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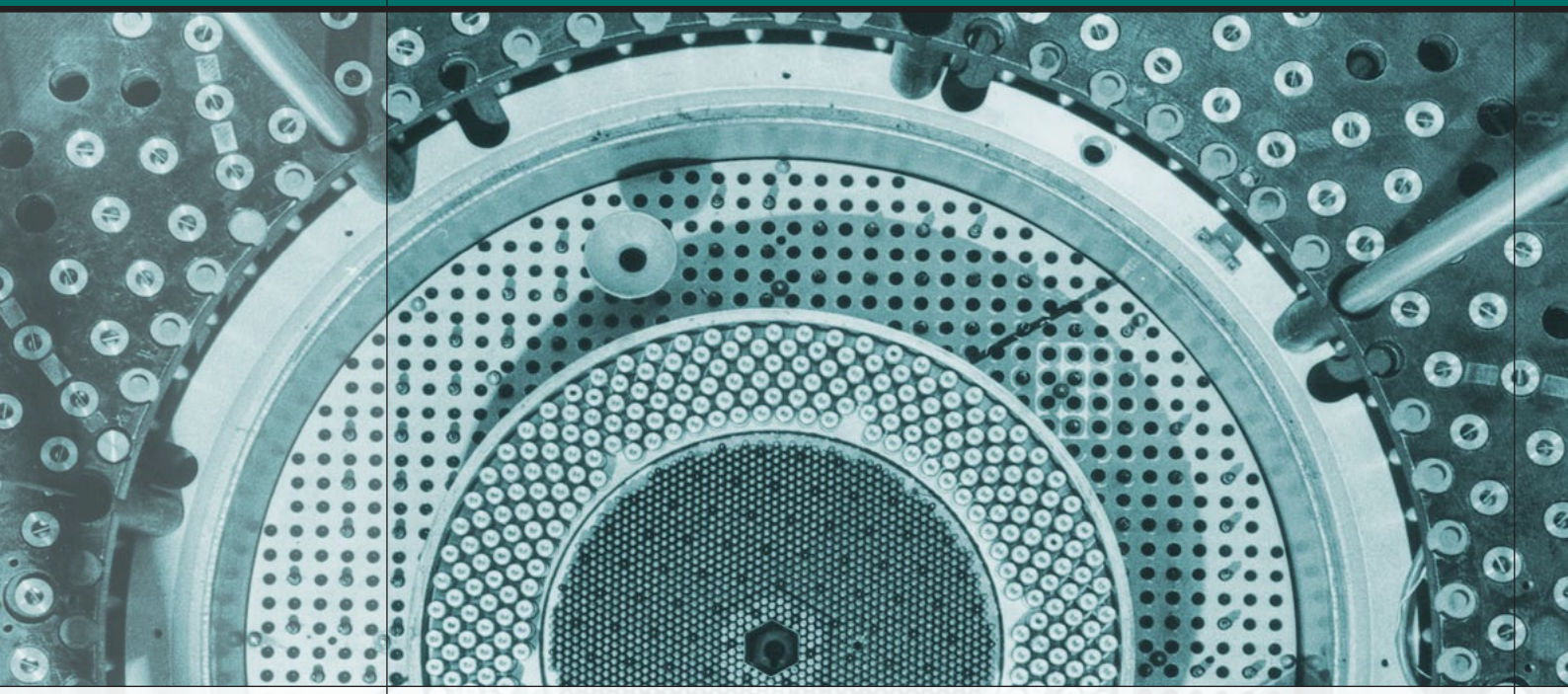
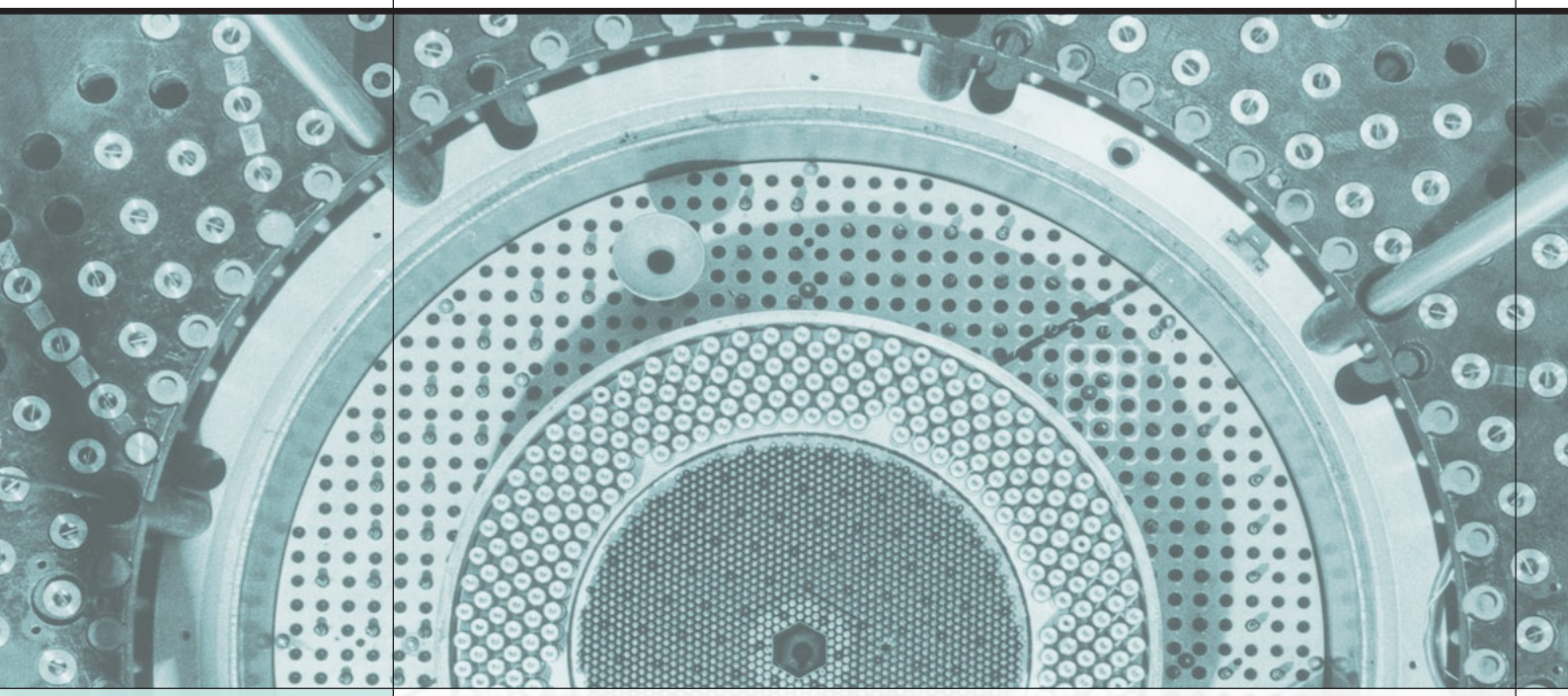


Scientific Highlights 2008

Nuclear Energy and Safety

Cover photo:

Top view of PROTEUS zero power reactor facility with the central test concentrically surrounded by the buffer, heavy water and graphite driver zones.



Scientific Highlights 2008

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Nuclear Energy and Safety Research Department (NES) 5

The strategic areas of activity of NES comprise the following:

- contributions to the safe and economic operation of the existing Nuclear Power Plants (NPP) in Switzerland and proof of the safe geological storage of radioactive waste by reinforcing the scientific bases of the technologies in the appropriate areas;
- support to the reactor operators and safety authority in Switzerland, as well as the securing of stand-by functionality in key areas, particularly those requiring the services of a Hot Lab;
- preparation of inputs to 'stakeholders' for decision-making purposes;
- promotion of nuclear energy by means of R&D in terms of increased sustainability, safety and economy;
- training of young nuclear specialists over a broad spectrum of disciplines, including those with experience of other energy systems;
- support and participation in the worldwide 'renaissance' of nuclear energy, and of its relevance to the current needs within Switzerland.

NES is structured into five research laboratories according to its specific scientific and technical areas of competence. It operates the only Hot Laboratory in the country, and the Reactor School offers education and training programmes for present and future reactor operators.

◀ **Jean-Marc Cavedon**
Head of the Research Department
Nuclear Energy and Safety.

The Nuclear Energy and Safety Department and the safe and sustainable use of nuclear energy

Jean-Marc Cavedon
Nuclear Energy and Safety Department, PSI

Nuclear energy is an integral part of not only the Swiss but also the global sustainable energy mix, and as such is an important component of PSI's energy research portfolio. The scientific and technical challenges of further enhancing the safety and cost-effectiveness of nuclear electricity production, and at the same time decreasing the associated risks, can be very effectively influenced by the work at PSI. The PSI campus brings together a rare blend of highly qualified physicists, chemists and solid-state scientists, large- and medium-scale experimental facilities of world class, and internationally recognized engineers in all the key disciplines of energy production. Highlights of the scientific and technical contributions made during 2008 in this stimulating environment constitute the sections which follow.

"The debate over the benefits and risks of nuclear energy has certainly not ended, but the tide of opinion has turned. The turbulence in the oil and gas markets, and the now obvious need to restrict the emission of greenhouse gases, jointly compel today's governments to look with new eyes at their nuclear options. Public opinion, until now cautious, is finally leaning towards the positive." This is not the isolated opinion of the NES management, but is actually epitomized in the headline of a recent compilation of newspaper articles from Spain, the United Kingdom, Germany, India and Japan entitled: "Nuclear, the great comeback" (Courrier International, Nr. 956, Feb.-March, 2009). A growing number of European governments are starting to invigorate their civilian nuclear programmes, and presenting them as the most pragmatic option for fighting greenhouse-gas emissions. Sweden and Italy are the most spectacular examples: their governments have very recently announced a 'phase-out of the previous nuclear phase-out policy'.

In Switzerland too, the wind of change in the attitude to nuclear energy is also blowing more strongly. During 2008, three requests for general site permits for nuclear power plants have been submitted: for Beznau, Mühleberg and Niederamt. In addition, the national nuclear waste cooperative, Nagra, has disclosed six potential sites for underground waste repositories, all accompanied by a rather moderate level of protest from the media.

For us researchers, geared towards the safe and sustainable use of nuclear energy, all this is a sign of the growing acceptance of our basic conviction: that nuclear electricity generation is a recognized asset to life in Switzerland today, and one that will remain tomorrow. Our goal is to integrate nuclear energy in the sustainable energy mix even more comprehensively by reinforcing its positive side (low cost, very low CO_2 emission, independence of energy supply, etc.) while simultaneously reducing its negative image, through reduced risk, and less waste for long-term disposal.

Strategic collaborations and tools

The Nuclear Energy and Safety Department (NES) is an active partner in the overall Swiss energy scene. It is our privilege and duty to deliver objective judgments and rational methods to the stakeholders involved in the decision-making processes. We are also strongly embedded in the international nuclear energy research community, where we collaborate formally or informally with our contemporaries in other countries. Examples of this involvement are, for example, our active presence in the EU-based Sustainable Nuclear Energy Technology Platform; our formal commitment in support of the VHTR and GFR systems within the Generation IV International Forum (GIF); and our membership of the numerous working groups, committees and projects of the IAEA and the OECD Nuclear Energy Agency.

Last but not least, NES is fully integrated in PSI's research portfolio. For example, the use of the large facilities at PSI for addressing basic, as well as far-reaching, problems regarding the structure of matter is combined with application to practical, present-day issues, such as the sorption mechanism of radionuclides on specific clays or cements, and the ageing

process of the metals used in current reactors. The state-of-the-art analytical, experimental and computer-supported tools available at PSI are an asset to the technologies of today, and will serve future applications in the decades to come.

Fundamental and applied research

In nuclear research, the focus on practical applications can be seen in our involvement in the safety and operational issues relevant to present-day operating plants (Generation II), as well as our drive to a deeper understanding of plants offering even higher safety and reliability standards, such as those (Generation III plants) now being constructed worldwide, and envisaged for Switzerland too. The development of the next generation of nuclear plants, for which increased sustainability is a central issue, is our contribution to the long-term nuclear perspective. Further, we participate in the advancement of Generation IV designs, which aim to maintain the advantages of safety and cost-effectiveness of today's plants, while decreasing dramatically the consumption of the planet's fissile resources and recycling a significant share of the radioactive waste.

Six laboratories and a common strategy

Our portfolio concentrates on selected topics of nuclear science and technology. It is organised into six units. The Laboratory of Reactor Systems (LRS) focuses on the high-fidelity numerical simulation of nuclear reactor systems under normal operational conditions, and their transition to abnormal situations. As a counterpoint, an experimental platform on reactor physics is maintained, providing hands-on experience of neutronic behaviour for various reactor concepts. LRS is also involved in developing better understanding of advanced reactor cores operating with fast neutrons.

The Laboratory for Thermal Hydraulics (LTH) addresses the reactor cooling issues. For Generation II reactors, the coolant is water at high pressure and temperature. Both single- and two-phase flows are studied, the latter including mixtures containing water and steam bubbles, steam with water droplets, and their related heat transfer phenomena. The long-term goal of the research is to link instrumentation of high spatial and time resolution with solutions of the basic equations of fluid motion, not only for water-cooled reactors, but for the variety of coolants which feature in future design concepts, such as gases, liquid-metals and (possibly) molten salt.

Materials, either in the form of oxides or ceramic fuels, or as metallic structural components, ultimately determine both the reliability and lifetimes of nuclear reactors, and thereby their overall economic viability. Material behaviour also determines the operational limits for reactors. The Laboratory for Nuclear Materials (LNM) has a long tradition in the study of nuclear fuels, and in the ageing of structural components under the hostile conditions that exist in nuclear power plants over decades of active service. With an eye to the future, LNM has recently developed experimental and modelling skills in advanced ceramics and metals for high-temperature environments.

Examination of materials following irradiation is the main focus of the Hot Laboratory at PSI. The Hot Lab (AHL) serves the users of all the PSI irradiation facilities, both in regard to their industrial operational needs, and in the context of advanced materials research. Dedicated measurement points for the safe handling of radioactive samples are also installed in other large, less-specific facilities at PSI, such as SINQ and SLS.

Nuclear reactions produce fission products as waste, and with an associated risk of radioactive contamination of the biosphere. The Laboratory for Nuclear Waste (LES) investigates the retention capabilities of certain geological layers in isolating the waste from the biosphere over the long time periods commensurate with the longest decay times of the radionuclides present: that is, from tens of thousands to millions of years.

Finally, the responsibility of the Laboratory of Energy Systems Analysis (LEA), which is associated with both Energy Departments at PSI, is to offer a global perspective of nuclear energy, vis-à-vis the other sustainable energy technologies of interest to Switzerland. The technologies are considered over their entire life-cycles, encompassing their ecological, economic and social implications.

Highlights

It is my pleasure to introduce you to the following pages of selected highlights of our activities over the past year. The articles aim to give a representative view of the variety of tasks needed to further our understanding of nuclear reactors, both present and future, and of the nuclear fuel cycle.

PHYSOR 2008: International Conference on the Physics of Reactors

Rakesh Chawla
Laboratory for Reactor Physics and Systems Behaviour

The International Conference on the Physics of Reactors (PHYSOR 2008) was held under the theme "Nuclear Power: a Sustainable Resource" from 14-18 September, 2008 in Interlaken, Switzerland. PSI and the Swiss Nuclear Society – in collaboration with the American Nuclear Society and the OECD Nuclear Energy Agency – were the main organizers, with EPFL, Swissnuclear and AREVA as the principal sponsors. The conference structure was defined from the outset in terms of 16 technical tracks resulting in 62 separate technical sessions which covered a very wide variety of topics. These ranged from basic neutronics, through operational and safety aspects of current-day reactors, to the multi-physics modelling of advanced systems and the closure of the nuclear fuel cycle. The PHYSOR 2008 Technical Program Committee finally accepted 450 papers (see http://www.physor2008.ch/) out of well over 600 extended abstracts from potential contributors. These papers were presented orally either during five parallel sessions on each of the four principal conference days, or as part of the three separate poster sessions. The record conference attendance of more than 550 participants from 35 different countries is a clear reflection of the worldwide renaissance which nuclear power is currently undergoing, and identifies nuclear power as a potentially strong contributor to a sustainable energy supply of the future.

The International Conference on the Physics of Reactors (PHYSOR 2008) was held under the theme "Nuclear Power: a Sustainable Resource" from 14-18 September, 2008 in Interlaken, Switzerland. PSI and the Swiss Nuclear Society – in collaboration with the American Nuclear Society and the OECD Nuclear Energy Agency – were the main organizers, with EPFL, Swissnuclear and AREVA as the principal sponsors. The conference, the largest of its kind ever held in Switzerland, carried on the tradition of the previous (bi-annual) PHYSOR conferences; the most recent were held in Seoul (2002), Chicago (2004) and Vancouver (2006).

The PHYSOR 2008 conference structure was defined from the outset in terms of 16 technical tracks:

1. Nuclear Data
2. Transport Theory
3. Monte Carlo Developments
4. Core Analysis Methods
5. Advanced Fuel & Core Design
6. Criticality Safety
7. NPP Transients
8. Actinide Management
9. Fast Reactor Design & Safety
10. Research Reactors & Spallation Sources
11. Integral Experiments & Analysis
12. Nuclear Standards & Benchmarks
13. Fuel & Materials Behaviour
14. Facilities for Safety Research
15. Radiation Applications & Nuclear Safeguards
16. Nuclear Power & Sustainable Development.

While many of the tracks correspond to the "usual" areas (e.g. Core Analysis Methods) which have characterized past PHYSOR conferences, certain tracks (e.g. Fuel and Materials Behaviour) served to emphasize the fact that the scope of the R&D interests of reactor physicists has broadened considerably in recent years.

The PHYSOR 2008 Technical Program Committee (TPC) consisted of 170 experts from universities, research centres, regulatory bodies and industry from as many as 21 different countries. Together, they reviewed well over 600 extended abstracts from potential contributors, with between 10 and 13 TPC members constituting the reviewing body for each of the 16 tracks. As such, all abstracts submitted received multiple reviews, with the *track leaders* coordinating the final selection process.

Finally, 450 papers were accepted; see: http://www.physor2008.ch/. These papers were presented orally, during

five parallel sessions on each of the four principal conference days, or as part of the three separate poster sessions. The record conference attendance of over 550 participants, from 35 different countries, is a clear reflection of the worldwide renaissance that nuclear power is currently undergoing as a potentially strong contributor to a sustainable energy supply of the future.

The 62 separate PHYSOR 2008 technical sessions covered a very wide variety of topics, ranging from basic neutronics, through operational and safety aspects of current-day reactors, to the multi-physics modelling of advanced systems and the closure of the nuclear fuel cycle. The scientific quality of the papers presented was unusually high. Apart from the *Best Student Paper* (see Fig.1) and *Best Poster* prizes, 26 of the PHYSOR 2008 papers were selected for publication in a special issue of the journal: Annals of Nuclear Energy (ANE). These papers had been identified by the various track leaders as reflecting the conference in a representative manner, the criteria for selection being: (a) one to two papers per track, (b) originality, novelty and potential impact of the reported work, and (c) the quality of the presentation given at the conference.

Following detailed peer review, the selected papers have now been brought together, and constitute the April 2009 issue of the journal (ANE, Volume 36, Issue 3). This is available on-line at the following web address:
http://www.sciencedirect.com/science/journal/03064549

In addition to the various technical sessions, two workshops were also held as part of the PHYSOR 2008 conference, one entitled *Monte Carlo Methods Development,* and the other *Reactors for Actinide Management.* Finally, on the closing day, a choice of technical tours was made available to the participants: to CERN, PSI, or the Grimsel Laboratory. The next PHYSOR conference will be held in Pittsburgh, USA in May 2010.

Figure 1: **Hanna Kröhnert receiving one of the Best Student Paper awards from Nam Zin Cho, Technical Co-chair of PHYSOR 2008. Hanna is a NES-EPFL doctoral student carrying out her research at the PSI experimental reactor PROTEUS.**

NES facts and figures for 2008

Peter Hardegger
Nuclear Energy and Safety Research Department, PSI

Federal funds for nuclear research have remained stable in recent years, and the small annual growth in third-party funding continued during 2008. The turnover rate of personnel within NES remained high, as in 2007. The renaissance in nuclear energy has resulted in many attractive options becoming available to suitably qualified individuals in the nuclear sector. This meant, from the NES standpoint, that the recruitment market was "dry" in some research areas. In addition, major changes in the Swiss pension scheme led to a number of senior NES staff taking early retirement. In total, 32 new staff members were recruited during the year, almost compensating for the 35 who left.

General Situation

Whereas the 1990s were characterised by a steep decline in federal funds for nuclear research, which could only be partially compensated by third-party financing, the funding situation stabilized after the year 2000. Indeed, since 2005, even a small growth could be sustained. This general trend seems to have accelerated during 2008, and is based solely on the additional third-party funding that has become available during the year.

Despite the positive overall climate for nuclear research, the employment situation in 2008 for NES remained as difficult as it was in 2007. Some experienced staff left to go to jobs in industry, new recruitment was sluggish, and the year saw a larger than average number of people seeking early retirement.

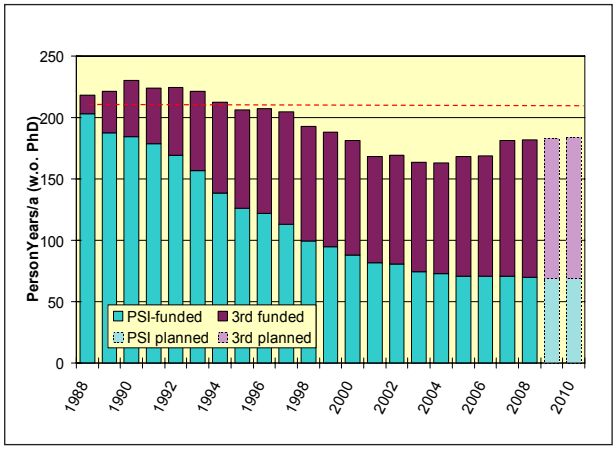


Figure 1: **History of NES funding resources**

Personnel

The staff turnover within NES, which was very high in both 2007 and 2008, has resulted in an accelerated change in the overall age structure of the department. For each of these two years, more than 30 people have been recruited, partially to compensate for a high number of retirements, a situation that was particularly exacerbated in 2008 by the new government pension scheme coming into force on June 1, which resulted in 13 senior members of NES going into early retirement at the end of May.

The high number of open positions advertised during this time very much reflects this general picture, which is also mirrored in the major restructuring of the senior management of NES which has taken place. Over these same two years, about two thirds of the management staff has had to be replaced, though in most circumstances suitable replacements could be found internally.

The number of open positions peaked at over 30 during 2008, but had been reduced to 15 by the end of the year.

In total, 35 NES staff left during 2008, out of which 6 were

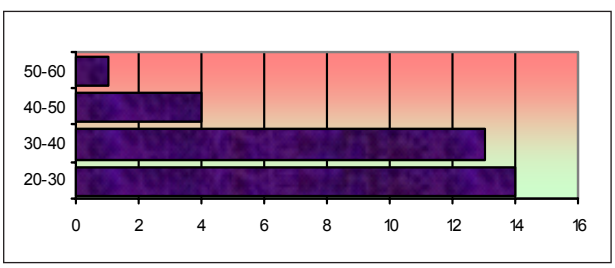


Figure 2: **Age structure of 2008 recruitments**

doctoral students who had successfully completed their theses. The vacancies created could almost be compensated by the new staff members, doctoral fellows and doctoral students recruited during the year (32 in total). Indeed, the number of doctoral students and postdoctoral fellows has increased substantially in recent years, and now stands at 24 and 17, respectively.

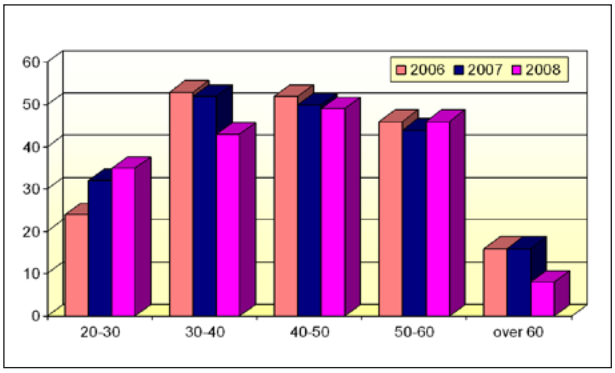


Figure 3: **NES age structure for the years 2006, 2007 and 2008**

Finances

PSI resources, that is the money made available through direct ETH-domain funding, remained constant during 2008. However, the funds made available for consumables and expenses were reduced slightly.

Over the last two years, third-party funds, based to a large extent on long-term contracts, have been updated to take account of inflation. In addition, some new contracts, with new partners, could be initiated, so that overall third-party funding increased slightly.

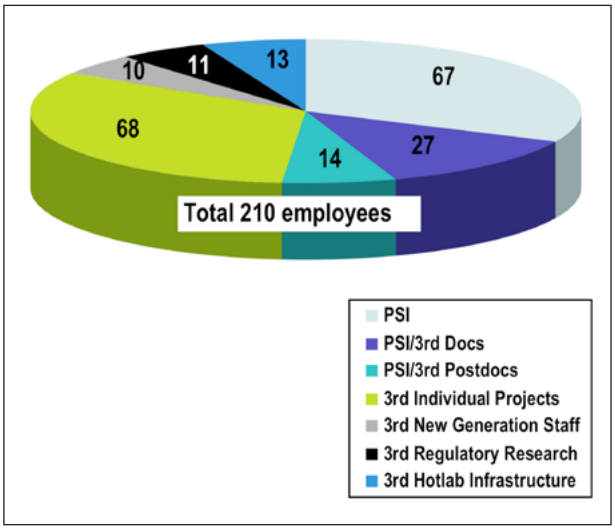


Figure 4: **NES staff funding sources**

In total, 6.9 Mio CHF were available for investments and maintenance, made up of 1.7 and 5.2 Mio CHF from PSI and third-party funds, respectively.

Partners/Contracts

The main emphasis of the research within NES (38%) is on safety research for the existing nuclear plants within Switzerland. These activities are mainly supported by Swissnuclear (the association of operators of the Swiss nuclear plants), which is the largest single third-party funding source for the department. Research on new and future reactors (17%) is mainly funded from international collaborations (e.g. EU and OECD projects). The third largest activity is waste management research, at 13%, partly funded by Nagra.

On the expenditure side, an important part (9%) of the budget is the investment made in Energy Systems Analysis, a common venture with the General Energy Department, and the costs associated with the operation of large facilities, e.g. the Hot Laboratory and PROTEUS, which amounted to about 23% of the available funds during 2008.

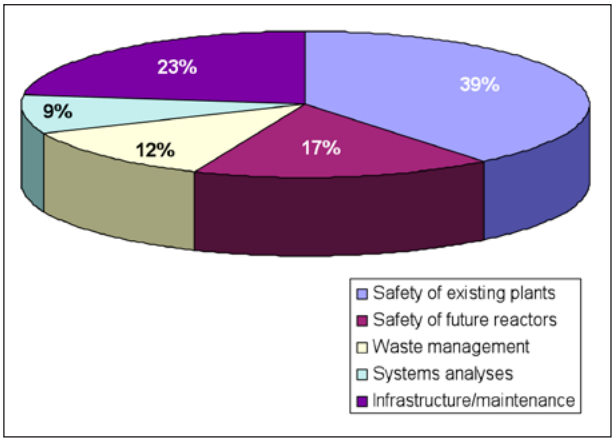
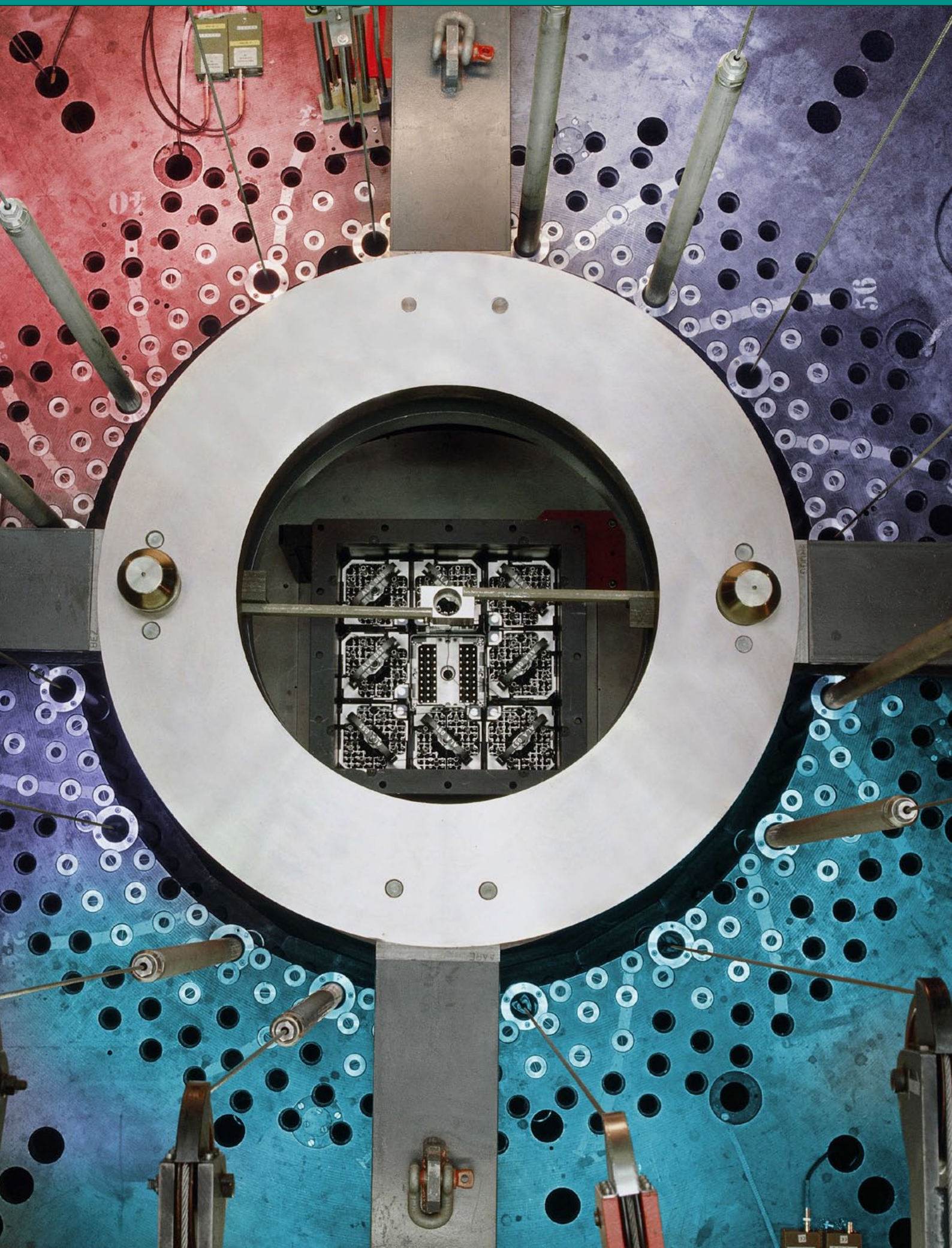


Figure 5: **Distribution of resources for 2008**

In 2008, several important new contracts were signed. The most important was the renewal of the contract with Nagra for the funding of the waste management activity. In addition, several new EU contracts were signed (FUEL-BRIDGE, ACSEPT, NURISP, RECOSY), and a new infrastructure cooperation with AREVA was started.

Within the framework of our existing contracts, 16 work statements/orders were signed (2 on HRA, 3 on STARS, 6 for the Hot Laboratory and 5 with Swissnuclear). Finally, a Systems and Project Agreement in the GIF framework was signed in connection with the Very High Temperature Reactor (VHTR) initiative.



Laboratory for Reactor Physics and Systems Behaviour (LRS) 13

Current activities within LRS are centred on four principal project areas.

LWR-PROTEUS
Measurements are being taken of basic reactor physics data for modern, complex fuel bundles in a critical facility (PROTEUS). The data collected are subsequently used for the validation of computer codes, and the reduction in their uncertainties.

LWR-UPGRADE
The project is concerned with the conversion and fitting of the PROTEUS reactor for measurements of highly burnt fuel.

STARS
STARS is a long-standing project aimed at the development, maintenance and application of a complex code and database system to be used for investigations on the behaviour of the Swiss nuclear reactors. Focus areas include combined system transient and uncertainty analysis, fuel modelling and neutronics.

FAST
Appropriately named, this activity is aimed at the development and implementation of a code system representing state-of-the-art safety analyses of nuclear systems incorporating fast neutron spectra.

The research projects within LRS additionally provide motivation and subject material for doctoral and diploma theses in support of training in nuclear technology at EPFL, and are strongly coupled with the joint EPFL-ETHZ Nuclear Masters programme.

◀ **A recent PROTEUS core featuring Leibstadt BWR assemblies surrounding a section of a Gösgen PWR assembly for measuring reactivities and neutron emissions of spent fuel segments.**

Coupling classical thermal hydraulics with Computational Fluid Dynamics for nuclear reactor systems

Davide Bertolotto, Annalisa Manera, Rakesh Chawla, *Laboratory for Reactor Physics and Systems Behaviour, PSI*
Simon Frey, Horst-Michael Prasser, *Laboratory for Thermal Hydraulics, PSI*

The use of Computational Fluid Dynamics (CFD) codes to address nuclear safety issues for improving the accuracy of nuclear system transient analyses has grown significantly in recent years. Nonetheless, the high computational costs associated with CFD simulations have restricted their use to local areas of the plant. Consequently, traditional 1-D system codes still represent the main workhorses for analysing thermal-hydraulic plant behaviour. Within the STARS project at PSI, a tool capable of simultaneously performing detailed 3-D CFD component and traditional 1-D system analyses is being developed.

As part of the safety assessment and licensing procedures for Nuclear Power Plants (NPPs), a wide range of analyses are carried out using best-estimate system codes. These have been developed and validated over many years for a wide variety of accident scenarios and transients. In these codes, the conservation equations (mass, momentum and energy) describing two-phase flow and heat transfer are based on 1-D approximations, the thermal-hydraulic models employing an appropriate set of correlations (closure relationships) to represent the phase exchanges. The model for a specific NPP is then constructed by connecting together a number of 1-D modular components (pipes, tees, pumps, valves, etc.).

There are, however, certain components for which strong asymmetries may occur (e.g. in boron concentration and temperature) in the flow of coolant in the Reactor Pressure Vessel (RPV). These asymmetries depend largely on the coolant mixing taking place in the downcomer and lower plenum. The mixing phenomena are turbulent, and strongly 3-D in character. In such circumstances, 1-D approximations are inappropriate.

For single-phase mixing applications, CFD codes have reached a satisfactory level of maturity for providing reliable modelling for such multi-dimensional flows, but have the disadvantage that their computational overheads are large. The coupling of system and CFD codes is therefore a logical step in nuclear safety applications, especially for those in which 3-D flow plays an important role.

Coupling

A coupling algorithm has been developed between the US NRC best-estimate system code TRACE and the commercial CFD code ANSYS-CFX [1], with the PVM (Parallel Virtual Machine) environment being used to manage the information exchange between the two codes. The exchange of variables takes place at the common boundaries between the codes. The conversion from a 1-D to a 3-D boundary condition is crucial, since additional information on the flow is then required: for example, the inlet velocity profile, which is not accessible using a 1-D approximation. Another critical issue is the numerical stability of the coupling procedure: namely, whether it is developed following an explicit or semi-implicit scheme, which limits the choice of the temporal and spatial discretization schemes that can be adopted.

The currently implemented coupling algorithm is being verified against simple numerical tests, and is now being validated against data from an experiment involving 3-D mixing effects.

Double T-junction experiment

The experimental set-up used for the validation procedure consists of two loops connected by a double T-junction, with

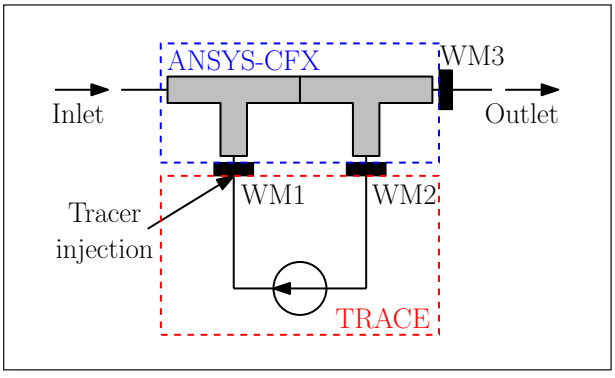


Figure 1: **Schematic of the double T-junction experimental arrangement.**

a recirculation loop connecting the two branches (Fig. 1). The operating fluid is tap water, and the mass flow rate ratio between the inlet and the re-circulating path is 1:1. The loop is instrumented with three wire-mesh sensors [2] to measure the cross-sectional distribution of a tracer injected at location WM1, labelled in Fig. 1. During the transient, the tracer is partially re-circulated to location WM2, and partially ejected via WM3. Eventually, the tracer is completely expelled from the system. To test the coupling algorithm, the double T-junction was modelled using ANSYS-CFX, while the recirculation loop was modelled using TRACE [3].

Results

The velocity field inside the double T-junction is strongly multi-dimensional (Fig. 2), and a TRACE simulation alone could never capture the correct amount of tracer recirculated in the side loop (a 1-D code will partition the tracer according to the mass flow ratio between the junctions themselves). A clear improvement of the computational results is obtained when the coupled tool CFX-TRACE is employed (Fig. 3), with some small discrepancies due to the unstable velocity field in the proximity of the outlet boundary at WM3.

Parametric studies indicate a clear influence of the inlet velocity profile on the simulation results [1]. In the results presented here, a fully developed turbulent profile has been employed, this being representative of the actual experimental conditions.

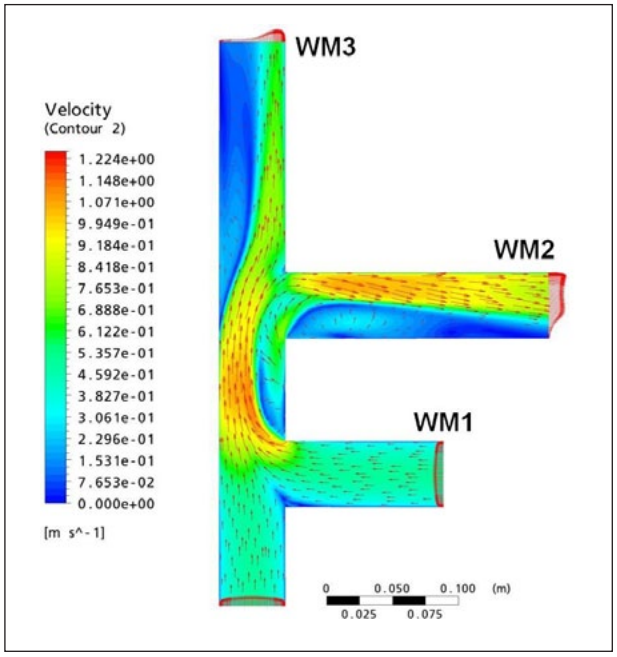


Figure 2: **Velocity field in the double T-junction configuration, as computed by the CFX code.**

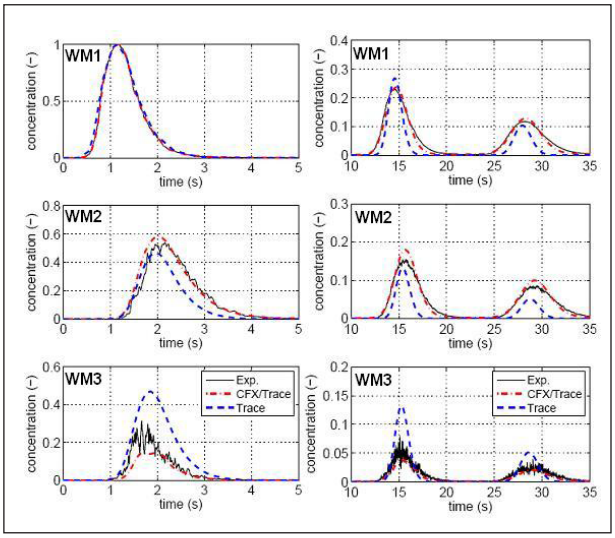


Figure 3: **Comparison of experimental data with TRACE and coupled TRACE/CFX simulation results at each wire-mesh sensor location at early and late times: injection and first splitting (left); first and second re-circulations (right).**

Conclusions

A coupling algorithm between the 1-D system code TRACE and the 3-D CFD code ANSYS-CFX has been developed, and the first steps are being undertaken in the verification and validation procedures. A validation experiment has been carried out, in circumstances in which the 3-D nature of the flow is important. Comparison between experimental and simulation results, as measured by the averaged concentration histories at the wire-mesh sensor locations, indicates that there are definite advantages in using the coupled tool, as opposed to the stand-alone system code.

References

[1] D. Bertolotto, et al., Ann. Nucl. Energy, **36**(3), 310-316 (2009).

[2] H.-M. Prasser, A. Bottger, J. Zschau, Flow Meas. Instrum., **9**, 111–119 (1998).

[3] TRACE V5., Office of Nuclear Regulatory Research. US NRC, 2007.

FALCON-PSI: an improved tool for evaluating fuel performance

Grigori Khvostov, Martin A. Zimmermann
Laboratory for Reactor Physics and System Behaviour, PSI

After the GRSW-A model for fission gas release and gaseous swelling in the uranium dioxide fuel was explicitly coupled with the FALCON code, an exhaustive verification and validation programme has been followed to ensure adequacy and numerical robustness of the improved code over a wide application area. This includes analysis of fuel behaviour during base irradiation, slow power ramps and fast transients. Progress made during the year 2008 is reported here.

A new model for fission-gas release (FGR) and gaseous swelling in uranium dioxide fuel has recently been developed at PSI. In general, the model, GRSW-A [1], predicts macroscopic characteristics of the state of the fuel by analysing the meso- and microscopic processes which occur in the fuel material. Specifically included in the model are: (1) intra-granular processes, including the kinetics of point defects in the lattice, gas mono-atom diffusion, as well as nucleation, migration, coalescence, trapping, irradiation-induced resolution and point-defect-diffusion-controlled growth of the gaseous bubbles; and (2) processes related to the grain boundaries of the fuel: namely, formation and growth of large gaseous pores (resulting in grain-boundary swelling) and FGR into the free volume of the fuel rod.

