SKC Annual Report 2013

Swedish Centre for Nuclear Technology

March 2014
SKC 14-01

SKC, KTH/AlbaNova, Roslagstullsbacken 21, **SE-106 91 STOCKHOLM**
www.swedishnuclear.se janbl@kth.se +46 (0)76 7878 336
www.swedishnuclear.se alavyoon@kth.se +46 (0)8 5537 8819

Summary of 2013

Nuclear education and academic research has been in a steady-state mode in 2013. The power utilities are under certain financial pressure, due to low electricity sales prices. This in turn reflects reduced demand for electricity as a consequence of the finacial crisis that started in 2008, which resulted in the closing of several paper and metal plants that were large electricity consumers. On a European perspective but not to a large extent yet in Sweden, the introduction of wind and solar electricity has resulted in reduced profitability in base-load electricity production. All this has resulted in cost-cutting pressure at power utilities, which to some extent has lead to reduced funding for academic work.

The last call for research funding under the contract on 11.3 MEUR on cooperation with France signed a few years ago was issued. The final call was targeting fuel issues for future fast reactors. This framework comprises work packages on access to training reactors in Saclay for Swedish students, transfer of nuclear physics experimental research equipment to the GANIL laboratory in Caen, as well as access for Swedish PhD students to the research centres in Cadarache and Marcoule. Three major research projects have started in 2012 with the admission of a number of PhD students. Moreover, laboratory tutorials in France for students are now routine operation.

A contract for a new SKC period has been negotiated and signed. Compared to the previous years, there are three differences:

- First, SSM leaves the collaboration. From now on, SSM will spend about the same amount as before, but through direct contracts.
- Next difference is that it comprises three years, in contrast to the six-year commitments of the last two previous periods. This is due to changed rules of two of the four remaining industrial companies.
- Finally, the total amount is slightly reduced.

The Sigvard Eklund price to the best PhD thesis of the year was awarded to Claudio Lousada for his work on radiation-induced processes at interfaces between water and solid oxides relevant to reactor chemistry and nuclear waste management. Claudio Torregrosa Martin won the price for the best masters´ thesis for his work on the impacts of core melt accidents in the Nordic Boiling Water Reactors. Finally, Johan Erlandssson and Patrik Berg shared the price in the bachelors' thesis class for work on turbulence models for CFD.

Contents

SKC-Partners, Tasks and Goals

By Jan Blomgren,
Director of SKC until 2013-12-31

SKC – Swedish Center for Nuclear Technology or Svenskt Kärntekniskt Centrum in Swedish – has been active since 1992 in providing support to education and research within the nuclear power area. From the first of January 2008 the SKC partners have entered a new six-year period of support to KTH, Chalmers and Uppsala University for senior positions at these universities and for research projects.

The partners have been:

- Swedish Radiation Safety Authority (SSM, Strålsäkerhetsmyndigheten)
- Forsmark Kraftgrupp AB
- Ringhals AB
- OKG AB
- Westinghouse Electric Sweden AB

and the three universities:

- Kungliga Tekniska Högskolan (KTH)
- Chalmers Tekniska Högskola AB
- Uppsala Universitet

SKC is active within three research programs:

1) Nuclear Power Plant Technology and Safety
2) Reactor Physics and Nuclear Power Plant Thermal Hydraulics
3) Materials and Chemistry

An education program is also supported by financial contributions to senior positions at the universities.

Within the research programs the focus has been on the areas of primary interest to the SKC partners, as shown in the following list:

- Thermal-Hydraulics
- Core Physics
- Core and Plant Dynamics
- Chemistry
- Material physics and engineering
- Safety & Severe Accidents
- Reactor Diagnostics
- Detectors and measurement
- Safeguards
- Fuel Technology

SKC has been established to provide long-term support to securing knowledge and competence development at an academic level for the Swedish nuclear technology programs. The intention has been to be a basis for providing resources to the Swedish nuclear industry and its regulator. This means that SKC has strived to contribute to a safe, effective and thus reliable nuclear energy production, which is an important part of the Swedish energy supply.

SKC has had five top-level goals for reaching its vision:

1. Increase the interest among students to enter nuclear technology education.
2. Make sure that the needs of the SKC financing parties to recruit qualified personnel with a nuclear technology education are met. To meet this goal, the universities will offer relevant basic education, execute research projects and support continued education of engineers already active in the nuclear technology area.
3. Offer attractive education in the nuclear technology area.
4. Maintain strong and internationally acknowledged research groups within areas that are vital for and unique to the nuclear technology area.
5. Create organizations and skills at the universities such that research can be performed on account of the financers of the SKC also outside the boundaries of the SKC agreement.

Formally, SKC has been organized as a center within the School of Sciences at KTH.

For further information see:
www.swedishnuclear.se

SKC – preparing for the future

A message from the directors - the former and present

"It is difficult to make predictions – especially about the future…"

This old saying seems like a good summary of the present situation for academic education and research in the nuclear sector. There have been few, if any, periods in time when the volatility in the preconditions have been larger.

All major power utilites in Europe face profitability challenges. The electricity demand has decreased as a consequence of the financial crisis since 2008, which has pushed some large users of electricity out of the market. At the same time, the subsidized introduction of large volumes of intermittent power has pushed down sales prices, reducing the business results for base-load production. Occasionally, *negative* prices have appeared, signaling a non-functional market. All this has resulted in cost-cutting pressure, which negatively affects the industry support to universities.

At the same time, there is a pending application by Vattenfall for nuclear new-build in Sweden. At present writing, SSM is working on outlining the requirements for a full-scale application, planned to be available during 2015. When the requirements are available, industry might – or might not – proceed with an investment decision. In case of a new-build decision, next phase would require recruitments several hundred full-time staff at Vattenfall, as well as a smaller but significant number also at SSM. Given that the entire nuclear power industry hires about several hundred persons per year, this would make a significant increase in staffing needs. If E.On decides to go for new-build as well, the numbers would obviously be even higher.

Thus, the prospects for nuclear education range from cost-cutting pressure to rapid increase, and it is presently no strong consensus of the future predictions. It seems unlikely though that an investment decision will be taken within three years from now. Maintaining the capacity for rapid growth in case of a future new-build decision presents a difficult challenge for the coming three-year SKC period. The financing parties of SKC have declared a resolve to continue supporting education at present level and content.

On the research side, however, there has been a slow but steady shift in interest over the years from reactor physics and thermal hydraulics towards materials issues in general, and aging of materials in particular. This is a natural consequence of the evolution of the industry. In its early years (1970-90), challenges for operation were often linked to reactor physics and thermal hydraulics. Thanks to research and development in the last 40 years, many of these issues have been solved or at least are under better control today, and the further need for research for the present LWR fleet in these fields is not as large now.

Instead, the interest in materials degradation has increased. This is also logic; a nuclear power plant is relatively expensive to build but the operational costs are comparatively low. As a consequence, there is profound business logic in prolonged operation as long as availability and safety can be upheld high. Aging of materials is one of the limiting factors for prolonged operation, and henceforth materials research has a strong business case.

This has resulted in a gradual shift in interest in industry under the SKC agreement of 2008-13 towards increased attention on materials research. This shift in attention will continue in the new SKC.

It should be underlined that this shift is primarily in research. When it comes to education, the traditional areas, like nuclear and reactor physics as well as thermal hydraulics, will maintain their strong presence. It is difficult to imagine materials aging as intellectual basis for an educational program in nuclear engineering. Finding viable formats for maintaining strong academic education and research in the traditional nuclear engineering fields with simultaneous growth in materials research, in a situation of cost-cutting pressure presents a challenge for SKC in the coming years.

The challenges outlined above are not unique to SKC, but are pertinent to all education and research in the nuclear sector. SKC has played an important role as bridge between universities, regulator and industry. In spite of the structural changes and financial challenges, we are convinced SKC will play a vital role also in the years to come.

Jan Blomgren

SKC director (2009-02-01 – 2013-12-31)

Farid Alavyoon

SKC director (from 2014-01-01)

Organization and funding

SKC financing organizations provide 17 million Swedish kronor annually to the universities.In addition, SKC administrates a grant on 3 million SEK for education.

Svenskt Kärntekniskt Centrum – SKC – started a new organizational model January 1, 2008, which has been in operation since, and the present organization was terminated December 31, 2013.

The funding organizations have been:

- Forsmarks Kraftgrupp AB
- OKG AB
- Statens Strålsäkerhetsmyndighet
- Ringhals AB
- Westinghouse Electric Sweden AB

The contract stated that the funding organizations should contribute 17 million SEK annually to senior positions at the universities and to research activities. About half the support has been provided as a guaranteed base funding, and the rest has been possible to re-distribute between the universities.

An advisory council has been formed in which discussions on strategy and funding has taken place. The members have been selected to cover the most important areas of nuclear technology, and a relatively even representation of the funding organizations has been strived for. The delegates did, however, not represent their organizations in the council. The council provided advice to the board, but took no decisions.

During 2013, the advisory council has consisted of:

- Per Brunzell, chairman
- Farid Alavyoon, Forsmarks Kraftgrupp AB
- Henrik Dubik, OKG AB
- Björn Forssgren, Ringhals AB
- Ninos Garis, SSM
- Ingemar Jansson, Westinghouse
- Elisabeth Tengborn, SSM

In addition, Jan Blomgren has attended the meetings as secretary.

The SKC Board has consisted of:

- Karl Bergman, Chairman, Vattenfall
- Lars Berglund, Forsmarks Kraftgrupp AB
- Johan Dasht, OKG AB
- Lennart Eckegren, Ringhals AB
- Eva Simic, SSM
- Anders Andrén, Westinghouse
- Gustav Amberg, KTH, replaced by Leif Kari 2013-09-20
- Irene Kolare, Uppsala University
- Mats Viberg, Chalmers

In addition, Jan Blomgren has attended the board meetings but has had no vote.

A new SKC perid starts 2014-01-01 and lasts three years. The parties and organization are the same, except that SSM does no longer participate. The total volume for the three years is 32 300 000 SEK.

Farid Alavyoon takes over as SKC Director starting 2014-01-01.

SKC financials in 2013

The following table summarises the SKC financials for 2013

Received from financing parties		17 000 000 SEK
Balance from previous years SKC		-1 645 603 SEK
Balance from previous year French Lab		+464,940 SEK
French laboratory support + other income		3 141 894 SEK 1 446 495 SEK
KTH	6 300 000 SEK	
Chalmers	5 100 000 SEK	
Uppsala University	3 300 000 SEK	
SKC centrally	2 300 000 SEK	
French laboratory costs	2 444 614 SEK	
Balance French Lab YE		+1 162 220 SEK
Balance SKC YE		-107 704 SEK

The contributions from the financing organizations are split as follows:

SKI/SSM	33%
Westinghouse	20%
Ringhals	19%
Forsmark	14%
OKG	14%

Comment: The negative balance from previous years is due to a large marketing campaign motivated by the collaboration with France established 2010 and on. It has been paid off during the remaining SKC contract period, to balance at the end of 2013. The remaining balance at the end of 2013 has been transferred to the new SKC.

Winners of the Sigvard Eklund Price in 2013

Left to right, standing: Johan Erlandsson, Patrik Berg, Cláudio Miguel Lousada Patricio and Jan Blomgren. Below: Claudio Torregrosa Martin. Picture from the prize ceremony at Gimo manor during the SKC annual symposium.

Cláudio Miguel Lousada Patricio, KTH, was awarded the prize for the best PhD thesis, which has the title "Reactions of aqueous radiolysis products with oxide surfaces: An experimental and DFT study". His work is characterized by the review committee:

The work combines experimental and computational approaches to study radiation induced processes at interfaces between water and solid oxides relevant to reactor chemistry and nuclear waste management. It contributes to a deeper understanding of solid-liquid interfacial processes at atomic and molecular scales thanks to the mastering of several relevant techniques including γ-irradiation to study surface reaction kinetics, spectrophotometry for tracking the concentration of radiolysis products, inductively coupled plasma spectroscopy for trace elemental analysis, titration methods, gas chromatography, micromeritics and X-ray diffraction.

The experimental results, discussed at the light of the density functional theory, provide new knowledge of radiolysis products interaction with surfaces of oxides of d- and f-elements.

Claudio Torregrosa Martin, KTH, was awarded the prize for the best Masters' thesis, which has the title "Coupled 3D Thermo-mechanical Analysis of Nordic BWR Lower Head Failure in case of Core Melt Severe Accident". His work is characterized by the review committee:

Claudio Torregrosa Martin's master thesis advances the understanding of the impacts of core melt accidents in the Nordic Boiling Water Reactors. The ways a core melt can be released from the reactor pressure vessel is determined using models of the melt behaviour and the structural strength of the reactor vessel and its penetrations. The results of the work are presented in a

comprehensive way that is transparent despite the complexity of the subject.

The thesis covers a long term issue which is also of current importance to the safety demonstration of nuclear power plants. It demonstrates the dominant ways a core melt may be released from the reactor pressure vessel and thus provides an important basis for ensuring its final coolability and melt confinement.

The scope and quality of Claudio Torregrosa Martin's work exceed what is expected of a master thesis. This is supported by the fact that part of it has also been published at an international conference (NURETH-15).

Johan Erlandsson and Patrik Berg, Uppsala University, shared the prize for the best Bachelors' thesis, which has the title "Analysis of turbulence models for CFD". Their work is characterized by the review committee:

A solid work where the authors have successfully penetrated a complex topic and made interesting comparisons of experimental data and various turbulence models. The report is well written with extensive treatment of theory and results, and an in-depth discussion.

Chalmers University of Technology

Overview of Activities in 2013

The Sustainable Nuclear Energy Centre

A new centre, called the Sustainable Nuclear Energy Centre (SNEC), was created on January 31, 2012 at Chalmers, and was formally inaugurated on October 8, 2012. This centre allows coordinating and structuring research, education, and communication about all aspects of nuclear energy and uses of radioactive elements in a comprehensive, responsible, and critical manner.

The main focus of the centre is on a Forum where researchers, MSc students, PhD students, as well as industry members, meet to discuss and exchange ideas, information, and knowledge, thus contributing to a better networking between the industry, the academia, and its students.
The key feature of the Forum is that the industry representatives are in direct contact with Chalmers researchers, and can thus directly interact with them. It also creates a unique opportunity to discuss any issue with a variety of competences, thus favouring the actual problem formulation. Problem formulation and definition are often the most important steps towards a solution.

At present, the following research areas, each led by a senior scientist, are actively pursued at Chalmers:

- Computational and experimental fluid mechanics.
- Reactor physics and dynamics.
- Multi-physics and multi-scale modelling of nuclear systems.
- Deterministic safety analyses.
- Severe nuclear accidents.
- Fusion plasma physics.
- Radiation protection.
- Nuclear techniques.
- Particle and heavy ion Monte Carlo simulations.
- Degradation of nuclear materials.
- Non-destructive testing.
- Nuclear Safeguards.
- Nuclear fuel integrity management.
- Safety related to fuel coolant interactions.
- Novel nuclear fuel production.
- Separation/transmutation.
- Final repository.
- Technology assessment of nuclear expansion.
- Political aspects of spent nuclear fuel.

The Forum is mainly managed via a web-based platform used for assuring the proper dissemination of information within the centre and to the industrial SNEC members. The platform includes more than 120 users, gathering Chalmers researchers and students, as well as the representatives of the industrial partners supporting SNEC.

The 2013 industry members in SNEC include:

- E-ON.
- Studsvik Scandpower.

The coordination of SNEC is assured by a coordination group. Only the divisions at Chalmers being full SNEC members participate to the coordination group. The following Chalmers divisions/departments are participating to the coordination of SNEC:

- Div. of Nuclear Chemistry, Dept. of Chemical and Biological Engineering.
- Div. of Nuclear Engineering, Dept. of Applied Physics.
- Div. of Materials Microstructure, Dept. of Applied Physics.
- Div. of Advanced Non-destructive Testing, Dept. of Materials and Manufacturing Technology.
- Div. of Physical Resource Theory, Dept. of Energy and Environment.
- Div. of Fluid Dynamics, Dept. of Applied Mechanics.

The following Chalmers divisions/departments are participating to some extent to the Forum only, but are not full SNEC members:

- Dept. of Political Science (University of Gothenburg).
- Dept. of Literature, History of Ideas, and Religion (University of Gothenburg).
- Dept. of Mathematical Sciences, Chalmers.
- Div. of Materials and Surface Theory, Dept. of Applied Physics, Chalmers.
- Div. of Transport Theory, Dept. of Earth and Space Sciences, Chalmers.
- Div. of Dynamics, Dpt. of Applied Mechanics, Chalmers.
- Div. of Subatomic Physics, Dept. of Fundamental Physics, Chalmers.
- Fraunhofer Chalmers Centre.

Formal decisions are taken by a steering group, which is also responsible for the overall strategy of the centre. The departments having one of its divisions being a full SNEC member are represented in the steering group. The steering group also gathers one representative per industry member.

In 2013, SNEC has been intensively working on structuring the activities of the centre, and its internal as well as external communication.

For the external communication, a homepage http://www.chalmers.se/snec was created, with all the main information about SNEC available at one single location. Newsletters are also regularly dispatched (at a frequency of 4 newsletters per year) and sent out to the nuclear community Chalmers has contact with – both nationally and internationally. One of the main investments made by SNEC was professional IT solutions allowing both live-streaming and on-demand viewing of seminars/meetings. With the SNEC seminar series running in 2013, additional invited guest researchers/speakers, and special events, there are already more than 20 recorded technical presentations, all of them being freely available in the web archive. Some Master of Science project presentations were also recorded. The system was also used with great success for distant education.

A web-based platform restricted to the SNEC members was also purchased and allows better structuring the flow of information between the SNEC members. Some of the main research tracks tackled at Chalmers use the platform for sharing/discussing scientific matters and projects, as well as for project management. The internal web-platform counts more than 130 members (academia, industry representatives, and students).

In 2013, three special events were organized by SNEC: a career guide day for the students (in the spring), and more recently the SNEC day, which gathered more than 100 participants to discuss the future of nuclear energy. During that day, the documentary Pandora's Promise was also shown, and a panel discussion arranged. SNEC was also involved in organizing a seminar on the possible future of nuclear-powered ships.

Use of the SKC funding

The SKC funding is currently supporting three Divisions at Chalmers:

- Div. of Nuclear Chemistry, Dept. of Chemical and Biological Engineering.
- Div. of Nuclear Engineering, Dept. of Applied Physics.
- Div. of Materials Microstructure, Dept. of Applied Physics.

The facilities and tools available at these Divisions are as follows:

- A pulsed beam for variable energy slow positrons.
- A portable 14 MeV pulsed neutron generator.
- Access to all major system codes for neutronic and thermal-hydraulic calculations.
- Laboratories for α, ß, γ experiments and activity measurements.
- A hot cell laboratory for γ activity.
- A special laboratory for research on advanced nuclear fuels (collaboration with KTH), including both a SEM and XRD facility.
- Several irradiation sources including a 18 kGy/h ^{60}Co and ^{137}Cs facilities ranging from 50 Gy/h and down to 1 Gy/h.
- An Atom Probe Tomography Instrument.*
- Three Transmission Electron Microscopes.*
- Two Scanning Electron Microscopes.*
- Two Focused Ion Beam Workstations.*

*Managed by the infrastructure unit at the Dept. of Applied Physics

The following PhD projects were supported, either fully or partially, by SKC during 2013:

- Development of an integrated neutronic/thermal-hydraulic model using a CFD solver (PhD student: Klas Jareteg; supervisor: Professor Christophe Demazière).
- Investigation of the use of thorium in LWRs for improving reactor core performance (PhD student: Cheuk Wah Lau; supervisor: Adjunct Professor Henrik Nylén).

Highlights of the year

Some of the highlights of the year are given below:

- On April 24th, 2013, seven successful senior experts were gathered at Chalmers to participate in the first edition of SNEC's Career Guide. Together with the senior experts were about 30, curious, students. By organizing events of this character, students and the nuclear industry find a platform to interact where they can exchange ideas and experience. This, hopefully, yielded new contacts and experience for all involved parts. The career guide was divided into two parts, a panel discussion and individual career talks.
- On November 26th, 2013, SNEC arranged its annual convent, the SNEC Day, during which the future of nuclear power was discussed. Brought to the table were three alternatives for the use of nuclear power, specifically: (i) running the existing reactor fleet as long as possible, (ii) building new units or (iii) closing and decommissioning the existing reactors. Participating in the convent were over 100 representatives from academia and industry, as well as general public. The core of the convent was to reflect on the word Sustainability – a word with diverse interpretations. By bringing together actors from various disciplines, the centre allowed different standpoints to meet on common ground to touch on aspects of nuclear energy in a comprehensive, responsible and critical manner. The technical presentations were followed by a screening of the documentary "Pandora's Promise", directed by Robert Stone, who himself presented the documentary via Skype. The documentary had only been shown in selected movie theatres and at selected events, mostly in USA, England and Scotland. The film has been the subject of discussion because of its positive stance towards nuclear energy in a climate mitigation perspective. A panel discussion followed the screening.

Picture taken during the SNEC Day, with Lina Färm (on the left) acting as a moderator during the entire event and Prof. Christian Ekberg, SNEC Scientific Leader (on the right) introducing the day. © Christophe Eléhn

- On November 27th, 2013, SNEC was also involved in organizing a seminar on the possible future of nuclear-powered ships. During this event, experts from academia and industry joined forces to discuss the various aspects of nuclear powered ships, involving nuclear technology and economics of nuclear power, as well as safety and risk, sustainability and maritime environment.
- Prof. Imre Pázsit was appointed on December 1st, 2013, by Elsevier as Executive Editor of Annals of Nuclear Energy, the premier European journal of nuclear engineering, succeeding Professor

M.M.R. Williams of Imperial College, who has been the European Editor of the journal over 40 years.

- Prof. Christian Ekberg was appointed new member of the Royal Swedish Academy of Engineering Sciences (IVA).
- Dr. István Pusztai, a former PhD student of the Department of Applied Physics, was awarded the 2013 European Physical Society, Plasma Physics Division PhD Research Award for his thesis titled "Turbulent and neoclassical transport in tokamak plasmas". Dr. Pusztai did his PhD Studies in the Fusion theory group, Division of Nuclear Engineering, supervised by Prof. Tünde Fülöp. The award was announced at the opening ceremony of the 40th European Physical Society Conference on Plasma Physics in Espoo, Finland.
- 38,5 MSEK were awarded from Knut and Alice Foundation (KAW) to a project, led by Prof. Tünde Fülöp, dedicated at boosting the technology of plasma based compact ion sources. The project combines expertise in theoretical and experimental high-intensity laser physics, plasma physics and strong-field physics. Advanced simulations of laser-matter interactions will be performed, novel experimental scenarios (using e.g. nano-structured targets) will be investigated and new parameter regimes will be explored. Apart from providing new and fundamental knowledge in the field of laser-plasma physics, the project will yield clear directions for increasing the efficiency and beam quality of ion sources driven by table-top high-repetition-rate lasers. This will have a wide range of potential applications: from cancer treatment to engineering diagnostics and material structure analysis.

