seminar in 1999. The execution has been based on annual plans prepared by the project leaders and programme staff under the guidance of the project reference groups and accepted by the steering group. The results have been summarised as annual reports.

In the organisation of steering and support functions of the programme, strong coupling was ensured between the funding bodies, research organisations and the end-users of the results, both at the nuclear safety regulator and at the power companies. The main duty of the steering group was to supervise the overall performance of the programme. The steering group set up reference groups for the research projects and nominated strategic planning groups on the main themes.

The project reference groups contributed to the planning of the projects, e.g. by suggesting new research topics. They advised on the projects and evaluated the results against the plans. An important task of the reference groups has been to communicate between the research groups and the users of the results.

The strategic groups evaluated the priorities and discussed the challenges of the whole programme against national needs, as well as contributed to planning the main contents of the next programme [4].

The steering group and the project reference groups typically met 3–4 times a year, while the strategic planning groups met twice during the programme. The organisation scheme of the FINNUS programme is shown in Figure 1.

The steering and reference groups evaluated the FINNUS programme in connection with the mid-term seminar in 2000. With the focus also on the next programme, the projects and their results, their educational value, applications and targets were more thoroughly evaluated again in the beginning of 2002 by the reference groups. A final evaluation will be carried out in 2003.

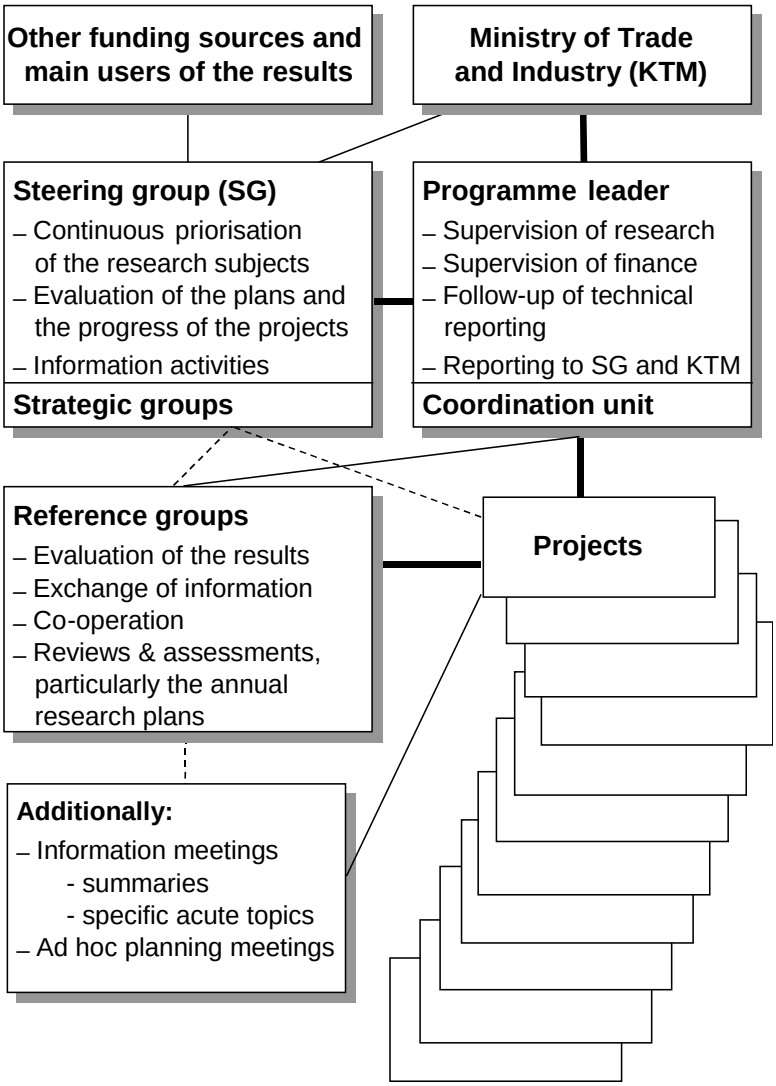

Figure 1. Organisation of the FINNUS programme.

In FINNUS there have been 11 research projects in the fields of ageing, accidents and risks, as indicated in Table 1. There were natural connections between the projects, and one objective of the programme was to strengthen these links. All the projects were planned for the four-year period, but detailed objectives varied during the execution of the programme. VTT has co-ordinated the FINNUS programme and also performed most of the research with a significant contribution from LTKK, which has also offered the thermal hydraulics research laboratory for the use of the programme.

Table 1. Names and research organisations of the FINNUS projects.

Main theme Project name (Project Acronym) / *Project name in Finnish*	Research organisations
Ageing	
Ageing phenomena (AGE) / *Vanhenemisilmiöt*	VTT Industrial Systems VTT Processes
Structural integrity (STIN) / *Lujuuden varmistaminen*	VTT Industrial Systems VTT Processes
In-service inspections and monitoring (INSMO) / *Tarkastukset ja kunnonvalvonta*	VTT Industrial Systems VTT Building Technology
Accidents	
Transient behaviour of high burnup fuel (KOTO) / *Korkeapalamaisen polttoaineen transientti- ja onnettomuuskäyttäytyminen*	VTT Processes
Reactor physics and dynamics (READY) / *Reaktorifysiikka ja -dynamiikka*	VTT Processes
Thermal-hydraulic experiments and code validation (TOKE) / *Termohydrauliset kokeet ja ohjelmistojen kelpoistus*	Lappeenranta University of Technology VTT Processes
Modelling and simulant experiments of severe accident phenomena (MOSES) / *Vakavien reaktorionnettomuuksien mallinnus ja simulanttikokeet*	VTT Processes VTT Industrial Systems
Risks	
Fire safety research (FISRE) / *Paloturvallisuus*	VTT Building Technology
Programmable automation system safety integrity assessment (PASSI) / *Ohjelmoitavan automaation turvallisuuden arviointi*	VTT Industrial Systems
Methods for risk analysis (METRI) / *Riskianalyysin menetelmät*	VTT Industrial Systems
Working practices and safety culture in NPP operations (WOPS) / *Toimintatavat ja turvallisuuskulttuuri ydinvoimalaitoksessa*	VTT Industrial Systems
Administration and information of the research programme (HALTI) / *Tutkimusohjelman hallinto ja tiedotus*	VTT Processes

2.2 Description of the projects and their main results

The research objectives of the FINNUS programme were classified under three themes, **ageing**, **accidents** and **risks** aiming at integrity, safety and reliability. The relationships of the projects to these themes are shown in Figure 2.

Figure 2. Locations of the projects in the "triangular research field" of FINNUS.

Ageing

The ageing field covers material sciences of the metallic structures in a nuclear power plant, structural integrity studies and in-service inspection and monitoring methods. Three research projects, **AGE, STIN** and **INSMO** mainly concentrate on these issues.

The research in the **Ageing phenomena project AGE** was mainly oriented on ageing to ensure or to extend the operating lifetime of the components of nuclear power plants. New degradation mechanisms such as stress corrosion cracking of some weld metals and irradiated stainless steels have recently been discovered in aged materials. These latest ageing mechanisms are not included in the existing life management plans. Such degradation mechanisms observed in old facilities should also be avoided when planning new reactor units. Material technology contributes significantly both to the scientific background of fundamental research, as well as to everyday engineering work during all phases of life time of the plants. Most of the work is focused on the passive structures and components that have long life and are very difficult to repair or replace.

In the AGE project, a bellows-loaded fatigue-testing capability has been created. Corrosion fatigue tests can be carried out to define the materials' lifetime and the nucleation of cracks. Rising displacement crack growth rate measurements can be

conducted under LWR conditions and various interrelationships for environmentally assisted cracking can be understood. A Mixed Conduction Model (MCM) for the inner oxide layer on construction materials in primary circuits has been developed in order to understand how the water chemistry influences corrosion and activity incorporation. An experimental set-up has been constructed that enables electrochemical studies of construction materials even in low-conductivity high-temperature water such as BWR coolant, with the option to detect dissolving species as well. A model has been created to estimate the effects of irradiation/annealing cycles on the mechanical properties and on the re-embrittlement. Water chemistry, chemical composition of materials, corrosion potentials and oxide film as well as mechanical properties and loading parameters form an interacting circle determining environmentally assisted cracking phenomena in NPPs.

The main goal of the **Structural integrity project STIN** was to create verified experimental and computational methods, and to verify the existing methods for assessing the remaining lifetime of components and structures and their ability to withstand the possible accident situations. During the four-year project period, the main focus was on developing material characterisation methods, methods for defining loading conditions and developing fracture mechanism analysis methods.

