SKC Annual Report 2017

Swedish Centre for Nuclear Technology

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SKC 18-01

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Summary and highlights of 2017

In 2017 SKC celebrated 25 years of fruitful collaboration between industry and academia on nuclear technology, with direct connections to industrial needs, coordination of efforts and the funding of academic research in nuclear technology! This marks a corner stone in how industry can be involved in research and how academia has a channel to the future activities of their students. This dialogue has been ongoing since 1992 even if, at that time, the centre was called KTC (Kärntekniskt centrum) and included only KTH. SKC was initiated as a response to the diminishing funding in nuclear research, and the number of researchers approaching retirement. It is fair to say that SKC has supported nuclear technology so that it has overcome and survived many ups and downs in the energy debate over the years in Sweden. A jubilee logo was also prepared for the year:

After the energy agreement in 2016 in Sweden, there is now a growing understanding that, gloabally, nuclear will play a crucial role in decreasing the needs for fossile electricity production. This has been further detailed in the latest prognosis of the energy production by IEA.

The World Energy Outlook 2017 report published by the International Energy Agency (IEA), foresees a substantially expanded role for nuclear energy if the world is to meet the challenges of people's development needs, while reducing greenhouse gas emissions to avoid dangerous levels of climate change.

The WEO-2017 Sustainable Development Scenario examines what it would take to achieve the main energy-related components of the "2030 Agenda for Sustainable Development" adopted in 2015 by member states of the United Nations, such as achieving universal energy access to modern energy by 2030; urgent action to combat climate change; and to dramatically reduce the pollutant emissions that cause poor air quality.

IEA therefore proposes that nuclear generation more than doubles from 2476 TWh in 2016 to 5345 TWh in 2040, as the electricity demand increases from 24,765 TWh in 2016 to 35,981 TWh in 2040, with nuclear energy supplying 15% of that demand.

Agneta Rising, Director General of World Nuclear Association has set an even higher goal of delivering 25% of the global electricity demand, as the need for electricity to reduce CO-2 emissions might even be higher than what WEO envisaged.

> "We agree with the IEA that there would need to be increased support for low carbon sources such as nuclear and innovative market designs if the aims of the Sustainable Development Scenario are to be met. We also agree there needs to be support for RD&D for innovative technologies. New technologies such as small modular reactors will mean nuclear energy can be used in more remote areas and in a broader range of applications, such as desalination and providing power for electricity vehicles."

SKC has in the present agreement a lower budget than before, but keeps the ongoing projects running with strong commitment from the parties to support the research groups including education in nuclear technology. The results from our efforts are seen in several publications, and confererence contributions. SKC meets also with students at the annual career days Charm, Utnarm and Armada. We also held a lunch seminar at Chalmers for new chemistry students, where Teodora Retegan and Christian Ekberg presented the Nuclear Chemistry department and the different courses available for these students during their time at Chalmers.

Unfortunately, the number of students following the Master programme in Nuclear Engineering at Chalmers has decreased over the years, and in 2018 the programme will not invite new students. The programme will end with the present students by spring 2019. Instead, there is a plan to start a new Master programme at Chalmers closer to nuclear chemistry, with a planned start in August 2019.

The annual SKC symposium was held this year outside Enköping, at Fargerudd Conference, 10-11 October. This event highlighted the first 25 years of SKCs activities, and ended with a panel discussion on the next 25 years of nuclear technology in Sweden. The plenary session also included an outlook on the Gen-IV status, presented by Sara Bortot, KTH. Invited speakers from CEA, SKS (Svenskt kärntekniskt sällskap) and Swedenergy contributed to a good discussion and possibilities with nuclear development in Sweden.

The Sigvard Eklund prize was given attention as the winners presented their work at the plenary session. See more about them below.

Nils-Olov Jonsson organized two Advisory board meetings, in May and October, where the research projects and our strategy were discussed.

In the SKC board, Olof Karis is the new representative of Uppsala University. During 2017, Dag Svensson, Head of HR at Vattenfall AB, and Anna Alvestav at SSM have been invited as observers during the meetings.

Goals and focus

The SKC cooperation is aimed at contributing to a **safe, effective and thus reliable nuclear energy production**, which is an important part of the Swedish need for electric power. Ensuring safety is the major prerequisite to achieve the goal of life time extension. This is taken care of through work at several departments, shown in Appendix 1-3 from, Chalmers, KTH and Uppsala University respectively.

Regarding education, several levels are required to pursue the future need in the nuclear industry. The courses are deveoloping more and more into platforms using e-learning at various stages, which makes courses more accessible as well as easier to manage. This is therefore one focus area of SKC now. Another approach to education is the contract education for ongoing knowledge improvement of professionals in the field. This could also benefit from the e-learning activities within SKC, initiated in 2017.

As a response to the industry's needs and demands of research, a large part of the SKC project funding has been allocated to the **MÅBiL** project, which is research within material, ageing and fuel, and consists of the following areas:

- ✓ Study of materials with respect to Accident Tolerant Fuels (ATF).
- ✓ Study of materials with respect to ageing.
- ✓ Study of nuclear physical processes during normal and/or transient conditions which affect the aforementioned points.

A more detailed account of MÅBiL and its activities is presented in Appendix 4.

During 2017, SKC participated in the student fairs at Chalmers (Charm) during two days, at Uppsala University (Utnarm) which lasts one day, and KTH (Armada) for two days. It was noted that the presence of our Swedish nuclear industry was lower than before at Charm and Armada. However, the interest from students is still at a good level. We have performed a quiz (written by Mattias Lantz at Uppsala university) where students respond to every-day questions related to applied nuclear physics, and we have about 40-60 students responding at each fair. The best responses get at prize in a draw each hour of the day.

The Sigvard Eklund Prize to the best Ph.D. thesis of the year was awarded to Zsolt Elter at Chalmers for his thesis related to signals from fission chambers. Mimmi Bäck, KTH, received the prize for the best masters' thesis for her work on weld techniques. The prize ceremony was held at the dinner of SKC's annual symposium, October 10. No prize was awarded in the bachelor thesis category in 2017.

A major challenge is to keep a strong national nuclear competence to allow for continuous operation of the Swedish nuclear industry. This was further accentuated by the governmental demand to SSM to investigate the national situation and to prepare a strategy. One attempt from SKC is to continue improving and finding new ways of educating students and professionals in nuclear technology. A project on e-learning activities has been initiated in 2017 and this will have an impact on the overall SKC actitivies linked to securing an excellent nuclear competence nationally.

SKC is intended to continue serving as a bridge between universities and industry even in a time of structural changes and financial challenges. The aim now is to listen to the nuclear industry, keep a direct dialog with academia, to find new partners, and to develop the cooperation on the long-term.

Hans Henriksson, SKC Director, 2018-03-29

Contents

SKC-Partners, Tasks and Goals

Swedish Centre for Nuclear Technology SKC – (**S**venskt **K**ärntekniskt **C**entrum www.swedishnuclear.se) was originally founded in 1992 under the name of KTC, Kärntekniskt Centrum, at KTH. The centre is a collaboration administrated at the School of engineering sciences at KTH (KTH/SCI). The SKC collaboration follows a three-year contract, at present running until December 31, 2019.

The partners in the SKC collaboration are the nuclear industry (financing parties)

- Forsmarks Kraftgrupp AB (www.vattenfall.se/om-oss/var-verksamhet/var-elproduktion/forsmark)
- OKG AB (http://www.okg.se)
- Ringhals AB (www.vattenfall.se/om-oss/var-verksamhet/var-elproduktion/ringhals)
- Westinghouse Electric Sweden AB (http://www.westinghousenuclear.com)

and academy

- Chalmers University of Technology (www.chalmers.se)
- KTH Royal Institute of Technology (www.kth.se)
- Uppsala University (www.uu.se)

SKC supports education and research in disciplines applicable to nuclear technology. The education programme is also supported by financial contributions to senior positions at the universities.

SKC's research funding is used within three research programmes:

- Nuclear Power Plant Technology and Safety
- Reactor Physics and Nuclear Power Plant Thermal Hydraulics
- Materials and Chemistry

Some areas of interest to the SKC partners within the research programmes are:

- Core Physics and Plant Dynamics
- Chemistry
- Detectors and measurement
- Material physics and engineering
- Fuel Technology
- Reactor Diagnostics
- Thermal-Hydraulics

SKC was established to provide long-term support to securing knowledge and competence development at an academic level for the Swedish nuclear industry. SKC strives to contribute to a continued safe, effective and thus reliable electricity production.

The overall goals of SKC during 2017:

- ✓ Increase interest among students to enter nuclear technology education.
- ✓ Enable the SKC financing partners to recruit qualified personnel with a nuclear technology education.
- ✓ Offer attractive education in the nuclear technology area.
- ✓ Maintain strong and internationally acknowledged research groups within areas that are vital for and unique to the nuclear technology area.
- ✓ 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.

Organization and funding

SKC runs according to three-year contract periods of which the present contract started Jan 1, 2017. The total volume for the three years is 25,4 MSEK.

SKC's financing partners in the present contract period (2017-2019) are:

- Forsmarks Kraftgrupp AB
- Oskarshamns Kraftgrupp AB
- Ringhals AB
- Westinghouse Electric Sweden AB

The contract states that the financers should contribute 8,46 MSEK annually to senior positions at the universities and to research activities. Support has been provided as base funding, specific funding of e-learning projects and specific support to a number of research projects, of which most are connected through the MÅBiL-collaboration.

An Advisory Council serves as a reference group in which discussions on strategy and funding are taken place. The members are selected such that their professional backgrounds cover the areas of nuclear technology that is considered relevant to the financers during the present contract period. The council provides advice to the SKC board and the director but takes no decisions.

During 2017, the Advisory Council consisted of:

- Nils-Olov Jonsson, Chairman
- Mattias Olsson, Forsmarks Kraftgrupp AB
- Georg Lagerström, Oskarshamns Kraftgrupp AB
- Björn Forssgren, Ringhals AB
- Ingemar Jansson, Westinghouse Electric Sweden AB

The Swedish Radiation Safety Authority, Strålsäkerhetsmyndigheten (SSM), was represented in the Advisory Council during 2016 by Anna Alvestav as observer. Hans Henriksson, the Director of SKC, act as secretary during the meetings.

During 2017, the SKC Board consisted of:

- Karl Bergman, Chairman, Vattenfall AB
- Peter Wedin, Forsmarks Kraftgrupp AB
- Pontus Tinnert, Oskarshamns Kraftgrupp AB
- Henric Lidberg, Ringhals AB
- Eva Simic, Strålsäkerhetsmyndigheten – observer status (until July 2017)
- Anders Andrén, Westinghouse Electric Sweden AB
- Leif Kari, KTH Royal Institute of Technology
- Olof Karis, Uppsala University (replaced Åsa Kassman Rudolphi in July 2017)
- Leif Åhman, Chalmers University of Technology
- Dag Svensson, Vattenfall AB – observer status

SSM was represented in the Board according to the SKC contract that allows an observer status for the regulator. Eva Simic left SSM in July 2017, and is temporarily replaced by Anna Alvestav who was invited to the board meetings as observer. Four board meetings were held in 2017. The Director of SKC attends the Board meetings, reports the progress as well as presents proposals to the board. The Director has also an observer position in the SSM Research Board, and attended three meetings in 2017.

SKC Financial statements 2017

Revenues, SEK

Payment Forsmarks Kraftgrupp AB	2 380 000 kr
Payment Oskarshamns Kraftgrupp AB	793 333 kr
Payment Ringhals AB	3 173 333 kr
Payment Westinghouse Electric Sweden AB	2 116 667 kr
Payment to SKC for French laboratory support	*250 000 kr*
Sum incoming payments	**8 713 333**

Spendings, SEK

Payout Chalmers	2 800 000 kr
Payout KTH	2 100 000 kr
Payout UU	2 600 000 kr
Payout SKC central administration [1]	963 333 kr
Payout SKC administration of French laboratory support [2]	250 000 kr
Sum Payout	**8 713 333**

Specifications of the French Laboratory support account (account administrated by SKC)

Balance on account 1/1 2017	3 970 189
Income from interest	31 041
Payout to SKC for French laboratory support [2]	-250 000
Remaining funds 21/12 2017 [3]	**3 751 230**

The contributions from the financing partners during 2017 of SKC to the budget split as follows:

Forsmark	28,1%
OKG	9,4%
Ringhals	37,5%
Westinghouse	25,0%

Comments

1. The account for central administration contains a remaining fund of 337 kSEK to cover late invoiced costs in 2017, such as the fee for Armada, and minor changes in activities to be distributed during 2018 within SKC.
2. The remaining funds for the French Laboratory Support is planned to be used during the period 2017-2018, according to a proposal of agreement between KTH and CEA, with SKC as administrator. For 2017 an administrative cost of 250 kSEK was transferred from the French support to SKC's central administration.
3. The cost in 2017 for French Laboratory support (not yet accounted for) includes training sessions in December for KTH of 117,5 k€.

SKC 25-year anniversary

SKC celebrated its 25-year anniversary in connection the the annual symposium, this year organised at Fagerudd conference centre outside Enköping. The symposium was well attended by 65 participants.

Fig 1. Present and former SKC directors, Hans Henriksson, Tomas Lefvert, Nils-Olov Jonsson, Jan Blomgren

The symposium consisted of a plenary session with highlights from Chalmers, KTH and Uppsala University, followed by a summary of the MÅBiL-project. The symposium was hosted by Westinghouse, and they offered a presentation about innovation and new techniques at Westinghouse by Lena Willman. This was followed by an update on the progress of Gen-IV reactors, by Sara Bortot, KTH. The Sigvard Eklund-prize winners were presenting their studies at the end of day 1. Westinghouse offered some snacks to the historical review of SKC before the dinner. During the dinner, Per Brunzell, former chairman of SKC board, chairman of the advisory board, and former CEO of ABB Atom, held a talk about the Swedish nuclear journey, and the development of SKC.

Fig 2. Participants at the SKC symposium 2017 in Fagerudd, Enköping

Day two consisted of PhD presentations before lunch. After lunch, Pierre-Yves Cordier from CEA, France gave a presentation about the progress of the French nuclear technology, followed by Cheuk Wah Lau, president of SKS (Swedish Society of Nuclear Technology) presented nuclear development projects in China. Day 2 ended with a panel discussion regarding SKC the next 25 years. The panel consisted of Carl Berglöf, Ane Håkansson, Pierre-Yves Cordier, Margaretha Tanse Larsson and Jan Blomgren, with Per Brunzell as the moderator.

Fig 3. Concluding panel at the SKC symposium in Fagerudd, Oct 11, 2017, on the topic "The next 25 years of SKC". From left to right: Carl Berglöf, Ane Håkansson,Margaretha Tanse Larsson, Pierre-Yves Cordier, Jan Blomgren, Per Brunzell, and Hans Henriksson (standing).

Winners of the Sigvard Eklund Prize

SKC organises each year a prize ceremony to the memory of Sigvard Eklund, former IAEA Secretary General. The Director of SKC handed over the Sigvard Eklund Prize in two categories, best Master and best Doctoral thesis, during the SKC symposium at Fagerudd, October 10, 2017.

Fig. 4.The Sigvard Eklund Prize Winners: Ph.D. Zsolt Elter, Chalmers/UU, Master Mimmi Bäck, KTH/OKG, together with Hans Henriksson, Director of SKC.

The prize for best Master thesis, 35 000 SEK, has been awarded Mimmi Bäck at the MSc programme on Material design at KTH, for her thesis: "Welding of dissimilar metals in different welding positions". Mimmi is now working as materials expert at OKG.

The prize for best Doctoral thesis, 50 000 SEK, was given to Zsolt Elter, Chalmers. The thesis is entitled: "Neutron monitoring based on the higher order statistics of fission chamber signals". Zsolt is now a PostDoc at the department of Applied Nuclear Physics at Uppsala University.

Fig.5. Material testing of weld, from thesis by Hanna Johansson

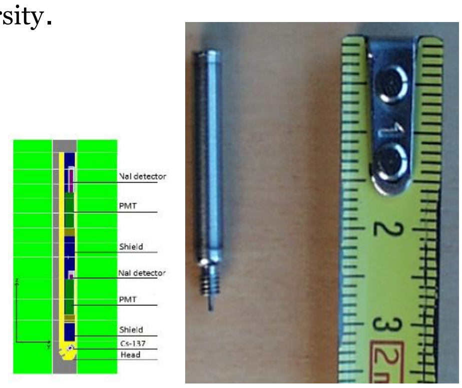


Fig. 6. Fission chamber design, from thesis by Zsolt Elter

Appendix 1 - Chalmers University of Technology

CHALMERS

Sustainable Nuclear Energy Centre

Overview of Activities in 2017

The following Chalmers divisions/departments are engaging actively in research and education related to nuclear technology:

- Div. of Energy and Materials, Nuclear Chemistry, Dept. of Chemistry and Chemical Engineering.
- Div. of Subatomic and Plasma Physics, Dept. of Physics.
- Div. of Materials Microstructure, Dept. of Physics.
- Div. of Advanced Non-destructive Testing, Dept. of Materials and Manufacturing Technology.

These units also offer nuclear education at MSc and PhD level. In 2017, the number of MSc students has increased compared with earlier years, although the MSc-level education is about to undergo major restructuring in coming years. The PhD level education is very active, with 20 PhD students having been active in 2017. Five new PhD students were recruited during 2017 and another two PhD projects are currently in the recruitment process.

The nuclear research environments are very active, in particular within international research projects. Several EU-funded projects were successfully completed in 2017, and several new projects were started with Chalmers involvement (both as coordinators and participants) and international funding. Thus, Chalmers has contributed strongly to attracting international funding for supporting the Swedish nuclear competence base and nuclear research infrastructure.

In 2017, the Sustainable Nuclear Energy Center at Chalmers was replaced by the national center SAINT (Swedish Academic Initiative in Nuclear Technology Research). The center currently involves Uppsala University and Chalmers, and focuses on:

- Generating synergies and maintaining high educational quality of national education within radiation sciences
- Work for a national strategy within radiation science research
- Assist, coordinate and encourage researchers in their science outreach
- Act as an independent source of information for industry, the public and other actors
- Increase the impact of the academic actors by speaking with a common voice

Planned activities include a networking event for students and employers, participation in the Gothenburg science festival (with an activity introducing secondary school children to radiation) and a conference for researchers within radiation sciences in Sweden.

Use of the SKC funding

The SKC base funding supports activities at three units at Chalmers:

- Nuclear Chemistry, Dept. of Chemistry and Ch. Engineering: 300 000 kr
- Subatomic and Plasma Physics, Dept. of Physics. 850 000 kr
- Materials Microstructure, Dept. of Physics. 250 000 kr

In addition, the MÅBiL project supports PhD students Aneta Herman (was Sajdova) at Nuclear Chemistry (450 000 kr) and Kristina Lindgren at Materials Microstructure (450 000 kr). Adding this to the base funding, the total SKC support has been used as outlined in the following tables. Note that the funds used in the projects exceed the SKC funding.

Division of Subatomic and Plasma Physics

Cost category		***Comments***
Personell costs	563 783,78	*Salaries for B Niceno*, C Demaziére, P Vinai, K Jareteg, and A Nordlund*
Equipment	54 019,66	
Bought services	0.00	
Travel and conferences	83 204,96	
OH	317 071,50	
Other	36 228,21	
Total	***1 054 308,11***	

* B. Niceno was co-supervisor of K. Jareteg.

Division of Materials Microstructure

Cost category		***Comments***
Personell costs	484 662.79	*Salary K. Lindgren*
Equipment	0.00	
Bought services	31 751.79	
Travel and conferences	29 117.04	
OH	229 067.80	
Other	0.00	
Total	***774 599.42***	

Division of Energy and Materials, Nuclear Chemistry

Cost category		***Comments***
Personell costs, senior scientists	199 861,36	*Salary C. Ekberg, M Hedberg*
PhD student	251 521,14	*Salary A. Herman (on maternity leave since fall 2017)*
Travel and conferences	7 524,14	*C. Ekberg, M. Hedberg*
OH	302 426,28	
Total	***761 332,92***	

Activities and common resources

The facilities and tools available at the supported divisions are as follows:

- A pulsed beam for variable energy slow positrons.
- Access to all major system codes for neutronic and thermal-hydraulic calculations.
- Fully equipped laboratories for α, β, γ experiments and activity measurements, e.g. HPGe-, LSC- and PIPS-detectors.
- 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 10 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.*
- Three Scanning Electron Microscopes.*
- Two Focused Ion Beam Workstations.*

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

The following PhD projects were supported, either fully or partially, by SKC during 2017:

- Development of an integrated neutronic/thermal-hydraulic model using a CFD solver (PhD student: Klas Jareteg; main supervisor: Professor Christophe Demazière; co-supervisors: Assoc. Prof. Paolo Vinai and Prof. Srdjan Sasic).
- Accident tolerant nitride based fuel (PhD student: Aneta Herman (was Sajdova); supervisor: Professor Christian Ekberg).
- Ageing of Reactor Pressure Vessel Steel Welds (PhD student: Kristina Lindgren; supervisor: Associate Professor Mattias Thuvander)

Some noteworthy accomplishments during 2017:

- Previous Chalmers PhD student Zsolt Elter, now post-doc at Uppsala University, received the Sigvard Eklund prize for best PhD thesis.
- New recruitments:
  - PhD student Thea Authen, was recruited for work on separation for transmutation within the GENIORS project at Nuclear Chemistry.
  - PhD student Luis Gonzales was recruited to the division of Nuclear Chemistry for work on chemistry of severe nuclear accidents. The project is funded by APRI.
  - PhD student, Maria Semenova (from National research nuclear university MEPhI in Moskva), was recruited to the division of Engineering Materials, Department of Industrial and Materials Science, for the project titled “Development of the simulation tool UTDefect and non-destructive characterization of operation induced defects” division of Engineering Materials, Department of Industrial and Materials Science. The project is funded by SSM.
  - PhD student Huaiqian Yi was recruited to the division of Subatomic and Plasma Physics for work within the CORTEX project (see below).
  - PhD student Niklas Hansson was recruited do the division of Nuclear Chemistry, for research on the chemistry of final repositories, funded by SKB.
  - Post-Doc researcher Antonios Mylonakis was recruited to the division of Subatomic and Plasma Physics, also for CORTEX.
  - Post-Doc researcher Emma Lopez-Alonzo was recruited to the division of Nuclear Chemistry for work on chemistry of severe nuclear accidents. The project is funded by SSM.
- Received grants:
  - An application to coordinate a major European project during the period 2017-2021 called CORTEX (CORe monitoring Techniques and EXperimental validation and demonstration) was

approved for funding by the European Commission in the Euratom 2016-2017 work program, under the Horizon 2020 framework. The consortium led by the Division of Subatomic and Plasma Physics, Department of Physics, includes in total 20 partners (with 2 non-European partners: 1 from Japan and 1 from USA). The project also includes an Advisory End-User Group, made of utilities, fuel vendors, NPP manufacturers, and a TSO, to keep the research focused on the industrial needs. The CORTEX project aims at developing core monitoring techniques that can be used to detect and characterize operational problems, before they have any inadvertent effect on plant safety and availability. The project officially started on September 1st, 2017. More info at http://www.cortex-h2020.eu

  - The Division of Subatomic and Plasma Physics, Department of Physics, is also involved in another project funded by the European Commission in the Euratom 2016-2017 work program, under the Horizon 2020 framework: ESFR-SMART – European Sodium Fast Reactor Safety Measures Assessment and Research Tools. The project is coordinated by PSI, Switzerland. More info at http://esfr-smart.eu/
  - The Division of Energy and Materials, Nuclear Chemistry, Department of Chemistry and Chemical Engineering, is involved in the EC-funded project GENIORS (GEN IV Integrated Oxide fuels Recycling Strategies, more info at www.geniors.eu)
  - The Nuclear Chemistry group is also involved in the EC-funded project MEET-CINCH (A Modular European Education and Training Concept In Nuclear and radiochemistry, more info at www.cinch-project.eu)
  - Mattias Thuvander at the division of Materials Microstructure was granted funding through the programme for GenIV research (Swedish Research Council) for a project on steels for liquid lead applications.
  - Marcus Hedberg at the division of Nuclear Chemistry was granted funding through the programme for GenIV research (Swedish Research Council) for a project on Nitride fuels for GenIV

- The following projects were successfully completed:
  - DREAM4SAFER - Development of Revolutionary and Accurate Methods for Safety Analyses of Future and Existing Reactors – VR support.
  - X-TREAM - neXt generation numerical Techniques for deterministic REActor Modelling – NORTHNET support.
  - FIRE - FIne mesh deterministic REactor modelling – SKC support.
  - DEMO-JHR - DEterministic MOdeling of the Jules Horowitz Reactor – VR support.
- Internships/visiting researchers:
  - A PhD student (Mr. Nicolás Olmo) from UPV, Spain spent 3 months in the spring at the Division of Subatomic and Plasma Physics, Department of Physics. He worked on the development of a methodology to compare frequency-domain noise calculations to time-domain calculations.
  - Omar Alejandro Olvera Guerrero (visitor, PhD student at UAM/Autonomous Metropolitan University, Mexico City, Mexico) stayed at the Division of Subatomic and Plasma Physics between 11 January – 10 July, working on signal analysis for BWR stability and core-barrel motion, contributing to the Ringhals project on noise diagnostics.
  - Dr. Yasunori Kitamura, from Kyoto University Research Reactor Institute, visited the Division of Subatomic and Plasma Physics for 6 months, working on stochastic neutron transport for core diagnostics and nuclear safeguards.
- A book proposal "Neutron multiplicity counting and applications" by Chen Dubi, Stephen Croft, Andrea Favalli and Imre Pázsit was accepted by Elsevier, to be published as part of the Woodhead Publishing Series in Energy.