- Also this year Chalmers was awarded projects in the Swedish-French collaboration on nuclear issues administrated by the Swedish Research Council (VR). This time the focus was on fuel related matters and the approved project led by Prof. Christian Ekberg aims at understanding the interactions between oxide fuels/coolant and cladding material. The size of the project is two post doc years to be spent at CEA Cadarache, France.
- A new edition of the book Radiochemistry & Nuclear Chemistry, by Gregory Choppin, Jan-Olov Liljenzin, Jan Rydberg, and Christian Ekberg, was published by Academic Press.
- The DREAM task force (Deterministic REActor Modelling), led by Prof. Christophe Demazière, gave in the Spring period a course in nuclear reactor modelling, but this time in a web-based format. The course was attended by Chalmers students, as well as external students (1 student from Finland, 1 student from Norway, 1 student from the industry, 5 students from Uppsala University, and 3 students from the Royal Institute of Technology). The course, which received very positive feedback, will again be given in a web-based format in the Spring of 2014.
- Assist. Prof Paolo Vinai, working at the Div. of Nuclear Engineering, Dept. of Applied Physics, was promoted Docent on November 5th, 2013.

In SKC-related subjects, the following Master theses were successfully presented during 2013:

- A. Azadrad. Statistical analysis of plant data for revision of operating rules minimizing risk of PCI failure in BWRs.
- F. Di Dedda. Definition of a dynamic source term module within RASTEP.
- F. Larsson. Validation of new fuels for storage in the dry storage facilities of the Nuclear Power Plant at Oskarshamn using MCNP.
- A. Maripuu. Handling of risks of events with low probability and severe consequences at a nuclear power plant.
- H. Halldin and K. Rosenqvist. MCNP5 Criticality Safety Modeling and Validation for LWR Fuel Cycle Application.
- D. Ostrovskii. Trend analysis in input data for PSA.
- R. Sarwar. Validation of POLCA7 cross section model.
- W. Ziguan. General Analytical Solution for Two-group, Two-point Variance-to-mean Formulas and Their Application to Safeguards.
- E. Larsson. Uncertainty in measurement for operability verification tests.
- J. Eriksson and J. Eriksson. Modelling of new Feedwater Control Strategies in Ringhals 4.
- S. Zamir. A study of the discrepancies between measured and calculated reactivity at Ringhals PWR.
- D. Åström. Modeling Heat Transfer in the Seawater Cooling System of Ringhals 3 and 4.
- R. Magnusson. Modeling of PWR LOCA experiments in RELAP5 based on PREMIUM benchmark.

- J. Hempel and O. Lindgren. Development of a two way fluid structure interaction model for pipe system analysis.

In SKC-related subjects, the following Licentiate theses were successfully presented during 2013:

- A. Mollén. Turbulent impurity transport in tokamaks.

In SKC-related subjects, the following PhD theses were successfully presented during 2013:

- H. Hedström. Radium sulphate and its co-precipitation behaviour with barium and strontium.
- L. Intiso. Fundamental studies on the high temperature corrosion mechanisms of a 22Cr austenitic stainless steel in environments related to oxy-fuel combustion.
- G. Papp. The role of magnetic perturbations in runaway electron and sawtooth dynamics.
- F. Zylbersztejn. Developments and application of neutron noise diagnostics of sodium cooled fast reactors.
-

Master education

The Div. of Nuclear Engineering, Dept. of Applied Physics, Div. of Materials Microstructure, Dept. of Applied Physics, and the Div. of Nuclear Chemistry, Dept. of Chemical and Biological Engineering, together with the Div. of Advanced Non-destructive Testing, Dept. of Materials and Manufacturing Technology, and the Div. of Physical Resource Theory, Dept. of Energy and Environment, organize a two-year international master program in Nuclear Engineering. This master program is based on a contract between E.ON and Chalmers, and is also financially supported by SKC.

A vast majority of the master theses have been performed in collaboraton with the nuclear industry.

As opposed to earlier courses in nuclear engineering, the new program is more engineering oriented and aims at students with backgrounds in physics, chemistry, mechanical or electrical engineering. The master programme is the only nuclear education in Sweden combining physics and chemistry in one educational program. The philosophy of this programme is to have a “top-down” approach in teaching the physics of nuclear reactors, i.e. starting with an overview of how nuclear reactors work, followed by a detailed description of the main governing physical phenomena and corresponding equations, and finally elective and specialized courses.

A few highlights for 2013:

- A new course in Nuclear materials was developed and given for the first time during the Spring period of 2013. Several guest lecturers from industry gave lectures in this course.
- The master program was presented for students both at CHARM and later at information sessions preparing the students for selecting master programs.
- In 2012, a guest lecturer from WANO (World Association of Nuclear Operators) was invited for two days to talk about safety culture. This was appreciated by the students and repeated autumn 2013.
- Within a French-Swedish agreement regarding exchange of nuclear services as part of the European Spallation Source, the students for the master program have been to a research reactor in Saclay, France in spring 2013. The exercise was in form of a two-and-a half day laboratory exercise on a small open pool reactor.
- An inventory of courses has started, and will proceed with the aid of SNEC. Some elective specialized courses have very few students and it might be necessary to substitute these with other courses.

PhD education

The Doctoral School in Nuclear Engineering has on the average about 10 enrolled PhD students. The Doctoral School was designed in such a way that students with various backgrounds could be accepted to the Doctoral School. This corresponds to the fact that nuclear engineering is by essence a cross-disciplinary area, and consequently might attract students with various backgrounds (physics, chemistry, mechanical engineering, electrical engineering). Such a mix of students within one single Doctoral School creates a very rich and stimulating environment for the students during their PhD studies. Correspondingly, the list of compulsory courses is kept at a strict minimum so that the students can best choose the courses depending on their background and their research project.

Another strength of the school is the fact that the elective courses that are offered in the Master of Nuclear Engineering and corresponding to an advanced level can also be taken as PhD courses. The resulting mix between MSc students and PhD students favours discussions between the students, each having his/her own paradigm. This also creates a natural bridge between the MSc and PhD educations, which will ultimately result in more students interested in pursuing an academic career.

The PhD students enrolled in the school have also the possibility to attend courses at other universities both in Sweden and abroad.

Publication statistics

Some data taken from the Chalmers Publication Library (CPL) about the 2013 publications from the Divisions getting some SKC financial supports are given below.

	Div. of Nuclear Chemistry	Div. of Nuclear Engineering	Div. of Materials Microstructure	Total
Number of peer-reviewed journal articles	24	43	21	88
Number of peer-reviewed conference articles	1	23	2	26
Number of PhD theses	1	2	1	4
Number of Lic. theses	-	1	-	1
Number of MSc theses	-	14	-	14
Number of reports	-	3	-	3
Total number of publications	26	86	24	136

KTH – Royal Institute of Technology

Overview of Activities in 2013

KTH is the largest technical university in Sweden providing a broad spectrum of research and education in the nuclear engineering field. Both the theoretical and experimental research is performed employing a high-bay experimental infrastructure for investigations of, e.g., thermal margins in nuclear reactors, nuclear and construction material properties, new nuclear fuels and severe accidents scenarios and phenomena in nuclear power plants. Nuclear engineering research performed at KTH has a very high international reputation, resulting from numerous publications and citations. KTH-based PhD research has received 5 (out of 10) Sigvard Eklund's Prizes for best PhD theses in nuclear engineering area. KTH provides excellent education on the undergraduate level through the Master Program in Nuclear Energy Engineering. The program was established in 2007 and is already highly ranked in Europe. In 2013 the program received prestigious and highest grade "Very High Quality" (Mycket Hög Kvalitet) in an assessment performed by the Swedish Higher Education Authority (Universitetskanslersämbetet, UKÄ), together with 5 other programs (out of 35 assessed) at KTH. Nation wise KTH's Master Programme in Nuclear Energy Engineering turned to get the highest evaluation grade in this field of education. Our Master program is also highly appreciated by Swedish industry receiving 8 (out of 10) Sigvard Eklund's Prizes for best Master theses in nuclear engineering area. The Centre for Nuclear Energy Engineering at KTH (CEKERT) has currently 14 faculty members. Research and education within the field of nuclear energy engineering is carried out in several divisions within the School of Engineering Sciences and the School of Chemical Science and Engineering.

Highlights and major research outcome

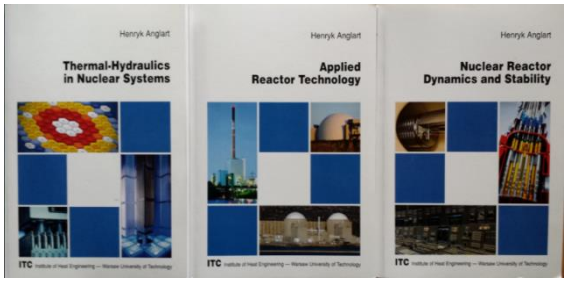
Pär Ljustell successfully defended his PhD thesis on February 1, 2013. The thesis title is Fatigue crack growth experiments and analyses from small scale yielding to large scale yielding at constant and variable amplitude loading. Faculty opponent was Professor Gunnar Härkegård from NTNU in Trondheim. Dr Ljustell's work was partially financed by the Swedish nuclear regulatory agency SSM.

Pål Efsing was invited lecturer at an IAEA Regional Training Course on Material Degradation Mechanisms and Ageing Management Programme in Nuclear Power Plants, in Ljubljana, Slovenia and sponsored by the Slovenian government in October 2013 with participants from the former Soviet Union and Eastern Europe countries employing Russian reactor technology as part of the IAEA technology transfer program.
Merja Pukari defended her PhD thesis ahead of schedule on June 14, 2013. The thesis title is Experimental and theoretical studies of nitride fuels. Faculty opponent was Professor Toru Ogawa from the University of Nagaoka in Japan.
Jonas Faleskog was invited to give a key note lecture entitled "Ductile Failure at Low Stress Triaxiality" at "2nd International Workshop on Physics-Based Modelling of Material Properties and Experimental Observations with special focus on Fracture and Damage Mechanics", organized by European Commission Joint Research Centre, Petten, The Netherlands, May 15-17, 2013. The Workshop was funded by the EU Enlargement & Integration Action (E&IA) and, co-organized by the Institute of Energy and Transport and the Joint Research Centre (JRC) and TOBB University of Economics and Technology (TOBB ETU).
Henryk Anglart served as a member of the technical program committee during the NURETH-15 conference and was co-organizing three workshops on "Nuclear Industry and Academic Cooperation in Research and Education", "CHF Evaluation and Experiments" and "Teaching Nuclear Thermal Hydraulics Tomorrow" during the conference.

Henryk Anglart became a corresponding international member of the Japanese Two-Phase Flow Society.
Henryk Anglart was invited by the Dean of Xi'an Jiaotong University (XJTU), School of Nuclear Sciences, to deliver lectures on recent advancements in CFD applications to nuclear fuel related research.

Prof. H. Anglart lecturing at XJTU, Xi'an, China, 6-8 May, 2013.

Henryk Anglart published during 2013 three books within the field of nuclear engineering:



Nuclear Reactor Dynamics and Stability, Warsaw University of Technology Publishing House, ISBN 978-83-7814-089-4, 159p, 2013.

Applied Reactor Technology, Warsaw University of Technology Publishing House, ISBN 978-83-7814-088-7, 208p, 2013.

Thermal-Hydraulics in Nuclear Systems, Warsaw University of Technology Publishing House, ISBN 978-83-7814-090-0, 234p, 2013.

Henryk Anglart has been invited to serve as a member of the technical program committee of the NUTHOS-10 conference.
Collaboration agreements in nuclear power safety have been signed with KIT, Germany, KAERI, Korea and POSTECH, Korea.
NPS organized "The 5th Meeting of European MELCOR User Group" on May 2-3, 2013 in KTH and co-organized international DPSA Workshop on NURETH-14 conference.
In collaboration with CEA, France, KTH continued new safety research project for ASTRID sodium-cooled fast reactor.
KTH further developed cooperation with Japan assisting MHI in experimental study of steam explosion during corium melt spreading under the water.

Several new test facilities have been designed and are under construction and commissioning:

- facility for study fragmentation of metal melt jets and debris formation;
- TALL-3D liquid metal loop for validation of coupled STH and CFD codes in application to thermal hydraulic and safety analysis of heavy liquid metal cooled systems;
- MICROBO facility for investigation of liquid film dynamics at boiling.

The EU-financed project MAXSIMA on methodology, analysis and experiments for support of the safety assessments of MYRRHA lead-bismuth cooled reactor has reached a good progress.

KTH continued several projects for safety improvement of Nordic BWR reactors and provided technical support to SSM in coupled neutronic/thermohydraulic analysis of different NPP units and in MELCOR simulation of severe accidents. KTH participated in OECD benchmark on Oskarshamn-2 BWR 1999 Stability Event.
Mats Jonsson gave the following invited talks: 28th Miller Conference on Radiation Chemistry, 14-19 March 2013, Israel.
1st Russian-Nordic Symposium on Radiochemistry, 21-24 October 2013, Moscow, Russia.
2nd Summer School of Nuclear Chemistry and Engineering, 16-20 September 2013, University of Warsaw, Poland.
Mats Jonsson delivered the following oral presentations:
14th International Conference on the Chemistry and Migration Behaviour of Actinides and Fission Products in the Geosphere, 8-13 September 2013, Brighton, UK.
MRS Scientific Basis for Nuclear Waste Management XXXVII, 29 September-3 October, Barcelona, Spain.

PhD education

The following PhD and Licentiate Theses were completed during year 2013:

Roman Thiele, "Prediction of forced convection heat transfer to lead-bismuth eutectic", lic. thesis, Nuclear Reactor Technology, 2013.

Joanna Peltonen, "Effective spatial mapping for coupled code analysis of thermal-hydraulics/neutron-kinetics of boiling water reactors", PhD Thesis, Nuclear Power Safety, ISBN:978-91-7501-661-0, June 2013.

Merja Pukari, "Experimental and theoretical studies of nitride fuels", PhD Thesis, Reactor Physics, ISBN 978-91-7501-794-5, June 2013.

Zhongwen Chang, "Modelling of Dislocation Bias in FCC Materials", Lic. Thesis, Reactor Physics, 2013.

Cláudio Miguel Lousada Patrício, Reactions of aqueous radiolysis products with oxide surfaces - An experimental and DFT study, 12 April.

Veronica Diesen, Heterogeneous TiO2 Photocatalysis - Fundamental Chemical Aspects and Effects of Solid Phase Alterations, 12 December.

The following PhD projects were carried out during the year:

Ionut Anghel: "Post-dryout heat transfer in channels with flow obstacles", supported by SKC. PhD defence scheduled in March 2014.

Reijo Pegonen: "Development of new procedures for thermal-hydraulic analyses of the Jules Horowitz Reactor", PhD thesis project supported by VR.

Anders Riber-Marklund: "Acoustic leak detection in sodium applications", PhD thesis project supported by VR.

Roman Thiele: "Prediction of wall temperature characteristics with focus on thermal fatigue of nuclear materials", PhD thesis project partly supported by SKC and the THINS project.

Mattia Bergagio: "Experimental and analytical investigation of wall temperature characteristics with focus on thermal fatigue of nuclear materials", PhD thesis project partly supported by SKC.

Michel Sedlak; Mechanical modelling of stress-corrosion cracking in sensitized stainless steel 316 in BWR water; partly funded by SKC.

Rickard Shen; Influence on Microstructure and Residual stress on Stress Corrosion Cracking in Nickel Based Alloys; funded by Vattenfall, E.On and Fortum.

Martin Bjurman; Thermal ageing of cast and welded austenitic structures containing ferrite.

Viet-Anh Phung, “Development of a method for the treatment of two-phase flow patterns in nuclear reactor thermal hydraulic system code”, supported by SKC and APRI-8 projects.

Hua Li, “Condensation and mixing phenomena in a BWR suppression pool”, supported by NORTHNET-RM3 and NKS.

Kaspar Kööp, “Passive safety systems in advanced nuclear power plants: design, performance analysis and integrated assessment”, supported by SKC, SSM-DPSA and THINS projects.

Sachin Thakre, “Simulation of fuel coolant interactions and corium coolability during a severe accident of LWRs”, supported by the APRI-8 and SARNET2 projects.

Marti Jeltsov, “Coupling of system code with CFD for nuclear reactor thermal hydraulic and safety analysis”, supported by the THINS and SILER project.

Simone Basso, “Particulate Debris Spreading and Debris Bed Coolability in Light Water Reactor Severe Accident”, supported by APRI-8 and MHI-HQ projects.

Sebastian Raub, “Safety analysis of ASTRID core catcher”, supported by ASTRID-Safety project.

Sergey Galushin “Integrated Approach to Risk Oriented Analysis of Severe Accidents”

Louis Manickam, “Investigation on micro-interactions of high-temperature droplets with coolant during a postulated severe accident of light water reactors”, supported by the APRI-8 project.

Erdenichimeg Sudvatseneg, “Design studies of lead cooled reactors”.

Pertti Mallki, “Fabrication, characterization and testing of nitride fuels for light water reactors”, PhD thesis supported by SKC.

Zhonwen Chang, “Multi-scale modelling of swelling in Fe-Cr-Ni alloys”, VR supported PhD project in the GENIUS programme.

Luca Messina, “Modelling of radiation induced ageing in iron based alloys”, PhD thesis project supported by Vattenfall.

Antoine Claisse, “Modelling of fission gas release in PuN fuel”, PhD thesis project supported by SKB.

Kyle Johnson, “Fabrication and dissolution performance of nitride fuels”, PhD thesis project supported by the ASGARD EU project.

Hussein Al-Jaberi, “Concept of advanced nuclear reactor for emerging nuclear power countries”, PhD thesis funded by the Iraqi government.

C. Lousada: Interfacial radiation chemistry, Partly funded by SKC.

Å. Björkbacka: Radiation induced corrosion of Copper, Funded by SKB.

K. Nilsson: Oxidative dissolution of spent nuclear fuel, Funded by SKB.
K. K. Norrfors: Colloid facilitated transport, Funded by SKB.

B. Dahlgren: Theoretical study of interfacial radiation chemistry, Funded by KTH (School of Chemical Science and Engineering).

M. Yang: Experimental study of interfacial radiation chemistry, Funded by CSC.

A. Barreiro Fidalgo: Radiation induced dissolution of spent nuclear fuel, Funded by SKB.

V. Diesen: Photocatalytic purification of water, Funded by Wallenius Water AB

Undergraduate education

KTH divisions have been successfully running the Master Program in Nuclear Energy Engineering since 2007. During that time the program has gained high international reputation and the courses taught within the program have attracted many international and domestic students. The following major courses were given in 2013:

"Nuclear reactor technology", H. Anglart, 8 ECTS, (25 students).
"Thermal-hydraulics in nuclear systems", H. Anglart, 6 ECTS, (13 students).
"Nuclear reactor dynamics and stability", J. Dufek, 6 ECTS, (16 students).
"Nuclear power safety", P. Kudinov, 6 ECTS, (26 students).
"Miljöfysik" - P. Olsson & J. Wallenius, 9 ECTS, (120 students)
"Modern physics" – T. Bäck & P. Olsson, 8 ECTS, (120 students)
"Reactor physics" - W. Gudowski (25 students)
"Management in nuclear industry" - O. Runevall (15 students)
"The nuclear fuel cycle" - M. Pukari (15 students)
"Generation IV reactors" - J. Wallenius (12 students)
"Numerical methods in nuclear engineering" - V. Arzhanov (10 students)
"Non-proliferation of nuclear materials" - J. Wallenius (10 students)
"Transmutation of nuclear waste" - J. Wallenius (5 students)
"Chemistry and physics of nuclear fuels" - M. Jolkkonen (5 students)
"Neutron transport theory" - V. Arzhanov (5 students)
"Radiation damage in materials" – P. Olsson, 6 ECTS, (12 students)
"Reactor Chemistry", - M. Jonsson, 6 ECTS, (11 students)
"Photo, Radiation and Radical Chemistry", - M. Jonsson, 7.5 ECTS, (15 students)
"The Chemistry of the Nuclear Fuel Cycle", - M. Jonsson, (9 students)

In addition, nuclear technology is taught in the "Sustainable Power Generation" course, 9 ECTS given by Energy Technology department.

Recently 2 unique courses have been offered for the students in nuclear: "Safety Leadership in Nuclear Power Industry" and "Elements of the Back-end of the Nuclear Fuel Cycle: Geological storage in Precambrian bedrock".

The course "Safety Leadership in Nuclear Power Industry" gives knowledge about the demands for safety culture and safety leadership in nuclear activities and why they are absolutely necessary, having in mind lessons learned from nuclear accidents and incidents. Students are educated to be able to use established system indicators to ensure a high level of safety culture in companies and organizations involved in nuclear activities and to identify situations where the principle of **"safety first"** would appear to be in conflict with other operational objectives.

These two new courses got extraordinary good evaluation of the 2013 students, over 6.5 out of 7 possible.
KTH's Master Program in Nuclear Energy Engineering is a part of the European Dual Master Diploma Program: European Master in Innovative Nuclear Engineering (EMINE). The first year of the study at KTH can be combined with a second year of study at the top French universities either in Paris (ParisTech – a cluster of universities in Paris) or in Grenoble (Grenoble Institute of Technology – INP) resulting in a dual diploma master degree. EMINE program has been assessed to be the best Master Program in Knowledge and Innovative Community – Innoenergy Program of the European Institute of Innovation and Technoloigy.

Moreover, KTH has prepared in 2013 an agreement on a Dual Diploma Master Program in Nuclear Energy Engineering with Tsinghua University in Beijing. This agreement will be signed in March 2014.

P. Olsson and M. Pukari gave lectures in the education package for secondary high school teachers in physics “Fysik i framkant – nyheter från forskningsfronten”.

At the Department of Solid Mechanics, no specific nuclear science related course has been given during 2013, but the Department is hosting approximately 25 under graduate students on a yearly basis. Courses in Solid Mechanics, Fracture Mechanics and Fatigue, Mechanical testing, Materials Mechanics, Finite Element modelling, Paper Mechanics and Fatigue, reliability and design at undergraduate/advanced level are given on a regular basis, whereas courses in more specialized areas such as Fatigue and Deformations Mechanisms are given when suitable.

The following Master and Bachelor Theses have been completed during 2013:

David Haces Manzano, “U-RANS and LES conjugate heat transfer analysis of the thermal fluctuations in a high difference temperature mixing zone using OpenFOAM”, June 2013.

Ignacio Gallego-Marcos, “Thermal Mixing CHT Simulations with OpenFOAM: URANS and LES”, June 2013.

Andrei Goronovski: “Influence of In-vessel Pressure and Corium Melt Properties on Global Vessel Wall Failure of Nordic-type BWRs”, Master Thesis of KTH, Nuclear Power Safety, 2013.