The results obtained in the development of methods for small specimen toughness characterisation of irradiated materials led to major improvements in the reliability and material usage of fracture toughness testing. At the same time the transferability of basic test results to structural integrity assessment was significantly improved. The computational tools and methods for assessing structures under thermal and impact loading conditions were developed and verified. Local approach fracture mechanics computation methods were found viable and worth pursuing in the predictions of material toughness as well as ductile crack propagation and brittle fracture initiation. A calibration methodology for linking the Master Curve method to a local approach with Weibull statistics was identified. The methodology is dependent on determining the normalisation fracture toughness and provides a nearly identical fracture toughness temperature dependency to that of the Master Curve.

The **In-service inspections and monitoring project INSMO** has concentrated on the techniques and systems that are applied to examine the structural integrity of critical components by non-destructive evaluation (NDE) methods. Additionally, the monitoring of material properties has been considered to some extent. The conventional non-destructive methods are usually applied to metallic components and materials. The reinforced concrete structures have been an interesting additional area, which has brought together people with different background competence. New problems from the

standpoint of the conventional NDE have been brought out. Based on the measurement trials performed, it seems possible to find solutions to many of these challenges.

Methods to produce suitable artificial reflectors for the qualification samples of ultrasonic inspection have been examined and these reflectors have been measured and analysed. Two computer codes for simulation of ultrasonic inspection have been installed and applied in the project, as well as to some extent in practice. A new method based on spectral analysis of the ultrasonic signals has been designed and programmed in order to offer future possibilities to measure material characteristics.

Accidents

The accident field covers fuel research, reactor physics and dynamics, experimental and computational thermal hydraulics and severe accidents, which have been studied in the **KOTO, READY, TOKE** and **MOSES** projects.

Reactor analyses become more and more demanding for several reasons: higher discharge burnups are pursued, best-estimate type approach is increasingly favoured, and acceptance criteria assessments are becoming more sophisticated. The purpose of the **Transient behaviour of high burnup fuel project KOTO** has been to keep in pace with this development as far as fuel performance modelling is concerned.

The project supports assessing the licensing criteria and evaluating the consequences of efforts for improved fuel utilisation. Statistical methods for fuel analyses have been elaborated for extensive applications. Two parallel steady-state and accident code pairs are now well established and in operation at VTT: the USNRC codes FRAPCON-3 and FRAPTRAN, and independently, ENIGMA and SCANAIR. A new development with the READY project, featuring advanced thermal hydraulics coupled with a fuel accident performance model, the FRAPTRAN-GENFLO code, is opening an unparalleled capability for realistic transient simulation.

Additional high burnup data, for materials and for rod integral behaviour are available from recently launched international programmes. The Finnish organisations are very well placed in the most essential of these, with the arrangement of participation and application mainly managed by VTT. High burnup effects must not be overlooked as regards postulated accident behaviour. STUK has lately granted the utilities a new assembly burnup limit of 45 MWd/kgU for the fuel types now in use. The methods and expertise due to the KOTO project were among those that supported both STUK and the utilities in assessing this upgrade.

In the **Reactor physics and dynamics project READY** and in its predecessors, a computer code system and competence has been created and maintained for carrying out all reactor physics calculations needed in Finland. Additionally, a comprehensive and independent computer code system and expertise for reactor safety analyses have been developed, thus providing tools from basic nuclear data to three-dimensional transient and accident analyses.

As a result of upgrading, adapting, developing and validating several reactor physics and dynamics codes of VTT's code system, more accurate calculations and predictions of physical phenomena can now be performed. Three-dimensional reactor physics codes have been introduced and validated for various applications, especially for out-of-core flux, criticality safety, and dose rate calculations. A multi-temperature MCNP cross-section and scattering law library have been created. Most recently, the Monte Carlo technique has been applied in burnup calculations. The development of a new, sophisticated nodal model has resulted in a highly promising new BWR simulator code, ensuring independent computational capabilities for steady-state and safety analyses. Validation of VTT's three-dimensional BWR dynamics code has been completed, thus enabling analyses with three-dimensional core models to be carried out for BWR, PWR and VVER type reactors. Until now, the transient analyses for BWRs have been done with one-dimensional models. Fuel models of the dynamics codes have been improved, and USNRC's fuel behaviour code has been coupled with VTT's advanced hydraulics model in co-operation with the KOTO project. The coupled code has been delivered to the USA in agreement with USNRC. The development and application of a sophisticated hydraulics solver in reactor dynamics has resulted in a BWR circuit model that has been tested in steady-state calculations.

The **Thermal-hydraulic experiments and code validation project TOKE** addressed both the experimental and computational aspects of nuclear safety studies. Integral VVER-related experiments dealing with a steam generator collector header rupture incident and with non-condensable gas behaviour in the primary circuit were carried out in the Parallel Channel Test Loop (PACTEL). Local loading effects due to water flow and thermal stratification in a T-joint of a hot horizontal pipe and a cold vertical tube were investigated in a purpose-built test loop in co-operation with the STIN project. The behaviour of non-condensable gas during the first seconds of a conceivable large break loss-of-coolant accident (LBLOCA) blowdown to a BWR condensation pool was also studied in a subproject related to separate effect tests. For this purpose, a test rig with a scaled down water pool, blowdown pipes, an emergency core cooling system (ECCS) strainer and a pump were designed and constructed in LTKK. Thermal hydraulic and computational fluid dynamics (CFD) calculations with the codes APROS and Fluent, respectively, supported the planning and analysis of both the integral and separate effect tests.

The **Modelling and simulant experiments of severe accident phenomena project MOSES** has systematically investigated phases of severe reactor accidents relevant to Finnish NPPs. The areas of research have been pressure vessel failure mode, core debris coolability, fission product behaviour, including chemistry, containment thermal hydraulic loading, especially hydrogen detonations and phenomena relevant for long-term severe accident management. The outcome of the project has been novel analysis tools, procedures and tools to perform multi-disciplinary analyses and new experimental results reducing noticeably uncertainties that existed in the field of severe accidents.

A new FEM-model was developed and validated against experiments for 2D- and 3D-analyses of pressure vessel lower head creep behaviour. The model is suitable for assessing failure of lower head with or without penetrations. The coolability of particulate core debris in the containment water pool has been assessed with simulant experiments. The particle bed characteristics were chosen to be representative to the Olkiluoto plant. In collaboration with the STIN project, a capability of analysing consequences of supersonic, energetic hydrogen combustion has been developed comprising 3-dimensional simulation of thermal hydraulic loads, and analysis of the structural response of concrete walls and steel pipelines to the loads. Long-term severe accident management issues have been studied by evaluating the radiation levels in the containment atmosphere and water pools, and the effects of radiation on the water pool chemistry. The results can be used to assess human accessibility into the containment and the survivability of various accident management devices in the high radiation field.

Risks

The risk field covers topics on fire safety **FISRE,** programmable automation **PASSI,** methods of risk analysis **METRI** and human factors **WOPS.**

The **Fire safety research project FISRE** was organised into three subprojects: effect of smoke and heat on electronics, modelling of fire scenarios for probabilistic safety assessment (PSA), and studies on active fire protection equipment. The strategic goal of the FISRE project was to improve the quantitative capability of fire-PSA in NPPs. Using technology transfer, experiments and modelling of phenomena, a new in-depth understanding of fire problems has been obtained. Furthermore, new measuring and smoke detection techniques have been proposed. The methods developed find wide application also outside the nuclear field, as shown by examples of recently constructed buildings. A Monte Carlo calculation platform was made for estimating probability distribution for the time of damage of the second train in a cable tunnel of a NPP, given the ignition of the first train. Realistic data were collected from utilities for both the cable tunnels and an electronics room, and both cases were calculated. The tool has been released outside VTT. Literature studies, experiments and modelling lead to a

quantitative understanding of the acute effects of smoke, humidity or both, on the loss of insulation resistance of control electronics in NPPs. A quantitative calculation formula for the effectiveness of protective coating was proposed.

In general, the **Programmable automation system safety integrity assessment project PASSI** aims to provide support for the authorities and utilities in the licensing process of programmable automation systems. In the PASSI project, new reliability assessment methods and practices for software-based systems have been developed and tested. The key assessment method developed and tested in the project is based on Bayesian statistics and in particular its technical solution called Bayesian networks. Bayesian networks enable the combined implementation of reliability evidence from disparate sources providing at the same time a consistent way of reasoning the assessor's beliefs on the relationship of the different kinds of evidence. The method was tested in an experimental application study on a qualitative reliability estimation of a software-based motor protection relay. The results gained on the use of the method were encouraging and further testing of the methodology will be practised in the benchmark exercise next year. A study on the failure mode and effects analysis of software-based systems was carried out and the results of the study will be utilised in the future example cases. Information related to the ageing of modern instrumentation and control (I&C) equipment was gathered and a preliminary test plan for the simulation of certain operational ageing was prepared.

The **Methods for risk analysis project METRI** focused both on PSA methodology and its applications, especially in multi-criteria decision-making situations where PSA results are combined with other, deterministic criteria to select an optimal decision alternative. The project has promoted the use of risk-informed approaches by developing methods for PSA qualification and expert panels to support risk-informed decision-making. Application areas are the optimisation of in-service inspections, risk-informed safety classification of systems and components, and the reliability of advanced passive systems. The main topics concerning PSA methodology were model uncertainties and human reliability analyses.