Education

Master education

Chalmers students are offered a broad range of nuclear energy related courses, of which most have been given to students during 2017, see list below. The courses include topics on nuclear chemistry, physics, and materials, energy systems and radiation protection, providing future nuclear engineers with a systems perspective.

An international master's program has been in operation at Chalmers starting in 2009 and will continue until the end of 2018. The program is open to Swedish and foreign students with a bachelor's degree in engineering physics, chemical, mechanical or electrical engineering or the equivalent. Within the program it is possible to specialize in different topics with advanced elective courses.

95 students have taken the full master's program in nuclear science and technology, and in addition approximatively 130 students have taken one or more elective course in nuclear engineering subjects. A vast majority of the students from the program entered employment in the nuclear field.

The interest among Swedish students for pursuing an education within the nuclear field has been low in later years, most importantly due to the series of events starting with the Fukushima accident, followed by the German "Energiewende" and Swedish reactor shutdown decisions. In addition, the Department of Physics (the host department for the MSc program) has chosen to replace some of its MSc programs with low numbers of students with a new MSc program in physics. Due to these circumstances, the master's program in nuclear science and technology will be discontinued by the end of 2018. In connection with this, some nuclear related courses will expire. Courses which were given for the last time in 2017 are marked with "†", courses which will expire in 2018 are marked with "*".

Collaboration partners are being sought to continue offering the e-courses "Physics of nuclear reactors" and "Modelling of nuclear reactors". As mentioned new MSc program in physics is under development, and may include elements of nuclear engineering. At the same time, work is in progress with developing a new MSc program with a wider scope of radiation sciences, in collaboration with the University of Gothenburg.

Thus, Chalmers will continue to be an important source of competent engineers for the nuclear industry also in coming years.

A few highlights for 2017:

- The master program saw an increase in the number of students compared with previous years. Eight students follow the program, of which three are from Chalmers and the remaining five from abroad. As in previous years, over 20 applications were received from foreign students, a few of which were deemed to be qualified for following the program.
- The master program was presented to students both at CHARM and later at information sessions preparing the students for selecting master programs.
- As in previous years, a guest lecturer from WANO (World Association of Nuclear Operators) was invited for two days in October to talk about safety culture.
- The course "Physics of nuclear reactors" was offered, for the third time in a row, as a flipped course, making use of pre-recorded videos and on-line quizzes combined with in-class activities. Data about students' pre-class activities were continuously analysed in order to adjust the in-class activities depending on the students' needs, following a Just-in-Time Teaching – JiTT – approach.
- The course "Modelling of nuclear reactors" was offered, for the fifth time in a row, as a flipped course, following the same pedagogical principles as the course "Physics of nuclear reactors". The course is also offered through Chalmers Professional Education as a professional education course.

SKC-relevant courses

The following SKC-relevant courses were given, with the number of students in parenthesis, where such data could be obtained.
The courses listed with Swedish names are given by the Gothenburg University (GU) and are eligible for the students of the MSc program. These courses are given in Swedish.

- Nuclear materials TIF265, 7.5 ECTS (8) *
- Introduction to nuclear reactors TIF215, 7.5 ECTS (13)†
- Physics of nuclear reactors TIF210, 7.5 ECTS (10)†
- Modelling of nuclear reactors TIF205 (2)*
- Applied nuclear engineering TIF195, 7.5 ECTS (2)*
- Nuclear reactor safety TIF250, 7.5 ECTS (1)*
- Sustainable energy futures FFR170, 7.5 ECTS
- In-service inspection technologies MTT065, 7.5 ECTS (6)
- Nuclear chemistry I KBT192, 7.5 ECTS (13)
- Nuclear chemistry II KBT168, 7.5 ECTS (9)
- Radioecology and radioanalytical chemistry KBT216, 7.5 ECTS (1)
- Radiofarmaceutical chemistry KBT221, 7.5 ECTS (2)
- Computational fluid dynamics MTF072, 7.5 ECTS (55)
- Grundläggande strålningsfysik RFA400, 7.5 ECTS
- Nationell strålskyddsberedskap RFA410, 7.5 ECTS
- Strålskydd vid katastrofmedicinska insatser RFA420, 7.5 ECTS
- Detektorer och mätmetoder inom strålskydd och beredskap RFA430, 15 ECTS
- Strålskydd och miljöeffekter i kärnbränslecykelns olika skeden RFA440, 7.5 ECTS

The following courses were also offered, but not chosen by any students:

- Solvent Extraction KBT196, 7.5 ECTS
- Noise techniques in nuclear systems TIF245, 7.5 ECTS *
- Chemistry of Lanthanides, Actinides and Super-Heavy Elements KBT171, 7.5 ECTS
- Fusion energy RRY115, 7.5 ECTS *

PhD education

Chalmers educates a large number of fully employed (no scholarships) PhD students in a wide field of nuclear engineering subjects, which emphasizes the cross-disciplinarity of the nuclear engineering field. Since courses are offered within a wide range of subject areas, the PhD students have the possibility to get an overview of not only their own area of research, but also adjacent topics, making them highly employable in the nuclear industry.

The following PhD students have been active at Chalmers during 2017:

- Klas Jareteg (Subatomic and Plasma Physics, coupled LWR simulations)
- Alberto Ghione (Subatomic and Plasma Physics, thermal hydraulics for JHR)
- Adam Stahl (Subatomic and Plasma Physics, runaway electrons in fusion plasmas)
- Ola Embréus (Subatomic and Plasma Physics, runaway electrons in fusion plasmas)
- Stefan Buller (Subatomic and Plasma Physics, particle and heat transport in fusion plasmas)
- Linnea Hesslow (Subatomic and Plasma Physics, fast electron dynamics in plasmas)
- Mathias Hoppe (Subatomic and Plasma Physics, fusion plasma physics)
- Marcus Hedberg (Nuclear Chemistry, nitride fuels for GenIV)

- Jenny Halleröd (Nuclear Chemistry, solvent extraction for reprocessing)
- Lovisa Bauhn (Nuclear Chemistry, fuel leaching in final repositories)
- Thea Authen (Nuclear Chemistry, separation for transmutation)
- Fredrik Espegren (Nuclear Chemistry, source term research on tellurium)
- Artem Matyskin (Nuclear Chemistry, radium chemistry)
- Niklas Hansson (Nuclear Chemistry, radiolytic fuel dissolution)
- Aneta Herman (Nuclear Chemistry, accident tolerant uranium nitride fuels)
- Silvia Tuzi (Materials Microstructure, oxidation of nickel alloy X-750)
- Kristina Lindgren (Materials Microstructure, radiation effects on pressure vessel welds)
- Maria Semenova (Division of Engineering Materials, Department of Industrial and Materials Science, nuclear applications of non-destructive testing)

In addition, one double-degree PhD student is pursuing his education at both Chalmers and the Technical University of Budapest (BME):

- Lajos Nagy (Subatomic and Plasma Physics, theory of subcritical reactivity measurements)

Research

Completed theses

In SKC-related subjects, the following master theses were successfully presented during 2017:

- Federico López-Cerón Nieto, RELAP5 to TRACE model conversion for a Pressurized Water Reactor (performed at Universitat Politecnica de Valencia, Spain)
- Sebastian Carbol, Development of hybrid neutron transport methods for core calculations (performed at Subatomic and Plasma Physics)
- Niklas Hansson, Study of radium and barium complex formation with EDTA in alkaline sodium chloride media using the specific ion interaction theory (performed at Nuclear Chemistry)
- Simon Persson, Development of a Test Suite for Verification & Validation of OpenFOAM (performed at Subatomic and Plasma Physics)
- Michael Johansson, Numerical analysis of hyperbolic multi-phase flow using entropy stable schemes (performed at Subatomic and Plasma Physics)
- Mathias Hoppe, Synthetic synchrotron diagnostics for runaways in tokamaks (performed at Physics and Astronomy)
- Sriram Venkatesan, Optimization of parameters for ab initio molecular dynamics simulation of displacement cascades (performed at KTH (Pär Olsson as supervisor), examiner Thuvander)
- Joakim Högman, High Z materials liquid solutions for shielding and radiopacity purposes (performed at Nuclear Chemistry)
- Jessica Lybark, Application pf Deterministic Codes for Transient Analyses in Accelerator Driven Systems (performed at Subatomic and Plasma Physics)
- Huaiqian Yi, Uncertainty and Sensitivity Analysis for Nuclear Reactor Noise Simulations (performed at Subatomic and Plasma Physics)
- Lovisa Westlund Gotby, Intensity Modulated Proton Therapy for Hepatocellular Carcinoma (performed at Subatomic and Plasma Physics)

In an SKC-related subject, the following licentiate thesis was successfully presented during 2017:

- Aneta Herman, Accident tolerant uranium nitride

In SKC-related subjects, the following PhD theses were successfully presented during 2017:

- Silvia Tuzi, Electron Microscopy of Oxide Formed on Nickel Alloy X-750 in Simulated Boiling Water Reactor Environment
- Klas Jareteg, Development of fine-mesh methodologies for coupled calculations in Light Water Reactors
- Lovisa Bauhn, The interaction of dissolved hydrogen with α-radiolytic oxidants during nuclear fuel dissolution
- Alberto Ghione, Assessment and improvements of thermal-hydraulic correlations and methods for the analysis of the Jules Horowitz Reactor
- Adam Stahl, Momentum-space dynamics of runaway electrons in plasmas

Publications

Publications from 2017, which were published within SKC-financed projects (including MÅBiL), are listed below.

Lindgren, K. ; Boasen, M. ; Stiller, K. et al. (2017). Evolution of precipitation in reactor pressure vessel steel welds under neutron irradiation. Journal of Nuclear Materials. 488 s. 222-230.

Lindgren, K. ; Stiller, K. ; Efsing, P. et al. (2017). On the Analysis of Clustering in an Irradiated Low Alloy Reactor Pressure Vessel Steel Weld. Microscopy and Microanalysis. 23 (2) s. 376-384.

Demazière, C. ; Dykin, V. ; Jareteg, K. (2017). Development and test of a new verification scheme for transient core simulators, Transactions of the American Nuclear Society, San Francisco, CA, USA, June 11-15, 2017. 116 s. 1025-1026.

Demazière, C. ; Dykin, V. ; Jareteg, K. (2017). Development of a point-kinetic verification scheme for nuclear reactor applications. Journal of Computational Physics. 339 s. 396-411.

Jareteg, K. ; Sasic, S. ; Vinai, P. et al. (2017). A numerical framework for bubble transport in a subcooled fluid flow. Journal of Computational Physics. 345 s. 373-403.

Jareteg, K. (2017). Development of fine-mesh methodologies for coupled calculations in Light Water Reactors. Gothenburg: Chalmers University of Technology. ISBN/ISSN: 978-91-7597-626-6

Jareteg, K. ; Ström, H. ; Sasic, S. et al. (2017). On the dynamics of instabilities in two-fluid models for bubbly flows. Chemical Engineering Science. 170 (SI) s. 184-194.

Sardina, G. ; Jareteg, K. ; Ström, H. et al. (2017). The nature of instabilities in bubbly flows - a comparison between eulerian-eulerian and eulerian-lagrangian approaches, Conference Proceedings of the 14th Conference on Multiphase Flows in Industrial plants (MFIP17)

Sajdová, A. (2017). Accident-tolerant uranium nitride. Gothenburg: Chalmers University of Technology.

Specific project reporting

The SKC financed PhD project at Chalmers "Development of an integrated neutronic/thermal-hydraulic model using a CFD solver" (PhD student Klas Jareteg) was completed in 2017. The thesis is available at http://publications.lib.chalmers.se/records/fulltext/251490/251490.pdf

Projects which were part of the MÅBiL collaboration are reported separately.

Planned activities for 2018

- A workshop on reactor dynamics and the theory of small space-time fluctuations (i.e. neutron noise) will be organized on June 18-21, 2018 at Chalmers, as part of the CORTEX project. The course will be a flipped course. More information will be posted on the CORTEX website http://www.cortex-h2020.eu
- An introductory web-based course on nuclear science and technology will be developed as a joint effort between Chalmers and Uppsala University.
- A PhD student, Johan Eriksson (previously from Forsmark), will be employed in the Materials Microstructure group for research on cladding tubes, with funding from EPRI, WSE, OKG and Vattenfall).
- An industrial PhD student, funded by SSM and the industry, will be employed at the division of Engineering Materials, Department of Industrial and Materials Science for a project of nuclear applications of non-destructive testing.
- As part of a French-Swedish agreement regarding exchange of nuclear services as part of the European Spallation Source, the students enrolled last autumn for the master program will go to a research reactor in Saclay, France in spring 2018. The exercise is in form of a two-and-a-half-day laboratory exercise on a small open pool reactor.

Appendix 2 - KTH Royal Institute of Technology

Overview of activities in 2017

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. The Centre for Nuclear Energy Engineering at KTH (CEKERT) has currently 12 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.

In 2017 KTH researchers received a substantial financial support (over 46% of the total amount allocated) from the Swedish Research Council (VR) to perform research on new generation IV reactors. In particular, research on heat transfer, fuel stability in aquatic systems and high entropy alloys for generation IV reactors have been supported.

A record number of 44 students were admitted to our Master Program in Nuclear Engineering (TNEEM) in 2017. Due to the program's high national and international reputation, the number of applicants is dramatically increasing each year and reached over 350 in 2017. Further developments of the program, including implementation of Technology Empowered Energy Education and new electronic examination have been accomplished. Last but not least, KTH's student Mimmi Bäck received Sigvard Eklund's Prize for best Master Thesis with a title "Welding of dissimilar metals in different welding positions".

Staff directly involved in SKC activities

Reactor Physics group:

- 3 Professors - Waclaw Gudowski, Janne Wallenius and Pär Olsson (head of research group)
- 0.5 Ph.D. student – Elin Toijer (shared with Nuclear Chemistry) - 80% SKC

Reactor Technology group:

- 1 Professor - Henryk Anglart (head of research group)
- 1 Assoc. Prof. - Jan Dufek
- 1 Ph.D. student - Mattia Bergagio – 50% SKC

Solid Mechanics group:

- 2 Professors – Bo Alfredsson and Jonas Faleskog (member of SSM:s research council)
- 1 Adj Professor – Pål Efsing
- 2 Researchers – Carl Dahlberg and Martin Öberg

- 4 Ph D Students – Michel Sedlak (70% SKC), Magnus Boåsen (25% SKC, 50% SSM, 5% NKSS) and André Tengstrand (20% SKC, 20% SSM) are full time students, and Martin Bjurman (RAB/OKG/FKA/SSM/Studsvik) is Industrial Ph. D. student on 70%

Nuclear Chemistry group:

- 1 Professor – Mats Jonsson
- 0.5 Ph.D. student – Elin Toijer(shared with Reactor Physics) – 80% SKC

Highlights and major research outcome

- Over 20 MSEK financial support from the Research Council (Vetenskapsrådet) for KTH to perform research on Generation IV reactors.
- 44 students enrolled to Master Program in Nuclear Energy Engineering (TNEEM).
- Pär Olsson was promoted to Professor.
- Sigvar Eklund's Prize was aworded to KTH's student Mimmi Bäck for best Master Thesis on "Welding of dissimilar metals in different welding positions".
- Reijo Pegonen defended his PhD dissertation on "Development of an Improved Thermal-Hydraulic Modelling of the Jules Horowitz Reactor".
- Anders Riber Marklund defended his PhD dissertation on "Passive acoustic leak detection in energy conversion systems of sodium fast reactors".
- KTH Reactor Physics was in 2017 awarded four European H2020 projects in the field of nuclear materials science (P. Olsson): M4F (Domain Leader), INSPYRE (Task Leader), GEMMA and IL TROVATORE (Task Leader).
- Reactor Physics was also awarded an Enabling Research Grant from the EUROfusion programme for development of materials characterization methods (CHEDDAR: Coordinator P. Olsson) and a postdoc grant from EUROfusion for Luca Messina (MEATBALL: Host P. Olsson).
- KTH Reactor Physics won an SSF industrial PhD grant together with Westinghouse for development of accident tolerant fuel.
- KTH Reactor Physics (P. Olsson) won a VR-grant (PI Mattias Thuvander, Chalmers) for development and modelling of materials for Gen-IV reactor systems.
- KTH Reactor Rechnology (H. Anglart) won a VR-grant for investigation of heat transfer to supercritical water in Gen-IV reactors.

Major archival publications

Bergagio, M., Thiele, R. and Anglart, H., "Analysis of temperature fluctuations caused by mixing of non-isothermal water streams at elevated pressure," Int. J. Heat and Mass Transfer, vol. 104, pp. 979-992, 2017.

Li, H. and Anglart, H., "CFD prediction of droplet deposition in steam-water annular flow with flow obstacle effects," Nuclear Engineering and Design, vol. 321, pp. 173-179, 2017.

Pegonen R., Bourdon S, Gonnier C. and Anglart, H., "An improved thermal-hydraulic modelling of the Jules Horowitz Reactor using CATHARE2 system code," Nuclear Engineering and Design, vol. 311, pp. 156-166, 2017.

Bergagio, M. and Anglart, H., "Experimental investigation of mixing of non-isothermal water streams at BWR operating conditions," Nuclear Engineering and Design, vol. 317, pp. 158-176, 2017.

Olsen, B. and Dufek, J., Stabilization effect of fission source in coupled Monte Carlo simulations, 2017, Nuclear Engineering and Technology.

Olsen, B. and Dufek, J., Fission source sampling in coupled Monte Carlo simulations, 2017, Kerntechnik.

G. Bonny, N. Castin, C. Domain, P. Olsson, B. Verreyken, M.I. Pascuet, D. Terentyev, *Density functional theory-based cluster expansion to simulate thermal annealing in FeCrW alloys,* Phil Mag. 97 (2017) 299.

T. Schuler, D.A. Lopes, A. Claisse, P. Olsson, *Transport properties of C and O in UN fuels*, Phys. Rev. B 95 (2017) 094117.

M. Chiapetto, L. Messina, C.S. Becquart, P. Olsson, L. Malerba, *Nanostructure evolution of neutron-irradiated reactor pressure vessel steels: Revised Object kinetic Monte Carlo model*, Nucl. Instr. Meth. B 393 (2017) 105.

L. Messina, M. Chiapetto, P. Olsson, C.S. Becquart, L. Malerba, *An object kinetic Monte Carlo model for the microstructure evolution of neutron-irradiated reactor pressure vessel steels,* Physica Status Solidi A 213 (2017) 2974.

L. Messina, N. Castin, C. Domain, P. Olsson, *Introducing ab initio-based neural networks for transition-rate prediction in kinetic Monte Carlo simulations*, Phys. Rev. B 95 (2017) 064112.

G. Bonny, A. Bakaev, P. Olsson, C. Domain, E.E. Zhurkin, M. Posselt, *Interatomic potential to study the formation of NiCr clusters in high Cr ferritic steels,* J. Nucl. Mater. 484 (2017) 42.

N. Castin, L. Messina, C. Domain, R. C. Pasianot, P. Olsson, *Improved atomistic Monte Carlo models based on ab-initio-trained neural networks: Application to FeCu and FeCr alloys,* Phys. Rev. B 95 (2017) 214117.

C.S. Becquart, R.N. Happy, P. Olsson, C. Domain, *A DFT study of the stability of SIAs and small SIA clusters in the vicinity of solute atoms in Fe,* J. Nucl. Mater. 500 (2018) 92.

A. Bakaev, D. Terentyev, Z. Chang, M. Posselt, P. Olsson, E.E. Zhurkin, *Effect of isotropic stress on dislocation bias factor in bcc iron: an atomistic study,* Phil. Mag. 98 (2018) 54.

N. Castin, M.I. Pascuet, L. Messina, C. Domain, P. Olsson, R.C. Pasianot, L. Malerba, *Advanced atomistic models for radiation damage in Fe-based alloys: contributions and future perspectives from artificial neural networks,* Comp. Mater. Sci (Accepted 2018).

S.C. Middleburgh, A. Claisse, D.A. Andersson, R.W. Grimes, P. Olsson, S. Mašková, *Solution of hydrogen in accident tolerant fuel candidate material: U3Si2*, J. Nucl. Mater. (Accepted 2018).

E. Bubelis, J. Wallenius, et al., *System codes benchmarking on a low sodium void effect SFR heterogeneous core under ULOF conditions,* Nucl. Eng. Des. 320 (2017) 325.

K. Johnson, V. Ström, J. Wallenius, D.A. Lopes, *Oxidation of accident tolerant fuel candidates*, J. Nucl. Sci. Tech. 54 (2017) 280.