Claudio Torregrosa Martín: “Coupled 3D Thermo-mechanical Analysis of Nordic BWR Lower Head Failure in case of Core Melt Severe Accident”, Master Thesis of KTH, Nuclear Power Safety, 2013 (**Sigvard Eklund prize for the best MSc thesis in 2013**).

Martin Lundholm: “Cost analysis of Lead Cooled Fast Reactors and the ELECTRA Project”, Master Thesis of KTH, Reactor Physics, 2013.

Eleftherios Karachalias: “Investigation and calibration of various detection systems which can be used for emergency internal contamination checks”, Master Thesis of KTH – in collaboration with SCK-CEN, Belgium, Reactor Physics, 2013.

Johnny Lazo: “Numerical simulation of Microstructural Evolution of Iron Alloys under Irradiation”, Master Thesis of KTH – in collaboration with EDF R&D, France, Reactor Physics, 2013.

Levon Ghasabyan: “Use of Serpent Monte-Carlo code for development of 3D full-core models of Gen-IV fast-spectrum reactors and
preparation of group constants for transient analyses with PARCS/TRACE coupled system”, Master Thesis of KTH – in collaboration with PSI, Switzerland, Reactor Physics, 2013.

National and international projects

KTH is participating in numerous national, European and international cooperation projects. In 2013 several new project were initiated.

Nuclear Reactor Technology was involved in the following European projects: NURESAFE – on development of simulation tools for nuclear engineering applications; THINS – on development of thermal-hydraulics methods for new innovative nuclear systems; HPMC – on development of high performance Monte-Carlo methods.

The Department of Solid Mechanics has three on-going long term projects and one short-term project related to the nuclear industry and to the sponsors of SKC. These are:

- Modelling of stress corrosion cracking, with emphasis on initiation and short crack growth;

- Stress corrosion cracking in Alloy 690 and;

- Thermal ageing and decomposition of cast and welded austenitic materials;

- Continuum modeling of nodular cast iron using a porous plastic model with pressure-sensitive matrix— experiments, model calibration & verification.

Of these, the program on modelling of Stress Corrosion Cracking has financial support, 50%, from SKC. The project on stress corrosion cracking in Alloy 690 is fully financed by the owners of the Swedish Nuclear Power Plants, Vattenfall, E.On and Fortum as part of the agreement on the placement of Efsing at the department. The project on Thermal ageing is financed by SSM and the Swedish nuclear power plants materials utility group. Finally, the short-term project on nodular cast iron was financed by SKB.

Nuclear Power Safety has been involved in the following European projects: SILER – on seismic issues of heavy liquid metal cooled reactors; THINS for experiment and analysis of thermal-hydraulics new innovative nuclear systems; NURESAFE for development of simulation tools for nuclear engineering applications. Nuclear Power Safety is also performing the international projects: MHI-APWR-HQ, MHI-SES-TRDC and NKS-DECOSE and ENSI-MSWI for study on corium coolability and steam explosion risk. Nuclear Power Safety has the national projects: APRI-8 for research on corium coolability and steam explosion in BWRs; DSA for transient and severe accident safety analysis for Swedish nuclear power plants; NORTHNET-RM1 for experimental study on micro-hydrodynamics of flow boiling and CHF mechanisms; NORTHNET-RM3 for simulation of condensation and mixing phenomena in a BWR suppression pool.

Reactor physics is involved in the following European projects: FREYA – on reactivity monitoring in Accelerator Driven Systems; ASGARD – on advanced/novel nuclear fuels fabrication and their respective reprocessing issues for Generation IV reactors; MAXSIMA and MARISA – on the development and safety assessment of the MYRRHA reactor concept; ARCADIA – on development of new reactors through an integrated approach; ESNII+ - on preparing ESNII for Horizon 2020; MATISSE – on radiation damage in nuclear materials for current and future generation reactors. P. Olsson is coordinating the Swedish effort in the materials research for the European Fusion Development Agreement.

Conferences and publications

The divisions actively participated in major international conferences within nuclear engineering field and also published in several reputed journals. The most important publications within 2013 are as follows:

Rickard Shen and Martin Bjurman has both formally published literature reviews on their respective project under a Materials in Nuclear Reactor systems course held at Altoo Univeristy in Helsinki, Finland.

Atom probe tomography characterization of high nickel, low copper surveillance RPV welds irradiated to high fluences, M.K. Miller, K.A: Power, R.K. Nanstad and P. Efsing, J. of Nuclear Materials, Vol 437 (2013), pp. 10-115

Flux effects on radiation induced aging behaviour of low alloy steel weld material with high Nickel and Manganese content, P. Efsing, J. Rouden, and P. Nilsson, Presented at ASTM International Conference on Radiation effects on Materials, paper Id: ASTM-STP 2013-0112

CARINA – A programme for experimental investigation of the irradiation behaviour of German reactor Pressure Vessel materials, H. Hein, E. Keim, E. Bechler, P. Efsing, J. Ganswind, R. Konbel, G. König, M. Widera and A de Jong, VGB PowerTech, 2013, #5, pp. 43-49.

Effect of BWR environment on the fracture toughness of AlloyX-750, A. Jensen, M. König, P. Efsing, B. Forssgren, B. Bengtsson, M. Cocco and P. Ekström, Presented at the 16th International conference on Environmental Degradation of materials in nuclear power systems – Water reactors, Asheville, NC., USA, NACE, 2013.

P. Ljustell and B. Alfredsson, Variable amplitude fatigue crack growth at monotonic large scale yielding experiments on stainless steel 316L, *Engineering Fracture Mechanics*, vol. 109, pp. 310-325, 2013.

P. Ljustell, Fatigue crack growth experiments on specimens subjected to monotonic large scale yielding, *Engineering Fracture Mechanics*, vol. 110, pp. 138-165, 2013.

Thiele, R. and Anglart, H., “Numerical modeling of forced-convection heat transfer to lead-bismuth eutectic flowing in vertical annuli,” *Nuclear Engineering and Design*, vol. 254, pp. 111-119, 2013.

Jaromin, M. and Anglart, H., “A numerical study of heat transfer to supercritical water flowing upward in vertical tubes under normal and deteriorated conditions,” *Nuclear Engineering and Design*, vol. 264, pp. 61-70, 2013.

Caraghiaur, D., Adamsson, C. and Anglart, H., “A model for inertial drop deposition suitable to predict obstacle effect,” *Nuclear Engineering and Design*, vol. 260, pp. 121-133, 2013.

Dufek J. and Anglart, H., “Derivation of a Stable Coupling Scheme for the Monte Carlo Burnup Calculations with the Thermal-Hydraulic Feedback,” *Annals of Nuclear* Energy, 62:260-263, 12/2013.

Jan Dufek, Dan Kotlyar, Eugene Shwageraus, The stochastic implicit Euler method – A stable coupling scheme for Monte Carlo burnup calculations, *Annals of Nuclear Energy*. 10/2013; 60:295 - 300.

Aarno Isotalo, Jaakko Leppänen, Jan Dufek, Preventing xenon oscillations in Monte Carlo burnup calculations by enforcing equilibrium xenon distribution, *Annals of Nuclear Energy*. 10/2013; 60:78-85.

Jan Dufek, Dan Kotlyar, Eugene Shwageraus, Jaakko Leppänen, Numerical stability of the predictor–corrector method in Monte Carlo burnup calculations of critical reactors, *Annals of Nuclear Energy*. 06/2013; 56:34-38.

I.G. Anghel, H. Anglart, “On post-dryout heat transfer in channels with flow obstacles,” accepted to *Nuclear Engineering and Design*.

J. Eduard Hoogenboom, Jan Dufek, Optimised Iteration in Coupled Monte Carlo - Thermal-Hydraulics Calculations, SNA+MC 2013, Paris, October 27-31.

Caraghiaur, D., Adamsson, C. and Anglart, H., ”Deposition of Inertial Drops in Eulerian Formulation,” Proc. 15th Int. Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-15), Pisa, Italy, May 12 – 17, 2013.

Roelofs, F., Rohde, M., Otic, I., Brillant, G., Tiselj, I., Anglart, H., Niceno, B., Duponcheel, M., Stalino, E., Ambrosini, W., Lakehal, D., Baglietto, E., Hassan, Y. A., and Cheng, X., ”European Development in Single Phase Turbulence for Innovative Reactors,” Proc. 15th Int. Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-15), Pisa, Italy, May 12 – 17, 2013.

Jaromin, M. and Anglart, H., ”A Numerical Study of the Turbulent Prandtl Number Impact on Heat Transfer to Supercritical Water Flowing Upward Under Deteriorated Conditions,” Proc. 15th Int. Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-15), Pisa, Italy, May 12 – 17, 2013.

Le Corre, J.-M., Trisic, I., Palko, D. and Anglart, H., ”Transient Responses and Analyses of Three Thermal-Hydraulic Models to Typical BWR Accident Scenarios,” Proc. 15th Int. Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-15), Pisa, Italy, May 12 – 17, 2013.

Anglart, H., ”Investigation of Local Dryout Conditions in Tubes and Annuli,” Proc. 15th Int. Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-15), Pisa, Italy, May 12 – 17, 2013.

Anghel, I.G. and Anglart, H., ”Experimental Study of Post Dryout Heat Transfer in Double Heated Annulus with Flow Obstacles,” Proc. 15th Int. Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-15), Pisa, Italy, May 12 – 17, 2013.

Thiele, R. and Anglart, H., ”Prediction of Natural Circulation of Liquid Lead and Pressure Drop in the ELECTRA Core,” Proc. 15th Int. Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-15), Pisa, Italy, May 12 – 17, 2013.

Kudinov, P., Karbojian, A., Tran, C.-T., Villanueva, W., “Experimental Data on Fraction of Agglomerated Debris Obtained in the DEFOR-A Melt-Coolant Interaction Tests with High Melting Temperature Simulant Materials,” *Nuclear Engineering and Design*, 263, October 2013, Pages 284-295, 10.1016/j.nucengdes.2013.06.011.

Kudinov P., Davydov M.V., “Development and validation of conservative-mechanistic and best estimate approaches to quantifying mass fractions of agglomerated debris,” *Nuclear Engineering and Design*, 262, September 2013, pp. 452-461.

Tran C.-T. and Kudinov P., "The Effective Convectivity Model for Simulation of Molten Metal Layer Heat Transfer in a Boiling Water Reactor Lower Head," *Science and Technology of Nuclear Installations*, vol. 2013, 14 pages, 2013.

Yakush S., Kudinov P., and Lubchenko N., “Coolability of heat-releasing debris bed. Part 1: Sensitivity analysis and model calibration,” *Annals of Nuclear Energy*, 52, February 2013, pp. 59-71.

Yakush S., Kudinov P., and Lubchenko N., “Coolability of heat-releasing debris bed. Part 2: Uncertainty of dryout heat flux,” *Annals of Nuclear Energy*, 52, February 2013, pp. 72-79.

Pohlner G., Buck M., Meignen R., Kudinov P., Ma W., Polidoro F., Takasuo E., "Analyses on Ex-Vessel Debris Formation and Coolability Performed in the Frame of WP5.3-EXCOOL Sub Work Package of SARNET," ERMSAR 2013, Avignon (France), Palais des Papes, 2-4 October, 2013.

Grishchenko D., Konovalenko A., Karbojian A., Kudinova V., Bechta S., and Kudinov P., "Insight into steam explosion in stratified melt-coolant configuration," 15th International Topical Meeting on Nuclear Reactor Thermal Hydraulics, NURETH 15, May 12 to 17, 2013, Pisa, Italy, Paper 599. **(Best paper award)**

Jeltsov, M., Kööp, K., Kudinov, P., and Villanueva, W., "Development of a Domain Overlapping Coupling Methodology for STH/CFD Analysis of Heavy Liquid Metal Thermal-Hydraulics," 15th International Topical Meeting on Nuclear Reactor Thermal Hydraulics, NURETH 15, May 12 to 17, 2013, Pisa, Italy, Paper 466.

Torregrosa, C., Villanueva, W., Tran, C.-T., and Kudinov, P., "Coupled 3D Thermo-Mechanical Analysis of a Nordic BWR Vessel Failure and Timing," 15th International Topical Meeting on Nuclear Reactor Thermal Hydraulics, NURETH 15, May 12 to 17, 2013, Pisa, Italy, Paper 495.

Goronovski, A., Villanueva, W., Tran, C.-T., and Kudinov, P., "The Effect of Internal Pressure and Debris Bed Thermal Properties on BWR Vessel Lower Head Failure and Timing," 15th International Topical Meeting on Nuclear Reactor Thermal Hydraulics, NURETH 15, May 12 to 17, 2013, Pisa, Italy, Paper 500.

Yakush S. E., Lubchenko, N.T., and Kudinov P., "Surrogate Models for Debris Bed Dryout," 15th International Topical Meeting on Nuclear Reactor Thermal Hydraulics, NURETH 15, May 12 to 17, 2013, Pisa, Italy, Paper 278.

Yakush, S. E., Lubchenko, N. T., and Kudinov, P., "Risk and Uncertainty Quantification in Debris Bed Coolability," 15th International Topical Meeting on Nuclear Reactor Thermal Hydraulics, NURETH 15, May 12 to 17, 2013, Pisa, Italy, Paper 283.

Yakush, S. E., Kudinov, P., Villanueva, W., and Basso, S., "In-Vessel Debris Bed Coolability and its Influence on the Vessel Failure," 15th International Topical Meeting on Nuclear Reactor Thermal Hydraulics, NURETH 15, May 12 to 17, 2013, Pisa, Italy, Paper 464.

Manickam L., Kudinov P, Bechta S., "On the Influence of Water Subcooling and Melt Jet Parameters on Debris Formation," 15th International Topical Meeting on Nuclear Reactor Thermal Hydraulics, NURETH 15, May 12 to 17, 2013, Pisa, Italy, Paper 512.

Bandini G., Bubelis E., Schikorr M., Stempnievicz M.H., Lázaro A., Tucek K., Kudinov P., Kööp K., Jeltsov M., Mansani L., "Safety Analysis Results of Representative DEC Accidental Transients for the ALFRED Reactor," International Conference on Fast Reactors and Related Fuel Cycles: Safe Technologies and Sustainable Scenarios (FR13), Paris, France, 4-7 March 2013 Conference ID: 41987 (T1-CN-199), IAEA-CN-199/260.

S.J. Gong, W.M. Ma and L.X. Li, "An experimental study on the effect of liquid film thickness on bubble dynamics", *Applied Thermal Engineering*, Vol.51, pp.459-467, 2013.

S. Thakre, W.M. Ma and L.X. Li, "A numerical analysis on hydrodynamic deformation of molten droplets in a water pool", *Annals of Nuclear Energy*, Vol.53, pp.228-237, 2013.

I. Gajev, W.M. Ma and T. Kozlowski, "Space-time convergence analysis on BWR stability using TRACE/PARCS", *Annals of Nuclear Energy*, Vol.51, pp.295-306, 2013.

W.M. Ma, "Analysis of station blackout scenarios of a boiling water reactor using MELCOR code", Proc. of NURETH-15, Pisa, Italy, May 12-15, 2013.

S. Thakre, W.M. Ma and L.X. Li, "Numerical analysis of reactor scale ex-vessel fuel coolant interactions phenomena using MC3D code", Proc. of NURETH-15, Pisa, Italy, May 12-15, 2013.

L.X. Li, W.M. Ma and S. Thakre, "An experimental study on coolability of radially and triangularly stratified debris beds", Pro. of NURETH-15, Pisa, Italy, May 12-15, 2013.

Y.J. Zhang, W.M. Ma and S.J. Gong, "An experimental study on liquid film dynamics and interfacial wave of air-water two-phase flow in a horizontal channel", Proc. of ICONE21, Chengdu, China, July 29 - August 2, 2013.

X. Hu, M. Xing and W.M. Ma, "TRACE analysis of LOCA transients performed on FIX-II facility", Proc. of ICONE21, Chengdu, China, July 29 - August 2, 2013.

M. Xing, X. Hu, Y.D. Cheng and W.M. Ma, "Validation of TRACE code against ROSA/LSTF test for SBLOCA of pressure vessel upper-head small break", Proc. of ICONE21, Chengdu, China, July 29 - August 2, 2013.

J. Zakova and J. Wallenius, "Multirecycling of Pu, Am and Cm in BWR", *Annals of Nuclear Energy*, Vol.58, pp.255-267, 2013.

Y. Zhang, J. Wallenius and M. Jolkkonen, "Transmutation of americium in a large sized sodium-cooled fast reactor loaded with nitride fuel", Vol.53, pp.26-34, 2013.

Z. Chang, P. Olsson, D.A. terentyev and N. Sandberg, "Dislocation bias factors in fcc copper derived from atomistic calculations", Journal of Nuclear Materials, Vol.441, pp.357-363, 2013.

M. Pukari, P. Olsson and N. Sandberg, "He, Kr and Xe diffusion in ZrN - An atomic scale study", Journal of Nuclear Materials, Vol.438, pp.7-14, 2013.

A. Claisse and P. Olsson, "First-principles calculations of (Y, Ti, O) cluster formation in body centred cubic iron-chromium", Nuclear Instruments & Methods in Physics Research Section B-Beam Interactions with Materials and Atoms, Vol.303, pp.18-22, 2013.

L. Messina, Z. Chang and P. Olsson, "Ab initio modelling of vacancy-solute dragging in dilute irradiated iron-based alloys", Nuclear Instruments & Methods in Physics Research Section B-Beam Interactions with Materials and Atoms, Vol.303, pp.28-32, 2013.

P. Olsson and C. Domain, "*Ab initio* modelling of radiation damage in iron and iron alloys" Symposium ZZ on nanostructured materials in extreme environments, MRS fall meeting, Boston, 1-6 Dec 2013.

P. Olsson and J. Ejenstam, "Ab initio based kinetic Monte-Carlo simulations of phase transformations in FeCrAl", Structural Materials for Innovative Nuclear Systems (SMINS-3), NEA-OECD conference in Idaho Falls, Oct 7-10, 2013.

L. Messina M. Nastar and P. Olsson, "Exact calculation of transport coefficients and RIS tendencies in ferritic dilute iron alloys", Structural Materials for Innovative Nuclear Systems (SMINS-3), NEA-OECD conference in Idaho Falls, Oct 7-10, 2013.

Z. Chang, P. Olsson, D.A. Terentyev and N. Sandberg, "Dislocation bias calculations in fcc Cu and Ni", Structural Materials for Innovative Nuclear Systems (SMINS-3), NEA-OECD conference in Idaho Falls, Oct 7-10, 2013.

P. Olsson, "Density functional theory studies of primary damage in structural materials", Modelling of radiation damage and its effects, Oxford, Sept 25-27, 2013.

Cláudio M. Lousada, Martin Trummer and Mats Jonsson, Reactivity of H2O2 towards different UO2-based materials - The relative impact of radiolysis products revisited, Journal of Nuclear Materials, Vol. 434, No. 1/3, pp. 434-439, 2013.

Veronica Diesen and Mats Jonsson, Effects of O2 and H2O2 on TiO2 photocatalytic efficiency quantified by formaldehyde formation from tris(hydroxymethyl)aminomethane, Journal of AOTS. Advanced Oxidation Technologies, Vol. 16, No. 1, pp. 16-22, 2013.

Claudio Miguel Lousada, Jay A. LaVerne and Mats Jonsson, Enhanced hydrogen formation during the catalytic decomposition of H2O2 on metal oxide surfaces in the presence of HO radical scavengers, Physical Chemistry, Chemical Physics - PCCP, Vol. 15, No. 30, pp. 12674-12679, 2013.

Inna L. Soroka, Nadezda V. Tarakina, Pavel A. Korzhavyi, Vladimir Stepanenko and Mats Jonsson, Effect of synthesis temperature on the morphology and stability of copper(I) hydride nanoparticles, CrysteEngComm, Vol. 15, No. 42, pp. 8450-8460, 2013.

Veronica Diesen, Mats Jonsson and Ivan Paul Parkin, Improved Texturing and Photocatalytic Efficiency in TiO2 Films Grown Using Aerosol-Assisted CVD and Atmospheric Pressure CVD, Chemical Vapor Deposition, Vol. 19, No. 10-12, pp. 355-362, 2013.

Åsa Björkbacka, Saman Hosseinpour, Magnus Johnson, Christofer Leygraf and Mats Jonsson, Radiation induced corrosion of copper for spent nuclear fuel storage, Radiation Physics and Chemistry, Vol. 92, pp. 80-86, 2013.

Sara Sundin, Björn Dahlgren, Olivia Roth and Mats Jonsson, H2O2 and radiation induced dissolution of UO2 and SIMFUEL in HCO3- deficient aqueous solution, Journal of Nuclear Materials, Vol. 443, No. 1-3, pp. 291-297, 2013.

Miao Yang, Alexandre Barreiro Fidalgo, Sara Sundin and Mats Jonsson, Inhibition of radiation induced dissolution of UO2 by sulfide-A comparison with the hydrogen effect, Journal of Nuclear Materials, Vol. 434, No. 1-3, pp. 38-42, 2013.

Cláudio Miguel Lousada Patricio, Adam Johannes Johansson, Tore Brinck and Mats Jonsson, Reactivity of metal oxide clusters with hydrogen peroxide and water - a DFT study evaluating the performance of different exchange-correlation functionals, Physical Chemistry, Chemical Physics - PCCP, Vol. 15, No. 15, pp. 5539-5552, 2013.

Claudio Miguel Lousada, Miao Yang, Kristina Nilsson and Mats Jonsson, Catalytic decomposition of hydrogen peroxide on transition metal and lanthanide oxides, Journal of Molecular Catalysis A, Vol. 379, pp. 178-184, 2013.

Inna L. Soroka, Andrey Shchukarev, Mats Jonsson, Nadezda V. Tarakina and Pavel A. Korzhavyi, Cuprous hydroxide in a solid form - does it exist?, Dalton Transactions, Vol. 42, No. 26, pp. 9585-9594, 2013.

Mauro Claudino, Mats Jonsson and Mats Johansson, Thiol-ene coupling kinetics of D-limonene - a versatile 'non-click' free-radical reaction involving a natural terpene, RSC Advances, Vol. 3, No. 27, pp. 11021-11034, 2013.

Sara Skoglund, Troy A. Lowe, Jonas Hedberg, Eva Blomberg, Inger Odnevall Wallinder, Susanna Wold and Maria Lundin, Effect of Laundry Surfactants on Surface Charge and Colloidal Stability of Silver Nanoparticles, Langmuir, Vol. 29, No. 28, pp. 8882-8891, 2013.

Troy A. Lowe, Jonas Hedberg, Maria Lundin, Susanna Wold and Inger Odnevall Wallinder, Chemical Speciation Measurements of Silver Ions in Alkaline Carbonate Electrolytes Using Differential Pulse Stripping Voltammetry on Glassy Carbon Compared With Ion Selective Electrode Measurements, International Journal of Electrochemical Science, Vol. 8, No. 3, pp. 3851-3865, 2013.