Along with the increasing use of PSA in safety-related decision-making, the development of decision analytical methods and tools to facilitate the risk-informed regulation and safety management has become important. The integration of different expertise in the decision process calls for formal approaches in order to achieve a balanced result. It is also important to verify the quality of PSA in relation to the decision in question, so that an appropriate weight can be given to the PSA results in risk-informed decision-making. The METRI project has addressed topics related to the reliability analysis of passive systems, the analysis of human errors of commission, and methods for uncertainty analysis.

The **Working practices and safety culture in nuclear power plant operations project WOPS** has concentrated on human and organisational factors. The project focused on two main topics, the development of the competencies of control-room operators and the organisational culture in high-reliability organisations. Within these topics, several studies were concluded in which practically relevant problems of the Finnish NPPs were tackled. Thus, the studied issues were transformation of operational expertise in a generation change situation, constraints on control-room operators in fire situations, organisational culture in the Nuclear Reactor Regulation department of STUK, and organisational culture in the maintenance department of the Loviisa NPP. As a background of the latter study, an analysis of human errors in maintenance was conducted. New empirical results were obtained in these studies. The work also contributed to a long-term methodological aim to develop a new framework for the analysis of human conduct in dynamic, complex and uncertain situations.

2.3 Co-operation between the projects

The achievements of the projects have been summarised in the previous chapter. There were natural connections between the projects and one objective of the programme was to strengthen these links. In Figure 3, the projects and their connections during the FINNUS programme are shown.

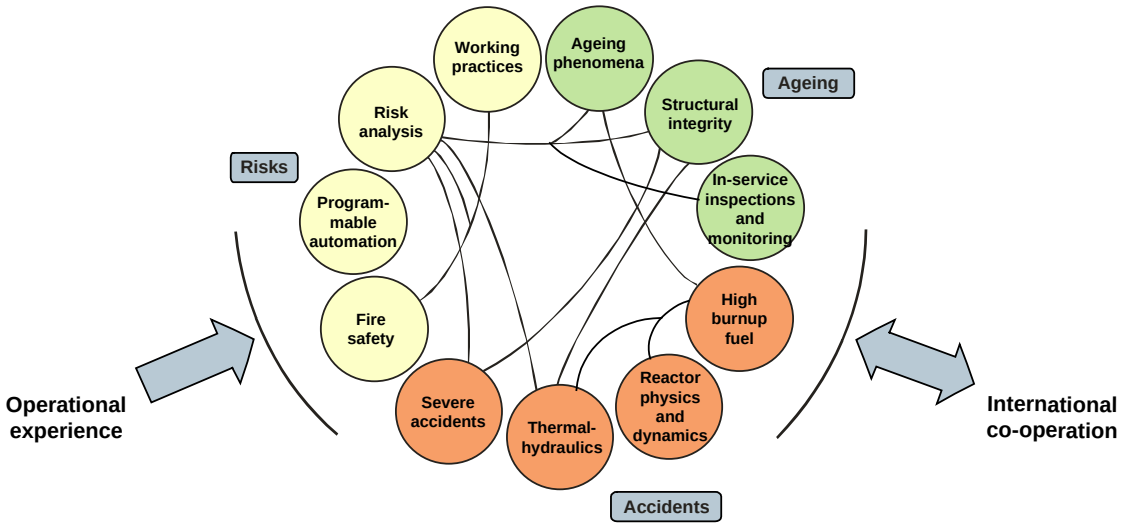

Figure 3. The 11 research projects under the three themes of the FINNUS programme. The projects associated with a certain theme are strongly inter-coupled. Couplings materialised during the programme, especially between the themes, are indicated. Also the connections with the end-users have been strengthened in many projects during the programme.

The links in Figure 3 describe the following tasks:

Thermal hydraulics / Structural integrity: experiments and calculations on local loading effects due to thermal stratification in a T-joint, and design calculations for condensation pool experiments.

Severe accidents / Structural integrity: hydrogen detonation pressure loads on the containment structures during severe accidents.

Risk analysis / Severe accidents: phenomenological uncertainties.

Risk analysis / Thermal hydraulics: passive safety system reliability.

Risk analysis / Ageing phenomena, Structural integrity, In-service inspections and monitoring: risk informed in-service inspection, and investigation of failure modes of degraded pressure equipment, i.e. structural reliability.

Working practices / Fire safety, Risk analysis: method for analysis of management of fire situations in NPPs.

Ageing phenomena / High burnup fuel: corrosion and material phenomena of high burnup fuel.

High burnup fuel / Reactor physics and dynamics: coupling of USNRC's fuel performance code with VTT's thermal hydraulics code that is utilised also in simulators and severe accident calculations.

In addition, other types of co-operation have emerged within the programme framework. Long-term severe accident management issues have been studied both by chemists and physicists. The experience of the material research unit of VTT has been utilised also in the construction and performance of the tests on the severe accident experimental facility. Nuclear power plant buildings have been surveyed to identify possible problem areas where non-destructive inspection or measurement methods used in the primary circuit inspections could be applied. One important function of this task has been the familiarisation of the specialists of building technology with nuclear constructions and the co-operation of NDE specialists from different fields.

A small country has limited national resources for research. However, the well-organised nuclear community has enabled novel couplings between different research fields extending the know-how of the scientists. The external experts participating in the work of the reference groups of the projects have also benefited from the

interdisciplinary approaches and extensions of the projects. People with different background competence have worked in co-operation.

2.4 Statistics

VTT has performed most of the research with a significant contribution from LTKK. The main funding sources have been KTM, VTT, STUK, TVO and Fortum. The main part (about 4/5) of the costs comprises salaries. The annual volume and funding of the projects are shown in Table 2. The total volume of the programme resources has remained fairly even during the four-year period.

Table 2. Annual volume and funding of the projects.

Project (Acronym)	**Volume** [person years]				**Funding** [thousand Euro]			
	99	00	01	02 plan	99	00	01	02 plan
Ageing phenomena (AGE)	5.3	4.4	4.5	3.1	661	567	628	528
Structural integrity (STIN)	2.7	3.7	2.8	3.0	342	436	397	415
In-service inspections and monitoring (INSMO)	1.2	1.3	0.9	0.8	167	160	148	123
Transient behaviour of high burnup fuel (KOTO)	2.4	1.9	1.6	1.7	215	188	170	182
Reactor physics and dynamics (READY)	6.7	5.4	5.2	4.7	547	495	512	487
Thermal-hydraulic experiments and code validation (TOKE)	4.4	3.3	4.2	4.0	514	445	411	466
Modelling and simulant experiments of severe accident phenomena (MOSES)	3.3	2.5	2.3	1.7	445	412	431	366
Fire safety research (FISRE)	1.0	1.1	0.9	1.3	102	141	117	115
Programmable automation system safety integrity assessment (PASSI)	1.7	1.7	2.0	1.7	137	175	231	222
Methods for risk analysis (METRI)	2.3	2.4	2.4	2.1	247	224	268	251
Working practices and safety culture in NPP operations (WOPS)	2.2	2.5	2.5	2.0	188	293	227	266
Administration and information of the research programme (HALTI)	0.9	0.7	0.7	0.9	118	96	97	120
Total	**34.1**	**30.9**	**30.0**	**est. 30.0**	**3683**	**3578**	**3639**	**3541**

Until the publication of this report, the FINNUS programme has produced a total of 564 reports in various categories. In Table 3, the number of publications is arranged project by project. A major publishing channel has been conference presentations but also refereed scientific articles have been produced. Many detailed technical results were documented as working reports with limited distribution.

Table 3. Publications of the projects.

Project	Scientific publications	Conference papers	Research institute reports	Others	Total
AGE	21	47	4	16	**88**
STIN	11	34	2	16	**63**
INSMO	-	8	1	12	**21**
KOTO	-	11	-	-	**11**
READY	2	31	6	54	**93**
TOKE	2	13	-	18	**33**
MOSES	3	11	11	34	**59**
FISRE	2	26	1	15	**44**
PASSI	-	4	2	6	**12**
METRI	10	24	12	23	**69**
WOPS	5	20	12	17	**54**
HALTI	1	4	4	8	**17**
Total	**57**	**233**	**55**	**219**	**564**

The research programme contributed to education of new experts in the field of nuclear safety in co-operation with the universities. Six doctoral theses, two licentiate and 18 master's theses were completed. Their distribution among the projects is shown in Table 4. In 2002, the programme employed a total of 25 young researchers and research trainees participating in the research projects as summer trainees, or with a purpose of graduating. On-going studies for licentiate and doctoral degrees in the projects include both young researchers and senior experts.

Table 4. Academic degrees awarded in the projects.