M. Jolkkonen, P. Malkki, K. Johnson, J. Wallenius, *Uranium nitride fuels in superheated steam*, J. Nucl. Sci. Tech. 54 (2017) 513.

V. Diesen, K. Forsberg and M. Jonsson, "Effects of cellulose degradation products on the mobility of Eu(III) in repositories for low and intermediate level radioactive waste," Journal of Hazardous Materials, vol. 340, pp. 384-389, 2017.

M. Yang, I. Soroka and M. Jonsson, "Exploring the limitations of the Hantzsch method used for quantification of hydroxyl radicals in systems of relevance for interfacial radiation chemistry," Radiation Physics and Chemistry, vol. 130, pp. 1-4, 2017.

K. Nilsson, O. Roth and M. Jonsson, "Oxidative dissolution of ADOPT compared to standard UO2 fuel,"Journal of Nuclear Materials, vol. 488, pp. 123-128, 2017.

Å. Björkbacka et al., "Radiation Induced Corrosion of Copper in Humid Air and Argon Atmospheres,"Journal of the Electrochemical Society, vol. 164, no. 4, pp. C201-C206, 2017.

I. Soroka et al., "Radiation-induced synthesis of nanoscale Co- and Ni-based electro-catalysts on carbon for the oxygen reduction reaction," Dalton Transactions, vol. 46, no. 30, pp. 9995-10002, 2017.

C. M. Lousada et al., "Synthesis of copper hydride (CuH) from $CuCO_3 \cdot Cu(OH)_2$ – a path to electrically conductive thin films of Cu," Dalton Transactions, vol. 46, no. 20, pp. 6533-6543, 2017.

K. Lindgren, M. Boåsen, K. Stiller, P. Efsing and M. Thuvander, Evolution of precipitation in reactor pressure vessel steel welds under neutron irradiation, J. of Nuclear Materials, vol. 488, 2017, pp 222-230.

M. Boåsen, P. Efsing and U. Erhnsten, On flux effects in a low alloy steel from a Swedish reactor pressure vessel, J. of Nuclear Materials, vol. 484, 2017, pp 110-119.

R. Shen, P. Efsing, Overcoming the drawbacks of plastic strain estimation based on KAM, Ultramicroscopy, vol. 184, 2018, pp. 156-163

Major conference presentations and posters

Anglart, H., “Current Challenges in Numerical Modelling of Single- and Multi-Phase Flows and Heat Transfer,” Keynote Presentation at REMOO-2017 Conference, Venice, Italy, May 10-12, 2017.

Li, H. and Anglart, H., “Mechanistic Modeling of Annular Two-Phase Flow with Heat Transfer,” 53rd European Two-Phase Flow Group Meeting, Gdansk, Poland, May 22-24, 2017.

Bergagio, M. and Anglart, H. “Measurement of Wall Temperature Oscillations due to Mixing of Water Streams at High Temperatures and Pressures,” 9th World Conference on Experimental Heat Transfer, Fluid Mechanics and Thermodynamics, Iguazu Falls, Brazil, June 12-15, 2017.

Li, H. and Anglart H, “CFD Modeling of Annular Two-Phase Flow for Dryout Prediction,” Proc. 17th Int. Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-17), Xi’an, China, Sept. 3-8, 2017.

Anglart, H., “CFD Modeling of Annular Two-Phase Flow and Heat Transfer,” Invited Keynote Lecture, Proc. 17th Int. Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-17), Xi’an, China, Sept. 3-8, 2017.

Anglart, H. and Li, H., “Mechanistic Modeling of Dryout and Post-Dryout Heat Transfer,” Proc. 13th RDPE Conference, Warsaw, Poland, Nov. 28-Dec. 1, 2017.

P.Olsson [Invited], D. Karlsson, A. Rasmussen, C.S. Becquart, C. Domain. *Dynamic DFT simulations of defect formation in metals*. EMN Meeting on Computation and Theory 2017, Dubai, UAE, 7-10/11 2017.

P. Olsson [Invited], A. Claisse, M. Pukari, D. Adorno Lopes, M. Freyss, K. Johnson, M. Klipfel, T. Schuler. *Thermodynamics and kinetics of fission products and impurities in nitride fuels*. EUROMAT 2017, Thessaloniki, Greece, 17-22/9 2017.

P. Olsson [Invited]. *Hårda material*. NaNu-2017. Helsingfors Universitet, Helsingfors, Finland, 10/4 2017.

E. Toijer, M. Jonsson, *Radiation Induced Corrosion of Steel – Impact of Water Radiolysis*, 30th Mille Conference on Radiation Chemistry, 7-11/10 2017, Castellammare del Golfo, Italy.

M. Jonsson: Radiation induced dissolution of UO_2- based nuclear fuel. –Impact of H_2 and dopants., INCC 2017, 27 August – 1 September, 2017, Gothenburg, Sweden.

M. Jonsson: On the mechanism of radiation induced corrosion of copper in anoxic water and humid atmospheres, EUROCORR 2017, September 3–7, 2017 Prague, Czech Republic.

M. Jonsson: Radiation synthesis of metal oxide nanoparticles, 1st Pan American Congress of Nanotechnology, 27-30 November, 2017, Guaruja, Brazil.

M. Sedlak B. Alfredsson and P. Efsing, Modelling of IGSCC Mechanism Through Coupling of a Potential -Based Cohesive Model and Fick's Second Law, Proc. 14th International Conference on Fracture ICF14, Rhodes, Greece, June 18-23, 2017.

M. Bjurman, K. Lindgren, M. Thuvander, P. Ekström, P. Efsing, Microstructural Evolution of Welded Stainless Steels on Integrated Effect of Thermal Aging and Low Flux Irradiation, Proc. of 17th Conference on Environmental degradtion on Water reactors, Portland, Oregon, Aug 13-17, 2017.

M. Bjurman, B. Forssgren and P. Efsing, Fracture mechanical testing of in-service thermally aged cast stainless steel, In Proceeding from ASTM Fatigue and fracture test planning, test data, acquisitions and analysis, ASTM-STP 1598, 2017

6 posters at the 30th Miller Conference on Radiation Chemistry, 7-11 October, 2017, Castellammare del Golfo, Sicily, Italy

Fixed funding

The fixed funding has been used to support teaching in the nuclear engineering field. The main goal has been to continue providing high quality teaching within the Master Programme and in particular, in the core areas of nuclear engineering such as:

- Reactor physics,
- Reactor technology,
- Thermal-hydraulics.

The fixed funding was distributed to support teacher positions as follows:

Professor position in Reactor Physics	555 kkr
Professor position in Reactor Technology	555 kkr
Associate professor position in Reactor Technology	390 kkr

The fixed funding has been used according to the planned budget for year 2017.

Education

Report on educational activities in Nuclear Energy Engineering (TNEEM)

- **Programme Director – Waclaw Gudowski**

The Master Program in Nuclear Energy Engineering (TNEEM) is developing well and reaches new achievements. In 2017 TNEMM program reached a record number of **44 students**.

TNEEM is today a part of few dual diploma agreements in nuclear energy engineering:

1. In European Master in Innovative Nuclear Energy Engineering – EMINE, a part of KIC InnoEnergy educational program, in which students are getting Dual Diploma with either of ENSTA - University Paris-Saclay, Paris or Grenoble Institute of Technology, Grenoble-INP. We educate between 15-20 DD Masters each year.
2. Dual Diploma in Nuclear Energy Engineering with Tsinghua University, Beijing. Tsinghua University is a strategic partner for KTH, and KTH centrally is strongly supporting this cooperation. Last year we received 10 DD students from Tsinghua, sending only one KTH student to China. Being aware of this imbalance we work together with the KTH management on finding a way to balance this exchange within the whole KTH, not solely within TNEEM
3. Dual Diploma in Nuclear Energy Engineering with Korea Advanced Institute of Science and Technology, KAIST. The first DD KTH student is finishing his term now at KAIST. We receive KASIT students for the Summer Course SH262V
4. Few international students each year are enrolled to TNEEM in the frame of KTH's dual diploma agreement in civil engineering and within the ERASMUS program,

TNEEM is getting many applicants and more enrolled students each year. Fig. 1 shows the statistics over applicants and enrolled students. It is really encouraging dynamics.

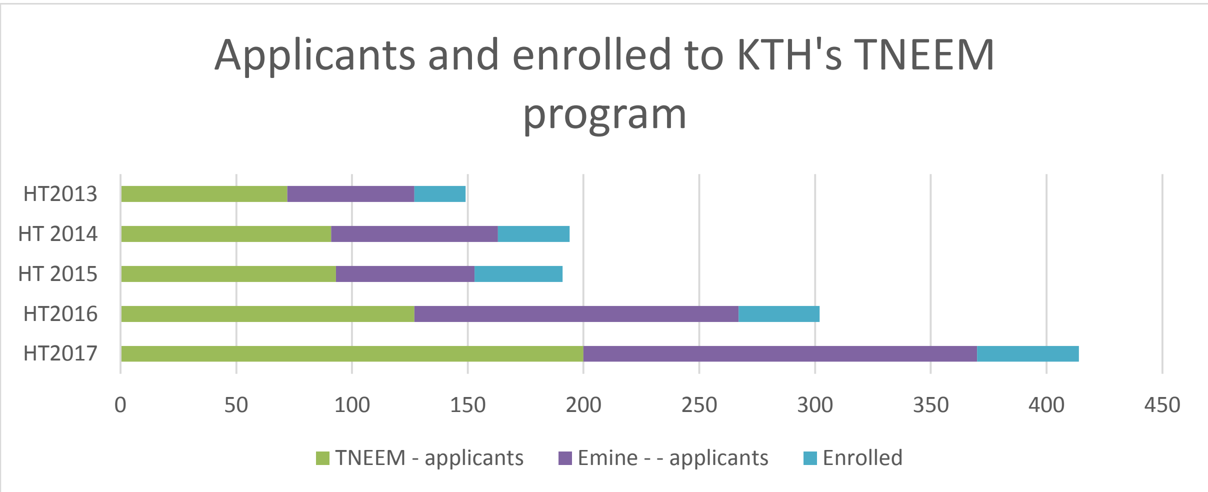


Fig. 7. Development of TNEEM program in terms of applicants and enrolled students

In 2017 strong efforts have been on E-learning platform development which is now called at KTH – Technology Empowered Engineering Education – TEEE or **TE3**. Many courses have being recorded and made available for the students during their studies at the dedicated internet site accessible via KTH's Learning Management System (LMS) – CANVAS.

Further development of examination and home assignments within the TE3 resulted in very successful improvements of those tools. Students of Reactor Physics major course 2017 benefited in more efficient in-learning processes and a very successful final examination. Figure 2 shows students during TE[3] examination.

Fig. 8. TE3 examination. Students solve the problems supervised by the computer

Figure 3 shows a distribution of grades for the final exam in Reactor Physics. This distribution resembles grade distribution of the previous "paper based" examination.

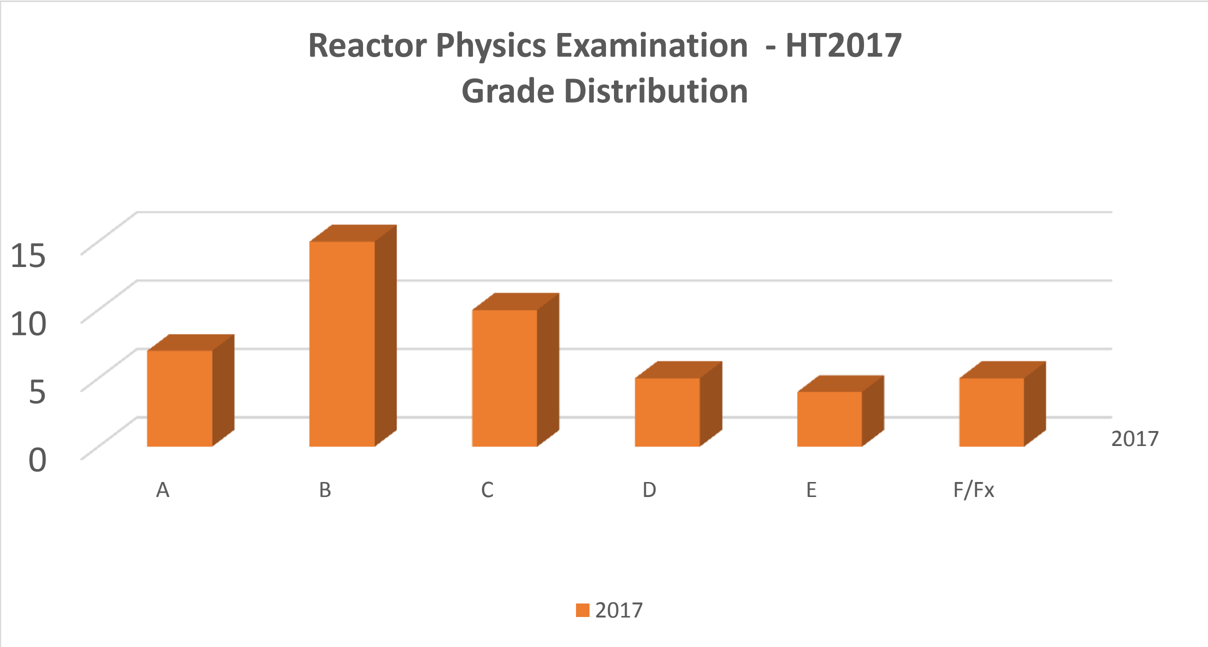


Fig. 9. Grade distribution of the final examination in Reactor Physics, 2017.

Our InnoEnergy EMINE program was extensively evaluated in 2017 by the experts of the European Institute of Innovation and Technology in so called "EIT labelling" evaluation. EMINE Program was awarded with the highest grade, resulting in continuous and stable funding for the coming 5 years. Really a great achievement giving stable foundations for the further development of EMINE.

In spite of the serious formal problems in paper processing of the prolongation of the KTH-CEA agreement concerning reactor laboratories at ISIS reactor in Saclay we succeeded – as planned – all the laboratory sessions in Saclay. 46 students of Reactor Physics could perform all the laboratory exercises thanks to friendly approach of the CEA management – see Figure 10.

Fig.10. Laboratory exercises at ISIS reactor at CEA, Saclay.

Development of the Summer Course: Elements of the Back-end of the Nuclear Fuel Cycle: Geological Storage of Nuclear Spent Fuel (Code SH262V, 7.5 ECTS)

This Summer Course is an exceptional example of a successful cooperation of KTH with other stakeholders, like nuclear industry, local communities and other universities. The most important development features of 2017 were:

a) The course has been designed and organized by the Royal Institute of Technology (**KTH**), the Center for University Studies Research and Development (**Nova - Oskarshamn**) and by the Swedish Nuclear Fuel and Waste Management Company (**SKB**) and supported by the Linnaeus University and the University of Illinois at Urbana-Champaign (UIUC).
b) The European Project Brilliant (Baltic Region Initiative for Long Lasting Innovative Nuclear Technologies - 662167) contributed to the Summer Course in 2017
c) In 2017 a new partner joined the Summer Course: Nanyang University of Technology (Singapore)

d) The course consists of a combination of classroom lectures and field excursions and work The unique feature of the course is that the students visit Clab (an interim geological repository for spent fuel), the Laxemar Site (study area for bedrock and surface geology), the Äspö Hard Rock Laboratory (research laboratory for geological spent fuel disposal), and the Canister Laboratory (development center for spent fuel encapsulation technology).
e) In 2017 special sessions at KSU Reactor Simulator took place
f) The course is heavily sponsored and funded by the local Oskarshamn community and SKB
g) A comprehensive multimedia report has been produced including video recorded lectures and students presentations. Click the link: https://www.dropbox.com/s/rpp10889lccp90u/Summer_Course_SH262V-Report-2017.pdf?dl=0
h) A dedicated text book has been published for this course in 2017

All course lectures of 2017 were recorded and are now available on the internet via a following link:

https://mediasite.neutron.kth.se/Mediasite/Catalog/catalogs/sh262v-june-2017

Moreover a special video clip promoting the Summer Course has been published on internet at the following link:

https://youtu.be/8REAgLxphWY

Fig.11. Summer Course students at Äspö Hard Rock Laboratory

The Summer Course had unusual coverage in the local media.

Internationell kurs i geologiskt slutförvar av använt kärnbränsle hålls i Oskarshamn

Deltagare 2016. I år antogs 48 studenter från ett 10-tal länder, t.ex. Sydkorea, Polen, Kina och Indien. Foto: Kungliga Tekniska Högskolan, KTH

Publicerad av
Markku Björkman - 11 jun 2017

6 Oskarshamn

NYHETERNA
Måndag 19 juni 2017

Ett femtiotal studenter från alla världens hörn befinner sig nu vid Äspö för att studera den svenska slutförvarslösningen. FOTO: ANNA-LENA KARLSSON

Internationella studenter på intensivkurs vid Äspö

Ett 50-tal studenter från världens alla hörn är nu samlade vid Äspölaboratoriet för att ta en närmare titt på den svenska lösningen när det gäller använt kärnbränsle.

ÄSPÖ. Det är nu femte sommaren i rad som kursen "Geological Storage of Nuclear Spent Fuel" (Geologiskt slutförvar av använt kärnbränsle) anordnas i Oskarshamn.

Denna gång antogs 48 studenter från ett 10-tal länder, däribland USA, Sydkorea, Polen, Kina och Indien.

Kursen, som är två veckor lång, arrangeras av Kungliga Tekniska Högskolan, KTH, och Linnéuniversitetet i samarbete med SKB och Nova - Utbildning FoU & Affärsutveckling.

I kursen, som kommer att pågå fram till den 22 juni, medverkar ett stort antal lärare och specialister från KTH, Linnéuniversitetet och SKB.

På plats finns även gästföreläsare från exempelvis USA, Kina och Singapore.

– Ansvarsfull hantering av använt kärnbränsle är en fråga om att "vara eller inte vara" för kärnkraften, säger kursansvarige professor Waclaw Gudowski, KTH.

– **Sverige, och** Oskarshamn i synnerhet, har väldigt mycket att bidra med inom kunskaps- och kompetensutvecklingsområdet, och vi är övertygade om att vår kurs kommer att bidra till att flera länder kommer att ändra sina "wait and see-strategier" och följa det svenska spåret.

De närmare 50-talet internationella studenter som tittar närmare på den svenska lösningen med slutförvar i berggrunden, har lite olika bakgrund.

– Några är geologer. Andra kärntekniker eller kemister, berättar Waclaw Gudowski.

Syftet med de intensiva veckorna i Oskarshamn är att studenterna ska få bredda sina horisonter - allt för en djupare förståelse för hur allting hänger ihop.

Det är många discipliner som är med och utvecklar slutförvaren. Inte sällan är kännedomen om varandras ansvarsområden inte så stor.

Och det är just det kursen i Oskarshamn syftar till att se helheten.

Så under veckorna vid Äspö får deltagarna bland annat delta i en rad olika föreläsningar om bland annat geologi och geologisk historia, kärnteknik och mycket, mycket annat.

Allting varvas dessutom med intensiva studier i fält.

– Ingen annanstans i världen än just här i Oskarshamn finns så mycket samlat på ett och samma ställe, säger professor William Roy från Illinois.

På plats i Oskarshamn för att föreläsa finns bland andra professor William Roy från Illinois.

TEXT
ANNA-LENA KARLSSON

OSKARSHAMN / A 6

Succé för internationell sommarkurs

Studenter från hela världen träffades på femte upplagan av Novas sommarkurs

Kinesiska studenter redovisar grupparbete på Nova i Oskarshamn. Från vänster: Chi Zhang, Boxian Chen, Guohua Wu och Boxuan Yu från Tsinghua University - ett av de mest välrenommerade universiteten i Asien - samt Yifan Zheng från KTH i Stockholm. FOTO: MAGNUS GUSTAFSON

Rekordmånga deltagare när Nova bjöd in till internationell sommarkurs

48 studenter från ett tiotal länder, varav majoriteten från Kina, samlades i Oskarshamn den gångna veckan för att lära sig mer om kärnbränslehantering.

OSKARSHAMN. För femte sommaren anordnades kursen "Geologiskt slutförvar av använt kärnbränsle" i Oskarshamn. Årets upplaga lockade rekordmånga deltagare.

– Allt fungerade perfekt. Vi hade mycket engagerade studenter och väldigt bra internationell stämning, säger kursansvarige professor Waclaw Gudowski.

Syftet med kursen är att sprida kunskap om kärnbränslehantering. Geologer, kemister och fysiker från olika delar av världen träffas och utbyter erfarenheter och får nya perspektiv på sina studier.

Förutom föreläsningar ingår också studiebesök på SKB:s anläggningar i Oskarshamn: Mellanlagret för använt kärnbränsle, Äspölaboratoriet och Kapsellaboratoriet. Studenterna gör även grupparbeten.

Kursen arrangeras av Kungliga Tekniska Högskolan, KTH, och Linnéuniversitetet i samarbete med Svensk Kärnbränslehantering, SKB, och Nova forskning och utveckling.

MAGNUS GUSTAFSON

Studenterna Chen Wang, Kevin Kewal, Yulia Mishchenko, André Ramirez Alvarez, Oscar Pastor Serrano och Edyta Wyszkowska kommer alla från olika länder för att lära sig om kärnbränsle. FOTO: ANNA LYGNEBRANDT

Kurs lockar internationellt

I två veckor har 48 studenter från tio länder varit på kurs i Oskarshamn för att lära sig mer om kärnbränslecykeln.

OSKARSHAMN. Sommarkursen Geologiskt slutförvar av använt kärnbränsle lockade i år 48 studenter från tio länder. För femte året arrangerades kursen av Linnéuniversitetet och KTH, Kungliga Tekniska högskolan, i samarbete med SKB och Nova. Under två veckor har studenterna bland annat haft föreläsningar av olika experter, besökt SKB:s alla anläggningar och bedrivit fältstudier på Äspö och i Laxemar.

– Det är ganska unikt att vi är så öppna med att visa kärnbränslecykeln så här och kan besöka SKB:s alla anläggningar, säger Christine Ström, kommunikationskoordinator på Nova.

En av studenterna är polska Edyta Wyszkowska som har arbetat på CERN, världens största partikelfysiklaboratorium.

– Kursen har varit intensiv men väldigt lärorik och spännande, säger Edyta Wyszkowska.

Kursen lockar inte bara studenter från hela världen utan också professorer och experter i ämnet.

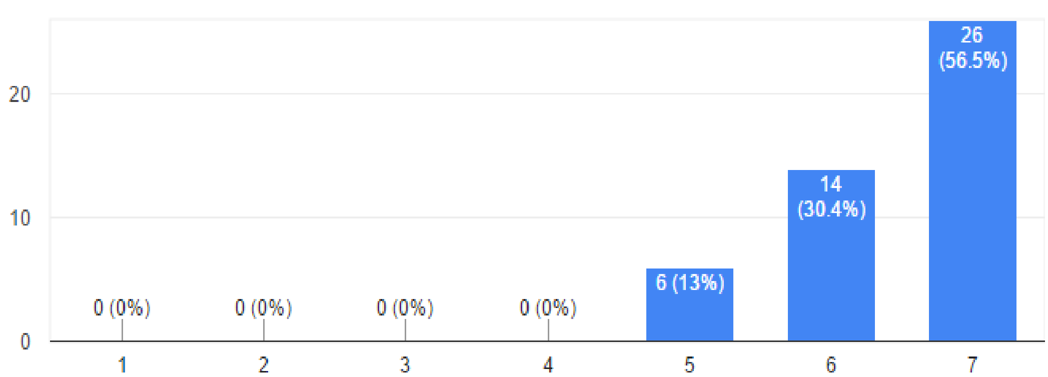
– Det är fantastiskt hur man kan samla så mycket kunskap på ett och samma ställe, säger Christine Ström.