Uppsala University

Overview of Activities in 2013

Division of Applied Nuclear Physics

Summary

Since last year, the division has grown with an additional 10 persons and comprises now some 60 employees (researchers/teachers and Ph.D. students). Although size does not necessarily matters, the development indicates that the Division of Applied Nuclear Physics (ANP) at Uppsala University today certainly fills the role of being an important actor on the scene of research and education within nuclear technology.

ANP: s ambition is to continuously develop its concepts in research and education. For example, the elements of interdisciplinary actions within the Nordic Academy for Nuclear Safety and Security (NANSS), the new reactor physics group and the increased collaboration within materials research, which are all parts of a comprehensive strategy to create a stable and a high-quality research node that could serve and support the surrounding society.

As noted in last year's Annual Report, ANP today is a large research environment in which the research and education activities within nuclear technology are firmly anchored in the needs of the society as well as in the present scientific and didactic issues. Following the strategy outlined in earlier SKC reports, the areas below are in our focus for extensive research:

- Nuclear fuel diagnostics and core monitoring (gen II, III, III+, IV).
- Nuclear data and Total Monte Carlo approach (experimental uncertainties and their propagation in core simulators and other relevant tools).
- Offering of nuclear expertize internationally (considering the fact that many developing countries now contemplate of initiating nuclear power programmes).
- Structural materials (radiation assisted stress corrosion cracking and aging).
- Reactor physics and design.
- Nuclear safeguards (more efficient and less intrusive technologies).

A determining factor for us to focus on these areas is the considerable international interest for our research and education we have gained. Regarding structural material we have, together with the Division of material theory, initiated collaboration with UC Berkeley and Los Alamos National Lab (LANL) in the US. Specifically this collaboration deals with designing and constructing a materials testing irradiation facility at Ångström Laboratory (ICE3) for investigating irradiation assisted corrosion and aging. This work is coordinated by Prof. Mattias Klintenberg. We also initiate collaboration with UCB in reactor physics issues through our new reactor physics group. In an additional collaboration within safeguards, Dr. Steve Tobin at LANL, coordinator of the U.S: programme "Next Generation Safeguards Initiative", funded by the Department of Energy, is now employed as a guest researcher during the period July 2013 to August 2015. Dr. Tobin will besides his work on safeguards instrumentation also assist in the supervision of Ph.D. students.

The collaboration with NRG, Petten in the Netherlands enhances our field in nuclear data and Total Monte Carlo calculations. This collaboration has gained by the fact that Dr. Arjan Koning is an adjoint professor at UU.

Considering education, highly interesting collaborations are being developed with the IAEA and the World Nuclear University. In addition, discussions have been initiated with Kenya to assist them in their capacity building as a part of the Kenyan "Vision 2030" programme that includes the implementation of nuclear power in Kenya.

We believe that focussed efforts on the above areas also create feasible platforms for collaboration with relevant groups at Chalmers and KTH in order to achieve a more efficient use of the available national funding. As a concrete result, we have to SKC proposed collaboration with Chalmers, KTH and UU within the areas Accident Tolerant Fuels and material ageing.

ANP has a long-time engagement with the European Safeguards Research and Development Association (ESARDA). Our engagement has been under coordination of SSM but from spring 2013, ANP is a full member of ESARDA. As a consequence, Sophie Grape is now vice-chair of the working group of Training and Knowledge Management. We also have participation in the NDA working group and working group on Verification Technologies and Methodologies.

The activities within NANSS have continued during 2013. The number of interested parties increases steadily and at present the universities of Stockholm, Gothenburg and Trondheim participate and discussions have been initiated with Finland through University of Jyväskylä. Also the group with Carl Rollenhagen at KTH are interested to contribute to NANSS as is SIPRI. The IAEA is supporting NANSS and at the end of May, NANSS arranged a seminar on Knowledge Management in Uppsala. This event was conducted as a joint venture between NANSS and the IAEA and was directed towards the management functions of the Swedish nuclear industry and SSM. The Ministry of Foreign Affairs was also participating.

The core group of NANSS, i.e. Uppsala University, SSM and IFE, work with course packages that was planned to be issued during autumn 2013. However, the economic situation in the nuclear industry was and still is such that we were forced to postpone several courses to 2014.

With these introductory remarks we conclude that our activities during 2013 were successful and we look with confidence towards the future.

For more information about the Division for Applied Nuclear Physics: http://www.physics.uu.se/en

Education

Teaching and education continue to be areas of considerable importance for ANP. The long-term-strategy to increase the number as well as the scope of courses offered to engineering students at Uppsala University within the fields of energy physics and nuclear engineering, teaching has been fruitful and presently students on most engineering programs have the option of taking one or more courses directly related to nuclear technology. The division is responsible for managing two engineering programs, the Bachelor of science in engineering programme with a specialisation in nuclear engineering, i.e., Högskoleingenjörsprogrammet i kärnkraftteknik (KKI), which is on its 4th year since the start in autumn 2010 and the Master of science in engineering programme with a specialisation in energy systems engineering, i.e., Civilingenjörsprogrammet i energisystem (ES), which is the largest master of science in engineering programme at Uppsala University. In addition to courses within these programmes, division staff also provides courses in nuclear technology, energy physics and technical thermodynamics within the framework of other UU engineering programmes.

Since 2003 ANP has an agreement with *Kärnkraftsäkerhet och Utbildning AB* (KSU) about UU providing higher education for the nuclear power industry. The objective of this contract education is to secure competence building of existing and newly recruited personnel, primarily within reactor operation and radiation protection. Presently KSU is reorganizing, and developing a new business plan and ANP are in a situation where we are well prepared to accommodate different approaches for competence building and continued education in the future.

During 2013 UU has been actively involved in activities within the IAEA “International Nuclear Security Education Network” (INSEN), primarily with the objective of formalizing international collaborations about e.g., nuclear knowledge management for future courses at UU.

All ANP staff involved in teaching has taken teacher training courses as part of the UU continuing education program. During 2013/2014, ANP staff has performed a didactic study about student learning within the KKI programme. As an outcome of this study two UU funded projects have been started with

the objective of developing a progressive training module spanning many courses, that will provide students with a structured approach for improving their oral and written communication skills.

During 2013 the Swedish Higher Education Authority (Universitetkanslerämbetet, UKÄ) has performed a national evaluation of all Swedish engineering programs with a focus on the learning outcomes of programmes and how well they fulfil the requirements laid down in the Higher Education Act (Högskoleförordningen). In the evaluation, which was based on the assessment of the students´ degree project reports, the institutions self-evaluations and interviews with students and teaching staff, UKÄ found that the Bachelors' and Masters' programmes of UU maintain a high quality with no obvious weaknesses. In particular, in the evaluation report it was noted that the Bachelor students following the nuclear power programme *exhibited a very high degree of awareness and understanding of the possibilities and limitations of technology, its role in society and the responsibility of the individual for how it is used, including social and economic aspects as well as environmental and occupational health and safety aspects*.

Bachelor of science in engineering with a specialisation in nuclear engineering

The Bachelor's programme in nuclear engineering is a one-year educational programme aimed at students with at least 2 years of prior studies in primarily mechanical or electrical engineering at a Swedish university or technical college. The programme, which is the only one of its kind, is supported by the Swedish NPPs with the objective of securing a supply of engineers with a good, non-site specific knowledge of nuclear technology at the Bachelor's level. Graduates from the programme are awarded a "Högskoleingenjörsexamen i kärnkraftteknik". The main objectives of the programme are to 1) increase the volume of employable people available to the nuclear industry and 2) decrease the industry's total training cost by reducing the need for on-the-job education and training.

The programme, which comprises 60 hp, contains the following courses:

- Introduction to nuclear engineering (5 hp)
- Reactor physics (5 hp)
- Nuclear thermal hydraulics and steam turbine technology (5 hp)
- Light water reactor technology (5 hp)
- Chemistry, materials and fuels for reactor applications (5 hp)
- Nuclear power safety (5 hp)
- Power Engineering (5 hp)
- Nuclear power operation (5 hp)
- Future nuclear energy systems (5 hp)
- Degree project in nuclear power technology (15 hp)

In many of the courses experts from industry and authority are involved as guest teachers, collaborating with the UU teachers.

An important aspect of the learning process is for the student to gain knowledge about the nuclear process and the different actors within the nuclear industry. With that in mind a number of study visits are included in the programme. During 2013 students have made study visits to FKA, OKG and RAB, the SKB facilities in Oskarshamn, the Westinghouse nuclear fuel fabrication plant in Västerås, Siemens Turbomachinery in Finpång (steam turbines) and ABB in Ludvika (generators and transformers). There has been no study visit to SSM, but SSM staff is actively involved as teachers in the course Nuclear power operation.

During the first semester the students participate in a one-week reactor training session at the ISIS training reactor in Saclay, France as part of the course in reactor physics. Following the Reactor physics and Thermo-hydraulics courses, the course Light water reactor technology includes a one week session at the Barsebäck NPP in order for the students to gain a practical understanding of the principles of LWRs, workmanship, radiation protection and various operational procedures at NPPs. The course also includes a training session in KSU's simulators in Studsvik.

Recruitment

Considerable effort is devoted to student recruitment activities. Recruitment activities are focused on arranging lunch seminars at several engineering colleges and universities around Sweden and also participation in student careers fairs, e.g., UTNARM, CHARM and LARM. Whenever possible these activities are conducted in collaboration with industry and SKC. Additionally, the programme is marketed through advertisements in various media such as educational supplements distributed with newspapers, SKC's Atomen, and also through mailings to students.

As shown in Table 1 below, since its inception in 2010 when the "nuclear renaissance" was at its peak, the programme has experienced a decrease in the number of students enrolling in the programme. From our contact with students it is clear that students' choice of educational programs is heavily influenced by public opinion and debate. The Fukushima accident, the German "Energiewende" and its possible influence on Swedish energy policy and lately the cost down-sizing and lay-offs advertised by the power companies have had a strong influence on student interest. With that in mind it is important that the nuclear industry conveys a positive message to prospective students about the possibility of a career within the field. In order to help the general public and prospective students in particular to form a realistic opinion about the future role of nuclear power in the Swedish energy system, ANP has been actively involved in providing relevant information about nuclear energy trough participation in social media, science fairs, debate articles and lectures for the public, schools and organisations.

On the positive side the drop-out rate during the programme is very low and the students report a high degree of satisfaction with the quality of education. In a programme evaluation the class of 2012/2013, when questioned about their experience of the overall quality of the programme, gave the mark 4.7±0.5 on a scale from 1 (unacceptable) to 5 (excellent).

Table 1. Recruitment statistics for the period 2010-2013 (source: Verket för högskolestudier)

Study year	Applicants	1st-hand applicants	Applicants admitted to the program	Students registered at start of first semester	Students active at end of semester 2
2010/2011	80	47	34	21	19
2011/2012	57	26	36	12	11
2012/2013	60	29	36	14	12
2013/2014	46	22	21	10	8 (feb 2014)

Students' achievements

At the time of writing (February 2014) 31 students have successfully completed their Bachelors theses. A summary of the theses produced during 2013 is found at the end of this chapter. In 2013 Johan Erlandsson och Patrik Berg, received the Sigvard Eklund award for best diploma work on the Bachelor's level for their diploma work "Analys av turbulens-modeller för CFD" performed at FKA. Previously Azur Bajramovic (2012) and Katja Göller (2011) from the Uppsala Bachelors' program have received the Sigvard Eklund award for best Bachelors' thesis.

The students' integral achievements for the academic years 2010/2011 2011/2012 and 2012/2013 are shown in Figure 1 below, whereas the students' achievements for the academic year 2013/2014 are shown in Figure 2.

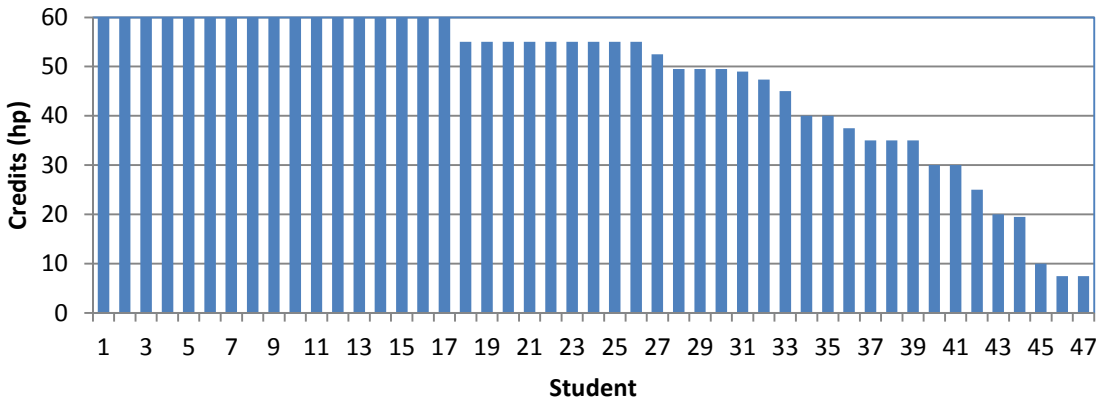


Figure 1: Student achievements for the academic years 2010/2011, 2011/2012 and 2012/2013 for all students enrolled in the program. Data were extracted in February 2014 and following re-exams during the spring semester further improvement in students' achievements are expected.

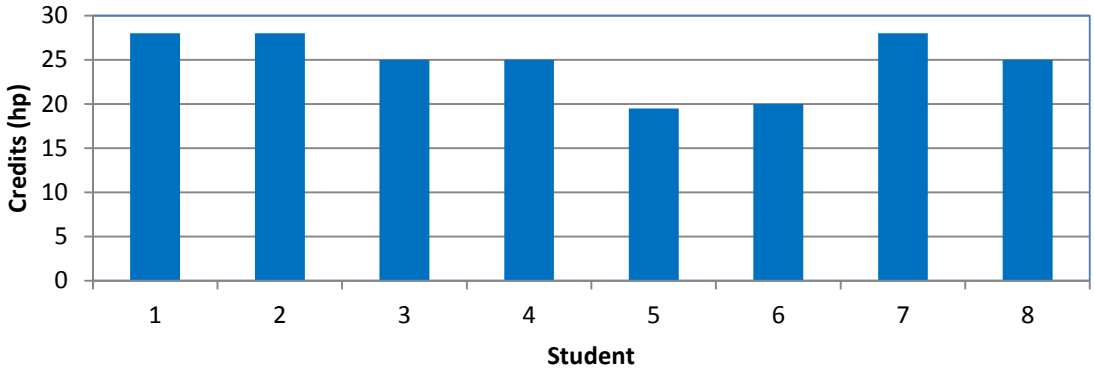


Figure 2: Student achievements for the autumn semester of the academic year 2013/2014 for the studentsenrolled in the program. The maximum credits possible is 30 hp.

Employment

Almost without exception the students graduating from the Bachelors' programme have been employed within the nuclear industry. Of those students a large majority has taken up positions with the NPPs and we are happy to note that the interest among those students to pursue a career within NPP operation is continuously very high. Increasing the supply of candidates for this staff category was one of the original objectives of the programme. Within industry there is on-going work to adapt the on-the job training of turbine and reactor operators in order to take advantage of the higher education level of the new recruits compared to what has previously been required.

Contract education for the industry

The fact that the Swedish nuclear industry have entered a period of cost down-sizing and low electricity prices is reflected in a lower than usual number of course participants in the courses provided by ANP to industry through a long-term agreement with KSU. However, during 2013 ANP provided 17 weeks of courses, an increase by 4 weeks from the previous year.

During spring 2013 the thoroughly revised FS1 radiation protection course was given for the first time with a good learning outcome. Following the specifications laid down by the FORS-group the course has been extended from 2 to 3 weeks with considerable more time devoted to course participant driven case studies, exercises and increased student-teacher interaction. For the future the FORS-group will look

into the role of the course in relation to prerequisite courses and the development of literature for the radiation protection courses.

Students' theses during 2013

PhD theses

Ali Al-Adili: "Measurement of the 234U(n,f) Reaction with a Frisch-Grid Ionization Chamber up to En=5 MeV". The thesis finished in December 2012 and successfully defended on January 18 2013 with Patrick Talou from Los Alamos National Laboratory as faculty opponent.

Licentiate theses completed

Matilda Åberg Lindell: " Proliferation resistances of Generation IV recycling facilities for nuclear fuel". Available at http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-209098.

A. Shepidchenko, "Te-antisite in deformed CdTe - a first principles study".

Masters theses completed

- **Christian Alex**: "Optimization of RIA-calculations: Simulating Falling Control Rods at Forsmark Nuclear Power Plant" – in collaboration with Forsmarks Kraftgrupp
- **Erik Dalborg**: " MCNP-modell för beräkning av neutrondos och DPA på reaktortanken vid Ringhals 2" – in collaboration with Vattenfall Nuclear Fuel
- **Moa Eriksson**: "Förutsättningar för ett parallellt generation IV system vid svensk nybyggnation av kärnkraft"
- **Lisa Angeli Svanholm**: "Improvement of ultrasound backing on non destructive testing probes"
- **Linn Bydell**: "Evaluation of the thermal-hydraulic software GOTHIC for nuclear safety analyses"
- **Malin Fitz**: "Control rod drop during hot zero power: RIA in BWR"
- **Petter Helgesson**: "UO-2 vs MOX: Propagated nuclear data uncertainty with burnup using Fast Total Monte Carlo"
- **Louise Östangård**: "Reactivity Analysis of Nuclear Fuel Storages: The Effect of ^{238}U Nuclear Data Uncertainties"

Masters diploma works in progress

- **Tom Bjelkenstedt**: "Dimensionering av detektorelement inom transmissionstomografi med snabba neutroner".
- **Sara Wiberg**: "Non-destructive assay methods for deep geological disposal of spent nuclear fuel" – in collaboration with SKB.
- **Anders Jansson**: "CFD simulation of pool dynamics in a nuclear reactor's condensation pool", Westinghouse.
- **Gustav Robertsson**: "Investigation of pin-power calculation method used by the nodal code SIMULATE-5", Vattenfall Nuclear Fuel.
- **Christopher Strandberg:** "Geoenergi"

Bachelors theses completed (KKI)

- **Thomas Carlsson**: "Analys av konstruktionsprocessen inom FTC", FKA.
- **Johan Westlin**: "Analys av konstruktionsprocessen inom FTC", FKA.

- **David Johnsson, Daniel Nyberg**: ”Mät- och loggningsutrustning för spänningstransienter”, FKA.
- **Kenny Josefsson**, **Måns Mattisson**: ”Effektiviseringspotential i projekt”, FKA.
- **Josef Abou-Soultan**, **Ammar Al-Bagdadi**: ” Effektivisering av uppföljning av revisionstidplaner under revision på Forsmark”, FKA.
- **Mikael Tollman**: ”Kärnkraftverks störningstålighet mot transienter”, FKA.
- **Erik Mattson**: ”Analys av planeringsarbetet för revision, FMP2”, FKA.
- **Joel Sundmark**, **Lars Spansk**: ”Analys av nivåproblematik i dränagetank på Ringhals 1”, RAB.

Bachelors diploma works in progress (KKI):
Ammar Al-Bagdadi, Josef Abou-Soultan: ”Effektivisering av uppföljning av revisionstidplaner under revision” (prel. title) – in collaboration with Forsmarks Kraftgrupp.

Research

New personnel

Senior personnel
In July 2013, **Steve Tobin**, a researcher from Los Alamos National Laboratory who is heading the Next Generation Safeguards Initiative Spent Fuels Project, started working at Uppsala University as a guest researcher on spent fuel assay with focus on Swedish needs for encapsulation and final storage. Steve shares his time between Uppsala University and SKB.

Staffan Qvist was hired as a postdoc within GenIV research in August 2013, after finishing his PhD degree at UC Berkeley in May. Staffan works on reactor core design and control as well as on code development for design assessment.

Anna Davour was employed for communicating our activities internally UU as well as to the surrounding society. Anna has a PhD in hadron physics and a Master in journalism. She has produced numerous of spots in, e.g. “Vetenskapsradion”. She is working on a 50 % basis and, currently, also a limited time contract. During 2014 we will investigate if we can prolong her contract.

Ali Al-Adili: after finishing is PhD student work, Ali was hired as researcher on a 2-year contract. He is continuing his collaboration with the Joint Research Centre of the EU at Geel, Belgium, supporting the AlFONS project for fission yield measurements and acting as teacher in, e.g., the reactor physics course in the nuclear engineering bachelor program.

Erik Anderson-Sundén, former PhD student from our division who had worked at SSM was hired as research engineer to support the development of our new detector development laboratory and the neutron source bunker in the FREIA hall at Ångström. He is also supporting various research activities in the division.

Ph.D. students
During 2013 the following Ph.D. students were recruited:

Tomáš Martinik was appointed as a PhD student in January 2013 to work within the Next Generation Safeguards Initiative, covering new measurement techniques for assessing the fissile content in spent nuclear fuel. The project is performed in collaboration with Los Alamos National Laboratory (LANL).

Erik Branger got his PhD student appointment in the nuclear safeguards area in November 2013, with focus to study the response of the Digital Cherenkov Viewing Device (DCVD) for assessment of spent nuclear fuel and to investigate and strengthen its capabilities for partial-defect detection.

Petter Helgesson started as PhD student in the Total Monte Carlo project group during autumn. He did his diploma work, which led to a journal publication, on "UO-2 vs MOX: Propagated nuclear data uncertainty with burnup using Fast Total Monte Carlo" with Henrik Sjöstrand as supervisor. Petters project is described below and will be conducted in close collaboration with NRG in the Netherlands.

Ph.D. student projects
The following PhD students perform research of high relevance for reactor operation and nuclear fuel performance, with direct support from SKC in terms of PhD salary and/or supervisor salary:

Void monitoring in thermal-hydraulic test loops using neutron transmission tomography
PhD student: **Peter Andersson**
Main supervisor: Ass.prof. Staffan Jacobsson Svärd
Assistant supervisor: Ass. Senior Lecturer Henrik Sjöstrand

Proper knowledge of the distribution of void and water in BWR fuel during reactor operation is important for fuel design and for optimization of the reactor operation. Accordingly, extensive research on two-phase flow and heat transfer is carried out at various experimental facilities, such as the HWAT loop at KTH in Stockholm and the FRIGG loop at Westinghouse in Västerås. There are several techniques for assessing void in these thermal-hydraulic test loops. Neutron tomography is a promising new alternative, without some of the drawbacks of e.g. gamma-ray tomography that was previously applied at FRIGG. Firstly, an accelerator-based neutron source may be used, which can be turned off when not used, and secondly, neutrons are more sensitive to the content of water/void in the object as compared to the construction material.