Project	Doctor (DTech, PhD)	Licentiate (LicTech, LicPhil)	Master (MScTech, MSc, MA)	Total
AGE	2	-	1	**3**
STIN	-	-	1	**1**
INSMO	-	-	-	**-**
KOTO	-	-	1	**1**
READY	-	1	4	**5**
TOKE	1	1	3	**5**
MOSES	1	-	1	**2**
FISRE	-	-	5	**5**
PASSI	-	-	1	**1**
METRI	2	-	-	**2**
WOPS	-	-	1	**1**
Total	**6**	**2**	**18**	**26**

2.5 Nuclear energy research in Finland

The total volume of nuclear energy related R&D efforts in Finland in 1999 were about Euro 27 million, Figure 4; no dramatic changes have occurred since then. The power companies directly fund more than half of the total volume, and the public sector about one third. Half of the total volume is spent on nuclear waste management issues, mainly conducted by the power companies. Nearly 40 % of the resources are used for reactor safety, out of which about half is allocated for fully or partly public research programmes.

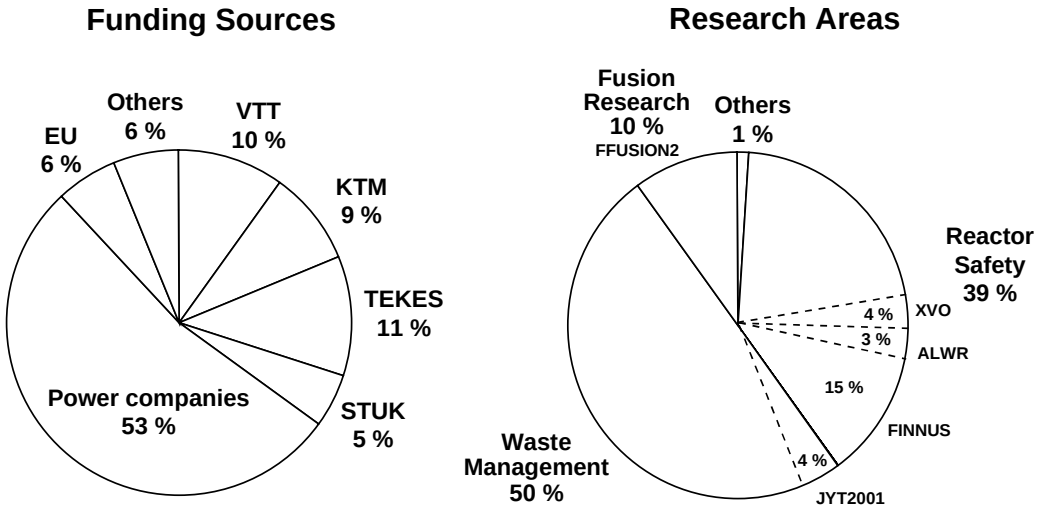

Figure 4. Resources of nuclear energy research in Finland in 1999. The public funding comes from the Ministry of Trade and Industry (KTM), the Technical Research Centre of Finland (VTT), the National Technology Agency (Tekes) and from the Radiation and Nuclear Safety Authority (STUK).

The largest of the public research programmes is FINNUS, which has concentrated on nuclear reactor safety related issues of the existing power plants. The Advanced Light Water Reactor programme ALWR has dealt with possible future solutions of nuclear power generation. The Plant Life Management Programme XVO was directed towards plant-specific ageing problems with particular support from the power companies. JYT2001 was the public nuclear waste management programme. These programmes have mainly been conducted at the various research units of the Technical Research Centre of Finland (VTT). Universities have also contributed to these programmes. Similar programmes have been continued further; in 2002 the National research programme KYT for waste management and the project RKK for ageing were started. KTM has also commissioned a long-term-plan for the next national nuclear safety programme for the years 2003–2006, called preliminary SAFIR (Safety of nuclear power plants – Finnish national Research programme) [4].

3. Summary

The main motive for public nuclear safety research is to guarantee independent resources for the Finnish regulatory body in the safety evaluation of nuclear power production. This aim includes the development of tools and practices, the education of experts and efficient communication about the latest technology and know-how. The results of the public research are also at the disposal of the nuclear power companies. During the last 13 years, various fields of nuclear safety research have been organised as national research programmes, which have been launched and administrated by the Ministry of Trade and Industry. The Finnish Research Programme on Nuclear Power Plant Safety FINNUS (1999–2002) was conducted mainly at the Technical Research Centre of Finland (VTT) and Lappeenranta University of Technology (LTKK) and co-ordinated by VTT Processes.

In FINNUS, the fields of structural integrity and operational safety and reliability have been combined into three main themes of ageing, accidents and risks. A total of 11 research projects have been conducted under these themes. The effects of **ageing** on nuclear power plants have been studied intensively in order to evaluate the safe remaining lifetime of the components and the efficiency of the corrective measures. The programme has mainly concentrated on studies in ageing effects on material properties and degradation mechanisms of metallic structures, structural integrity and in-service inspection as well as monitoring methods, including reinforced concrete structures as a new area. The **accident** theme has concerned the operational aspects of nuclear power plant safety. The issues of nuclear fuel behaviour, reactor physics and dynamics modelling, thermal-hydraulics and severe accidents were addressed under the theme by conducting both computational and experimental studies. In the **risk** field, attention has been paid to advanced risk analysis methods and their applicability, and to the evaluation of fire risks, safety critical applications of software-based technology, as well as human and organisational performance.

The annual volume has been about Euro 3.6 million and 30 person-years. Until the publication of this report, the FINNUS programme has produced a total of 564 reports in various categories. A major publishing channel has been conference presentations but also 57 refereed scientific articles have been produced. Many detailed technical results were documented as working reports with limited distribution.

International co-operation has been vital in all the fields of the programme. In addition to publishing activities in various international forums, the research staff have contributed to working groups and networks, as well as defined and solved international benchmarks and participated in round robin exercises. The programme was presented to national and international technical communities and nuclear safety organisations.

The research programme contributed to the education of new experts in the field of nuclear safety in co-operation with the universities. Six doctoral theses, two licentiate and 18 master's theses were completed. In 2002 the programme employed a total of 25 young researchers and research trainees participating in the research projects as summer trainees or with a purpose of graduating. On-going studies for licentiate and doctoral degrees in the projects include both young researchers and senior experts.

In the steering and selection of research goals of the FINNUS programme, the Radiation and Nuclear Safety Authority (STUK) has had a dominant role. The research is also mainly funded from public sources. In order to combine limited national resources, the expertise of the power companies is also exploited in the steering and reference groups of the programmes. The power companies also contributed to funding of selected research topics of the FINNUS programme.

In FINNUS there were natural connections between the 11 research projects, and one objective of the programme was to strengthen these links. The nuclear community of a small country has been an advantage when creating novel couplings between different research fields. The interdisciplinary approaches of the projects have extended the know-how of both the research scientists and the external experts participating in the work of the reference groups.

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Appendix A: Highlights of FINNUS

Bellows-loaded fatigue-testing capability

Capability to carry out corrosion fatigue tests

- to define materials lifetime
- to define nucleation of cracks
- to conduct rising displacement crack growth rate measurements under Light Water Reactor (LWR) conditions
- to understand various interrelationships for Environmentally Assisted Cracking (EAC)

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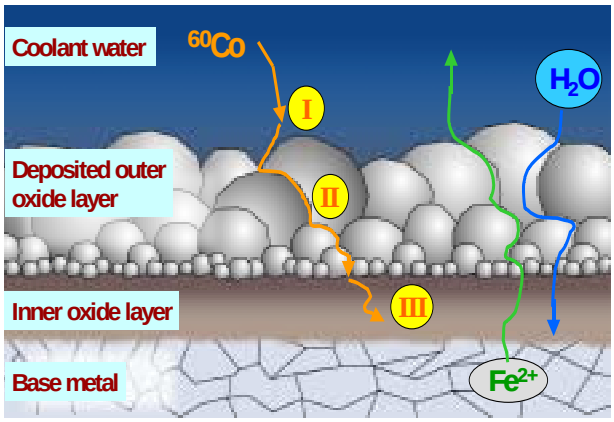
Mixed Conduction Model (MCM)

A model for the inner oxide layer on construction materials in primary circuits providing a basis for understanding how the following factors influence corrosion and activity incorporation:

- currently used water chemistries
- novel, modified water chemistries
- water chemistry transients



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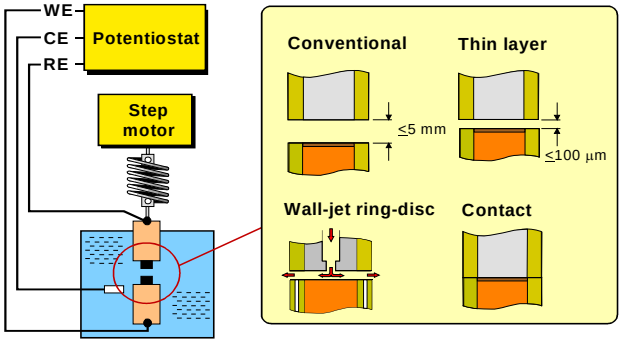
Controlled-Distance Electrochemistry (CDE) arrangement