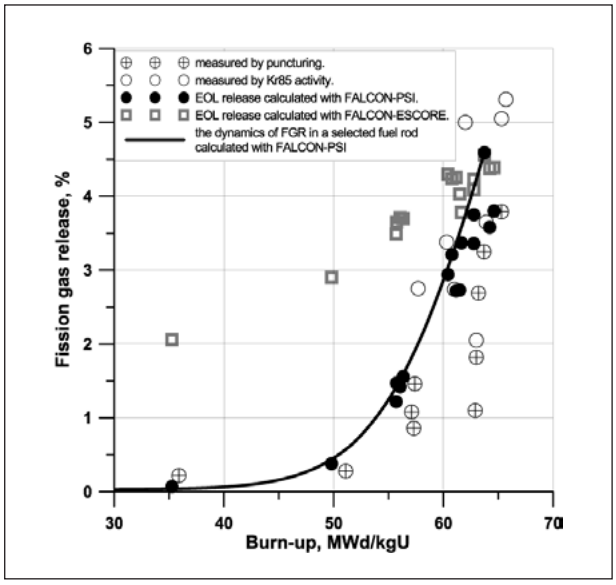


Figure 1: **Calculated and measured FGR as a function of rod-averaged burn-up for selected fuel rods irradiated in KKL**

The latter group of phenomena are represented in the GRSW-A model using an original dynamic approach [2]. Both intra- and inter-granular behaviour are considered to be closely linked to the phenomena of intra-granular fuel polygonization and high burn-up structure (HBS) formation under low-temperature irradiation, as is the process of equiaxial grain growth at higher temperatures. Also included is a special model devoted to the behaviour of the as-fabricated, intra-granular pore behaviour, related to the macroscopic effects of low-temperature, irradiation-induced densification and high-temperature sintering.

Previously, the GRSW-A model was explicitly coupled to the FALCON code [3]. With this new configuration, a comprehensive verification and validation programme needs to be carried out.

FGR and gaseous swelling during base irradiation

The improved FALCON code has been successfully applied to the analysis of the thermo-mechanical behaviour and FGR in high burn-up fuel rods from the Leibstadt nuclear power plant (KKL), from base irradiation to a peak of 70 MWd/kgU. As shown in Fig. 1, a significant improvement over the standard FALCON code results has been achieved in predicting FGR during base irradiation.

Moreover, calculated pellet swelling during steady-state irradiation in a LWR is found to be consistent with the experimental data for pellet burn-up, extending up to 100 MWd/kgU, as shown in Fig. 2.

There is very good agreement between the calculation made using FALCON-PSI and experiment [4] in regard to the decrease in intra-granular pellet swelling rate with burn-up. This is due

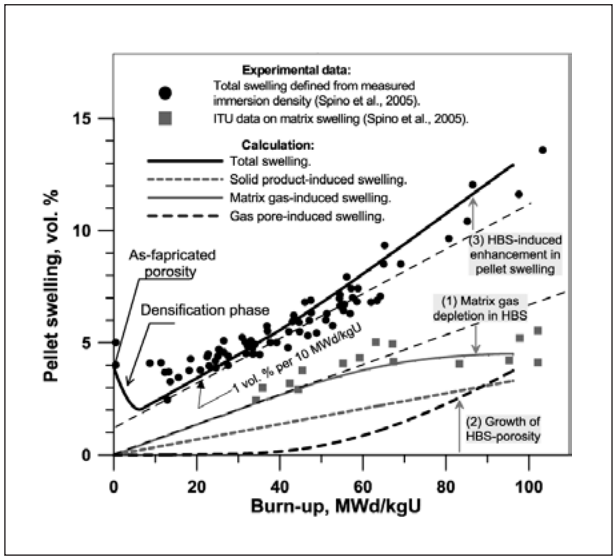


Figure 2: **Predicted pellet-averaged swelling in a high burn-up LWR fuel rod during irradiation compared with experimental data**

to depletion of the matrix fission gas on the pellet periphery subjected to intra-granular polygonization, which entails the onset and further growth of grain-boundary bubble swelling due to the formation of High Burn-up Structure (HBS) pores. The resulting increase in the rate of total pellet swelling with burn-up, as predicted by the calculation, also shown in Fig. 2, is likewise in a good agreement with the available experimental data for pellet density, as measured by the immersion method.

Gaseous swelling during power ramps

The power ramps conducted in the Studsvik research reactor within the SCIP project have also been analysed using the modified version of the FALCON code. This exercise has enabled validation of the code to be carried out against data from fuel rods with different cladding materials: namely, re-crystallized Zry-2 and M5, as well as stress-relieved Zry-4 and ZIRLO. The tested fuel segments had been extracted from both BWR and PWR fuel rods, and subject to different power ramps: short-term and long-term, high-power hold, with stepwise increase in the heat generation rate. Analysis of the SCIP cases has significantly contributed into the code's validation matrix.

It is worth noting that the predicted radial deformation of the cladding caused by the power ramps is in perfect agreement with measurement, confirming the efficacy of the code modification, and implicitly providing evidence of the significant impact of gaseous swelling on fuel rod thermo-mechanical behaviour during slow thermal transients.

RIA test analysis

Important results have also been obtained from application of the improved FALCON code to the analysis of fuel rod behaviour during the Reactivity-Initiated Accident (RIA) simulated in the Nuclear Safety Research Reactor (NSRR) in Japan within the ALPS project [5]. On the one hand, previous calculations indicated only a minor role being played by gaseous swelling on the failure of the LS-1 test fuel rod, evidently due to the relatively early cracking of the cladding, which, according to the present analysis, is expected to occur at a cladding tensile strain purely in the elastic regime. On the other hand, the more recent analysis, which took into account the extra residual cladding ductility under the higher temperature and pressure conditions (HTHP-capsule) typical of a LWR, highlighted the potentially significant effect of gaseous swelling on the cladding stress-strain conditions during the RIA. This hypothesis has been shown to be consistent with the predicted cladding hoop stress, which displayed early transfer to the plastic regime under the HTHP-capsule conditions.

In summary, by taking into account gaseous swelling of the pellets, an increase in plastic strain of the cladding of about 150% was predicted.

References

[1] G.A. Khvostov, M.A. Zimmermann, TM-41-08-07, PSI Internal Report, 2008.

[2] G. Khvostov et al., Proc. Int. Conf. on WWER Fuel Performance, Modeling and Experimental Support, pp. 392-407Albena-Varna, ,Bulgaria, Sept. 29 – Oct. 3, 2003.

[3] Y.R. Rashid, R.S. Dunham, R.O. Montgomery, Technical Report ANA-04-0666, Vol. 1, ANATECH Corp., Palo Alto (2004).

[4] J. Spino, J. Rest, W. Goll, C.T. Walker, *J. Nucl. Mater.,* **346**, 131 (2005).

[5] G. Khvostov, M.A. Zimmermann, T. Sugiyama, T. Fuketa, Int. Conf. on the Physics of Reactors, Nuclear Power: A Sustainable Resource (PHYSOR 2008), Paper No. 213, Interlaken, 14-19 Sept., 2008.

Modelling of two-phase sodium flow using the TRACE code

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In the framework of the FAST code system being developed at PSI, the TRACE thermal-hydraulics code is being extended to model two-phase sodium flow. As the most recent, official code version (TRACE v.5) is limited to the modelling of single-phase sodium, its applicability range is insufficient for studying the behaviour of a Generation-IV Sodium-Cooled Fast Reactor (SFR) during transients in which boiling is anticipated. Through the simulation of a Loss-Of-Flow (LOF) experiment, it has been shown that the current extension of the TRACE code is capable of reproducing the main sodium-boiling phenomena (including 2D effects) quite satisfactorily. Supplementary studies are needed, however, for the further improvement in accuracy.

The SFR is currently considered by the Generation-IV International Forum (GIF) as one of the most promising candidates in the near future for offering safe and reliable fast-breader reactor technology. One of the key R&D issues is to fully demonstrate the safety of the reactor. In this context, sodium-boiling phenomena play an important role, since (i) the void distribution in the core is one of the parameters controlling the reactivity during a (postulated) accident, and (ii) boiling may lead to dryout, and ultimately the melting of the fuel cladding. As SFR transient behaviour depends strongly on the coupled neutronics/thermal-hydraulics response of the core to external perturbations, extension of the TRACE thermal-hydraulics code [1] to model two-phase sodium flow is presently being undertaken.

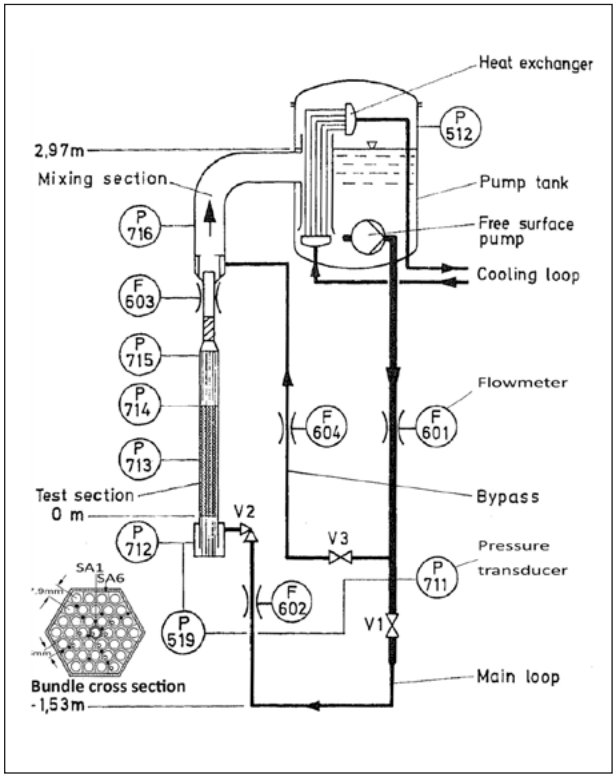


Figure 1: **Simplified diagram of the KNS sodium boiling loop, showing details of the bundle cross-section**

Extension of the TRACE two-fluid model

The original non-homogeneous, non-equilibrium model for steam-water flow in TRACE has been adapted for the representation of two-phase sodium flow. The two-fluid, six-equation model considers each phase separately in terms of a set of conservation equations governing the balance of mass, momentum and energy for each phase, together with the exchange terms between the phases. The code modifications include a number of changes to the internal logic, the addition of equations of state (EOSs) for liquid and gaseous sodium, and the implementation of sodium-specific physical models for the representation of the interfacial exchange terms. The EOSs have been tested and validated against an existing, well-established 'sodium' code: SIMMER-III [2]. Different closure relations, specific to liquid metals, have been implemented as options in TRACE for two-phase sodium flow representation. The set of models used in the SABENA code [3], which uses a simplified flow-regime map, with annular flow dominating, is currently considered the best option available for representing interfacial heat and momentum exchange.

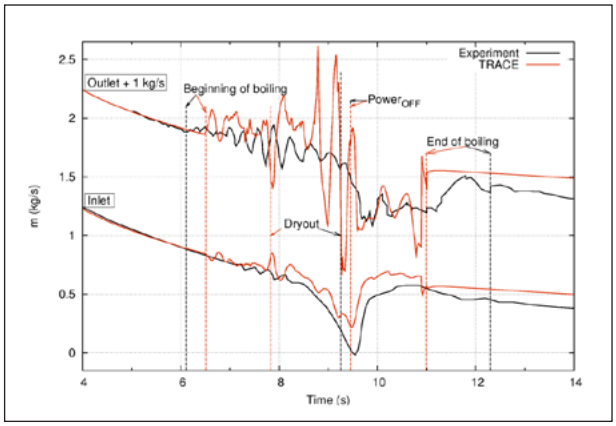


Figure 2: **Inlet and outlet mass flow rates**

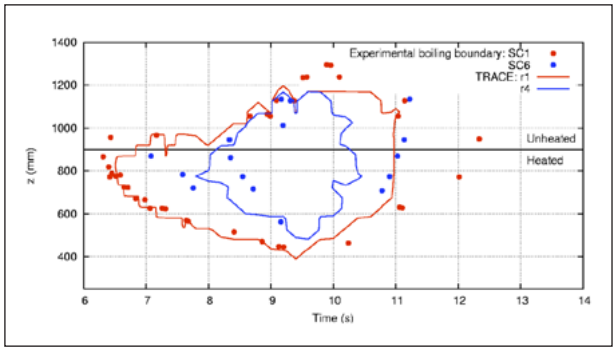


Figure 3: **Expansion of the boiling region**

Simulation of the 37-pin bundle LOF experiment

The Kompakter Natriumsiede-Kreislauf (KNS) facility, shown schematically in Fig. 1, was a sodium loop used for boiling tests in the 1980s. One experiment, simulating a loss-of-flow accident in a 37-pin bundle [4] with thermal-hydraulics conditions representative of a SFR fuel element, has been selected to assess the capabilities of the new computational tool. Both 1D and 2D TRACE representations of the test section have been considered. As there are significant spatially-dependent effects in the transient, 2D calculations are to be preferred. Results are discussed below.

Figure 2 shows the predicted and measured inlet and outlet mass flow-rate variations during the transient; the characteristic events are labelled. After the inception of boiling, the boiling region expands radially (Fig. 3), the pressure oscillating around a constant, average value. This period is well reproduced by TRACE, as can be seen from the calculated pressure evolution shown in Fig. 4(a), while Fig. 4(b) shows the void fraction history at the centre (r1) and periphery (r4) of the bundle.

It is seen that TRACE is capable of reproducing the radial expansion of vapour during the first stage of boiling (the inception of boiling in the outer subchannel is predicted 1.5s after the onset of boiling in the centre of the bundle). As soon as

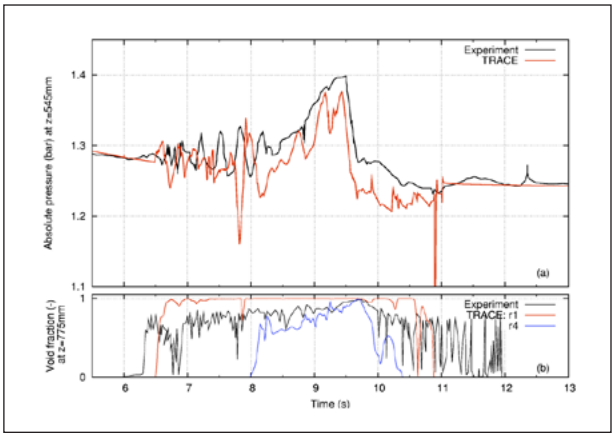


Figure 4: **Time histories of (a) absolute pressure and (b) void fraction**

the boiling front reaches the wall of the test section, the pressure rises abruptly, and the decrease in flow is faster.The downward expansion of vapour also compares very well with experiment. The calculated duration of boiling of 4.5s (Fig. 1) is about 2s shorter than the experimental value: the results indicate a numerical instability at the time of void collapse.

The study of different interfacial closure relations indicates that the prediction of boiling collapse is very sensitive to the correlations used in the model. Further study is needed to improve the correspondence between calculation and experiment for the two-phase flow period.

Conclusions

The modifications currently being implemented in the TRACE code have extended the code's capabilities to predict two-phase sodium flow. Sensitivity analyses confirm the dependence of the accuracy of the two-phase model on the assumed constitutive relations. From the investigations conducted to date, it has been found that use of a simplified flow regime map (with annular flow dominating), in conjunction with the interfacial-exchange models used in the SABENA code, yield the best results. Supplementary studies of the appropriateness of the physical models in the simulation of other experiments are planned to further improve the two-phase sodium modelling capability in TRACE.

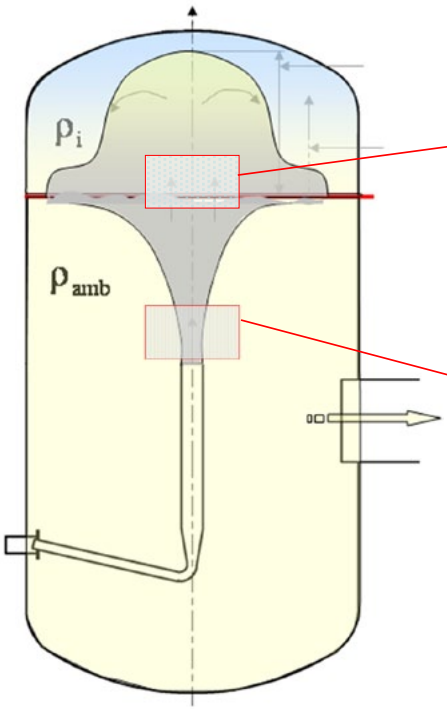
References

[1] J. W. Spore, et al., LA-UR-00-910, LANL Report, Los Alamos, USA, and Penn State University, USA, 2000

[2] Y. Tobita, et al., Nuclear Technology, **153** (3), 245-255 (2006)

[3] H. Ninokata, T. Okano, Nucl. Eng. Des., **120**, 349-367 (1990)

[4] M. Bottoni, et al., Nucl. Techn., **89**, 56-82 (1990)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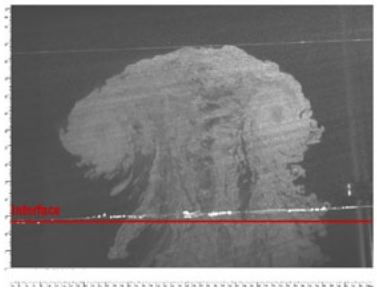
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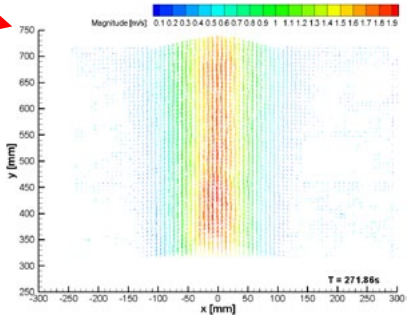
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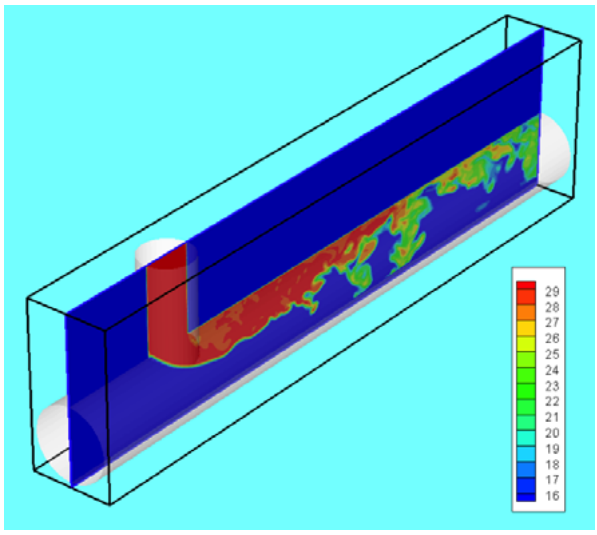
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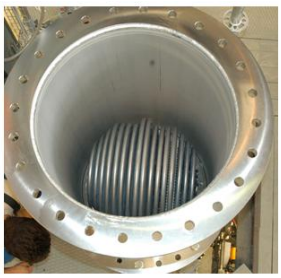

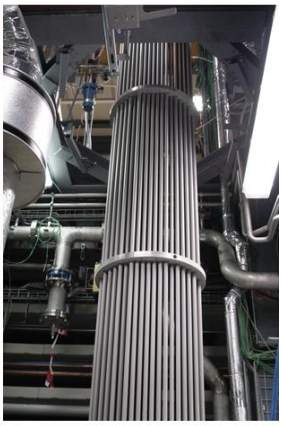

Laboratory for Thermal Hydraulics (LTH) 21

The activities within LTH are concerned with the application of state-of-the-art technologies to the heat/mass transfer processes and hydraulics relevant to the safety and efficiency of current and future nuclear reactors: both design-basis and beyond-design-basis accident conditions are considered.

Efforts fall broadly into two main project areas.

ALPHA

The project was originally conceived to provide confirmation of the characteristics of passive safety systems for advanced LWRs, and was centred around the large-scale, integral test facility PANDA. More recently, the experimental base has been broadened to incorporate investigations of fundamental phenomena in both the primary circuit and containment, and includes the study of two-phase flow phenomena (such as bubbly flows), the prediction of critical heat flux, and mixture/stratification phenomena. A number of additional small- and medium-scale, single-effect test facilities are now also included under the project heading. At all three scales, experimentation is accompanied by the development and application of novel instrumentation techniques able to measure the distributed parameters characteristic of 3D flow fields.
In parallel, there is an ongoing development and validation programme for the accompanying numerical tools, particularly CFD (Computational Fluid Dynamics), but including also multi-scale modelling approaches to basic phenomena such as boiling.

Source-Term Evaluation

Activities here are centred around the ARTIST test facility, which reproduces, at reduced scale, aerosol deposition behaviour during a severe accident following a postulated steam generator tube rupture. General considerations of iodine chemistry are being investigated, with specific application to nuclear power plants. The experimental programme is balanced by the development and validation of numerical models, the overall theme being aimed at replacing the existing empirical models by mechanistic modelling using CFD. All activities are directed towards source-term evaluation relevant to the Swiss NPPs.

◀ **Multiscale fluid-dynamic modeling in nuclear reactor technology – from the solution of fundamental equations to applied safety analyses.**

Water mixing studies on the way to predict thermal loads relevant to plant lifetime

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As nuclear plants age, and as it is generally desirable to extend their lifetimes, the issue of high-cycle, thermal fatigue to structures becomes increasingly important. Cyclic thermal loads can occur in different parts of the plant, and are invariantly associated with the mixing of coolant streams of different temperatures. One example of such mixing occurs in T-junctions, where hot and cold streams meet, but are not completely mixed. Here we report on activities aimed at developing methods to measure and numerically predict these phenomena.

In T-junctions, particularly in the regions where hot and cold streams meet, but are not completely mixed, significant temperature fluctuations can occur at the pipe walls. Such fluctuations may induce cyclic thermal stresses in the wall material, and may eventually lead to fatigue cracking. These problems were first investigated for Liquid-Metal Fast Breeder Reactors (LMFBRs) in the 1980s. Although the problem is particularly relevant to such reactors, due to the high thermal conductivity of the liquid-metal coolant, cyclic thermal loading is also an issue for Light Water Reactors (LWRs). Incidents of high-cycle fatigue have been observed in T-junctions, such as the one at the Civaux-1 plant in France in 1998 [1]. Recent research activity in this area includes the experiments and benchmarks undertaken by Vattenfall in Sweden, and the comprehensive European 5th Framework Programme THERFAT. Currently, similar research is being undertaken at PSI, as part of the Plant Life Management (PLiM) project of Swiss Nuclear.

Experiments

The high-cycle nature of the phenomena makes them difficult to monitor using conventional thermocouple instrumentation, due to the limited sensor response time. Nonetheless, reliable prediction of thermal fatigue loads is an important part of managing the risk posed by the loads. Temperature fluctuations at frequencies up to several Hz, induced by turbulent motions, present the highest risk in terms of material thermal fatigue. Significantly higher frequencies than these appear not to pose a threat, as they are strongly attenuated by the thermal inertia of the pipe material.

Using the analogy between turbulent mass and thermal transport in mixing, isothermal experiments have been performed using ionized and de-ionized water. The set-up consists of a horizontal T-junction geometry comprising Plexiglas pipes of 50 mm inner diameter. Regular (ionized) tap water flows in the main pipe, and de-ionized water in the branch pipe.

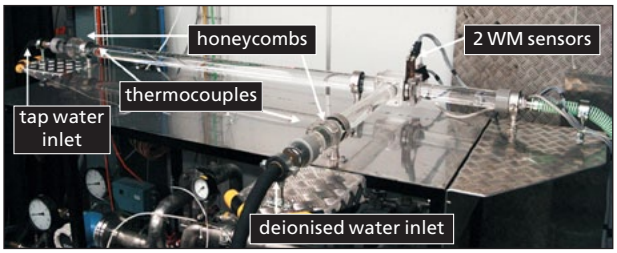

Figure 1: **The PSI T-junction test section**

A photograph of the test section is shown in Fig. 1. The two streams mix at and downstream of the T-junction, the mixture being drained through the (green) flexible hose shown on the right. Close to the inlets of the pipes, honeycomb flow-straighteners are positioned. Both pipes are sufficiently long to ensure developed flow profiles as the fluids arrive at the T-junction, giving well-defined boundary conditions for the accompanying CFD simulations. In the arrangement shown, the instrumentation consists of two wire-mesh sensors (WMSs), placed one behind the other, 50 mm downstream of the junction. The wire-mesh sensors consists of a matrix of 16×16 wires, constituting a grid of 236 measurement points (of the 256 possible combinations, some points are missing in the corners due to the circular pipe geometry). The 3 mm pitch of the measurement grid defines the spatial resolution of the measurements; the time resolution is 600 frames per second.

Calculations

The calculations presented here are based on the Large Eddy Simulation (LES) model of turbulence, and were carried out using the FLUENT 6.3 commercial CFD package. Previous studies [2,3] showed this model to be superior to the Reynolds-Averaged Navier-Stokes (RANS) and Scale-Adaptive Simulations (SAS) models. However, LES computations are an order of magnitude more computationally intensive than those employing SAS, and two orders of magnitude more expensive than RANS [3].

Results

Figure 2 shows a comparison of the conductivity distributions over the pipe cross-section at a distance $x/D = 1$ downstream the tee. As can be seen, the LES model is able to quantitatively predict the conductivity distribution very well.
The high conductivity region has a distinctive 'half-moon' shape, which is well captured by the LES calculation. The most obvious difference is the slight anti-clockwise tilt visible in the experiment, which is due to the buoyancy of the side flow, and not accounted for in the simulation. The recirculation region (blue in Fig. 2) exhibits a characteristic feature in which higher conductivity fluid is transported back to the measuring plane. This effect is also well captured by the simulation.

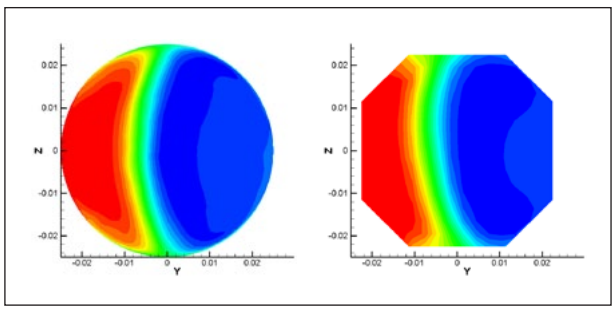

Figure 2: **Computed (left) and measured (right) conductivities in the measuring plane at *x/D* = 1**

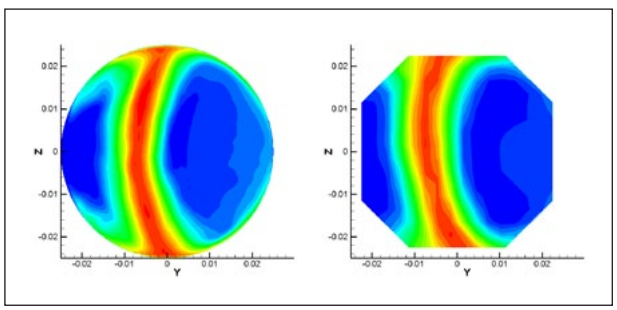

Figure 3: **Computed (left) and measured (right) rms values of conductivity in the measuring plane at x/D = 1**

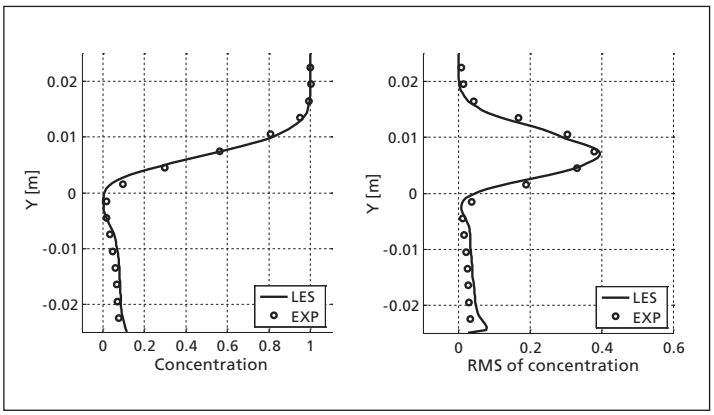

Figure 4: **Mean conductivity (left) and its rms value (right) at the midline of the measuring plane at x/D = 1**

The root-mean-square (rms) values of conductivity at the same location are shown in Fig. 3, and are accurately reproduced by the calculation. The sharp interface region (red) is associated with high rms values, and is a consequence of the strong shear between the two streams. The rms value has a minimum in both the high-velocity and the recirculation regions, since they are not yet mixed at this location. The interface region (crescent-shaped) is thin for both the experiment and the LES simulation, and has a similar thickness.
Figure 4 shows the mean and rms values of conductivity along the midline of the measuring plane. The accuracy of the LES predictions is striking for both quantities.

Conclusions

Studies are being performed with the objective of finding suitable measuring techniques for supplying data to improve the numerical modelling aspects of mixing in T-junctions. The use of WMSs is particularly suited for such flows, because of the fine spatial resolution and high frequency of the data. From the numerical point of view, LES offers the most accurate modelling approach due to its ability to capture the details of the large, coherent, turbulent structures of the flow, but is very intensive computationally. Future experimental and numerical investigations will focus on the important near-wall region.

References

[1] D. Jungclaus et al., NEA/CSNI Specialist Meeting on Experience with Thermal Fatigue in LWR Piping caused by Mixing and Stratification, OECD/NEA, Paris France, 8 – 10 June, 1998

[2] R. Zboray et al., Proc. NURETH-12, Pittsburg PA, USA, 30 Sept. – 4 Oct., 2007

[3] B. Niceno et al., Proc. TOPSAFE, Dubrovnik, Croatia 30 Sept. – 3 Oct., 2008

Vertical jet impact on a density-stratified atmosphere in a model LWR Containment

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For some accident scenarios, hydrogen accumulation in the upper part of the containment vessel is a serious concern in regard to plant safety. In the framework of the OECD/SETH-2 project, the PANDA facility is being used to study the transport of steam, air and hydrogen, and possible stratification break-up, in a model containment, induced by vertical jet flow. These tests will be used to validate and improve advanced lumped parameter and 3-D codes which aim to capture the fundamentals of post-accident thermal-hydraulic conditions in containments.

Hydrogen generation, transport and accumulation in Light Water Reactor (LWR) containments in the context of severe accident scenarios is of serious safety concern for some nuclear plants. The subsequent build-up of a hydrogen-rich layer in the upper part of the containment, and the possible mechanisms by which the concentration may be diluted, thereby reducing the risk of a possible explosion, is one of the issues being addressed in the experiments currently being conducted in the PANDA facility at PSI as part of the OECD/SETH-2 project. These investigations are aimed at creating an experimental database suitable for the improvement and validation of advanced lumped-parameter and 3-D simulation tools. The issue is important in view of the use of the codes in safety analyses [1], and with respect to reactor lifetime extension or power upgrading, which may necessitate reducing the degree of conservatism in estimating safety margins by using more accurate simulation models that properly account for the heterogeneity in the distribution of steam and non-condensable gases in the containment. Large-scale facilities, such as PANDA, approaching prototypical thermal-hydraulic conditions, enable the distortion effects associated with geometrical scaling to be minimised.

Experiments

For the tests under consideration, two large vessels, each having a volume of 90 m^3, and connected by an elbowed pipe of about 1 m diameter, are first heated and pressurised using steam [2]. Then, helium, which is used to simulate the hydrogen released during a severe accident, is introduced through a pipe at the top of one of the vessels to create a helium-steam layer of 2 m depth, the volume below remaining filled with pure steam.

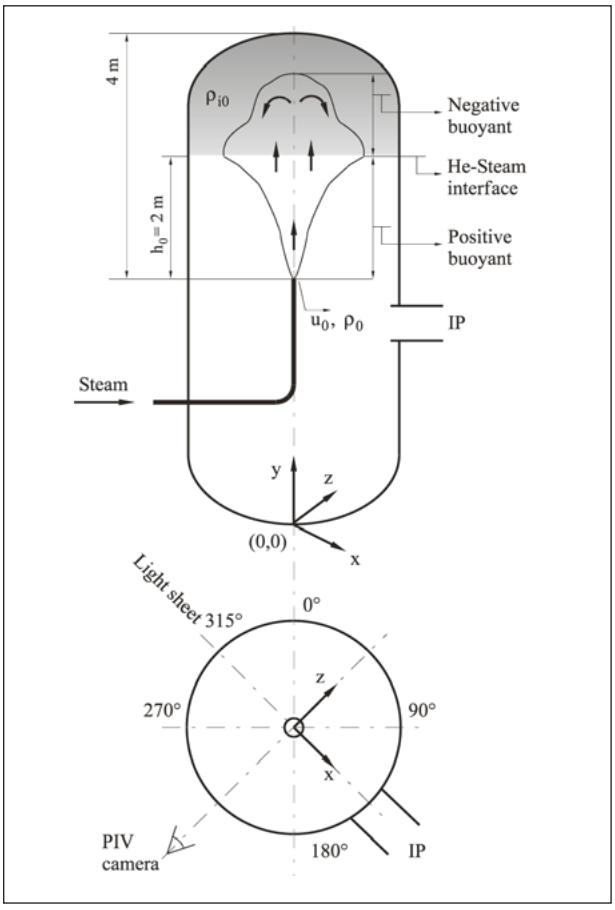

Figure 1: **Jet flow in a stratified atmosphere in PANDA.**

Jets of different strengths are created by injecting steam from a vertical pipe, located at the centre of the vessel, 2 m below the helium-steam mixture (Fig. 1). The main experimental parameters are: (i) the steam injection flowrate, and (ii) the helium-steam composition. Measurements of fluid and wall temperatures, absolute and differential pressures, flowrates,

gas concentrations and flow velocities have all been taken [2]. For the low momentum jet case, two components of the gas velocity were measured in the x-y plane (Fig. 1) by means of Particle Image Velocimetry (PIV).

Results

Axial velocity measurements are displayed in Fig. 2. The initial transition region between helium and pure steam is located in the middle of the image. Distortions imposed by an instrumentation wire have been eliminated, and the velocities accordingly set to zero (shadows).

The helium-steam layer, being less than the pure steam below it, initially (t=16s) acts as a 'soft' obstacle, the jet being deflected horizontally outwards, and even downwards near the vessel walls. Accordingly, the initial jet penetration depth is

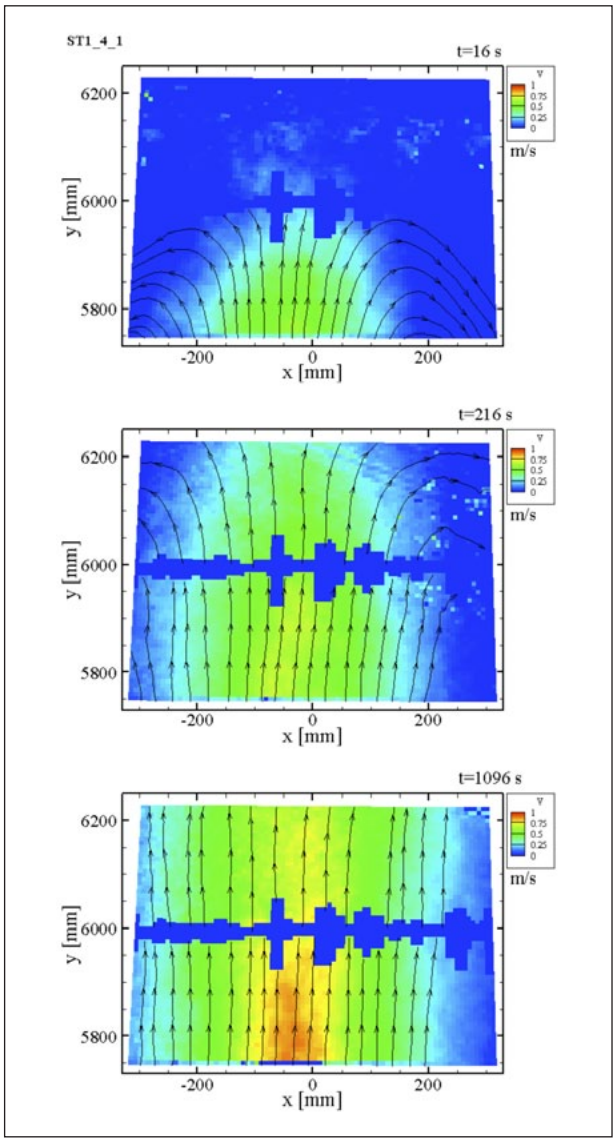

Figure 2: **Axial velocities for the low momentum jet case at different times.**

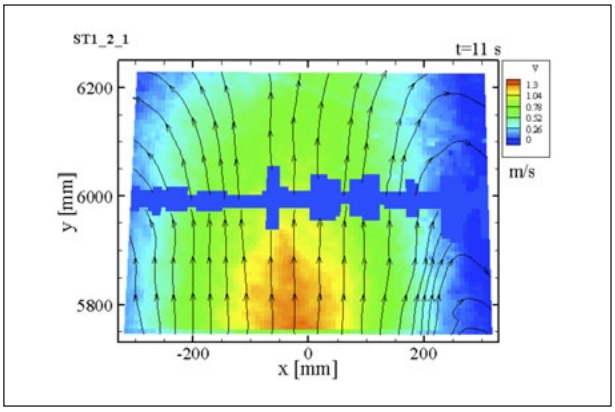

Figure 3: **Axial velocity for the high momentum jet case at t=11s.**

weak, and the velocities measured in the upper part of the vessel (y > 6000 mm) are close to zero. The jet experiences negative buoyancy as a consequence of the jet/layer interaction, and continuously erodes the helium layer, transporting the helium mixture downwards (16s to 216s). This process decreases the helium concentration continuously in the helium-rich layer, and accordingly decreases the negative buoyancy force acting against the rising jet. Once the lower part of the helium-rich layer has been eroded (1096s), a flow similar to a classical jet with vanishing horizontal velocity component in the field of view (FOV) is observed. Whereas the low momentum jet needed 220s to erode the He-layer in the FOV (Fig. 2), in the case of a high momentum jet, this already occurs after 11s (Fig. 3) for the same penetration depth.

Conclusions

Tests to investigate the effects of the impingement of jets of different strengths on helium-rich layers have been conducted in the framework of the OECD/SETH-2 project. The helium layer acts as a 'soft' barrier, and initially deflects the jet horizontally, so that the jet/layer interaction takes the form of an erosion process, transporting the helium outwards and downwards. Increasing the jet momentum effectively increases the initial penetration depth into the helium layer, and results in enhanced mixing, leading to faster layer erosion. Further analysis of these experiments will help improve the understanding of buoyant jet behaviour in initially stratified conditions and provide data for code validation.

References

[1] G. Yadigaroglu, M. Andreani, J. Dreier, P. Coddington, Nucl. Eng. Des., **221**, 205-223 (2003).

[2] R. Kapulla, G. Mignot, D. Paladino, R. Zboray, S. Gupta, Proc. Int. Congr. on Nuclear Engineering (ICONE-17), Brussels, Belgium, July 12-16, 2009.

Outcome and analysis of the QUENCH-13 experiment on the release of Ag-In-Cd control-rod material

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The prediction of reflood criteria for a PWR core under design-basis-accident conditions, i.e. at temperatures up to 1200°C, has long been established with a high degree of confidence. The QUENCH programme was launched at the Forschungszentrum Karlsruhe (FZK) to address the core reflood issue at temperatures up to 2000°C, where the rapid exothermic reaction between the Zircaloy cladding of the fuel and steam, together with the onset of clad melting, can hinder the reflood process, and could trigger a major oxidation excursion. The QUENCH-13 experiment focussed on the release of Ag-In-Cd absorber materials, which can affect the transport and release of fission products.

A total of 15 QUENCH experiments have been performed since the beginning of the programme in 1994 [1]. The bundle contains typically 20 fuel rod simulators, electrically heated over a length of one metre. The facility and bundle cross-section are shown schematically in Figs. 1 and 2.
The first experiments in the series covered a range of reflood conditions, such as the rate and timing of water/steam injection. More recent experiments have addressed the effects of different bundle configurations (Western PWR, VVER), cladding alloys (Zircaloy-4, M5, etc.), the presence of an Ag-In-Cd or B4C control rod, and air ingress, all of which may influence the accident progression and its possible consequences.
Each experiment comprises five phases: (i) establishment of stable initial conditions, (ii) a power ramp to achieve a prescribed temperature, (iii) pre-oxidation at constant temperature, (iv) thermal escalation, and (v) reflood. All the QUENCH experiments have been supported by systematic planning calculations and post-test interpretive analyses, activities in which PSI has played a prominent role since 2001, collaborating closely with FZK in all phases of the test preparation.