Peter Andersson is now in the finishing phase of his PhD project on neutron transmission tomography for void monitoring. At the start of 2013, Peter had finalized the investigations on how to construct an experimental device for neutron tomography with performance parameters making it of use for thermal-hydraulic studies with particular focus on HWAT, and a laboratory device had been manufactured. Also, artificial test objects had been manufactured, imitating the type of two-phase flow objects that are the main target for this new measurement technique. During January-March 2013, Peter performed demonstration measurements using this device at the The Svedberg Laboratory in Uppsala, with a neutron generator borrowed from Chalmers (generously offered from Anders Nordlund). After the measurements, comprehensive analyses of the data have been performed both in terms of the quality of neutron radiography projections as well as in terms of accuracy and precision of the tomographic reconstructions made of the internal void distribution of the test objects.

Furthermore, the prerequisites for applying the technique on FRIGG have been studied.
A reference group meeting was arranged at the 2013 SKC symposium in Gimo in October. Peter presented the results obtained in the test measurements, and attention was paid to the time required and the expected performance for a tomographic measurement on a larger FRIGG-type object. So far, Peter has published his research in two scientific papers (two journal papers and two conference papers). In addition, two journal papers are in manuscript and one more conference papers is planned for. A comprehensive accountancy of these papers and additional conclusions will be reported in the PhD thesis. The dissertation is scheduled for June 4th 2014.

Advanced diagnostics of nuclear fuel based on tomographic techniques and high-resolution gamma-ray spectroscopy
PhD student: **Scott Holcombe**
Main supervisor: Ass.prof. Staffan Jacobsson Svärd
Assistant supervisor: Prof. Ane Håkansson

Nuclear fuel performance is of highest importance for safe and economic operation of commercial power plants. Therefore, extensive efforts are put into development and testing of new fuel designs, where the final steps include test irradiation in research reactors and irradiation of lead assemblies in commercial power plants. Among the strains that nuclear fuel has to be able to withstand are temperature and

neutron flux transients, which may occur in accidental scenarios. Such transients can only be tested in a few research reactors in the world, e.g. at the HBWR of the OECD Halden Reactor Project (OECD-HRP). Among the fuel characteristics that are studied at such reactors are burnup, power and fission gas

release distributions. However, with previous techniques such as gamma scanning, the assembly has to be cooled and disassembled before measurement of pin quantities, implying an inadequacy to measure short-lived fission products.
In this PhD project, Scott Holcombe develops a tomographic technique for fuel assessment, allowing for the characterization of all fuel rods in an assembly without disassembly. The project is run in collaboration with Westinghouse Electric Sweden AB as a part of OECD-HRP, with Scott as a secondee in Halden. The project has financial support from the Swedish research council (VR).

During 2013, Scott has published two papers in scientific journals and one peer-reviewed conference paper, covering spectroscopic gamma-ray measurement of short-lived fission gasses, identification of leaking rods by means of tomographic measurements of the gas plenum, respectively assessment of the radial origin of released fission gasses in a fuel pin.
A device for tomographic measurements on irradiated fuel at the Halden reactor (HBWR) is currently being manufactured and experiments will take place during spring 2014. The fuel to be measured has been thoroughly characterized during 2013, being long-cooled HBWR driver fuel with an irradiation history comprising relatively high linear heat generation rates and thus interestingly high levels of fission gas release. Once introduced by the reactor, the device will allow measurements to be performed on test fuel with short cooling times (1-2 days) enhancing the capabilities of e.g. fission-gas assessment significantly, while allowing for the fuel to be re-introduced into the core after measurement.

So far, Scott has published 7 scientific papers (2 journal papers and 5 conference papers) and 5 additional papers are expected during 2014. According to schedule, the PhD thesis will be finalized and presented in December 2014.

"Measurements of the ^{234}U(n,f) reaction with a Frisch-Grid Ionization Chamber up to E_n=5 MeV"
PhD student: **Ali Al-Adili**
Main supervisor: Prof. Stephan Pomp
Assistant supervisor: Dr. Franz-Joseph Hambsch, Univ. lekt. Michael Österlund

Ali Al-Adili has presented his thesis on fission of ^{234}U in December (and defended on Jan 18, 2013). Details were reported already in the last annual report. For his thesis work, Ali has received the ENEN prize 2013.

"MAssive Computational methodology for Reactor Operation – MACRO".
PhD student: **Erwin Alhassan**
Main supervisor: Bitr. univ. lekt. Henrik Sjöstrand.
Assistant supervisors: Univ. lekt. Michael Österlund, Prof. Stephan Pomp, Dr. Dimitri Rochman.

Erwin started his PhD studies in 2011. He is using the Total Monte Carlo method (TMC) to study the impact of nuclear data uncertainties on reactor parameters. Using TMC, uncertainty propagation was carried to study the impact of nuclear data uncertainties on future reactor systems. Recent developments in his project concern, e.g., the use of benchmarks to constrain model calculations to give a more realistic determination of derived uncertainties for main safety parameters. Results have been presented at several conferences during 2013. Erwin will present his licentiate thesis in May 2014.

"Nuclear data uncertainty propagation with Total Monte Carlo – method development and applications"
PhD student: **Petter Helgesson**
Main supervisor: Bitr. Univ. lekt. Henrik Sjöstrand
Assistant supervisor: Prof. Arjan Koning, Dr. Dimitri Rochman (NRG, Nederländerna), Prof. Klaes-Håkan Bejmer, Prof. Stephan Pomp

Petter Helgesson started his PhD studies in August 2013 in collaboration with Nuclear Research and Consultancy Group (NRG) in Petten, the Netherlands. The studies cover quantification and propagation of nuclear data uncertainties both using and developing the Total Monte Carlo method (TMC) which is mainly developed at NRG.

The work has so far been focused towards development of the methodology, namely on how to incorporate experimental data into the method in a way which is more statistically solid compared to

the method as of today. By this, the confidence in the uncertainty estimates will be increased, enabling stronger conclusions to be drawn. Also, the improvement is believed to reduce the uncertainties since more knowledge is added. As the methodology matures, the updated method will be applied primarily to LWR systems. The development of the method and a simple application will be presented at the CW2014 Workshop, April 2014 in Santa Fe, New Mexico.

During 2013, one paper has been submitted and accepted by Nuclear Science and Engineering. Parts of this work, an analysis of the uncertainties obtained with TMC applied to a PWR with different fuel types, was presented at the SKC symposium at Gimo Herrgård in October.

In excess of supervisors at UU and NRG, Petter is supervised by Klaes-Håkan Bejmer at Vattenfall Nuclear Fuel and there is a continuous discussion to ensure that the work is relevant for real-world applications. The method development will also allow for the use of the reactor relevant benchmarks in order to reduce the uncertainties in e.g. fuel storage pools and shielding properties of shielding assemblies. This is something that has been specifically been requested by Vattenfall.

Petters work will also be directed to lay the foundation for using the TMC methodology for studies in aging and material damage effects due to radiation as outlined in the SKC project description of the Materials and Fuels consortium.

“Neutron-induced nuclear reactions at intermediate energies”
PhD student: **Kaj Jansson**
Main supervisor: Bitr. Univ. lekt. Dr. Cecilia Gustavsson
Assistant supervisor: Prof. Stephan Pomp, Dr. Alexander Prokofiev

Kaj started during spring 2012 as the first PhD student on the NFS project. He has mainly been working on detector simulations for the upgrade of the Medley setup with PPAC detectors, design and programming of a data acquisition system and … . The Medley is currently being equipped with a low pressure gas system and will, after completing local detector tests, move to NFS, GANIL, France towards the end of 2014. Prime goal of the campaign at NFS is the performance of precision measurement of fission cross sections used as reference standards.

In addition light-ion production induced by fast neutrons (several MeV up to a few tens of MeV) impinging on different targets will be studied. The results will, e.g., improve our knowledge on gas production in reactor materials through the (n,¤) process.

“Measurements of independent fission yields from a fast neutron spectrum”
PhD student: **Andrea Mattera**
Main supervisor: Prof. Stephan Pomp
Assistant supervisor: Dr. Mattias Lantz, Univ. lekt. Michael Österlund

Andrea started in spring 2011 as the first Ph.D. student within the AlFONS project. AlFONS, co-financed by SSM and SKB, aims at measuring independent fission yields in thermal and fast neutron spectra at the IGISOL facility in Jyväskylä, Finland. That facility offers the possibility for precision measurements of the yields for products with lifetimes as short as a few hundred milliseconds. The results will be used as guidance for nuclear reaction modelling and will decrease uncertainties in fuel inventory calculations.

The IGISOL facility uses an intense proton beam to produce neutrons in a Be target which is located close to the fission target. This leads to a high neutron flux on the target and ensures that measurements with good counting statistics can be performed. During 2013 the preparatory studies for the IGISOL measurements have been presented at several conferences. A first measurement campaign, however still using the proton beam on target, at the new IGISOL-4 beamline was conducted in June 2013. The first run using the proton beam for neutron production for the neutron-induced fission studies are planned for spring 2014. Andrea will present his licentiate thesis during 2014.

“Studies of independent fission yields from fast neutrons”
PhD student: **Vasileios Rakopoulos**
Main supervisor: Dr. Mattias Lantz
Assistant supervisor: Prof. Stephan Pomp, Dr. Andreas Solders

Vasileios joined the division in spring 2012 to work on the AlFONS project together with Andrea Mattera. He has been involved in the TSL measurements for determining the neutron energy spectrum at IGISOL. Vasileios works in parallel with Andrea Mattera but with different actinide targets and with the goal to perform precision measurements of fission yields in fast and thermalized neutron spectra.

There are plans to conduct measurements for, e.g., Pu and Am isotopes for which no measurements exist at all. Such data will proof to be important use for inventory calculations especially at high burnup. Besides getting access to suitable targets, an important challenge is the characterisation of the neutron spectrum to which the actinide target is exposed. While the neutron energy spectra resemble spectra in thermal and fast reactor designs, there will still be differences that need to be corrected. Hence good knowledge of both the neutron spectrum and nuclear models for the energy dependence of fission yields are needed. The project is closely linked to the efforts in nuclear modelling with TALYS and the TMC project and it is worth mentioning that our research group, through the efforts of Vasily Simutkin, has managed to include a new state-of-the-art fission model code into the new TALYS 1.6 version.

The following PhD students perform research within nuclear safeguards, being partly supported by SKC funding 2013, whereas from 2014 and onwards we expect funding from SSM separately from SKC:

Verification of nuclear fuel for safeguards purposes using non-destructive assay techniques for the future Swedish encapsulation facility
PhD student: **Tomáš Martiník**
Main supervisor: Dr. Sophie Grape
Assistant supervisor: Dr. Peter Jansson, Prof. Ane Håkansson, Dr. Peter Jansson, Ass.Prof. Staffan Jacobsson Svärd

The Next Generation Safeguards Initiative (NGSI) was launched in the U.S. in 2008 as one of the largest research efforts in nuclear safeguards in modern time, with the purpose to enhance safeguards assessment capabilities in terms of quantifying important safeguards parameters and fissile content. In the NGSI Spent Fuel project, 14 promising measurement techniques were initially selected for more thorough studies, and from these a number of complementary sub-sets have been selected for experimental evaluations.

Tomas Martinik started as a joint student between Uppsala University and Los Alamos National Laboratory (LANL) in January 2013. During this first year, he spent 4 months at LANL to study the Differential Die-Away (DDA) technique together with LANL expertise on the topic.

The purpose of Tomas’ project is to contribute to the NGSI techniques being developed and to bring a Swedish back-end perspective into their evaluation. The project concerns simulations, analysis and experimental assessment of the DDA technique applied on of spent nuclear fuel. Based on the simulations and modelling in 2013, Tomas works on his first paper to be submitted to a scientific journal during spring 2014.

Studies of Cherenkov light emission and detection for nuclear safeguards purposes
PhD student: **Erik Branger**
Main supervisor: Dr. Sophie Grape
Assistant supervisors: Ass. Prof. Staffan Jacobsson Svärd, Dr. Peter Jansson

The Digital Cherenkov Viewing Device (DCVD) is a valuable tool for IAEA inspectors when verifying the presence and integrity of irradiated nuclear fuel assemblies in storage pools. In spite of its current use, there are still a number of properties of Cherenkov light emission and detection not fully understood, and a better understanding together with improved analysis routines are expected to enhance its capabilities for safeguards assessments.

Erik Branger started his PhD studies in November 2013, with a research focus on the DCVD and its performance for partial-defect verification of spent nuclear fuel assemblies. Erik will study and describe the basic physics behind Cherenkov light emission and detection as well as methodologies for recording and processing images of spent nuclear fuel. As a first task, he has looked into image analysis and the possibilities to enhance the detection capabilities using imaging concepts.

The following PhD students are active within the research on Gen IV reactor technologies. Although outside the research framework of SKC, these projects are relevant from a general knowledge and competence building perspective:

Core Monitoring in Lead-Cooled Fast Reactors
PhD student: **Peter Wolniewicz**
Main supervisor: Prof. Ane Håkansson
Assistant supervisors: Dr. Carl Hellesen, Dr. Peter Jansson, Ass.Prof. Staffan Jacobsson Svärd, Ass.Prof. Michael Österlund

This project investigates the capabilities of in-core and/or near-core detector systems for monitoring anomalies in core operation by means of changes in the neutron energy spectrum. In particular, Peter Wolniewicz has been working on the development of a methodology to detect coolant void in Lead-cooled Fast Reactors. The project has progressed significantly during 2013 with two accepted and published articles. The first article entitled “Detecting neutron spectrum perturbations due to coolant density changes in a small lead-cooled fast nuclear reactor” was accepted 13 March 2013 in Annals of Nuclear Energy. The second article titled “Feasibility study of detection of coolant void in liquid metal cooled fast reactors using changes in the neutron spectrum” was accepted 18 October 2013 in Nuclear Engineering and design (NED).

In late 2013, a third article by Carl Hellesen et al. with Wolniewicz as a co-author was submitted as contribution to the PHYSOR conference (Kyoto). The latest work was submitted to NED and will be slightly revised according to the reviewer´s comment. A fifth article was initiated during the end of 2013 and covers dynamical response to various void scenarios of the demonstrator reactor ALFRED. This work is done in collaboration with P. Kudinov et al. at KTH.

The forthcoming work will be focussed on the actual detection of coolant void based on the methodology developed in the first paper mentioned above and is planned to result in a sixth paper. Based on these papers, Peter will finalize his PhD thesis, which is to be defended at a public dissertation in autumn 2014.

Instrumentation and safeguards evaluations of a Generation IV reprocessing facility
PhD student: **Matilda Åberg Lindell**
Main supervisor: Dr. Sophie Grape
Assistant supervisors: Prof. Ane Håkansson, Ass.Prof. Staffan Jacobsson Svärd

Matilda Åberg Lindell studies nuclear safeguards for future GenIV systems. The aims of this research project have over time been specified to (1) develop methodologies for evaluating diversion resistance for Gen IV systems and (2) assign safeguards instrumentation to be used in sensitive parts of the cycle.

During 2013, Matilda has concluded her work on the first goal and accordingly, she has finalized three publications on methodologies for evaluating diversion resistance in Gen IV systems. One of the papers was published in a scientific journal (Annals of Nuclear Energy), while the other two papers were contributions to two international conferences: the ESARDA symposium in Bruges and Global2013 in Salt Lake City; in both cases the papers were presented orally. The latter of the two conference contributions was peer-reviewed. Matilda also finalized her Licentiate thesis on this topic, which she successfully defended on October 18, with Dr. Roland Carchon, having his background from SCK-CEN and IAEA, as the scrutinizer.
Matilda’s future work will focus on the safeguards instrumentation for a recycling facility. On a practical level, this means that she will model the composition of dissolved spent nuclear fuel material occurring in the advanced recycling process Ganex in selected locations in the recycling facility in order to

characterize the gamma and neutron signals that may be recorded and analysed in these locations. In the course of this work, she will model the detection of these signals with different types of safeguards measurement equipment. Matilda will also plan and conduct an experimental measurement campaign together with Teodora Retegan at Chalmers University of Technology, using small amounts of dissolved spent nuclear fuel.

The simulation and modelling work and the analyses of experimental results will result in two additional papers, which together with the already published papers will constitute the basis for her PhD thesis. Matilda's dissertation is planned for autumn 2015.

Core Diagnostics in the ASTRID Sodium Fast Reactor (CODIAS)
PhD student: **Vasudha Verma**
Main supervisor: Dr. Carl Hellesen
Assistant supervisors: Ass.Prof. Staffan Jacobsson Svärd, Prof. Ane Håkansson, Dr. Peter Jansson, Ass.Prof. Michael Österlund

Vasudha Verma is a PhD student within the Swedish-French collaboration on GenIV research directed specifically to the ASTRID Sodium Fast Reactor, who started in November 2012. Her PhD project is entitled "Core Diagnostics in the ASTRID Sodium Fast Reactor (CODIAS)", and it is part of the framework program "Core physics, diagnostics and instrumentation for enhanced safety of the sodium cooled fast reactor ASTRID", which is coordinated by prof. Imre Pazsit at Chalmers.

After spending her first 10 months in Uppsala, taking PhD student classes and being introduced to the subject and to the tools used for the investigations, Vasudha moved to France in September 2013 to work in Cadarache with her French supervisor, Christian Jammes. The collaboration is appreciated from both parts, and the first topic of Vasudha's investigations; detection of inadvertent removal of a control rod, is moving quickly forward so that a first publication is expected during 2014.

Development of radiation detector materials
PhD student: **Anna Shepidchenko**
Main supervisor: Prof. Mattias Klintenberg
Assistant supervisors: Prof. Susanne Mirbt, Prof. Ane Håkansson

This year the main attention was paid to the Cd vacancy (V_{Cd}) in CdTe. This defect, as well as previously studied CdTe, is one of the most interesting defect types in this material. Even though the cadmium vacancy seems to be a well-known defect type in CdTe, there are still many disagreements between experimental and theoretical study.

In previous theoretical work geometries of all charged states of the vacancy are determined as T_d-symmetrical. In contradiction, there are a number of experiments that claim some states of the Cd vacancy to be out of T_d-symmetry. For example, EPR (Electron Paramagnetic Resonance) analysis shows that the V_{Cd} in -1 charge state has to have lower C3v symmetry due to the hole localization in vicinity of one neighbouring Te. Calculations based on Local Density Approximation (LDA) do not confirm this fact. So, there are two ways of explanation of this situation. Either the experimental interpretation was wrong, or the simulation method is still not good enough to reproduce correct geometry of this defect.

In our work concerning V_{Cd} modelling we have used one of the latest and successful ab-initio approaches: HSE06 Hybrid Functional. This approach is known as one of the best in predicting correct band gaps of semiconductors. It can predict small electron localizations on the defect sites, while LDA fails do this in many cases.
Our calculations have shown that Cd-vacancy in zero-charged state has different from T_d symmetry, namely D_{2d}. This symmetry assumes formation of the dimer of two Te instead of high symmetrical tetrahedron of 4 Te, and this construction leads to forming of 4 new defect levels deep in the valence band of CdTe. Such a way, we prove that zero-charged Cd-vacancy does not form a defect level in the band gap.

Cd-vacancy (-2) energy levels behave almost in the same way as neutral one (no levels in the bandgap), even though V_{Cd} does not loose T_d-symmetry. Cd-vacancy (-1) is the most difficult one. Our calculations show very fine deviation from the Td-symmetry, most likely due to the small polaron, which appears in

vicinity of one of Te, positioned close to the vacancy. LDA cannot capture this phenomena and it is quite difficult to do even with HSE06, so we have to perform very accurate modelling.

Also we have calculated energies of Te-antisite in different charge states. Formation energies of Te-antisite and Cd-vacancy, (0) and (-1) were calculated, and they dramatically deviate from those,

obtained earlier with LDA. This information will change current understanding of these defects concentrations in the CdTe. The paper is in progress now.
At the same moment, calculations of the hydrogen - Cd-vacancy complex defect are on-going.

"Massive computation methodology applied to nuclear technology"
PhD student: **Gustav Wallin**
Main supervisor: Prof. Stephan Pomp
Assistant supervisor: Bitr. Univ. lekt. Henrik Sjöstrand, Bitr. Univ. lekt. Cecilia Gustavsson, Univ. lekt. Michael Österlund

Gustav started in 2010 as Ph.D. student within the Genius project and was supposed to work with the TMC method. However he was on long-term sick leave and much of his work was redirected towards the project of Erwin Alhassan (see above). In December Gustav tragically passed away.

Publications and conferences

Work published/accepted in scientific journals

The following scientific papers were published during 2013:
S. Grape, S. Jacobsson Svärd and B. Lindberg, "Verifying nuclear fuel assemblies in wet storages on a partial defect level: A software simulation tool for evaluating the capabilities of the Digital Cherenkov Viewing Device", Nuclear Instruments and Methods in Physics Research Section A, 698, 66-71, January 2013.

S. Holcombe, S. Jacobsson Svärd, K. Eitrheim, L. Hallstadius and C. Willman, "Feasibility of identifying leaking fuel rods using gamma tomography", Annals of Nuclear Energy, 57, 334-340, July 2013.

P. Wolniewicz, C. Hellesen, A. Håkansson, S. Jacobsson Svärd, P. Jansson, M. Österlund, "Detecting neutron spectrum perturbations due to coolant density changes in a small lead-cooled fast nuclear reactor", Annals of Nuclear Energy, 58, 102-109, August 2013.

S. Holcombe, S. Jacobsson Svärd, K. Eitrheim, L. Hallstadius and C. Willman, "Method for Analyzing Fission Gas Release Based on Gamma-ray Measurements of Fuel Rods with Short Decay Time", Nuclear Technology, 184 (1), 96-106, October 2013.
Åberg Lindell, M., Grape, S., Håkansson, A., Jacobsson Svärd, S., "Assessment of proliferation resistances of aqueous reprocessing techniques using the TOPS methodology", Annals of Nuclear Energy, 62, 390-397, December 2013.

P. Wolniewicz, A. Håkansson, P. Jansson, S. Jacobsson Svärd, " Feasibility study of detection of coolant void in liquid metal cooled fast reactors using changes in the neutron spectrum", Nuclear Engineering and Design, 265, 1255-1265, December 2013.

S. Grape, S. Jacobsson Svärd, B. Lindberg, "Evaluation methodology for partial defect verification in nuclear safeguards using the Digital Cherenkov Viewing Device (DCVD)", Accepted for publication in Nuclear Technology in early 2014.

A. Shepidchenko et al., J. Phys.: Condens. Matter: doi: doi:10.1088/0953-8984/25/41/415801

T. Moriguchi, M. Lantz, et al., “Density distributions of ^{11}Li deduced from reaction cross-section measurements”, Physical Review C **88**, 024610 (2013).

V.S. Kolhinen, M. Lantz, A. Mattera, A. Solders, et al., “Recommissioning of JYFLTRAP at the new IGISOL-4 facility”, Nucl. Inst. Meth. Phys. Res. B **317**, 506 (2013).

D. Rochman, A. Koning, H. Sjöstrand, P. Helgesson, et al., ”Efficient use of Monte Carlo: uncertainty propagation”, Nuclear science and engineering (2013).