An experimental set-up enabling electrochemical studies of construction materials even in low-conductivity high-temperature water such as Boiling Water Reactor (BWR) coolant, with the option to detect dissolving species as well

- The CDE arrangement makes it possible to assess the effect of anionic impurities, Fe/Ni ratio and other water chemistry parameters on material electrochemistry related e.g. to stress corrosion cracking and to activity incorporation



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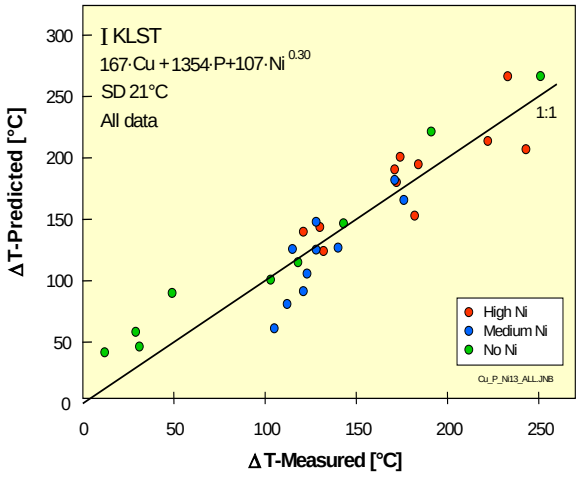
Model for materials embrittlement

The ability to estimate the effect of irradiation, annealing and reirradiation cycles on the mechanical properties of steels

- Techniques to utilise and interpret FEGSTEM microscopy in micro-mechanistic studies
- Chemical composition based correlation with mechanical properties



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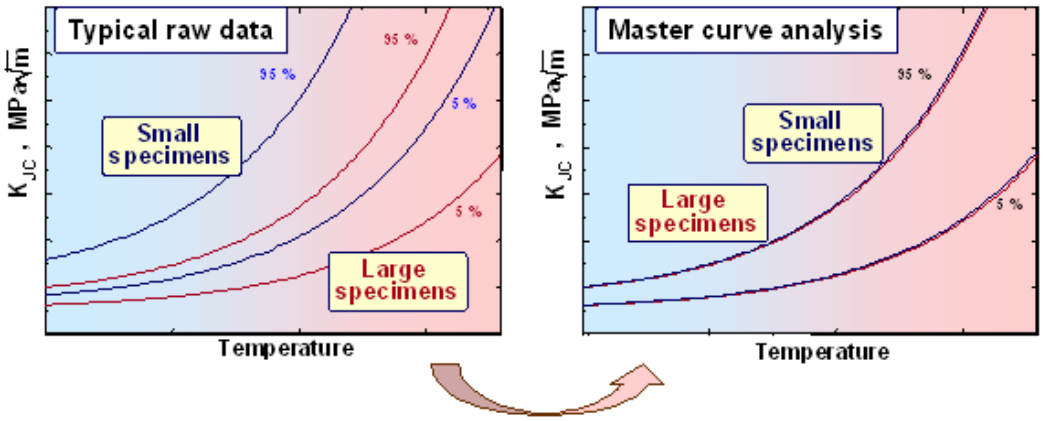
The Master Curve approach



- The Master Curve (MC) method combines a theoretical description of the scatter, statistical size effect and temperature dependence of fracture toughness, which is thus described solely with the transition temperature T_0 in the transition region.
- The basic MC standard ASTM E1921 is the first standard that accounts for the statistical specimen size effect and variability in brittle fracture toughness.
- The MC methodology has evolved, from being a testing and analysis procedure, to a tool addressing many more SI issues like constraint and parameter transferability.

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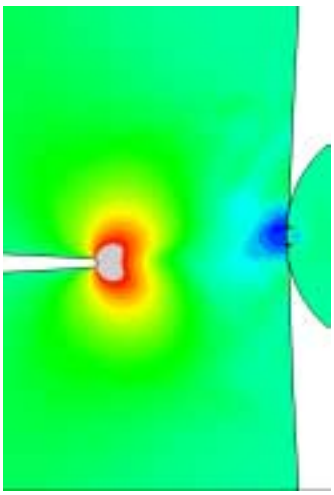
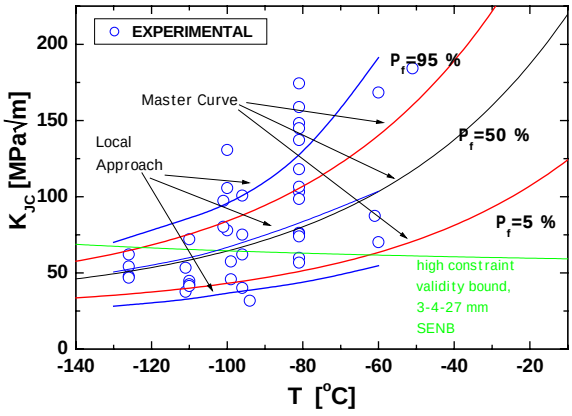
Local approach methods for fracture evaluation





- Material failure micromechanisms founded constitutive material models for ductile and brittle fracture including the transition region.
- Numerical evaluation of the functional fracture toughness/resistance using computational simulation. Quantification of material property variations arising from constraint, crack geometry, interaction of failure mechanisms etc.
- Provision of statistically sound estimates of failure response, enabling risk informed fitness for service and Structural Integrity (SI) analysis.

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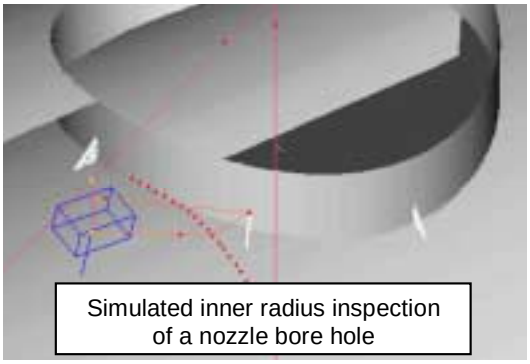
Simulation of ultrasonic inspection

- Simulation is a fast and effective tool to examine basic requirements and conditions of an inspection task.
- Complicated inspection geometry can be visualised and examined using three-dimensional component models on which inspection simulations are performed.
- Simulations can be used to substitute practical trials thus fabrication of expensive test specimens and inspections on them can be reduced.



- Basic facilities to perform simulations that take into account the geometric conditions of component and defect location are established.

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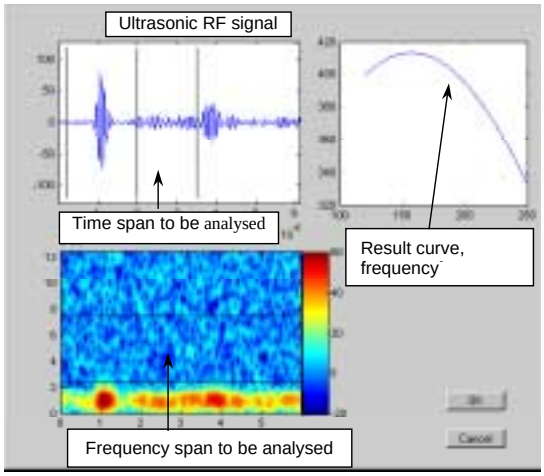
Frequency analysis of ultrasonic signals



- New analysis tool is developed to extract additional information from ultrasonic data.
- Conventional data analysis is using amplitude and time domain information of signals. In this analysis also the frequency domain is included into analysis.
- The objective of the system is to provide methods that can be used for material degradation assessment but also for interpretation of defect signals.
- Data acquisition is performed using normal mechanised automatic ultrasonic systems thus accurate data including positioning information can be used in analysis.