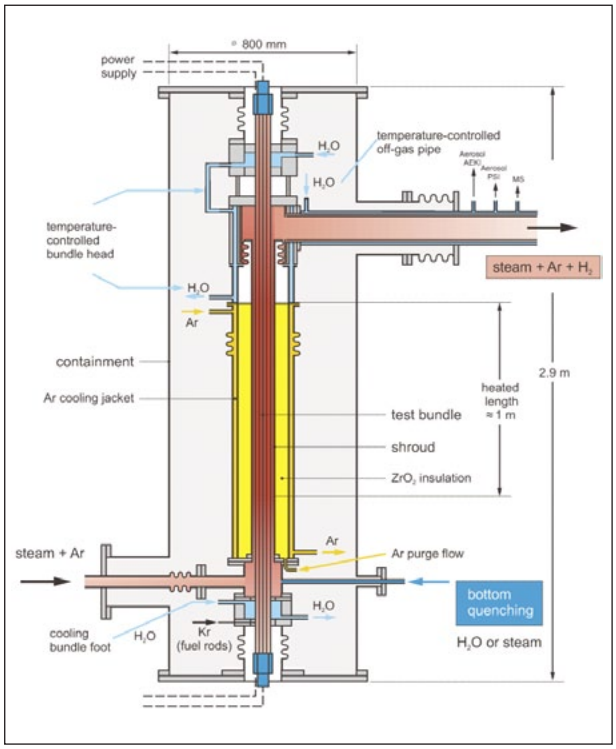


Figure 1: **Schematic of the QUENCH facility at FZK**

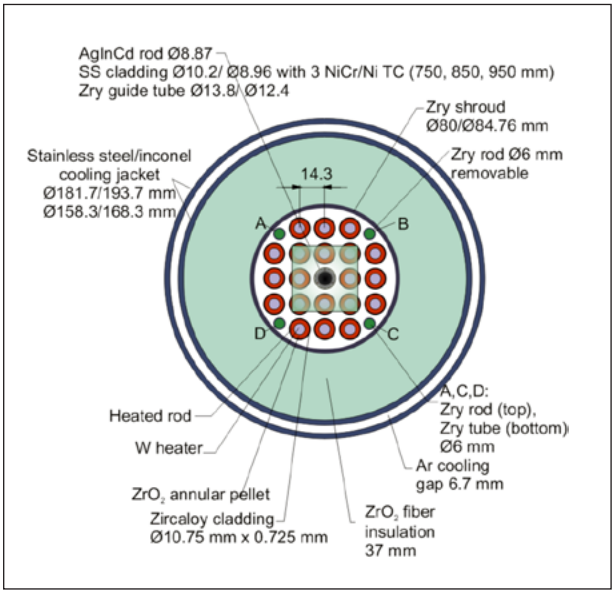


Figure 2: **Cross-section of the QUENCH bundle**

Experiment

The QUENCH-13 experiment was successfully carried out in November, 2007 [2]. The test needed to be carefully defined in order to achieve suitable conditions for studying the control rod behaviour, and planning support was performed by means of a coordinated effort [3] between PSI, FZK, Gesellschaft für Reaktorsicherheit (GRS), and Electricité de France (EDF). The transient is summarised in Fig. 3, which shows the control rod temperature and observed aerosol release histories, and together with the control rod behaviour.

PSI also installed and operated an aerosol sampling system in the off-gas line, to provide continuous on-line monitoring of the aerosol transport, and to collect samples at discrete times during the period following failure of the control rod. The PSI measurements were complemented by those from the sampling system installed and operated by AEKI, Hungary. [4].

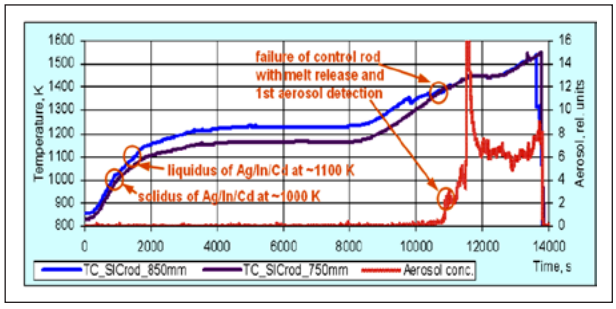


Figure 3: **Summary of the QUENCH-13 transient**

Analyses and discussion

Analyses of the QUENCH-13 data by PSI, GRS, EDF and IRSN (Institut de Radioprotection et de Sûreté Nucléaire) showed that the thermal response could be satisfactorily reproduced. However, the calculated releases exhibited large discrepancies compared with measured data, indicating a need to acquire additional data on the release process [5,6]. This is evident from Table 1, showing comparisons of the Ag-In-Cd releases. The predicted release of cadmium, the most volatile component, is in quite good agreement with measurement, but the releases of Ag and In differ from experiment, and from each other. The experiments showed that some of the aerosol release mechanisms appear not to be taken into account in the current models, or are incorrectly represented. The release models are all based on direct evaporation from a molten pool, but with a range of assumptions for heat transfer, and for the activation parameters that characterise the non-ideality of the Ag-In-Cd mixture. Current investigations by IRSN aim to close the gaps in the thermodynamic data.

	Ag	In	Cd
MELCOR (PSI)	11	11	23
ASTEC (IRSN)	0.008	17	21
ATHLET-CD (GRS)	0.02	0.11	21
MAAP-4 (EDF)	2.5	4.5	8.5
Experimental estimate	~ 0.1	~ 1.5	~10

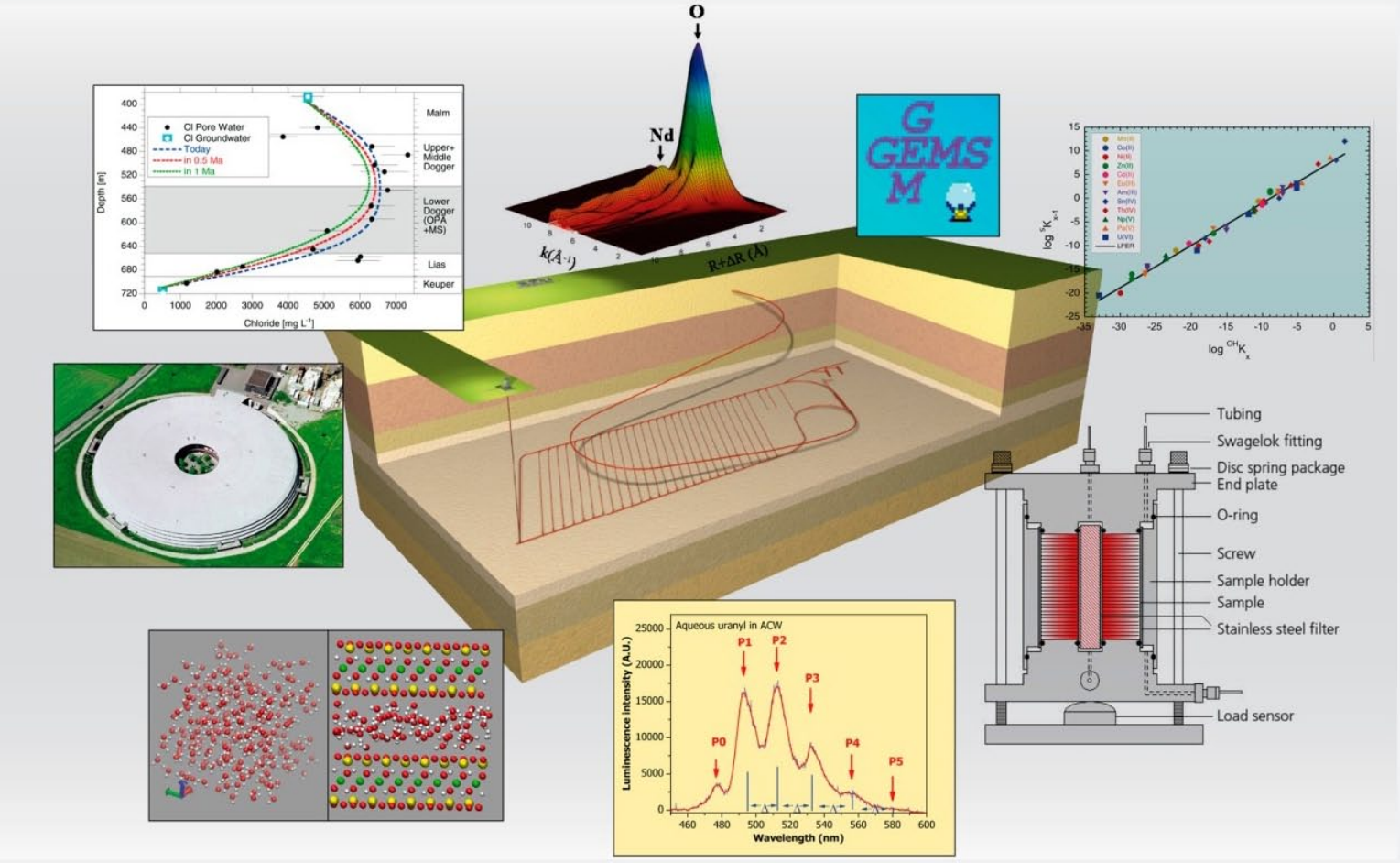
Table 1: **Comparison of calculated and measured Ag-In-Cd releases as a percent of the total inventory**

In addition, liquid droplets may have been entrained due to rapid boiling, especially at the time of the observed peak aerosol transport. However, this effect is not considered in any of the models. FZK have also performed tests on control rod samples to characterise the mode and temperature of failure that might occur under the different conditions. Widely contrasting failure modes were observed, depending on the sample configuration, all of which would be expected to result in different release kinetics.

The combined test preparation and analysis effort was part of the Source Term work package of the EU 6th Framework Programme, SARNET. Studies are continuing within the follow-up programme: SARNET-2.

References

[1] L. Sepold et al., Nucl. Eng. Des., **237**, 2157-2164 (2007).
[2] L. Sepold et al., FZK Report: NUKLEAR 3416, 2008.
[3] T. Haste et al., Paper 8065, Proc. ICAPP'08, Anaheim, USA, 8-12 June, 2008.
[4] T. Lind et al., J. Nucl. Materials (submitted 2008).
[5] R. Dubourg et al., Paper 3.6, Proc. ERMSAR 2008, Nessebar, Bulgaria, Sept. 23-25, 2008.
[6] J. Birchley et al., Paper 9011, ICAPP'09, Tokyo, Japan, May 10-14, 2009.


Cl Pore Water
Cl Groundwater
Today
in 0.5 Ma
in 1 Ma
Malm
Upper+ Middle Dogger
Lower Dogger (OPA +MS)
Lias
Keuper
Depth [m]
Chloride [mg L-1]
O
Nd
k(Å-1)
R+ΔR (Å)
G
GEMS
M
log ⁵K x+1
log OH K x
Tubing
Swagelok fitting
Disc spring package
End plate
O-ring
Screw
Sample holder
Sample
Stainless steel filter
Load sensor
Aqueous uranyl in ACW
P0
P1
P2
P3
P4
P5
Luminescence intensity (A.U.)
Wavelength (nm)

Laboratory for Waste Management (LES) 29

LES has two principal functions: (a) to carry out a R&D programme to strengthen the scientific basis for the ultimate disposal of nuclear waste; and (b) to operate a microXAS beamline, a joint venture with the SLS (Swiss Light Source) team.

Current LES activities devolve around the following two projects.

NAGRA Support

This is an ongoing commitment, overseen by the federal government, to ensure the safe disposal of radioactive waste from the medical and nuclear industries, but including also that arising from nuclear research. The activities cover fundamental waste-disposal chemistry, the physics and chemistry of radionuclides, and investigation of the geological boundaries for radionuclide transport. Results will ultimately find use in the comprehensive application of safety criteria.

MicoXAS Beamline

The aim here is to employ a SLS beamline to perform spectroscopic studies using hard X-rays to achieve high spatial resolution. The FEMTO project for the investigation of time-dependent phenomena is encompassed in this undertaking.

◀ **To strengthen the scientific basis for the ultimate disposal of nuclear waste many fields of competence work together at LES.**

Influence of carbonate complexation on the sorption of actinides/lanthanides on clays

Maria Marques Fernandes, Bart Baeyens, Mike Bradbury
Laboratory for Waste Management, PSI

Radioactive waste has to be isolated from the environment for the duration of its toxicity. Deep geological disposal offers continuous protection from the dangers over long time periods. Physical and chemical retention of radio-nuclides on clay minerals, important constituents of the back-fill material and host rock, is an important safety barrier for preventing radioactive substances dissolved in water being transported to the biosphere. The presence of inorganic carbon in the deep groundwater can have a significant effect on the retention of trivalent actinides/lanthanides, since they form strong aqueous complexes. Recent investigations have clearly indicated that ternary actinide/lanthanide-carbonate surface complexes actually form on the clay surfaces, and hence contribute in a significant manner to their immobilization.

Assessing the long-term safety of a radioactive waste repository can be greatly assisted by a molecular-level understanding of the behaviour of radio-nuclides in the geo-sphere. This knowledge is needed to establish reliable thermodynamic data to quantify the retention and transport of radionuclides in deep groundwater. The transport of released radionuclides in geological environments is primarily controlled by the sorption/desorption processes occurring on mineral surfaces. Clay minerals, as major constituents of the potential host rock formations, thus need to be considered in the design of a high-level radioactive waste repository.

The sorption of metal ions is strongly dependent, among other things, on the ionic strength, pH value, and the presence of organic or inorganic ligands in solution. A detailed understanding of the sorption mechanisms taking place at the mineral surface over a representative range of relevant conditions is essential for performance assessment studies.

Dissolved carbonate is ubiquitous in deep groundwater, and has a large complexation affinity for actinides. Such complexes in the aqueous phase can potentially lead to a decrease in sorption, and thus an increase in the migration rates of actinides.

Thermodynamic and structural data for lanthanide/ actinide, carbonate-mineral systems are sparse, though the data are needed, since clay rock pore-waters often contain quite high carbonate concentrations. For trivalent actinides and U(VI), it has been reported [1–3] that the formation of ternary (hydroxo-) carbonate surface complexes may contribute to surface sorption reactions (Fig. 1). Taking the latter into account necessitates the unambiguous identification of the mixed-surface species. The objective of the current study is to determine, with a combination of wet chemistry, geochemical modelling and spectroscopic studies, whether or not ternary Ln(III)/An(III)-carbonate complexes actually form at the surface of clay minerals.

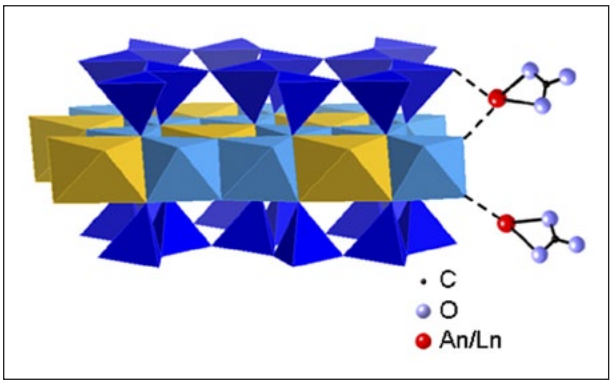


Figure 1: **Schematic representation of the formation of ternary Ln(III)/An(III)-carbonate complexes on clays.**

Macroscopic and microscopic investigations

To quantify the influence of inorganic carbon on the sorption of trivalent actinides/lanthanides on different clay minerals, macroscopic sorption experiments have been carried out, both in the presence and absence of carbonate. Sorption measurements were made as functions of pH value in the presence of various inorganic carbon concentrations. The measurements show that there is a pronounced decrease of sorption in the presence of carbonate (Fig. 2).

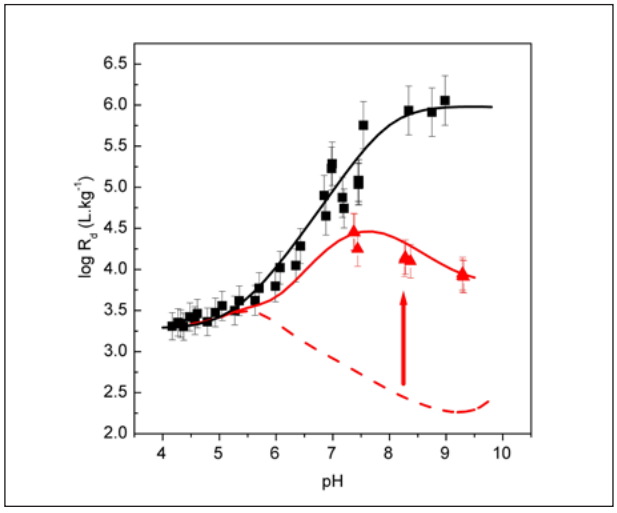


Figure 2: **Sorption of Eu(III) on clay, both in the absence of carbonate (■), and in the presence of 20 mM $NaHCO_3$ (▲). The respective modelling predictions are shown by the solid lines.**

Simulation, using the 2-**S**ite **P**rotolysis **N**on-**E**lectrostatic **S**urface **C**omplexation and **C**ation **E**xchange (2SPNE SC/CE) sorption model [4] under the assumption that carbonate complexes do not sorb, largely underpredicts the experimental data (red dashed line in Fig. 2). Consequently, other surface sorption reactions, ones involving carbonate complexes, must be considered. The experimental data for Ln(III)/An(III) could only be successfully reproduced using the 2SPNE SC/CE sorption model by including two additional surface complexation reactions: those forming $\equiv S^SOAnCO_3$ and $\equiv S^SOAnOHCO_3^-$ surface species [3].

Time-resolved laser fluorescence spectroscopy (TRLFS) has proven to be a versatile tool for Cm(III) speciation studies, as well as for sorption studies on various solids [5,6]. TRLFS measurements have been carried out on Cm(III)-loaded clay pastes at T < 20 K. In a preliminary step, an iron-poor clay mineral, kaolinite, was chosen in order to avoid any fluorescence quenching by iron. The excitation spectra of the Cm(III) kaolinite samples were measured by scanning the excitation wavelength in the range of the $^6D_{7/2} \rightarrow {}^8S_{7/2}$ transition [595–625 nm], recording simultaneously the corresponding Cm(III) emission spectra.

Figure 3a shows the excitation spectra of the Cm(III)/kaolinite samples prepared both in the absence (black line) and in the presence (red line) of 20 mM $NaHCO_3$. Figure 3b shows the fluorescence emission decay curves of Cm(III) obtained for both systems, exciting at two different wavelengths. Similar behaviour was observed for the montmorillonite system. The fluorescence features of the Cm(III)-carbonate-mineral systems (red-shift and the shape of the excitation spectra, bi-exponential decay and increase of the fluorescence lifetime) differ strongly from those of the carbonate-free systems, indicating different coordination environments for Cm(III). This is clear evidence that ternary An(III)/(hydroxy)-carbonate surface complexes form on the clay edge surface, as postulated in the macroscopic study.

References

[1] J.G. Catalano, G.E. Brown, Geochim. Cosmochim. Acta, **69**, 2995 (2005).
[2] T. Stumpf et al., Radiochim. Acta, **90**, 345 (2002).
[3] M. Marques Fernandes et al., Radiochim. Acta, **96**, 691 (2007).
[4] M.H. Bradbury, B. Baeyens, J. Contam. Hydrol., **27**, 223 (1997).
[5] T. Rabung, et al., Geochim. Cosmochim. Acta, **69**, 5393 (2005).
[6] T. Stumpf et al., J. Colloid and Interface Science, **276**, 118 (2004).

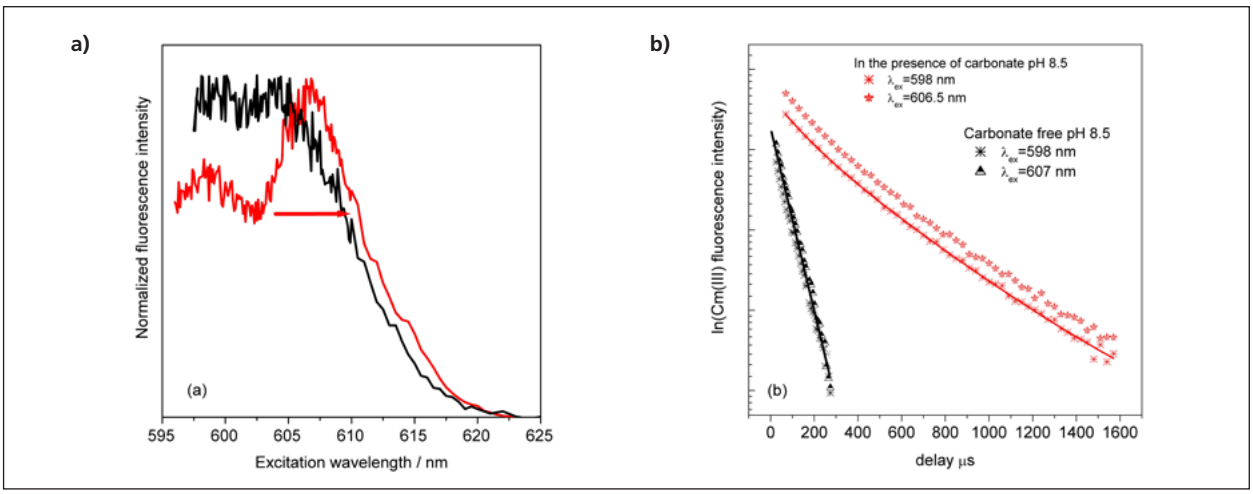


Figure 3: **(a) Excitation spectrum of Cm(III)-loaded clay samples prepared in the absence of carbonate (—) and in the presence of 20 mM $NaHCO_3$ (—); (b) fluorescence lifetimes of the same samples in the absence of carbonate (black symbols) and in the presence of 20 mM $NaHCO_3$ (red symbols).**

Reactive transport modelling of laboratory experiments: caesium diffusion in Opalinus clay

Andreas Jakob, Wilfried Pfingsten, Luc Van Loon,
Laboratory for Waste Management

In the frame of the long-term activities of LES, small-scale diffusion experiments have been carried out and analysed. The study has clearly shown that simplified, single-species models are inappropriate for correctly accounting for the observed tracer breakthrough data. Only a more sophisticated, multi-species model for radionuclide transport, incorporating the entire water chemistry, a complex sorption model, and accounting for the effects of sorption competition, is able to model the data and to produce reliable predictions.

Several European countries (including France, Belgium and Switzerland) are considering deep-lying argillaceous formations as potential host rocks for the safe disposal of radioactive waste. The underlying reasons for this choice are that the hydraulic permeability of such formations are very low, and their capability for an efficient retardation of mobile radionuclides is high. These features make them most suitable for isolating radioactive waste over very long periods. Due to the absence of fractures, even on a microscopic scale, and because of the low hydraulic permeability of the clay, the main transport process for radionuclides is molecular diffusion. It is therefore essential to understand, at a fundamental level, the diffusion and sorption of radio nuclides in such compacted argillaceous formations, and to determine radionuclide-dependent values for the diffusion coefficient and sorption capacity.

It is common practice to determine the diffusion and sorption coefficient values from small-scale, through-diffusion experiments, and from diffusion tests in the field. In order to achieve tracer breakthrough within reasonable times in such small-scale diffusion tests, only non-sorbing and weakly sorbing tracers can be used. With regard to nuclide/rock interaction, such diffusion studies have to be supported by specific (batch) sorption investigations, for which the partition of the tracer between the solution and the solid phase is studied.

There are marked differences in techniques between batch sorption tests and diffusion experiments. Batch sorption tests are carried out with a high liquid/solid ratio, while diffusion experiments are carried out with a very low liquid/solid ratio. Batch sorption experiments are the favoured method for determining the sorption behaviour of a given argillaceous rock, since such experiments are much less time-consuming than diffusion tests, and allow sorption models to be developed. However, it is still a somewhat unresolved issue whether

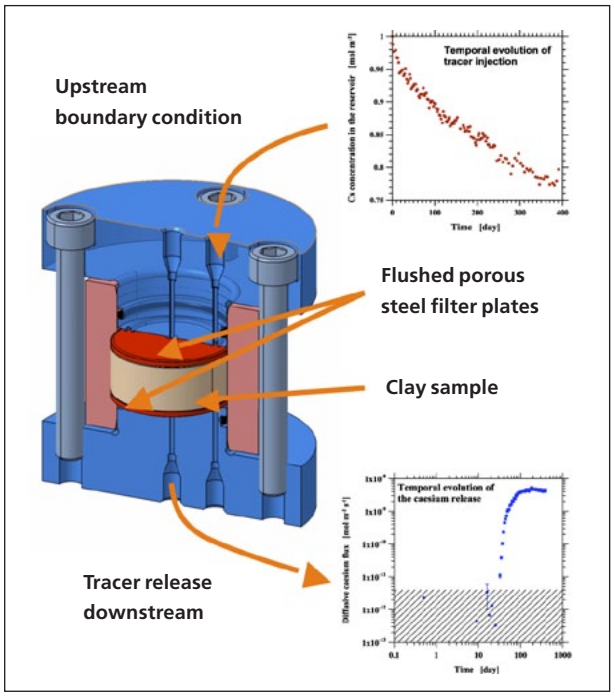


Figure 1: **Cross-section through the stainless steel diffusion apparatus (blue and pink). Continuous tracer injection occurs via a circular channel on top of the upper filter plate. The diffused tracer is collected at the centre port of the lower re-circulation loop, providing the time history of tracer breakthrough.**

sorption data from batch sorption experiments can be compared with data deduced from (small-scale) diffusion experiments. In general, single-species models are applied for analysing diffusion tests, though more complex models are also used, especially in those cases for which single-species models fail. In our study [1], we have demonstrated that even for chemically simple tracers such as caesium, the single-species models are not capable of adequately reproducing results

from such diffusion experiments. Instead, a multi-species model for solute transport, together with a sophisticated sorption model for caesium, is needed to successfully reproduce the experimental data, and to make reliable predictions.

Experiment

The Opalinus clay (OPA) sample used in the diffusion experiment originated from the Mont Terri underground rock laboratory near Saint Ursanne in Canton Jura. A cylindrical sample of diameter 2.54 cm and thickness 1.1 cm was machined from a bore core, bounded by two porous stainless steel filter plates, and placed in a diffusion apparatus; a schematic is shown in Fig. 1. The diffusion experiment was carried out using ^{134}Cs as tracer on the 10^{-3} molar total caesium concentration level. In order to avoid additional gradients as driving forces for migration, an artificial Opalinus porewater was applied. As illustrated in Fig. 1, the temporal evolution of the caesium concentration in the reservoirs was monitored at both boundaries. Complementary to the long-term diffusion experiment, batch sorption tests were also carried out to determine the nature and strength of caesium sorption onto OPA.

Analysis

A first analysis of the experimental data was undertaken using a single-species model, which only accounted for transport and non-linear sorption of caesium (sorption is dependent on the caesium concentration in solution). The through-diffusion data could only be modelled if the sorption data were strongly reduced. Such a procedure is in total contradiction to results of sorption measurements carried out on intact OPA samples. In addition, tracer out-diffusion and mass balances could not be predicted, clearly demonstrating the shortcomings of this type of model.

In a second attempt, a multi-species transport model was applied which included the entire water chemistry and a sophisticated sorption model for caesium [2]. Adjusting the effective diffusion coefficient, D_e, both through- and out-diffusion data could be predicted satisfactorily, as well as the mass balances.

Main results and conclusions

A best-fit in terms of the multi-species model was achieved with $D_e = 1.8 \times 10^{-10}$ m^2 s^{-1}, which appears to be rather high, but is corroborated by the results from a parallel molecular modelling study.

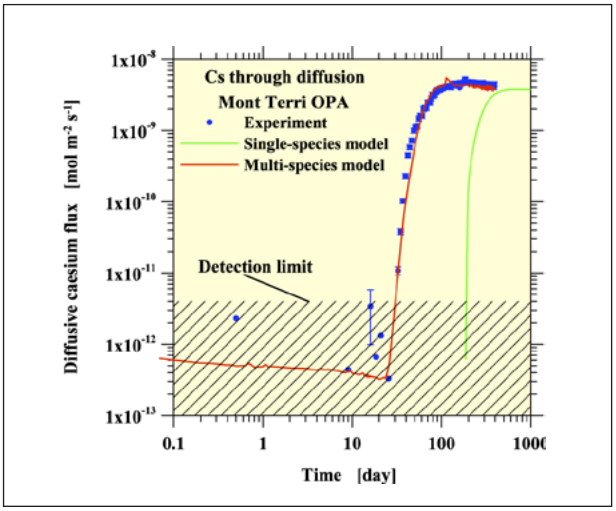


Figure 2: **Best fits to experimental Cs breakthrough data in terms of the single- and multi-species models. The models are based on sorption data and models from batch sorption experiments.**

When caesium diffuses through an OPA sample, ions of potassium, sodium, calcium, etc. are released, and caesium ions are sorbed. The released cations diffuse to lower concentration regions according to their individual concentration gradients within the OPA sample. Since locally the cation concentration for potassium, etc. is increased, sorption of these cations is also locally enhanced, affecting in turn the sorption behaviour of the migrating caesium. Hence, caesium sorption is influenced by sorption competition effects from all of the other cations in solution, and consequently the sorption behaviour of caesium in such diffusion experiments can no longer be modelled by a simple, non-linear isothermal formalism. An analysis of such single-tracer diffusion experiments, and any predictive modelling, therefore requires the combined description of transport (diffusion) and sorption of many cations, as well as the entire complex water chemistry of the system. We conclude that single-species models can only be applied with caution in the concentration ranges considered here.

References

[1] A. Jakob, W. Pfingsten, L. Van Loon, Effects of sorption competition on caesium diffusion through compacted argillaceous rock, Geochimica et Cosmochimica Acta, **73**, 2441–2456 (2009).

[2] M.H. Bradbury, B. Baeyens, A generalised sorption model for the concentration dependent uptake of Cs by argillaceous rock, Journal of Contaminant Hydrology, **42**, 141–163 (2000).

Chemical mechanisms for the immobilisation of lanthanides in cementitious materials

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The release of radionuclides from the cementitious near-field of a repository for low- and intermediate-level radioactive waste is primarily controlled by their interaction with cement minerals. Calcium silicate hydrates (C-S-H) are the most important, and most stable, minerals in hydrated cement. Recent spectroscopic studies of the binding mechanisms of Eu(III) clearly show that, in the long term, trivalent lanthanides/actinides will be immobilised in the C-S-H structure. This process significantly retards their release to the geological environment.

Cement is the major constituent of the engineered barrier system of a deep geological repository for low- and intermediate-level radioactive waste. The latter may contain significant inventories of trivalent actinides, such as $^{241/243}$Am(III) and $^{239/240}$Pu(III). Trivalent lanthanides, such as Eu(III), are regarded as suitable chemical analogues for trivalent actinides, based on their comparable ionic radii and similarities in their complexation behaviour. The release of trivalent lanthanides/actinides from the cementitious near-field into the surrounding host rock is primarily controlled by their interaction with cement minerals. A molecular-level understanding of the chemical processes governing radionuclide immobilisation by cement has been gained from the use of laser- and synchrotron-based spectroscopic techniques, and has greatly assisted in the improvement of detailed long-term predictions of the safe disposal of cement-stabilized waste forms.

Calcium silicate hydrates (C-S-H) are the most important constituent of hydrated cement, since not only are they abundant, but they exhibit a wide diversity of structural sites exposed for cation binding. In addition, C-S-H phases are the most stable cement minerals during the evolution of the cementitious near-field. For example, 11Å tobermorite (Fig. 1) is a crystalline C-S-H phase for which the structure is well known [1]. The layered structure is built up of sheets of Ca polyhedra, linked through non-bridging oxygens to chains of silicate tetrahedra on both sides. The interlayer space between the sheets may contain water and calcium cations. The structure of tobermorite is also closely related to those of amorphous C-S-H phases, which form in hydrated cement [2,3].

Three different modes of Eu(III) interaction with 11Å tobermorite can be envisaged: (1) surface complexation, label 1; (2) uptake in the interlayer, label 2; and (3) incorporation in the Ca sheets, label 3. Time-resolved laser fluorescence spectroscopy (TRLFS) has proven to be a versatile tool in Eu(III) surface speciation studies aimed at elucidating binding mechanisms on solids [4]. Hence, TRLFS measurements have been carried out on Eu(III)-loaded C-S-H pastes at T<20K using different Eu(III) loadings. The samples had been aged for 1 day, 90 days and 570 days, respectively. The excitation spectra were measured by scanning the excitation wavelength in the range of the ^{5}Do $\rightarrow$^{7}Fo transition (576–582 nm), and recording simultaneously the Eu(III) emission spectra.

Figure 2 shows the fluorescence emission decay curves of Eu(III) obtained at a loading of 7 µmol/g. The decay curve of the fluorescence lifetime of the sample aged for 1 day could be fitted using a tri-exponential function, revealing the pres-

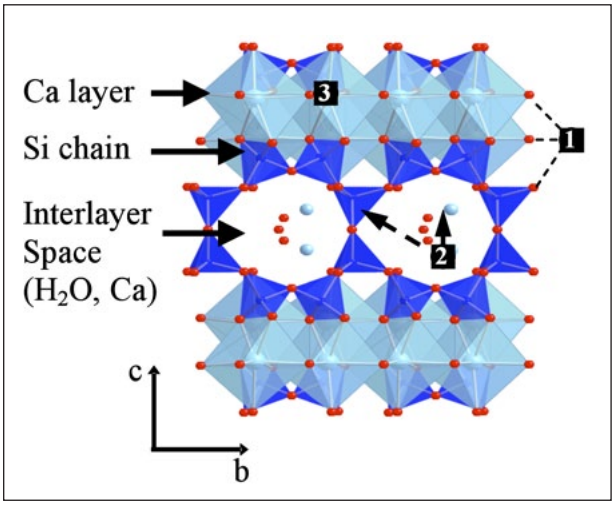


Figure 1: **The crystalline structure of 11Å tobermorite showing possible positions of Ca in the Ca layers and interlayer Ca (•), together with those of structural oxygens and water molecules in the interlayer (•). Labels 1, 2, 3 refer to potential sites for Eu sorption and structural incorporation (•).**

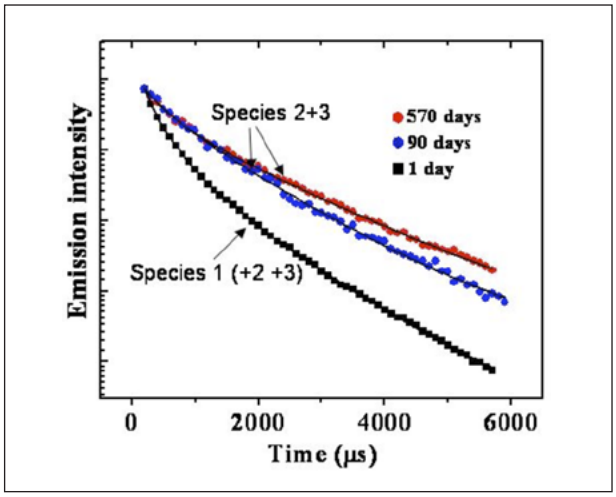


Figure. 2: **Time dependency of the Eu(III) emission: Eu(III)-loaded 11Å tobermorite (7 µmol/g), aged for 1 day, 90 days and 570 days.**

ence of 3 Eu(III) species with different lifetimes (τ_1 = 200±10 µs, τ_2 = 650±60 µs and τ_3 = 2020±150 µs). Previous studies for comparable systems [4] showed that the fluorescence lifetime decreases with increasing number of water molecules bound to Eu(III). Using a well-established relationship to determine the hydration state of the Eu(III) species [5], we found that the fluorescing species with the shortest lifetime had about five H_2O molecules in its coordination sphere, consistent with the notion of a surface-bound Eu(III), as seen in Fig. 1. The two other Eu(IIII) species, with longer lifetimes, have one or no H_2O molecules in the coordination sphere, which can be explained by Eu(III) being incorporated in the interlayer, or in the Ca sheets of tobermorite, respectively. Furthermore, Fig. 2 reveals that with increasing ageing time, the concentration of the incorporated Eu(III) species increases, while that of the surface-bound Eu(III) species decreases.

The use of EXAFS spectroscopy

Incorporation of Eu(III) in the structure of 11Å tobermorite was further confirmed using extended X-ray absorption fine structure (EXAFS) spectroscopy. EXAFS measurements were carried out on Eu(III)-loaded samples (7 and 35 µmol/g) which had been aged for 120 and 480 days. Figure 3 shows the experimental and modelled EXAFS data. The type of neighbouring atoms, as well as the coordination number (N) and bond distances (R) of the neighbouring atoms, were determined from a multi-shell analysis in the range R+ΔR = 1.5–4.0 Å. The radial structure functions (RSFs) of all samples show a peak at R+ΔR ~ 2.0 Å, which reflects the presence of seven oxygen atoms at a distance of $R_{Eu\text{-}O}$ = 2.39–2.40 Å. The presence of further back-scattering atoms is indicated by the broad peak in the Fourier transforms at R+ΔR ~ 3.0Å. This peak could be fitted by considering, about five neighbouring Si atoms ($R_{Eu\text{-}Si}$ = 3.76±0.02 Å) and four neighbouring Ca atoms ($R_{Eu\text{-}Ca}$ = 3.82±0.02 Å), respectively. The structural parameters were found to be similar at high and low Eu(III) loadings. The high coordination numbers determined with EXAFS spectroscopy confirm that Eu(III) was bound in the structure of 11Å tobermorite.

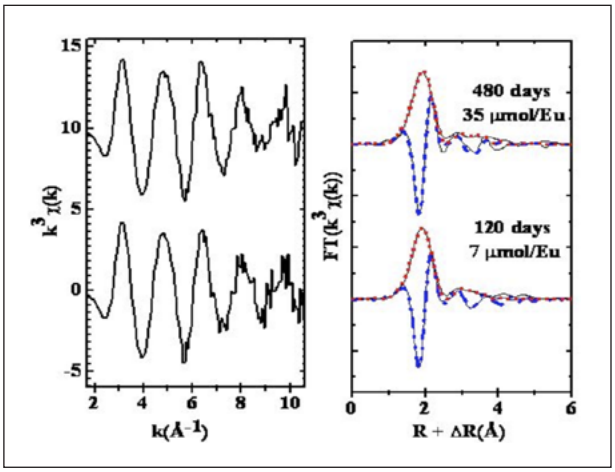


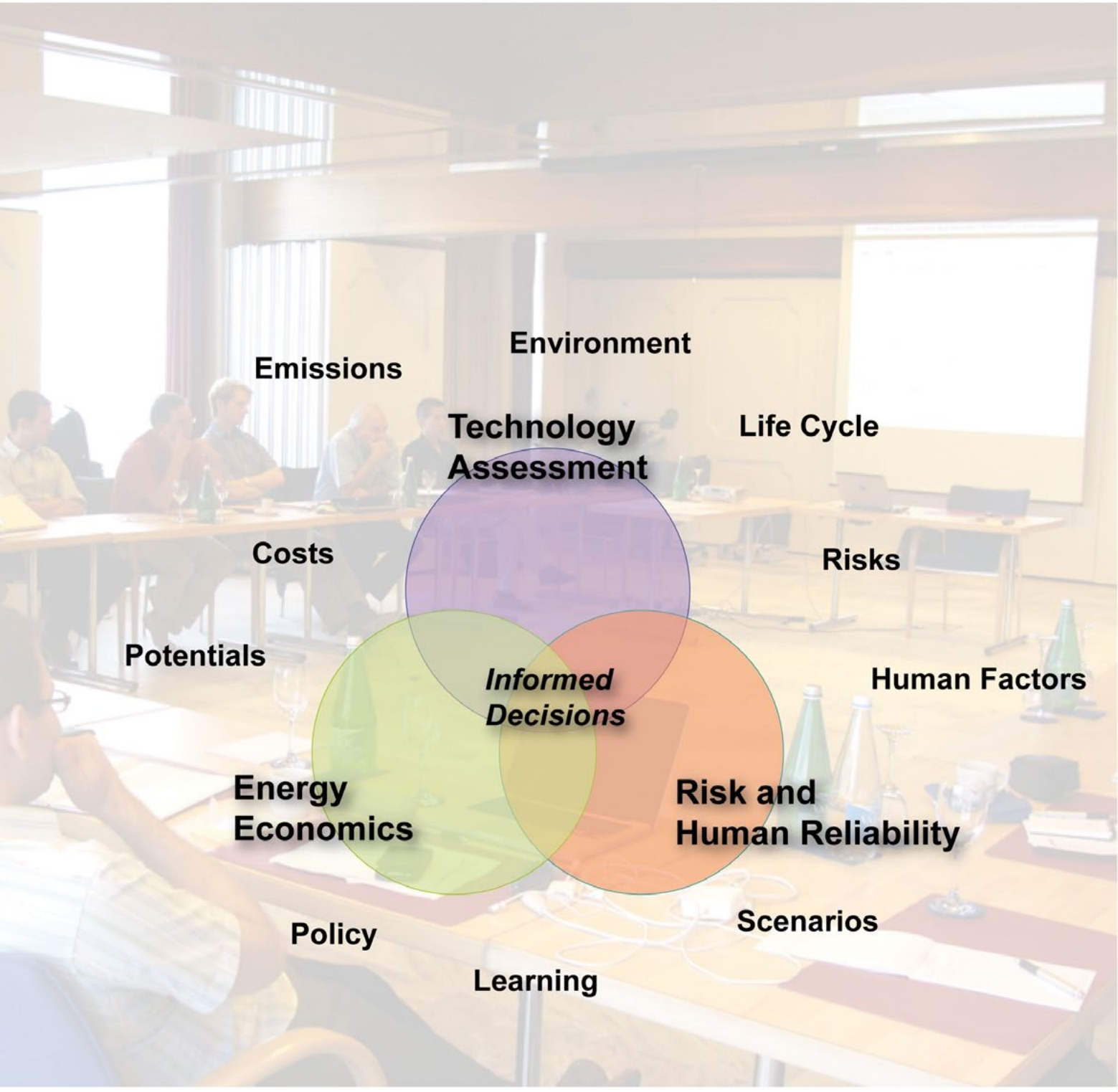
Figure 3: **(a) The k^3-weighted EXAFS spectra, and (b) the corresponding Fourier transforms, of experimental (solid line) and modelled (dashed and dotted lines for the imaginary and the real parts, respectively) Eu L_{III}-EXAFS of Eu(III)-loaded 11Å tobermorite (7 and 35 µmol Eu/g) for different reaction times.**

Conclusions

Both TRLFS and EXAFS spectroscopy provide clear evidence for the incorporation of Eu(III) in the structure of C-S-H phases. The latter finding, in combination with the observed long-term stability of C-S-H phases in the cementitious near field, implies that trivalent lanthanides/actinides will be incorporated in the structure of C-S-H phases for very long times, strongly reducing their release rates. This knowledge is important for long-term predictions of the behaviour of trivalent lanthanides/actinides in cement-based repositories.

References

[1] S. Merlino, et al., Eur. J. Mineral., **13**, 577 (2001).
[2[I. G. Richardson, Cem. Concr. Res., **34**, 1733 (2004).
[3] B. Lothenbach, E. Wieland, Waste Management, **26**, 706 (2006).
[4] T. Stumpf et al., Environ. Sci. Technol., **41**, 3186 (2007).
[5] W. D. Horrocks, D. R. Sudnick, J. Am. Chem. Soc., **101**, 334 (1979).


Environment
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Technology Assessment
Life Cycle
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Risks
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Informed Decisions
Human Factors
Energy Economics
Risk and Human Reliability
Scenarios
Policy
Learning

Laboratory for Energy Systems Analysis (LEA) 37

LEA is an interdisciplinary laboratory supporting both NES and the General Energy Department (ENE). The Laboratory aims to contribute to effective decision-making on long-term technology strategies in energy supply and demand by ensuring the full integration of the relevant environmental, economic and social factors. LEA also develops methodologies, and carries out the associated risk analyses, within the framework of Human Reliability Assessment (HRA).