P. Helgesson, D. Rochman, H. Sjöstrand, E. Alhassan, A. Koning, ” UO-2 vs MOX: Propagated Nuclear Data Uncertainty for k-eff, with burnup”, Nuclear science and engineering (2013).

L. Bläckberg, H. Sjöstrand, et al., “Memory effect, resolution, and efficiency measurements of an Al2O3 coated plastic scintillator used for radioxenon detection”, Nucl. Inst. Meth. Phys. Res. A **714**, 128 (2013).

Conference contributions

The following refereed conference contributions were published or accepted for publication during 2013:

Åberg Lindell, M., Grape, S., Håkansson, A., Jacobsson Svärd, S., ”Schematic design and safeguards instrumentation of a Gen IV fuel recycling facility”, 35th ESARDA Annual Meeting, Bruges, Belgium, May 27-30 2013.

S. Grape, S. Jacobsson Svärd, “Recent modelling studies for analysing the partial-defect detection capability of the Digital Cherenkov Viewing Device”,35th Annual ESARDA meeting on Safeguards and Nuclear Non-Proliferation, Bruges, Belgium, May 27-30 2013.

C. Hellesen, S Grape, A Håkansson, S Jacobsson Svärd, P. Jansson, “Improving proliferation resistance of high breeding gain generation 4 reactors using blankets composed of light water reactor waste”, 35th Annual ESARDA meeting on Safeguards and Nuclear Non-Proliferation, Bruges, Belgium, May 27-30 2013.

P. Jansson, S. Jacobsson Svärd, S. Grape, A. Håkansson, “A laboratory device for developing analysis tools and methods for gamma emission tomography of nuclear fuel”, 35th Annual ESARDA meeting on Safeguards and Nuclear Non-Proliferation, Bruges, Belgium, May 27-30 2013.

S. Tobin, S. Grape, P. Jansson, “Prototype Development and Field Trials under the Next Generation Safeguards Initiative Spent Fuel Non-Destructive Assay Project”, 35th Annual ESARDA meeting on Safeguards and Nuclear Non-Proliferation, Bruges, Belgium, May 27-30 2013.

S. Holcombe, S. Jacobsson Svärd, K. Eitrheim, L. Hallstadius, “A Nondestructive Method for Investigating the Origin of Released Fission Gasses in Nuclear Fuel Rods”, presented at the 2013 Water Reactor Fuel Performance Meeting in Charlotte, North Carolina, USA, Sept. 15-19, 2013 (Peer-reviewed paper).
M. Åberg Lindell, S. Grape, A. Håkansson, S. Jacobsson Svärd, ”Proliferation resistance assessments during the design phase of a fuel recycling facility as a means of reducing proliferation risks”, GLOBAL 2013: International Nuclear Fuel Cycle Conference, Salt Lake City, USA, 29 Sept – Oct 3 2013 (Peer-reviewed paper).

C. Hellesen, S. Grape, A. Håkansson, S. Jacobsson Svärd, P. Jansson, “Improving the proliferation resistance of generation IV fast reactor fuel cycles using blankets manufactured from spent nuclear fuel”, Global 2013 conference, Salt Lake City, USA, Sept 29-Oct 3 2013 (Peer-reviewed paper)

A. Shepidchenko et al., “Tailoring of defect levels by deformations: Te-antisite in CdTe”, International Conference on Defects in Semiconductors, Bologna, Italy.

A. Shepidchenko et al., “Tailoring of defect levels by deformations: Te-antisite in CdTe”, 2013 IEEE Nuclear Science Symposium and Medical Imagining Conference and Workshop on Room-Temperature Semiconductor X-Ray and Gamma-Ray Detectors (IEEE NSS/MIC/RTSD 2013), Seoul, Korea.

E. Alhassan, et al., “Uncertainty analysis of Lead cross sections on reactor safety for ELECTRA”, Joint International Conference on Supercomputing in Nuclear Applications + Monte Carlo, Paris, October 27-31, 2013.

A. Al-Adili, et al., “Sensitivity of measured fission yields on prompt-neutron corrections”, International conference on nuclear data for science and technology, 4-8 March, 2013, New York USA, accepted for publication in Nuclear Data Sheets.

E. Alhassan, et al., “Combining Total Monte Carlo and Benchmarks for nuclear data uncertainty propagation on an LFR’s safety parameters”, International conference on nuclear data for science and technology, 4-8 March, 2013, New York USA, accepted for publication in Nuclear Data Sheets.

R. Bevilacqua, et al., “Light-ion production from O, Si, Fe and Bi induced by 175 MeV quasi-monoenergetic neutron”, International conference on nuclear data for science and technology, 4-8 March, 2013, New York USA, accepted for publication in Nuclear Data Sheets.

J. Duan, et al., “Uncertainty study of nuclear model parameters for the n+^{56}Fe reactions in the fast neutron region below 20 MeV”, International conference on nuclear data for science and technology, 4-8 March, 2013, New York USA, accepted for publication in Nuclear Data Sheets.

C. Gustavsson, et al., “Status report on the analysis of inelastic neutron scattering from carbon, iron, yttrium and lead at 96 MeV”, International conference on nuclear data for science and technology, 4-8 March, 2013, New York USA, accepted for publication in Nuclear Data Sheets.

K. Jansson, et al., “Measuring light-ion production and fission cross sections versus elastic np-scattering at the upcoming NFS facility”, International conference on nuclear data for science and technology, 4-8 March, 2013, New York USA, accepted for publication in Nuclear Data Sheets.

M. Lantz, et al., “Design of a High Intensity Neutron Source for Neutron-Induced Fission Yield Studies”, International conference on nuclear data for science and technology, 4-8 March, 2013, New York USA, accepted for publication in Nuclear Data Sheets.

A. Mattera, et al., “Characterization of a Be (p, xn) neutron source for fission yields measurements”, International conference on nuclear data for science and technology, 4-8 March, 2013, New York USA, accepted for publication in Nuclear Data Sheets.

D. Rochman, et al., “Efficient use of Monte Carlo: uncertainty propagation”, International conference on nuclear data for science and technology, 4-8 March, 2013, New York USA, accepted for publication in Nuclear Data Sheets.

V. Simutkin, et al., “Experimental Neutron-Induced Fission Fragment Mass Yields of 232Th and 238U at Energies from 10 to 33 MeV”, International conference on nuclear data for science and technology, 4-8 March, 2013, New York USA, accepted for publication in Nuclear Data Sheets.

H. Sjöstrand, et al., “Propagation of nuclear data uncertainties for ELECTRA burn-up calculations”, International conference on nuclear data for science and technology, 4-8 March, 2013, New York USA, accepted for publication in Nuclear Data Sheets.

A. Solders, et al., “Accurate fission data for nuclear safety”, International conference on nuclear data for science and technology, 4-8 March, 2013, New York USA, accepted for publication in Nuclear Data Sheets.

A. Mattera, et al., ”Neutron energy spectra from a Be(p,xn) source for fission yield measurements“, NEUDOS 2013, Aix-en-Provence, June 2013, accepted for publication in Radiation Protection Dosimetry.

S. Pomp, et al., ”High-energy quasi-monoenergetic neutron fields: existing facilities and future needs“, NEUDOS 2013, Aix-en-Provence, June 2013, accepted for publication in Radiation Protection Dosimetry.

H. Sjöstrand, et al., ”Total Mone Carlo Evaluation for Dose Calculations“, NEUDOS 2013, Aix-en-Provence, June 2013, accepted for publication in Radiation Protection Dosimetry.

A. Al-Adili, et al., ” Corrections of Prompt-neutron Emission in Fission-fragment Experiments”, Phys. Proc. **47**, 131 (2013).

Other conferences and reports

S. Holcombe, S. Jacobsson Svärd, K. Eitrheim, L. Hallstadius, "A non-destructive gamma-spectroscopy-based method for investigating the radial origin of released fission gasses from high burnup fuel pellets" presented at the 2013 Enlarged Halden Program Group Meeting, Storefjell, Norway, March 2013.

S. Holcombe, “Gamma Tomography at the Halden Reactor”, presented at the 16th Meeting on Reactor Physics in the Nordic Countries (RPNC-2013), Kjeller, Norway, 18-19 April, 2013.

S. Grape, S. Jacobsson Svärd, P. Jansson, M. Österlund, “Students’ approaches to learning from other students’ oral presentations”, presented at Teknisk-naturvetenskapliga fakultetens Universitetspedagogiska Konferens (TUK), Uppsala, Sweden, 19 April 2013.

M. Åberg Lindell, ”Proliferation resistance of Generation IV recycling facilities”, presented at SSM research days, Stockholm, Sweden, 24-25 October 2013.

P. Jansson, “Gamma emission tomography of spent nuclear fuel; Objectives and status of the IAEA UGET project”, presented at SSM research days, Stockholm, Sweden, 24-25 October 2013.
T. Martinik and S. Tobin, “Next generation safeguards initiatives, spent fuel project and recent developments with the DDA technique”, presented at SSM research days, Stockholm, Sweden, 24-25 October 2013.

M. Åberg Lindell, “Proliferation resistance of Generation IV facilities”, Annual Meeting of the GENIUS programme, Uppsala, Sweden, 10-11 October 2013.

P. Wolniewicz, “Detection of coolant bubbles in LFR's”, Annual Meeting of the GENIUS programme, Uppsala, Sweden, 10-11 October 2013.
S. J. Tobin and P. Jansson, “Nondestructive Assay Options for Spent Fuel Encapsulation”, Los Alamos National Laboratory (LANL) Technical Report LA-UR-13-22050, March 2013.
Available at http://dx.doi.org/10.2172/1070056

A.Shepidcheno, “Te-antisite in a deformed CdTe lattice”, IFA seminar.

A.Shepidcheno , “Development of Semiconductor Detectors Materials”
Genius meeting.

S. Pomp, et al., “High-energy quasi-monoenergetic neutron fields: existing facilities and future needs”, EURADOS Report 2013-02 (ISSN 2226-8057; ISBN 978-3-943701-04-3), Braunschweig, Germany, May 2013.

A. J. Koning, et al., “TENDL-2013: TALYS-based evaluated nuclear data library”, ftp://ftp.nrg.eu/pub/www/talys/tendl2013/tendl2013.html.

G. Ericsson and S. Pomp, “Comments on the report" Indications of anomalous heat energy production in a reactor device containing hydrogen loaded nickel powder"[arXiv: 1305.3913] by G. Levi, E. Foschi, T. Hartman, B. Höistad, R. Pettersson, L. Tegnèr, H. Essén”, arXiv: 1306.6365 (2013).

Additional information of interest to SKC

Achievements and commitments

- A thematic day on final reposition of Swedish nuclear waste ("Slutförvarsdagen") was arranged at Uppsala University – Ångströmlaboratoriet on April 26. There were presentations from politicians, technicians and researchers in a various subjects for an interested audience of students and scientists.
- Uppsala University became individual member of the European Safeguards Research and Development Association (ESARDA) after a decision in the ESARDA board at their meeting in May.
- Sophie Grape was elected vice-chair of the ESARDA working group of Training and Knowledge Management, with Karin Persson as an additional group member.
- Peter Jansson and Staffan Jacobsson Svärd became members of the ESARDA working group on Non-Destructive Assay.
- Matilda Åberg Lindell became member of the ESARDA working group on Verification Technologies and Methodologies.
- Sophie Grape became member of Kärnavfallsrådet.
- On behalf of SSM, five of the division's researchers headed by Sophie Grape performed a scrutiny assessment of three SKB reports describing their plans for encapsulation and final storage.
- In October, we hosted the annual GENIUS meeting for the Swedish collaborative research on Gen IV systems.
- On November 25, we showed the film Pandoras Promise at Ångström Laboratory. In addition to this we arranged a debate panel where, among others, the director of the movie, Robert Stone, participated.
- Four of the division's teachers performed a didactics study of nuclear power engineering students' approach to learning during seminar presentation, and the results were presented at a pedagogics conference. One of the purposes with the study was to enhance the quality of the KKI program with respect to students' skills in oral presentation.
- Mattias Lantz has been appointed chairperson of KSUs "Analysgruppen". While continue to be employed by UU, he started January 1 2013 spending 50% of his duty on this task.
- National Gen IV efforts (GENIUS and ASTRID).
- New research activities e.g. radiation assisted effects on different materials at the Ion Physics group and a new reactor physics group.
- Ali Al-Adili was awarded the ENEN Prize 2013 for his thesis.

<u>Networking and collaborations</u>

- Sweden: KTH, Chalmers, Stockholm University, Gothenburg University and SIPRI
- Belgium: Joint Research Centre IRMM in Geel, CSK-CEN in Mol
- The Netherlands: NRG
- Finland: Univ. of Jyväskylä
- France: GANIL, IPNO and CEA
- Japan: Kyushu University
- Switzerland: CERN
- Thailand: Chiang Mai University
- Kenya: University of Nairobi
- USA: LANL, UCB, LBNL, LLNL, NPNL
- Norway: OECD Halden Reactor Project and IFE, Technical University in Trondheim

Outreach

- Talk in Piteå entitled "Grön el – varför miljövänner borde gilla kärnkraft"
- Talk at Föreningen Vetenskap och Folkbildning on nuclear power.
- Talk at Spektrumdagarna på Ångström (seminar for teachers at Swedish Gymnasia) entitled "Globala utmaningar och framtidens kärnkraft"
- Reply on an article in Skånskan by Maj Wechselmann och Håkan Larsson.
- Participation in a panel debate at Riskkollegiet´s seminar on the theme "Svensk kärnkraft - är riskbilden förändrad, finns anledning till oro?" http://www.riskkollegiet.nu/seminarier/svensk-karnkraft-ar-riskbilden-forandrad-finns-anledning-till-oro/

- Reply in Norrköpings Tidning on an article by Mona Nilsson (secretary for Strålskyddsstiftelsen) entitled "Ovärdigt försök att skrämma föräldrar". http://www.nt.se/24nt/arkiv/2013/05/27/Tidningsdebatt/8574983/Ov%E4rdigt-f%F6rs%F6k-att-skr%E4mma-f%F6r%E4ldrar.aspx
- Reply in Motala och Vadstena tidning on article by Tore Fahlström (chairman of Strålskyddsstiftelsen) entitled "Ovärdigt skrämma småbarnsföräldrar". http://mvt.teknomedia.se/asikter/insandare/?articleid=8582156. In priciple the same text as in Norrköpings Tidning.

- Talk at the seminar ENYGF-2013's Unconference at KTH http://www.enygf2013.com/index.php/conference-program/technical-program/unconference), entitled "How do we debunk nuclear myths?"

Visions and Plans

The mission for ANP is to work for achieving safe, secure and sustainable nuclear energy systems. On the global level this seems as imperative in order to solve the monumental issues mankind faces. To obtain this we believe that new Generation III and III+ power reactors together with adequate waste disposal systems is the first step in this direction. Such a development is mainly an undertaking for the industrial part of the world and in order to address the needs of the developing countries, it seems reasonable that the industrial countries take measures to enter a step two, i.e. developing Generation IV systems for the long-term perspective. Small autonomous systems could then be located in regions of the world that are not considered feasible for today's technology.

To realize our mission it is important to enhance our ability to use nuclear physics knowledge/know-how to assist in reactor design, monitoring, safety issues, fuel cycle etc. To succeed here we have expanded our competence in reactor physics and utilised the high-quality activities in materials theory (Prof. Mattias Klintenberg) and the Tandem accelerator Laboratory at Ångström Laboratory.

Below is a brief account on important parts of the strategy to fulfil our mission.

Visions

To contribute to the environmental-friendly energy supply in the world by:

- enhancing safety and security in current nuclear power plants,
- contributing to the development of new nuclear power technologies that are sustainable in a long-term perspective,
- educating future workers, experts and researchers within the nuclear field.

Plans

Education

- Making the bachelors nuclear engineering program a full three-year program.
- Offering "nuclear tracks" in several masters engineering programs.
- Continuing to train and educate personnel from nuclear industry and authorities within our commissioned education for KSU.
- Adding courses to the NANSS portfolio and direct these also for international stakeholders.

Research

- Strengthening our collaboration with OECD Halden Reactor Project (OECD-HRP), which is supported by our application for a separate OECD-HRP membership:
  - setting up a research program within core and fuel diagnostics with experiments to be carried out at the HBWR,
  - setting up a research program within materials and aging with experiments to be carried out at the HBWR.
- Continuing our efforts to contribute to Gen IV research within our fields of expertise, a field of research that is attractive to students and young scientists:

  - European collaborations (ASTRID, MYRRHA, ELSY …),
  - national collaborations to form a continuous Swedish Gen IV program,
  - researching on autonomous Gen IV systems with a high degree of passive safety.
- Enhancing our contributions to Swedish and international safeguards research:
  - assessing and designing safeguards for future nuclear systems, including reactor designs with safeguards aspects taken into account,
  - providing technologies and methodologies for spent fuel assay, with particular focus on enhancing IAEA's capabilities to detect partial defects.
- Intensifying our efforts to provide efficient assessment technologies for spent fuel prior to encapsulation and storage:
  - taking part in the design of new measurement system, making use of the latest research achievements in fuel assay,
  - performing experimental campaigns on spent fuel for evaluation purposes.

Collaborations

- OECD-HRP (as above).
- Enhancing our collaboration with UC Berkeley, e.g. by hosting a summer school on measurements and fuel diagnostics.
- Inviting international scientists for guest researcher positions and seminars.

Overview of the above mentioned Ph.D. projects at UU

1. **Peter Andersson**: "Void monitoring in thermal-hydraulic test loops using neutron transmission tomography".
   Main supervisor: Univ. lekt. Staffan Jacobsson Svärd.
   Assistant supervisor: Bitr. univ. lekt. Henrik Sjöstrand.

2. **Scott Holcombe**: "Advanced diagnostics of nuclear fuel based on tomographic techniques and high-resolution gamma-ray spectroscopy".
   Main supervisor: Univ. lekt. Staffan Jacobsson Svärd.
   Assistant supervisor: Prof. Ane Håkansson

3. **Tomáš Martinik**: "Verification of nuclear fuel for safeguards purposes using non-destructive assay techniques for the future Swedish encapsulation facility".
   Main supervisor: Ph.D. Sophie Grape.
   Assistant supervisor: Dr. Peter Jansson.

4. **Lisa Bläckberg**: Optimisation and modelling of detector materials for ionising radiation.
   Main supervisor: Prof. Mattias Klintenberg
   Assistant supervisor: Bitr. univ. lekt. Henrik Sjöstrand, Dr. Anders Ringbom (FOI).

5. **Kaj Jansson**: "Neutron-induced nuclear reactions at intermediate energies"
   Main supervisor: Dr. Cecilia Gustavsson
   Assistant supervisor: Prof. Stephan Pomp, Dr. Alexander Prokofiev

6. **Andrea Mattera**: "Measurements of independent fission yields from a fast neutron spectrum"
   Main supervisor: Prof. Stephan Pomp
   Assistant supervisor: Dr. Mattias Lantz, Univ. lekt. Michael Österlund

7. **Vasileios Rakopoulos**: "Studies of independent fission yields from fast neutrons"
   Main supervisor: Dr. Mattias Lantz
   Assistant supervisor: Prof. Stephan Pomp, Dr. Andreas Solders

8. **Vasudha Verma**: "Core Diagnostics in the ASTRID Sodium Fast Reactor (CODIAS)"
   Main supervisor: Dr. Carl Hellesen.
   Assistant supervisor: Univ. lekt. Staffan Jacobsson Svärd, Prof. Ane Håkansson, Dr. Peter Jansson, Univ. Lekt. Michael Österlund.

9. **Anna Shepidchenko**: “Novel Detector Materials for Monitoring and Safeguards”.
   Main supervisor: Prof. Mattias Klintenberg.
   Assistant supervisor: Univ. lekt. Susanne Mirbt.

10. **Matilda Åberg Lindell**: “Instrumentation and safeguards evaluations of a Generation IV reprocessing facility”.
    Main supervisor: Dr. Sophie Grape.
    Assistant supervisors: Prof. Ane Håkansson, Univ. lekt. Staffan Jacobsson Svärd.

11. **Erwin Alhassan**: “MAssive Computational methodology for Reactor Operation – MACRO”.
    Main supervisor: Bitr. univ. lekt. Henrik Sjöstrand.
    Assistant supervisors: Univ. lekt. Michael Österlund, prof. Stephan Pomp, Dr. Junfeng Duan, Dr. Dimitri Rochman.

12. **Peter Wolniewicz**: “Core Monitoring in Gen IV Reactors”.
    Main supervisor: Prof. Ane Håkansson.
    Assistant supervisors: Dr. Carl Hellesen, Dr. Peter Jansson, Univ. lekt. Staffan Jacobsson Svärd, Univ. lekt. Michael Österlund.

13. **Erik Branger**: “Studies of Cherenkov light emission and detection for nuclear safeguards purposes”.
    Main supervisor: Dr. Sophie Grape
    Assistant supervisors: Ass. Prof. Staffan Jacobsson Svärd, Dr. Peter Jansson.

Research projects

Below, SKC relevant research projects are presented grouped by their respective university in alphabetic order, i.e., first Chalmers, followed by KTH (regarding the on-going PhD projects in Uppsala, we refer to the chapter Uppsala University above).

Development of an integrated neutronic/thermal-hydraulic model using a CFD solver

PhD student: Klas Jareteg, Division of Nuclear Engineering, Chalmers University of Technology
Supervisor: Professor Christophe Demazière

Background

The core of a Light Water Reactor (LWR) involves many different physics problems, such as neutron transport, fluid dynamics and heat transfer. Inherently, all fields are coupled, and to determine the state of the reactor all perspectives need to be considered concurrently.

In many of the currently applied methodologies, the coupled problem is divided in its constituent parts, and consequently solved in a segregated manner. Often the coupling is approximated by static or simplified expressions, whereas in other cases an a posteriori coupling is achieved by combining different tools. Such splitting approaches introduce approximations in terms of the interdependent parameters, and also represent an obstacle for highly resolved coupled calculations.

The reactor core is also a multiscale environment, with important phenomena ranging from the size of the reactor tank itself to scales relevant for the fuel pellet, and further smaller approaching particle scales. Since fully resolved simulations on length scales smaller than the fuel pellet are still considered to be extremely heavy computations, the reactor core problem is commonly solved on larger scales. Unavoidably, such a coarsening introduces homogenization, not only in terms of geometrical details but also in the models used to represent the underlying physics.

In contrast, a fine-mesh tool able to resolve the finer scales would also allow resolved coupled calculations to be performed. Such a coupled tool could be used to assess the approximations in the coarser methods, as well as determining the fine scale, local behavior of the physics in the fuel bundles. Development of fine-mesh tools can give an important contribution to safety since they have the potential for reproducing the physical phenomena of a nuclear system with a higher degree of fidelity.

Goals of the project

This project is aimed at developing models and implementing a high-resolution coupled tool for fine scale simulations of the reactor core. This includes formulating a fully consistent model, directly coupling the modeling of neutron transport in the core, of fluid dynamics in the moderator and of conjugate heat transfer between the moderator and the fuel pins.