ANNA LYGNEBRANDT
0491-575 00

The Summer Course has been well evaluated by the students (7 is the highest grade):

1. How do you evaluate the concept of the course?

46 responses



Development of the course : Leadership for Safety in the Nuclear Energy Industry (Code SH2610, 6 ECTS)

This course is a very good example of KTH's cooperation with industrial/external partners.

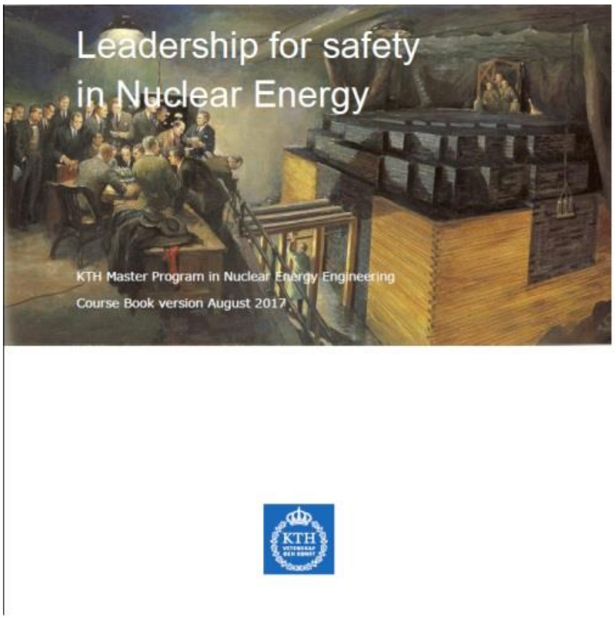
Lectures, coordinated by prof. Waclaw Gudowski are given by:

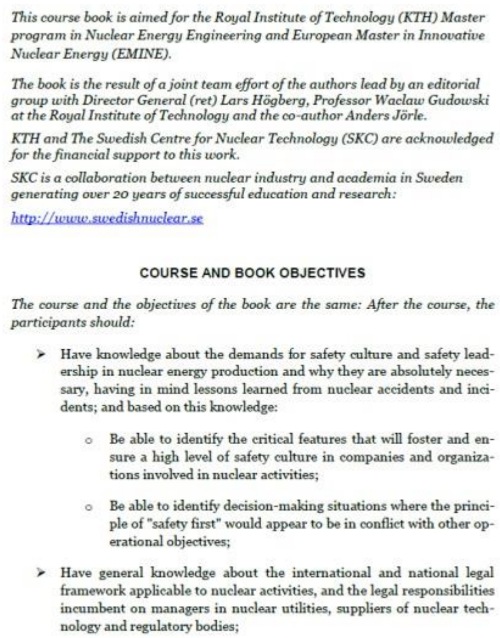
1. Lars Högberg, former Director General of the Swedish Nuclear Power Inspectorate (SKI)
2. Lennart Karlsson, senior advisor at **Swedish Radiation Safety Authority (**SSM)
3. Kerstin Dahlgren, senior safety expert at **Vattenfall**
4. Lars Axelsson, (SSM), senior expert in nuclear and airline safety.
5. Anders Jörle, vice president **Public Affairs of Swedish Space Corporation**, former director of information at SKI and media spokesperson at the Swedish Ministry of Foreign Affairs.
6. Lars Gunnar Larsson, senior expert in nuclear power, former Deputy Director General of SKI, former nuclear power expert in the European Bank for Reconstruction and Development.
7. Per Lindell, former CEO E.ON Nuclear Sweden, former chairman of **E.ON Nuclear Safety Council**.
8. Judith Melin, former Director General of the Swedish Nuclear Power Inspectorate (**SKI**) and of the Swedish Coastal Guard; member of E.ON Nuclear Safety Council
9. Tord Sterner, formerly ASEA-ATOM
10. Leif Öst, former CEO, **Barsebäck Kraft AB**

This course was put fully at the **TE3** platform and can be e easily viewed at the following link:

https://mediasite.neutron.kth.se/Mediasite/Catalog/catalogs/mediasiteadmin-sh2610-ht17

In 2017 an update of the course book : Leadership for safety in Nuclear Energy has been published. Financial support from SKC has been respectfully acknowledged: *KTH and The Swedish Centre for Nuclear Technology (SKC) are acknowledged for the financial support to this work* .





This course book is aimed for the Royal Institute of Technology (KTH) Master program in Nuclear Energy Engineering and European Master in Innovative Nuclear Energy (EMINE).

The book is the result of a joint team effort of the authors lead by an editorial group with Director General (ret) Lars Högberg, Professor Waclaw Gudowski at the Royal Institute of Technology and the co-author Anders Jörle.

KTH and The Swedish Centre for Nuclear Technology (SKC) are acknowledged for the financial support to this work.

SKC is a collaboration between nuclear industry and academia in Sweden generating over 20 years of successful education and research:

http://www.swedishnuclear.se

COURSE AND BOOK OBJECTIVES

The course and the objectives of the book are the same: After the course, the participants should:

- Have knowledge about the demands for safety culture and safety leadership in nuclear energy production and why they are absolutely necessary, having in mind lessons learned from nuclear accidents and incidents; and based on this knowledge:
  - Be able to identify the critical features that will foster and ensure a high level of safety culture in companies and organizations involved in nuclear activities;
  - Be able to identify decision-making situations where the principle of "safety first" would appear to be in conflict with other operational objectives;
- Have general knowledge about the international and national legal framework applicable to nuclear activities, and the legal responsibilities incumbent on managers in nuclear utilities, suppliers of nuclear technology and regulatory bodies;

Fig. 12. The cover of the text book: Leadership for safety in Nuclear Energy

In May-June 2017 a poll has been done assessing gender related problems in our nuclear engineering education. This poll was done more than 4 months **before the famous "#metoo"** international initiative putting gender problems in society in focus. Target of the poll were students and alumni of the KTH Master Program in Nuclear Energy Engineering and the European Master in Nuclear Energy (EMINE). Number of persons answering the poll was 25 females and 42 males.

Students and Alumni of nuclear faculties answered the following questions:

Questions

No.	Question	Answer options
1	Did you have any contact with nuclear engineering before you choose this career?	No, Some, Yes
2	Do you feel you were sufficiently informed about the nuclear engineering field before choosing this studies?	No, Moderately, Yes
3	Did you have enough information on the possible jobs and career development before you made your nuclear engineering choice?	No, Moderately, Yes
4	Do you find nuclear engineering field being gender neutral?	1 to 10 1 – not at all, 10 - neutral
5	Did/do you face any embarrassing or undesirable gender related issues during your professional career?	1 to 10 1 – frequently, 10 - never
6	Can you give any examples of embarrassing or undesirable gender related issues during your studies?	No, Few, Yes
7	Were the courses conducted in a way that makes it interesting for you?	1 to 10
8	How well integrated do you feel regarding your classmates?	1 to 10 1 – not at all, 10 – very integrated
9	How implicated were you in the group projects you had to do with your teammates?	1 to 10 1 – not at all, 10 – very implicated
10	What were the main reasons to choose Nuclear Engineering career?	Descriptive

11	How could the overall communication be improved, according to you?	Descriptive
12	What are, according to you, the strengths of the nuclear engineering master program?	Descriptive
13	What are, according to you, the weaknesses of the nuclear engineering master?	Descriptive
14	Are there some courses that you expected but they were not offered in the nuclear engineering master program?	Descriptive
15	How would you do to improve the course?	Descriptive
16	What was your general feeling regarding the group dynamics in your professional field? (individual involvement, communication, team members listening to each other's ideas, ...)	Descriptive

The conclusions from this poll were very satisfactory and can help us to develop the program in a way meeting expectations of the students:

1. Nuclear education at KTH and within EMINE is considered to be really gender neutral without any particular burning problem
2. Well promoted job opportunities, in particular for women, will make this program much more attractive for women and more balanced!
3. Official mentor program could/should be introduced. Also, more aggressive social media appearance could be helpful.
4. **Government should support such programs**
5. We have lots of career fair but most of the times, nobody wants nuclear people. **So nuclear engineer career fair maybe.**
6. Bring in more experts from Regulatory agencies and also from nuclear power plant.
7. Promote more active participation.

Summary

A very successful year 2017 for TNEEM program development at KTH:

- Fantastic dynamics of applicants and enrolled students to nuclear engineering program at KTH. The highest number of enrolled TNEEM master students ever
- Technology Empowered Engineering Education project development: many courses on TE^3 platform
- Two course books updated and published with a strong support of SKC and industrial partners
- EMINE program got the highest grade in the EIT evaluation of the European Master Programs

Master Theses

The following Master Theses have been completed during 2017:

Student	Title	Reference	Examiner
Turquais Benjamin	Influence of the steel properties on the progression of a severe accident in a nuclear reactor	Trita: 2017;57	Waclaw Gudowski
Berger Jonas	Impact of fuel assembly bowing on the power density distribution and its monitoring in Siemens/KWU-PWR	Trita: 2017;60	Henryk anglart
Gerard Castaing Nicolas	Review of a calculation chain combining APOLLO2 and CRONOS2	Trita: 2017;27	Henryk Anglart
Kovács István Soma	Simplified Simulator for BWR Instabilities	Trita: 2017;41	Henryk Anglart
Nanopoulos Dionysios	Mechanistic modelling of swelling in the accident tolerant fuel candidate U3Si2	Trita: 2017;75	Pär Olsson

Reported number of theses from Nuclear Engineering and Solid Mechanics

Number of Master theses: 24
Number of Bachelor theses: 9
Licentiate exams: 3
Ph.D. exams: 8

Research Project funding and outcome during 2017

Note, that research carried out within the MÅBiL-collaboration is presented in Appendix 4 below.

Experimental analysis of thermal mixing at reactor conditions

- Ph.D. student: Mattia Bergagio
- Supervisor: Prof. Henryk Anglart

Funds spending

The project has been supported by SKC with 500 kkr during 2017. The funds were used for partial covering of the salary cost of the PhD student.

Activities within the project under 2017

The focus of the research during 2017 was on the development of a numerical method to solve inverse transient heat conduction problem with special attention to transients relevant to thermal fatigue applications. Such transients are characterized by modes with frequencies in a range from 0.1 to 10 Hz resulting from mixing of a cold laminar water stream with a hot turbulent water stream, as it occurs in guide tubes of BWR control rods. In present study period a robust algoritm for solving boundary inverse heat conduction problems (IHTP) has been implemented. The algorithm allows estimation of transient temperature over the entire domain by exploiting redundant measurements from accessible boundaries. The considered problems are transient and nonlinear, given that some of the material properties might be temperature-dependent. The difficulty with IHTP approaches is that in general they are ill-posed and very sensitive to errors, originating from either input (typically measured) data and rounding. The advantage of IHTP is that the temperature field, both stationary and transient, can be obtained even when the conditions on certain boundaries are not known. The figure below demonstrates a capability of the present algorithm to predict the temperature distribution on outer surface of a cylinder as a forward problem (left) and as an inverse problem (right). It can be seen that the algorithm correctly reproduce the spatial and temporal characterisitcs of the temperature field. Future work during 2018 includes finishing of two journal papers and writing of the dissertation.

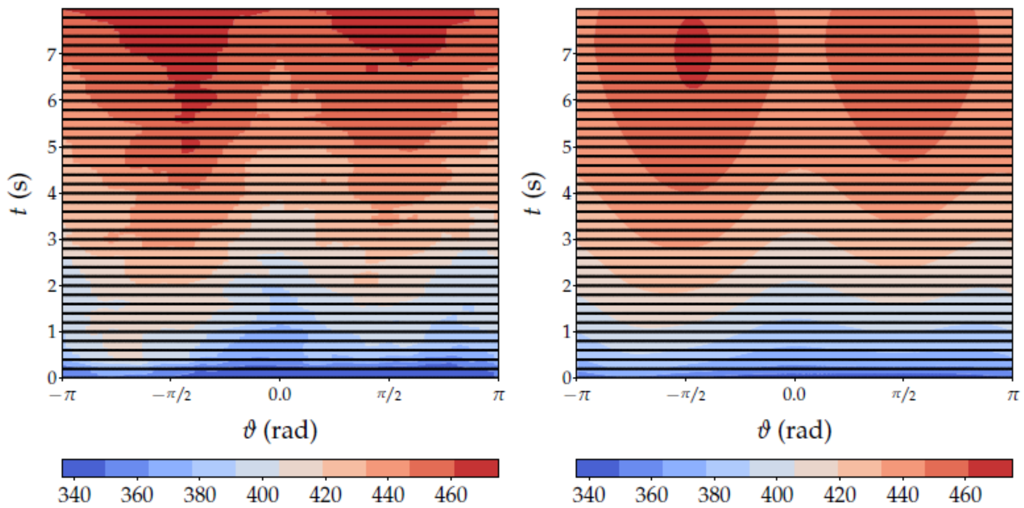


Fig. 13. Temperature distribution on a cylinder surface found as a forward (left) and an inverse heat conduction problem (right)

Department of Solid Mechanics at KTH

Solid Mechanics is a classic discipline within engineering sciences, ranging from basic to applied science. The subject can be regarded as a link between material science and applied mechanics with emphasis on the latter. Solid Mechanics deals with the mechanical properties of materials and structures. Research at the department is focused on computational mechanics, fracture mechanics, composite mechanics, contact mechanics, material mechanics, paper mechanics and fatigue. A primary goal of the research is to develop methods fr reliable design of structures, materials, systems and processes.

The education in solid mechanics consists of basic courses in strength of materials and solid mechanics, elasticity and FEM, and advanced courses in more specialized areas such as, for example, material mechanics, fracture and fatigue, testing techniques, biomechanics, paper mechanics and dynamic problems in solid mechanics. There is a close interaction between research and teaching on all levels. New developments in solid mechanics are reflected in a continuous updating of the content of the courses.

Presently the department has 8 full professors, 2 associate professors and 1 adjunct professor. Furthermore, there are 2 researcher, 3 post-doctors and approximately 16 PhD students in the PhD-programme in Solid Mechanics. The department has a well-equipped laboratory and a work shop with two engineers and two technicians.

Fixed funding

The department recieves no fixed funding from SKC. All activities are funded from research projects, commission or educations.

Personnel active in operations in the SKC area

- Adjunct professor Pål Efsing (Adjunct from Vattenfall AB)
- Professor Bo Alfredsson
- Professor Jonas Faleskog (member in SSM's research council)
- Dr Carl Dahlberg
- Mr Martin Öberg Head of Laboratory
- Dr Irene Linares Arregui Laboratory Engineer
- Michal Sedlak (70% SKC) PhD student in Mechanical modelling of intergranular stress corrosion in stainless steel
- Magnus Boåsen (25% SKC) PhD student in Radiation effects on material mechanical properties of low alloyed reactor pressure vessel steel
- André Tengstrand (20% SKC 20% SSM) Failure risk (crack propagation) due to aging of NPP components from thermal and mechanical loads
- Martin Bjurman (100% Studsvik) Industrial PhD student in Thermal ageing of cast and welded austenitic structures with ferrite

Research Project funding and outcome during 2017

Mechanical modelling of intergranular stress corrosion in stainless steel

- Ph.D. student: Michal Sedlak
- Supervisor: Bo Alfredsson, Pål Efsing

Funds spending

Michal Sedlak 80% and Bo Alfredsson 10% of respective time in the project. Total cost of salary was 855 000 SEK. Budget funding was 600 kSEK from SKC and 255 SEK from KTH in-kind. No deviation from budget.

Activities within the project under 2017

The FEM model of the IG-SCC was completed in 2015. In 2016, the model has been adapted to the material data for ductile and brittle fracture. Numerical reference results have been developed for the cohesive element. In 2017 the model was adapted to a hydrogen embrittlement experiment. The fracture mechanics simulation techniques have been described in the first manuscript which is submitted for publication in an international scientific journal.

Work on paper two continues. This paper will deal with the coupled processes of diffusion, corrosion, degradation of fracture mechanical properties and fracture. Work for experimental verification of the model continues with accelerated IG-SCC testing.

Milestones achieved during the period. The coupled and modular numerical model for IG-SCC was finalized. An IG-SCC experiment was successful. The model was adapted to an hydrogen embrittlement experiment taken from the literature.

Failure risk (crack propagation) due to aging of NPP components from thermal and mechanical load

- Ph.D. student: André Tengstrand
- Supervisor: Bo Alfredsson, Pål Efsing, Henryk Anglart

Funds spending

André Tengstrand 40% and Bo Alfredsson 5% of respective annual time in the project. Total cost of salary was 288 000 SEK. Budget funding was 200 kSEK from SSM and 88 SEK from KTH in-kind. No deviation from budget.

Activities within the project under 2017

The project started in August 2017 with hireing of André Tengstrand as PhD student. The project started with definition of pilot case, the control rods at Forsmark/Oskarshamn. During 2017 some preliminary mechanical tests of material properties were performed. CFD data were attained from the second part of the project, from PhD student Mattia Bergagio at Nuclear Reactor Technology.

The project is coupling with Nuclear Reactor Technology where CFD computations are made. These will serve as load for the fracture mechanics and fatigue investigation.

Influence of secondary/residual stresses on risc of developing environmentally induced degration in Alloy 690 in high temperature water

- Ph.D. student: Rickard Shen
- Supervisor: Pål Efsing, Jonas Faleskog

Activities within the project under 2017

Rickard successfully defended his thesis "On the low primary water stress corrosion cracking susxeptibility of deformed Alloy 690" on March 29th at KTH. From the work, currently 4 papers have been accepted for publication in the open literature and 2 more are pending finallization.

Influence of thermal and irradiation induced ageing in Low Alloy Steels

- Ph.D. student: Magnus Boåsen
- Supervisor: Pål Efsing, Jonas Faleskog

Funds spending

Cost of salaries: Covered by funding from SSM and NKS. No deviation from the budget. Supervision by Efsing was funded by agreement between KTH and Ringhals AB.

Activities within the project under 2017

Magnus has participated in the development of specifications for material extraction from the reactor pressure vessel at Barsebäck 2. The report has been distributed via NKS.

Magnus has been part of further publications published as a collaboration between CTH (Lindgren/Thuvander) and KTH (Boåasen/Efsing) regarding mechanical and microstructural properties of thermally and irradiation aged materials.

Milestones achieved during the period: Analysis of the material requirement for the implementation of fracture mechanics assessment of reactor pressure vessel at Barsebäck 2.

Appendix 3 - Uppsala University

UPPSALA UNIVERSITET

SKC relevant research and education within the Division of Applied Nuclear Physics, Division of Materials Theory and Division of Materials Physics

Preface

The Division of applied nuclear physics together with the Divisions of materials theory and materials physics comprises research and education within a broad range of applications. Among these applications, the safe operation of nuclear power constitutes an important part of our efforts to fulfil the three duties of a Swedish university; education, research and cooperation with the society at large, i.e. the "third task". Obviously this part of our activities is also of direct relevance for SKC and in this annual report we present an overview of the most important features of the year 2017.

The political agreement, "Energiuppgörelsen", regarding the future electricity supply in Sweden has created a refreshing effect on the ongoing activities within the field at large. For example, the phase-out of the nuclear power tax will create a more robust financial situation for the industry, which is beneficial in several aspects. Furthermore, the realisation that nuclear power will continue to be a vital part of the Swedish electricity supply has opened up a political dialogue regarding the all-important competence supply and the prerequisites for capacity building within the field.

The various actors on the scene: SSM, Vetenskapsrådet, the academy, the industry and the political sphere are all interwoven in a network that needs to be harmonised as regards measures and means in order to address the foreseeable challenges. Steps have recently been taken in that direction through the governmental initiative to: 1) map the future national competence needs within the nuclear field and 2) identify the actions needed to create national capacity building. Together with other universities, industry and stakeholders in general, Uppsala University participate in this initiative operated by the SSM through its reference groups created in support to the process. In this context it is also appropriate to mention the most welcomed outreach adopted by the industry. This undertaking is of utmost importance in order to increase attractiveness and show young people that there is indeed a future within the nuclear industry, which, in turn, may increase the interest for studies in nuclear subjects from Swedish students.

During the SSM reference group meetings, Uppsala University has pointed out the inadequate governmental funding of nuclear research and education within the academy as a particular issue. It is fair to say that the nuclear industry for a long time has taken responsibility beyond its core to secure, on some level, academic research and education. However, to be able to further secure research and, in particular, nuclear education, it is now time for a national undertaking where e.g. SSM, Vetenskapsrådet and Energimyndigheten are authorised to canalize adequate funding to the academy.

Now, there is a need for not only project funding but also basic funding. There is, however, no viable way of canalising such basic funding directly to researchers that in the same time coheres with the authorities' regulations. One way of solving this issue is to create some sort of hub that receives funding and eventually canalise this funding to researchers. Currently SKC holds such a function through its industrial funding but, as it has turned out; governmental bodies hesitate to provide funding to research centres in which the influence from the nuclear industry is strong. To that end, the Swedish Academic Initiative in Nuclear Technology, SAINT, was created as a legal, solely academic, collaboration platform within radiation sciences, including nuclear technology. SAINT is currently operated by Uppsala University and Chalmers but is open to any university interested. It is here appropriate to emphasise that SAINT is by no means to be considered as a competitor to SKC but rather as a complement in an attempt to make more funding to the academy available, which would be beneficial for all parties.

As in previous years, the role of nuclear power in the Swedish society and its capability to produce large amount of almost CO2-free electricity has been the focus of our outreach also during 2017. This outreach has been manifested by discussions with the political sphere, participation in Almedalsveckan, posts in social media, addressing students in various occasions, work in several referral groups and through the work being done in Analysgruppen. These activities are all part of our extensive work within the third task

Finally, it is with great satisfaction we conclude that our join efforts to impel the political sphere to resurrect the proposition from 2008, where research funding for new nuclear technology was made available, were successful. Discussions with the Ministry of Education and Research and with the Swedish Research Council regarding the abovementioned proposition resulted in a call from Vetenskapsrådet in August that regarded Gen IV research. From this call, Uppsala University received two establishing grants, one individual project grant and one joint project grant together with materials researchers at Chalmers and KTH. Although the total annual amount of money available within this initiative is relatively small in the light of the importance of nuclear power in Sweden (15 million SEK / year), it still constitutes a valuable contribution to the Swedish nuclear community.

With these introductory words, we hereby submit the Annual Report from Uppsala University for the year 2017.