The activities within LEA, in cooperation with its external partners, cover the following three project areas.

Technology Assessment (GaBE)
The project involves analyses of fossil, nuclear and renewable energy technologies. It is based on an interdisciplinary framework, thus enabling comparisons to be made between current and future options for the electricity, heating and transport sectors.

Energy Economics
Analyses are undertaken of energy systems, and associated technological changes, at the Swiss, European and global levels, all aimed at improving understanding of available options for the realization of more sustainable energy mixes for the future.

Risk and Human Reliability
Main contributions here are to the solution of current and future issues concerning the handling of human factors in the context of Probabilistic Safety Assessment (PSA). Furthermore, innovative PSA applications for complex facilities are pursued.

◀ **The research and activities of LEA's three groups produce results that inform decision-making related to a range of issues in energy technology and policy.**

Environmental and economic assessment of future fossil technologies

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Laboratory for Energy Systems Analysis, PSI;
Oliver Mayer-Spohn, Markus Blesl,
Institut für Energiewirtschaft & Rationelle Energieanwendung (IER), University of Stuttgart, Germany

Power generation based on fossil fuels will continue to contribute substantially to the world's growing electricity demand in the few decades to come. Nonetheless, considering the ambitious goals set for climate change mitigation, and the increasing scarcity of resources, further improvements in fossil technology are essential. Application of the Life Cycle Assessment (LCA) method indicates that a significant reduction in Greenhouse Gas (GHG) emissions can be achieved, but that only the employment of Carbon Capture and Storage (CCS) will allow the targeted renewable technology GHG levels to be achieved by 2050. However, CCS will substantially increase the costs and consumption of fossil resources.

The recently completed EU project NEEDS (New Energy Externalities Developments for Sustainability) incorporated a comprehensive environmental and economic assessment of a broad spectrum of current and future power generation technologies. This evaluation underpins the further development of a sound European energy strategy. Among other tasks, and in collaboration with IER, PSI has taken responsibility for the assessment of advanced fossil systems, including CCS technologies [1].

Scope and methodology

The analysis undertaken covered hard coal, lignite (both in the form of pulverized coal and integrated-gasification-combined-cycle (IGCC) units) and natural-gas-combined-cycle (NGCC) power plants (with and without CCS), as well as natural-gas-fuelled plants, for decentralized combined heat and power generation. Three scenarios were identified by the study: estimation of pessimistic, realistic/optimistic and very optimistic technology developments, all of which could reflect evolutionary technological progress up to 2050. The three most promising options for CO_2 capture, post-, pre- and oxyfuel-combustion, have been considered, along with CO_2 storage in saline aquifers (to a depth of 800 m) and depleted gas fields (at 2500 m), these representing the two types of storage sites most likely to be implemented in Europe on a large scale [2].
The environmental assessment was based on LCA methodology, taking into account complete energy chains, and including not only the operation of power plants but all steps in the energy chain: e.g. the extraction and processing of resources,

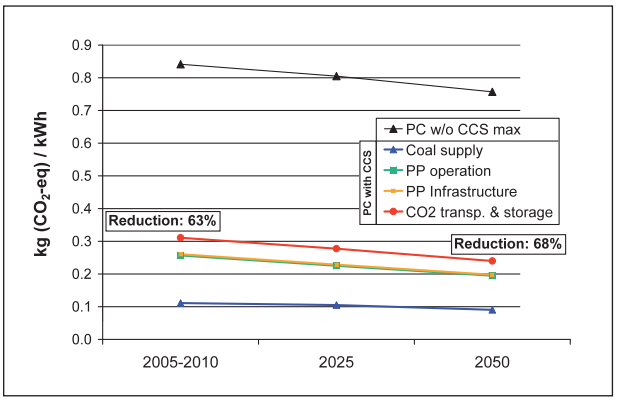

Figure 1: **GHG emissions from hard coal (PC) chains according to the 'worst case' scenario.**

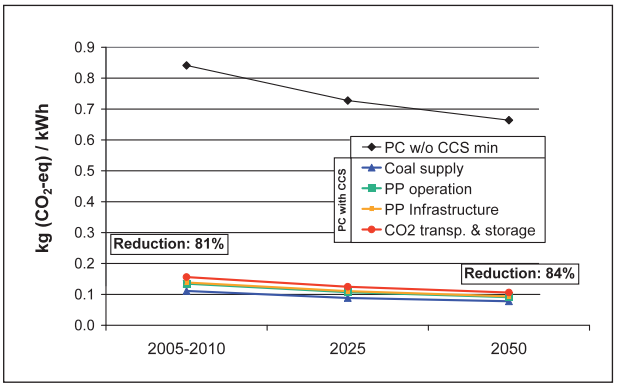

Figure 2: **GHG emissions from hard coal (PC) chains according to the 'best case' scenario.**

the construction of an infrastructure, transport and waste disposal. Cumulative environmental burdens (emissions to air, water and soil, land use, and the consumption of resources) were calculated per kWh (electric) at the busbar of a power plant using *ecoinvent*, the world's leading LCA database [3]. Central elements of these data, such as the European electricity mix (and considering new generation technologies), the production processes for metals and building materials, and transport processes, were modified to reflect technological progress throughout the economy [4]. The estimates of future electricity production costs given here are based on learning curves and literature sources [5,6].

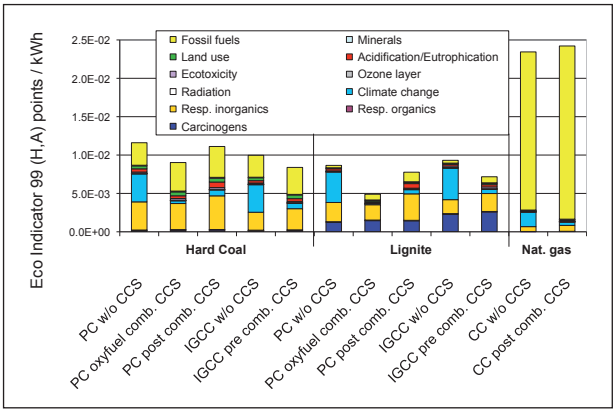

Figure 3: **LCIA results for the fossil electricity technologies for the year 2050 according to the realistic/optimistic scenario.**

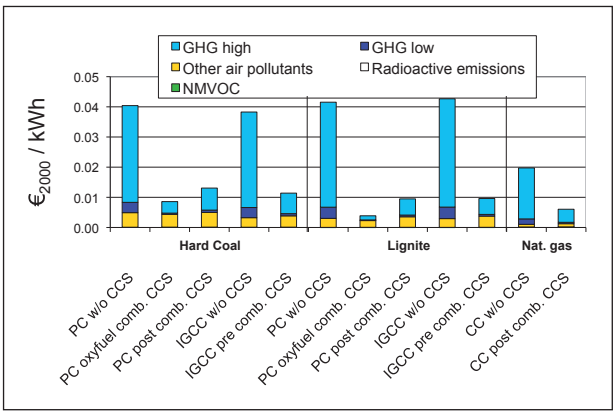

Figure 4: **External costs of fossil electricity technologies for the year 2050 according to the realistic/optimistic scenario (GHG low: 5 €/t (CO_2-eq), high: 52 €/t (CO_2-eq)).**

Selected results and conclusions

The LCA results given in Figs. 1, 2 show the 'worst case' and 'best case' scenarios for hard coal; the former assumes CCS with post-combustion capture and depleted gas field storage of CO_2, while the latter (very) optimistic scenario considers CCS with oxyfuel-combustion capture and saline aquifer storage. Advanced power plants with higher efficiencies (due to the use of new Ni-based alloys, which can withstand combustion temperatures up to 750°C) will allow, in the best case, GHG emissions to be reduced from the 840 g(CO_2-eq.)/kWh achievable today to around 650 g(CO_2-eq.)/kWh by 2050, which still exceed the emission levels of the natural gas chains by almost 100%. Application of CCS leads to a more substantial reduction, with about 30–250 g (CO_2-eq.)/kWh of cumulative emissions (red lines in Figs. 1, 2). While hard-coal supply alone is responsible for about 100 g (CO_2-eq.)/kWh, lignite with CCS, due to the minor emissions associated with mining and transport, and natural gas chains with CCS, could reach GHG levels of 30–40 g (CO_2-eq.)/kWh. The rate of CO_2 capture (90% for post- and 100% for oxyfuel-combustion), energy demand for CO_2 injection (which depends on the depth of the reservoir), and the contributions from the fuel supply, are the principal factors determining the GHG performance of fossil energy chains with CCS.

Using Life-Cycle Impact Assessment (LCIA) methods and external costs, and aggregating a wider spectrum of environmental impacts, reduces the advantages of CCS (Figs. 3, 4). Carbon dioxide capture considerably decreases power plant efficiency, and so more fuel is required for the same power generation, which in turn results in higher environmental burdens being placed on the fuel supply. Coal chains with IGCC, and PC plants, perform similarly in terms of environmental burdens. Due to the high weighting of the scarcer natural gas compared to hard coal and (especially) lignite, the gas chains perform less efficiently using the LCIA method. However, the external costs (not including the monetization of resource consumption) of those natural gas chains that emit less CO_2 and fewer pollutants are lower.

The economic assessment performed indicates a reduction of capital costs of a few percent only for fossil plants by 2050. However, CCS will increase electricity generation costs significantly by 2050: for hard coal and lignite by approximately 35% (resulting in production costs of about 4 €cents/kWh) and for natural gas by almost 50% (resulting in 8.7 €cents/kWh).

References

[1] C. Bauer et al., NEEDS Deliverable 7.2, 2009.
[2] IPCC Special Report on Carbon Capture & Storage, Working Group III of IPCC, 2005.
[3] Ecoinvent data v1.3, www.ecoinvent.ch, 2004.
[4] R. Frischknecht et al., NEEDS Deliverable 15.1, RS 1a, 2008.
[5] C. Hendriks, UNFCCC Secretariat Financial and Technical Support Programme, 2007.
[6] E.S. Rubin et al., Energy Policy, **35**, 4444–4454 (2007).

Climate change adaptation measures in the European energy conversion sector

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Laboratory for Energy Systems Analysis, PSI

The Energy Economics Group at PSI is undertaking first of-a-kind research to analyze the impact of climate change on the energy sector using detailed, bottom-up energy systems models. This work aims to provide information concerning adaptation strategies to policy and other decision-makers in the energy sector. The analysis identifies which technology changes are needed to adapt the energy system to climate change, some of the potential costs and investment needs, and generally provides guidance on the choice of the most promising technologies to lower the costs associated with climate change.

The European energy conversion sector faces a number of challenges during the first half of the 21st Century, including satisfying increased energy demand, replacing old electricity generation capacity, mitigating greenhouse gas (GHG) emissions, and managing the security of the energy supply. In addition, the energy conversion sector faces a challenge from the increasing temperatures resulting from climate change: higher temperatures lead to reduced generation efficiencies, reduced cooling water availability, and higher transmission losses of fuels and electricity. Further, higher temperatures are expected to shift peak electricity demand from winter to summer [1], and the availability of renewable energy (especially hydropower) will also change [2,3]. The objective of our research is to determine the impact of climate change on the energy conversion sector in depth, and to quantify the additional investments needed in the sector to cope with any related challenges.

Approach

Different adaptation options have been investigated, together with the associated costs to the energy conversion sector under different scenarios of climate change. Particular attention is paid to the need for investment in new electricity generation, installation/retrofitting of cooling towers, and upgrades to transmission lines to cope with the combination of higher temperatures, changes in water availability, and changes in demand. To this purpose, the multi-regional MARKAL model EuroMM is used, this being a partial-equilibrium, perfect-foresight, 'bottom-up' model with a detailed representation of energy technologies [4].

EuroMM describes the energy conversion sector for the 27 members of the EU (plus Norway and Switzerland), separated into 18 distinct European regions. The model is calibrated according to today's electricity and heat generation mix and refining capacities, and accounts for the future production and trade of energy carriers, the necessary infrastructure (including new capacity investment), as well as CO_2 emissions. Moreover, a high level of detail is included in the representation of the technology options in the electricity sector, beyond that seen in many other similar models [5], including the impact of higher temperatures on energy technologies up to the year 2050. Under a business-as-usual scenario, the average global temperature is estimated to increase by 2°C during this period. A submodel has been developed to assess the impact of higher air temperatures on river water temperatures, which have a direct impact on the effciency and availability of power plants [6]. Together with changes in the river runoff patterns (in terms of quantity and seasonality), the parameters for generation technologies within the model were also modified. Other parameters influenced and depicted in the model under changed climate conditions include the efficiency of the electricity transmission and distribution network, and changes in the demands for electricity, heat and other energy carriers [1,7,8].

Impact on energy supply

Among the demand-side changes, one of the most important is the shift in peak electricity demand from winter to summer, as a result of climate change. Northern European countries may profit from lower demand for heating, reducing the need

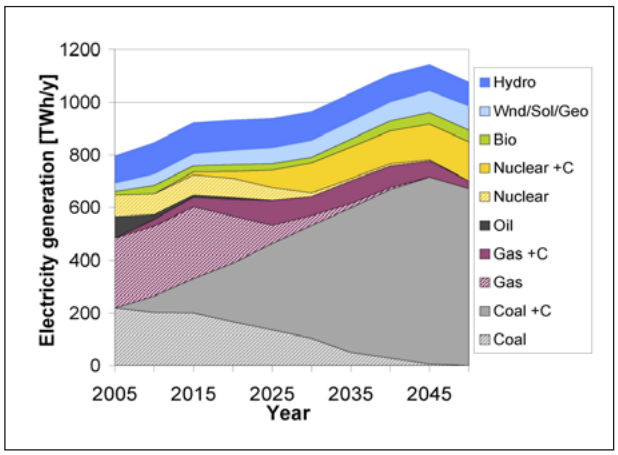

Figure 1: **Aggregated electricity generation for the southern European countries (BG, RO, GR, IT, ES and PT) adaptation scenario, depicting the shift from conventional to advanced (+C) cooling systems for power generation in response to climate change. Coal will continue to be the main contributor to power generation in this scenario, provided there are no CO_2 abatement restrictions.**

for investments in heat production capacity and distribution networks for low temperature heat, in addition to reducing primary fuel demand. In particular, Nordic countries such as Norway and Sweden will profit from lower heating demands in winter, as well as from higher hydropower output, as a result of increased precipitation (~10 percent, [3]), and higher reservoir availability. However, new investment in storage capacity may be needed to fully exploit the additional hydropower potential.

Southern Europe is likely to see higher electricity demands for space cooling in summer, coinciding with lower power plant availability and efficiency. With rising air temperatures, the efficiency of conventional thermal power plants will be reduced by about 0.1% for each additional degree (C) of the cooling medium. In addition, water availability for cooling purposes is likely to decrease due to changing runoff patterns, primarily through changes in precipitation and evaporation. Moreover, environmental regulations regarding the use of water for cooling purposes may restrict whether power plants can operate at all during certain periods.

Higher temperatures in countries such as Italy and Greece will therefore create higher adaptation pressures for investment in new cooling systems, as well as a greater need for additional generation capacity to overcome an expected decline in hydropower output.

As can be seen in Figure 1, which shows the electricity generation mix in southern Europe under the scenario of climate change without mitigation efforts, higher temperatures require a shift away from conventionally-cooled, thermal-based electricity plants over the first half of the century, with all power plants requiring improved cooling systems by 2050 to avoid production shortages during summer. The total output of hydropower may be reduced by about 15% relative to that of today [3].

Adaptation and investment

Adapting to climate change will require additional investment in the energy conversion sector in Europe, amounting to an increase of about 6% compared with a scenario assuming no climate change (representing US$80 billion by 2050). However, more than 50% of the additional investment would be required in the southern European countries, representing overall a much larger increase. In the light of these considerations, it is clear that utilities and regulatory authorities need to begin planning appropriate investment and policy measures to guarantee secure power generation. It should also be mentioned that some of the potential impacts not considered here, such as a higher incidence of extreme heatwaves, and additional electricity needs for irrigation and desalination, could pose further adaptation challenges to the electricity sector.

Further work on the model will include considerations of scenarios with CO_2-emission reduction targets for estimating the cost of limiting climate change.

Acknowledgements

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References

[1] M. Jakob, ADAM project, unpubl. data, 2008.
[2] B. Lehner et al., Energy Policy, 33, 839-855 (2005).
[3] A. Held, ADAM project, unpubl. data, 2008.
[4] R. Loulou et al., http://www.etsap.org/MrklDoc-I_Std-MARKAL.pdf. 389p., 2004.
[5] L. Mantzos et al., European Energy and Transport Scenarios on Key Drivers, DG TREN, Luxembourg, 262p., 2004.
[6] L. Ullmann, ETHZ Bachelor thesis, 2008.
[7] W. Eichhammer, ADAM project, unpubl. data, 2008.
[8] W. Schade, ADAM project, unpubl. data, 2008.

Application of Probabilistic Safety Assessment to the CERN Large Hadron Collider

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Laboratory for Energy Systems Analysis, PSI

Probabilistic Safety Assessment (PSA) is an accepted methodology for the analysis and quantification of safety in the context of nuclear power plants. But it can also be applied to other complex systems. The PSA recently undertaken for the Target Collimator Dump Quadrupole (TCDQ) system at the CERN Large Hadron Collider (LHC) has demonstrated that the novelty of such studies actually lies in the adaptations required. The present study has resulted in the quantification of the safety level afforded by the TCDQ system, and in the identification of the most significant system weaknesses.

Two Target Collimator Dump Quadrupole (TCDQ) systems have been installed at point IR6 of the Large Hadron Collider (LHC) accelerator ring at CERN, one per beam, as seen in Fig. 1. Each system contains a mobile dilution block to protect the Q4 quadrupole magnet and the downstream LHC machine elements from damage in the event of an asynchronous beam dump, a situation which occurs if the LHC Beam Dump System (LBDS) fails to switch on within a 3μs particle-free energy gap [1]. The time stamp of this event is 90 μs, the beam revolution frequency in the (27 km) LHC ring.

The present study focuses on the risk associated with the TCDQ not being in the configuration required to protect the LHC machine elements at the instant of an asynchronous beam dump. A PSA approach has been applied, and the results interpreted in the framework of the IEC 61508 safety standard [2, 3].

Figure 1: **A view of the TCDQ assembly in the LHC tunnel (by courtesy of CERN)**

The functioning principles of the TCDQ

The TCDQ system is controlled and supervised by a Programmable Logic Controller (PLC), which generates the inputs to the two DC motors which move the absorber block in and out of the beam vacuum chamber [4, 5]. The position of each block is calculated according to the actual beam position and size, these depending on the beam energy and the current operational phase. During the ramping phase (about 30 minutes), the beam energy changes, and the TCDQ has to adjust its position accordingly. However, the beam energy does not change at injection (450 GeV), nor during the colliding phase at peak energy (7 TeV), and during these phases the position of the TCDQ remains fixed.

TCDQ operation is monitored continuously. Detected errors in alignment generate an interlock (ILK). The local Beam Interlock Controller (BIC) oversees the ILKs from the PLC, and issues a beam dump request to abort operation if necessary. During operation, the operator in the control room may manually adjust the position of the block. After a beam dump, but before the new fill, the TCDQ is moved back to the initial injection position. This is actually an implicit check of its functionality.

Risk assessment and PSA

PSA methodology [3] has been applied to calculate the probability of the TCDQ not being properly configured to protect the LHC elements, TCDQ failure due to misalignment being

modelled using a fault-tree approach. The data used for the analysis are the probabilities and rates of failure events, in part collected from previous reliability studies [1].

Quantification of the risk is made in terms of the frequency of the asynchronous beam dump event, which actually occurs about once per year, or more precisely 0.8/y [1]. The consequences are considered to be serious: i.e. more than three months downtime, and involving very expensive repair costs. This criterion determines the Safety Integrity Level (SIL) of the TCDQ, and is used as the basis of the risk reduction value [2].

Results and design implications

The operation scenario comprises 400 beam fills, each of 10 hours duration, during which the TCDQ system is assumed to maintain its position for 78% of the time, and to track the beam for the remaining 22%. The analysis has returned an average probability of failure of the two TCDQs of 3.64×10^{-5}. Two major underlying assumptions are: (1) the input data to operate the TCDQs are correct; and (2) the system is operated only in servo (automatic) mode, with no manual adjustment of the TCDQ position being undertaken. Under these assumptions, the TCDQs will satisfy the SIL4 requirement [4].

Three dominant contributions to TCDQ failure have been identified, see Fig. 2. The most important ones are listed below.

1. Failure of the PLC timing card to transmit the start signal to the PLC at the start-up of the LHC ramp (60%): a possible remedial measure is to acknowledge the start signal, and to verify that the PLC state is consistent with the LHC operational phase.
2. Failure of the PLC central processor, affecting both TCDQ controls and their supervision (28%). A possible remedial measure here would be to implement the controls and the supervision in two separated PLCs.
3. Another 10% contribution to failure is due to the possible failure of the interlock functions. The risk can be reduced by checking them at regular intervals.

A sensitivity analysis has revealed a vulnerability to manual operation of the TCDQ, thereby increasing the probability of it not being properly configured. At an assumed rate of one intervention per ten fills, the TCDQ failure probability would drop to SIL2 [1×10^{-3} to 1×10^{-2}]. However, detailed analysis of this vulnerability effect has not yet been carried out.

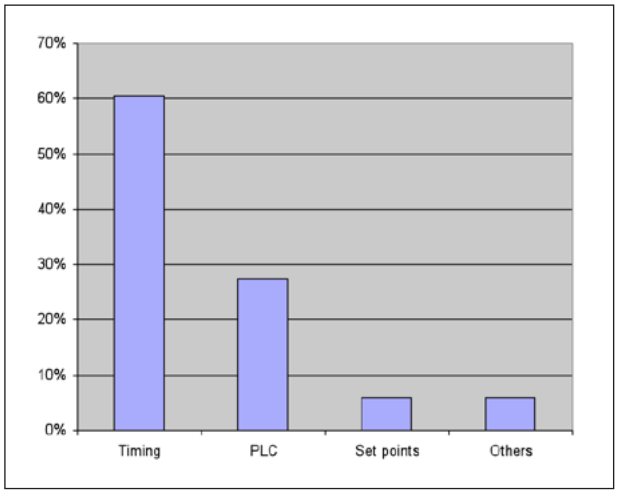


Figure 2: **Contributors to TCDQ unavailability**

Conclusions and Outlook

A safety study of the Target Collimator Dump Quadrupole (TCDQ) systems in the Large Hadron Collider at CERN has returned a low probability for TCDQ failure in the event of an asynchronous beam dump, corresponding to a safety level of SIL4. Possible system modifications have been suggested to address the specific weaknesses identified by the PSA. In particular, single points-of-failure events can be eliminated. While the risk associated with automatic TCDQ operation is found to be low, a sensitivity analysis has shown that the risk may increase significantly if the TCDQ is manually operated. As a consequence, it is recommended that analysis of the manual adjustment tasks, procedures and human performance conditions be performed in order to confirm the effectiveness of the defences currently in place, and to highlight possible improvements.

Acknowledgements

The authors are grateful to Dr. J. Uythoven and his staff at CERN for their collaboration in this study.

References

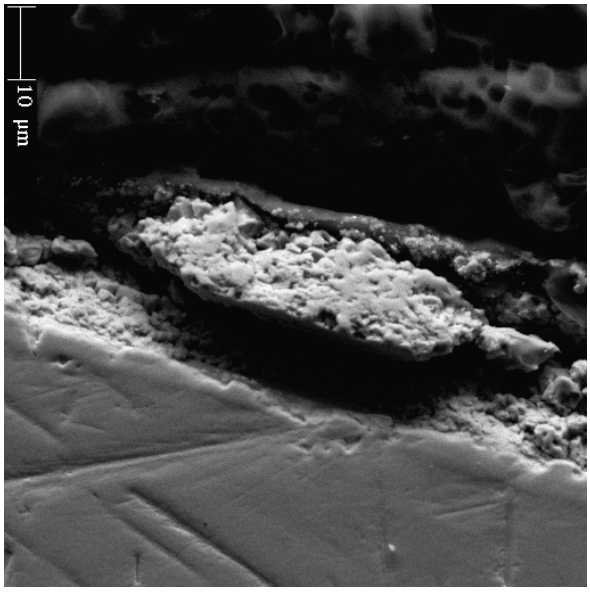
[1] R. Filippini, J. Uythoven, Update and Summary of the Dependability Assessment of the LHC Beam Dumping System, EPAC, Edinburgh, UK, 26-30 June, 2006.

[2] International Electrotechnical Commission (IEC), Functional Safety of Electrical-Electronic-Programmable Electronic Safety Related Systems, IEC 61508 International Standard, Geneva, 1998.

[3] R.R. Fullwood, Probabilistic Safety Assessment in the Chemical and Nuclear Industries, Butterworth-Heinemann, Woburn, Massachusetts, USA (2000).

[4] C. Boucly, Low-level software for embedded TCDQ/TCDS control, CERN EDMS document, 15-11-2007.

[5] W. Weterings, B. Goddard, Control requirements for TCDS and TCDQ, CERN document, 10-09-2007.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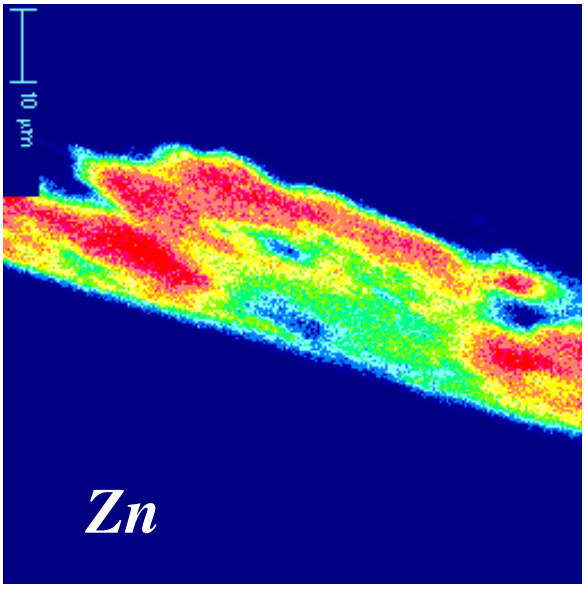
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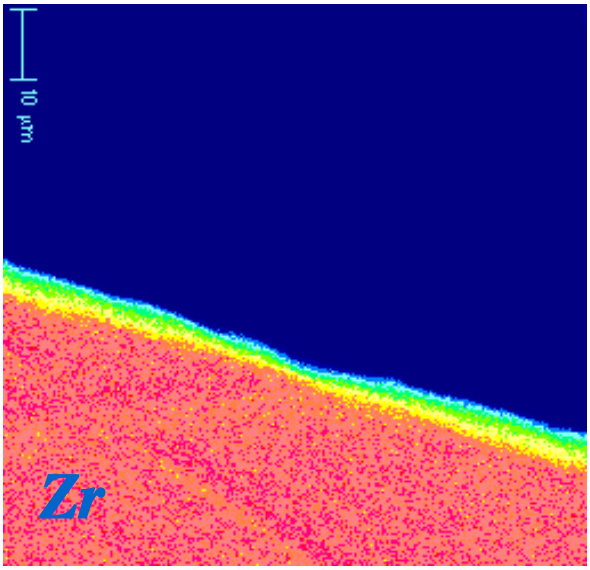
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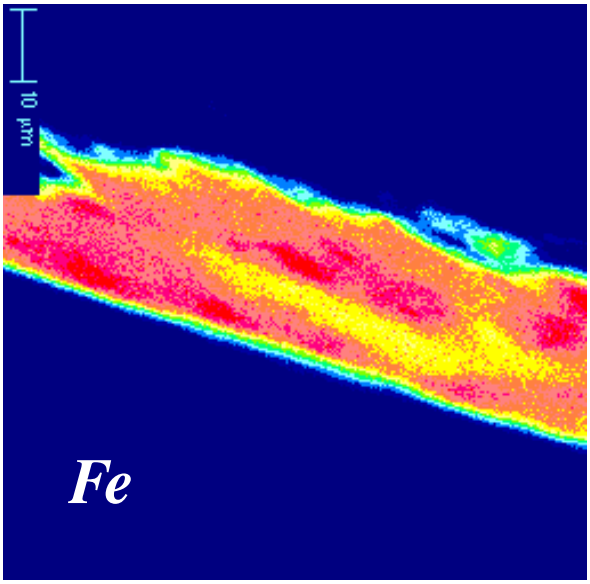
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Fe

Laboratory for Nuclear Materials (LNM) 45

The primary function of LNM is to examine and understand the changes that take place in the structure of (in particular, strongly radioactive) materials and components in an intense radiation environment. Activities incorporate: (a) the study of the ageing process, and associated component damage; (b) analysis of the behaviour of current and future nuclear fuels; and (c) modelling of the micro-structural changes occurring in nuclear materials, and the associated experimental validation of such models.

Currently, LNM focuses on three main project areas.

High-Temperature Materials

This activity involves characterisation of materials to be used in the future Generation IV reactors (particularly gas-cooled reactors), which will operate at significantly higher temperatures, and are subject to a more intense radiation environment than current Gen II reactors. Mechanistic models are being developed for the prediction of material behaviour, from the atomic level up to the scale of the continuum. Experimental validation of the models is also undertaken using advanced spectroscopic methods and, in particular, synchrotron radiation.

Nuclear Fuels

This project involves micro-structural/micro-mechanical examination of the ageing of core internals (fuel rods, structural materials), and the development of associated theoretical models. In particular, investigation of fuel damage, and identification of possible causes of failure, are also being carried out. Methods for the production of Gen IV fuels, and their associated fuel cycles, are also under consideration.

Component Safety

The focus here is the detection of fatigue and stress corrosion cracks at an early stage of their development by means of non-destructive examination techniques based on micro-structural changes (e.g. electro-chemical noise, Seebeck coefficient and micro-magnetic characteristics). In-house experiments are conducted (as part of international efforts) to collect quality-assured data on stress-corrosion cracking and thermo-mechanical fatigue in reactor-grade steels under conditions appropriate to operating nuclear plants.

◀ **Chemical analysis of a crud deposit on a highly radioactive fuel rod from a Swiss nuclear power plant by Electron-Probe Micro Analysis.**

On the mechanical testing of micro- and nano-sized samples

Manuel Pouchon, Maria Samaras, Jiachao Chen, Annick Froideval, Wolfgang Hoffelner
Laboratory for Nuclear Materials, PSI

Nuclear plants are designed for long-term operation in demanding environments. Limited operational experience with the materials used in such plants necessitates reliable assessment of damage and the residual life of components. Non-destructive monitoring of damage is difficult, if not impossible, for many materials. Nonetheless, periodic examination of small samples taken from well-defined locations in the plant could provide an attractive method of damage assessment. The possibilities are being explored at PSI.

Reactors, and particularly advanced reactors, are exposed to high temperatures, non-aqueous environments, and high dose levels. In addition, the reactor materials (coarse-grained, nickel-based alloys, etc.) are expected to differ considerably from those used in present-day plants. These facts suggest there is a need for Non-Destructive Evaluation (NDE). One major challenge is the initial envisaged plant design lifetime of 60 years, and possibly beyond. For such circumstances, information describing the actual condition of components becomes extremely important, as no long-term experience has yet accrued for such plants. Complementary to conventional NDE techniques, analysis of very small samples taken from key locations in the plant could provide more detailed information regarding damage potential.

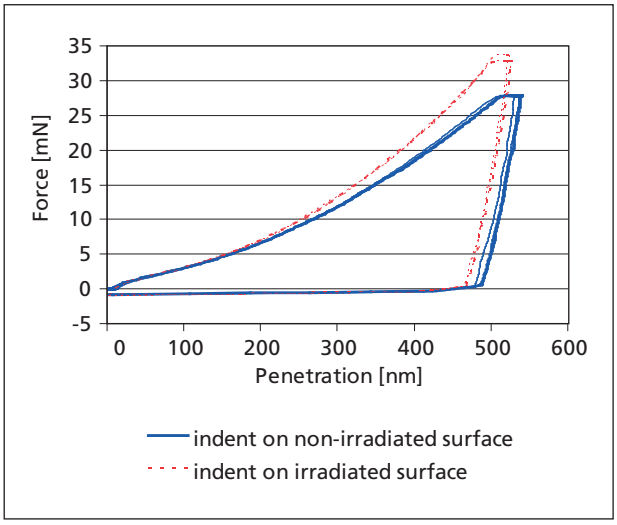

Figure 1: **Nano-indenter signals for the oxide-dispersion-strengthened (ODS) material PM 2000 (annealed) in both non-irradiated and irradiated conditions.**

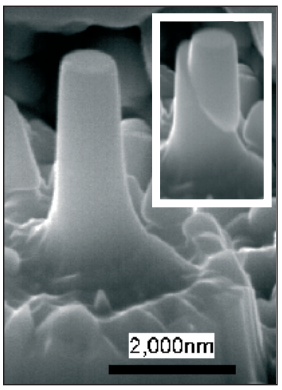

Figure 2: **Micro-pillar of a ferritic ODS steel after a compression test.**

Stress-strain information can be obtained from punch tests, in which discs of 3 mm diameter and about 200 µm thickness are deformed, either using a small ball (of 1 mm diameter) or by a cylindrical punch of similar diameter. The resulting load-displacement curves can be converted into stress-strain curves using finite element analysis – a well-established method for determining irradiation hardening. Dog-bone-shaped samples, 100–200 µm thick, can be used for performing tensile and creep tests. Even less material is needed for nano-indentation of micro/nano-sized samples, such as for so-called micro-bend bars and micro-pillars.

Figure 1 shows the load-displacement response of a ferritic-oxide-dispersion strengthened (ODS) steel, tested before and after irradiation. The implantation creates irradiation damage (point-defect clusters), leading to hardening of the material, which can be clearly seen.

Samples of µm dimensions can be manufactured using a focused ion beam (FIB), the samples then being deformed using the head of the nano-indenter. Figure 2 shows a small pillar, tested under compression. The material is again the ferritic ODS steel. This alloy has very large grains, and so the pillar

consists of a single crystal. The shear plane is clearly visible, and a correlation with the critical shear stress can thus be established. The shear stress measured using dog-bone samples in tension compare very well with the measurements obtained from micro-pillar compression. This is not necessarily always the case, and considerable size-dependent effects can be found in some micro-pillar tests, particularly for single-phase materials [1]. Most important for condition monitoring is the relative change in mechanical properties resulting from damage.

Figure 3 shows results from compression tests of the ferritic ODS steel before and after helium implantation. The sample material was the same as that for the nano-indenter case, the results of which are shown in Fig. 1. Irradiation hardening of about 20% was found for both the indenter and the micro-pillar tests.

Important additions to micro-mechanical investigations are micro-characterisation, using an electron microscope, and advanced beamline techniques, such as extended X-ray absorption fine-structure (EXAFS) measurements. These techniques allow quantitative assessments of damage to be made, such as the analysis of point-defect clusters, or coordination analysis.

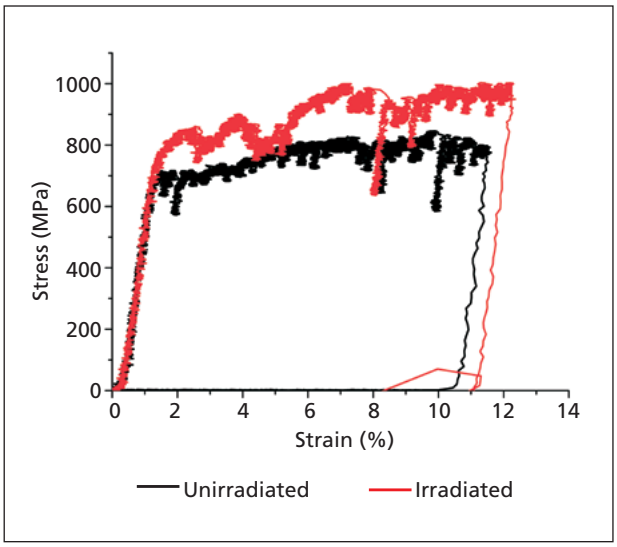

Figure 3: **Stress-strain curve of a ferritic ODS steel before and after helium implantation, as determined by micro-pillar compression.**

Mechanical Properties

Another important issue concerns the quantitative understanding of damage with respect to component life. Constitutive equations and other parameterisations of material properties are usually applied with time-independent coefficients and exponents using the properties of the virgin material. These can change as the microstructure changes. Conversion of these changes into mechanical responses could provide for better assessments of the development of mechanical properties with time. The inclusion of multi-scale modelling tools for describing materials over several length (and time) scales, starting at the atomic level up to that of the finite element analysis, is also expected to enhance the capabilities of the current modelling schemes. Dislocation dynamics (DDD) modelling is a tool for linking mechanical properties with micro-structural features, such as dispersoids, precipitates or helium-bubbles. A detailed discussion of these methods is given in [3].

Conclusions

Surveillance sampling and non-destructive testing are currently used to determine the damage to the structural materials of Gen II reactors. Mechanical testing of small samples, together with advanced analytical methods and materials modelling, provide a very promising alternative for the future, though too new a technique to be used at present. These combined tools could be used to assess the residual life of components with expected lifetimes of 60 years or more. Even very small samples (not affecting the integrity of the component) can be examined. Taking such a “fingerprint” of the condition of the material at scheduled time intervals would provide the exact local exposure parameters as functions of time, and assist in applying the correct material parameters and design rules. Using these fingerprints in a synergy with a multi-scale modelling scheme would result in a more fundamental understanding of the mechanisms causing material ageing. Information from such methods of condition monitoring goes far beyond the possibilities of current NDE approaches. It is proposed that micro-sample/micro-scale modelling for condition monitoring should be used to complement conventional non-destructive methods in providing a reliable picture of the status of the material of a component. This information could then be used for safety analysis and risk assessment.

References:

[1] C. A. Volkert, E. T. Lilleodden, Phil. Mag., **86**, 5567–5579 (2006).

[2] M. A. Pouchon, J. Chen, R. Ghisleni, J. Michler, W. Hoffelner, Experimental Mechanics, doi10.1007/s11340-008-9214-5 (2009).

[3] M. Samaras, M. Victoria, Materials Today, **11**(12), 54-62 (2008).

Irradiation creep behaviour of ODS steels

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Laboratory for Nuclear Materials

Ferritico ODS (oxide-dispersed-strengthened) steels with different micro-structures have been in-beam creep tested for a temperature range of 300°C to 500°C; irradiation was by means of He-ions. Elongation of the specimens was determined as a function of stress and irradiation dose, and damage ascertained by transmission electron microscopy. Thorough analysis of the loops developing during irradiation creep did not reveal any dependence of orientation or size on the direction of the applied stress. In contrast to expectations from the literature, no pronounced influence of micro-structure or dispersoid size on the irradiation creep behavior has been detected.

Oxide-dispersion-strengthened (ODS) steels are candidate materials for a variety of nuclear applications, including advanced cladding concepts and structural components. The main interest in this class of materials comes from its very good thermal creep properties, making them ideal for high-temperature applications. Deformation under static load occurs at much lower temperatures, if simultaneously irradiation occurs, and is known as irradiation creep. Technically, this type of creep is important only at temperatures below 550°C. Irradiation creep could become a design issue for components exposed only to moderate temperatures during steady-state or transient conditions, such as start-up in high temperature reactors.

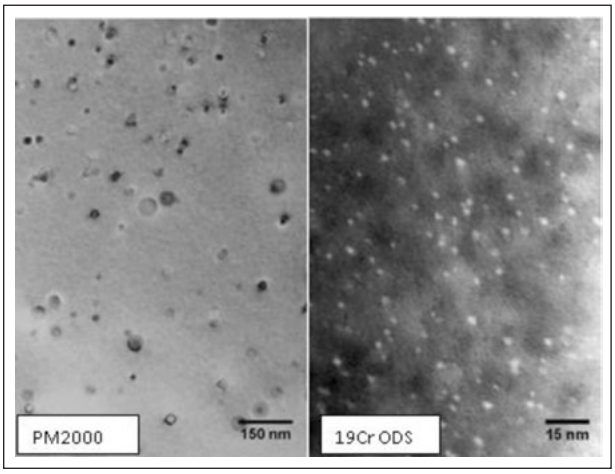

Figure 1: **Dispersoid sizes, distributions and micro-structural features of the materials investigated. Note that the two micrographs are at different magnifications**

Materials and Testing

The investigations were performed with two ferritic ODS steels containing about 20% chromium. The first one (PM2000) is commercially available in annealed condition, supplied by Plansee, Austria. (It should be mentioned that this material is no longer produced by the company.) The other material is a fine-grained Japanese ferritic ODS steel (19 Cr ODS) called K1, with nano-sized dispersoids supplied by Kyoto University. Typical dispersoid distributions in both materials are shown in Fig. 1. The size and number densities of dispersoids are 28 nm and $5.1\times10^{20}/m^3$ in PM2000, and 2.1 nm and $1.2\times10^{24}/m^3$ in 19 Cr ODS, respectively. The grain sizes of PM2000 and K1 vary from below 500 nm to several cm.

In-situ irradiation creep under He-implantation was performed at the compact cyclotron at FZJ, Juelich. Dog-bone samples with a gauge length of 10 mm, width 2 mm, and thickness of 0.1 mm were used. Creep strains were estimated based on an average of two linear variable differential transformer (LVDT) signals from two rod-pipe-type extensometers; the resolution of the creep strain measurements was 3×10^{-6}. More details of the experimental set up are described in [1]. Samples of 0.1 mm thickness were homogeneously irradiated in three dimensions, under constant uniaxial stress conditions, using 24 MeV $^4He^{++}$ ions passing through a magnet scanning system, and a degrader wheel with 24 Al-foils of different thicknesses. The dose level reached per creep test at each temperature was about 0.2 dpa.