The developed tool is aimed at better capturing the phenomena, both by resolving the physics and introducing a direct coupling on the fine levels. The primary target are LWRs, i.e. Pressurized Water Reactors (PWRs) and Boiling Water Reactors (BWRs), with BWRs representing the most interesting case due to the large fluid heterogeneities induced by the two-phase flow of concurrently appearing steam and liquid water.

A successful implementation of such a tool relies on the use of high performance computing (HPC), including efficient methods as well as the use of fully parallelized algorithms and solvers. Consequently, the computational aspects are also a major focus in the current project.

Organization

The work is performed by PhD student Klas Jareteg under the supervision of Professor Christophe Demazière and assisting supervision of Associate Professor Paolo Vinai (Division of Nuclear Engineering, Department of Applied Physics) and Associate Professor Srdjan Sasic (Division of Fluid dynamics, Department of Applied Mechanics). The members of the reference group are: Ninos Garis (SSM), Urban Sandberg (Ringhals), Henrik Eisenberg (OKG), Farid Alavyoon (Forsmark) and Erwin Müller (Westinghouse).

Methodology

In the first stage of the project a coupled tool was implemented based on the open source C++ library OpenFOAM. The existing single phase fluid dynamics and heat transfer solvers in the library were extended to suit the fuel assembly calculations and further complemented by a neutron diffusion solver for the neutronic calculations. The code includes fully implicit conjugate heat transfer between the fuel pins and the moderator, the use of fine unstructured meshes in all regions and a high resolution coupling between the thermophysical state and the cross-sections used for the neutronics. This tool was applied to a lattice of 5x5 fuel pins, and used to determine the axial and radial dependencies of the neutron flux distributions, the moderator density and velocity and the temperature in the fuel as well as the moderator [1,2].

In the second stage of the project, a discrete ordinates solver for the neutronics was added to the coupled framework. This method allows for an angular dependence in the neutron flux, resulting in a more accurate prediction of the neutron distribution in heterogeneous lattices. This method severely increases the computational burden and further emphasizes the need for fully parallelized methods, making it possible to apply sufficient computational resources. The discrete ordinates solver was compared to the earlier diffusion solver using the coupled calculations of a heterogeneous 5x5 fuel assembly including burnable absorbers [3]. An example of the resulting moderator temperature distribution is seen in Figure 1.

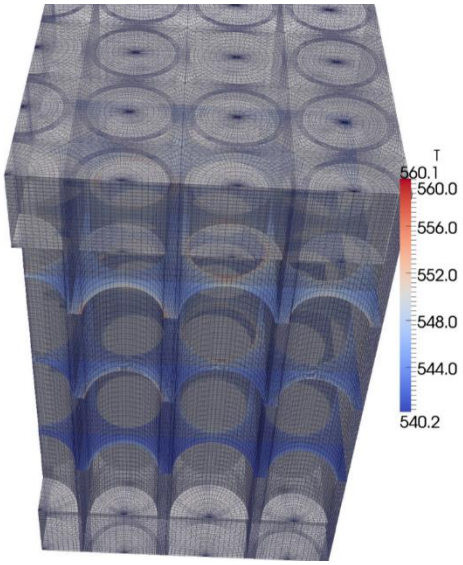


Figure 1. Moderator temperature in a 5x5 fuel pin system, with the computational grid displayed. Axial direction no to scale.

In the third and current stage, the single phase solver is complemented by a two-phase solver for the moderator. Such extension poses interesting challenges not only in the multiphase models transporting the steam, but also in the coupling framework and in the cross-section generation.

In all stages major focus is placed on the consistency in the coupling between the fields, ensuring resolved dependencies at the finest level and with fully conservative schemes. To achieve this, solving neutronics and thermal-hydraulics within the same code is of major importance, since all types of external or a posteriori couplings are avoided. To implement the high-resolution models unavoidably requires using high performing algorithms and solvers. The computational tool also includes the use of fully parallelized implementations to allow for the fine mesh to be resolved for a system of the size of a fuel bundle, still handling sub-pin resolution everywhere in the assembly and within a reasonable time on a computational cluster [4].

References

1. K. JARETEG, P. VINAI, and C. DEMAZIÈRE, "Investigation of the possibility to use a fine-mesh solver for resolving coupled neutronics and thermal-hydraulics", M&C 2013, Sun Valley, Idaho, USA
2. K. JARETEG, P. VINAI, and C. DEMAZIÈRE, "Fine-mesh deterministic modelling of PWR fuel assemblies: proof-of-principle of coupled neutronic/thermal-hydraulic calculations", Annals of Nuclear Energy (2014), http://dx.doi.org/10.1016/j.anucene.2013.12.019
3. K. JARETEG, P. VINAI, S. SASIC, and C DEMAZIÈRE, "Influence of an SN solver in a fine-mesh neutronics/thermal-hydraulics framework", submitted to PHYSOR 2014, Kyoto, Japan
4. K. JARETEG, P. VINAI, S. SASIC, and C DEMAZIÈRE, "Coupled fine-mesh neutronics and thermal-hydraulics - modelling and implementation for LWR fuel assemblies", to be submitted to Annals of Nuclear Energy

PhD Possible re-vaporisation of ruthenium in the containment

PhD student: Ivan Kajan, Department of nuclear chemistry, Chalmers University of Technology.
Supervisor: Professor Christian Ekberg.

Background

During a severe nuclear accident significant release of ruthenium may occur if the fuel is oxidized during an air-ingress accident. Ruthenium can be released to the containment via the reactor coolant system as different ruthenium oxides. The main species will be ruthenium tetroxide vapor and ruthenium dioxide aerosols. These ruthenium compounds can condensate in the water phase or on different surfaces in the containment. The deposited ruthenium will mainly be in form of solid ruthenium dioxide. Due to a high radiation field in the containment during a severe accident there will be a continuously formation of oxidation agents like ozone via the radiolysis of air. These oxidation agents may react with ruthenium deposits on the surfaces in the containment and reproduce volatile ruthenium species, which can be released from the containment.

Goals of the project

Work is focused on estimation of the re-vaporized fraction of ruthenium under radiation. For the experiments will be used gamma cell on nuclear chemistry department with dose relevant to severe nuclear accident scenario. Possibilities and quantity of ruthenium re-vaporisation will be examined on surfaces of copper, zinc and aluminium. As ruthenium in form of ruthenium tetroxide is strong oxidising agent there is possibility of oxidise iodine deposits on surfaces. Iodine in case of nuclear accident is released sooner than ruthenium so it is already deposited on surfaces. As ruthenium tetroxide is then released into the atmosphere it can affect re-volatilising deposits of iodine formed previously. This interaction will be also studied.

Organization

The work is performed by PhD student Ivan Kajan under supervision of Professor Christian Ekberg. Co-supervision is performed by Mark Foreman. For consultations there are two external co-supervisors Henrik Glänneskog and Joachim Thorn both from Vattenfall company.

Methodology

We performed deposition of samples containing epoxy paint with ruthenium tetroxide. Surface of samples was then analysed with several methods (ESCA, SEM, EXAFS) to estimate composition of deposited layer. Current work is focusing on re-vaporisation phenomena caused by gamma radiation. As source of gamma radiation we use Cobalt 60 filled source gamma cell 220 producing dose rate of approximately 11 kGy per hour. This dose rate fits well with dose rates expected in severe accident conditions.

Results

During the re-vaporization experiments in the humid air atmosphere by gamma radiation, a release of ruthenium from the deposits on the epoxy paint was observed. This proved the possibility of the oxidation of ruthenium deposits to the volatile state. In the case of dry air experiments, no re-oxidation of ruthenium to the volatile state was found. Experiments showed that the hydroxyl radical, produced by the radiolysis of water, plays a significant role in the possible re-oxidation of the ruthenium from deposits.

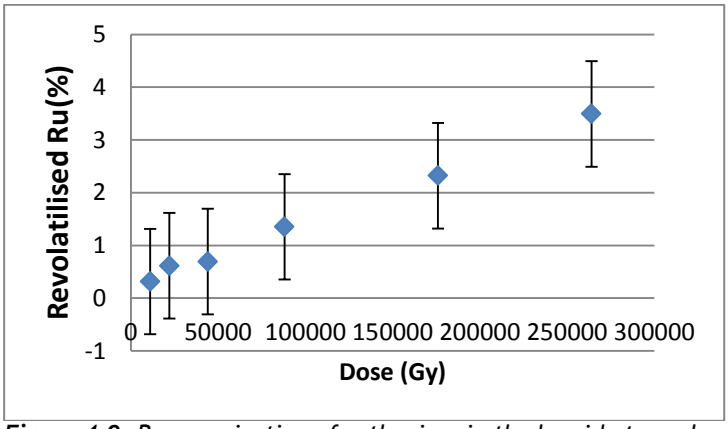


***Figure 4.9**. Re-vaporization of ruthenium in the humid atmosphere*

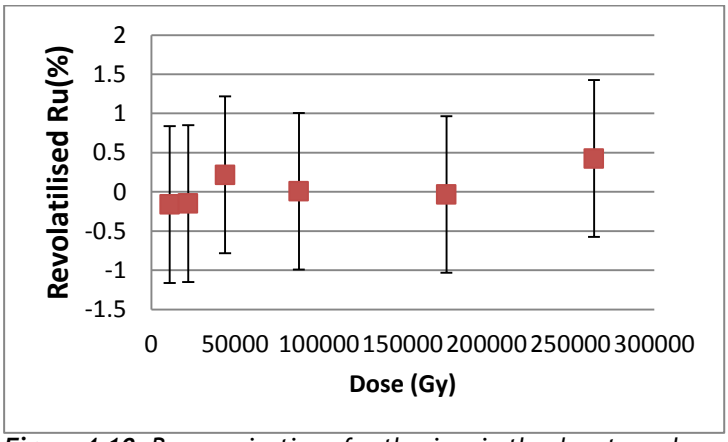


***Figure 4.10**. Re-vaporization of ruthenium in the dry atmosphere*

Investigation of the use of thorium in LWRs for improving reactor core performance

Research leader: Adjunct Professor Henrik Nylén
Research scientist: Cheuk Wah Lau

Background

The increasing share of renewable energy is essential to tackle the reduction of green house gases. In 2012, the world wide investment on renewable energy was 244 billion USD and most of it was solar and wind power [1]. However, solar and wind power will create great imbalance between production and consumption of electrical energy [2]. Therefore, the demands on regulating power will increase and load-following nuclear power could be one of the solutions [3]. In France, the majority of the nuclear reactors are used to stabilize the power grid, but uranium based nuclear fuel has its limitation, such as skewed power distributions and local power oscillations.

Thorium plutonium mixed oxide (Th-MOX) fuels have been a hot topic to use for plutonium incineration [4], because irradiated thorium has low transuranium production and good thermal properties as a fissile carrier to incinerate plutonium. Chalmers University of Technology has developed a new concept on load-following Th-MOX cores, currently investigated to understand its load-following capabilities.

Goals of the project

The PhD project aims at investigating the use of thorium in LWRs with emphasis on utilization of thorium to improve PWR core characteristics in terms of larger safety margins and higher flexibility. The first part of the investigation consists of an innovative use of thorium in PWR fuel assemblies to control the excess of reactivity at beginning of life, and generate more even core power distribution, are now finished [5,6]. The second part of the investigation, also the current research, aims at Th-MOX core capabilities, applications and limitations [7].

Organization

The work is performed by PhD student Cheuk Wah Lau under the supervision of adjunct professor Henrik Nylén, and co-supervision of Prof. Christophe Demazière and Prof. Imre Pázsit. The members of the reference group are: Ninos Garis and Elisabeth Rudbäck, SSM, Urban Sandberg, Ringhals, Tommy Einarsson, Forsmark, Christer Netterbrant, OKG, and Per Seltborg, Westinghouse.

The Department of Nuclear Engineering is also supervising Klara Insulander Björk's PhD thesis on "Development of thorium based nuclear fuel for light water reactors", a project that is carried out at Thor Energy, Oslo, Norway. The collaboration between the Klara Insulander Björk and Cheuk Wah Lau was mostly focused on Th-MOX cores for PWRs, and resulted in joint papers.

Methodology

For the calculations and study, the Ringhals-3 PWR model was used to simulate realistic scenarios with the 2D lattice code CASMO-4E and 3D nodal code SIMULATE-3, which are widely used in the industry.

Recent findings

The study on Th-MOX cores have shown some notable differences compared with traditional UOX cores such as: lower fraction of delayed neutrons, lower boron worth, lower control rod worth and stronger Doppler feedback. The differences have lead to a study on reducing the share of Th-MOX fuel assemblies from 100 to 33 % of the core. The results showed more similar core properties to traditional UOX cores and simplify the possible introduction of Th-MOX fuels in PWRs.

Th-MOX cores shown a considerably more even power distribution and no local power oscillations during step wise power changes compared with UOX cores. In figure 1, the UOX core has larger axial power oscillations (axial offset), after step wise power changes, compared with Th-MOX core. Furthermore, Th-

MOX cores have shown to be almost insensitive to changes in Xe-135 concentration that causes axial offset oscillations. Additionally, after Th-MOX cores shutdown, Xe-135 induced reactivity loss is minimal. Therefore, Th-MOX cores have better load-following capabilities. This work will soon be submitted to a journal.

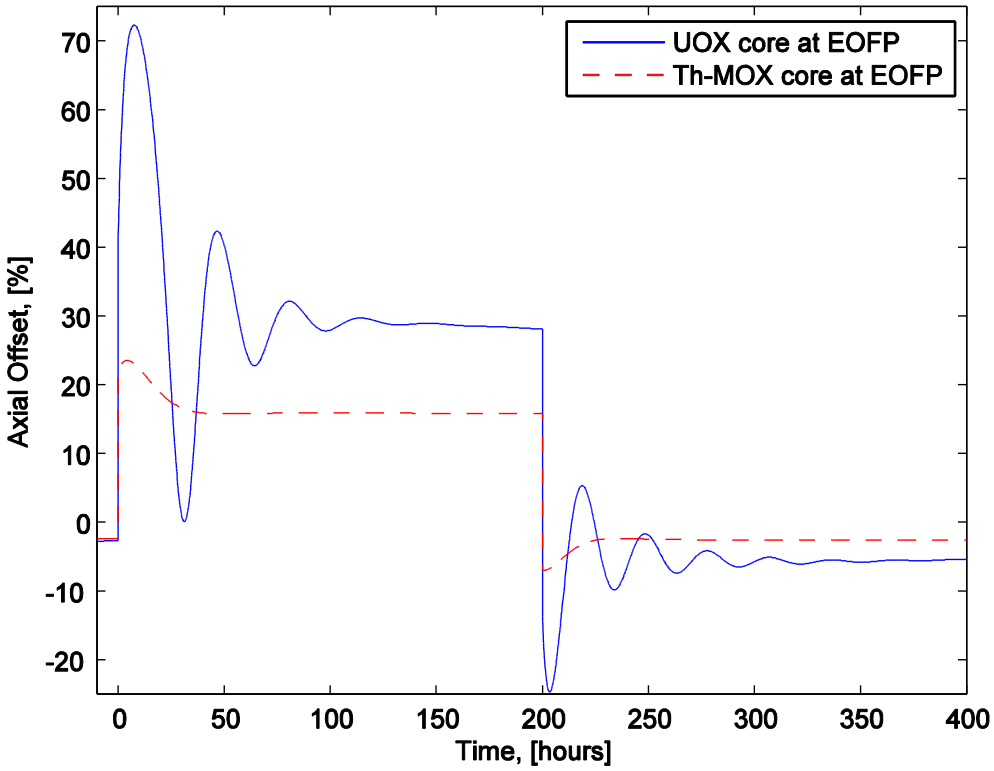


Figure 1. The axial offset as function of time in the UOX- and Th-MOX core at end of full power (EOFP). The core power is 100 % before 0 hours and after 200 hours. The core power between 0 and 200 hours is 50 %.

Cheuk Wah Lau participated to the TOP FUEL 2013 in Charlotte, USA, and the ICAPP 2013 to present a paper in Jeju island, South Korea. The PhD defence is planned to be in May 2014.

References

1. Frankfurt School-UNEP Centre/BNEF, "GLOBAL TRENDS IN RENEWABLE ENERGY INVESTMENT 2013", (2013).
2. H. Ludwig, T. Salnikova, A. Stockman, U. Waas, "Load cycling capabilities of German Nuclear Power Plants (NPP)", *International Journal for Nuclear Power*, **55**, (2010).
3. J. Persson, K. Andgren, H. Henriksson, J. Loberg, C. Malm, L. Pettersson, J. Sandström, T. Sigfrids, "Additional Cost for Load-following Nuclear Power Plants", Elforsk rapport 12:71, (2012).
4. E. Shwageraus, P. Hejzlar, M. S. Kazimi, "USE OF THORIUM FOR TRANSMUTATION OF PLUTONIUM AND MINOR ACTINIDES IN PWRs", *Nuclear Technology*, **147**, 53-68, (2003).
5. C. W. Lau, C. Demazière, H. Nylén, and U. Sandberg, "Improvement of LWR thermal margins by introducing Thorium" *Progress in Nuclear Energy*, **61,** 48-56 (2012).
6. C. W. Lau, H. Nylén, C. Demazière, and U. Sandberg, "Investigation of the Equilibrium Core Characteristics for the Ringhals-3 PWR with Improved Thermal Margins Using Uranium-thorium Fuel", Submitted to ICAPP 2013, Jeju Island, South Korea, April 14-18, 2013.
7. K. Insulander Björk, C. W. Lau, H. Nylén, U. Sandberg, " Study of Thorium-Plutonium Fuel for Possible Operating Cycle Extension in PWRs", *Science and Technology of Nuclear Installations*, Article ID 867561, (2013).

Complexation of iodine species with organic molecules under severe accident conditions in LWR`s

PhD student: Sabrina Tietze, Department of Chemical and Biological Engineering, Nuclear Chemistry, Chalmers University of Technology
Supervisor: Professor Christian Ekberg[1]*, Dr. Mark Foreman*[1]*, Dr. Henrik Glenneskog*[2]

[1] Nuclear Chemistry, Chalmers University of Technology, Göteborg
[2] Vattenfall Power Consultant, Göteborg

Background

During severe nuclear accidents significant amounts of gaseous elemental iodine and cesium iodide aerosols will be released from damaged fuel in LWR`s. Both species can partly dissolve in the containment pools and steam and thus will be immobilized as iodide and iodate ions. Under severe accident conditions (heat, irradiation) remaining gaseous elemental iodine can react in complex reactions with organic materials (paint, cable coatings) or the organic substances released from organic materials in gaseous phase to form highly volatile airborne organic iodine species such as methyl iodide and ethyl iodide. These iodine species cannot be retained with the same efficiency as elemental iodine with the present used safety installations (sprays, charcoal filter, wet-scrubber filter) in Swedish nuclear power plants. The properties of the currently used filter materials are chosen to efficiently retain elemental iodine. However, organic iodides show a different chemical behaviour due to their organic and more hydrophobic characteristics and thus require different filter materials. For example, the currently in wet scrubber used alkaline sodium thiosulfate solution is about 20 times less efficient to retain methyl iodide. Consequently, those organic species have a high potential to be released into the environment and thus to cause biological harm.
Since iodine is essential for the human body, it gets concentrated in the thyroid gland and thus increases the risk of cancer. Organic iodides which have been uptaken additionally have an organic chain in their molecule such as a methyl group in methyl iodide which is able to cause additional methylation effects as known from workplaces with usage of ethyl bromide. Of especially high relevance for the public are longer lived iodine species such as ^{131}I which has a half-life of circa 8 days which is long enough for harmful bioaccumulation.

Goals of the project

The formation of organic iodides is not well investigated both quantitatively and qualitatively. The formation of those species is studied from different paint products used in nuclear facilities and the single components used within this products. As well other organic materials such as cable plastics and pump oil are studied with respect of the impact of heat and irradiation.

The distribution behaviour of commonly identified alkyl iodides such as methyl and ethyl iodide is studied in the FOMICAG (Facility set-up for On-line Measurements of the Iodine Concentration in an Aqueous and Gas phase) facility, which is a model of the Swedish BWR Oskarsham 3 and the data are used for a newly developed model (The Chalmers Model) to e.g. estimate the remaining quantity of these species in gaseous phase which could be potentially released into the environment.

While paint surfaces can act as a source for organic iodides, they can as well act as a sink for gaseous iodine species and lead to the formation of new volatile or non-volatile iodine species. Thus, the interactions (sorption and revaporisation) of gaseous inorganic (CsI, I_2, IxOy) and organic iodine species (MeI, EtiI, ButI, Benzyl-I, Allyl-I etc.) are studied with differently long aged paint surfaces (Teknopox Aqua VA) in comparison with common metal surfaces (Al, Cu, Zn, SS). The interactions on the surfaces are affected by the presence

of other fission products such as RuO_4 or radiolysis and pyrolysis products such as hydrochloric acid, nitric acid, carbon monoxide and ozone.

A fraction of the iodine species will remain in gaseous phase in an accident scenario. To decrease the fraction of volatile iodine species already in the containment new paint formulations are developed to retain different iodine species permanently.
Furthermore, modifications of the currently used scrubber solution are investigated to more efficiently retain gaseous organic iodides in case of a containment venting.

Organization

The work is performed by the Ph.D. student Sabrina Tietze under the supervision of Prof. Christian Ekberg, Ass.Prof.Dr. Mark Foreman and Dr. Henrik Glänneskog. The experimental work is performed at the Nuclear Chemistry department, Chalmers University of Technology. Some experimental work on IxOy and CsI aerosol interactions was performed in collaboration with VTT Technical Research Centre of Finland. Material samples of paint products and cable plastics have been provided from Vattenfall, Ringhals and Forsmark. Analytical support on pyrolysis GC-MS was given by Dr. Barth van Dongen (Manchester University) and for gel permeation chromatography on irradiation damaged polymer chains by Fred Davis (Reading University).

The first part of the work was presented in the Licentiate thesis and was successfully defended on September 10, 2012 at Chalmers University of Technology. The opponent of the defense was Per-Olof Aronsson (former Ringhals).
The PhD defence is planned for spring 2015.

Methodology

The formation (qualitative and quantitative) of organic iodides from organic materials (cable, paint, plasticizer, oil) is studied using temperature controlled thermolysis experiments and radiolysis experiments (gamma source, dose rate = 10, 5, 3 kGy/h) together with gas chromatographic equipment (GC-MS, pyrolysis GC-MS).
The formation of organic iodides from the polymer resin is furthermore studied by synthesizing model compounds to investigate the impact of the different functional groups on the organic iodides. The degradation of the polymer backbone under gamma irradiation and the effects on the chemistry are studied using viscosity measurements, TOC measurements, gel permeation chromatography and NMR measurements.