Education

Uppsala University continues its efforts within teaching and education with the objective of providing high quality education for the need of Swedish society in general and the nuclear industry in particular. During 2017 the Division of applied nuclear physics' staff have been responsible for managing three education programmes. These are:

- The Master Programme in Energy Systems Engineering, Civilingenjörsprogrammet i energisystem, ES), which one of the large master of science in engineering programmes at Uppsala University,
- The Bachelor Programme in Physics, (Kandidatprogramme i fysik),
- The Bachelor Programme in Nuclear Engineering, (Högskoleingenjörsprogrammet i kärnkraftteknik, KKI).

Ass. Prof. Henrik Sjöstrand, Ass. Prof. Matthias Weiszflog and Ass. Prof. Michael Österlund, respectively, are coordinators for the three educational programmes. Cecilia Gustavsson, who is a senior lecturer with applied nuclear physics, is one of two directors of undergraduate studies within the Department of Physics and astronomy.

In addition to courses within the programmes mentioned above, division staff provides nuclear energy relevant courses, i.e., nuclear technology, energy physics and technical thermodynamics, within the framework of other Uppsala University engineering programmes.

The Nuclear Power Track

The Master of Energy Systems (ES) Engineering programme offers a nuclear engineering track where students are given the opportunity to develop their skills and abilities in a relevant context. The package focuses on physics, modelling, and simulation. The ES programme also contains an introduction to nuclear technology for all students of the program.

Courses included in the nuclear engineering track:

- Modern Physics 5 credits, level = basic.
  Provides basic nuclear physics
- Nuclear Power Technology and Systems, 10 ECTS credits, level = advanced.
  A course that gives the students a good overview of the nuclear energy system and the methods used from the reactor to the final repository.
- Future nuclear energy systems - analyses and simulations 5 credits, level = advanced.
  Focus on Gen IV and reactor modelling and simulation using Monte Carlo codes.
- Applied reactor physics 5 credits, level = advanced.
  The course is given together with Vattenfall Fuel. This course specialises in industry-relevant issues such as enrichment optimization from an economic perspective.
- Empirical Modelling 10 credits, level = advanced.
  In this course, the students get acquaintance with reactor stability margins, etc., using actual measurement data.
- Safety analyses in the energy sector 5 credits, level = advanced.
- Probabilistic and Deterministic Safety Analysis.

More information is available on the Uppsala University web[1].

The track generates students who are well prepared to perform their master thesis in nuclear engineering work, and master theses are conducted annually. Since Fukushima, the number of applicants for the track has declined, but in 2017 this trend was broken with an increasing number of participants. The support from SKC is crucial for offering this wide track to our students. The programme Manager for the Energy Systems programme is Henrik Sjöstrand, and the track manager for the nuclear power track is Carl Hellesen, both active at the Department of Applied Nuclear Physics.

Courses provided by applied nuclear physics for the Engineering Master Programmes

Within the Engineering and Physics Master Programmes, the following courses with relevance for nuclear power are given by the division's personnel:

- Introduktion till kärnfysik och dess tillämpningar
  - Kandidatprogram fysik
  - 5 hp, grundnivå, 9 studenter

- Energifysik I
  - Teknisk fysik, kandidatprogram fysik, masterprogram fysik
  - 5 hp, grundnivå, 45 studenter

- Energifysik II med kärnkraft
  - Teknisk fysik, masterprogram fysik
  - 10 hp, avancerad nivå, 9 studenter

[1] http://www.teknat.uu.se/student/program-och-kurser/energisystem/kurser/kurspaket/

- Öppen fördjupningskurs i tillämpad fysik
  - Teknisk fysik
  - 5 hp, avancerad nivå, 1 student med fördjupning mot kärnkraft

- Kärnkraft – teknik och system
  - Energisystem
  - 10 hp, avancerad nivå, 8 studenter
- Framtida nukleära energisystem
  - Energisystem, KKI
  - 5 hp, avancerad nivå, 6 studenter

- Säkerhetsanalyser inom energisektorn
  - Energisystem
  - 5 hp, avancerad nivå, 5 studenter

- Energisystemfysik
  - STS
  - 10 hp, grundnivå, 28 studenter

- Tillämpad reaktorfysik
  - Fristående kurs
  - 5 hp, avancerad nivå, 11 studenter

- Introduktion till kärnkraft
  - Fristående kurs
  - 5 hp, grundnivå, 2 studenter

- Kärnkraftdrift
  - Fristående kurs
  - 5 hp, grundnivå, 2 studenter

In 2017, in total 126 students followed at least one course in which nuclear technology was presented and examined.

Bachelor of Science in engineering with a specialisation in nuclear engineering

The Bachelor's programme, which is described in detail in the 2016 SKC-report, grinded to a temporary halt after the spring semester 2017 with only one student active within the program.
This very unfortunate situation is a consequence of the dwindling interest from Swedish engineering students on the Bachelors' level for nuclear technology education. Most likely, this is a result of the political uncertainties concerning the long-term role of nuclear power in the Swedish energy system and the decision by industry to shut down the reactors with no new build in sight. During the last year, the situation was aggravated by signals from the industry indicating a low demand for new staff and in some instances, staff reductions. Since the demand for engineers on the Bachelors' level within other industrial sectors remains very high, the outcome is not surprising. Consequently, after discussions with the stakeholders, the Uppsala University's Faculty of Science and Technology has decided to put the programme on hold with a possibility of re-starting the programme in the autumn of 2019. In late 2017, the situation with regard to the recruitment needs of staff for the NPPs appears to have changed quite suddenly and a steady, long-term demand for new engineers with nuclear competence is now foreseen within some parts of the industry.

In order to enable a successful restart of the programme in 2019, industry must promote student interest for a career within the nuclear energy sector. Discussions between stakeholders in industry and Uppsala University about initiatives and concerted actions in order to achieve such a change of mind with students have been initiated.

Contract education for the industry

Contract education continues to be a focus area and during 2017 these activities has continued with courses being provided both in Uppsala and on-site at nuclear power plants. Ass. Prof. Michael Österlund remains director of studies for nuclear contract education.

The objective of the contract education activities, which commenced in 2003, is to ensure the continued education and competence building of existing and newly recruited personnel within the nuclear industry. A new long-term agreement with OKG is negotiated in addition to the already existing agreements with FKA/RAB. The agreements provide the power plants access to various courses provided by Uppsala University on a demand basis while ensuring Uppsala University the possibility of maintaining teaching staff for the contract education courses. Our teachers, active within contract education, also participate in research within the Division of applied nuclear physics. The collaboration with KSU AB concerning teaching materials and simulator training for course participants will continue in the same way as before.

NANSS (Nordic Academy for Nuclear Safety and Security), a Uppsala University competence centre managed by the Division of applied nuclear physics, has evolved into the natural contact point between industry and Uppsala University for contract education. NANSS handles the administrative aspects of the contract education, provide information about available courses and handles course admissions. A web portal has been developed for these purposes, http://www.nanss.uu.se.

During 2017 the Uppsala University provided industry with 15 weeks of contract education courses (Table 2) within the agreements on higher education. In some instances where the majority of course participants were from the same power plant, courses were given on-site.

By request from RAB, a variant of the one week reactor physics course for turbine and reactor operators under training was developed for already existing reactor operators and shift managers at RAB. The course was given on two occasions including participants from all four Ringhals reactors with very good course reviews from the participants.

Course	Credits / duration
Kärnkraftteknologi (H1)	12 hp
Tillämpad reaktorfysik	5 hp
Fördjupad strålskyddsutbildning (FS1)	6 hp
Fördjupad strålskyddsutbildning, repetition (FS2)	1 w
Aktivitetsmätning m. Ge-detektorer	1 w
Värme- och strömningslära (operatörsutbildning RAB)	2 w
Reaktorfysik (blivande operatörer), RAB)	1 w
Reaktorfysik, bränsleskador och svåra haverier (befintliga operatörer, skiftchefer, RAB 1-4)	4 d

Fig. 17. Contract education courses provided on one or more occasions during 2017.

Development of teaching education in the nuclear field

E-learning development (SKC-funded project)

Presently Uppsala University, in common with many other universities world-wide, are introducing e-learning techniques in courses and education programmes. Pedagogic/didactic research has shown that student learning may be encouraged and enhanced by the proper use of different e-learning techniques in teaching, i.e., the flipped classroom etcetera. E-learning techniques are used mainly for two purposes; as one of one of several tools in on-campus education (blended learning) and for web based, off-campus distance education.

From 2017 onwards, Chalmers and Uppsala University collaborate in a SKC funded e-learning project with the objective of introducing e-learning techniques in new or existing courses provided by the universities in concert or individually. During 2017 we have commenced a collaborative development of a new introductory course on nuclear technology for non-nuclear engineering students at Swedish universities. The principal objective is to create interest for the subject and encourage students to consider taking more advanced courses and also for them to consider a career within “nuclear”. The course will make extensive use of e-learning techniques and will be made available as an off-campus distance course for students at any Swedish university. Another consideration is that the sub-modules of the course material should eventually be made available to teachers at other universities who wish to incorporate one or more modules into their own course curriculums.

Locally at Uppsala University, during 2017 a team of teachers within the Division of applied nuclear physics have developed the KKI course “Introduktion till kärnkraft”, 5hp into an e-learning course where many of the flipped classroom concepts have been introduced. This was done in order for the teachers to learn how to use e-learning tools effectively, how to produce study materials (primarily videos) for e-learning, and to evaluate the effectiveness of the e-learning techniques. During the autumn semester 2017, the course was given as an on-campus pilot for a limited number of students with previous experience of e-learning in distance education. The outcome is very encouraging both from the student’s and teacher’s perspectives. The students very much appreciated the content of the recorded videos and the follow up lessons that to a large extent replaced traditional lectures. The teachers appreciated the fact that students were well prepared for the lessons where many stimulating student initiated questions and discussions took place. The lessons learned from this pilot course will be incorporated in the Chalmers-Uppsala University course under development

Advanced Networking for Nuclear Education, Training and Transfer of Expertise (ANNETTE)

Uppsala University is one of about 25 organizations, and the only Swedish university to be involved in the EU project ANNETTE. The project ultimately aims at developing an “Advanced Master” training programme for professionals in the nuclear business by developing a set of courses available professionals in Europe as contract education. The project is coordinated by the European Nuclear Education Network (ENEN), and will run during 2016-2019. During 2017 and 2018 Uppsala University is developing two courses within the scope of the project; Safeguards and Human-Technology-Organisation and Human Factors for Nuclear Safety. In addition to collaborations with other partners in the ANNETTE projects, ESARDA and IFE-Halden respectively, are involved in the course development. The courses will be provided for the first time during the study year 2018/2019, for professionals within the European nuclear energy sector.

Student's theses during the study year 2016/2017 (Civilingenjörer)

- Anna Franzén
  - "R3/4 knippesböjning: Evaluation of Fuel Assembly Bow Penalty Peaking Factors for Ringhals 3 - Based on a Cycle Specific Core Water Gap Distribution"
  - Energisystem, examensarbete, 30 hp
  - Prof. Klaes-Håkan Bejmer (handledare)
  - Dr. Peter Andersson (ämnesgranskare)
  - Avslutat: 2017-06-30

- Hanna Lundgren
  - "Compaction of Lattice Data: Improved Efficiency in Nuclear Core Calculation"
  - Energisystem, examensarbete, 30 hp
  - Sten-Örjan Lindahl, Westinghouse (handledare)
  - Ass. Prof. Henrik Sjöstrand (ämnesgranskare)
  - Avslutat: 2017-10-15

- Marcus Westlund
  - "Bowing effects of nuclear power fuel assemblies"
  - Teknisk fysik, examensarbete, 30 hp
  - PSI (handledare)
  - Ass. Prof. Henrik Sjöstrand (ämnesgranskare)
  - Pågående

- Mattias Åkerman
  - "Förbättrade effektmarginaler med radiell anrikningsfördelning för PWR-bränsle"
  - Energisystem, examensarbete, 30 hp
  - Prof. Klaes-Håkan Bejmer (handledare)
  - Dr. Augusto Hernandez Solis (ämnesgranskare)
  - Avslutat: 2017-06-15
  - http://uu.diva-portal.org/smash/get/diva2:937339/FULLTEXT01.pdf

- My Löfberg
  - "Visualisering av värmestrålning med hjälp av värmekamera"
  - Kandidatprogram i fysik, examensarbete, 15 hp
  - Ass. Prof. Matthias Weiszflog (handledare)
  - Ass. Prof. Cecilia Gustavsson (ämnesgranskare)
  - Avslutat: 2017-07-06
  - http://uu.diva-portal.org/smash/get/diva2:1118109/FULLTEXT01.pdf

- Sophie Thorell
  - "Att med värmekamerans hjälp se det osynliga"
  - Kandidatprogram i fysik, examensarbete, 15 hp
  - Ass. Prof. Matthias Weiszflog (handledare)
  - Ass. Prof. Cecilia Gustavsson (ämnesgranskare)
  - Avslutat: 2017-07-06
  - http://uu.diva-portal.org/smash/get/diva2:1119340/FULLTEXT01.pdf

- Emilie Dul

  - "Monte Carlo simulation of the spatial response function of a SPECT measurement device for nuclear fuel bundles"
  - Medicinsk fysik (Stockholm universitet), examensarbete, 13,5 hp
  - Dr. Peter Jansson, Ass. Prof. Staffan Jacobsson Svärd (handledare)
  - SU (ämnesgranskare)
  - Avslutat: 2017-08

- Dany Gabro
  - "Virtual Studies of Nuclear Fission: A comparison of n- and p- induced fission using GEF"
  - Teknisk fysik, kandidatarbete, 15 hp
  - Dr. Ali Al-Adili, Vasileios Rakopoulos (handledare)
  - Changqing Ruan (ämnesgranskare)
  - Avslutat: 2017-06-14
  - http://uu.diva-portal.org/smash/record.jsf?pid=diva2%3A1108293&dswid=-5967

- Gjertrud Langaas
  - "Measurements of radioactivity in plant and soil samples taken near a nuclear power plant"
  - Teknisk fysik, kandidatarbete, 15 hp
  - Prof. Johan Nyberg, Dr. Mattias Lantz (handledare)
  - Martin Sjödin, SU (ämnesgranskare)
  - Avslutat: 2016-06-10
  - http://www.diva-portal.org/smash/get/diva2:937722/FULLTEXT01.pdf

- Carl Eriksson
  - "Osäkerhetsanalys av PSA-resultat - Metodutveckling och parameterinventering för osäkerhetsanalys av PSA-resultat gällande härdskadefrekvens"
  - Energisystem, examensarbete, 30 hp
  - Lloyd's Register (handledare)
  - Dr. Mattias Lantz (ämnesgranskare)
  - Avslutat: 2017-10

- Carl Utterström
  - "Characterization and verification of a Safecast dosimeter"
  - Teknisk fysik, kandidatarbete, 15 hp
  - Dr. Mattias Lantz (handledare)
  - Teknikvetenskaper (ämnesgranskare)
  - Påbörjat 2017-04-07

Ph.D. theses

Vasudha Verma.; "Development of a Neutron Flux Monitoring System for Sodium-cooled Fast Reactors"; Publisher: Acta Universitatis Upsaliensis; ISBN: 978-91-554-9897-9; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-319945; (2017)
Mattera A.; "Studying neutron-induced fission at IGISOL-4 : From neutron source to yield measurements and model comparisons"; Publisher: Acta Universitatis Upsaliensis; ISBN: 978-91-513-0052-8; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-328484; (2017)

Kaj Jansson.; "Measurements of Neutron-induced Nuclear Reactions for More Precise Standard Cross Sections and Correlated Fission Properties"; Publisher: Acta Universitatis Upsaliensis; ISBN: 978-91-513-0085-6; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-329953; (2017)

Research projects

The research projects from Uppsala University within MÅBiL are presented in Appendix 4 below. In addition, a number of projects of high relevance for reactor operation and nuclear fuel performance have been carried out within the division during 2017, funded from other sources than SKC. A short account of some major research projects are described below.

Studies of independent yields from fast neutron-induced fission

Ph.D. student: **Andrea Mattera**
Main Supervisor: Prof. Stephan Pomp
Assistant Supervisor: Dr. Mattias Lantz, Dr. Andreas Solders

Andrea Mattera started working on the AlFONS project in the spring, 2011. 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. To this end, a Be(p,xn)-converter has been developed together with a dedicated ion-guide for neutron induced fission. Mattera has been responsible for the design and characterization of the ion-guide in experiments at TSL (Uppsala) as well as on site in Jyväskylä.

In December 2016, the first measurements of neutron induced fission yields were carried out at IGISOL. The result has been analysed during 2017 and resulted in a publication by Mattera titled Production of Sn and Sb isotopes in high-energy neutron induced fission of natU that has been accepted to EPJA. Mattera has also made a systematic comparison of fission model codes and the first result was presented at the International Conference on Nuclear Data for Science and Technology in September 2016. In 2017, he has continued this work to include more codes in the comparison.

In October 2017 Mattera defended his doctoral thesis. In the thesis, the design and characterization of the neutron source for IGISOL is presented together with the experimental results and his work on the comparison of fission codes.

Studies of isomeric yield ratios in proton induced fission

Ph.D. student: **Vasileios Rakopoulos**
Main Supervisor: Dr. Mattias Lantz
Assistant Supervisor: Prof. Stephan Pomp, Dr. Andreas Solders

Vasileios Rakopoulos joined the division in spring 2012 to work on the AlFONS project together with Andrea Mattera. He has been involved in tests and characterization measurements of the converter and ion guide. Rakopoulos main focus has been on measurements of isomeric yield ratios (IYR), the production rate of an isomeric state relative to the ground state in fission, and the comparison of experimental data with theoretical calculations using TALYS and GEF.

In April 2016, Rakopoulos defended his licentiate thesis entitled Measurements of Isomeric Yield Ratios of Proton-Induced Fission of natU and natTh using data that had been acquired in experiments between 2010 and 2014, in proton induced fission of uranium and thorium. This data will also be published in a refereed journal.

In an experiment at IGISOL in January this year, Rakopoulos acquired data on more than 15 IYR in 25 MeV proton induced fission of uranium, most of which were measured for the first time. These data will, together with the ones described above, form the basis of Rakopoulos doctoral thesis to be defended in June 2018.

Multi variate analysis within nuclear safeguards

Post doc: **Li Caldeira Balkeståhl**
Other participants: Dr. Sophie Grape, Dr. Zsolt Elter

Within the Next Generation Safeguards Initiative Spent Fuel (NGSI-SF) project, several new non-destructive assay techniques have been developed. Some of the NGSI-SF aims are to verify initial enrichment (IE), burnup (BU) and cooling time (CT) of spent fuel assemblies (SFA) and to detect missing or replaced pins from SFA. One of the techniques studied is the differential die-away self-interrogation (DDSI), which is a passive neutron coincidence technique. A prototype DDSI detector has been built in Los Alamos National Laboratory and tested on fresh fuel, and measurements on spent fuel are planned for 2018.

The Uppsala project on multivariate analysis (MVA) techniques for nuclear safeguards has shown that multivariate regression on relative intensities of peaks from a HPGe spectrum can determine IE and BU for known CT. SFA with long cooling times become problematic since there are less gamma peaks available, and a natural extension of the project is to include other measurements to compensate for this. The next steps are to include neutron detection in both passive and active interrogation, and the DDSI signal is the first to be investigated. Another extension of the MVA project is to use MVA techniques to classify cases with missing pins.

My (Li Caldeira Balkeståhl) part in the project is to simulate the neutron detection. Since starting my postdoc in June, I have modelled the prototype DDSI detector in MCNP and performed simulation of the detector response to simulated spent fuel assemblies. The spent fuel assemblies are simulated with Serpent2 and include a large range of CT, BU and IE, as well as two scenarios of 30% replaced pins wit IE = 3.5%.

For the partial defects (missing pins) investigated so far, the classification using just the HPGe detector works so well that including the neutrons gives no improvement. We expect the neutron signal to play a role when include more scenarios with other geometries for pin replacement, or when including a wider range of IE, but this is still to be investigated.

For the IE, BU and CT determination, the inclusion of the neutron signal in the MVA analysis is still to be done. The DDSI response is taken as the early die-away time, the decay constant of an exponential fit to the histogram of neutron coincidence counts in time bins, performed for bins with time 4 to 52 µs. The early die-away time shows a strong correlation with BU and IE, but is almost constant with CT, which will hopefully be a good complement to the gamma signals.

Multi-variate analysis for Partial defect verification

Post doc: **Zsolt Elter**
Other participants: Dr. Sophie Grape, Dr. Li Caldeira Balkeståhl

The fuel pins made of UO2 in cladding are strong attenuators of gamma rays. Therefore, during passive gamma spectroscopy mainly the outer rods of the assembly are contributing to the signal. However the attenuation strongly depends on the energy of the gamma ray. Namely, in a passive gamma measurement setup consisting of a spent fuel assembly placed in a pool as source and a well-collimated gamma spectroscopy detector, low energy (around 600-700 keV) gamma rays can contribute to the detector signal only if they were emitted from the peripheral region of the assembly. However, higher energy gamma rays may reach the detector even when emitted from the central pins of the assembly.

Therefore, one expects that by replacing different parts of an assembly with non-radioactive, but strong attenuating materials, i.e. partial defect, one may observe a different change in the passive gamma spectra for lower and higher energy gamma peaks compared to the spectra of an unperturbed assembly with the same burn-up, initial enrichment and cooling time values. The goal of this project is to show with simulations whether the detection of such changes in the gamma spectrum due to partial defects is possible.

For the study, the passive gamma measurement station at the Swedish central interim storage facility for spent nuclear fuel (Clab) was considered. The MCNPX model of the station was created in order to simulate the gamma transport between a 17x17 PWR spent fuel assembly (i.e. the source) and a high purity Germanium detector. Since the geometry is heavily shielded and collimated several variance reduction methods were applied. Namely, the gamma spectrum is computed in two steps: first a point detector tally is used to determine the gamma flux at the detector region and then a separate simulation is carried out to compute the detector response due to the flux.

The source term (i.e. the concentration of the gamma-ray emitting isotopes) for the gamma transport computations was computed with the Serpent2 code for various burnup (20-50 Mwd/kgU), initial enrichment (1.5 - 4.5 %) and cooling time (1.5 - 40 years) parameters with standard operational histories. From the computed isotope inventory the concentration of 12 gamma-emitting isotopes were extracted, and the activity of their gamma lines was calculated. The final source term (with 35 energy lines) was set as the gamma source in the MCNPX computations.

In a preliminary work (submitted and accepted to the Physor2018 conference [1]), two simple partial defect scenarios were considered: in one case 80 steel dummy rods were interspersed within the assembly, and in the other 80 peripheral rods were substituted with steel dummies. It was shown that one can train a multivariate logistic regression model in order to classify the spectra of unknown assemblies (ie. test cases) as normal or partially defected.

Currently, as the continuation of the work, other partial defect scenarios are investigated, such as cases when 80 or less fuel rods are replaced randomly within the assembly. An experimental campaign is planned to verify whether such methods could be applied on measured data as well.