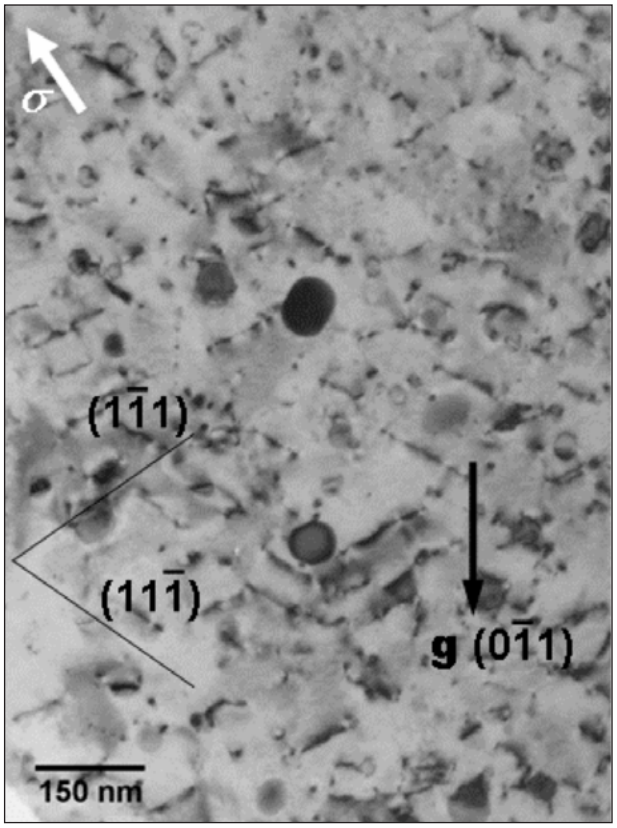

Figure 2: **Bright-field TEM images taken from z=[011] under 2-beam dynamical conditions for a sample implanted at 400°C. The g-vectors are shown as thick black arrows, while the (1$\underline{1}$1) and (11$\underline{1}$) planes are indicated by the thin lines. The direction of the applied stress is indicated by the thick white arrow.**

Results and Discussion

Micro-structural changes occurring as a result of irradiation creep have been analyzed for PM2000 using transmission electron microscopy. Loops of types $^1/_2$<111> (111) and <100> (100), respectively, were detected at 300°C and 400°C. At 500°C, a dislocation network was observed in addition to the loops.

Loop diameters varied with temperature by up to one order of magnitude, and loop densities by three orders of magnitude. The most important result, however, was that the loops were circular, and no correlation between loop orientation or geometry and the direction of the applied stress could be established, as can be seen from Fig. 2. This is in contradiction to current understanding of irradiation creep, as described in more detail in [2].

Strain rates determined from irradiation creep curves showed a steady-state creep behaviour similar to thermal creep. In Fig. 3, the ratio between strain rates and dose rates is plotted as a function of the applied stress. Some scatter in the data can be observed, which is usual for the mechanical properties of small samples. However, no significant differences between

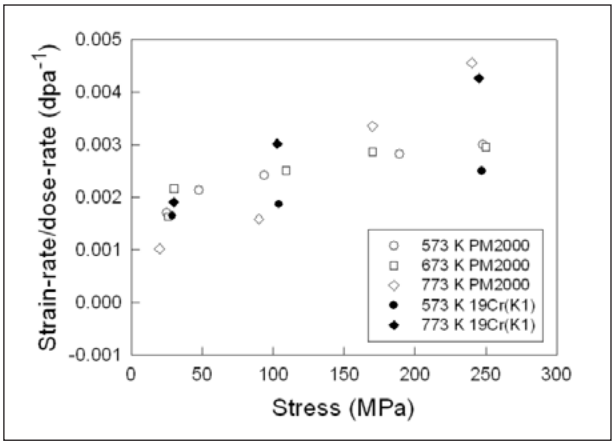

Figure 3: **Ratio of strain rate and dose rate as a function of applied stress for two ferritic ODS steels measured at 300°C to 500°C.**

the two materials PM2000 and 19 Cr ODS could be found. The slopes of the creep curves (irradiation creep compliance) are listed in Table 1 (see also [3]).

T (°C)	PM2000	ODS 19 Cr
300	5.7×10^{-6}	4.0×10^{-6}
400	5.7×10^{-6}	
500	18×10^{-6}	11×10^{-6}

Table 1: **Irradiation creep compliances (in units of dpa-1MPa-1) for the two steels at different temperatures**

Conclusions

Irradiation creep of ferritic 20% Cr ODS alloys has been investigated in the temperature range 300°C to 500°C. Microstructural investigations revealed no correlation between loop size or loop shape and the applied stress. This behaviour, which is not predicted from established irradiation creep models for bcc matrix alloys, warrents further investigation. The most interesting finding is that the size and distribution of dispersoids do not have a significant influence on the irradiation creep behaviour. Thus, it might be inferred that irradiation creep is a purely matrix phenomenon.

References:

[1] J. Chen, P. Jung, M. Pouchon, T. Rebac, W. Hoffelner, J. Nucl. Mater., **373**, 22–27 (2008)

[2] J. Chen, P. Jung, W. Hoffelner, H. Ullmaier, Acta Materialia, **56**, 250–258 (2008)

[3] J. Chen, M.A. Pouchon, A. Kimura, P. Jung, W. Hoffelner, Irradiation creep and micro-structural change in an ODS ferritic steel with very fine oxide particles after helium implantation under stress, ICFRM2007/47, J. Nucl. Mater., **386**, 143-146 (2009)

Detection of stress corrosion cracking in a BWR environment by electrochemical noise

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The electrochemical noise (EN) measurement technique is a promising tool for continuous, in-situ corrosion monitoring in industrial systems, and has the potential to detect nucleation and initiation of localised corrosion processes. The potential and limitations of this technique for the detection of stress corrosion cracking (SCC) initiation in austenitic stainless steels under simulated Boiling Water Reactor (BWR) conditions has been investigated using notched tensile and fracture mechanics specimens in autoclaves by means of Constant Extension Rate Tests (CERTs). These have revealed that early SCC detection by EN is possible in oxygenated high-temperature water under stable and stationary laboratory conditions.

The formation and growth of cracks due to SCC in the otherwise corrosion-resistant stainless steel and Nickel-based alloy components of the primary circuit of Nuclear Power Plants (NPPs), induced by the combined influence of tensile stress and a corrosive environment, has led to dramatic losses in capacity worldwide over the last three decades. Therefore, an issue of increasing importance is the implementation of optimised, strategic and pro-active plant ageing and life-management methods for cost-effective operation of NPPs at high safety levels. Advanced, non-destructive monitoring tools are required for the early detection of SCC initiation in the technical pre-crack stage. The EN measurement technique is a promising tool for continuous, in-situ corrosion monitoring of structural components of Light Water Reactors (LWRs), and has the potential to detect SCC initiation [1,2]. The potential and limitations of the technique for the detection of SCC initiation in austenitic stainless steels under simulated BWR conditions is thus being investigated in the context of a small feasibility study.

Materials and experimental procedures

For the SCC initiation tests with EN measurements, a rod material of the high-carbon austenitic stainless steel AISI 304 was used, since this steel could be easily sensitised, and showed a sufficiently high susceptibility to intergranular SCC. The tests were conducted with both round and flat tensile and compact-tension specimens.
Sophisticated, refreshing, high-temperature water loops, with autoclave and integrated electro-mechanical loading systems,

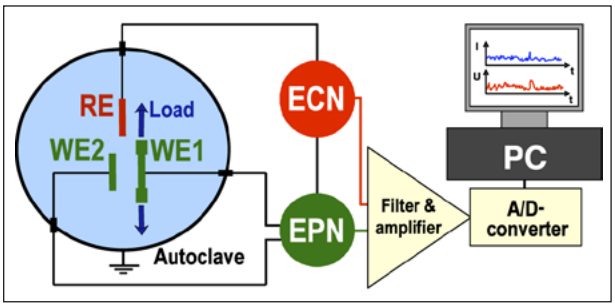


Figure 1: **Schematic of the experimental EN measurement set-up: RE = reference electrode, WE = working electrode.**

were used for the CERTs under simulated BWR conditions. The tests were performed in oxygenated, high-purity, high-temperature water at 250°C or 288°C, and with 2 ppm dissolved oxygen and 50 ppb sulphate content. To initiate SCC, the specimens were loaded with a constant pull-rod stroke rate. Electrochemical potential (EPN) and electrochemical current noise (ECN) were either recorded simultaneously, as schematically shown in Fig. 1, or the EPN was measured alone. In some tests, SCC initiation in compact-tension specimens was simultaneously monitored using the reversed direct-current potential-drop (DCPD) method.

Results and discussion

The SCC initiation tests in autoclaves usually revealed a simultaneous cathodic drop of the EPN signal, and an anodic increase of the ECN signal, with superimposed characteristic potential and current transients, indicating crack initiation.

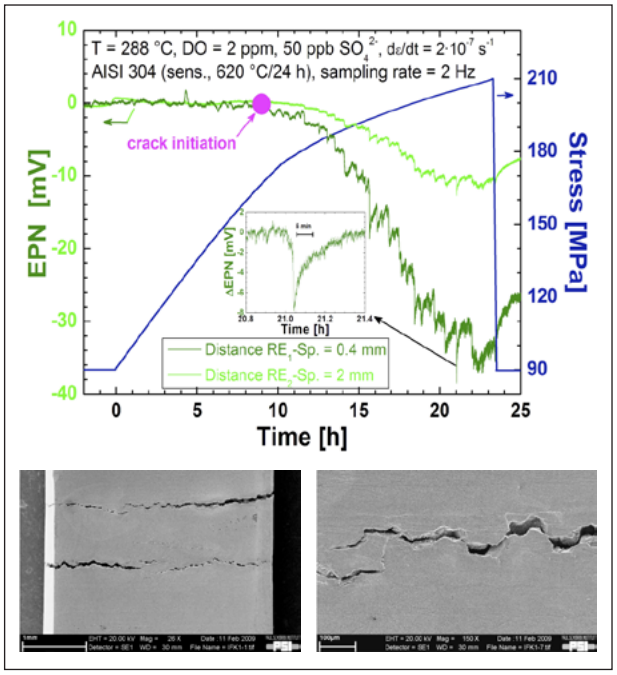


Figure 2: **Effect of distance between reference electrode (RE) and specimen surface on the EPN during a CERT with a flat tensile specimen and two REs (Pt-wires). SCC was confirmed by post-test fractography using a scanning electron microscope.**

Figure 2 shows results from an experiment involving the simultaneous measurement of two EPN signals (measured at different distances from the specimen surface): the typical course of the EPN during SCC initiation can be clearly seen. This test was used to investigate the effect of the distance of the electrode to the specimen surface (or cracking location) on the EPN behaviour, as this plays an important role in high-purity BWR water of very low conductivity. After SCC initiation, the drop in the EPN signal for single EPN transients could be increasingly resolved with decreasing distance to the specimen surface. This is in good agreement with the limited 'throwing power' of the current in the high-purity water. The experiments confirmed that detection sensitivity increases with decreasing distance between specimen surface and reference electrode. To confirm these results with a second independent SCC detection method, tests were performed with combined EPN and DCPD measurements using compact-tension specimens. The result of one such test is shown in Fig. 3. After about eight hours of constant straining of the specimen, the EPN signal started to drop, indicating SCC initiation. This was confirmed by the DCPD technique, which showed the onset of crack advance at the same time. Subsequent fractographic analysis using a scanning electron microscope revealed intergranular SCC initiation, and growth along the whole notch-root. Due to disturbances in the EPN signal, the expected individual potential transients in the EPN from single crack initiation events could not be resolved. About three hours after SCC initiation had been detected according to the DCPD signal (Fig. 3), the

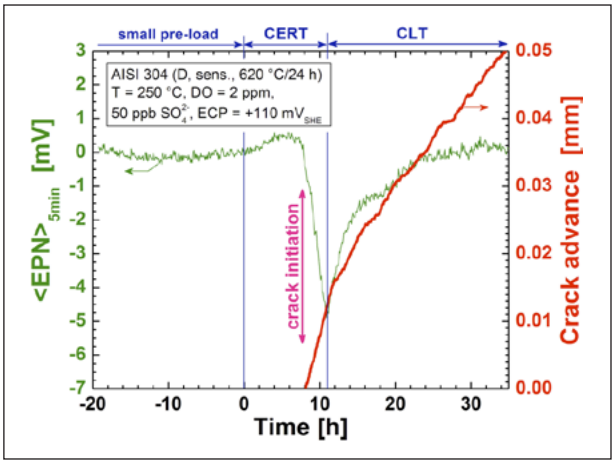


Figure 3: **Mean values of the potential noise <EPN> and crack advance, as measured by the DCPD method.**

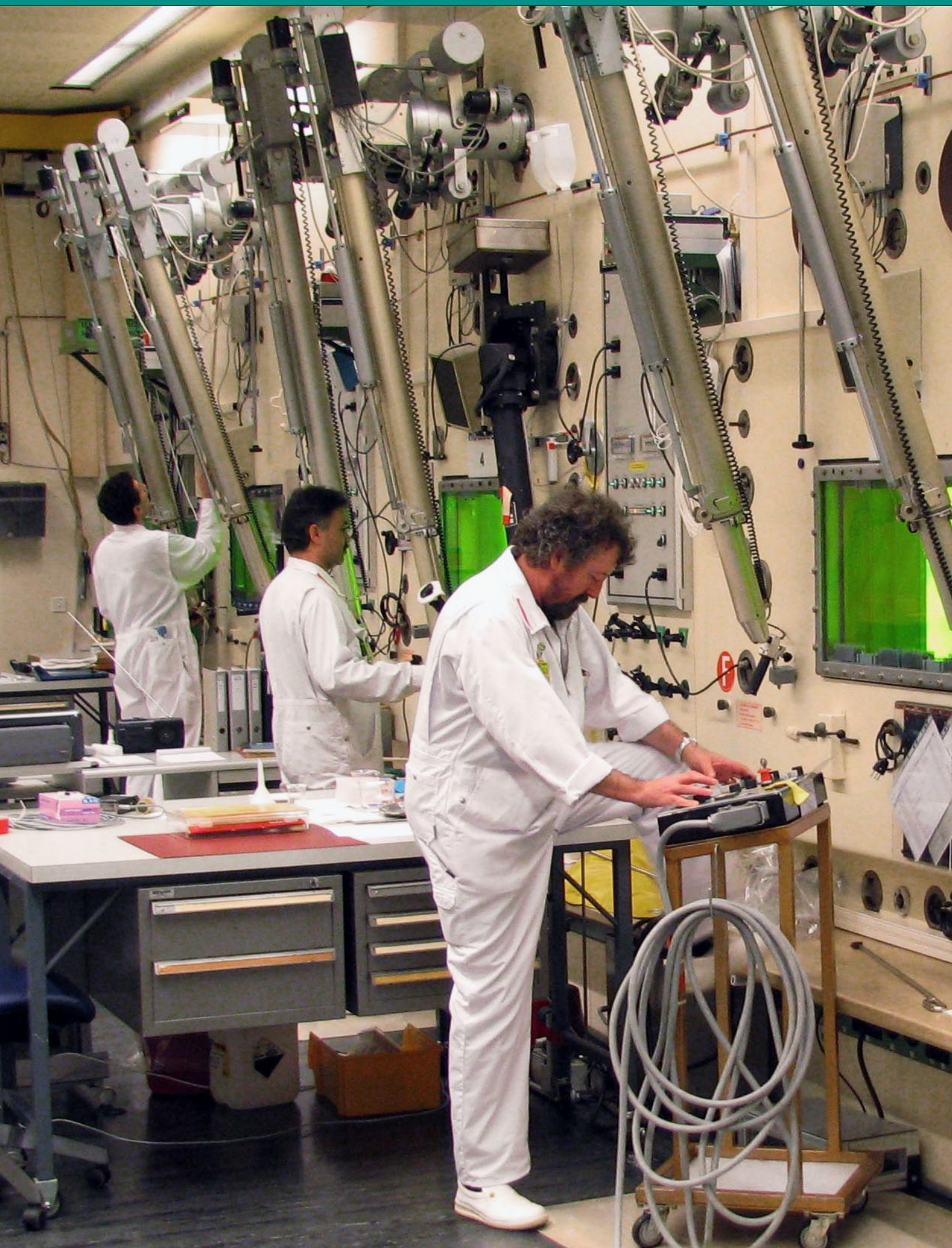
loading mode was switched to constant load: the crack continued to grow. Rather surprisingly at first glance, the EPN signal rose again, ending up near the original level. The reason for this is probably the absence of any further surface crack growth along the notch-root and the high-purity water electrolyte of very low conductivity. Once the SCC surface crack had spread along the whole notch-root, the active crack-tip apparently grew in depth only, moving away from the surface and reference electrode. Thus the EPN signal from the crack front accessible outside the crack became small. It appears then, that only crack initiation and subsequent surface (or near-surface) crack growth are detectable using EN measurements in low-conductivity electrolytes.

Summary and conclusions

The SCC initiation experiments with independent online crack growth monitoring using DCPD indicate that early SCC detection by EN measurements is possible under stable and stationary laboratory conditions in oxygenated high-temperature water. Individual, small, intergranular, semi-elliptical surface flaws with a surface crack length and crack depth of about 150 µm can be detected by EN measurements. Only crack initiation and the subsequent surface or near-surface growth can be detected by EN measurements in high-purity water with low conductivity. Maintaining a small distance between the surface of the specimen (or cracking location) and the reference electrode is crucial in achieving high sensitivity.

References

[1] S. Ritter and H.P. Seifert, TM No. 43-07-01, Jan. 2007.
[2] H.P. Seifert and S. Ritter, PSI Report No. 09-03, March 2009.



Hot Laboratory Division (AHL) 53

The Hot Laboratory (Hot Lab) is the largest nuclear research facility under the supervision of the Swiss Federal Nuclear Safety Inspectorate (ENSI), and the only Swiss research facility capable of examining large quantities of radioactive materials. The Hot Lab incorporates a complex infrastructure to ensure that all radioactive materials inside the building are contained, and to guarantee a safe workplace for its staff. AHL is the operator of the Hot Lab, as well as being its main user. The two main tasks of the division are to ensure a safe and efficient utilization of its infrastructure, and to conduct state-of-the-art service work for the Swiss nuclear industry.

Highlights of current activities are listed below.

- AHL offers Hot Lab users modern analytical tools for the manipulation and investigation of radioactive materials. In particular, the laboratory is very well equipped for structural and chemical analyses of the materials used in nuclear power plants and accelerator facilities.
- The Hot Lab is one of the nominated 'PSI User Lab Facilities', and is responsible for the preparation and handling of radioactive specimens prior to their deployment in the large facilities at PSI: namely, SINQ, SLS and PROTEUS.
- AHL has strong links to the Swiss nuclear power plants, and undertakes the necessary detailed material investigations for ensuring their continuing safe and economic operation. AHL also collaborates with several research projects concerned with the fuel and structural materials used in nuclear installations. Through this involvement, AHL has established within the nuclear material research community worldwide recognition of its competence.
- AHL benefits directly from its very competent staff, in that it is also successfully developing new analysis methods and infrastructure for tackling the challenging and ever-changing needs of the nuclear community, and is also able to undertake its own safety evaluation to ensure its continuing safe operation.

◀ **Hotcell line for research on nuclear fuel rods, for material testing and mechanical material processing. Manipulators are being operated through walls of one meter in thickness.**

The Hot Laboratory – multiple facilities for the examination of radioactive samples

Didier Gavillet, Ines Günther-Leopold, Daniel Kuster, Matthias Martin
Hot Laboratory, PSI

The Hot Laboratory (HOTLAB) at PSI is a unique facility in Switzerland for the handling and analysis of large quantities of radioactive materials: in particular, components from the nuclear power plants in Switzerland are routinely examined. The facility hosts different internal and guest (EPFL) research groups active in the analysis of radioactive materials. In short, the HOTLAB at PSI offers a wide spectrum of analytical tools for the experimental investigation of highly radioactive materials, together with the basic infrastructure needed for their safe handling, storage and disposal.

The Hot Laboratory (HOTLAB) began operation in 1963, at the time of the Eidgenössiches Institut für Reaktor-forschung (EIR). Since then, it has been extended to include the Pu-Laboratories, dealing with the production, study and storage of advanced (non-irradiated) nuclear fuel for future generations of nuclear reactors. The infrastructure of the HOTLAB has been steadily upgraded to meet the ever more stringent safety requirements for the safe handling of hazardous materials, and major efforts have been made over the years to keep the facility abreast of the needs and expectations of its users, but also to offer new possibilities for detailed analysis of radioactive materials. Most of the research activities realised in the HOTLAB start with the delivery of highly radioactive batches of materials in the large, concrete hot-cell chain, and continue with detailed, and often very sophisticated, analysis.

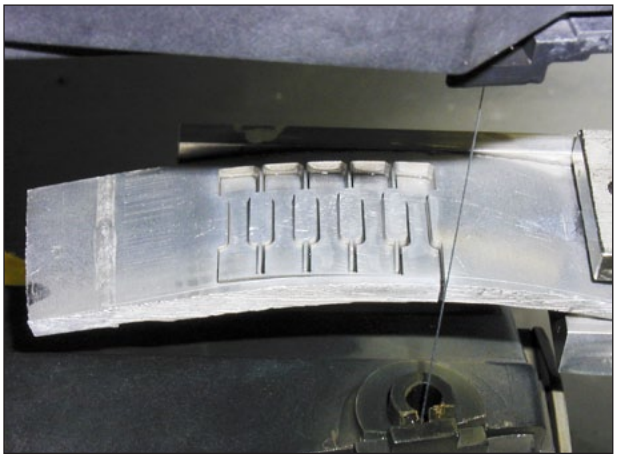


Figure 1: **Sub-specimen production in large cells**

The concrete hot-cell chain

The heavy transport flasks used for the (often international) transport of radioactive materials are unloaded in one of the five large concrete hot cells. Cell No. 1 can accept full-length Light Water Reactor (LWR) fuel rods for detailed, non-destructive examination. Visual inspection of the rod surface, measurement of the oxide layer depth, and the variation of rod diameter and rod length with regard to their nominal values, enable a detailed assessment of the state of the rod to be given. This first characterisation of the flaws resulting from service life of the rod in the reactor is essential for the prediction of the lifetimes of new rod designs.

Smaller batches of material, those irradiated in accelerator facilities at PSI, and in small research reactors around the world, are unloaded in the smaller concrete cells. For example, irradiated test materials for future neutron sources based on liquid-metal technology are delivered, sorted and cleaned in these cells for the target development group at PSI. Likewise, irradiated materials developed for future fusion reactors by the fusion technology group at EPFL are similarly handled. After delivery, the smaller samples must very often be prepared for further detailed analysis.

The HOTLAB has to modify commercially available equipment on a regular basis for remote handling in the cells. An example is the Electrical Discharge Machine (EDM), which is used to produce specimens of complex shape, as seen in Fig. 1.

After cutting, the samples are dispatched to the many shielded analytical facilities available in the laboratory, where further inspection of the material structure is often required.

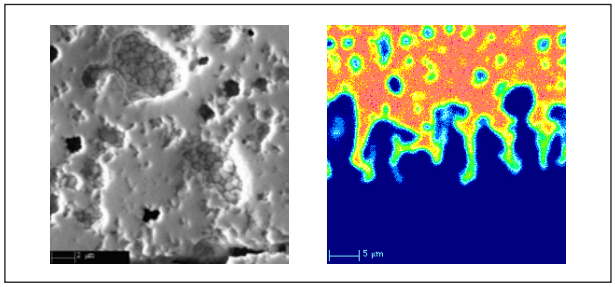


Figure 2: **EPMA observation of fuel restructuring at high burn-up. Left: sub-micron grains and fission products are seen in the pores. Right: U-distribution at the fuel-cladding interface –blue indicating low and red indicating high concentrations.**

Solid-surface analytical tools

Irradiation induces changes in material structures through neutron bombardment, as well as inducing thermal and chemical processes. These changes can be observed at micron and submicron length-scales on polished specimens using an Optical Microscope (OM), a Scanning Electron Microscope (SEM), or Electron Probe Micro-Analysis (EPMA). The HOTLAB has two shielded cells dedicated to the preparation of such specimens, enabling structural modifications to a material to be observed, such as in the case of the nuclear fuel restructuration occurring at very high burn-up (Fig. 2, left).

Elemental and isotopic analytical tools

Irradiation also induces modification of the element distribution in materials. EPMA allows the distribution of the major elements in a sample to be visualised, which helps to understand the thermal and nuclear processes that had occurred during reactor operation. For example, observation of the Uranium distribution at the fuel/cladding interface (Fig. 2, right) provides information on the corrosion processes relevant to the integrity of the LWR fuel rod.

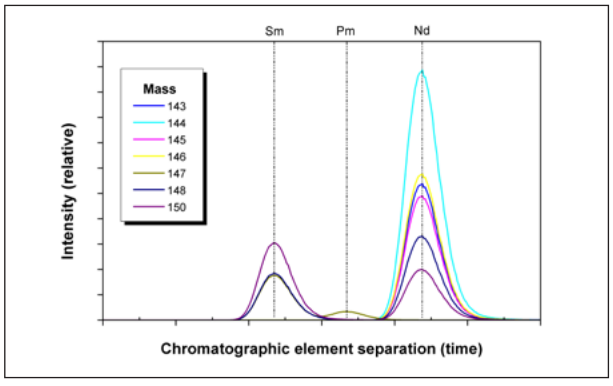


Figure 3: **ICP-MS elemental and isotopic separation of Sm, Pm and Nd with the HPLC-ICP-MS technique.**

Often the elemental information alone is not sufficient, and isotopic details are needed to fully understand the effects of irradiation. This is often critical for the validation of the very sophisticated modelling software available today. The HOTLAB is a leader in the development of Secondary Ion Mass Spectrometer (SIMS) and Inductively Coupled Plasma Mass Spectroscopy (ICP-MS) techniques for the isotopic examination of highly radioactive materials. For example, ICP-MS, coupled with High Performance Liquid Chromatography (HPLC), enables the separation of different isotopes of neighbouring elements to be observed, as shown in Fig. 3 for the analysis of fission products in nuclear fuel.

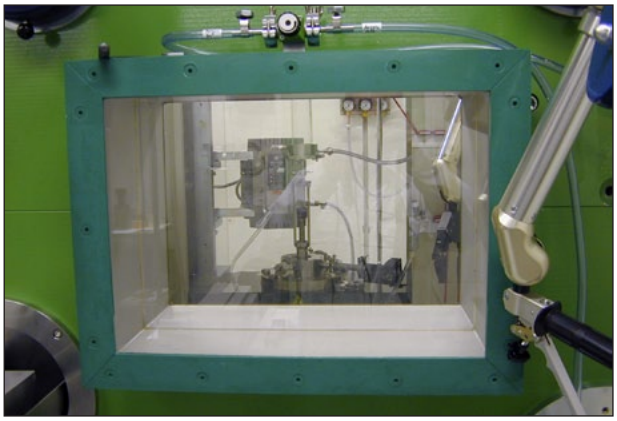


Figure 4: **A remotely operated mechanical test machine, as seen behind its shielding.**

Mechanical properties

Finally, structural and chemical modification of materials can have a critical effect (often a degrading one) on their mechanical properties. The HOTLAB offers the basic infrastructure for examining irradiated specimens in shielded environments, including the transfer, loading and unloading of specimens in dedicated test facilities. Different machines have been developed for the shielded boxes. These are operated by PSI and EPFL research groups, and allow detailed investigation of the mechanical properties of irradiated materials at different temperatures and in different environments to be performed (Fig. 4).

Summary

The PSI Hot Laboratory offers a state-of-the-art infrastructure for the experimental study of radioactive material behaviour, and is constantly used by many internal and external research groups. Further information can be found on our website: http://ahl.web.psi.ch.

Analysis of unexpected corrosion damage on stainless steel tanks for effluent radioactive water

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All the sewage water from the laboratories of PSI (East) handling radioactive materials are collected and transferred to special steel tanks in the Hot Laboratory (HOTLAB) for treatment, filtering and control. At the beginning of 2008, periodical inspection revealed traces of corrosion damage in the upper section of some of these tanks. Detailed analysis of the damage has been undertaken in the HOTLAB itself, and the cause of the problem identified as a pitting corrosion due to deposits on the inner surface of the tanks. The analysis has led to remedial procedures being defined to insure the continued, long-term and safe use of the tanks.

Radioactive materials are routinely investigated in different buildings of PSI (East). All the sewage water from these buildings is transferred to special stainless steel tanks located inside the Hot Laboratory (HOTLAB) for treatment, filtering and control. The tanks are part of the safety infrastructure of the HOTLAB, and are regularly inspected to insure safe, leak-free treatment of (possibly) radioactive water.

During a regular inspection at the beginning of 2008, corrosion damage to the inner surface of some of the tanks was detected. The corrosion was unexpected, and led to a detailed investigation of the stainless steel material being launched. The HOTLAB is well-equipped, and has the necessary competence to carry out such an investigation.

The main goal of the analysis was to determine the root cause of the corrosion process, in order to instigate an appropriate reparation plan to insure the further, long-term safe use of the tanks.

Figure 1: **Macro-photograph of the inner surface of the corroded tank showing deposit layer (Sample 2)**

Damage Analysis

In order to perform a detailed analysis of the steel, two small (about 100 cm^2) samples were cut from the top of one of the corroded tanks, at the location of the inlet of the sewage water. The first sample (Sample 1), acting as reference material, was extracted from the upper region of the tank, where the steel was almost never in contact with the effluent water. The second sample was cut from a lower region, where the sewage water would be flowing almost continuously over the wall surface, and also where the highest traces of corrosion had been detected (Sample 2).

Visual inspection of Sample 2 indicated the presence of thick deposits, and a highly corroded inner surface of the tank (Fig. 1). In contrast, the upper sample (Sample 1) exhibited only light staining of the surface (in the form of brownish spots).

Following visual inspection, the deposit layer was removed, dissolved in nitric acid, and then filtered to remove any non-dissolvable residue. During the dissolution process, some gas (CO_2) was discharged, indicating the presence of carbonates. The resulting solution was analyzed using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) and Ion Chromatography (IC) for the presence of steel elements, the usual water contaminants, and anions such as chloride and sulfate. Mainly steel elements (Fe, Cr, Ni) were present, together with sulfur. Some 75% of the sulfur was in the form of sulfate, the rest could have been sulfide (bad smell). The sum total of all the analyzed elements amounted to about one third of the total mass, the rest must have been organic material and carbonate. However, the analyses gave no clear insight into the root cause of the corrosion.

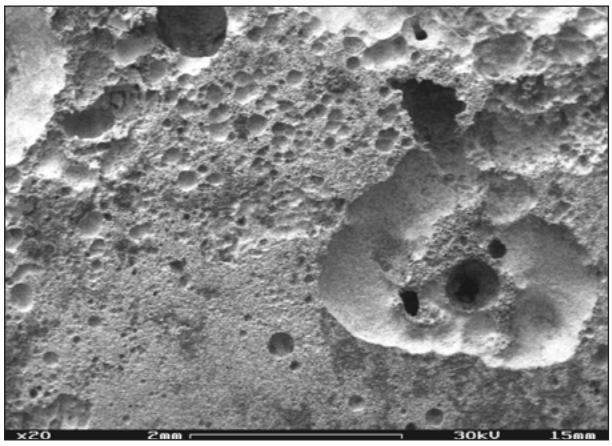

Figure 2: **SEM of the cleaned tank inner surface showing corrosion due to pitting (Sample 2)**

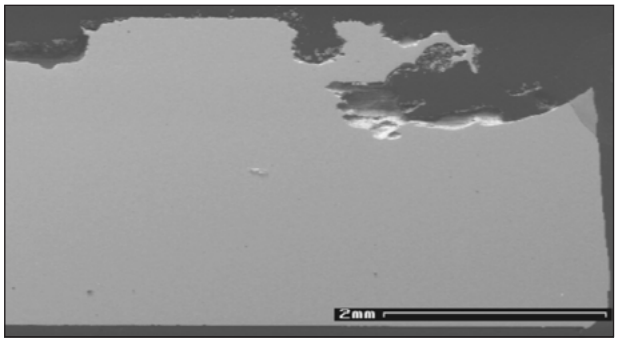

Figure 3: **Cross-section of image obtained using SEM showing material loss due to corrosion (Sample 2)**

The cleaned inner surface of the tank was subsequently analyzed using Scanning Electron Microscopy (SEM). This revealed that the metal exhibited very intense corrosion due to pitting, with grain disintegration (Fig. 2). Even on the reference sample, a light inter-granular attack has been detected.

In order to obtain a better picture of the extent of the pitting, cross-sections of both specimens were prepared and analyzed using SEM. On the corroded piece (Sample 2), massive loss of material due to corrosion is clearly visible, accompanied by a reduction of about 50% in the tank wall thickness in the observed region. The fact that some trace of corrosion had been observed on the external surface of the tank proves that, at least in some regions, the pitting had locally produced small holes.

The shape of the corroded patch seen in Figs. 2, 3 is typical of corrosion due to pitting in stainless steel, when stagnant water is present, together with some material deposits or very rugged surfaces. This type of corrosion is known to occur in almost all steels, proceeding at different rates, even with very low concentrations of the corrosive material in the water [1].

Root cause of the corrosion process

The deposit layer, and the continuous presence of corrosive media (sewage water with chemical contaminant), provided ideal conditions for crevice corrosion, and subsequently pitting corrosion, even in stainless steel. Between the deposit layer and the underlying metal, the corrosive elements present in the waste water (chlorides, sulfides, salts, organic and inorganic dirt, etc.) will be concentrated, creating highly corrosive conditions. The continuous flow of water had ensured a regular supply of corrosive chemicals, and additionally had removed the water-soluble corrosion products, thereby cleaning the surface for further corrosion activity.

Conclusion

Careful and detailed analysis of the corroded material in the sewage tank for lightly radioactive water in the HOTLAB has enabled the root cause of the corrosion to be determined. Understanding the corrosion process has also provided information of the repairs necessary to restore the integrity of the tank, and to prevent further corrosion. The corroded parts of the tanks will first be removed, and then replaced by new material. Then, a new immersion pipe for the sewage water inlet will be inserted to avoid any new deposit on the inner tank surface from occurring. The proposed repair to the tanks has been approved by the regulatory authority (ENSI), the procedures implemented during 2009.

In summary, regular inspection of the relevant infrastructure, combined with the general safety awareness of PSI, and in particular by the HOTLAB employees, have resulted in early detection of a possible threat to the integrity of the (lightly) radioactive sewage system at PSI (East). Also, the competence at PSI in regard to its research goals, in particular in the field of materials research, has enabled the corrosion process to be rapidly identified.

Acknowledgement

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Reference

[1] L. Engel, H. Klingele, Rasterelektronenmikroskopische Untersuchung von Metallschäden, Carl Hanser Verlag, 1982 (ISBN 3-446-13416-6).

Comparative study of X-ray micro-analyses of CRUD deposit on nuclear fuel rods

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In Boiling Water Reactors (BWRs), corrosion products are deposited on the fuel rods during their service lifetime. This deposit, which is called CRUD, can have a significant influence on corrosion of the cladding material, and also on the fuel behavior through decrease in thermal conductivity. The exact CRUD formation process is still not fully understood and a basic study of its structure and composition, comparing two available analysis methods, are being undertaken at the PSI Hot Laboratory.

The elemental composition of CRUD deposit on a nuclear fuel rod is made up of oxides of Fe, Zn, Ni, Mn and Cr. It has been investigated using two analysis methods: electron probe micro-analysis (EPMA) and scanning electron microscopy (SEM). The first employs wavelength dispersive X-ray spectroscopy (WDS), while the second uses energy dispersive X-ray spectroscopy (EDS). Both techniques [1,2] measure the characteristic X-rays generated from the chemical elements present in a sample taken from the rod surface by bombardment with a high-voltage electron beam. By this means, in addition to obtaining the scanning electron microscopy (SEM) image, local quantitative element concentrations can be measured, as well as the element distribution mappings of the surface. Data acquisition and analysis by EDS is very fast, since the necessary information is contained in a single spectrum, all the X-ray lines being acquired simultaneously. With WDS, the lines are obtained sequentially. Calibration of a reference material is then necessary, which makes quantification very time consuming. However, WDS spectrometers are shielded against the β- and γ-radiation emitted by the sample, which can cause high 'dead times' and spurious background count rates. Further important advantages of WDS are the much better spectral resolution it offers, and the peak-to-background ratio, particularly useful for measuring low concentrations.

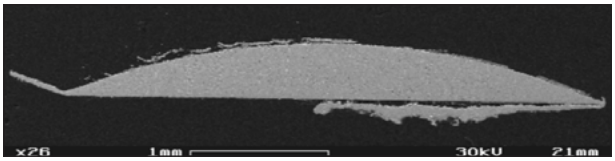


Figure 1: **Cross-section of an embedded and polished segment of a fuel rod (SEM-image).**

The characteristics of the two methods are compared in Table 1. In drawing up this Table, it has been assumed from the composition, and from the porous, granular texture of the CRUD, that the unshielded SEM-EDS is comparable to WDS for this type of analysis, even for dose rates up to 100 μSv/h in 10 cm.

	EPMA-WDS	SEM-EDS
Spectra acquisition and element identification	slow	fast
Speed of element quantification	very slow, sequential, necessity to calibrate	fast, simultaneous
Spectral resolution, line width	very good, 10 eV	poor, 138 eV
Peak/background ratio	high	low, especially for active samples
Quality of point analysis	very good	good, but with some interference, no trace analysis
Topographical influence	high	moderate
Element mapping	only qualitative or semi-quantitative with old EPMA	fully quantitative mapping possible
Analysis of active samples	very good	limited

Table 1: **Comparison of EPMA-WDS with SEM-EDS X-ray spectroscopy techniques**

Sample preparation

In 5 mm long segments of an irradiated fuel rod, longitudinal cuts were made using a diamond-tipped wheel saw. To reduce the dose rate, segments of 1 mm length were then cut using

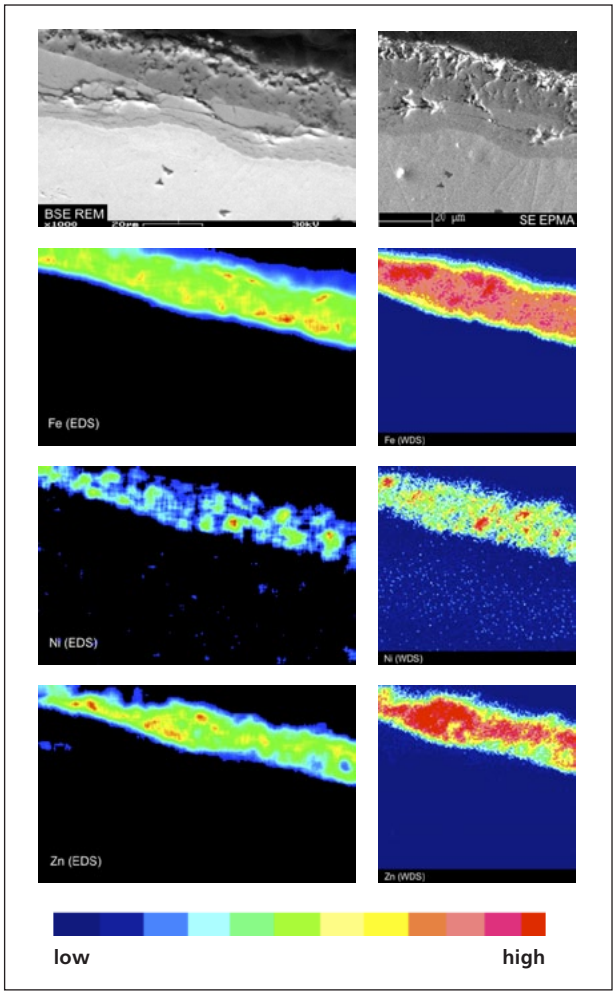


Figure 2: **SEM/BSE images and corresponding element mappings of a cross-section of the outside surface of a fuel rod made using SEM-EDS (left: quantitative) and EPMA-WDS (right: qualitative).**

a diamond-tipped wire saw and the pieces embedded in epoxy resin. Polishing of the samples was then performed using diamond paste to a finish of 1 µm. A typical cross-section is shown in Fig. 1.

Results

Images of a section of a fuel rod segment with CRUD are shown in Fig. 2 using elemental EPMA-WDS mappings made by beam scanning of the surface (qualitative), and by SEM-EDS mappings (quantitative). The cross-section (SEM/BSE-image) reveals the base metal zircaloy and the granular CRUD adhering to a corrosion layer of ZrO_2. The overall acquisition times for both methods were the same. Nonetheless, the acquisition time for each element in the WDS modus was about four times less, which led to a decrease in lateral resolution, even though the spectral resolution was good. The qualitative element mappings obtained using EDS were also poor, because of line

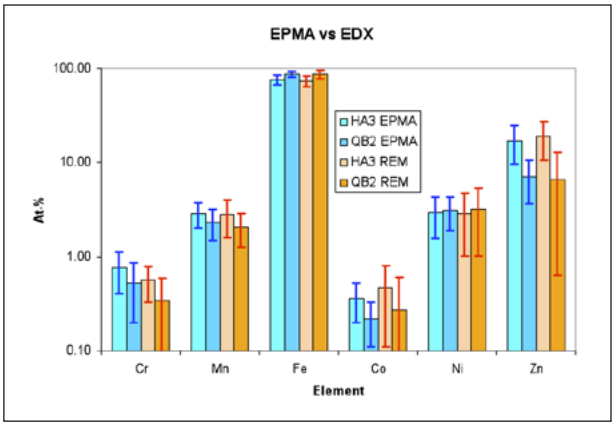


Figure 3: **Quantitative point analyses of CRUD deposits on nuclear fuel rods measured using EPMA-WDS and SEM-EDS showing concentrations of metal atoms in at%. The histogram is shown in logarithmic scale.**

overlaps and low peak-to-background ratios, there being additional fluorescence and absorption effects for both these methods.

In contrast, the quantification of the EDS mappings reveals, through the higher spatial resolution, that the element distributions are in fact much more scattered, and that there are distinct concentration changes on a micron scale.

Quantitative point analyses of the CRUD on two rod segments (HA3, QB2) taken at different rod elevations were made using the two techniques. The results are illustrated in Fig. 3. More than 30 measurement points were taken, which is statistically narrow with regard to the heterogeneous element distribution, as already indicated by the dot mappings. The standard deviation bands reflect the scattering of the concentrations. Differences in results are well within the individual error bands, so that analysis by SEM may be regarded as equivalent to that of WDS. The Cr concentrations display larger differences, due to its very heterogeneous distribution.