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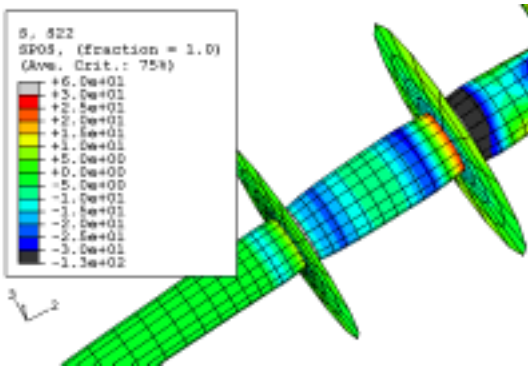
Effects of thermal stratification causing thermal fatigue

Experimental and numerical studies

- Experiments on local loading effects due to thermal stratification in a piping system dead leg were carried out at LTKK
- Heat loads were evaluated with Computational Fluid Dynamic (CFD) calculations and transferred to structural analysis for the determination of stresses and strains



- Calculations were validated with temperature and strain gauge measurements

Applications

- A tool for combining thermal hydraulic and structural analysis was developed
- New co-operation between thermal hydraulics and structural integrity branches of the FINNUS research programme was created

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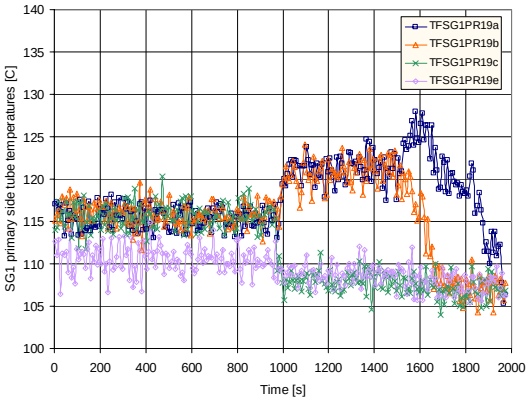
Noncondensables in VVER primary circuit

PACTEL experiments at LTKK

- Effects of non-condensable gas on system thermal hydraulics and on heat transfer in a horizontal steam generator were studied
- Gas distribution and system response strongly depend on the gas in question
- A need for more detailed experiments was evidenced



APROS simulations at VTT

- New application of the APROS code to the calculation of thermal hydraulics in the presence of helium gas was developed

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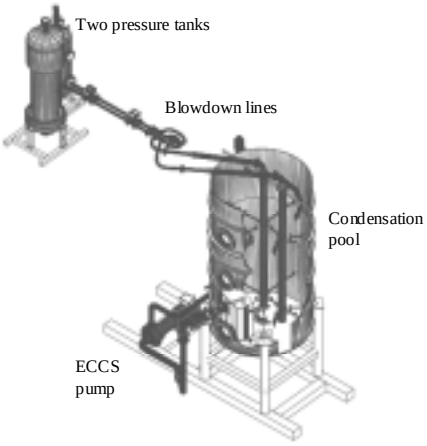
Condensation pool experiments at LTKK

Direct connection to plant conditions

- Non-condensable gas blowdown to BWR suppression pool during Large Break Loss of Coolant Accident (LBLOCA)
- Gas may flow inside Emergency Core Cooling System (ECCS) strainers and disturb the performance of ECCS pumps



Experiments with a scaled down test rig

- Gas bubbles forming at the blowdown pipe vent touched the ECCS strainer but only a fraction of gas was transported through the strainer into the pump intake
- Threshold for critical gas volume fraction in the ECCS pump flow was measured
- Test rig relevant for passive safety system studies of the next generation plants

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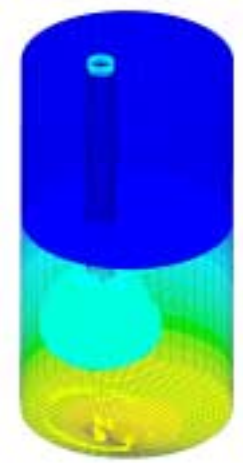
Design calculations for condensation pool experiments

Computational Fluid Dynamics (CFD)

- Fluent 5 code calculations supported the design of the test rig and the planning of the experiments
- Post test calculations confirmed the ability of CFD codes to simulate the behaviour of noncondensables in a water pool



Structural analyses

- Design and post test calculations with the ABAQUS Finite Element Method (FEM) code.
- Loading transients obtained from CFD results.

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Thermal hydraulic simulations

Plant scale CFD models

- Three-dimensional sector model of the Olkiluoto plant wetwell for internal circulation studies following a main steam line break
- Practical exercises for developing and maintaining comprehensive and independent computational expertise

General five-equation flow model GENFLO of VTT

- Wetted wall, dry-out, post dry-out heat transfer modes; quenching; parallel channels; upper, lower plena
- Applications: fuel behaviour analyses, severe accidents

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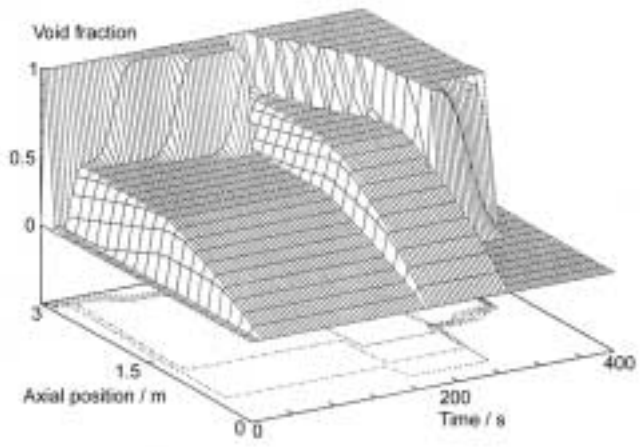
Thermal hydraulics modelling

- **Piecewise Linear Interpolation Method (PLIM)** is a highly accurate hydraulic solution method developed at VTT
- **The solver CFDPLIM based on PLIM** further developed for the applications
- **CFDPLIM** to be implemented in reactor dynamics codes: improves e.g. tracking of boron and temperature fronts in transients and can also handle reversed flows



- Mathematical verifications performed and the potential of the method demonstrated by successfully calculating several demanding flow problems
- Improving the hydraulics models of the reactor dynamics codes is long-term research, challenging both scientifically and computationally, and continued effort is needed in this field to fulfil the inherent application promises of the new models.

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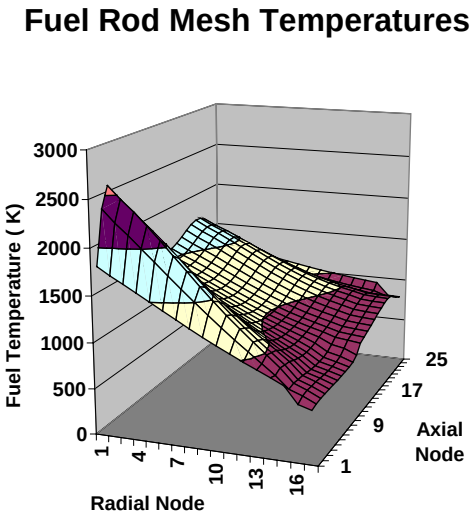
Coupled fuel behaviour and thermal hydraulics modelling

The FRAPTRAN-GENFLO coupled code development

- Elaborated fuel behaviour code FRAPTRAN (in collaboration with the USNRC) with high burnup effects modelled up to 60 MWd/kgU
- Advanced general five-equation flow model GENFLO developed by VTT

Test cases

- Loviisa VVER Large Break Loss-of-Coolant Accident (LBLOCA)
- BWR Anticipated Transients Without a Scram (ATWS)



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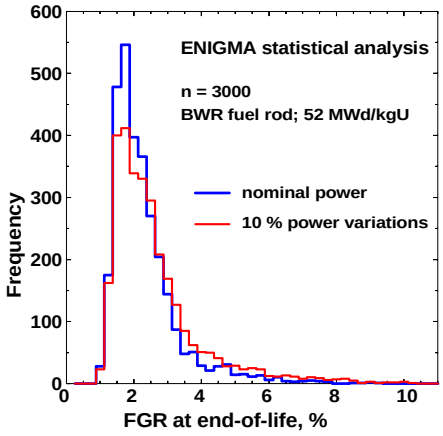
Statistical Fuel Behaviour Assessments

ENIGMA and FRAPCON-3 steady-state fuel performance codes with a Monte Carlo sampling and calculation procedure

- In: Distributions of design and operation data and of model parameters
- Out: Distributions of selected variables

Fuel performance and licensing calculations

- Comparisons of fuel types, evaluation of burnup effects



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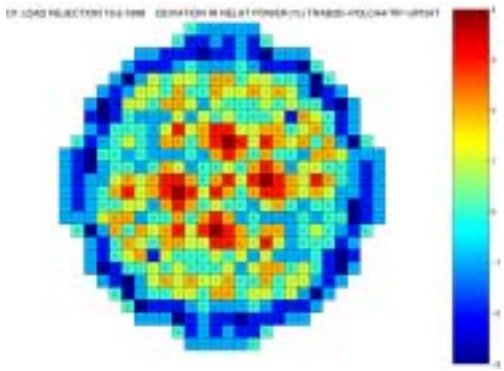
BWR and PWR transient and accident analyses

The TRAB-3D reactor dynamics code



- Three-dimensional neutronics in rectangular fuel bundle geometry
- Core and boiling water and pressurized water reactor circuit hydraulics with models for control systems

TRAB-3D validation summary

- International benchmark exercises with comparison to results of other similar computer codes. Real Olkiluoto plant transients with available measurement data
- All calculated cases show good agreement with other codes or measurements

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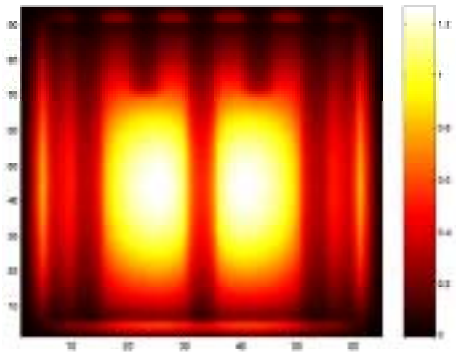
A new BWR core simulator ARES



Reasons of existence

- Evaluation and benchmarking of less sophisticated but routinely used nodal codes
- Independent simulation capabilities for e.g. safety analyses
- Ensuring sufficient knowledge in future

Models

- Neutronics solution is based on the analytical function expansion method enabling e.g. straightforward pin power reconstruction. ARES includes also new thermal hydraulics, cross section and burnup modules.
- First cold and hot-state calculations have been made with good results to test the coupled neutronics-thermal-hydraulics models.