[1] Zs. Elter, L. Caldeira Balkeståhl, S. Grape, C. Hellesen: Partial defect identification in PWR spent fuel using Passive Gamma Spectroscopy, PHYSOR 2018, Cancun, Mexico, Been accepted

Studies of Cherenkov light emission and detection for nuclear safeguards purposes

Ph.D. student: **Erik Branger**
Main supervisor: Dr. Sophie Grape
Assistant supervisors: Ass. Prof. Staffan Jacobsson Svärd, Dr. Peter Jansson

Erik Branger is a Ph.D. student working with the nuclear safeguards instrument device called the Digital Cherenkov Viewing Device (DCVD). The purpose of the instrument is to verify spent nuclear fuel with respect to both gross defect and partial defect evaluation. Within the project, Erik's focus is on improving the abilities and performance of the instrument via improvements in prediction ability, measurement procedure and evaluation methodology.

During the last year Erik has been working on characterizing the detectable Cherenkov light emissions originating from fuel assemblies neighbouring the assembly being measured. This cross-talk, also called the near-neighbour effect, was characterized through simulations. The detectable contribution was quantified as a function of fuel assembly type, storage rack configuration, and distance between the assemblies in storage. A prediction model was developed to assess the magnitude of the near-neighbour effect in measurements, to compensate for this effect. Like the newly developed assembly intensity prediction model, this model requires a significant one-time computation to parameterize the near-neighbour effect for various assembly types and storage conditions, but once done the near-neighbour intensities can be predicted quickly, using only limited access to computer resources.

The IAEA has recently performed a DCVD measurement campaign on short-cooled PWR fuel assemblies, and the data was made available for this project. During the last year, Erik has been analysing this data set, applying the previously developed assembly intensity prediction model and near-neighbour prediction model to the data. The result includes a quantitative analysis of the performance of these models, showing a significant improvement over the old prediction model. Further work is however required to thoroughly quantify the accuracy of the near-neighbour prediction model, since the near-neighbour effect was relatively weak for this data set. The results of this analysis will be published shortly.

During the last year Erik has also been working on extending the simulation code package used to also include Cherenkov light transport to a detector position, and the formation of the resulting images. The aim of this work is to obtain the capability of simulating the resulting images of fuel assemblies with partial defects, where some of the rods have been replaced with non-radioactive ones. Initial results of simulated intact assemblies show good qualitative agreement between simulated and measured images, and also good agreement between quantitative intensity predictions based on the simulated images, as compared to the previous predictions based on the production of Cherenkov light in the assemblies.

Publications

1. Branger, E, Grape, S, Jacobsson Svärd, S, Jansson, P, Andersson Sundén, E. On Cherenkov light production by irradiated nuclear fuel rods. Journal of instrumentation, 2017.

2. Branger, E, Grape, S, Jacobsson Svärd, S, Jansson, P, Andersson Sundén, E. Comparison of prediction models for Cherenkov light emissions from nuclear fuel assemblies. Journal of instrumentation, June 2017.

3. Branger, E, Grape, S, Jansson, P, Jacobsson Svärd, S. Investigating the Cherenkov light production due to cross-talk in closely stored nuclear fuel assemblies in wet storage. Presented at the 2017 ESARDA symposium, to be published in the ESARDA bulletin.

Total Monte Carlo and TENDL

Research leader: Ass. Prof. **Henrik Sjöstrand**

Activities and outcome

The main activity for TMC work outside MÅBiL during 2017 has been the development of the so-called correlation fast correlation method. This work was both presented at the 4th edition of the International Workshop on Nuclear Data Covariances and is briefly described below.

Monte Carlo (MC) methods are increasingly used for Nuclear Data (ND) evaluation and propagation. In particular, the Total Monte Carlo (TMC) method has proved to be a powerful tool. When TMC is combined with Monte Carlo codes, statistical uncertainties are also introduced. For nuclear data uncertainty propagation, this was addressed with the so-called Fast TMC method, which today is the standard route for TMC uncertainty propagation.

Today, the standard way to visualize and interpret ND covariances is by the use of the Pearson correlation coefficient.

$$\rho = \frac{\mathrm{cov}(x, y)}{\sigma_x \cdot \sigma_y},$$

where *x or y* can be any parameter dependent on ND. σ_x has both an ND component, σ_{ND}, and a statistical component σ_{stat}: $\sigma_x^2 = \sigma_{ND}^2 + \sigma_{stat}^2$. The contribution from σ_{stat} decreases the value of ρ, and hence it is easy to underestimate the impact of the correlation. To address this, a so-called fast correlation coefficient was defined:

$$\rho_{fast} = \frac{\mathrm{cov}(x, y) - \mathrm{cov}(x_{stat}, y_{stat})}{\sqrt{\sigma_x^2 - \sigma_{x,stat}^2} \cdot \sqrt{\sigma_y^2 - \sigma_{y,stat}^2}}$$

During 2017 we used the method to explore three examples, using synthetic data correlations; correlations from the NRG High Flux Reactor spectrum for dosimetry calibration; and correlations between different integral criticality experiments. The 2017 results were promising and will continue to use the method.

In addition, some important papers where the majority of work stemmed from 2016 were completed and published 2017 (see publication list).

Unattended Gamma Emission Tomography for Partial-Defect Verification (GET)

Participating researchers: Dr. Peter Jansson, Ass. Prof. Staffan Jacobsson Svärd

The International Atomic Energy Agency (IAEA) initiated two support programme projects in 2012, UGET and PGET, which were executed during 2013-2015. The projects comprised researchers from Sweden (UU) and the U.S. (PNNL and LLNL) as well as participants from Finland, EC, IAEA and SSM. The capabilities for Gamma Emission Tomography for unattended verification of nuclear fuel assemblies were evaluated, and a final report was published as PNNL report 25995. Funding was granted by SSM via the Swedish Support Programme to the IAEA. In the project, the feasibility of verification of individual pins and in addition the verification of the declared burnup history has been studied for a variety of fuel assembly types and for different cooling times. The quality of the assessment has been determined in terms of ROC curves, showing the detection probability as a function of false-positive rate. The UGET project have since been merged together with the PGET project into a GET project, aimed at further developing the tomographic measurement technique for nuclear safeguards.

During 2017, in support of IAEA safeguards, the Swedish Radiation Safety Authority financed two projects as part of the GET project; Both projects aimed at developing algorithms and software for tomographic evaluation. Worthy of note is that, in the end of 2017, the PGET instrument was authorised by IAEA to be used in safeguards.

Characterization of Spent Fuel in connection to Encapsulation and Final

Responsible researcher: Dr. Peter Jansson

With funding from the Swedish Nuclear Fuel and Waste Management Company, methods for characterization of spent nuclear fuel using gamma ray- and neutron measurement techniques are developed. During 2017, the SPIRE ("Spent fuel characterization Program for the Implementation of geological REpositories") consortium, a research collaboration between several European and international organisations, developed into being a part of a proposal to European Joint Programming in the field of radioactive waste management and disposal. Dr. Peter Jansson coordinates the work package "Spent Fuel Characterisation and Evolution until Disposal" within the programme to be proposed.

Measurements of neutron-induced reactions at GANIL-NFS

Ph.D. student: **Kaj Jansson**
Research leader: Prof. Stephan Pomp
Participants: Dr. Alexander V. Prokofiev, Dr. Diego Tarrío, Ass. Prof. Cecilia Gustavsson.

The aim of this project is to provide with high-accurate data on cross-sections of different reactions induced by neutrons. With that purpose, we are part of the NFS (Neutrons For Science) collaboration, which will be using a neutron facility currently under construction at the GANIL nuclear research laboratory (in Caen, France). The facility, expected to be operational at the beginning of 2019, will provide with two kinds of neutron beams (either quasi-monoenergetic beams or continuous in energy) covering a wide energy range from below 1 MeV up to 40 MeV with a high time-averaged flux.

We are contributing to the NFS facility with our existing experimental setup called Medley that will be used during the commissioning of the NFS neutron beams as well as for two different research projects that we have proposed: LIONS (devoted to measure production cross-section of light ions in materials relevant for nuclear technology) and FISHES (with the aim of reducing the uncertainties in the standard fission cross-sections of U-235 and U-238).

During the year 2017, different design and service works on the Medley chamber have been performed in order to ensure its proper installation at the NFS experimental area. For this purpose, Alexander Prokofiev, Diego Tarrío and Stephan Pomp have travelled to GANIL in two occasions this year, in particular for a trial run with Medley detectors and also to discuss about different technical aspects on the installation of Medley in the neutron beam, as well as about the needs on the electronics and on the data-acquisition system, in order to perform the experiments.

The study and characterization of the Silicon and CsI detectors, that are planned to be used for LIONS and FISHES experiments, has also continued during 2017 at our premises in Uppsala. In particular, specific preamplifiers built at GANIL have been satisfactorily tested at our premises at Uppsala, showing their applicability for our projects.

The FISHES project requires also the development of a specific type of gas-ionization detectors, called PPAC (Parallel Plate Avalanche Counters), to detect fission fragments. This development work is currently being driven by Diego Tarrío. Preliminary results on the PPAC characterization, as well as on the general development of the aforementioned projects, have recently been presented at different scientific conferences and also published as proceedings:

- Meeting of the Spanish Physical Society. Santiago de Compostela (Spain) July 2017;
- FIESTA School & Workshop. Santa Fe (USA) September 2017;
- Swedish Nuclear Physics Meeting. Stockholm, October 2017;
- NFS workshop. GANIL (France) November 2017;
- D. Tarrío, A. V. Prokofiev, C. Gustavsson, K. Jansson, E. Andersson-Sundén, A. Al-Adili, and S. Pomp. Characterization of the Medley setup for measurements of neutron-induced fission cross sections at the GANIL-NFS facility. EPJ Web of Conferences, 146:03026, 2017.

Next journal publication on the development of the setup is in preparation.

In November 2017, Kaj Jansson has defended his Ph.D. thesis "Measurements of Neutron-induced Nuclear Reactions for More Precise Standard Cross Sections and Correlated Fission Properties" that stemmed partially from the work in the NFS project.

A diploma student, Matthias Carlsson, has been employed in the group recently, with the tasks including in particular development of PPACs of a new generation, with thin electrodes that are "transparent" for fission fragments. The student is co-supervised by Alexander Prokofiev and Diego Tarrío.

Research projects towards Generation IV reactors.

The following research projects confine work within Gen IV technology. Although outside the research framework of SKC, these projects are relevant from a general knowledge and competence building perspective.

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, Dr. Peter Andersson

Matilda Åberg Lindell is approaching the end of her PhD studies on nuclear safeguards aspects related to Generation IV (Gen IV) energy systems that has been financed by Vetenskapsrådet, SSM and Uppsala University. The thesis which will be defended at Uppsala University on the 23rd of February 2018 will consist of five publications [1-5] covering a broad range of aspects, from proliferation resistance assessment for a Gen IV system to multivariate analysis (MVA) assessments using simulated nuclear fuel data. The latter is focussed on i) discrimination between UOX and MOX fuel and to ii) verifying or determination of fuel parameters and fuel characteristics based on only passive gamma spectroscopy measurements and no operator declared information.

The research shows that one of the most proliferation sensitive parts of the Gen IV system is the recycling facility and that group actinide extraction processes are preferred. To enhance the proliferation resistance in this type of facility, one should adopt the Safeguards by Design approach and iteratively evaluate the proliferation resistance starting already before construction of the facility. Furthermore, it appears important to accurately verify the fuel in the reception area of a recycling facility, and here, measurement using non-destructive assay before dissolution of the fuel material is recommended.

Using simulated passive gamma spectroscopy data, it is shown that one can indeed distinguish UOX fuel from MOX fuel, should Continuity of Knowledge be lost. Furthermore it seems that using MVA tools may be viable in order to determine fuel parameters such as initial enrichment, burnup and cooling time with high confidence. It even appears that the plutonium content may be extracted from this type of input data. However, all results remain to be experimentally verified.

Publications

[1] M. Åberg Lindell, S. Grape, A. Håkansson, S. Jacobsson Svärd (2013), Assessment of proliferation resistances of aqueous reprocessing techniques using the TOPS methodology. Annals of Nuclear Energy, 62, 390-397.

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

[3] M. Åberg Lindell, S. Grape, A. Håkansson, S. Jacobsson Svärd (2013), 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, 29 September - 3 October 2013, Salt Lake City, USA. (Peer-reviewed conference paper.)

[4] M. Åberg Lindell, P. Andersson, S. Grape, C. Hellesen, A. Håkansson, M. Thulin (2018) Discrimination of irradiated MOX fuel from UOX fuel by multivariate statistical analysis of simulated activities of gamma-emitting isotopes. Nuclear Instruments and Methods in Physics Research, A, 885, 67–78

[5] M. Åberg Lindell, P. Andersson, S. Grape, A. Håkansson, M. Thulin, Determination of irradiated nuclear fuel characteristics by nonlinear multivariate regression of simulated gamma-ray emissions. Submitted to Nuclear Instruments and Methods in Physics Research, A, 2017-12-10

Core Diagnostics in the ASTRID Sodium Fast Reactor (CODIAS)

Ph.D. 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

In 2017, Vasudha Verma finished her Ph.D. studies by successfully defending her thesis: "Development of a Neutron Flux Monitoring System for Sodium-cooled Fast Reactors". Vasudha's work has given valuable input to the ongoing ASTRID project and we continue the dialogue with the CEA probing for continuing collaboration.

In addition to above, there are research and education activities comprising various safety and security aspects of Gen IV systems. In particular research is ongoing regarding transient behaviour of fast reactor designs, fuel issues, monitoring and safeguards.

Publications and conferences

The following scientific papers were published during 2017:

1. Andersson P., Holcombe S.; "A computerized method (UPPREC) for quantitative analysis of irradiated nuclear fuel assemblies with gamma emission tomography at the Halden reactor"; Journal: Annals of Nuclear Energy; Vol: 110; DOI: 10.1016/j.anucene.2017.06.025; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-313485; (2017)

2. Ali Al-Adili, Diego Tarrío, Franz-Josef Hambsch, Alf Göök, Kaj Jansson, Andreas Solders, Vasileios Rakapoulos, Cecilia Gustavsson, Mattias Lantz, Andrea Mattera, Stephan Oberstedt, Alexander V. Prokofiev, Erik A. Sundén, Marzio Vidali, Michael Österlund and Stephan Pomp; "Neutron-multiplicity experiments for enhanced fission modelling"; Journal: EPJ Web of Conferences; Vol: 146; Conference: International Conference on Nuclear Data for Science and Technology, Bruge (BE), September 11-16, 2016.; DOI: 10.1051/epjconf/201714604056 ; Permalink:urn:nbn:se:uu:diva-339390; (2017).

3. Kaj Jansson, Ali Al-Adili, Riccardo Bevilacqua, Cecilia Gustavsson, Franz-Josef Hambsch, Stephan Pomp and Marzio Vidali; "Measurement of the 6Li(n,α)t neutron standard cross-section at the GELINA facility"; Journal: EPJ Web of Conferences; Vol: 146; Conference: International Conference on Nuclear Data for Science and Technology, Bruge (BE), September 11-16, 2016.; DOI: 10.1051/epjconf/201714611047 ; Permalink: urn:nbn:se:uu:diva-339370; (2017)

4. Kaj Jansson, Marc Olivier Frégeau, Ali Al-Adili, Alf Göök, Cecilia Gustavsson, Franz-Josef Hambsch, Stephan Oberstedt and Stephan Pomp; ; "The new double energy-velocity spectrometer VERDI"; Journal: EPJ Web of Conferences; Vol: 146; Conference: International Conference on Nuclear Data for Science and Technology, Bruge (BE), September 11-16, 2016.; DOI: 10.1051/epjconf/201714604016; Permalink: urn:nbn:se:uu:diva-339394; (2017)

5. Mattera A., Al-Adili A., Lantz M., Pomp S., Rakopoulos V., Solders A.; "A methodology for the intercomparison of nuclear fission codes using TALYS"; Journal: EPJ Web of Conferences; Vol: 146; Conference: International Conference on Nuclear Data for Science and Technology, Bruge (BE), September 11-16, 2016.; DOI: 10.1051/epjconf/201714604047; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-317442; (2017)

6. Mattera A., Pomp S., Lantz M., Rakopoulos V., Solders A., Al-Adili A., Passoth E., Prokofiev A., Andersson P., Hjalmarsson A., Bedogni R., Bortot D., Politecnico di Milano p., Esposito A., Gentile A., Gómez-Ros J., CIEMAT C., Introini M., Pola A., Gorelov D., Penttilä H., Moore I., Rinta-Antila S., Kolhinen V., Eronen T.; "A neutron source for IGISOL-JYFLTRAP : Design and characterisation"; Journal: European Physical Journal A; Vol: 53; No: 173; DOI: 10.1140/epja/i2017-12362-x; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-328569; (2017)

7. Tarrio D., Prokofiev A., Gustavsson C., Jansson K., Andersson Sundén E., Al-Adili A., Pomp S.; "Characterization of the Medley setup for measurements of neutron-induced fission cross sections at the GANIL-NFS facility"; Journal: EPJ Web of Conferences; Vol: 146; Conference: ND 2016: International Conference on Nuclear Data for Science and Technology; DOI: 10.1051/epjconf/201714603026; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-338734; (2017)

8. Helgesson P., Sjöstrand H., Arjan J., Rydén J., Rochman D., Alhassan E., Pomp S.; "Combining Total Monte Carlo and Unified Monte Carlo : Bayesian nuclear data uncertainty quantification from auto-generated experimental covariances"; Journal: Progress in nuclear energy (New series); Vol: 96; Publisher: Elsevier; DOI: 10.1016/j.pnucene.2016.11.006; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-313644; (2017)

9. Branger E., Grape S., Jacobsson S., Jansson P., Andersson Sundén E.; "Comparison of prediction models for Cherenkov light emissions from nuclear fuel assemblies"; Journal: Journal of Instrumentation; Vol:

12; DOI: 10.1088/1748-0221/12/06/P06007; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-309739; (2017)

10. Helgesson P., Sjöstrand H.; "Fitting a defect non-linear model with or without prior, distinguishing nuclear reaction products as an example"; Journal: Review of Scientific Instruments; Vol: 88; DOI: 10.1063/1.4993697; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-326313; (2017)

11. Leal-Cidoncha E., Duran I., Paradela C., Tassan-Got L., Audouin L., Leal L., Naour C., Noguere G., Tarrio D., Leong L., Altstadt S., Andrzejewski J., Barbagallo M., BÃ©cares V., BeÄ□vÃ¡Å™ F., Belloni F., Berthoumieux E., Billowes J., Boccone V., Bosnar D., Brugger M., Calviani M., CalviÃ±o F., Cano-Ott D., CarrapiÃ§o C., Cerutti F., Chiaveri E., Chin M., Colonna N., CortÃ©s G., CortÃ©s-Giraldo M., Diakaki M., Domingo-Pardo C., Dressler R., Eleftheriadis C., Ferrari A., Fraval K., Ganesan S., GarcÃ-a A., Giubrone G., GÃ³mez-Hornillos M., GonÃ§alves I., GonzÃ¡lez-Romero E., Griesmayer E., Guerrero C., Gunsing F., Gurusamy P., HernÃ¡ndez-Prieto A., Jenkins D., Jericha E., Kadi Y., KÃ€ppeler F., Karadimos D., Kivel N., Kokkoris M., KrtiÄ□ka M., Kroll J., Lampoudis C., Langer C., Lederer C., Leeb H., Losito R., Mallick A., Manousos A., Marganiec J., MartÃ-nez T., Massimi C., Mastinu P., Mastromarco M., Meaze M., Mendoza E., Mengoni A., Milazzo P., Mingrone F., Mirea M., Mondelaers W., Pavlik A., Perkowski J., Plompen A., Praena J., Quesada J., Rauscher T., Reifarth R., Riego A., Robles M., Roman F., Rubbia C., SabatÃ©-Gilarte M., Sarmento R., Saxena A., Schillebeeckx P., Schmidt S., Schumann D., Tagliente G., Tain J., Tsinganis A., Valenta S., Vannini G., Variale V., Vaz P., Ventura A., Versaci R., Vermeulen M., Vlachoudis V., Vlastou R., Wallner A., Ware T., Weigand M., WeiÃŸ C., Wright T., Åœugec P., Collaboration t.; "High accuracy 234U(n,f) cross section in the resonance energy region"; Journal: EPJ Web Conf.; Vol: 146; DOI: 10.1051/epjconf/201714604057; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-338741; (2017)

12. Anastasi A., Univ Messina D., Babusci D., Bencivenni G., Berlowski M., Bloise C., Bossi F., Branchini R., Budano A., Caldeira Balkeståhl L., Cao B., Ceradini F., Ciambrone R., Curciarello F., Univ Messina D., Novosibirsk State Univ N., Czerwinski E., D'Agostini G., Ist Nazl Fis Nucl S., Dane E., De Leo V., De Lucia E., De Santis A., De Simone R., Di Cicco A., Ist Nazl Fis Nucl S., Di Domenico A., Ist Nazl Fis Nucl S., Di Salvo R., Domenici D., D'Uffizi A., Fantini A., Ist Nazl Fis Nucl S., Felici G., Fiore S., Casaccia RC E., Gajos A., Gauzzi R., Ist Nazl Fis Nucl S., Giardina G., Giovannella S., Graziani E., Happacher F., Heijkenskjöld L., Johansson T., Kaminska D., Krzemien W., Kupsc A., Loffredo S., Lukin P., Budker Inst Nucl Phys N., Mandaglio G., Ist Nazl Fis Nucl G., Martini M., Univ Guglielmo Marconi D., Mascolo M., Messi R., Ist Nazl Fis Nucl S., Miscetti S., Morello G., Moricciani D., Moskal R., Papenbrock M., Passeri A., Patera V., del Rio E., Ranieri A., Santangelo R., Sarra I., Schioppa M., Ist Nazl Fis Nucl G., Selce A., Silarski M., Sirghi F., Tortora L., Venanzoni G., Wislicki W., Wolke M., Jegerlehner F., Deutsch Elektronen Synchrotron DESY P.; "Measurement of the running of the fine structure constant below 1 GeV with the KLOE detector"; Journal: Physics Letters B; Vol: 767; Publisher: ELSEVIER SCIENCE BV; DOI: 10.1016/j.physletb.2016.12.016; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-320023; (2017)

13. Rakopoulos V., Lantz M., Al-Adili A., Gorelov D., Jokinen A., Kolhinen V., Mattera A., Moore I., Penttilä H., Prokofiev A., Solders A., Pomp S.; "Measurements of isomeric yield ratios of fission products from proton- induced fission on natU and 232Th via direct ion counting"; Journal: EPJ Web of Conferences; Vol: 146; Conference: International Conference on Nuclear Data for Science and Technology, 11-16 september 2016, Bruges, Belgium; DOI: 10.1051/epjconf/201714604054; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-319348; (2017)

14. Salewski M., Nocente M., Jacobsen A., Binda F., Cazzaniga C., Ericsson G., Eriksson J., Gorini G., Hellesen C., Hjalmarsson A., Kiptily V., Koskela T., Korsholm S., Kurki-Suonio T., Leipold F., Madsen J., Moseev D., Nielsen S., Rasmussen J., Schneider M., Sharapov S., Stejner M., Tardocchi M.; "MeV-range velocity-space tomography from gamma-ray and neutron emission spectrometry measurements at JET"; Journal: Nuclear Fusion; Vol: 57; No: 5; Publisher: IOP PUBLISHING LTD; DOI: 10.1088/1741-4326/aa60e9; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-321793; (2017)