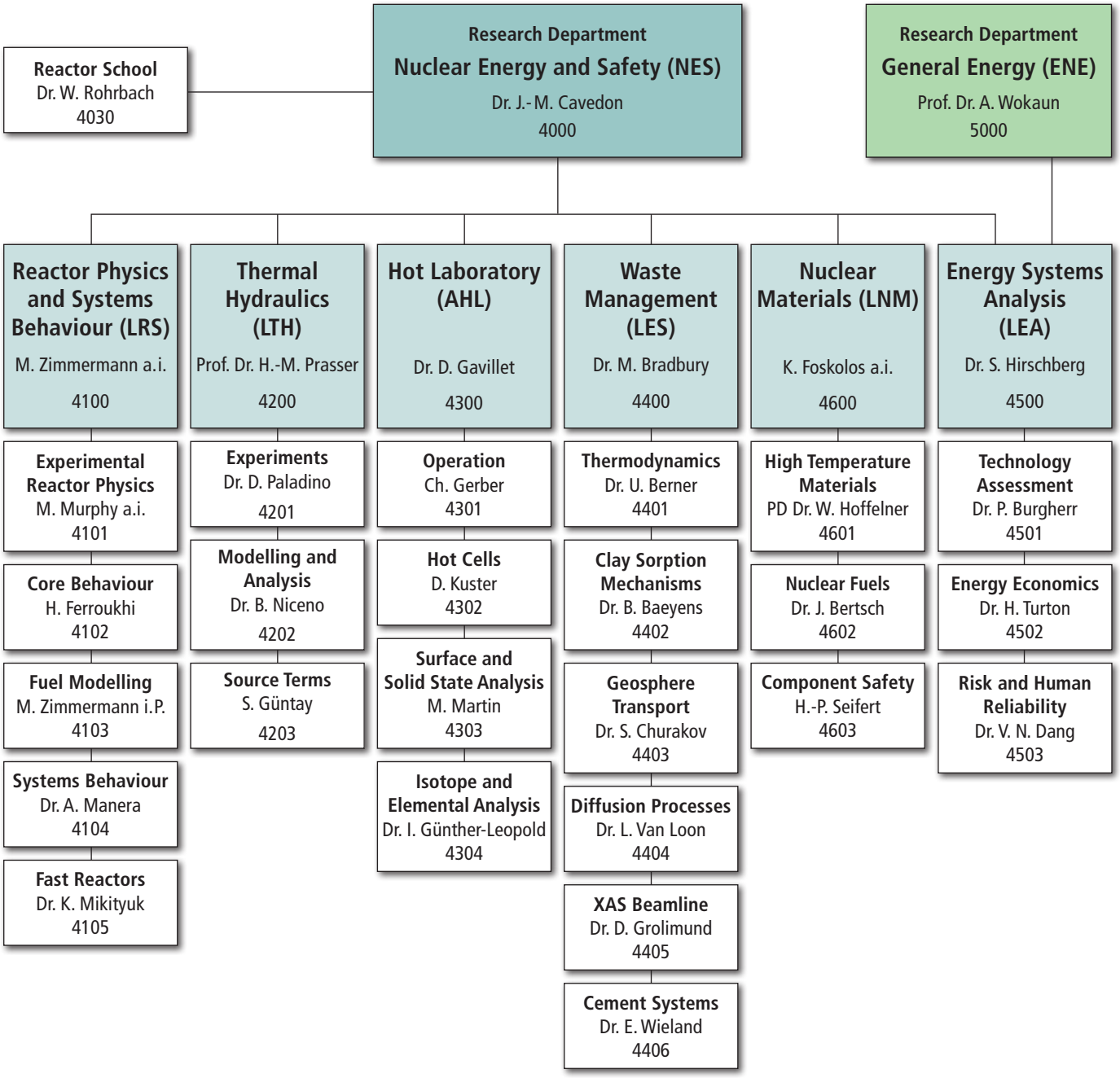
Conclusions

SEM-EDS is an efficient and fast surface-analysis method, and for the kind of analyses performed here is equivalent to EPMA-WDS. Moreover, SEM-EDS has the advantage of providing quantitative elemental mappings, with much better lateral resolution. Only the new EPMA facility (now in construction in the PSI Hot Lab) will be able to match this feature. However, SEM analysis does require sophisticated sample preparation to reduce background radiation exposure.

References

[1] J.I. Goldstein et al. (eds.), Scanning Electron Microscopy and X-ray Microanalysis, 2nd ed., Plenum Press, 1992.

[2] S.J.B. Reed, Electron Microprobe Analysis, 2nd ed., Cambridge Univ. Press, 1997.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◀ **Organisational chart of the Nuclear Energy and Safety Research Department.**

NES – Nuclear Energy and Safety

Publications in Scientific and Technical Journals

Alam A., Hellwig C.
"Cladding Tube Deformation Test for Stress Reorientation of Hydrides", J. ASTM Int. (ISSN 1546-962X), **5**(2), Paper ID: JAI101110, 15 pages (2008)

Aounallah Y.
"A Separate-Effect-Based New Appraisal of Convective Boiling and its Suppression", J. of Nucl. Sci. and Techn. (ISSN 0022-3131), **45**(2), 149-159 (2008)

Bako B., Weygand D.[1], Samaras M., Hoffelner W., Zaiser M.[2]
"Dislocation depinning transition in a dispersion-strengthened steel", Phys. Rev.B (ISSN 1098-0121), **78**, 144104-1, 5 pages (2008)
[1] University of Karlsruhe, DE
[2] University of Edinburgh, UK

Bart G., Botta F., Hoth C.[1], Ledergerber G.[2], Mason R.[1], Stratton R.[3]
"Comparative Irradiation Test of Mixed Carbide Fuel in the US Fast Flux Test Facility with Focus on Sphere-Pac Fuel Behaviour; Summary of a Joint USA-Swiss Experiment", J. Nucl. Mater. (ISSN 0022-3115), **376**(1), 47-59 (2008)
[1] LANL, Los Alamos, US
[2] KKL, Leibstadt, CH
[3] NOK AG, Baden, CH

Barten W., Jasiulevicius A., Manera A., Macian-Juan R., Zerkak O.
"Analysis of the capability of system codes to model cavitation water hammers: simulation of UMSICHT water hammer experiments with TRACE and RELAP5", Nucl. Eng. Des. (ISSN 0029-5493), **238**, 1129-1145 (2008)

Barten W., Manera A., Macian-Juan R.[1]
"One- and two-dimensional standing pressure waves and one-dimensional travelling pulses using the US-NRC nuclear systems analysis code TRACE", Nucl. Eng. Des. (ISSN 0029-5493), **238**, 2568-2582 (2008)
[1] TUM, Garching, DE

Birchley J., Haste T., Richner M.[1]
"Accident Management following Loss of Residual Heat Removal during Mid-Loop Operation in a Westinghouse Two-Loop PWR", Nucl. Eng. Des. (ISSN 0029-5493), **238**(9), 2173-2181 (2008)
[1] NOK AG, Baden, CH

Blair P., Khvostov G., Romano A.[1], Hellwig C.[2], Chawla R.
"Interpretation of High-Burnup Fuel Annealing Tests", J. of Nucl. Sci. and Techn. (ISSN 0022-3131), **45**(7), 639-646 (2008)
[1] ENUSA, Madrid, ES
[2] NOK AG, Baden, CH

Blanchet D., Huot N.[1], Sireta P.[1], Serviere H.[1], Boyard M.[2], Antony M.[1], Laval V.[1], Henrard P.[3]
"Qualification of a gamma-ray heating calculation scheme for the future Jules Horowitz material testing reactor (JHR)", Ann. Nucl. Energy (ISSN 0306-4549), **35**, 731-745 (2008)
[1] CEA, Cadarache, FR
[2] AREVA TA, Aix-en-Provence, FR
[3] University Blaise Pascal, Clermont-Ferrand, FR

Bubelis E., Castelliti D.[1], Coddington P., Dor I.[2], Fouillet C.[3], de Geus E.[4], Marshall T.[5], van Rooijen W.[6], Schikorr M.[7], Stainsby R.[8]
"A GFR benchmark: comparison of transient analysis codes based on the ETDR concept", Prog. Nucl. Energ. (ISSN 0149-1970), **50**, 37-51 (2008)
[1] CIRTEN, Pisa, IT
[2] CEA, Saclay, FR
[3] AREVA NP, Paris, FR
[4] NRG, Arnhem, NL
[5] ANL Argonne, Idaho Falls, US
[6] TU Delft, NL
[7] FZK, Karlsruhe, DE
[8] AMEC NCC Ltd., Knutsford, UK

Bubelis E., Coddington P., Mikityuk K.
"Verification of the TRACE Code against the MEGAPIE Transient Data", Ann. Nucl. Energy (ISSN 0306-4549), **35**, 1284-1295 (2008)

Bukowiecki N.[1], Lienemann P.[1], Zwicky C.[1], Furger M., Richard A., Falkenberg G.[2], Rickers K.[2], Grolimund D., Borca C., Hill M.[1], Gehrig R.[1], Baltensperger U.
"X-ray fluorescence spectrometry for high throughput analysis of atmospheric aerosol samples: the benefits of synchrotron X-rays", Spectrochimica Acta (ISSN 0584-8547), **B63**, 929-938 (2008)
[1] EMPA, Dübendorf, CH
[2] DESY, Hamburg, DE

Cammelli S., Degueldre C., Kuri G., Bertsch J.
"Study of a neutron irradiated reactor pressure vessel steel by X-ray absorption spectroscopy", Nucl. Instrum. Meth. B (ISSN 0168-583), **266**, 4775-4781 (2008)

Caruso S., Günther-Leopold I., Murphy M., Jatuff F., Chawla R.
"Comparison of optimised germanium gamma spectrometry and multicollector inductively coupled plasma mass spectrometry for the determination of ^{134}Cs, ^{137}Cs and ^{154}Eu single ratios in highly burnt UO_2", Nucl. Instrum. Methods Phys. Res., Sect. A (ISSN 0168-9002), **589**, 425-435 (2008)

Caruso S., Murphy M., Jatuff F., Chawla R.
"Nondestructive Determination of Fresh and Spent Nuclear Fuel Rod Density Distributions through Computerized Gamma-Ray Transmission Tomography", J. of Nucl. Sci. and Techn. (ISSN 0022-3131), **45**(8), 828-835 (2008)

Chawla R., Jatuff F., Tani F.
"Diagnostic analysis of pin-removal reactivity worth experiments in a SVEA-96+ test lattice", Ann. Nucl. Energy (ISSN 0306-4549), **35**, 495-502 (2008)

Chen J.C., Jung P.[1], Pouchon M.A., Rebac T., Hoffelner W.
"Irradiation creep and precipitation in a ferritic ODS steel under helium implantation", J. Nucl. Mater. (ISSN 0022-3115), **373**, 22-27 (2008)
[1] FZJ, Jülich, DE

Churakov S.
"Hydrogen bond connectivity in jennite from ab initio simulations", Cem. Concr. Res. (ISSN 0008-8846), **38**, 1359-1364 (2008)

Churakov S., Mandaliev P.
"Structure of the hydrogen bonds and silica defects in the tetrahedral double chain of xonotlite", Cem. Concr. Res. (ISSN 0008-8846), **38**, 300-311 (2008)

Cometto M., Wydler P., Chawla R.
"Management of actinide waste inventories in nuclear phase-out scenarios", Ann. Nucl. Energy (ISSN 0306-4549), **35**, 1447-1460 (2008)

Dai Y., Gavillet D., Restani R.
"Stressed capsules of austenitic and martensitic steels irradiated in SINQ Target-4 in contact with liquid lead-bismuth eutectic", J. Nucl. Mater. (ISSN 0022-3115), **377**, 225-231 (2008)

de Crécy A.[1], Bazin P.[1], Glaeser H.[2], Skorek T.[2], Joucla J.[3], Probst P.[3], Fujioka K.[4], Chung B.[5], Oh D.[6], Kyncl M.[7], Pernica R.[7], Macek J.[7], Meca R.[7], Macian-Juan R., D'Auria F.[8], Petruzzi A.[8], Batet L.[9], Perez M.[9], Reventos F.[9]
"Uncertainty and sensitivity analysis of the LOFT L2-5 test: results of the BEMUSE programme", Nucl. Eng. Des. (ISSN 0029-5493), **238**, 3561-3578 (2008)
[1] CEA, Grenoble, FR
[2] GRS, Garching, DE
[3] IRSN, Cadarache, FR
[4] JNES, Tokyo, JP
[5] KAERI, Daejeon, KR
[6] KINS, Daejeon, KR
[7] NRI, Rez, CZ
[8] UNIPI, Pisa, IT
[9] UPC, Madrid, ES

Degueldre C., Abolhassani-Dadras S., Kuri G., Raabe J.
"Zircaloy-2 secondary phase precipitate analysis by X-ray microspectroscopy", Talanta (ISSN 0039-9140), **75**(2), 402-406 (2008)

Degueldre C., Kastoryano M., Dardenne K.[1]
"Variable incidence angle X-ray absorption fine structure spectroscopy: a zirconia film study", Talanta (ISSN 0039-9140), **76**(4), 731-735 (2008)
[1] FZK, Karlsruhe, DE

Dehbi A.
"A CFD model for particle dispersion in turbulent boundary layer flows", Nucl. Eng. Des. (ISSN 0029-5493), **238**(3), 707-715 (2008)

Dehbi A.
"Turbulent particle dispersion in arbitrary wall-bounded geometries: a coupled CFD-Langevin-equation based approach", Int. J. Multiphase Flow (ISSN 0301-9322), **34**(9), 819-828 (2008)

Desgranges L.[1], Pasquet B.[1], Roure I.[1], Portier S., Brémier S.[2], Walker C.[2], Hasnaoui R.[2], Gavillet D., Martin M., Raimbault L.[3]
"Assessment of the Nd/U ratio for the quantification of neodymium in UO_2", Appl. Surf. Sci (ISSN 0169-4332), **255**, 863-865 (2008)
[1] CEA, Cadarache, FR
[2] JRC/ITU, Karlsruhe, DE
[3] Ecole des Mines, Paris, FR

Fazio C.[1], Gröschel F., Wagner W., Thomsen K., Smith B.L., Stieglitz R.[1], Zanini L., Guertin A.[2], Cadiou A.[2], Henry J.[3], Agostini P.[4], Dai Y., Heyck H., Dementjevs S., Panebianco S.[3], Almazouzi A.[5], Eikenberg J., Letourneau A.[3], Toussaint J.[3], Janett A., Perret Ch., Joray S., Patorski J., Leung W., Meloni P.[4], Turroni P.[4], Zucchini A.[4], Benamati G.[4], Konys J.[1], Auger T.[6], Gessi A.[4], Gorse D.[6], Serre I.[7], Terlain A.[3], Vogt J.B.[7], Batta A.[1], Class A.[1], Cheng X.[1], Fellmoser F.[1], Daubner M.[1], Gnieser S.[1], Grötzbach G.[1], Milenkovic R., Latgé C.[3], Knebel J.[1]
"The MEGAPIE-TEST project: supporting research and

lessons learned in first-of-a-kind spallation target technology", Nucl. Eng. Des. (ISSN 0029-5493), **238**(6), 1471-1495 (2008)
[1] FZK, Karlsruhe, DE
[2] SUBATECH, Nantes, FR
[3] CEA, Gif-sur-Yvette, FR
[4] ENEA, Bologna, IT
[5] SCK-CEN, Mol, BE
[6] CNRS-CECM, Vitry, FR
[7] CNRS-LMPGM, Villeneuve d'Ascq, FR

Froideval A., Degueldre C., Segre C.[1], Pouchon M.A., Grolimund D.
"Niobium speciation at the metal/oxide interface of corroded niobium-doped Zircaloys: an X-ray absorption near edge structure study", Corros. Sci. (ISSN 0010-938X), **50**, 1313-1320 (2008)
[1] CSRRI+BCPS, Illinois Institute of Technology, Chicago, US

Gavillet D., Martin M., Dai Y.
"SIMS investigation of the spallation and transmutation products production in lead", J. Nucl. Mater. (ISSN 0022-3115), **377**, 213-218 (2008)

Gimmi T.
"Modelling field diffusion experiments in clay rock: influence of numerical representation of borehole and rock interface", J. Environ. Sci. for Sustainable Society (ISSN 1881-5073), **2**, 61-68 (2008)

Girardin G., Rimpault G.[1], Morin F.[1], Bosq J.[1], Coddington P., Mikityuk K., Chawla R.
"Development and characterization of the control assembly system for the large 2400 MWth Generation IV gas-cooled fast reactor", Ann. Nucl. Energy (ISSN 0306-4549), **35**, 2206-2218 (2008)
[1] CEA, Cadarache, FR

Glaus M., Müller W., Van Loon L.R.
"Diffusion of iodide and iodate through Opalinus Clay: monitoring of the redox state using an anion chromatographic technique", Appl. Geochem. (ISSN 0883-2927), **23**, 3612-3619 (2008)

Glaus M., Van Loon L.R.
"Degradation of cellulose under alkaline conditions: new insights from a 12-year degradation study", Environ. Sci. Technol. (ISSN 0944-1344), **42**, 2906-2911 (2008)

Glaus M., Van Loon L.R., Schwyn B.[1], Vines S.[2], Williams S.[3], Larsson P.[3], Puigdomenech I.[3]
"Long-term predictions of the concentration of a-isosaccharinic acid in cement pore water", Mater. Res Soc. (ISSN 1615-2298), **1107**, 605-612 (2008)
[1] NAGRA, Wettingen, CH
[2] NDA, Harwell, UK
[3] SKB, Stockholm, SE

González F., Juranji F., Gimmi T., Van Loon L.R., Seydel T.[1], Unruh T.[2]
"Dynamics of super-cooled water in highly compacted clays studied by neutron scattering", J. Phys. Cond. Matter (ISSN 0953-8984), **20**, 415102, 9 pages (2008)
[1] Institut Laue-Langevin, Grenoble, FR
[2] Forschungsneutronenquelle Heinz Maier-Leibnitz, Garching, DE

González F., Juranji F., Gimmi T., Van Loon L.R., Unruh T.[1], Diamond L.[2]
"Translational diffusion of water and its dependence on temperature in charged and uncharged clays: a neutron scattering study", Journal Chem. Phys. (ISSN 0021-9606), **129**, 174706-(11) (2008)
[1] Forschungsneutronenquelle Heinz Maier-Leibnitz, Garching, DE
[2] University of Berne, CH

González F., Van Loon L.R., Gimmi T., Jakob A., Glaus M., Diamond L.[1]
"Self-diffusion of water and its dependence on temperature and ionic strength in highly compacted montmorillonite, illite and kaolinite", Appl. Geochem. (ISSN 0883-2927), **23**, 3840-3851 (2008)
[1] University of Berne, CH

Günther-Leopold I., Kivel N., Kobler Waldis J., Wernli B.
"Characterization of nuclear fuels by ICP mass-spectrometric techniques", Anal. Bioanal. Chem. (ISSN 1618-2642), **390**, 503-510 (2008)

Hartmann E.[1], Baeyens B., Bradbury M.H., Geckeis H.[1], Stumpf T.[1]
"A spectroscopic characterization and quantification of M(III)/clay mineral outer-sphere complexes", Environ. Sci. Technol. (ISSN 0944-1344), **42**, 7601-7606 (2008)
[1] KIT, Karlsruhe, DE

Hummel W.
"Radioactive contaminants in the subsurface: the influence of complexing ligands on trace metal speciation", Monatsh. Chem. (ISSN 0026-9247), **139**, 459-480 (2008)

Iannuzzi Mauri M.
"X-ray absorption spectra of hexagonal ice and liquid water by all-electron Gaussian and augmented plane wave calculations", J. Chem. Phys. (ISSN 0021-9606), **128**, 204506-(12) (2008)

Johnson S., Beaud P., Krasniqi F., Milne C.[1], Kaiser M.[1], Grolimund D., Abela R., Ingold G.
"Nanoscale depth-resolved coherent femtosecond motion in laser excited bismuth", Phys. Rev. Lett. (ISSN 0031-9007), **100**, 155501 (2008)
[1] EPFL, Lausanne, CH

Kolbe E., Vasiliev A., Ferroukhi H., Zimmermann M.A.
"Consistent evaluation of modern nuclear data

libraries for criticality safety analyses of thermal compound low-enriched-uranium systems", Ann. Nucl. Energy (ISSN 0306-4549), **35**, 1831-1841 (2008)

Kosa M.[1], Krack M., Cheetham A.K.[2], Parrinello M.[1]
"Modeling the Hydrogen Storage Materials with Exposed M^{2+} Coordination Sites", J. Phys. Chem. C (ISSN 1932-7447), **112**, 16171-16173 (2008)
[1] ETHZ, Zurich, CH
[2] University of Cambridge, UK

Kosakowski G., Churakov S., Thoenen T.
"Diffusion of Na and Cs in montmorillonite", Clays Clay Miner. (ISSN 0009-8604), **56**, 190-206 (2008)

Kosakowski G., McDermott C.[1]
"Modelling matrix diffusion – results of a benchmark study", J. Env. Sci. for Sustainable Society (ISSN 1881-5073), **2**, 57-62 (2008)
[1] University of Edinburg, UK

Krepel J., Rohde U.[1], Grundmann U.[1], Weiss F.P.[1]
"Dynamics of molten salt reactors", Nucl. Technol. (ISSN 0029-5450), **164**, 34-44 (2008)
[1] FZD, Rossendorf, DE

Küpper F.C.[1,2,3], Carpenter L.J.[4], McFiggans G.B.[5], Palmer C.J.[5,6], Waite T.[7], Boneberg E.-M.[2,8], Woitsch S.[2], Weiller M.[2], Abela R., Grolimund D., Potin Ph.[9], Butler A.[3], Lther III G.W.[7], Kroneck P.[2], Meyer-Klaucke W.[10], Feiters M.[11]
"Iodide in kelp: an inorganic antioxidant in life-impacting atmospheric chemistry", Proc. Nat. Acad. Sci. (ISSN 0027-8424), **105**(19), 6954-6958 (2008)
[1] Dannstaffnage Marine Laboratory, Oban, UK
[2] University of Konstanz, DE
[3] UCSB, Santa Barbara, US
[4] University of York, UK
[5] University of Manchester, UK
[6] University of Capetown, SA
[7] University of Delaware, US
[8] Biotechnologie Inst., Kreuzlingen, CH
[9] UPMC, Paris VI, FR
[10] European Molecular Biology Laboratory, Hamburg, DE
[11] University of Nijmegen, NL

Kuri G., Gavillet D., Doebeli M., Novikov D.[1]
"Structural changes in helium implanted $Zr_{0.8}Y_{0.2}O_{1.9}$ single crystals characterized by atomic force microscopy and EXAFS spectroscopy", Nucl. Instrum. Methods Phys. Res., Sect. B (ISSN 0168-583), **266**(8), 1216-1223 (2008)
[1] DESY, Hamburg, DE

Lenz M.[1,2], Van Hullebusch E.[1,3], Farges F.[4,5], Nikitenko S.[6,7], Borca C.N., Grolimund D., Lens P.N.L.[1,8]
"Selenium speciation in anaerobic biofilms assessed by X-ray absorption spectroscopy and sequential extraction procedures", Environ. Sci. Technol. (ISSN 0944-1344), **42**, 7587-7593 (2008)
[1] University of Wageningen, NL
[2] University of Paris-Est, La Marne, FR
[3] FHNW, Muttenz, CH
[4] MNHN, Paris, FR
[5] Stanford University, US
[6] NWO Den Haag, NL
[7] ESRF, Grenoble, FR
[8] UNESCO-IHE, Delft, NL

Liao, Y.
Letter to the editor: comment on the paper "Extensive study on laminar free film condensation from vapor–gas mixtures," Int. J. Heat Mass Transfer (ISSN 0017-9310), doi:10.1016/j.ijheatmasstransfer.2008.10.002 (2008)

Liao, Y., Vierow, K., Dehbi, A., Guentay, S.
"Transition from natural to mixed convection for steam–gas flow condensing along a vertical plate", Int. J. of Heat and Mass Transfer (ISSN 0017-9310), doi:10.1016/j.ijheatmasstransfer.2008.06.008 (2008)

Liu L.[1], Krack M., Michaelides A.[1]
"Density Oscillations in a Nanoscale Water Film on Salt: Insight from Ab Initio Molecular Dynamics", J. Am. Chem. Soc. (ISSN 0002-7863), **130**, 8572-8573 (2008)
[1] University College, London, UK

Maass R., Van Petegem S., Grolimund D., Van Swygenhoven H., Kiener D.[1], Dehm G.[1]
"Crystal rotation in Cu single crystal micropillars: *in situ* Laue and electron backscatter diffraction", Appl. Phys. Lett. (ISSN 0003-6951), **92**, 071905-071907 (2008)
[1] Montanuniversity, Leoben, AT

Maass R., Van Petegem S., Zimmermann J., Borca C., Van Swygenhoven H.
"On the initial microstructure of metallic micropillars", Scripta Materialia (ISSN 1359-6462), **59**, 471-474 (2008)

Manera A., Ozar B.[1], Paranjape S.[1], Ishii M.[1], Prasser H.-M.
"Comparison between wire-mesh sensors and conductive needle-probes for measurements of two-phase flow parameters", Nucl. Eng. Des. (ISSN 0029-5493), doi:10.1016/j.nucengdes.2008.06.015 (2008)
[1] Purdue University, West Lafayette, US

Marques Fernandes M., Baeyens B., Bradbury M.H.
"The influence of carbonate complexation on lanthanide/actinide sorption on montmorillonite", Radiochim. Acta (ISSN 0033-8230), **96**, 691-697 (2008)

Merlet, C.[1], Llovet, X.[2], Aufore, L.[3], Brémier, S.[4], Deschanels, X.[5], Dugne, O.[5], Lamontagne, J.[3],

Restani, R., Roche, C.[5], Tribet, M.[5], Van Renterghem, W.[6]
"Analysis of Pu by Virtual-Standard WDS-EPMA. Results of an Interlaboratory Round-Robin Test", Microsc. Microanal. (ISSN 1431-9276), **14**, 1094-1095 (2008)
[1] University of Montpellier II, FR
[2] University of Barcelona, ES
[3] CEA, Cadarache, FR
[4] JRC/ITU, Karlsruhe, DE
[5] CEA, Marcoule, FR
[6] SCK CEN, Mol, BE

Merlet C.[1], Llovet X.[2], Dugne O.[3], Brémier S.[4], Van Renterghem W.[5], Restani R.
"Virtual standard for wavelength-dispersive electron-probe microanalysis", Microchim Acta (ISSN 0026-3672), **161**, 427-432 (2008)
[1] University of Montpellier, FR
[2] IEC, Barcelona, ES
[3] CEA VRH, Pierrelatte, FR
[4] JRC/ITU, Karlsruhe, DE
[5] SCK, Mol, BE

Mikityuk K., Coddington P., Gröschel F.
"Analysis of radioactivity releases in the MEGAPIE reference accident", Nucl. Eng. Des. (ISSN 0029-5493), **238**(7), 1838-1844 (2008)

Murphy M., Jatuff F., Perret G., Plaschy M.[1], Bergmann U.[2], Chawla R.
"Comparison of 3D reaction rate distributions measured in an Optima2 BWR assembly with MCNPX predictions", Ann. Nucl. Energy (ISSN 0306-4549), **35**, 2042-2050 (2008)
[1] EOS, Lausanne, CH
[2] Westinghouse Electric Sweden AB, Västeras, SE

Niceno B., Dhotre M., Deen N.[1]
"One-equation sub-grid scale (SGS) modelling for Euler–Euler large eddy simulation (EELES) of dispersed bubbly flow", Chem. Eng. Sci. (ISSN 0009-2509), **63**(15), 3923-3931 (2008)
[1] University of Twente, NL

Niffenegger M., Leber H.
"Sensitivity of the magnetization curves of different austenitic stainless tube and pipe steels to mechanical fatigue", J. Nucl. Mater. (ISSN 0022-3115), **377**, 325-330 (2008)

Nilsson A.[1], Hedqvist I.[2], Degueldre C.
"Granitic groundwater colloids sampling and characterisation: a strategy for artefact elimination", Anal. Bioanal. Chem. (ISSN 1618-2642), **391**, 1327-1333 (2008)
[1] Geosigma, Dandery, SE
[2] SKB, Figeholm, SE

Paladino D., Huggenberger M., Schäfer F.[1]
"Natural Circulation Characteristics at Low Pressure Conditions – PANDA Experiments and ATHLET Simulations", Sci. Techn. Nuclear Installations (ISSN 1687-6075), Article ID 874969, doi:10.1155/2008/874969 (2008)
[1] FZK, Karlsruhe, DE

Paladino D., Zboray, R., Benz, P., Andreani, M.
"Three-gas-mixture plume inducing mixing and stratification in a mulit-compartment containment", Nucl. Eng. Des. (ISSN 0029-5493, doi:10.10.16/j.nucengdes.2008.07.014 (2008)

Perret G., Plaschy M., Murphy M., Jatuff F., Chawla R.
"Characterisation of radial reaction rate distributions across the 92-pin section of a SVEA-96 Optima2 assembly", Ann. Nucl. Energy (ISSN 0306-4549), **35**, 478-484 (2008)

Raabe D.[1], Ramesh M., Zhao Z.[2], Cuitiño A.[3], Raddovitzky R.[2]
"Investigation of three-dimensional aspects of grain-scale plastic surface deformation of an aluminum oligocrystal", Int. J. Plasticity (ISSN 0749-6419), **24**(12), 2278-2297 (2008)
[1] Max-Planck-Institut, München, DE
[2] MIT, Cambridge, US
[3] Rutgers University, Piscataway, US

Ritter S., Seifert H.P.
"Effect of Corrosion Potential on the Corrosion Fatigue Crack Growth Behaviour of Low-Alloy Steels in High-Temperature Water", J. Nucl. Mater. (ISSN 0022-3115), **375**(1), 72-79 (2008)

Rodríguez-Fortea A.[1], Iannuzzi Mauri M.
"First-Principles Molecular Dynamics Study of the Heterogeneous Reduction of NO_2 on Soot Surfaces", J. Phys. Chem. C (ISSN 1932-7447), **112**, 19642-19648 (2008)
[1] University Rovira i Virgili, Tarragona, ES

Rohde M.[1], Marcel C.[1], Manera A., van der Hagen T.[1], Shiralkar B.[2]
"Investigating the ESBWR stability with experimental and numerical tools: a comparative study", Nucl. Eng. Des. (ISSN 0029-5493), doi:10.1016/j.nucengdes.2008.01.016 (2008)
[1] TU Delft, NL
[2] GE, San Jose, US

Santarossa G.[1], Vargas A.[1], Iannuzzi Mauri M., Pignedoli C.A.[2], Passerone D.[2], Baiker A.[1]
"Modeling bulk and surface Pt using the "Gaussian and plane wave" density functional theory formalism: validation and comparison to k-point plane wave calculations", J. Chem. Phys. (ISSN 0021-9606), **129**, 234703-234714 (2008)
[1] ETHZ, Zurich, CH
[2] EMPA, Dübendorf, CH

Schumann D., Neuhausen J., Horn S., Kubik P., Günther-Leopold I.
"Radiochemical separation and analytical determination of ^{10}Be from proton-irradiated graphite targets", Radiochim. Acta (ISSN 0033-8230), **96**, 31-34 (2008)
[1] Tohoku University, JP

Seifert H.P., Ritter S.
"Stress Corrosion Cracking of Low-Alloy Reactor Pressure Vessel Steels under Boiling Water Reactor Conditions", J. Nucl. Mater. (ISSN 0022-3115), **372**(1), 114-131 (2008)

Seifert H.P., Ritter S.
"Strain-Induced Corrosion Cracking Behaviour of Low-Alloy Steels under Boiling Water Reactor Conditions", J. Nucl. Mater. (ISSN 0022-3115), **378**(3), 312-326 (2008)

Seifert H.P., Ritter S.
"Corrosion Fatigue Crack Growth Behaviour of Low-Alloy Reactor Pressure Vessel Steels under Boiling Water Reactor Conditions", Corros. Sci. (ISSN 0010-938X), **50**(7), 1884-1899 (2008)

Seifert H.P., Ritter S., Shoji T.[1], Peng Q.[1], Takeda Y.[1], Lu, Z.P. [1]
"Environmentally-Assisted Cracking Behaviour in the Transition Region of an Alloy 182/SA 508 Cl.2 Dissimilar Metal Weld Joint in Simulated Boiling Water Reactor Normal Water Chemistry Environment", J. Nucl. Mater. (ISSN 0022-3115), **378**, 197-210 (2008)

Smith B.L.
"Topical Issue on CFD4NRS", Nucl. Eng. Des. (ISSN 0029-5493), **238**(3), 443-444 (2008)

Smith, B.L., Dury, T.V., Ni, L., Zucchini, A.[1]
"Computational Fluid Dynamic Studies of the MEGAPIE Spallation Source Target and Safety Vessel", J. Nucl. Sci. Technol., **45**(12), 1334–1346 (2008)
[1] ENEA, Bologna, IT

Smith B.L., Shepel S.V.
"Heat Transfer Issues Associated with a Hypothetical Failure of the MEGAPIE Spallation Source Target Window", Nucl. Technol. (ISSN 0029-5450), **164**, 385-409 (2008)

Van der Veen R.[1], Milne C.[1], Pham V.[1], El Nahhas A.[1], Weinstein J.[2], Best J.[2], Borca C., Bressler C.[1], Chergui M.[3]
"EXAFS structural determination of the Pt2(P2O5H2)44– anion in solution", Chimia (ISSN 0009-4293), 62(4), 287-290 (2008)
[1] EPFL, Lausanne, CH
[2] University of Sheffield, UK

Van Engen Spivey A.[1], Borca C., Cundiff S.[2]
"Correlation coefficient for dephasing of light-hole excitons and heavy-hole excitons in GaAs quantum wells", Solid State Commun. (ISSN 0038-1098), **145**, 303-307 (2008)
[1] University of Puget Sound, Washington, US
[2] University of Colorado, US

Van Loon L.R., Glaus M.
"Mechanical compaction of smectite clays increases selectivity for cesium", Environ. Sci. Technol. (ISSN 0944-1344), **42**, 1600-1604 (2008)

Vargas A.[1], Santarossa G.[1], Iannuzzi Mauri M., Baiker A.[1]
"Chiral Recognition on Catalytic Surfaces: Theoretical Insight in a Biomimetic Heterogeneous Catalytic System", J. Phys. Chem. C (ISSN 1932-7447), **112**, 10200-10208 (2008)
[1] ETHZ, Zurich, CH

Vasiliev A., Ferroukhi H., Zimmermann M.A., Chawla R.
"On the effects of oxygen cross-sections in the fast neutron fluence analysis for a reactor pressure vessel scraping test", Ann. Nucl. Energy (ISSN 0306-4549), **35**, 565-569 (2008)

Vasiliev A., Kolbe E., Ferroukhi H., Zimmermann M.A., Chawla R.
"On the performance of ENDF/B-VII.0 data for fast neutron fluence calculations", Ann. Nucl. Energy (ISSN 0306-4549), **35**, 2432-2435 (2008)

Vasiliev A., Kolbe E., Zimmermann M.A.
"Towards the development of upper subcriticality limits on the basis of benchmark criticality calculations", Ann. Nucl. Energy (ISSN 0306-4549), **35**, 1764-1773 (2008)

Wenk H.[1], Voltolini M.[1], Mazurek M.[2], Van Loon L.R., Vinsot A.[3]
"Preferred orientations and anisotropy in shales: Callovo-Oxfordian shale (France) and Opalinus Clay (Switzerland)", Clays Clay Miner. (ISSN 0009-8604), **56**, 285-306 (2008)
[1] UCB, Berkeley, US
[2] University of Berne, CH
[3] ANDRA, Bure, FR

Wersin P.[1], Soler J.[2], Van Loon L.R., Eikenberg J., Baeyens B., Grolimund D., Gimmi T., Dewonck S.[3]
"Diffusion of HTO, Br^-, I^-, Cs^+ and $^{60}Co^{2+}$ in a clay formation: results and modelling from an in-situ experiment in Opalinus Clay", Appl. Geochem. (ISSN 0883-2927), **23**, 678-691 (2008)
[1] NAGRA, Wettingen, CH
[2] CSIC-IJA, Barcelona, ES
[3] ANDRA, Bure, FR

Wieland E., Tits J., Kunz D., Dähn R.
"Strontium uptake by cementitious materials: a

combined wet chemistry and EXAFS study", Environ. Sci. Technol. (ISSN 0944-1344), **42**, 403-409 (2008)

Wiltzius J.[1], Sievers S.[1], Sawaya M.[1], Cascio D.[1], Popov D., Riekel C.[2], Eisenberg D.[1]
"Atomic structure of the cross-beta spine of islet amyloid polypeptide (amylin)", Protein Sci. (ISSN 0961-8368), **17**, 1467-1474 (2008)
[1] Howard Hughes Medical Institute, Los Angeles, US
[2] ESRF, Grenoble, FR

Yadigaroglu G.[1], Simiano M., Milenkovic R., Kubasch J., Milelli M., Zboray R., de Cachard F., Smith B.L., Lakehal D.[1], Sigg B.
"CFD4RNS with a focus on experimental and CMFD investigations of bubbly flows", Nucl. Eng. Des. (ISSN 0029-5493), **238**(3), 771-785 (2008)
[1] ASCOMP, Zurich, CH

Yagnik S.K.[1], Ramasubramanian N.[2], Grigoriev N.[3], Sainte-Catherine C.[4], Bertsch J., Adamson R.[5], Kuo R.[6], Mahmood S.[7], Fukuda T.[8], Efsing P.[9], Oberländer B.[10]
"Round-Robin Testing of Fracture Toughness Characteristics of Thin-Walled Tubing", J. ASTM International (ISSN 1546-962X), **5**(2), JAI101140, 21 pages (2008)
[1] EPRI, Palo Alto, US
[2] Eccatec Inc., Scarborough, CA
[3] Studsvik Nuclear AB, Nyköping, SE
[4] CEA, Saclay, FR
[5] Zircology Plus, Fremont, US
[6] INER, Lung-Tan, KR
[7] Global Nuclear Fuel, San Jose, US
[8] Nuclear Fuel Industries, Osaka, JP
[9] Ringhals AB, Varberg, SE
[10] Institute for Energy Technology (IFE), Kjeller, NO

Yaroschchuk A.[1], Glaus M., Van Loon L.R.
"Diffusion through confined media at variable concentrations in reservoirs", J. Membr. Sci. (ISSN 0376-7388), **319**, 133-140 (2008)
[1] University of Catalonia, Barcelona, ES

Yaroschchuk A.[1], Van Loon L.R.
"Improved interpretation of in-diffusion measurements with confined swelling clays", J. Contam. Hydrol. (ISSN 0143-974X), **97**, 67-74 (2008)
[1] University of Catalonia, Barcelona, ES

Keynote Lectures at International Conferences

Smith B.L.
"Numerical Modelling of Turbulent Heat Transfer in Liquid Metals", Keynote Lecture, 7th Int. Symp. on Heat Transfer, 26-29 October 2008, Beijing, China, CD-ROM, 2008

International Conferences with Proceedings

Albiol T.[1], Haste T., Van Dorsselaere J.[1], Journeau C.[2], Meyer L.[3], Chaumont B.[4], Sehgal B.[5], Schwinges B.[6], Beraha D.[6], Annunziato A.[7], Zeyen R.[7]
"Summary of SARNET achievements", 3rd Eur. Review Meeting of Severe Accident Research (ERMSAR-2008), 23-25 September 2008, Nesseber, Bulgaria, CD-ROM, 2008
[1] IRSN, Cadarache, FR
[2] CEA, Grenoble, FR
[3] FZK, Karlsruhe, DE
[4] CEA, Cadarache, FR
[5] KTH, Stockholm, SE
[6] GRS, Garching, DE
[7] EC-JRC/ISIS, Ispra, IT

Albiol T.[1], Van Dorsselaere J.[1], Chaumont B.[2], Haste T., Journeau C.[3], Meyer L.[4], Sehgal B.[5], Schwinges B.[6], Beraha D.[6], Annunziato A.[7], Zeyen R.[7]
"SARNET: Severe Accident Research Network of Excellence", Paper A1-013, TOPSAFE, 30 Sept.–3 Oct. 2008, Dubrovnik, Croatia, CD-ROM, 2008
[1] IRSN, Cadarache, FR
[2] CEA, Cadarache, FR
[3] CEA, Grenoble, FR
[4] FZK, Karlsruhe, DE
[5] KTH, Stockholm, SE
[6] GRS, Garching, DE
[7] EC-JRC/ISIS, Ispra, IT

Albiol T.[1], Van Dorsselaere J.[1], Tromm W.[2], Journeau C.[3], Kljenak I.[4], Haste T.
"Status of SARNET 2", 3rd Eur. Review Meeting of Severe Accident Research (ERMSAR-2008), 23-25 September 2008, Nesseber, Bulgaria, CD-ROM, 2008
[1] IRSN, Cadarache, FR
[2] FZK, Karlsruhe, DE
[3] CEA, Grenoble, FR
[4] JSI, Ljubljana, SI

Andreani M., Paladino D., George T.[1]
"Simulation of Basis Gas Mixing Tests with Condensation in the PANDA Facility using the GOTHIC Code", 16th Int. Conf. on Nucl. Eng. (ICONE-16), 11-15 May 2008, Orlando, USA, CD-ROM, 2008
[1] Numerical Applications Inc., Richland, US

Auvinen A.[1], Brillant G.[2], Colombani J.[3], Davidovich N.[3], Dickson R.[4], Ducros G.[5], Giordano P.[2], Haste T., Holm J.[6], Kärkela T.[7], Lamy J.S.[8], Mun C.[2], Ohai D.[9], Pontillon Y.[10], Steinbrück M.[10], Vér N.[11]
"Ruthenium Behaviour under Air Ingress Conditions: Main Achievements in the SARNET Project", 3rd Eur. Review Meeting of Severe Accident Research

(ERMSAR-2008), 23-25 September 2008, Nesseber, Bulgaria, CD-ROM, 2008
[1] VTT Energy, Espoo, FI
[2] IRSN, Cadarache, FR
[3] Ente per le nuove Tecnologie, Bologna, IT
[4] AECL, Ottawa, CA
[5] CEA, Cadarache, FR
[6] Chalmers University of Technology, Gotheburg, SE
[7] VTT, Helsinki, FI
[8] EDF, France, FR
[9] INRNE, Sofia, RO
[10] FZK, Karlsruhe, DE
[11] KFKI, Budapest, HU