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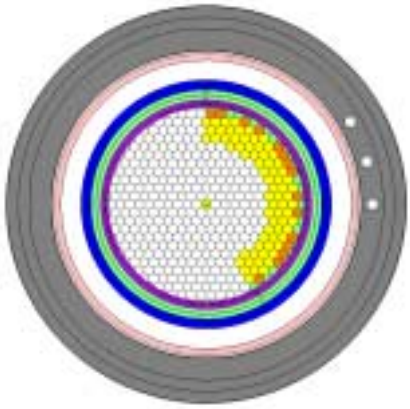
Validation and application of accurate Monte Carlo method

- **Monte Carlo method** is used in neutronics to solve complex problems in criticality and radiation shielding
- Advanced features of the MCNP Monte Carlo code and use of Monte Carlo method in burnup calculations studied
- **Monte Carlo method applied to calculate e.g.**
- Efficiency of VVER-440 control assembly
- Tokaimura criticality accident
- Kernels of the out-of-core detector signal model in the three-dimensional reactor dynamics code HEXTRAN of VTT
- **NJOY nuclear data processing code** applied to generate multi-temperature cross section data for MCNP
- Several applications in contract research



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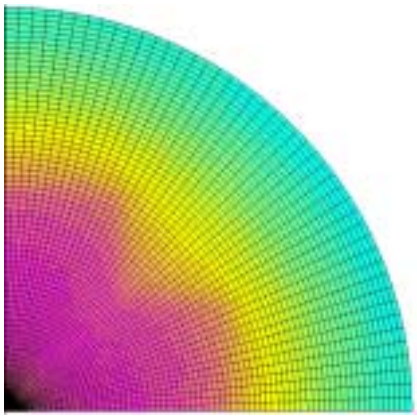
New three-dimensional out-of-core flux calculation system



- Three-dimensional neutron fluence calculations shown to be significantly more accurate than two-dimensional in an international intercomparison by the OECD/NEA
- Three-dimensional TORT discrete ordinate transport code validated against the international VENUS-3 benchmark, good agreement with reference results
- Further validation needed in order to replace VTT's present out-of-core calculation system with the more accurate three-dimensional system

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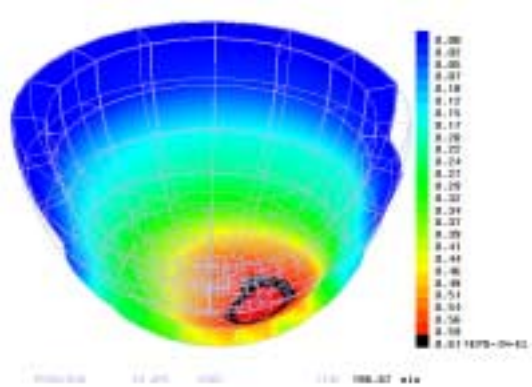
Pressure vessel lower head integrity

PASULA / FEM model for two- and three-dimensional mechanical analyses

- Detailed assessment of pressure vessel failure mode during a severe accident for PWR and BWR
- Fast-running code, efficient and flexible visualisation of results
- Both two- and three-dimensional models give excellent agreement with experimental data from Sandia's 1/5th scale OLHF lower head tests with and without penetrations and with KTH's FOREVER creep rupture tests
- Applications to Loviisa and Olkiluoto plants



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Melt coolability

Simulant material experiments on core debris bed coolability in containment water pool

- Particle bed characteristics representative to Olkiluoto plant - rough particles with wide size distribution and deep bed
- Pressure range in the tests from atmospheric to filtered venting set-point of Olkiluoto reactor
- Dryout heat fluxes, 232 - 451 kW/m^2, lower than generally predicted by models and measured for homogeneous, spherical particles
- Experimentally determined effective, average particle diameter was about 1/3 of the mass-averaged value

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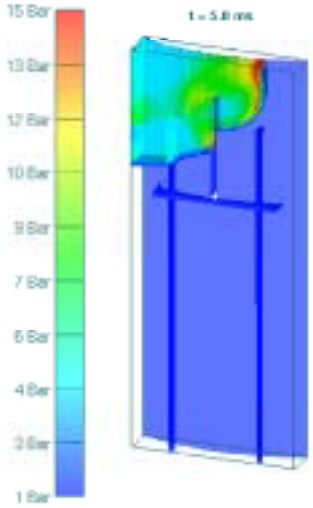
Hydrogen detonations

Containment integrity during a hydrogen detonation outside the containment for Olkiluoto reactor

- Three-dimensional simulations of hydrogen accumulation and detonation progression
- Mechanical response of reactor building walls and containment 321-pipe penetration to detonation
- Detonable H_2 concentrations may be accumulated
- Pressure and impulse maxima located in the corners (~7 MPa, 35 kPa-s, respectively)
- Reactor building walls may collapse, but pipeline penetration will survive



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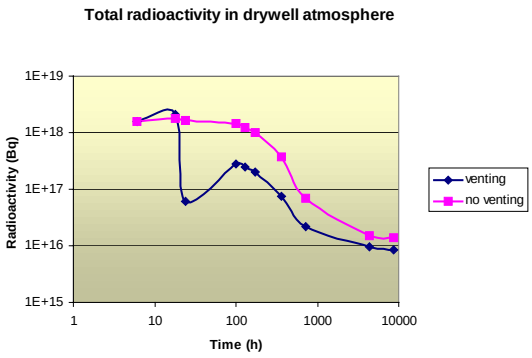
Long-term severe accident management

Radioactivity levels and the effects of radiation to chemistry in the containment from one month to several years after a severe accident

- Dose rate in water pools of Olkiluoto containment is 50-60 Sv/h after one year from accident with respective cumulative dose ~1 MSv
- Hydrogen production from water due to radiolysis ~700 kg per year
- Present pH control strategy in Olkiluoto generally favorable in minimising uranium solution into water pool



- Even small amounts of oxygen in containment will increase uranium solubility

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Reliability assessment methods for modern Instrumentation and Control (I&C) systems

A method for the reliability estimation of software-based I&C systems

- Combines both quantitative and qualitative reliability evidence from the whole life cycle of the I&C system
- Based on the use of Bayesian networks
- Provides support for the licensing of software-based I&C systems

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Reliability assessment methods for modern Instrumentation and Control (I&C) systems

Case studies on the reliability estimation of software-based I&C systems

- Reliability estimation of a software-based motor protection relay produced by ABB
- EU-benchmark exercise on safety evaluation of computer-based systems
- Test plan for ageing related reliability testing of modern I&C systems for chosen operatinal conditions

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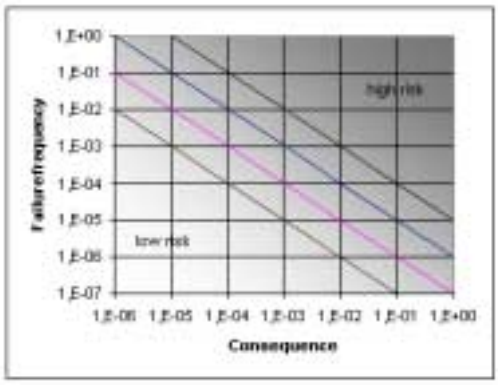
Risk-informed applications of Probabilistic Safety Assessment

Qualification of PSA applications

- A generic approach to be applied in various safety-related decision contexts
- PSA evaluators can use it as a decision aid for approving PSA applications
- Practitioners can find guidance to QA, modelling, analyses, and documentation



Expert panel methodology

- Approach to achieve a balanced utilisation of information and expertise from several disciplines in decision making, including PSA as one decision criterion
- Tested in categorisation of piping segments in Olkiluoto and Loviisa (RI-ISI i.e. Risk-Informed In-Service Inspection applications)