15. Meo S., Mancusi D., Massimi C., Tarrio D., Vannini G., Ventura A.; "Monte Carlo calculations of nucleon-induced fission in the GeV energy range"; Journal: EPJ Web Conf.; Vol: 146; DOI: 10.1051/epjconf/201714604049; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-329737; (2017)

16. Rochman D., Leray O., Hursin M., Ferroukhi H., Vasiliev A., Aures A., Bostelmann F., Zwermann W., Cabellos O., Diez C., Dyrda J., Garcia-Herranz N., Castro E., Marck S., Sjöstrand H., Hernandez Solis A., Fleming M., Sublet J., Fiorito L.; "Nuclear Data Uncertainties for Typical LWR Fuel Assemblies and a Simple Reactor Core"; Journal: Nuclear Data Sheets; Vol: 139; DOI: 10.1016/j.nds.2017.01.001; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-316069; (2017)

17. Hellesen C., Grape S., Jansson P., Jacobsson S., Åberg Lindell M., Andersson P.; "Nuclear Spent Fuel Parameter Determination using Multivariate Analysis of Fission Product Gamma Spectra"; Journal: Annals of Nuclear Energy; Vol: 110; DOI: 10.1016/j.anucene.2017.07.035; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-327108; (2017)

18. Bielewicz M., Kilim S., Strugalska-Gola E., Szuta M., Wojciechowski A., Tyutyunnikov S., Prokofiev A., Passoth E.; "(n,xn) cross section measurements for Y-89 foils used as detectors for high energy neutron measurements in the deeply subcritical assembly “QUINTA”"; Journal: EPJ Web of Conferences; Vol: 146; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-339472; (2017)

19. Branger E., Grape S., Jacobsson S., Jansson P., Andersson Sundén E.; "On Cherenkov light production by irradiated nuclear fuel rods"; Journal: Journal of Instrumentation; Vol: 12; DOI: 10.1088/1748-0221/12/06/T06001; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-309736; (2017)

20. Duran I., Ventura A., Lo Meo S., Agenzia Nazionale per le Nuove Tecnologie B., Tarrio D., Tassan-Got L., Paradela C.; "On the search for a (n,f) cross-section reference at intermediate energies"; Journal: EPJ Web of Conferences; Vol: 146; DOI: 10.1051/epjconf/201714602032; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-329739; (2017)

21. Verma V., Loic B., Filliatre P., Hellesen C., Jammes C., Jacobsson Svärd S.; "Self Powered Neutron Detectors as in-core detectors for Sodium-cooled Fast Reactors"; Journal: Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment; Vol: 860; DOI: 10.1016/j.nima.2017.04.011; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-314035; (2017)

22. Jansson K., Al-Adili A., Nilsson N., Norlin M., Solders A.; "Simulated production rates of exotic nuclei from the ion guide for neutron-induced fission at IGISOL"; Journal: European Physical Journal A; Vol: 53; No: 243; DOI: 10.1140/epja/i2017-12442-y; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-339371; (2017)

23. Qvist S., Hellesen C., Gradecka M., Dubberley A., Fanning T., Greenspan E.; "Tailoring the response of Autonomous Reactivity Control (ARC) systems"; Journal: Annals of Nuclear Energy; Vol: 99; DOI: 10.1016/j.anucene.2016.09.036; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-310730; (2017)

24. Ledoux X., Aiche M., Avrigeanu M., Avrigeanu V., Balanzat E., Ban-d’Etat B., Ban G., Bauge E., Balier G., BÃ©m P., Borcea C., Caillaud T., Chatillon A., Czajkowski S., Dessagne P., Dore D., Fischer U., Fregeau M., Grinyer J., Guillous S., Gunsing F., Gustavsson C., Henning G., Jacquot B., Jansson K., Jurado B., Kerveno M., Klix A., Landoas O., Lecolley F., Lecouey J., Majerle M., Marie N., Materna T., MrÃ¡zek J., Negoita F., NovÃ¡k J., Oberstedt S., Oberstedt A., Panebianco S., Perrot L., Plompen A., Pomp S., Prokofiev A., Ramillon J., Farget F., Ridikas D., RossÃ© B., Serot O., Simakov S., Å imeÄ□kovÃ¡ E., Å tefÃ¡nik M., Sublet J., Taieb J., Tarrio D., Tassan-Got L., Thfoin I., Varignon C.; "The neutrons for science facility at SPIRAL-2"; Journal: EPJ Web Conf.; Vol: 146; DOI: 10.1051/epjconf/201714603003; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-329738; (2017)

25. Helgesson P., Sjöstrand H., Rochman D.; "Uncertainty driven nuclear data evaluation including thermal (n,alpha): applied to Ni-59"; Journal: Nuclear Data Sheets; Vol: 145; DOI: 10.1016/j.nds.2017.09.001; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-315678; (2017)

26. Hellesen C., Qvist S., “Benchmark and demonstration of the CHD code for transient analysis of fast reactor systems”, Anals of Nuclear Energy, 109, November 2017, Pages 712-719

Papers submitted during 2017:

1. Helgesson P., Sjöstrand H., Rochman D., van der Marck S., Asquith N.; "Efficient use of Monte Carlo: The Fast Correlation Coefficient"; Conference: 4th edition of the International Workshop on Nuclear Data Covariances, 2017; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-339229; (2018)

2. Åberg Lindell M., Andersson P., Grape S., Håkansson A., Thulin M.; "Determination of irradiated nuclear fuel characteristics by nonlinear multivariate regression of simulated gamma-ray emissions"; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-337677; (2017)

3. K. Jansson, A. Al-adili, E.A. Sundén, A. Göök, S. Oberstedt, S. Pomp; “Defective fission correlation data from the 2E-2v method” Submitted to EPJA. 2017. https://arxiv.org/abs/1709.07443

4. Åberg Lindell M., Andersson P., Grape S., Hellesen C., Håkansson A., Thulin M.; "Discrimination of irradiated MOX fuel from UOX fuel by multivariate statistical analysis of simulated activities of gamma-emitting isotopes"; Journal: Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment; Vol: 885; DOI: 10.1016/j.nima.2017.12.020; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-337676; (2018)

Conference contributions

1. Helgesson P., Neudecker D., Sjöstrand H., Grosskopf M., Smith D., Capote R.; "Assessment of Novel Techniques for Nuclear Data Evaluation"; Conference: 16th International Symposium of Reactor Dosimetry (ISRD16); Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-322558; (2017).

2. Sjöstrand H., Helgesson P.; "Choosing Nuclear Data evaluation techniques to obtain complete and motivated covariances"; Conference: The Fourth DAE-BRNS Theme Meeting on Generation and use of Covariance Matrices in the Applications of Nuclear Data; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-339215; (2017)

3. Sjöstrand H., Helgesson P., Rochman D.; "Covariance in Ni-59 for JEFF 3.3 : A TMC based uncertainty approach"; Conference: JEFF Nuclear data week - NEA SG44; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-339234; (2017)

4. Sjöstrand H., Helgesson P., Rochman D., van der Marck S., Asquith N.; "Efficient use of Monte Carlo: The Fast Correlation Coefficient"; Conference: CW2017, 4th edition of the International Workshop on Nuclear Data Covariances, 2017, Aix en Provence, France, in October 2-6 2017 http://www.cw2017.com/; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-339206; (2017)

5. Andersson P., Holcombe S.; "Feasibility Study of Using Gamma Emission Tomography for Identification of Leaking Fuel Rods in Commercial Fuel Assemblies"; Conference: Water Reactor Fuel Performance Meeting (WRFPM), 10-14 September 2017, Jeju Island Korea; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-328197; (2017)

6. Andersson P.; "Gamma Emission Tomography of LOCA-transient test rods"; Conference: Nationell strålsäkerhet : utblick och forskning, 22–23 november 2017, Stockholm; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-338666; (2017)

7. Branger E., Grape S., Jansson P., Andersson Sundén E., Jacobsson Svärd S.; "Investigating the Cherenkov light production due to cross-talk in closely stored nuclear fuel assemblies in wet storage"; Conference: 2017 ESARDA symposium; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-323613; (2017)

8. Jacobsson Svärd S., Smith E., White T., Mozin V., Jansson P., Andersson P., Grape S., Davour A., Trellue H., Deshmukh N., Wittman R., Honkamaa T., Vaccaro S., Ely J.; "Outcomes of the JNT 1955 Phase I Viability Study of Gamma EmissionTomography for Spent Fuel Verification"; Conference: ESARDA 39:th Symposium; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-331156; (2017)

9. Hernandez A., Sjöstrand H., Helgesson P.; "Propagation of neutron-reaction uncertainties through multi-physics models of novel LWR's"; Vol: 146; Conference: ND 2016: International Conference on Nuclear Data for Science and Technology; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-330372; (2017)

10. Andersson P., Holcombe S., Tverberg T.; "Quantitative Gamma Emission Tomography Inspection of LOCA rod IFA-650.15"; Conference: EHPG; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-329961; (2017)

11. Sjöstrand H., Helgesson P., Alhassan E.; "TENDL adjustments using integral benchmarks"; Conference: Workshop on TALYS/TENDL developments, 13-15 November 2017, Prague; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-339210; (2017)

12. Rochman D., J. Koning A., van der Marck S., Sublet J., Bauge E., S H., Romain P., Morillon B., Duarte H., Goriely S., Sjöstrand H., Pomp S., Dzysiuk N., Cabellos O., Ferroukhi H., Vasiliev A.; "The TENDL library: Hope, reality and future"; Vol: 146; Conference: ND 2016: International Conference on Nuclear Data for Science and Technology; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-330371; (2017)

13. Helgesson P., Sjöstrand H.; "Treating model defects with a Gaussian Process prior for the parameters"; Conference: Workshop on TALYS/TENDL developments, 13-15 November 2017, Prague; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-339285; (2017)

Other reports and books

1. Jansson P., Lantz M.; "Räkneuppgifter till Säkerhetsanalyser inom energisektorn"; Publisher: Uppsala universitet; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-337569; (2018)

2. S. Grape and C. Hellesen, Safeguards and Non-proliferation, chapter 10, Molten Salt Reactors and Thorium Energy, eBook ISBN: 9780081012437, Hardcover ISBN: 9780081011263, https://www.elsevier.com/books/molten-salt-reactors-and-thorium-energy/dolan/978-0-08-101126-3

3. Mattera A.; "nIGISOL 2016 : Measurement of n-induced fission yields of tin and antimony"; Publisher: Uppsala University; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-326306; (2017)

4. Member State Support Programmes Participating in the ASTOR Task .., Jansson P.; "Technologies Potentially Useful for Safeguarding Geological Repositories : ASTOR Group Report 2011–2016"; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-330200; (2017)

5. Andersson P.; "Notes on the world energy supply"; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-326287; (2017)

Networking and collaborations

- Sweden: KTH, Chalmers, Stockholm University, Gothenburg University and SIPRI
- Belgium: Joint Research Centre IRMM in Geel, CSK-CEN in Mol
- The Netherlands: NRG Petten
- Spain: Tecnatom
- Finland: Univ. of Jyväskylä
- France: GANIL, IPNO and CEA
- Japan: Kyushu University, initiating collaboration with Tokyo Technical Institute
- Switzerland: CERN, PSI
- Thailand: Chiang Mai University
- Kenya: University of Nairobi
- USA: LANL, UCB, LBNL, LLNL, PNNL, ANL, ORNL
- Norway: OECD Halden Reactor Project and IFE, Technical University in Trondheim
- IAEA
- The World Nuclear University
- EU: CHANDA (35 partners)
- RADSAGA network project with about 25 participating organizations from academy and industry
- Nordic Academy for Nuclear Safety and Security, NANSS
- ENEN (European Nuclear Education Network): Via the ANNETTE project on the development of training for professionals in the nuclear business for an "Advanced Master" degree, Uppsala University has strengthened the collaboration with about 25 European organizations active in this project.
- ESARDA (European Safeguards Research and Development Association): Uppsala University is very active in this Europe-wide research association; Sophie Grape was chairing the ESARDA working group of Training and Knowledge Management, with Karin Persson as an additional group member, while Peter Jansson was chairing the ESARDA working group on Non-Destructive Assay.
- SKB, LANL: Research regarding nuclear fuel characterisation related to the back-end of the nuclear fuel cycle has been performed in close collaboration between Uppsala University, SKB AB and Los Alamos National Laboratory.
- MÅBiL project with participants from Uppsala University, KTH and Chalmers
- Initiating the Swedish Academic Initiative in Nuclear Technology, SAINT, together with Chalmers.

General Outreach

- Dr. Sophie Grape is a member of Kärnavfallsrådet.
- Dr. Mattias Lantz is chairman of Analysgruppen
- Initiating a dialogue with part of the Parliament's education committee.
- Meeting with MP Richard Nordin (C), energy policy spokesman and member of the energy commission.
- Dialogue with the Ministry of Education and research regarding funding for Gen IV research.
- Meeting with Vetenskapsrådet regarding funding for Gen IV research.
- Meeting with part of the Parliament's education committee regarding funding for nuclear education in Sweden.

Excerpt from our activities within popularisation of science

1. SciFest 2017.
2. Sjöstrand H.; "Improved nuclear data for enhanced nuclear safety"; Conference: Strålsäkerhetsmyndighetens forskningsdagar, Nationell strålsäkerhet – utblick och forskning; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-339236; (2017)
3. Helgesson P., Sjöstrand H.; "Treating defects in nuclear reaction models to improve material damage parameters and their uncertainties"; Conference: SKC årsmöte 2017; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-339238; (2017)
4. Zsolt Elter och Li Caldeira Balkeståhl: ”Development of multivariate analysis techniques for nuclear safeguards purposes”; Conference: Strålsäkerhetsmyndighetens forskningsdagar, Nationell strålsäkerhet – utblick och forskning
5. Carl Hellesen och Sophie Grape: ”Orsaker och konsekvenser av mätonoggrannhet”; Strålsäkerhetsmyndighetens forskningsdagar, Nationell strålsäkerhet – utblick och forskning
6. Erik Branger: ”Förbättrade metoder att förutspå Tjerenkovljusemission från kärnbränsle försafeguardändamål”; Strålsäkerhetsmyndighetens forskningsdagar, Nationell strålsäkerhet – utblick och forskning
7. March for Science
8. Ångströmlaboratoriet 20 years, open house
9. Intervju i Vattenfalls internnyheter om myter kring Fukushima. Ej offentliggjord utanför Vattenfall.
10. Intervju artikel i Reaktion (Vattenfalls tidning för Forsmark och Ringhals) om Safecast ”Är strålning farligare i Japan än i Rom?” (sid 10-11)
11. Podcast, "Om kärnkraft med Ane Håkansson"
12. Intervju i Verdens Gang, "Atomkraft: Klimaløsningen ingen vil ha"
13. Vattenfallseminarium om kärnkraftens kompetensförsörjning Almedalen
14. INSEN 2017 Annual GA meeting
15. Vetenskapsstudion om kärnvapen
16. Lärardag för ca 30 st ämneslärare i fysik, matematik, kemi och biologi på gymnasienivå.
17. Diskussioner och erfarenhetsutbyte mellan Lärarprogrammet vid Uppsala University och representanter för skola och kommun, avseende verksamhetsförlagd utbildning (VFU).
18. UTNARM
19. Seminar directed towards students at Rosendals gymnasium about radioactivity, its myths and academic nuclear research.
20.

Additional information and commitments during 2017

- NESSA - A neutron facility at Uppsala University. Applied Nuclear Physics plan to purchase a high-intensity neutron generator has evolved and we have identified a supplier for a 10^{11} neutrons per second source. The neutron generator will be situated in the FREIA hall of the Ångström laboratory and is tentatively called NESSA, NEutron Source in UppSAla. NESSA is planned to be used both as a part of research and education as well as an irradiation facility. NESSA can be used for both detector development and material studies. When commissioned, NESSA will constitute one of a few research facilities in Europe with this capability and we foresee it to be a valuable tool for research and development relevant for the nuclear power sector.

Procurement has started (2018-01-04) and will end March 13. Scrutiny of offers and signing of contract are planned to take place during March to April. Delivery of the neutron source is expected in February - March 2019 and SAT is planned to spring 2019. According to the current plan, the neutron source will be in operation autumn 2019.

Strategy and visions

One of our missions, relevant for SKC, is to work for achieving safe, secure and sustainable nuclear energy systems. On the global level this seems 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. However, in this context the role of the universities as providers of competence to the industry must thoroughly be addressed.

For the long-term perspective, Generation IV systems are likely to be considered and in order to address the needs of competence and capacity building, the role of the universities is imperative. As we see it, Gen IV is one efficient way to attract young scientists to the nuclear field, addressing not only future technology but also current technology. As these researchers also function as teachers enable us to augment our capacity to educate nuclear engineers for the current as well as future needs.

In addition, considering the need to electrifying developing countries and in the light of climate change, it is reasonable that the industrial and academic foundation of the industrialised countries is utilised for the safe and secure implementation of nuclear energy on the global scale. In this scenario applied nuclear physics in Uppsala shall play a role.

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

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 employees, experts and researchers within the nuclear field.

Appendix 4 - MÅBiL Annual Report 2017

Below follows descriptions of the ongoing MÅBiL collaboration (Materials, Ageing, and Fuel development) from all three research parties: Chalmers, KTH and Uppsala University.

Ageing of Reactor Pressure Vessel Steel Welds

Research leader: Mattias Thuvander, Division of Materials Microstructure, Department of Physics, Chalmers
PhD-student: Kristina Lindgren
Participants: Krystyna Stiller (Chalmers) and Pål Efsing (KTH)

Finances

The funds from SKC have been used for covering 80% of the cost of the Ph.D. student. Costs for instruments and supervision have been covered by Chalmers. The funds have been spent in accordance with budget.

Project activities

The reactor pressure vessel (RPV) is a life-limiting component of a nuclear reactor. Neutron irradiation during operation decreases the ductility of the RPV steel. The most important mechanism for making the steel brittle is the formation of nanometre-sized particles, consisting of Ni, Mn, Si and Cu, see Figure 1. In particular, welds are affected as they often contain higher concentrations of the listed elements. In the R3 and R4 reactors, the Ni- and Mn-contents are higher than in most other reactors, making studies of these important. The aim of this project is to study ageing of RPV steel welds, both the effect of neutron irradiation and purely thermal effects, to better understand the mechanisms of ageing and to provide a basis for predicting the lifetime of RPVs. Since the microstructural changes during irradiation are on a very small scale, atom probe tomography (APT) is the most suitable technique for this study.

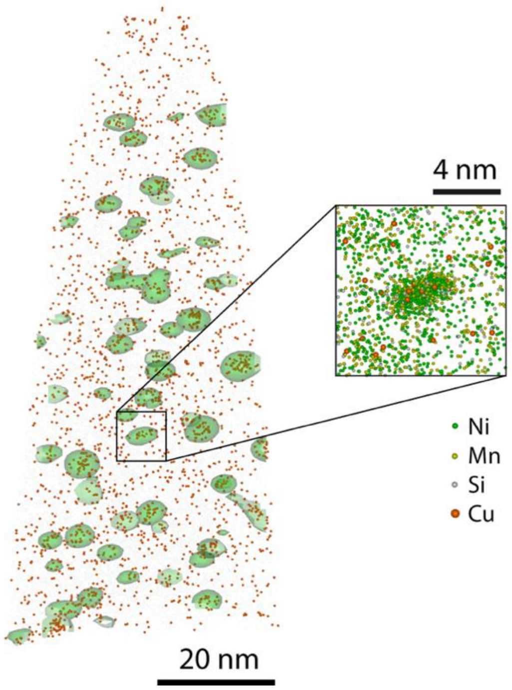


Fig. 20. An atom probe tomography reconstruction of an irradiated reactor pressure vessel steel of surveillance material. Green surfaces correspond to 12.43 at% of Ni, Mn and Si. Orange dots correspond to Cu atoms. The enlarged volume is 10x10x10nm³.

The project started in July 2014 and during 2014 un-irradiated reference materials were studied. Early in 2015, irradiated RPV samples were received from VTT, Finland, where mechanical testing had been undertaken. The samples had been irradiated in the Halden reactor to levels corresponding to operation for about 20 and 60 years, respectively. These samples are identical to the RPV welds of R4. During 2015, a large number of APT analyses of the sample series from Halden, together with one surveillance sample, have been made. In 2016, the work on the irradiated RPV material has been further analysed and summarised in two journal papers (no 2 and 3 in the publication list below, accepted early 2017), included in the licentiate thesis that was presented in November 2016.

During 2017, the collaboration with KTH (Magnus Boåsen) on post irradiation annealing (PIA) of the RPV steel was continued. The weld annealed at 390°C was analysed using APT, exposing the need of doing more PIAs and hardness measurements at higher temperatures. However, this needs to be done in a hotcell currently under construction at VTT (Finland), and thus this part of the project is postponed.

In addition to the irradiated samples, analyses have also been made on welds from a pressurizer (exchanged at Ringhals after ca. 28 years of operation), to try to understand the reason for their embrittlement. In this case, the ageing is purely thermal, but it is clear that nano-sized precipitates form at these relatively low temperatures (345°C), also without irradiation, after long enough time. The precipitates are mainly found along dislocations, which also contain segregated Mo, see Figure 2. Samples from the pressurizer have also been sent to Manchester University for TEM studies. In 2017, a manuscript (no 4) was submitted, and is now in the review process. Furthermore, an application for small angle neutron scattering (SANS) beam time was sent in and accepted, but the planned beam time was postponed from October 2017 to early 2018 due to technical issues at the neutron facility. SANS data will complement the APT results in terms of statistics of the inhomogeneously distributed clusters.

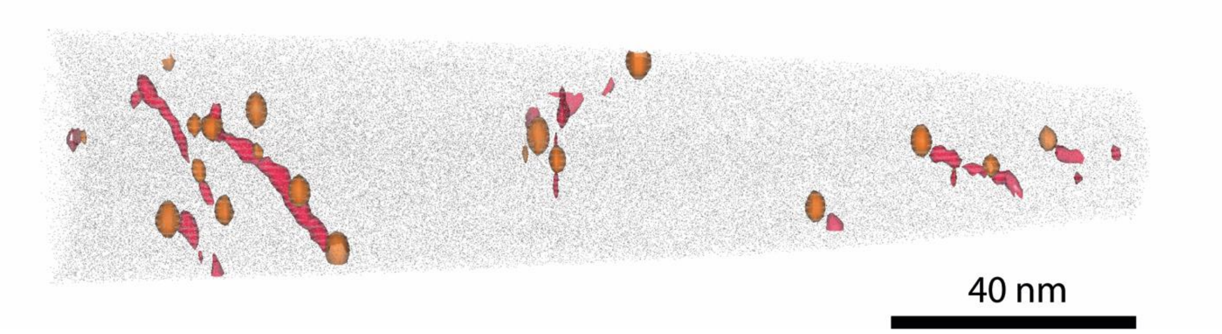


Fig. 22. Atom probe reconstruction of a pressurizer weld, thermally aged for 28 years at 345°C. Cu clusters (also enriched in Ni, Mn and Si) are found on dislocation lines, enriched in Mo, Mn and C. The orange surfaces correspond to 1.1 at% Cu, the red surfaces to 1.6 at% Mo.