Bertolotto D., Manera A., Prasser H.-M., Chawla R.
"CFD simulations of a single-phase mixing experiment", Int. Youth Nucl. Congr. (IYNC-2008), 20-26 September 2008, Interlaken, Switzerland, CD-ROM, 2008

Bertolotto D., Manera A., Smith B.L., Prasser H.-M., Chawla R.
"Single-phase mixing studies by means of a directly coupled CFD/system-code tool", Int. Conf. on the Physics of Reactors (PHYSOR'08), 14-19 September 2008, Interlaken, Switzerland, CD-ROM, 2008 (ISBN 978-3-9521409-5-6)

Birchley J., Austregesilo H.[1], Bals C.[1], Dubourg R.[2], Haste T., Lamy J.S.[3], Lind T., Maliverney B.[3], Marchetto C.[2], Pinter A.[4], Steinbrück M.[5], Stuckert J.[5], Trambauer K.[1]
"Post-Test Analysis of the QUENCH-13 Experiment", Nuclear Energy for New Europe (NENE 2008), 8-11 September 2008, Portoroz, Slovenia, CD-ROM, 2008
[1] GRS, Garching, DE
[2] IRSN, Cadarache, FR
[3] EDF, Clamart, FR
[4] KFKI, Budapest, HU
[5] FZK, Karlsruhe, DE

Birchley J., Haste T., Jaeckel B.S.
"Preliminary assessment of MELCOR1.8.6 using integral data", 14th Int. QUENCH Workshop, 4-6 November 2008, Karlsruhe, Germany, CD-ROM, 2008

Birchley J., Haste T., Jaeckel B.S.
"PSI Analytical Support for QUENCH-14", 14th Int. QUENCH Workshop, 4-6 November 2008, Karlsruhe, Germany, CD-ROM, 2008

Blanchet D., Pelloni S., Coddington P., Mikityuk K.
"Analysis of reactivity insertion transients in the ETDR – a small Gas-Cooled Fast Reactor", Int. Conf. on the Physics of Reactors (PHYSOR'08), 14-19 September 2008, Interlaken, Switzerland, CD-ROM, 2008 (ISBN 978-3-9521409-5-6)

Coindreau O.[1], Bals C.[2], Birchley J., Haste T., Hollands T.[3], Koch M.[3], Trambauer K.[2]
"Modelling of Accelerated Cladding Degradation in Air for Severe Accident Codes", 3rd Eur. Review Meeting of Severe Accident Research (ERMSAR-2008), 23-25 September 2008, Nesseber, Bulgaria, CD-ROM, 2008
[1] IRSN, Cadarache, FR
[2] GRS, Garching, DE
[3] RUB, Bochum, DE

Dreier J., Paladino D., Huggenberger M., Andreani M., Yadigaroglu G.[1]
"PANDA: a Large-Scale, Multi-Purpose Test Facility for LWR Safety Research", Int. Conf. on the Physics of Reactors (PHYSOR'08), 14-19 September 2008, Interlaken, Switzerland, CD-ROM, 2008 (ISBN 978-3-9521409-5-6)
[1] ASCOMP, Zurich, CH

Dubourg R.[1], Austregesilo H.[2], Bals C.[2], Barrachin M.[1], Birchley J., Haste T., Nagy I.[3], Lamy J.S.[4], Lind T., Maliverney B.[4], Marchetto C.[1], Pinter A.[3], Steinbrück M.[5], Stuckert J.[5], Trambauer K.[2], Vimi A.[3]
"Understanding the Behaviour of Absorber Elements in Silver-Indium-Cadmium Control Rods during PWR Severe Accident Sequences", 3rd Eur. Review Meeting of Severe Accident Research (ERMSAR-2008), 23-25 September 2008, Nesseber, Bulgaria, CD-ROM, 2008
[1] IRSN, Cadarache, FR
[2] GRS, Garching, DE
[3] KFKI, Budapest, HU
[4] EDF, France, FR
[5] FZK, Karlsruhe, DE

Dumaz P.[1], Epiney A., Alpy N.[1], Broxtermann P.[1], Malo J.[1], Tosello A.[1]
"Studies of Unprotected Transients and Alternative Decay Heat Removal System for the Gas-Cooled Fast Reactor (GFR)", Int. Congr. on Advanced Power Plants (ICAPP'08), 8-12 June 2008, Anaheim, USA, CD-ROM, 2008 (ISBN 0-89448-061-8)
[1] CEA, Cadarache, FR

Dury T.V., Dhotre M.
"Full-Size and Scaled 3-Loop Reactor Vessel Simulation for Boron Dilution Studies using CFD", Int. Congr. on Advanced Power Plants (ICAPP'08), 8-12 June 2008, Anaheim, USA, CD-ROM, 2008 (ISBN 0-89448-061-8)

Epiney A., Coddington P., Mikityuk K., Chawla R.
"New Analysis of the EIR GFR Thermal-Hydraulic Experiments", Int. Conf. on the Physics of Reactors (PHYSOR'08), 14-19 September 2008, Interlaken, Switzerland, CD-ROM, 2008 (ISBN 978-3-9521409-5-6)

Epiney A., Dumaz P.[1], Coddington P., Mikityuk K., Chawla R.
"Comparative transient analysis of the 2400 MWth GFR with the TRACE and CATHARE codes", Int. Conf. on the Physics of Reactors (PHYSOR'08), 14-19

September 2008, Interlaken, Switzerland, CD-ROM, 2008 (ISBN 978-3-9521409-5-6)
[1] CEA, Cadarache, FR

Ferroukhi H., Hofer K., Hollard J.M., Vasiliev A., Zimmermann M.A.
"Core Modelling and Analysis of the Swiss Nuclear Power Plants for Qualified R&D Applications", Int. Conf. on the Physics of Reactors (PHYSOR'08), 14-19 September 2008, Interlaken, Switzerland, CD-ROM, 2008 (ISBN 978-3-9521409-5-6)

Ferroukhi H., Hollard J.M., Zimmermann M.A., Chawla R.
"Estimation of the Fast Neutron Fluence at Control Rod Tips using a 3-D Diffusion/2-D Transport Calculation Scheme", Int. Conf. on the Physics of Reactors (PHYSOR'08), 14-19 September 2008, Interlaken, Switzerland, CD-ROM, 2008 (ISBN 978-3-9521409-5-6)

Ferroukhi H., Zerkak O., Chawla R.
"Comparative Study of CORETRAN and SIMULATE-3K for Main Steam Line Break Analyses", Int. Conf. on the Physics of Reactors (PHYSOR'08), 14-19 September 2008, Interlaken, Switzerland, CD-ROM, 2008 (ISBN 978-3-9521409-5-6)

Girardin G., Mikityuk K., Coddington P., Chawla R.
"A 3D full-core coupled thermal-hydraulics/kinetics TRACE/PARCS model of the 2400 MWth Generation IV Gas-Cooled Fast Reactor", Int. Conf. on the Physics of Reactors (PHYSOR'08), 14-19 September 2008, Interlaken, Switzerland, CD-ROM, 2008 (ISBN 978-3-9521409-5-6)

Giust F.[1], Grimm P., Jatuff F., Chawla R.
"Comparison of reconstructed radial pin total fission rates with experimental results in full-scale BWR fuel elements", Int. Conf. on the Physics of Reactors (PHYSOR'08), 14-19 September 2008, Interlaken, Switzerland, CD-ROM, 2008 (ISBN 978-3-9521409-5-6)
[1] NOK AG, Baden, CH

Grimm P., Murphy M., Jatuff F., Seiler R.
"Analysis of reactivity worths of highly-burnt PWR fuel samples measured in LWR-PROTEUS Phase II", Int. Conf. on the Physics of Reactors (PHYSOR'08), 14-19 September 2008, Interlaken, Switzerland, CD-ROM, 2008 (ISBN 978-3-9521409-5-6)

Guentay S., Dehbi A., Soldati A.[1], Deville M.[2]
"Direct Numerical Simulation of the Buoyancy-Driven Turbulence and Lagrangian Particle Tracking in a Cavity", Int. Conf. on Spectral and High Order Methods (ICOSAHOM07), 18-22 June 2007, Bejing, China, CD-ROM, 2008
[1] University of Udine, IT
[2] EPFL, Lausanne, CH

Gupta S., Paladino D., Benz P., Prasser H.-M.
"Experimental Analysis of Containment Atmosphere Mixing Stratification Induced by Vertical Fluid Release", 16th Int. Congr. on Nuclear Energy (ICONE-16), 11-15 May 2008, Orlando, USA, CD- ROM, 2008

Haste T., Birchley J., Klügel J.U.[1]
"Analysis of Station Blackout in the Gösgen Nuclear Plant", Int. Conf. on Advanced Power Plants (ICAPP'08), 8-12 June 2008, Anaheim, USA, CD-ROM, 2008 (ISBN 0-89448-061-8)
[1] KKG, Däniken, CH

Haste T., Birchley J., Lamy J.S.[1], Maliverney B.[1], Austregesilo H.[2], Bals C.[2], Trambauer K.[2], Steinbrück J.[3], Stuckert J.[3]
"Pre-Test Calculational Support for the QUENCH-13 Experiment", Int. Conf. on Advanced Power Plants (ICAPP'08), 8-12 June 2008, Anaheim, USA, CD-ROM, 2008 (ISBN 0-89448-061-8)
[1] EDF, France, FR
[2] GRS, Garching, DE
[3] FZK, Karlsruhe, DE

Herranz L.[1], Ball J.[2], Auvinen A.[3], Bottomely D.[4], Dehbi A., Housiadas C.[5], Piluso P.[6], Layly V.[7], Parozzi F.[8], Reeks M.[9]
"Progress in understanding key aerosol issues", 3rd Eur. Review Meeting of Severe Accident Research (ERMSAR), 23-25 September 2008, Nessebar, Bulgaria, CD-ROM, 2008
[1] CIEMAT, Madrid, ES
[2] AECL, Chalk River, CA
[3] VTT Energy, Espoo, FI
[4] JRC/ITU, Karlsruhe, DE
[5] NCSR, Athens, GR
[6] CEA, Cadarache, FR
[7] IRSN, Cadarache, FR
[8] IRSN, Fontenay-aux-Roses, FR
[9] University of Newcastle-upon-Tyne, UK

Hoffelner W., Samaras M., Bako B., Iglesias R.
"Materials Modelling – a Possible Design Tool for Advanced Nuclear Applications", Structural Materials for Innovative Nuclear Systems (SMINS), 4-6 June 2007, Karlsruhe, Germany, Vol. 1, 327-334, 2008 (ISBN 9789264048065)

Janssens K., Niffenegger M., Reichlin K.
"An Analysis of Cyclic Thermal Shock in Notched Ring Specimens", Materials Science & Technology 2008 Conf., 5-9 October 2008, Pittsburgh, USA, pp. 717-728, 2008

Jatuff F., Perret G., Murphy M., Grimm P., Seiler R., Chawla R.
"Impact of newly-measured gadolinium cross-sections on BWR fuel rod reaction rate distributions", Int. Conf. on the Physics of Reactors (PHYSOR'08),

14-19 September 2008, Interlaken, Switzerland, CD-ROM, 2008 (ISBN 978-3-9521409-5-6)

Joneja O.P., Perret G., Grimm P., Jatuff F., Chawla R.
"MCNP analysis of generic configurations in the context of the LIFE@PROTEUS experiments", Int. Conf. on the Physics of Reactors (PHYSOR'08), 14-19 September 2008, Interlaken, Switzerland, CD-ROM, 2008 (ISBN 978-3-9521409-5-6)

Kapulla R., Tuchtenhagen J.[1], Müller A.[1], Dullenkopf K.[1], Bauer H.-J.[1]
"Droplet Size Performance of Different Shadow Sizing Codes", Gala 16 Fachtagung, 9-11 September 2008, Karlsruhe, Germany, CD-ROM, 2008
[1] University of Karleruhe, DE

Khvostov G., Zimmermann M.A., Ledergerber G.[1], Kolstad E.[2], Montgomery R.[3]
"Parametric Study of the Behaviour of a Pre-Irradiated BWR Fuel Rod under Conditions of LOCA Simulated in the Halden In-Pile Test System with the FALCON Code", Water Reactor Fuel Performance Meeting (WRFPM 2008), 19-23 October 2008, Seoul, Korea, CD-ROM, 2008
[1] KKL, Leibstadt, CH
[2] Institute for Energy Technology, Halden, NO
[3] Anatech Corp., San Diego, US

Khvostov G., Zimmermann M.A., Stoenescu R., Ledergerber G.[1]
"Definition of optimal parameters of fuel rod design and test conditions for the high temperature LOCA experiment IFA-650.7 using the FALCON fuel behaviour code", Enlarged Halden Programme Group Meeting (EHPGM 2008), 18-23 May 2008, Loen, Norway, CD-ROM, 2008
[1] KKL, Leibstadt, CH

Khvostov G., Zimmermann M.A., Sugiyama T.[1], Fuketa T.[1]
"On the use of the FALCON code for modeling the behaviour of high burn-up BWR fuel during the LS-1 pulse-irradiation test", Int. Conf. on the Physics of Reactors (PHYSOR'08), 14-19 September 2008, Interlaken, Switzerland, CD-ROM, 2008 (ISBN 978-3-9521409-5-6)
[1] JAEA, Tokai-mura, JP

Kim T.W.
"Effect of Longitudinal Pitch on the Heat Transfer Characteristics of Aligned Tube Banks in Crossflow", 7th Int. Topical Meeting on Nuclear Reactor Thermal Hydraulics, Operation and Safety (NUTHOS-7), 5-9 October 2008, Seoul, Korea, CD-ROM, 2008

Krepel J., Pelloni S., Mikityuk K.
"Equilibrium cycle analysis of a Gas-Cooled Fast Reactor with the EQL3D procedure", Int. Conf. on the Physics of Reactors (PHYSOR'08), 14-19 September 2008, Interlaken, Switzerland, CD-ROM, 2008 (ISBN 978-3-9521409-5-6)

Kröhnert H., Murphy M., Perret G., Plaschy M.[1], Wagemans J.[2], Chawla R.
"Measurement of fission rate ratios in fresh UO_2 fuel utilising short-lived high-energy gamma activity", Int. Conf. on the Physics of Reactors (PHYSOR'08), 14-19 September 2008, Interlaken, Switzerland, CD-ROM, 2008 (ISBN 978-3-9521409-5-6)
[1] EOS, Lausanne, CH
[2] SCK, Mol, BE

Leber H., Tirbonod B., Niffenegger M., Ramesh M.
"Micro- and short crack network evolution during LCF in different austenitic stainless pipe steels", 6th Int. Conf. on Low Cycle Fatigue (LCF), 8-12 September 2008, Berlin, Germany, pp. 623-628, 2008

Liao Y., Vierow K.[1], Han J.[2]
"MELCOR validation against a PUMA facility Main Steam Line Break integral test", Int. Conf. on Advanced Power Plants (ICAPP'08), 8 - 12 June 2008, Anaheim, USA, CD-ROM, 2008 (ISBN 0-89448-061-8)
[1] Texas A&M University, College Station, US
[2] US NRC, Rockville, US

Niceno B., Smith B.L., Prasser H.-M.
"Computational Fluid Dynamics (CFD) as a Tool for Prediction of Thermal Fatique in T-junctions", TOPSAFE, 1-3 October 2008, Dubrovnik, Croatia, CD-ROM, 2008 (ISBN 978-92-9506-06-5)

Paladino D., Huggenberger M., Andreani M., Guentay S., Dreier J., Prasser H.-M.
"LWR Containment Safety Research in PANDA", Int. Conf. on Advanced Power Plants Int. Congr. on Advanced Power Plants (ICAPP'08), 8-12 June 2008, Anaheim, USA, CD-ROM, 2008 (ISBN 0-89448-061-8)

Pelloni S., Krepel J., Mikityuk K.
"EQL3D: methodology for simulation of equilibrium cycle for Advanced Fast Reactors", Int. Conf. on the Physics of Reactors (PHYSOR'08), 14-19 September 2008, Interlaken, Switzerland, CD-ROM, 2008 (ISBN 978-3-9521409-5-6)

Perret G., Murphy M., Jatuff F., Chawla R.
"Fission-rate distribution at the 84-pin radial section of a SVEA-96 Optima2 BWR assembly", Int. Conf. on the Physics of Reactors (PHYSOR'08), 14-19 September 2008, Interlaken, Switzerland, CD-ROM, 2008 (ISBN 978-3-9521409-5-6)

Petkevic P., Mikityuk K., Coddington P., Chawla R.
"GFR transient analysis employing a 2D thermomechanical model for the plate-type fuel", Int. Conf. on the Physics of Reactors (PHYSOR'08), 14-19 September 2008, Interlaken, Switzerland, CD-ROM, 2008 (ISBN 978-3-9521409-5-6)

Pfingsten W.
"The influence of the experimental set-up and the model approach on the determination of diffusion coefficients for radionuclides in laboratory column experiments", in J.C. Refsgaard, K. Kovar, E. Haarder and E. Nygaard (eds.), Calibration and Reliability in Groundwater Modelling: Credibility of Modelling. IAHS Publication No. 230, 9-13 September 2007, Wallingford, United Kingdom, Vol. 320, pp. 278-283, 2008 (ISBN 978-1-901502-49-7)

Poette C.[1], Brun-Magaud V.[1], Morin F.[1], Dor I.[1], Pignatela J.F.[1], Bertrand F.[1], Stainsby R.[2], Pelloni S., Every D.[3], Da Cruz D.[4]
"ETDR, The European Union's Experimental Gas-Cooled Fast Reactor Project", Int. Conf. on the Physics of Reactors (PHYSOR'08), 14-19 September 2008, Interlaken, Switzerland, CD-ROM, 2008 (ISBN 978-3-9521409-5-6)
[1] CEA, Cadarache, FR
[2] AMEC NCC Ltd., Knutsford, UK
[3] Nexia Solution LTD., Preston, US
[4] NRG, Petten, NL

Pouchon M.A., Froideval A., Degueldre C., Gavillet D., Hoffelner W.
"Synchrotron Light Techniques for the Investigation of Advanced Nuclear Reactor Structural Materials", Structural Materials for Innovative Nuclear Systems (SMINS), 4-6 June 2007, Karlsruhe, Germany, Vol. 1, 291-301, 2008 (ISBN 978-92-64-04806-5)

Proff C., Abolhassani-Dadras S., Dadras M.[1]
"In situ oxidation of zirconium binary alloys", Eur. Corrosion Congr. (EUROCORR 2008), 7-11 September 2008, Edinburgh, UK, CD-ROM, 2008
[1] University of Neuchâtel, CH

Repetto G.[1], Birchley J., Drath T.[2], Austregesilo H.[3]
"Progress on B4C Modeling in Severe Accident Codes in the Frame of SARNET Network of Excellence – Application to Phébus and QUENCH experiments", 3rd Eur. Review Meeting on Severe Accident Research (ERMSAR-2008), 23-25 September 2008, Nesseber, Bulgaria, CD-ROM, 2008
[1] IRSN, Cadarache, FR
[2] Ruhr-University of Bochum, DE
[3] GRS, Garching, DE

Richner M.[1], Zimmermann S.[1], Birchley J., Haste T.
"Realistic Evaluation of Shutdown Risk", Particulate System Analysis (PSA2008), 7-11 September 2008, Knoxville, USA, CD-ROM, 2008
[1] NOK AG, Baden, CH

Ritter S., Seifert H.P.
"Detection of Stress Corrosion Cracking by the Electrochemical Noise Technique under Simulated BWR Conditions – Preliminary Results", Annual Meeting of the International Co-operative Group on Environmentally-Assisted Cracking of Water Reactor Materials, 20-25 April 2008, Bastad, Sweden, CD-ROM, 2008

Ritter S., Seifert H.P.
"Detection of SCC Initiation by EN Measurements in Thiosulphate Solution at Room Temperature", 4th Eur. Cooperative Group on Corrosion Monitoring of Nucl. Materials (ECG-COMON) Meeting, 16-17 June 2008, Villigen, Switzerland, CD-ROM, 2008

Ritter S., Seifert H.P.
"Detection of Stress Corrosion Cracking in Simulated BWR Environment by Combining the Electrochemical Noise and DCPD Technique", Eur. Corrosion Congr. (EUROCORR 2008), 7-11 September 2008, Edinburgh, UK, CD-ROM, 2008

Ritter S., Seifert H.P.
"Corrosion Fatigue Crack Growth Behaviour of Austenitic Stainless Steels under Simulated LWR Conditions", 17th Int. Corrosion Congr.: Corrosion Control in the Service of Society, 6-10 October 2008, Las Vegas, USA, CD-ROM, 2008

Stuckert J.[1], Birchley J., Grosse M., Haste T., Sepold L.[1], Steinbrück J.[1]
"Experimental and Post-Test Calculation Results of the Integral Reflood Test QUENCH-12 with a VVER-Type Bundle", Int. Congr. on Advanced Power Plants (ICAPP'08), 8-12 June 2008, Anaheim, USA, CD-ROM, 2008 (ISBN 0-89448-061-8)
[1] FZK, Karlsruhe, DE

Suckow D., Guentay S.
"The DRAGON Aerosol Research Facility to Study Aerosol Behavior for Reactor Safety Applications", Int. Conf. on the Physics of Reactors (PHYSOR'08), 14-19 September 2008, Interlaken, Switzerland, CD-ROM, 2008 (ISBN 978-3-9521409-5-6)

Tits J., Fujita T.[1], Tsukamoto M.[1], Wieland E.
"Uranium(VI) uptake by synthetic calcium silicate hydrates", in: W.E. Lee, J.W Roberts, N.C. Hyatt, R.W. Grimes (eds.), Scientific Basis for Nuclear Waste Management XXXI. Materials Research Soc. (MRS), 16-21 September 2007, Sheffield, UK, Vol. 1107, 467-474, 2008 (ISBN 978-1-60511-079-0)
[1] JNC, Tokai, JP

Van Uffelen P.[1], Schubert A.[1], van de Laar J.[1], Gyori C.[1], Elenkov D.[2], Boneva S.[3], Georgieva M.[3], Georgiev S.[3], Hozer Z.[4], Märtens D.[5], Spykman G.[5], Hellwig C., Nordstroem A.L., Luzzi L.[6], Di Marcello V.[6], Abela R., Ott L.[7]
"Verification of the Transuranus Fuel Performance Code – an Overview", 7th Int. Conf. on WWER Fuel Performance, Modelling and Experimental Support, 17-21 September 2007, Varna, Bulgaria, CD-ROM, 2008

[1] JRC/ITU, Karlsruhe, DE
[2] Aachen University of Technology, DE
[3] Bulgarien Academy of Science, Sofia, BG
[4] KFKI, Budapest, HU
[5] TÜV NORD, Hannover, DE
[6] Politecnico, Milan, IT
[7] ORNL, Oak Ridge, US

Vasiliev A., Ferroukhi H., Kolbe E., Zimmermann M.A.
"On the use of importance factors from Monte-Carlo calculations for efficient fast-neutron fluence predictions", Int. Conf. on the Physics of Reactors (PHYSOR'08),14-19 September 2008, Interlaken, Switzerland, CD-ROM, 2008 (ISBN 978-3-9521409-5-6)

Vinai P., Macian-Juan R.[1], Chawla R.
"Propagation of void fraction uncertainty measures in the RETRAN-3D simulation of the Peach Bottom turbine trip", Int. Conf. on the Physics of Reactors (PHYSOR'08),14–19 September 2008, Interlaken, Switzerland, CD-ROM, 2008 (ISBN 978-3-9521409-5-6)
[1] TUM, Garching, DE

Zerkak O., Ferroukhi H.
"Effects of the core inlet mixing modelling on a Main-Steam-Line-Break analysis at hot full power", Int. Conf. on the Physics of Reactors (PHYSOR'08),14-19 September 2008, Interlaken, Switzerland, CD-ROM, 2008 (ISBN 978-3-9521409-5-6)

Zhao Z.[1], Ramesh M., Raabe D.[2], Cuitiño A.[3], Raddovitzky R.[1]
"Grain-scale roughness in ductile polycrystals", 8th World Congr. on Computational Mechanics (WCCM8), 30 June – 4 July 2008, Venice, Italy, CD-ROM, 2008
[1] MIT, Cambridge, US
[2] Max-Planck-Institut, München, DE
[3] Rutgers University, Piscataway, US

Talks delivered at Conferences, Workshops and Specialist Meetings (without Proceedings)

Abolhassani-Dadras S.
"Nanoscale conductivity measurement of semi-conducting metal-oxide interface", 14th Eur. Microscopy Congr., Aachen, Germany, 1-5 September 2008

Alam A.
"Study of Hydride Behavior and Damage in Fuel Cladding Tubes at Paul Scherrer Institute, Switzerland", PSI-CEA Meeting on Nuclear Fuel Cladding Mechanical Behavior, CEA, Saclay, France, 28 March 2008

Bako B.
"Depinning transition of a dislocation line in ferritic oxide strengthened steels", Eur. Materials Research Soc. (E-MRS), Strasbourg, France, 21-25 May 2008
[1] University of Stuttgart, DE

Bako B.
"Modeling of microstructure evolution in nuclear applications", 4th Int. Conf. on Multiscale Materials Modelling (MMM2008), Tallahassee, USA, 27-31 October 2008

Berg T.[1], Bredberg J.[1], Suckow D.
"CFD Simulation of ARTIST Break Stage and Comparisons with Measured Data", ANS Annual Meeting, Anaheim, USA, 8-12 June 2008
[1] Epsilon High Tech, Göteburg, SE

Bertsch J.
"Nuclear Fuels Research at PSI", PSI-CEA Meeting on Nuclear Fuel Cladding Mechanical Behavior, CEA, Saclay, France, 28 March 2008

Bertsch J.
"Mechanical Integrity Testing of Fuel Claddings", GRS Project and Workshop on Structural and Release Behaviour of LWR High-Burnup Fuel under Transport Accident Conditions, Gesellschaft für Reaktorsicherheit (GRS), Hanover, Germany, 4–5 December 2008

Borca C., Grolimund D., Willimann M., Meyer B., Maass R., Van Petegem S., Van Swygenhoven H., Farges F.[1], Van Hullebusch E.[2], Lenz M.[2], Lens P.[2], Farquharson M.[3], Froideval A.
"The μXAS beamline: a multitechnique hard X-ray microprobe station at the Swiss Light Source", X-ray Microscopy Conf., Zurich, Switzerland, 21-25 July 2008
[1] CNRS UMR, Paris, FR
[2] University Wageningen, NL
[3] City University, London, UK

Bredberg J.[1], Berg T.[1], Dehbi, A.
"Numerical Modeling of Flow in Dry Secondary Side of Steam Generator", ANS Annual Meeting, Anaheim, USA, 8-12 June 2008
[1] Epsilon High Tech, Göteburg, SE

Bressler C.[1], Grolimund D.
"The Bermuda Triangle of XAS Analysis. X-ray Spectroscopies: Theory and Experiment", Life Cycle Systems Group (ENAC-GECOS), EPFL, Lausanne, Switzerland, 30 January - 1 February 2008
[1] EPFL, Lausanne, CH

Bruna G.[1], Scott-de-Martinville E.[1], Storey P.[2], Teschendorff V.[3], Zimmermann M.A.
"The Safety Research in the European Strategic Research Agenda (SRA) of the Sustainable Nuclear Energy Technology Platform (SNE-TP)", EUROSAFE: Towards Convergence of Technical Nuclear Safety Practices in Europe, Paris, France, 3-4 November 2008

[1] IRSN, Cadarache, FR
[2] HSE, Bootle, UK
[3] GRS, Garching, DE

Budai J.[1], Larson B.[1], Ice G.[1], Liu W.[2], Rollett A.[3], Janssens K., Norton D.[4], Sartma D.[5], Shenoy G.[2]
"Submicron-resolution mapping of domains, texture and strain using X-ray micro-diffraction", 15th Int. Conf. on Textures of Materials (ICOTOM 15), The American Ceramic Society, Pittsburgh, USA, 1-6 June 2008
[1] ORNL, Oak Ridge, US
[2] ANL, Argonne, US
[3] Carnegie Mellon University, Pittsburgh, US
[4] University of Florida, Orlando, US
[5] Indian Institute of Science, Bangalore, IN

Cammelli S., Degueldre C., Kuri G., Bertsch J., Lützenkirchen-Hecht D.[1], Frahm R.[1]
"Study of atomic clusters in neutron irradiated reactor pressure vessel surveillance samples by extended X-ray absorption fine structure spectroscopy", Eur. Materials Research Soc. (E-MRS), Strasbourg, France, 21-25 May 2008
[1] BUGH, Wuppertal, DE

Chawla R.
"Nouvelle spécialité d'études de master 'Nuclear Engineering': un diplôme conjoint de l'EPFL et de l'ETHZ", 50 Jahre Nuklearforum Schweiz, Invited Talk, Nuklearforum Schweiz, Lausanne, Switzerland, 29 May 2008

Chen J.C., Pouchon M.A., Hoffelner W.
"Revisiting Irradiation Creep", XVIIIth Int. Conf. on Physics of Radiation Phenomena and Radiation Material Science, National Academy of Sciences of Ukraine, Alushta, Ukraine, 8-13 September 2008

Churakov S.
"Ab initio modelling of crystalline cement phases", Laboratory of Construction Materials, Invited Talk, EPFL, Lausanne, Switzerland, 15 May 2008

Churakov S.
"Structure of cement phases from ab initio modelling", 2nd Int. Workshop on Mechanisms and Modelling of Waste/Cement Interactions, Le Croisic, France, 12-16 October 2008

Dähn R.
"Determination of the speciation of radionuclides in cementitious materials by STXM and EXAFS", Invited Talk, 5th Workshop on Speciation, Techniques and Facilities for Radioactive Materials at Synchrotron Light Sources. Actinide XAS 2008, Saint-Aubin, France, 15-17 July 2008

Dähn R., Vespa M., Shuh D.[1], Tyliszczak T.[1], Wieland E.
"Spectromicroscopic Investigation of Metal Precipitate Formation in Nuclear Waste Repository Materials", 7th Int. Conf.on Nuclear and Radiochemistry, Budapest, Hungary, 24-29 August 2008
[1] LBNL, Berkeley, US

Degueldre C.
"Introducing the challenges of the nuclear materials symposium", Eur. Materials Research Soc. (E-MRS), Strasbourg, France, 21-25 May 2008

Degueldre C., Kuri G., Froideval A., Borca C., Gavillet D.
"Tracking irradiation effects in the bulk of reactor structural materials: an XAFS approach", Eur. Materials Research Soc. (E-MRS), Strasbourg, France, 21-25 May 2008

Degueldre C., Kuri G., Froideval A., Cammelli S., Pouchon M.A., Bertsch J.
"Advanced synchrotron radiation studies on nuclear materials at LNM", XAS-Meeting, PSI, Villigen, Switzerland, 7-8 October 2008

Dehbi A., Suckow D., Guentay S.
"Results from the ARTIST Flooded Bundle Tests", ANS Annual Meeting, Anaheim, USA, 8-12 June 2008

Dilnesa B.[1], Lothenbach B.[1], Wieland E., Ulrich A.[1]
"Solubility of Fe-containing hydrates", 2nd Int. Workshop on Mechanisms and Modelling of Waste/Cement Interactions, Le Croisic, France, 12-16 October 2008
[1] EMPA, Dübendorf, CH

Freixa J.[1], Manera A., Zerkak O.
"Post-Test Thermal-Hydraulic Analysis of ROSA Test 6.1 using TRACE", Code Assessment and Maintenance Meeting (CAMP) SPRING'08 Meeting, Pisa, Italy, 28-30 May 2008
[1] Politechnic University of Catalonia, Barcelona, ES

Froideval A.
"New advanced analytical methods for materials science", Deutsche Gesellschaft für Materialkunde – Fach-ausschuss Strahllinien, Deutsche Gesellschaft für Materialkunde e.V., Karlsruhe, Germany, 31 May 2008

Froideval A., Abolhassani-Dadras S., Gavillet D., Grolimund D., Borca C., Krbanjevic J., Degueldre C.
"Micro-spectroscopic investigations of a Zr-Nb cladding irradiated in a Pressurized Water Reactor", Eur. Materials Research Soc. (E-MRS), Strasbourg, France, 21-25 May 2008

Froideval A., Samaras M., Iglesias R., Pouchon M.A., Chen J.C., Grolimund D., Raabe J., Schuppler S.[1], Victoria M., Hoffelner W.
"Application of synchrotron radiation techniques for modeling/validation of advanced structural

materials", Materials Science and Engineering Conf. (MSE 08), Nürnberg, Germany, 1-4 Sept. 2008
[1] FZK, Karlsruhe, DE

Gavillet D.
"Quantification of the surface porosity in high burn-up fuel using image analysis tools", 45th Annual Meeting 'Hot Laboratories and Remote Handling', Kendal, UK, 22-23 September 2008

Gimmi T.
"Investigating transport through Opalinus Clay: laboratory and field activities", Int. Symp. on Computational and Experimental Methods for Processes in Deep Geological Environment, Invited Talk, Okayama, Japan, 18 January 2008

Grolimund D., Borca C., Gavillet D., Wieland E., Froideval A., Meyer B., Willimann M.
"Beaming in on radioactive materials: the micro-XAS beamline project at the Swiss Light Source", Invited Talk, 5th Workshop on Speciation, Techniques and Facilities for Radioactive Materials at Synchrotron Light Sources, (Actinide XAS 2008), Saint-Aubin, France, 15-17 July 2008

Grolimund D., Borca C., Meyer B., Willimann M.
"Micro-XAS Beamline Project: Beauty or Beast?", Int. Workshop on Hard X-ray Micro/Nano probe at PETRA III, HASYLAB/DESY, Invited Talk, Hamburg, Germany, 22-23 January 2008

Guentay S., Dehbi A., Suckow D.
"Introduction to the ARTIST Program", ANS Annual Meeting, Anaheim, USA, 8-12 June 2008

Günther-Leopold I.
"Kernbrennstoffe: vom Erz zum Brennstoffpellet", Vertiefungskurs "Kernbrennstoffe – Wirtschaftlichkeit und Versorgungssicherheit", Nuklearforum Schweiz, Olten, Switzerland, 20-21 November 2008

Hogan K.[1], Liao Y., Beeny B.[1], Vierow K.[1]
"Implementation of a New Diffusion Layer Model for Condensation with Non-condensable Gases into MELCOR", Cooperative Severe Accident Research Program (CSARP) and MELCOR Code Assessment Program (MCAP) Technical Review Meetings, Texas A&M University, Bethesda, USA, 16-19 September 2008
[1] Texas A&M University, College Station, US

Hummel W.
"Recent and prospective developments of the Nagra/PSI database", Séminaire Spéciation: Journées d'information CETAMA, Invited Talk, Montpellier, France, 22-23 January 2008

Janssens K., Niffenegger M., Reichlin K.
"Progress Report on Experimental Analysis and Finite Element Modeling of Cyclic Thermo-Mechanical Shock Loading in 316L Stainless Steel using Mixed Isotropic-Kinematic Hardening", 12th Int. Spring Meeting on Fatigue and Plasticity: from Mechanisms to Design, Société Francaise de Métallurgie et de Matériaux, Paris, France, 20-22 May 2008

Janssens K., Niffenegger M., Reichlin K.
"An Analysis Of Cyclic Thermal Shock in Notched Ring Specimens", Materials Science & Technology 2008 Conf., The American Ceramic Society, Pittsburgh, USA, 5-9 October 2008

Kapulla R., Danner S., Guentay S.
"Droplet Retention and Velocity Field in a Steam Generator", ANS Annual Meeting, Anaheim, USA, 8-12 June 2008

Kapulla R., Trautmann M., Guentay S.
"Quantitativer Vergleich von Wassertröpfchenmessungen mit einem Phasen-Doppler Anemometer und einer Schattenbildanalysemethode", Measurement 08, 20-21 February 2008, Göttingen, Germany, CD-ROM, 2008

Kivel N.
"Application of LA-MC-ICP-MS for the investigation of actinides in spent nuclear fuel", Working Group on Techniques and Standards for Destructive Analysis (WGDA) of the European Safeguards Research and Development Association (ESARDA) Workshop on Measurements of Minor Isotopes in Uranium, Institute for Reference Materials and Measurements (IRMM), Geel, Belgium, 10-11 April 2008

Kivel N.
"Determination of ^{60}Fe by MC-ICP-MS", Invited Talk, Appl. Math. Stat. (AMS) Seminar, Technical University of Munich, Garching, Germany, 19 November 2008

Kivel N., Kobler Waldis J., Wernli B., Günther-Leopold I.
"Determination of xenon isotope ratios in fission gas by MC-ICP-MS", 7th Int. SF-ICP-MS Conf., Rutgers University, New Brunswick, USA, 8-12 September 2008

Kobler Waldis J.
"Bestimmung der Xenon-Isotopenzusammensetzung mittels MC-ICP-MS", 8th Symp. über massenspektrometrische Verfahren der Elementspurenanalyse, Dresden, Germany, 17-19 September 2008

Kosakowski G., Jakob A.
"Modelling water and radionuclide transport in clays – results of a benchmark study", Int. Symp. on Computational and Experimental Methods for Processes in Deep Geological Environment, Invited Talk, Okayama, Japan, 18 January 2008

Krack M.
"Accelerating ab-initio molecular dynamics simulations", Invited Talk, Deutsches Zentrum für Luft- und Raumfahrt e.V., Cologne, Germany, 20 May 2008

Krack M.
"A Car-Parrinello-like Approach to Born-Oppenheimer MD: Method and Application", Thomas Young Seminar, Invited Talk, University College, London, UK, 20 August 2008

Kulik D.
"Improvement of the C-S-H solid solution model using recent spectroscopic and structural information", 2nd Int. Workshop on Mechanisms and Modelling of Waste/Cement Interactions, Invited Talk, Le Croisic, France, 12-16 October 2008

Kulik D., Berner U., Curti E., Hummel W., Thoenen T.
"Advanced solubility concepts and tools in geochemical modelling related to nuclear waste disposal", 13th Int. Symp. on Solubility Phenomena & Related Equilibrium Processes (ISSP), Invited Talk, Dublin, Ireland, 27-31 July 2008

Leupin O.[1], Dewonck S.[2], Savoye S.[3], Wersin P.[4], Van Loon L.R., Gimmi T., Samper J.[5], Soler J.[6], Eikenberg J., Baeyens B.
"Diffusion and retention experiment in clay formation: an international field, lab and modelling exercise", Goldschmidt Conf., Vancouver, Canada, 13-18 July 2008
[1] NAGRA, Wettingen, CH
[2] ANDRA, Bure, FR
[3] IRSN, Fontenay-aux-Roses, FR
[4] Gruner AG, Basel, CH
[4] University of La Coruna, ES
[5] CSIC-IJA, Barcelona, ES

Liao Y., Guentay S.
"Fission Product Release Boundary Conditions for a SGTR-Initiated Severe Accident", ANS Annual Meeting, Anaheim, USA, 8-12 June 2008

Liao Y., Guentay S., Dehbi A.
"A Probabilistic Model using ARTIST Data for Analysis of SGTR Fission Product Release Fraction", ANS Annual Meeting, Anaheim, USA, 8-12 June 2008

Lind T., Suckow D., Guentay S.
"Particle Retention in ARTIST Dry Bundle Tests", ANS Annual Meeting, Anaheim, USA, 8-12 June 2008

Lothenbach B.[1], Wieland E., Figi R.[1], Rentsch D.[1], Schwyn B.[2]
"Solubility of Fe-containing hydrates", 2nd Int. Workshop on Mechanisms and Modelling of Waste/ Cement Interactions, Le Croisic, France, 12-16 October 2008
[1] EMPA, Dübendorf, CH
[2] NAGRA, Wettingen, CH

Macé N., Harfouche M., Dähn R., Tits J., Scheinost A.[1], Wieland E.
"EXAFS investigation of U(VI) speciation in cementitious materials", 5th Workshop on Speciation, Techniques and Facilities for Radioactive Materials at Synchrotron Light Sources, Actinide XAS 2008, Saint-Aubin, France, 15-17 July 2008
[1] ESRF, Grenoble, FR

Macé N., Wieland E., Tits J., Dähn R., Kunz D., Geipel G.[1], Scheinost A.[2]
"Spectroscopic investigations of U(VI) speciation in cementitious materials", 2nd Int. Workshop on Mechanisms and Modelling of Waste/Cement Interactions, Le Croisic, France, 12-16 October 2008
[1] FZD, Rossendorf, DE
[2] ESRF, Grenoble, FR

Manera A., Antoni O.[1]
"Code-to-Code Comparison for Blowdown Transients at Supercritical Conditions", Jahrestagung Kerntechnik 2008, 27-29 May 2008, Hamburg, Germany, CD-ROM, 2008
[1] CEA, Grenoble, FR

Marques Fernandes M., Dähn R., Baeyens B., Scheinost A.[1], Bradbury M.H.
"Influence of carbonate complexation on the sorption of U(VI) on montmorillonite", 5th Workshop on Speciation, Techniques and Facilities for Radioactive Materials at Synchrotron Light Sources, Actinide XAS 2008, Saint-Aubin, France, 15-17 July 2008
[1] ESRF, Grenoble, FR

Martin M., Gavillet D., Portier S.
"Study of the influence of the crystallography on the implantation of B and Li in the Zircaloy oxide layer", 45th Annual Meeting: Hot Laboratories and Remote Handling, Kendal, UK, 22-24 September 2008

Meca S.[1], Colas E.[1], Rojo I.[1], Gaona J., Grivé M.[2], Duro L.[2], Rovira M.[1], Marti V.[1], De Pablo J.[1]
"Uranium(VI) interaction with cement-based materials", 2nd Int. Workshop on Mechanisms and Modelling of Waste/Cement Interactions, Le Croisic, France, 12-16 October 2008
[1] CTM, Manresa, ES
[2] Amphos, Valldoreix, ES

Merino J.[1], Guimera J.[1], Gaona J., Luna M.[1], Delos A.[1], Bruno J.[2]
"Risk assessment of a landfill for wastes containing naturally occurring radionuclides through infiltration to groundwater", Int. Conf. on Uranium Mining and Hydro-geology V, Freiberg, Germany, 14-18 September 2008
[1] Amphos, Valldoreix, ES
[2] ENVIROS, Valldoreix, ES