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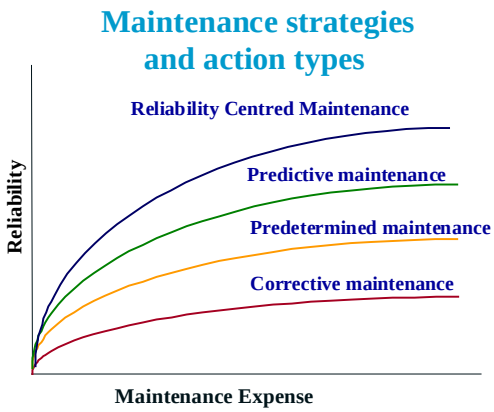
Maintenance strategies

Reliability Centered Maintenance (RCM)

- An experience based approach for planning and ranking of maintenance program improvements in operating plants with accumulated plant specific operating and maintenance reporting
- Models for utilisation of condition monitoring information for predictive condition based maintenance



Multi-criteria decision analysis support

- A model of objectives, attributes and measures for selection and ranking of maintenance and analysis significant items

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FACE — Framework for Analysing Commission Errors

Features

- Can be used for the analysis of various kinds of human failure events
- Gives guidance for identification of Commission Opportunities (CO) and related human failure events, as well as for PSA-modelling of commission opportunities and assessment of probabilities of defined outcomes of human actions

ANALYSIS STEPS
- Selection of human actions
- Identification of potential COs
- Screening COs
- Modelling important COs
- Assessing probabilities

Used in

- Human reliability analysis for PSA
- Analysis of operating experience

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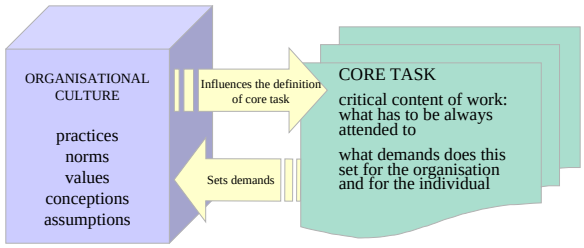
Contextual Assessment of Organisational Culture (CAOC) methodology

Why study culture

- Culture has an influence on the safety and efficiency of organisations
- Culture is not self-evident, it consists of conceptions and working practices that are taken-for-granted and not easily questioned



- Culture strives to resist outside influences but can develop deficient practices

CAOC methodology developed by VTT

- Identifies organisation's strengths and targets for development

Contributes to the:

- Design and allocation of work
- Design of organisational structures and processes
- Development of working practices and cooperation

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Core-Task Analysis for the analysis of human conduct in dynamic, complex and uncertain situations

CTA methodology developed by VTT

- Defines the essential content of work that has to be fulfilled in every situation through formative modelling of the domain and analysis of performance

Contributes to the:

- Design of training programs
- Design and validation of information technology tools and procedures
- Assessment and development of working practices and cooperation

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Method for analysis of management of fire situations

Criteria for

- Definition of the operators' task demands
- Identification of case-specific difficulties and risks
- Definition of risk-informed way of acting
- Identification of development needs in organizational support

FEATURES OF FIRE SITUATIONS

- complexity
- uncertainty
- hurry
- multiple tasks
- co-operational demands

Used in

- Development of operating procedures and instructions
- Simulator training and fire and rescue drills
- Fire risk analysis

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Insulation resistance of control electronics

Acute effect of smoke and high humidity on performance of electronic circuits

- Experiments and modeling on acute smoke and humidity effects on control electronics
- Insulation resistance drops from two to four decades due to smoke and/or humidity
- Malfunction of electronics may result
- Assessing tests and calculation tools developed
- Protective coating criterion developed for new control electronics

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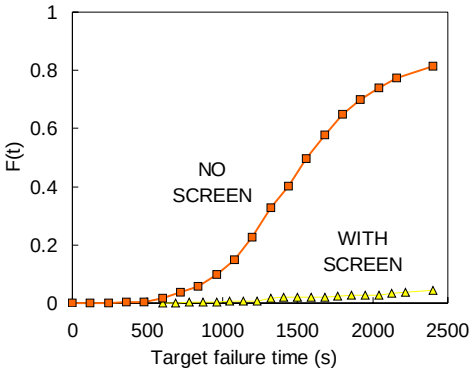
Probabilistic fire simulator

A general Monte Carlo simulation tool to estimate loss probabilities for fire scenarios

- General Monte Carlo simulation tool PDF developed to calculate probability estimates for given fire scenarions
- Commercial @RISK program + fire simulation tool CFAST



- Realistic data bank collected
- Application to incomplete physical partition between redundances in Olkiluoto cable tunnels
- Shows efficiency of partial screens for preventing ignition on the opposide side of tunnel

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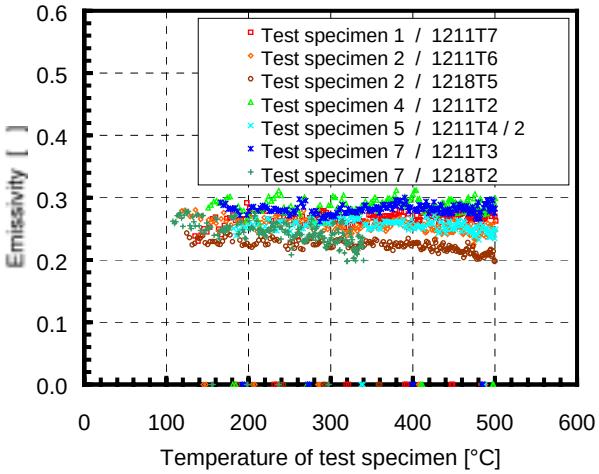
Emissivity of stainless steel surface

A new simple way of measuring total emissivity of steel surface

- Pressure measurements a critical part of control functions in a NPP
- Emissivity of surfaces of stainless steel pressure tubes needed to assess reliability of pressure measurements
- No simple way of measurement of total emissivity at high temperatures
- New calorimetric method developed and tested
- Yields results at moderate accuracy and applies to cases, where thick metal samples are available



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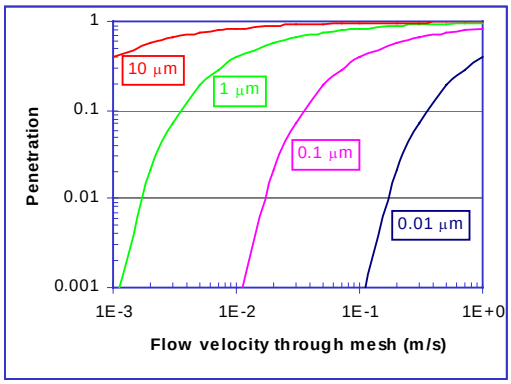
Detection of smoldering fires

Model for smoke detector time lag

- Early fire detection is essential for fire safety of Nuclear Power Plants (NPP)
- Smoldering fire is a characteristic in electronics and overheated cables
- Penetration of cold smoke in detector has a considerable time lag
- A threshold velocity observed, but its origin was firstly not understood
- A new model developed, where smoke particle penetration can be calculated for given particle size and ceiling jet velocity



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FINNUS The Finnish Research Programme on Nuclear Power Plant Safety 1999–2002

Executive Summary

Abstract

FINNUS (1999–2002) is the Finnish public research programme on nuclear power plant safety, launched and administrated by the Ministry of Trade and Industry (KTM). The programme has concentrated on the themes of ageing, accidents and risks. The general objectives of the programme have been to develop tools and practices for safety authorities and utilities, to provide a basis for safety-related decisions, to educate new nuclear energy experts, and to promote technology and information transfer. The technical objectives of the programme have been prepared under the guidance of the Radiation and Nuclear Safety Authority (STUK), but the views of the Finnish power companies have been taken into consideration. Funding of the programme has been mainly from public sources. The annual volume of the programme has been about Euro 3.6 million and 30 person-years. The research has been co-ordinated and mainly conducted by the Technical Research Centre of Finland (VTT) with a significant contribution from Lappeenranta University of Technology (LTKK).

The effects of **ageing** on nuclear power plants have been studied intensively in order to evaluate the safe remaining lifetime of the components and the efficiency of the corrective measures. The programme has mainly concentrated on studies in ageing effects on material properties and degradation mechanisms of metallic structures, structural integrity and in-service inspection as well as monitoring methods including reinforced concrete structures as a new area. The **accident** theme has concentrated on operational aspects of nuclear power plant safety. The issues of nuclear fuel behaviour, reactor physics and dynamics modelling, thermal hydraulics and severe accidents were addressed under the theme by conducting both computational and experimental studies. In the **risk** field, attention has been paid to advanced risk analysis methods and their applicability, and to the evaluation of fire risks, safety critical applications of software-based technology, as well as human and organisational performance.

This executive summary gives a brief description of the goals and results of the programme. The programme has published 57 scientific articles, 233 mainly international conference papers, and 274 other reports. Six doctoral theses, two licentiate and 18 master's theses were completed. The total volume of the programme during the four years has been about 130 person-years and Euro 14.4 million.

Keywords
FINNUS, nuclear power plants, reactor safety, corrosion, ageing, accidents, reactor physics, thermal hydraulics, modelling, fire safety, risk analysis, human factors

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