The distribution and hydrolysis behaviour of e.g. methyl iodide is studied using the FOMICAG (Facility set-up for On-line Measurements of the Iodine Concentration in an Aqueous and Gas phase) facility, which is a model of the Swedish BWR Oskarshamn 3. For e.g. this purpose synthesis methods for ^{131}I labelled organic iodide species have been developed.
The experimental data generated for different temperatures and over solutions of varying pH are used for the development of a mathematical model (The Chalmers Model) to describe the kinetic parameters of the partitioning and hydrolysis behaviour of e.g. methyl iodide to determine their partitioning coefficients.

The sorption and revaporisation behaviour of different inorganic (IxOy, CsI, I_2) and organic iodides (methyl iodide, ethyl iodide) in and withoout presence of other species under heat, irradiation, humidity, presence of other fission, radiolysis and ppyrolysis products is investigated using HPGe-, LSC- and e.g. autoradiography measurements.
The leaching of those species from wet paint surfaces is investigated using e.g. LSC measurements, TOC measurements, and ion chromatography.

Approaches to develop a modified paint formulation are based on the currently nuclear certified Teknopox Aqua VA epoxy paint by immersion of different inorganic and organic additives that preferably are non-leachable, irradiation stable, chemically retain iodine species under the expected conditons and do not alter the mechanical requirements of the measures given by the regulators.

The testing of modified scrubber solutions is performed mainly using the FOMICAG facility and a modification of it, wash-bottle cascades and shaking experiments. To distinguish the stability of the additives towards heat, irradiation and oxygen NMR and GC-MS analysis are performed.

Publications

1. S. Tietze, Formation, partitioning and interactions of organic iodides under severe nuclear accident conditions in LWR containments, Thesis for the degree of Licentiate of Engineering, ISSN: 1652-943X, Chalmers University of Technology, Sweden, September 2012.
2. S. Tietze, M. Foreman, C. Ekberg, Synthesis of I-131 labeled iodine species relevant during severe nuclear accidents in light water reactors, Radiochimica Acta, 101, 10, 675-680, 2013.
3. S. Tietze, M. Foreman, C. Ekberg, B. van Dongen, Identification of the chemical inventory of different paint types applied in nuclear facilities, Journal of Radioanalytical and Nuclear Chemistry, 3, 1981-1999, 2013.
4. S. Tietze, M. Foreman, C. Ekberg, Formation of organic iodides from containment paint ingredients caused by gamma irradiation, Journal of Nuclear Science and Technology, 50 (7), 689-694, 2013.
5. T. Haste, A. Auvinen, J. Colombani, F. Funke, G. Glowa, S. Güntay, J. Holm, T. Kärkelä, G. Langrock, G. Poss, B. Simondi-Teisseire, S. Tietze, G. Weber, Containment Iodine Experiments in the SARNET2 project, 5th European Review Meeting on Severe Accident Research (ERMSAR-2012) Cologne (Germany), March 21-23, 2012.
6. S. Tietze, T. Kärkelä, M.R.StJ. Foreman, C. Ekberg, A. Auvinen, U. Tapper, S. Lamminmäki, J. Jokiniemi, Adsorption and revaporisation studies on iodine oxide aerosols deposited on containment surface materials in LWR, NKS-R, NKS- 272, ISBN 978-87-7893-345-4, 2012.
7. S. Tietze, T. Kärkelä, C. Ekberg, , A. Auvinen, U. Tapper, J. Jokiniemi, Adsorption and revaporisation studies of thin iodine oxide and CsI aerosol deposits from containment surface materials in LWRs, NKS-R, NKS-285, ISBN 978-87-7893-360-7, 2013.
8. A. Auvinen, L. Bosland, S. Dickinson, G.A. Glowa, L.E. Herranz, H.C. Kim, S. Lamminmäki, T. Kärkelä, D.A. Powers, M. Salay, S. Tietze, Iodine-Paint Interactions, 6th European Review Meeting on Severe Accident Research (ERMSAR-2013), Avignon (France), Palais des Papes, 2-4 October, 2013.
9. A. Auvinen, Y. Ammar, L. Bosland, B. Clément, S. Dickinson, F. Funke, G. Glowa, T. Karkela, D A Powers, M. Reeks, S. Tietze, G. Weber, Experimental and modelling studies of iodine oxide formation and aerosol behaviour relevant to nuclear reactor accidents, 6th European Review Meeting on Severe Accident Research (ERMSAR-2013), Avignon (France), Palais des Papes, 2-4 October, 2013.
10. M. Foreman, S. Tietze, E. Aneheim, An organic experiment on the subject of SN2 chemistry which uses a radioisotope which is used in nuclear medicine and is relevant to nuclear accidents, The Journal of Chemical Education, Accepted for publication 2013.

Study of post-dryout heat transfer and internal structure of annular and mist two-phase flows in annuli with spacers

Research leader: Professor Henryk Anglart
PhD student: Ionut Anghel, Division of Nuclear Reactor Technology, KTH, Stockholm

Introduction

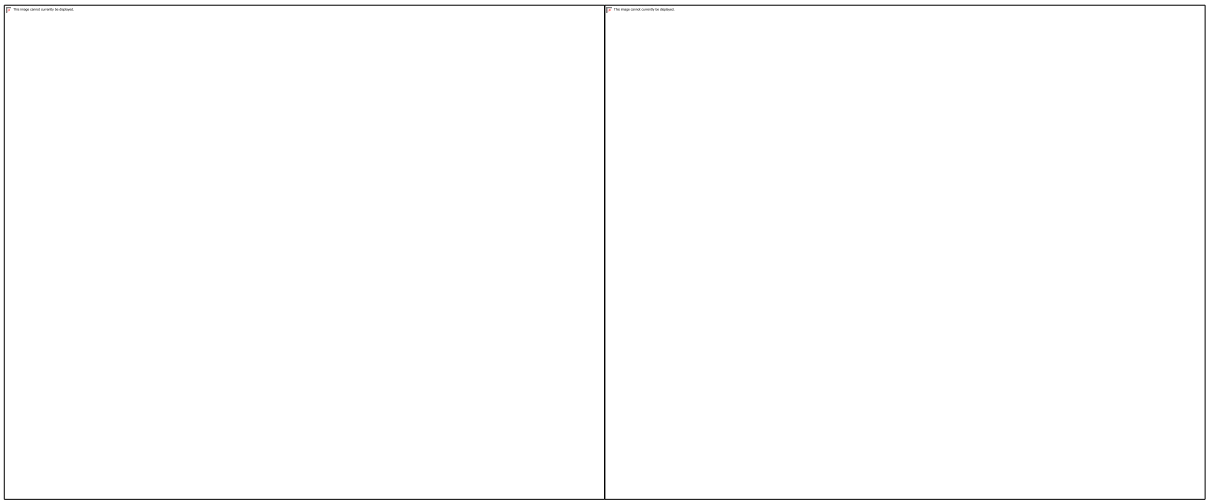
Accurate prediction of thermal margins during operation of nuclear reactors has important safety and economic implications. On the one hand the power level in a nuclear reactor must be low enough to avoid a sudden deterioration of heat transfer due to the occurrence of the boiling crisis. On the other hand, the power should be high enough to promote a good efficiency of the plant. In nuclear reactors the post-dryout heat transfer should not appear during the normal reactor operation. During certain anticipated transients, however, the local conditions may deteriorate and the onset of dryout may take place. Consequently a proper model to calculate the maximum clad temperature and time history of the temperature distribution is required. To validate such models, appropriate experimental data, such as provided through this project, are needed.

Objectives and methodology

The objective of this project has been to investigate the post-dryout heat transfer and in particular, to study the influence of spacers on the onset of dryout and on the post-dryout heat transfer. Using both the experimental and analytical approach, new more accurate methods to predict clad temperature in BWR fuel assemblies under post-dryout conditions are sought.

Results in 2013

In 2013 the new more accurate methods to predict clad temperature in BWR fuel assemblies under post-dryout conditions was developed, [1-3]. The approach is employing three important elements determining heat transfer in post-dryout: (1) the location of the critical quality point, (2) the developing post-dryout heat transfer region and (3) additional wall cooling effect caused by the increase of turbulence downstream of the spacer. Using this approach, a more accurate prediction of wall temperature is possible, as shown in Fig. 1(b) below.



(a) (b)

Fig. 1. Comparison of wall temperature measured in annulus with calculated from: (a) the standard Saha model [4], (b) the improved model developed within this project, [3].

An example of the wall temperature prediction using the new approach is shown in Fig.2.

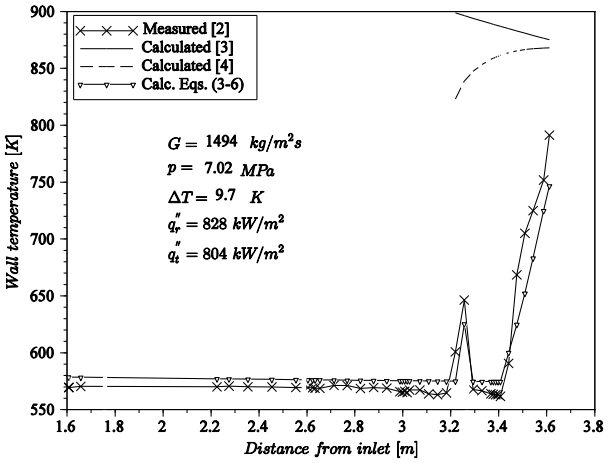


Fig. 2. Wall temperature distribution in an annular test section with pin spacers under post-dryout conditions [3].

References

[1] Anghel, I.G., *Experimental and Theoretical Study of Post-Dryout Heat Transfer in Annuli with Flow Obstacles*, PhD thesis, ISBN: 978-91-7501-909-3, KTH, 2013.

[2] Anghel, I.G. and Anglart, H, "On post-dryout heat transfer in channels with flow obstacles," accepted to *Nuclear Engineering and Design*.

[3] Anghel, I., Anglart, H., paper 14334, ICAPP 2014, Charlotte, USA, April 6-9.

[4] P. Saha, A nonequilibrium heat transfer model for dispersed droplet post-dryout regime,*Int. J. Heat Mass Transfer*, 23 (1980), pp. 483–492

Passive Safety Systems in Advanced Nuclear Power Plants: Design, Performance Analysis and Integrated Assessment

PhD student: Kaspar Kööp, Division of Nuclear Power Safety, KTH, Stockholm
Supervisor: Assoc. Prof. Pavel Kudinov

Introduction

Advanced nuclear power plants (Generations III, III+, and IV) are designed to meet increasingly stringent requirements on plant performance reliability, safety and economy. Toward the safety objective, it is paramount to ensure the plant's high resilience against external impacts and internal equipment malfunctions, as well as failures of the plant operator to timely perceive, and act effectively in, abnormal situations. A highly-publicized platform to develop such a resilient plant design (aka "fool-proof") is built on a so-called passive safety principle – a concept pioneered in a Swedish plant design during the 1980s known as PIUS (Process Inherently Ultimate Safe). Since then, passively-safe systems have successfully paved their way into design of several commercial nuclear power plants, such as Westinghouse's AP1000/AP600 and General Electric's ESBWR. The idea of passive safety is also considered in Generation IV designs, e.g. LFR (lead-cooled fast reactor).

In passive plants, both under normal operation and in emergency situations, Laws of Physics (e.g., natural circulation) and Forces of Nature (e.g., gravity) are used to drive reactor operation and ensure safety functions. However, the passive safety technology is only at the dawn of its development and deployment. Neither were all possibilities examined, nor were all implications understood. Although their components are tested part-by-part, the advanced passive plants – as a whole – have so far existed only on paper. The design's true merits and success can only be judged after decades of the plant operation. Yet, it is of both academic interests and practical significance that we understand the inner-workings and implications of the technology.

Project Goals

Taken broadly, the proposed research aims to develop a theoretical basis and to advance computational methodologies for the design analysis and performance characterization of passive safety systems in advanced nuclear power plant designs.

Research Approach

Both probabilistic and deterministic safety analysis methods will be addressed. The research will help establish a procedure to effectively search for credible scenarios and parameter ranges, when individually-tested passive-safety systems interact nonlinearly and fail to perform their pre-defined functions. Such a failure signifies the deficiency of the decomposition (divide-and-conquer) strategy adopted in system design and testing. Consequently, a vulnerability map for a passive system shall be devised for use in probabilistic treatments, similarly to the equipment failure rate of an active system.

Case studies include Generation III+ plant (AP1000), Generation IV experimental facility (TALL-3D) and Generation IV plant (ALFRED). The proposed research is expected to lead to recommendations on improving passive safety systems and operating procedures for the advanced plant designs under consideration.

The work is performed by Ph.D. student Kaspar Kööp under the direction of Dr. Pavel Kudinov. The contact reference group consists of Wiktor Frid (SSM), Pär Lansåker (Vattenfall) and Tomas Öhlin (Westinghouse).

Results in 2013

Advanced methodologies for design analysis and performance characterization (mentioned in the project goals) need to be validated against experimental data. Part of the work in 2013 was continuation of 2012

work on support calculations for TALL-3D facility experimental campaign, as this facility will play an important role in validating proposed safety analysis methods for passive systems. Preparations for single STH and coupled STH/CFD codes validation against TALL-3D experimental data were also started. In addition to computational work, technical support work in the experimental facility to prepare for initialization and first tests was performed.

Work on system thermal hydraulic (STH) and computational fluid dynamic (CFD) code coupling was continued in cooperation with PhD student Marti Jeltsov. This effort will allow accurate and efficient exploration of the deterministic event space in systems where strong feedbacks between 1D and 3D components exist (e.g. TALL-3D). In these systems (like pool type reactors) single STH or CFD codes are either not accurate enough or too computationally expensive to be deployed. Coupled codes manage to deliver accuracy without sacrificing efficiency allowing greater number of simulations to be run.

Still the efficiency of coupled codes is not enough to support event space exploration with IDPSA tools (e.g. GA-IDSPA) which require in order of thousand simulation runs. Therefore development of a surrogate model for TALL-3D test section was started in 2012 and continued in 2013. This surrogate model is based on physical phenomena identified from the CFD calculations and will replace CFD in the coupled code framework.

Work on ALFRED reactor model and search for vulnerabilities in its passive safety systems was started in 2013 and is expected to result in a journal publication in 2014.

Development of a Method for the Treatment of Two-Phase Flow Patterns in Nuclear Reactor Thermal Hydraulic System Code

PhD student: Viet-Anh Phung, Division of Nuclear Power Safety, KTH
Supervisor: Assoc. Prof. Pavel Kudinov

Background

Reactor thermal-hydraulic system codes such as RELAP5 and TRACE play an important role in assessing safety analysis for nuclear plants, designing thermal-hydraulic experimental facilities, research and commercial nuclear reactors. Main advantages of these codes are relatively small computational time and reasonably good results for system steady-states and transients. For closures, the codes, however, employ empirical correlations developed from separate effect and integral experiments of different scale. In many codes a two-fluid model with time- and volume-averaged parameters is used for simulation of two-phase flows. Neglected physical effects together with the volume averaging give a concern that the codes will fail in calculating complex system behavior such as strongly oscillating two-phase flows with rapid transitions among flow regimes. An adequate treatment of transient two-phase flow patterns in nuclear reactor thermal-hydraulic system codes is necessary

Objectives and methodology

First, this project will focus on investigating the capability of the system code to predict two-phase oscillatory flows. A number of experimental facilities with relevant data will be modeled using the system codes such as RELAP, TRACE, MELCOR.

Then, based on understanding of sensitive parameters of the system code and operating regimes of thermal-hydraulic systems, which strongly affect simulation result, a method for the treatment of two-phase flow pattern will be proposed. The method will be developed and implemented into the system code for a better two-phase system simulation.

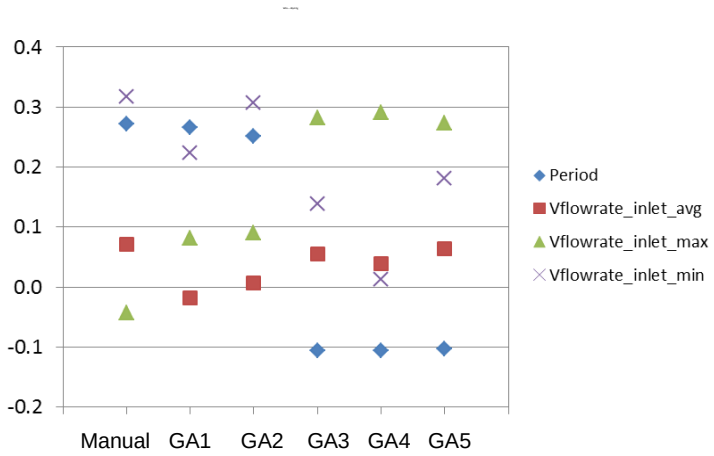
Organization

The work is performed by PhD student Viet-Anh Phung under the direction of scientific advisor Associate Professor Pavel Kudinov. The members of the reference group are: Ayalette Walter (SSM), Farid Alavyoon (Forsmark), Claes Halldin (OKG), Henrik Nylén (Ringhals) and Anders Andrén (Westinghouse).

Results in 2013

The main directions of the work during year 2013 were (i) further study of RELAP5 capability in predicting two-phase flow instability at low pressure condition in CIRCUS-IV single channel experiments for uncertainty reduction by input calibration and (ii) further study of the effect of recovery timing in different scenarios of core relocation process in a reference Nordic Boiling Water Reactor (BWR) using MELCOR.

In the first part of the work, a robust method was developed utilizing genetic algorithm tool GA-NPO coupled with RELAP5 for calibration of input parameters and quantification of uncertainty for code validation. The newly developed method can be especially useful for complex experiments with large number of uncertain parameters, but having multiple measurement parameters and multiple measurement points - complex physics, large uncertainty, but large number of constrains. The method can also help to reduce user uncertainty in code calculations (figure 1). It was applied successfully for



RELAP5 input calibration of two-phase flow instability in CIRCUS-IV experiments. The result also showed that user defined fitness function of the genetic algorithm plays an important role in identifying final optimal input models.

Figure 1: Comparison of inlet flow rate (period, average, maximum and minimum amplitude), manually calibrated RELAP5 result and top five GA-NPO/RELAP5 results from the same defined fitness function of CIRCUS-IV during instability (Tin = 93 °C). Results are normalized to the experimental value. Lower absolute value of the result is better.

The second part of the work was further analysis of influence of timing of safety systems' recovery on core relocation phenomena in a reference Nordic BWR. In the previous study, the effect of depressurization history on core relocation was investigated for station blackout scenario. In this part in addition, the recovery of low pressure water injection system was taken into account (timing and capacity). The analysis provided range of uncertainty of melt characteristics (composition, thermal conductivity, temperature, etc.). The results showed that melt characteristics could be sensitive to safety systems' recovery timing, and if the recovery timing is before about 6000s, the total mass of debris relocated to lower plenum of the vessel could be small (less than 4 tons) (figure 2).

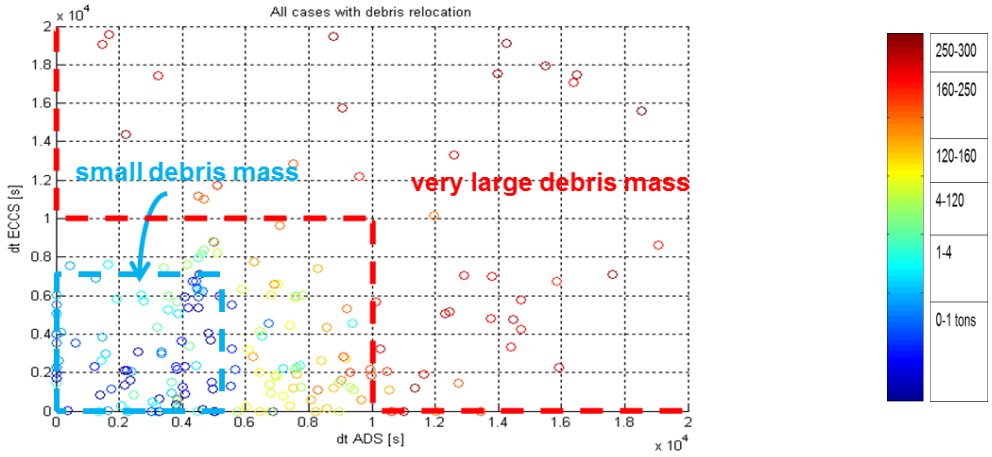


Figure 2: Variation of total mass debris in vessel lower plenum to depressurization and low pressure water injection history.

Prediction of wall temperature characteristics with focus on thermal fatigue of nuclear materials

Research leader: Professor Henryk Anglart
PhD student: Roman Thiele, Division of Nuclear Reactor Technology, KTH, Stockholm

Introduction

Thermal fatigue is one of the most frequent failure modes of construction materials in nuclear applications. Due to persistent propagation of temperature waves into solid material, deep crack and mechanical failures of structures can occur. This type of failure was observed during the refueling of Unit 3 of Oskarshamn nuclear power plant in October 2008. Thermal fatigue is intimately connected to mixing of two liquid streams of different temperatures. If the mixing pattern promotes creation and support of low-frequency temperature fluctuations, a condition necessary for the occurrence of the thermal fatigue is created.

Objectives and methodology

The objective of this project is to develop numerical models to predict time and space characteristics of a temperature field during mixing of two streams in proximity of a solid wall. This type of problems requires a detailed numerical approach that is able to resolve velocity and temperature fluctuations in a wide range of frequencies, typically from 0.2 to 10 Hz. In this project a conjugate heat transfer model with Large Eddy Simulation (LES) on the liquid side will be developed and validated against experimental data obtained at KTH.

Results in 2013

In 2013 several LES and VLES (Very Large Eddy Simulation) models with Conjugate Heat Transfer (CHT) have been tested [1,2]. It was demonstrated that the temperature patterns in the fluid and the solid are inter-dependent (see Fig. 1), which confirms the importance of CHT approach in the thermal fatigue studies.

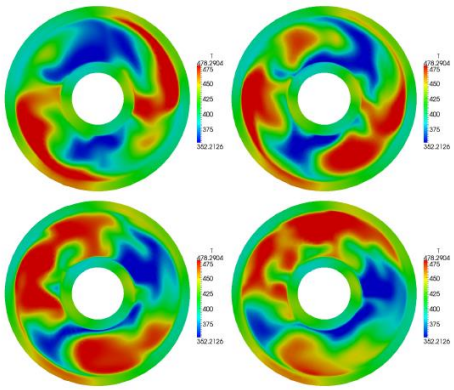


Fig. 1. Temperature distribution in liquid and colid wall during mixing [2].

References

[1] David Haces Manzano, “U-RANS and LES conjugate heat transfer analysis of the thermal fluctuations in a high difference temperature mixing zone using OpenFOAM”, Master Thesis, TRITA-FYS 2013:42, KTH, 2013.

[2] Ignacio Gallego Marcos, “Thermal Mixing CHT Simulations with OpenFOAM: URANS and LES”, Master Thesis, TRITA-FYS 2013:41, KTH, 2013.