Niceno B., Andreani M., Prasser H.-M.
"PSI-Boil, a Building Block Towards the Multi-Scale

Modelling of Flow Boiling Phenomena", Colloquium on Two-Phase Convective Boiling Flow Modelling, CEA, Grenoble, France, 8-9 September 2008

Niffenegger M.
"Monitoring the Embrittlement of Reactor Pressure Vessel Steels by using the Seebeck Coefficient", 12th Symp. on Thermo-Chemistry and Thermo-Physics of Nuclear Materials, University of Vienna, Austria, 30 August - 3 September 2008

Ogino M.[1], Kapulla R., Dehbi A.
"Fluent Simulation of Separator and Dryer Aerodynamics and Comparison with Data", ANS Annual Meeting, Anaheim, USA, 8-12 June 2008
[1] JAERI, Kashiwa, JP

Pfingsten W.
"Reactive Transport Modelling", Swiss Bentonite Workshop, Berne, Switzerland, 9 June 2008

Pfingsten W., Shao H.[1]
"Benchmark calculations using alternative geochemical modules implemented within reactive transport codes", Int. Workshop on Modelling Reactive Transport in Porous Media, Strasbourg, France, 21-24 January 2008
[1] University of Tübingen, DE

Pouchon M.A., Chen J.C., Froideval A., Janousch M., Degueldre C.
"Irradiation effects in helium implanted silicon carbide measured by X-ray absorption spectroscopy", Eur. Materials Research Soc. (E-MRS), Strasbourg, France, 21-25, May 2008

Pouchon M.A., Chen J.C., Hoffelner W.
"He implantation-induced microstructure- and hardness-modification of the intermetallic γ-TiAl", 16th Int. Conf. on Ion Beam Modification of Materials (IBMM 08), Dresden, Germany, 31 August – 5 September 2008

Pouchon M.A., Chen J.C., Hoffelner W.
"The Extended X-Ray Absorption Fine Structure as a Sensing Tool of Atomistic Defects", Materials Science and Engineering 2008 (MSE 08), Nürnberg, Germany, 1-4 September 2008

Ramesh M., Leber H., Kunze K.[1], Diener M.[1], Spolenak R.[1]
"Fatigue crack initiation behaviour during thermo-mechanical cyclic loading in austenitic stainless steel", 15th Int. Conf. on Textures of Materials (ICOTOM 15), Pittsburgh, USA, 1-6 June 2008
[1] ETHZ, Zurich, CH

Ramesh M., Leber H., Kunze K.[1], Diener M.[1], Spolenak R.[1]
"Thermomechanical and Isothermal Cyclic Loading in Austenitic Stainless Steel", Material Science Engineering (MSE 08), Nürnberg, Germany, 1-4 September 2008
[1] ETHZ, Zurich, CH

Reeks M.[1], Haste T.
"SARNET – Severe Accident Research Network: Use of CFD Methods", CFD Workshop on Test Cases, Databases & BPGs for Nuclear Power Plant Applications, Manchester, United Kingdom, 16 July 2008
[1] University of Newcastle upon Tyne, UK

Repetto G.[1], Birchley J., Drath T.[2], Austregesilo H.[3]
"Analysis of the Phebus FPT3 Core Degradation using Severe Accidents Codes (ICARE/CATHARE, ATHLET-CD, MELCOR)", ANS Annual Meeting, Anaheim, USA, 8-12 June 2008
[1] IRSN, Cadarache, FR
[2] Ruhr University of Bochum, DE
[3] GRS, Garching, DE

Roth A.[1], Seifert H.P., Hickling J.[2]
"Crack Initiation due to Environmentally Assisted Cracking in Carbon Steels and Low-Alloy Steels Exposed to High-Temperature Water – Part 2: Overview and Assessment of Operating Experience", Workshop on Detection, Avoidance, Mechanisms, Modeling, and Prediction of SCC Initiation in Water-Cooled Nuclear Reactor Plants, Beaune, France, 7-12 September 2008
[1] AREVA NP GmbH, Erlangen, DE
[2] EPRI, Palo Alto, US

Rozov K., Berner U., Taviot-Gueho C.[1]
"Synthesis, characterization and thermodynamics of hydrotalcite-like solid solutions", 2nd Int. Workshop on Mechanisms and Modelling of Waste/Cement Interactions, Le Croisic, France, 12-16 October 2008
[1] University Blaise Pascal, Clermont-Ferrand, FR

Seifert H.P., Hickling J.[1], Roth A.[2]
"Crack Initiation due to Environmentally Assisted Cracking in Carbon Steels and Low-Alloy Steels Exposed to High-Temperature Water. Part 1: Overview of Results from Laboratory Tests", Workshop on Detection, Avoidance Mechanisms, Modeling and Prediction of SCC Initiation in Water-Cooled Nuclear Reactor Plants, Beaune, France, 7-12 September 2008
[1] EPRI, Palo Alto, US
[2] AREVA NP GmbH, Erlangen, DE

Seifert H.P., Ritter S.
"Corrosion Fatigue of Austenitic Stainless Steels under LWR Conditions", "EAC Initiation in Carbon & Low-Alloy Steels in High-Temperature Water – Experimental Observations and Service Experience", "Effect of Chloride on EAC in LAS in High-Temperature Water", "Effect of Chloride on SCC Crack Growth in Low-Alloy RPV Steels under BWR/NWC-Conditions",

Annual Meeting of the Int. Co-operative Group on Environmentally-Assisted Cracking of Water Reactor Materials, Bastad, Sweden, 20-25 April 2008

Svedkauskaite-LeGore J., Kivel N., Günther-Leopold I.
"Online monitoring of fission products released from nuclear fuel samples by ICP-MS", 7th Int. SF-ICP-MS Conf., Rutgers University, New Brunswick, USA, 8-12 September 2008

Tits J., Macé N., Geipel G.[1], Eilzer M.[1], Wieland E.
"U(VI) uptake by calcium silicate hydrates", Goldschmidt Conf. 2008, Vancouver, Canada, 13-18 July 2008
[1] FZD, Rossendorf, DE

Tits J., Macé N., Geipel G.[1], Eilzer M.[1], Wieland E.
"Uranium(VI) uptake by calcium silicate hydrates", 2nd Int. Workshop on Mechanisms and Modelling of Waste/Cement Interactions, Le Croisic, France, 12-16 October 2008
[1] FZD, Rossendorf, DE

Uldry A.C.
"Magnetic properties of ferritic alloys by first-principle calculations and X-ray measurements", Centre Européen de Calcul Atomique et Moléculaire (CECAM) Workshop: Mineral Spectroscopy by Theory and Experiment, EPFL, Lausanne, Switzerland, 6-9 October 2008

Van Loon L.R.
"Effect of exchangeable cations and pore water chemistry on the diffusion of radionuclides in compacted bentonite", Int. Workshop on Iron-Bentonite Interaction, Invited Talk, Kanazawa, Japan, 18-19 November 2008

Van Loon L.R.
"Understanding diffusion of radionuclides in argillaceous materials: beyond applying Fick's Law", Invited Talk, Hokkaido Universtiy, Sapporo, Japan, 21 November 2008

Wieland E., Dähn R., Lothenbach B.[1], Vespa M.[2]
"Micro-spectroscopic investigations of the Al and S speciation in hardened cement paste", 2nd Int. Workshop on Mechanisms and Modelling of Waste/Cement Interactions, Le Croisic, France, 12-16 October 2008
[1] EMPA, Dübendorf, CH
[2] ESRF, Grenoble, FR

Wieland E., Mandaliev P., Dähn R., Tits J., Stumpf T.[1]
"Mechanisms of lanthanide binding by cementitious materials", 7th Int. Conf. on Nuclear and Radiochemistry (NRC-7), Budapest, Hungary, 24-29 August 2008
[1] FZK, Karlsruhe, DE

Zimmermann M.A.
"Quantification of Safety Margins", IAEA Regional Workshop, Protoroz, Slovenia, 22-26 September 2008

Zimmermann M.A.
"Development of Regulatory Practice for Power Uprates", IAEA National Workshop on Safety Margins, Daejeon, Korea, 17-21 November 2008

Zubler R., Bertsch J., Lauss B.
"Determination of irradiation resistance of glued glass – aluminum joints by mechanical testing", Poster at 45th Annual Meeting of the Working Group 'Hot Laboratories and Remote Handling', Kendal, UK, 21-23 September 2008

NES Colloquia

Baeyens B.
"Sorption on clays: towards a thermodynamic sorption database", 30 October 2008

Chawla R.
"PHYSOR'08: Nose, Palate and Finish", 27 November 2008

Mikityuk K.
"Analytical studies related to liquid-metal flow phenomena in the frame of the FAST project", 13 March 2008

Pfingsten W.
"Macroscopic modelling of multi-species radionuclide transport using microscopic information", 21 February 2008

Seifert H.P.
"Integrität des Reaktor-Primärkreislaufs", 29 May 2008

Svedkauskaite-LeGore J., Dang V.N., Iannuzzi Mauri M.
"NES Seed Action, Quo Vadis", 28 August 2008

University Level Teaching

Abolhassani-Dadras S.
"Introduction and Applications of Electron Energy Loss Spectroscopy (EELS)", Lecture given in the Course: Nanotools, University of Neuchâtel, Switzerland, Autumn Semester, 2008

Degueldre C.
"Comportement des radionuclides dans l'environnement, impact des reacteurs dans l'environnement", Centre universitaire d'étude des problèmes de l'énergie, Lecture Course, University of Geneva, Switzerland, Spring Semester, 2008

Dehbi A.
"Stochastic models for turbulent particle dispersion in general inhomogeneous flows", Lecture given in the Course: Modeling of Turbulent Dispersed Flows, EPFL, Lausanne, Switzerland, 28 May 2008

Gimmi T.
"Determination of Transport Parameters at the Laboratory Scale", "Determination of Transport Parameters at the Field Scale", "Natural Tracers: Transport at Very Large Scales"; Lectures given in Training Course, Okayama University, Japan, 14-18 January 2008

Gimmi T.
"Wasserbewegung im gesättigten und ungesättigten Untergrund–Implikationen für den Transport von Schadstoffen", Advanced Training Course, University of Berne, Switzerland, 11-12 September 2008

Gimmi T.
"Fluids in the Crust", Masters Course in Environmental and Resource Geochemistry, University of Berne, Switzerland, Autumn Semester, 2008

Girardin G.
"Reactor Experiments", Lectures given in the Course: Master of Nuclear Engineering, EPFL, Lausanne, Switzerland, Autumn Semester, 2008

Grolimund D.
"Cook and Look: Synchrotron Techniques", Masters Course on Hands-on Training, Villigen PSI, Switzerland, 23 June - 1 July 2008

Günther-Leopold I.
"Spent Fuel Reprocessing", Lectures given in the Course: Nuclear Energy Systems, ETHZ, Zürich, Switzerland, Spring Semester, 2008

Günther-Leopold I.
"Kernbrennstoffe", Strategic Exercise given in the Course: Analytische Chemie V, ETHZ, Zurich, Switzerland, 23 September 2008

Hoffelner W.
"Structural materials for nuclear reactors", "Structural materials for advanced energy applications", Lectures given in the Course: Nuclear Fuels and Materials, Masters Course, EPFL, Lausanne, Switzerland, Autumn Semester 2008

Hummel W.
Lectures given in the Course: Nuclear Energy Systems, ETHZ, Zurich, Switzerland, Spring Semester, 2008

Hummel W.
"Landfilling, nuclear repositories and contaminated sites", Lecture in Master of Biogeochemistry and Pollutant Dynamics and Master of Ecological Systems Design and Waste Management", ETHZ, Zurich, Switzerland, Autumn Semester, 2008

Janssens K.
"Cellular automata and microstructure evolution", Lecture on Workshop on Multi-Scale Modeling of Moving Interfaces in Materials, Leuven University, Belgium, 2-4 July 2008

Joneja O.P.
"Reactor Experiments", Lecture Course, EPFL, Lausanne, Switzerland, Autumn Semester, 2008

Kolbe E.
"Kernenergie 2 KP", Lecture Course, University of Basel, Switzerland, Autumn Semester, 2008

Kosakowski G.
"Computational and Experimental Methods for Processes in the Deep Geological Environment.", Lectures given in the 'Block Course', Okayama University, Japan, 14-18 January 2008

Kosakowski G.
"Geostatistics I", Lecture Course: Masters in Applied Environmental Geoscience, University of Tübingen, Germany, Spring Semester, 2008

Kosakowski G.
"Geostatistics II", Lecture Course: Masters in Applied Environmental Geoscience, University of Tübingen, Germany, Autumn Semester, 2008

Manera A.
"Thermal Hydraulic Systems Codes including Hands-On Training", Lectures given in the Kernreaktorpraktikum, ETHZ, Zurich, Switzerland, Spring Semester, 2008

Pouchon M.A.
"Application of Sol Gel process for manufacturing microspheres for 'Sphere Pac' coated fuel particles and fuel pellets", "Ammonia Internal Gelation Process – Preparation of UO_2, Mixed Oxide & Minor Actinide Bearing Oxide Microspheres", Lectures given at the IAEA National Workshop: Preparation and Characterization of UO_2– & ThO_2–based Powders, Sol-Gel Microspheres and Sintered Pellets, Istanbul, Turkey, 15-19 December 2008

Smith, B.L.
"Introduction to Computational Fluid Dynamics", "Governing Equations, Turbulence Modelling and Numerical Procedures", "Identification of Nuclear Reactor Safety Issues where Single-Phase CFD can Bring Real Benefits", "Error Control, Verification, Validation and Best Practice Guidelines", "Assessment Databases for Single-Phase CFD Applications with Emphasis on Nuclear Reactor Safety Issues", Lectures

given at IAEA Regional Workshop on Application of Computational Fluid Dynamic Codes to Nuclear Safety, Budapest University of Technology and Economics, Budapest, Hungary, 17-21 June, 2008.

Zimmermann M.A.
"Nuclear Materials I", Lectures given in the Course: Nuclear Fuels and Materials, Masters Course, EPFL, Lausanne, Switzerland, Autumn Semester, 2008

Habilitation, Doctoral, Master and Batchelor Theses

Ammar Y.
"Turbulent Agglomeration and Break-Up of Nuclear Aerosols", Doctoral Thesis, University of Newcastle, 2008.

Blair P.
"Modelling of Fission Gas Behaviour in High Burnup Nuclear Fuel", Doctoral Thesis No. 4084, EPFL, Lausanne, 2008.

Mandaliev P.
"Mechanisms of Nd(II) and Eu(III) uptake by cementitious materials", PhD Thesis No. 18095, ETHZ, Zurich, 2008

Petkevic P.
"Development and Application of an Advanced Fuel Model for the Safety Analysis of the Generation IV Gas-Cooled Fast Reactor", Doctroral Thesis No. 4180, EPFL, Lausanne, 2008

PSI and Other Reports

Allison C.M.[1], Bykov M.[2], Haste T., Lee S.[3], Makihara Y.[3], Tricot, N.[3], Uetsuka, H.[4]
"Computational Analysis of the Behaviour of Nuclear Fuel under Steady-State, Transient and Accident Conditions", IAEA-TECDOC-1578, December 2007 (ISBN 978-92-0-110507-3)

[1] Innovative Systems Software, LLC, US
[2] FSUE EDO "Gidropress", Podolsk, RU
[3] IAEA, Vienna, AT
[4] JAEA, Tokyo, JP

Glaus M., Van Loon L.R.
"Chemical reactivity of a-isosaccharinic acid in heterogeneous alkaline systems", PSI-Bericht Nr. 08-01, Nagra NTB 08-10

Mueller, K.[1], Toth[1], B.[1], Veshchunov, M.S.[2], Trambauer, K.[3], Jamond, C.[4], Dubourg, R.[4], Manenc, H.[4], Girault, N.[4], Kissane, M.[4], Repetto, G.[4], Plumecocq, W.[4], Taylor, P.[4], Haste, T., Birchley, J., Bottomley, D.[5], Schanz, G.[5], Stuckert, J.[6], Lemoine, F.[7], Davidovich, N.[8], Mason, P.[9]
"Final Interpretation Report of the PHEBUS Test FPT0 (Bundle Aspects)", EC Report: EUR 23222 EN, Oct. 2007 (issued April 2008)

[1] JRC, Petten, NL
[2] Russian Academy of Sciences, Moscow, RU
[3] GRS, Garching, DE
[4] IRSN, Cadarache, FR
[5] JRC/ITU, Karlesruhe, DE
[6] FZK, Karlesruhe, DE
[7] CEA, Cadarache, FR
[8] ENEA, Bologna, IT
[9] AEA Technology, Winfrith, UK

General Communications and Public Relations

Günther-Leopold, I.
"Nukleare Energie und Nachhaltigkeit", Presentation in the course of the PSI event 'Forscher im Zelt', Waldshut, Germany, 30 August 2008

Manera A.
"Nukleare Energie und Nachhaltigkeit", Presentation in the course of the PSI event 'Forscher im Zelt', Aarau, Switzerland, 23 August 2008

The Energy Departments (NES and General Energy)

LEA – Laboratory for Energy Systems Analysis

Publications in Scientific and Technical Journals

Barreto L., Kemp R.[1]
"Inclusion of Technology Diffusion in Energy-System Models: Some Gaps and Needs", J. of Cleaner Production. Special Issue on Cleaner Technologies Diffusion: Modelling, Case Studies and Policy (ISSN 0959-6526), **16**(1), Suppl. 1, 95-101 (2008)
[1] UNU-MERIT, Maastricht, NL

Burgherr P., Hirschberg S.
"Severe accidents in the oil chain with emphasis on oil spills", Strategic Insights (ISSN 1938-1670), **7**(1), 1-15 (2008)

Burgherr P., Hirschberg S.
"A comparative analysis of accident risks in fossil, hydro and nuclear energy chains", Hum. Ecol. Risk Assess. (ISSN 1080-7039), **14**(5), 947-973 (2008)

Filippini R., Sen S.[1], Bicchi A.[1]
"Towards soft robots you can depend on", IEEE Robotics and Automation (ISSN 1070-9932), **15**(3), 31-41 (2008)
[1] UNIPI, Pisa, IT

Kypreos S., Blesl M.[1], Cosmi C.[2], Kanudia A.[3], Loulou R.[4], Smekens K.[5], Salvia M.[2], Van Regemorter D.[6], Cuomo V.[2]
"TIMES-EU: a pan-European model integrating LCA and external costs", Int. J. Sustainable Development and Planning: Special Issue on Environmental Economics (ISSN 1743-7601), **3**(2), 180-194 (2008)
[1] University of Stuttgart, DE
[2] Istituto di Metodologie Avanzate di Analisi Ambientale, Tito Scalo, IT
[3] KANLO Sarl, Lyon, FR
[4] McGill University, Montreal, CA
[5] Energy Research Centre, Petten, NL
[6] University of Leuven, BE

Lafforgue G.[1], Magné B., Moreaux M.[2]
"Energy substitutions, climate change and carbon sinks", Ecol. Econ. (ISSN 0921-8009), **67**(4), 589-597 (2008)
[1] Toulouse Business School, FR
[2] University of Toulouse, FR

Podofillini L., Dang V.N., Thomsen K.
"Scoping-Level Probabilistic Safety Assessment of a complex experimental facility: challenges and first results from the application to a neutron source facility (MEGAPIE)", Nucl. Eng. Des. (ISSN 0029-5493), **238**(10), 2726-2738 (2008)

Podofillini L., Zio E.[1]
"Designing a Risk-Informed Balanced System by Genetic Algorithms: Comparison of Different Balancing Criteria", Reliab. Eng. Syst. Saf. (ISSN 0951-8320), **93**(12), 1842-1852 (2008)
[1] Polytechnic of Milan, IT

Podofillini L., Zio E.[1]
"Events group risk importance by genetic algorithms", Proc. IMechE Part O: J. Risk and Reliability (ISSN 1748-006X), **222**(3), 337-346 (2008)
[1] Polytechnic of Milan, IT

Rafaj P.[1], Kypreos S.
"The role of nuclear energy in the post-Kyoto carbon mitigation strategies", Int. J. Sustain. Devt. Planning: Special Issue on Environmental Economics (ISSN 1740-8822), **2**(1), 10-27 (2008)
[1] IIASA, Laxenburg, AT

Reer B.
"Review of advances in human reliability analysis of errors of commission, Part 1: EOC identification", Reliab. Eng. Syst. Saf. (ISSN 0951-8320), **93**(8), 1091-1104 (2008)

Reer B.
"Review of advances in human reliability analysis of errors of commission, Part 2: EOC quantification", Reliab Eng Syst Saf. (ISSN 0951-8320), **93**(8), 1105-1122 (2008)

Schulz T., Kypreos S., Barreto L., Wokaun A.
"Intermediate steps towards the 2000-watt society in Switzerland: an energy-economic scenario analysis", Energy Policy (ISSN 0301-4215), **36**(4), 1303-1317 (2008)

Turton H.
"ECLIPSE: an integrated energy-economy model for climate policy and scenario analysis", Energy (ISSN 0360-5442), **33**(12), 1754-1769 (2008)

Turton H., Moura F.[1]
"Vehicle-to-grid systems for sustainable development: an integrated energy analysis", Technol. Forecast Soc. Change (ISSN 0040-1625), **75**(8), 1091-1108 (2008)
[1] Technical University of Lisbon, PT

Publications in Books

Burgherr P., Hirschberg S.
"Nuclear Energy Outlook 2008 (NEA)", in comparative analysis of severe accident risks in the energy sector, NEA/OECD, Paris, 437-444, 2008 (ISBN 978-92-64-05410-3)

Lafforgue G.[1], Magné B., Moreaux M.[2]
"The Design of Climate Policy", in Roger Guesnerie and Henry Tulkens (Eds): The optimal sequestration policy with a ceiling on the stock of carbon in the atmosphere, The MIT Press, Ch. 14, pp. 273-304, 2008 (ISBN 0-262-07302-1)

[1] Toulouse Business School, FR
[2] University of Toulouse, FR

Keynote Lectures at International Conferences

Dang V.N.
"Quantifying the Human Factor – Time for a Change", Keynote Lecture, 9th Int. Conf. on Probabilistic Safety Assessment and Management (PSAM9), 18-23 May 2008, Hong Kong, China, CD-ROM, 2008

International Conferences with Proceedings

Bauer C., Dones R., Heck T., Hirschberg S.
"Ökobilanz und externe Kosten zukünftiger fossiler Stromerzeugungstechnologien mit CO_2-Abscheidung und Speicherung", 10th Symp. Energieinnovation, 13-15 February 2008, Graz, Austria, CD-ROM, 2008 (ISBN 978-3-90-2465-94-8)

Bauer C., Dones R., Heck T., Hirschberg S.
"Environmental assessment of current and future Swiss electricity supply options", Int. Conf. on the Physics of Reactors (PHYSOR'08), 14-19 September 2008, Interlaken, Switzerland, CD-ROM, 2008 (ISBN 978-3-9521409-5-6).

Bicchi A.[1], Bavaro S.[2], Boccadamo G.[1], De Carli D.[1], Filippini R., Grioli G.[1], Piccigallo M.[1], Rosi A.[1], Schiavi R.[1], Sen S.[1], Tonietti G.[1]
"Physical Human-Robot Interaction: Dependability, Safety, and Performance", 10th Int. Workshop on Advanced Motion Control (AMC'08), 26-28 March 2008, Trento, Italy, pp. 9-14, 2008

[1] Centro E. Piaggio, University of Pisa, IT

Burgherr P.
"Using GIS and multivariate analyses to visualize risk levels and spatial patterns of severe accidents in the energy sector", Eur. Safety and Reliability Conf. (ESREL 2008), 20-26 September 2008, London, UK, Vol. 1, 129-136, 2008 (ISBN 978-0-415-48514-2)

Burgherr P., Hirschberg S.
"Comparative risk assessment of severe accidents in the energy sector", Int. Disaster & Risk Conf., 25-29 August 2008, Davos, Switzerland, CD-ROM, 2008

Burgherr P., Hirschberg S.
"Severe accidents in the energy sector and their relevance for risk management in a CIP context", Invited Talk,1st Int. Conf. on CIP and Resilience (ICCR). An associated Conf. to the Int. Disaster & Risk Conf., 26-27 August 2008, Davos, Switzerland, CD-ROM, 2008

Chang Y.H., Mercurio D., Dang V.N., Mosleh A.[1]
"Recent Developments and Insights from Application of ADS-IDAC Dynamic PRA Platform", 9th Int. Conf. on Probabilistic Safety Assessment and Management (PSAM9), 18-23 May 2008, Hong Kong, China, CD-ROM, 2008

[1] University of Maryland, College Park, US

Dang V.N., Bye A.[1], Lois E.[2], Forester J.[3], Braarud P.[1]
"Benchmarking HRA methods against simulator data – design and organization of the international HRA Empirical Study", 9th Int. Conf. on Probabilistic Safety Assessment and Management (PSAM9), 18-23 May 2008, Hong Kong, China, CD-ROM, 2008

[1] OECD Halden Reactor Project, Halden, NO
[2] US NRC, Rockville, US
[3] SNL, Albuquerque, US

Dang V.N., Forester J.[1], Bye A.[2], Lois E.[3], Broberg H.[2], Parry G.[4], Julius J.[5]
"Results from a pilot benchmarking study of HRA methods – a comparison of method predictions against the outcomes observed in the simulator study", 9th Int. Conf. on Probabilistic Safety Assessment and Management (PSAM9), 18-23 May 2008, Hong Kong, China, CD-ROM, 2008

[1] SNL, Albuquerque, US
[2] OECD Halden Reactor Project, Halden, NO
[3] US NRC, Rockville, US
[4] US NRC, Bethesda, US
[5] Scientech, EPRI, US

Dang V.N., Podofillini L.
"Evaluation HRA Methods in the Simulator – the Problem of Operationalizing Performance Influences in HRA and in Data Analysis", Enlarged Halden Programme Group (EHPG) Meeting, 18-23 May 2008, Loen, Norway, CD-ROM, 2008

Dang V.N., Siu N.[1], Amri A.[2]
"Human Reliability – WGRisk Findings and Outlook for Data Collection and Exchange", ANS Topical Meeting on Probabilistic Safety Assessment (PSA›08), 7-11 September 2008, Knoxville, USA, CD-ROM, 2008 (ISBN 978-0-89448-065-2)

[1] US NRC, Bethesda, US
[2] OECD/NEA, Paris, FR

Forester J.[1], Dang V.N., Bye A.[2], Lois E.[3]
"Defining the HRA analysis task in HRA method benchmarking – approaches and outcomes in the International Empirical Study", 9th Int. Conf. on Probabilistic Safety Assessment and Management (PSAM9), 18-23 May 2008, Hong Kong, China, CD-ROM, 2008
[1] SNL, Albuquerque, US
[2] OECD Halden Reactor Project, Halden, NO
[3] US NRC, Rockville, US

Forester J.[1], Dang V.N., Bye A.[2], Lois E.[3], Parry G.[4], Julius J.[5]
"Benchmarking Human Reliability Analysis (HRA) method against simulator data – methods for the comparison", 9th Int. Conf. on Probabilistic Safety Assessment and Management (PSAM9), 18-23 May 2008, Hong Kong, China, CD-ROM, 2008
[1] SNL, Albuquerque, US
[2] OECD Halden Reactor Project, Halden, NO
[3] US NRC, Rockville, US
[4] US NRC, Bethesda, US
[5] Scientech, EPRI, US

Hirschberg S.
"Nuclear energy risks and benefits in perspective", Int. Conf. on the Physics of Reactors (PHYSOR'08), 14-19 September 2008, Interlaken, Switzerland, CD-ROM, 2008

Hirschberg S., Bauer C., Burgherr P., Cazzoli E.[1], Dones R., Heck T., Schenler W.
"Treatment of risks in sustainability assessment of energy systems", 9th Int. Conf. on Probabilistic Safety Assessment and Management (PSAM9), 18-23 May 2008, Hong Kong, China, CD-ROM, 2008
[1] Cazzoli Consulting, Nussbaumen, CH

Lois E.[1], Parry G.[2], Julius J.[3], Forester J.[4], Bye A.[5], Broberg H.[5], Dang V.N.
"The International Empirical HRA Study Using Simulator Human Performance Data", ANS Int. Topical Meeting on Probabilistic Safety Assessment (PSA'08), 7-11 September 2008, Knoxville, USA, CD-ROM, 2008 (ISBN 978-0-89448-065-2)
[1] US NRC, Rockville, US
[2] US NRC, Bethesda, US
[3] Scientech, EPRI, US
[4] SNL, Albuquerque, US
[5] OECD Halden Reactor Project, Halden, NO

Parry G.[1], Lois E.[2], Forester J.[3], Dang V.N., Julius J.[4], Bye A.[5]
"Insights from comparison of HRA method predictions with empirical data on human performance in accident scenarios", 9th Int. Conf. On Probabilistic Safety Assessment and Management (PSAM9), 18-23 May 2008, Hong Kong, China, CD-ROM, 2008
[1] US NRC, Bethesda, US
[2] US NRC, Rockville, US
[3] SNL, Albuquerque, US
[4] Scientech, EPRI, US
[5] OECD Halden Reactor Project, Halden, NO

Podofillini L., Dang V.N., Zio E.[1], Baraldi P.[1], Librizzi M.[1]
"Techniques for verification of expert models for dependence assessment in human reliability analysis", 9th Int. Conf. on Probabilistic Safety Assessment and Management (PSAM9), 18-23 May 2008, Hong Kong, China, CD-ROM, 2008
[1] Polytechnic of Milan, IT

Podofillini L., Reer B.
"Comparing CESA-Q human reliability analysis with evidence from simulator: a first attempt", Eur. Safety & Reliability Conf. (ESREL'08), Safety, Reliability and Risk Analysis, 22-25 September 2008, Valencia, Spain, Vol. 1, 233-241, 2008 (ISBN 978-0-415-48513-5)

Roth S.[1], Hirschberg S., Bauer C., Burgherr P., Dones R., Heck T., Schenler W.
"Sustainability of electricity supply technology portfolio", Int. Conf. on the Physics of Reactors (PHYSOR'08), 14-19 September 2008, Interlaken, Switzerland, CD-ROM, 2008 (ISBN 978-3-9521409-5-6)
[1] AXPO, Zurich, CH

Sani L.[1], Filippini R., Bolognesi P.[1], Bruno O.[1], Masini P.[1]
"Dependability study of a high-speed railway vehicle", 8th World Congr. on Railway Research, 18-22 May 2008, Seoul, Korea, CD-ROM, 2008
[1] University of Pisa, IT

Wilhelm E., Berry I.[1], Stevens M.[2], Schenler W.
"CARtography: Creating a Global Map-Based Fuel Use Calculator", 2008 American Soc. for Engineering Education Conf., 22-25 June 2008, Pittsburgh, USA, CD-ROM, 2008
[1] MIT, Cambridge, US
[2] University of Waterloo, CA

Wilhelm E., Schenler W.
"The Co-Evolution of Plug-In and Fuel Cell Hybrid Vehicles", Int. Advanced Mobility Forum, 11-13 March 2008, Geneva, Switzerland, CD-ROM, 2008

Talks delivered at Conferences, Workshops and Specialist Meetings (without Proceedings)

Bauer C.
"Energy supply", 2nd Int. ecoinvent Meeting, EPFL, Lausanne, Switzerland, 14 March 2008

Bauer C., Dones R., Heck T., Mayer-Spohn O.[1], Blesl M.[1]
"Life-cycle assessment and external costs of future fossil power technologies including carbon capture

and storage", Smart Energy Strategies 2008: Meeting the Climate Change Challenge, ETHZ, Zurich, Switzerland, 8-10 September 2008 (ISBN 978-3-7281-3218-5)

Gül T., Kypreos S., Turton H., Barreto L.
"Cost-effective technology choices in personal transport", 1st Int. Conf. on Mobility and Energy, Invited Talk, Vienna, Austria, 29 February 2008

Gül T., Turton H.
"Illustrating Perspectives of Energy and Mobility", Invited Talk, World Energy Council (WEC), Europe Regional Meeting, Istanbul, Turkey, 16 October 2008

Hirschberg S.
"Impact of efficiency improvements on the energy system: 2000 W society concept in perspective", NEEDS Forum 3 on External Costs Applied to Renewable Energies and Energy Efficiency in Southern and Eastern Mediterranean Countries: Opportunities and Challenges, Invited Talk, NEEDS, Cairo, Egypt, 28 January 2008

Hirschberg S.
"State-of-the-art indicators for comparative assessment: methodology, result examples and current developments", Invited Talk, Eur. Nuclear Energy Forum: Competitiveness, Brussels, Belgium, 21 April 2008

Hirschberg S.
"Role of nuclear energy in our energy strategy: risks and benefits", Invited Talk, Royal Flemish Engineers Association (KVIV) Seminar: The Future for Nuclear Energy in our Energy Strategy, Brussels, Belgium, 22 April 2008

Hirschberg S.
"Technology roadmap and stakeholder perspectives: relevant policy insights", Final Conf. of the CASES Project, Social Costs of Electricity Generation and Policy Design, Invited Talk, Milan, Italy, 29 September 2008

Hirschberg S.
"Technology roadmap and stakeholder perspectives: status and preliminary findings", Final Conf. of the CASES Project, Social Costs of Electricity Generation and Policy Design, Invited Talk, Milan, Italy, 30 September 2008

Hirschberg S.
"Nuclear Energy versus other energy sources", Conf. on Nuclear Energy in Poland: Opportunity or Necessity?, Invited Talk, Warsaw, Poland, 20-21 October 2008

Hirschberg S.
"Sustainability assessment of electricity supply systems", Eur. Inst. for Energy Research (EIFER) Seminar, Invited Talk, Karlsruhe, Germany, 11 December 2008

Hirschberg S.
"Selected topics in energy systems analysis", Invited Talk, AREVA NP, Paris, France, 18 December 2008

Kypreos S.
"Linking MM with MERGE to study national policies under consistent global developments", Invited Talk Energy Technology Systems Analysis Programme (ETSAP) Workshop, Paris, France, 3-4 July 2008

Kypreos S.
"The Transport Module: Integration in MERGE and some Scenarios", Invited Talk, Energy Technology Systems Analysis Programme (ETSAP) Meeting, Sophia-Antipolis, France, 15 December 2008

Kypreos S., Magné B.
"Uncertainty and Discounting in the Monte-Carlo Version of MERGE", International Energy Workshop 2008, Invited Talk, Paris, France, 30 June – 2 July 2008

Reiter U., Turton H.
"Impacts of Climate Change on Electricity Production in Europe - Adaptation Options for Power Producers", Int. Energy Workshop 2008, Invited Talk, Paris, France, 30 June - 2 July 2008

Turton H.
"Sustainable development and automobile transport: an integrated global scenario analysis", Int. Energy Agency (IEA), Int. Energy Workshop 2008, Invited Talk, Paris, France, 30 June - 2 July 2008

Turton H., Magné B., Kypreos S.
"Technology options for low stabilization pathways with MERGE", Int. Energy Workshop 2008, Invited Talk, Paris, France, 30 June – 2 July 2008

Weidmann N.
"Energy efficiency options for a sustainable Swiss energy system", EMPA PhD Student's Symposium 2008, Invited Talk, St. Gallen, Switzerland, 13 November 2008

Wilhelm E., Schenler W., Wokaun A.
"Heuristic Generation and Analysis of Vehicle Designs", MIT-PSI Workshop: Before a Transition to Hydrogen Transportation, Dearborn, USA, 7-9 May 2008

NES Colloquia

Burgherr P.
"Comparative analysis of accident risks in the energy sector: latest developments and outlook", 6 May 2008

University Level Teaching

Burgherr, P.
"Severe accident risks in the energy sector: comparative analysis and new developments", Lecture given in the Course: Centre des sciences naturelles de l'environnement, University of Geneva, Switzerland, 1 December 2008

Dang V.N.
"Human Reliability Analysis (HRA) – An Introduction", Lecture given in the Course: Methoden der Systemorientierten Risikoanalyse, ETHZ, Zurich, Switzerland, 1 October 2008

Hirschberg S.
"Nuclear Energy and Sustainability. Part 1: Life-Cycle Assessment", "Nuclear Energy and Sustainability. Part 2: Sustainability Assessment", "Nuclear Energy and Sustainability. Part 3: Energy Supply Challenges and Role of Nuclear Energy", Lectures given in the Course: Nuclear Energy Systems, ETHZ, Zurich, Switzerland, 8 May 2008

Hirschberg S.
"Comparative analysis of energy systems", Lecture given in the Course: Physique des systèmes énergetiques II, EPFL, Lausanne, Switzerland, 27 May 2008

Hirschberg S.
"Life-cycle analysis and multi-criteria assessment of energy systems in view of sustainability indicators", Lecture given in the Course: Renewable Energy Technology I, ETHZ, Zurich, Switzerland, 30 September 2008

Hirschberg S.
"Introduction: Overall approach, risk issues and technologies", "PSA Methodology Overview", Comparative Perspective on Risks", Lectures given in the Course: Centre des sciences naturelles de l'environnement, University of Geneva, Switzerland, 1 December 2008

Hirschberg S.
"Comparative analysis of energy systems", Lecture given in the Course: Advanced Fossil and Renewable Energy Systems, EPFL, Lausanne, Switzerland, 17 December 2008

Podofillini L.
"Genetic algorithms for the optimization of industrial systems: examples of applications on computer", Lecture given in the Course: Innovative techniques for the evaluation of the reliability and availability of industrial plants, Polytechnic of Milan, Italy, 15-18 September 2008

Podofillini L.
"Human Reliability Analysis (HRA) – An Introduction", Lecture given in the Course: Integrated Risk Management, Zürcher Hochschule für Angewandte Wissenschaften (ZHAW), Winterthur, Switzerland, 2 December 2008

Habilitation, Doctoral, Master and Batchelor Theses

Gül T.
"An Energy-Economic Scenario Analysis of Alternative Fuels for Transport", Doctoral Thesis No. 17888, ETHZ Zurich, 2008

Kellenberger M.
"Grössere Bedrohung: Auto- oder Klima-Crash", Bachelor Thesis, ETHZ, Zurich, 2008

Ullmann L.
"Effects of climate change on electricity production in Europe", Bachelor Thesis, ETHZ, Zurich, 2008

PSI and Other Reports

Bauer C.
"Life-cycle assessment of fossil and biomass power generation chains. An analysis carried out for Alstom", PSI-Bericht Nr. 08-05

Burgherr P., Hirschberg S.
"Severe accident database for comprehensive risk assessment in the energy sector", Eur. Safety and Reliability Association (ESRA) Newsletter, http://www.esrahomepage.org/newsletter.aspx, 2008

Dang V.N.
"HRA Data and Recommended Actions to Support the Collection and Exchange of HRA Data", CSNI Report NEA/CSNI/R(2008)9, OECD/NEA Paris, France, 2008

General Communications and Public Relations

Bauer C.
"Nukleare Energie und Nachhaltigkeit", Presentation in the course of the PSI event 'Forscher im Zelt', Baden, Switzerland, 16 August 2008

Bauer C.
"Die 2000-Watt-Gesellschaft, Patentlösung für mehr Nachhaltigkeit?", TechDay@KSL, Kantonsschule, Urdorf, Switzerland, 30 October 2008

Burgherr P.
"Energiesysteme im Vergleich: auf der Suche nach der besten Energiequelle", Tag der offenen Tür – am Puls der Forschung, PSI, Villigen, Switzerland, 26 October 2008

Hirschberg S.
"Energiesysteme im Vergleich", Invited Talk, Delegiertenversammlung der CVP Frauen Schweiz, Basel, Switzerland, 8 March 2008

Hirschberg S., Schenler W.
"Multi-Criteria Decision Analysis: Overview and Options for Trialog", Energietrialog CH, Zurich, Switzerland, 1 April 2008

Hirschberg S.
"Die Rolle der erneuerbaren, nuklearen und fossilen Technologien in der zukünftigen Schweizer Stromversorgung", KKL & KKB Colloquium, Leibstadt, Switzerland, 24 April 2008

Hirschberg S.
"Energiesysteme im Vergleich", Invited Talk, Young Generation, ETHZ, Zurich, Switzerland, 13 May 2008

Hirschberg S.
"Stärken und Schwächen der Kernenergie: Vergleich mit anderen Optionen", Invited Talk, Schweizerische Energie-Stiftung (SES) Fachtagung, Zurich, Switzerland, 12 September 2008

Hirschberg S.
"Zukunftsperspektiven der Energieversorgung: Stromerzeugungstechnologien und das Potenzial der Energieeffizienz", Wirtschaftsanlass, Invited Talk, AEK Energie AG, Solothurn, Switzerland, 22 September 2008

Hirschberg S.
"Life-cycle analysis of carbon dioxide emissions from different energy sources", Invited Talk, Confrontations Europe: Conf. on Optimizing the Mitigation of Carbon Dioxide Emissions in Europe, Sauvons Le Climat et Confrontations Europe, Brussels, Belgium, 7 October 2008

Hirschberg S.
"Electricity supply options in comparative perspective", Invited Talk, Alliance of Liberals and Democrats (ALDE) Workshop on Nuclear Energy in Europe, European Parliament, Brussels, Belgium, 12 November 2008

Hirschberg S.
"Nachhaltigkeitsaspekte verschiedener Energieversorgungssysteme", Lecture given in the Course: Kernbrennstoffe – Wirtschaftlichkeit und Versorgungssicherheit, Nuklearforum Schweiz, Olten, Switzerland, 20-21 November 2008

Hirschberg S.
"Szenarien für die Entwicklung eines wettbewerbsfähigen Energiesystems unter Berücksichtigung von Klimaschutzzielen und Versorgungssicherheit", PSI Veranstaltungsabend, Berne, Switzerland, 2 and 9 December 2008

Prevot A., Heck T., Baltensperger U.
"Caution – Particulates!", PSI Newsletter on Comprehensive Assessment of Energy Systems, Energie-Spiegel 19, 2008 (ISSN 1661-5093)

Schenler W.
"Strom aus Wellenkraft", Invited Talk, AGORA-Tagung, Pfäffikon, Switzerland, 28 February 2008

Simons A.
"Ökobilanzen: eine ganzheitliche Betrachtung", Schweizerische Interessengemeinschaft Baubiologie/ Bauökologie (SIB), Invited Talk, Berne, Switzerland, 15 October 2008

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