Neutron irradiation can be simulated using ion irradiation. During 2017 ion irradiation experiments were planned in order to understand the difference to neutron irradiation and the effect of composition.

Plans

The defence of Kristina is planned for December 2018. Until then, there are different parts that ideally will be finished; the SANS of the pressurizer, the PIA of the RPV steel, and the analysis of the ion irradiated materials. Later on, material retrieved from Barsebäck RPV will be analysed, but it is uncertain if it arrives in time for the analyses to be made within this project.

Milestones

M18: Investigation of Halden samples (2015)

M23: Submit paper to Microscopy&Microanalysis, Participate at APT&M (2016)

M24: Investigation of annealing of Halden samples (partly done 2017, halted)

M26: Investigation of pressurizer samples (2015)

M28: Licentiate thesis (2016)

M36: Investigation of pressurizer samples using SANS

M39: Investigation of ion irradiated weld samples

M45: Investigation of Barsebäck samples

M54: PhD thesis

Publications

1. Licentiate thesis: Radiation Induced Precipitation in Reactor Pressure Vessel Steel Welds, 2016.
2. On the analysis of clustering in an irradiated low alloy reactor pressure vessel steel weld, K. Lindgren, P. Efsing, K. Stiller and M. Thuvander, Microscopy and Microanalysis 23 (2017) 376-384.
3. Evolution of precipitation in reactor pressure vessel steel welds under neutron irradiation, K. Lindgren, M. Boåsen, K. Stiller, P. Efsing and M. Thuvander, Journal of Nuclear Materials 488 (2017) 222-230.

Planned publications: (*tentative titles and authors*)
4. Cluster Formation in In-service Thermally Aged Pressurizer Welds, K. Lindgren, M. Boåsen, K. Stiller, P. Efsing, M. Thuvander. Submitted to Journal of Nuclear Materials.
5. Cluster evolution in a post irradiation annealed high Ni & Mn, low Cu reactor pressure vessel steel weld, K. Lindgren, M. Boåsen, K. Stiller, P. Efsing, M. Thuvander.

Conference contributions

1. APT&M 2016, Gyeongyu, South Korea (Oral presentation)
2. NuMat 2016, Montpellier, France (Oral presentation)

Planned:
3. APT&M 2018, NIST Washington, US, abstract submitted
4. Fontevraud 9 2018, Avignon, France, accepted for oral presentation

Irradiation assisted stress-corrosion cracking

- Ph.D. student: Elin Toijer
- Supervisor: Pär Olsson, Mats Jonsson

Funds Spending

The project was not supported by SKC directly during 2017 – but by a shift in budget from 2016. The funds were used for partial covering of the salary cost of the PhD student.

Activities within the project under 2017

This PhD project is a collaboration effort between Reactor Physics (SCI) and Nuclear Chemistry (CHE) at KTH. Elin is working at Reactor Physics with modelling of grain boundaries in order to produce a model for grain boundary decohesion due to radiation accelerated diffusion. She is focusing on perfect grain boundaries in model metals and is adding in phosphorous and transition metal impurities. She has made good progress during 2017 at converging her results and a paper draft is under preparation. She is also studying radiation defect – impurity interactions in model metals, see example figure below.

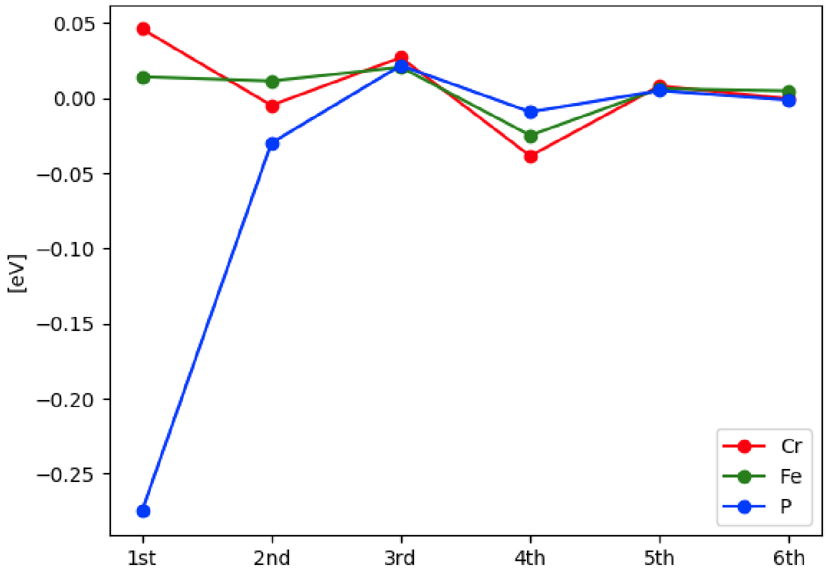


Fig. 23. Vacancy-solute binding energy in fcc Ni

Elin will embark starting 2018 on a dynamic study of defect properties in paramagnetic austenite, which is a very challenging first-of-a-kind work.

At Nuclear Chemistry Elin is performing reactivity experiments on austenitic steels. She is making good progress and has developed her knowledge and skills in the relevant chemistry that she didn't have with her in her diploma. She is studying the kinetic and mechanistic reactivity of hydrogen peroxide on stainless 304L powder in solution. She has been working on writing a review paper during 2017, to be finished early 2018.

H_2O_2 can be adsorbed at the surface of the metal and subsequently split into two adsorbed hydroxyl radicals. Hydroxyl radicals can also be adsorbed on the surface and produce H_2O_2, see figure 24 below.

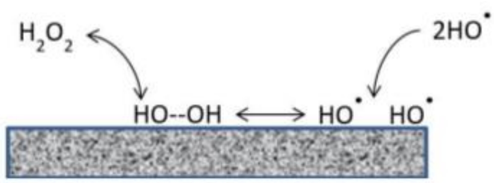


Fig. 24.

Hydrogen peroxide displays a low reactivity towards AISI 304-L, see figure below. A high yield of formaldehyde, and thus a high yield of hydroxyl radicals is also seen, indicating catalytic decomposition as the main reaction path. The low concentration of metal components in solution indicates only a small fraction of oxidative dissolution, which leads to the same conclusion.

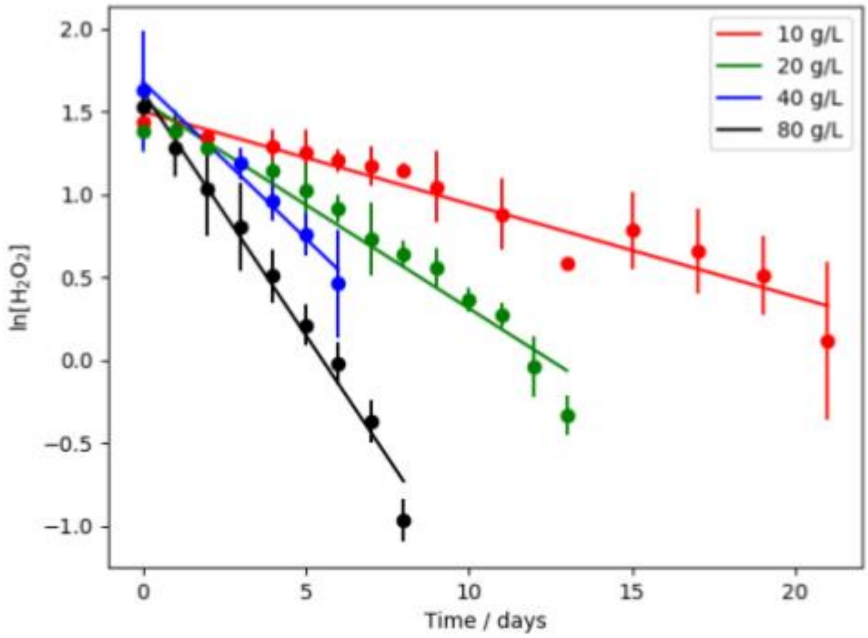


Fig. 25. Reactivity of hydrogen peroxide with 304-L steel. The decomposition exhibits a first order rate behaviour.

Publications and presentations

E. Toijer, M. Jonsson, *Radiation Induced Corrosion of Steel – Impact of Water Radiolysis*, 30th Miller Conference on Radiation Chemistry, 7-11/10 2017, Castellammare del Golfo, Italy.

Björn Dahlgren, Annika Maier, Elin Toijer, and Mats Jonsson, *Interfacial Radiation Chemistry – Fundamentals and Applications in Nuclear Technology*, INCC 2017. Göteborg 27/8-1/9 2017

MÅBiL fuel diagnostics

Research leader: **Peter Andersson**
Other participants: Dr. Scott Holcombe (HRP), Dr. Terje Tverberg (HRP), Dr. Wolfgang Wiesenack (HRP), Prof. Ane Håkansson (UU) and Ass. Prof. Staffan Jacobsson Svärd (UU)

Overview

The OECD Halden Reactor Project (HRP) is a world leading laboratory for research on the behaviour of nuclear fuels and materials in a reactor environment. Uppsala University has since many years established collaboration with the HRP in the field of nuclear fuel diagnostics that continue to be developed in the MÅBiL fuel diagnostics project. The direct aims of this project are listed below (from the original project plan).

1) To develop analysis methods for evaluation of nuclear fuel behaviour in connection to transient and accident scenarios.
2) To perform evaluation of fuel behaviour in the experiments performed in past and present at the HBWR.
3) To contribute to the development of Accident-Tolerant Fuels

4) To follow the research done in the OECD-HRP and contribute to the knowledge transfer to the Swedish industry.

Corresponding to aim 1, we have proposed the new measurement application of the gamma-emission tomography to obtain cross-sectional images of the relocated fuel distribution of high-burnup test fuels exposed to LOCA simulations in the Halden LOCA test series. The LOCA scenario is limiting to the burnup achievable in nuclear fuel due to the high degree of fuel fragmentation that has been observed at high burnups (above 50 GWd/ton). Therefore, an experimental campaign has been ongoing on the HRP over many years. We have identified that tomographic assessment of the test fuel at the site, prior to transportation to other PIE-facilities, would allow for a unique and detailed view of the state of the fuel when as conserved as possible. The first tests were carried out in 2016 and they were successful. In the LOCA experiment in 2017, the method was applied again, and the development of the analysis methods continues in order to enhance the information gained from the investigation.

Corresponding to aim 2 we have largely focused on experimental methods for non-destructive fission-gas measurements with the GET system. Here, rod-wise tomographic reconstructions have been performed to obtain the amount of ^{85}Kr in the fuel rods in the plenum region and ^{137}Cs in the fuel stack region. By accounting for differences in geometry and physical properties of the two nuclides, the released fraction of fission gas can be obtained. This was demonstrated in a NIM article in 2016. In addition, the use of the tomographic technique to identify leaker rods in commercial fuel assemblies (BWR and PWR) in poolside instrumentation has been investigated.

Activities during 2017

Reconstruction of fission gas content for leaker rod identification

In this year the focus has been on further development of the measurements of fission gasses using gamma emission tomography. A feasibility study was performed where pool-side instrument were considered for identification of leaking rods in an assembly. A number of candidate nuclides and gamma energies were identified and ^{135}Xe was selected for usage in this study. This isotope has a relatively high activity in the proposed time window 48 h after reactor shutdown. The transmission through a model of a fuel assembly plenum to detector positions was investigated using MCNPX. It was demonstrated that the 250 keV gamma peak from ^{135}Xe is possible to use for localization of the fuel rods of a test case PWR assembly with a burnup of 10 MWd/kgU and a release fraction of 1 %. Using the newly developed UPPREC reconstruction code, the fuel rod locations could be identified in the simulated tomograms.

The results have been reported in an article submitted and accepted for publication in WRFPM 2017 in South Korea. For future work, the utilization of migrating caesium nuclides (134 and 137) will be considered for investigation of leaking fuel assemblies. These isotopes are strong gamma emitters that can readily be examined in fuels of a broad range of cooling times, and they are potentially redistributed axially in the fuel rod as a result of fuel failures.

High resolution and quantitative tomographic reconstruction

A large effort has been made in order to enhance the quality of high-resolution GET of nuclear fuels by development of new algorithms and software for this purpose. As a result, the UPPREC code was created during the course of this MÅBiL project. The UPPREC algorithms were described in an article published in Annals of nuclear energy during 2017.

LOCA tomography

Quantitative Gamma Emission Tomography methods were used for to obtain the packing fraction of relocated fuel fragments in the balloon formation of high-burnup fuel rods. The results from the first application of this technique were presented at EHPG 2017, in Lillehammer. The technique, developed during the course of this MÅBiL project offers a unique capability to measure the fuel distribution of relocated fuel in a balloon in close vicinity of the test reactor, where the fuel can be transported with little perturbation of the state of the fuel.

In addition, a new LOCA-rod measurement was performed in December 2017, the latest LOCA transient test in the Halden reactor. This time, the rod was examined both before and after the execution of the transient simulation, which provides a before/after comparison of the fuel distribution in the rod. The overall aim of this test was to examine the influence on fuel relocation by the restriction to the cladding extension provided by a spacer grid.

The obtainable precision of packing fraction estimates based on the UPPREC reconstructions was examined using the Monte Carlo radiation transport code MCNP.

Plans

During the next year, the MÅBiL fuel diagnostics project will finish. The final efforts will be focused on presenting the method development and the fresh results from the LOCA tomography project.

The developments made during the MÅBiL fuel diagnostics will continue under a project financed by the Swedish Research Council (VR), which is focused on enhancing the spatial resolution obtainable in Gamma Emission Tomography of irradiated nuclear fuels. The objective in this project is to obtain an instrument design that offers a resolution of < 100 µm, which would constitute a non-destructive assay of nuclear fuels with microscopic capability, at the material test reactor site. The aim is to apply this technique on test fuels and claddings for Generation IV. However, the proposed technique may be similarly useful on e.g. accident tolerant fuels for today's generation of nuclear power plants.

Publications during 2017

P. Andersson, S. Holcombe, *Feasibility Study of Using Gamma Emission Tomography for Identification of Leaking Fuel Rods in Commercial Fuel Assemblies*. WRFPM 2017.

P. Andersson, S. Holcombe, *A computerized method (UPPREC) for quantitative analysis of irradiated nuclear fuel assemblies with gamma emission tomography at the Halden reactor*, Annals of Nuclear Energy https://doi.org/10.1016/j.anucene.2017.06.025.

P. Andersson, S. Holcombe, T. Tverberg, *Quantitative Gamma Emission Tomography inspection of LOCA rod IFA-650.15*, EHPG, 2017.

ICEWATER

Ph.D. student: **Erki Metsanurk**
Main supervisor: Prof. Mattias Klintenberg

Overview

The aim of the ICEWATER project is to design and build testing equipment for studying irradiation assisted stress corrosion cracking (IASCC) in different types of austenitic stainless steels. Whereas crack initiation and propagation studies using pre-irradiated materials have been fairly common, very few have been performed to assess the synergistic effect of irradiation and chemical environment. In addition, IASCC susceptibility tests performed on neutron-irradiated materials are expensive, time-consuming and require special handling and machinery due to high residual activity. Because it has been shown that the damage created by protons is similar in nature to that of the neutrons, but can be performed in much quicker, cheaper and safer ways, it could possibly pave way for more systematic studies behind the underlying mechanisms of IASCC.

In 2014 the planning was carried out which included theoretical understanding of IASCC and previous experiments.

In 2015 the water heating and circulation loop was built and tested, in addition the mechanical testing of different window (which separates the beamline vacuum and the high-temperature high-pressure environment) thicknesses and materials was performed.

In 2016 the loading cell and mechanism was designed and first irradiation tests on the window materials performed.

In 2017 the work branched out into solving several technical hindrances that would otherwise prevent the experiments to run successfully.

Local heating

The most important technical issue to be solved is the suppression of local temperature increase both in the sample and the water next to that. During 2017 we have investigated it in more detail and have much better understanding; however there is still work to be done. By design, the environmental cell has a weak point, a thin window through which the protons can pass. The strength of this window puts the upper limit on the internal pressure. At the same time the water has to be liquid at a temperature of about 300 °C which constrains the lower limit of the pressure and moreover to prevent local boiling it needs to be as high as possible. Optimizing for those constraints, results in narrow margins for both the window thickness and the possible pressures. Adding the effect of heating by the proton beam however can, and for reasonably high currents will, push the design out of these margins. The thin channel between the window and the sample will severely restrict the water flow and hence heat transport away from the beam spot.

Finite element analysis has shown that the temperature can under some conditions increase by up to 50 degrees under some conditions which would result firstly in steam rather than water environment and secondly unknown and uncontrollable temperature of the sample. We have performed both modelling and ambient environment experiments in order to better understand the issue. However, only experiments with the proton beam can fully characterize the resulting effect. We were not able to perform those in 2017 due to lack of fast closing valves in the beamline that would prevent the water from entering in case of a window rupture. Funding was acquired for the valves through a successful VR project part of which was the purchase of the necessary equipment.

Modelling

Due to the complex mechanical, thermal and flow constraints, the solution to the heating problem has to incorporate in one way or another computer simulations. Those help with understanding the stress, heat transport and flow profiles. It is however easy to neglect contributions either due to the model imperfections or overall problem complexity. On the other hand it is much more expensive and time-consuming to build and modify experiments.

Therefore the best solution is to combine both. A good and relevant example of that is the deformation of the window under pressure. A simple elastic model predicted tremendous stress in it which on one hand shows that the use of this model is improper, but also that it is likely that the material would fail either by deforming too much or even rupture. However, pressurization experiments under the same conditions showed the strength to be much higher than assumed and the material deforming much more than in simulations which would be attributed to plasticity.

To improve this part of the model by incorporating hardening we performed tensile tests in collaboration with the Applied Mechanics division at Ångström laboratory. Compared to the pressurization tests, the materials showed a lot less plasticity which made us reinterpret the pressure test results. A considerable amount of the deformation of the window in the pressure tests is likely due to it slipping out of its holder. This allows us to take it into account in the design of the window holder. Similar improvements are to be expected in 2018 for solving the other aforementioned issues.

Miscellaneous

- Part of the solution to the local heating problem is that a flow must exist between the window and the sample. During 2017 we came up with several possible ideas that could allow for that which include using the sample as a water inlet and combining the sample and window together into a single unit. In any case, as opposed to previous standard solution, all of those are novel and require preliminary testing, both in simulations and experiments, before being integrated into the final device. Work has been started in that direction.

- One solution to the possible window slipping is to manufacture the window and the window holder as a single part using additive manufacturing. There have been discussions regarding that matter during 2017.

- A backpressure regulator that keeps the system under desired pressure broke and was subsequently fixed during 2017. Instead of buying a repair kit we identified the broken part and asked it to be manufactured locally at Ångström workshop. This has the benefit of obtaining the part quickly and cheaply in the case of future breaks which are not unlikely. The probable cause of the failure was repetitive pressurization and rupture tests. In case of the rupture the pressure in the system will drop rapidly due to the low volume of water in the system having low inertia and that can induce rapid movement of parts inside the regulator which could result in a failure.

- The expected power density profile and damage in the window, water and sample can be calculated using SRIM (The Stopping and Range of Ions in Matter). It involves another series of optimizations since the upper energy of the protons is limited by requiring minimal activation and the lower energy by requiring the protons to hit the sample. There is also an expected lower damage threshold in order to induce IASCC. Unfortunately is has become apparent that different models within SRIM and by post processing its output can result in considerably different damage. In addition some of the discrepancies might also be attributed to bugs in the code. During 2017 some of the time was spend on attempts to reverse engineer the crucial parts in SRIM in order to understand the discrepancies. The work has not been finished yet, but it is likely that it will and in addition to being useful for the project could have an important contribution to a larger community who uses this program more often.

- Most of the work in 2017 has been theoretical. In order to proceed with the testing of all the gathered ideas, it is absolutely crucial that there exists a way to perform rapid prototyping, especially for the mechanical components. Practice has shown that realizing seemingly trivial ideas can for one reason or another take a lot longer than expected and that can hinder the progress quite significantly. We have been in contact with an engineering company that is specialized on mechanical and electronic prototyping and could provide the necessary collaboration.

Attended meetings

"EDDE Workshop on Dissipation Models", May 15-19, 2017, Leesburg, USA

Future plans

- Acquire fast protection valves and other necessary equipment for the beamline in order to proceed with proton irradiation experiments in water environment.
- Find a way to do faster mechanical prototyping in order to test all the possible solutions for current problems, mainly for the local heating one.
- Improve the knowledge and practical skills in mechanical, thermal and fluid dynamics simulations in order to guide the design.
- Build the final device.
- There are currently no publications but both the results and design improvements to the local heating issue will be of solid importance and easily publishable. Similarly in case the doubts about the SRIM bugs turn out to be true, it will certainly have a broader impact than just for this project alone.

Total Monte Carlo for fuel and material

Ph.D. student: **Petter Helgesson**
Main supervisor: Ass. Prof. Henrik Sjöstrand

Overview

In this project, we connect macroscopic fuel and aging parameters to the fundamental nuclear physics processes by using the world leading nuclear model code TALYS and the Total Monte Carlo method (TMC) [1]. With a Talys based code package, nuclear data libraries can be produced for all isotopes, reaction channels, and secondary particle productions for the entire nuclide map. This so-called TENDL library is in that respect superior to classical libraries such as ENDF/B-VII and JEFF3.0. Furthermore, the TENDL library has the advantage that it can produce complete covariance information, which is essential to calculate proper damage metrics.

In the project, we are using and improving the TENDL and JEFF library to address material issues coupled both to fuel and aging performance, such as flux at the reactor vessel, gas production, and input parameters to DPA calculations. The goal is to quantify these parameters including their uncertainties. The project is also part of the IAEA Coordinated Research Project: Primary Radiation Damage Cross-Sections [2]. One of the most important parts of this work is to calibrate the model input parameters and their uncertainties by using differential and integral experimental data. During 2017 we have found that by using Gaussian Processes (GP, see below) many of the issues coupled with nuclear data calibration, can be addressed.

Gaussian Processes

When model defects are present, the model for the underlying nuclear physics does not exactly reproduce reality, no matter what parameters are chosen for the model, i.e. when fitting a defect model to data, the results can become very misleading by introducing a bias which supersedes the estimated uncertainty. One way to treat model defects in a systematic way is to model the defect using a Gaussian Process (GP). A GP is a collection of random variables, any finite number of which has a multivariate normal distribution. We express the experimental data; their uncertainties; the model; and a model defect modelled by a GP as,

$$\mathbf{Y} = \mathbf{f}\left(\mathbf{x};\boldsymbol{\beta}\right) + \boldsymbol{\varepsilon}_{\mathbf{m}}\left(\mathbf{x}\right) + \boldsymbol{\varepsilon}\left(\mathbf{x}\right)$$

where **Y**[2] is the random vector from which experimental data is drawn from, $\mathbf{f}\left(\mathbf{x};\boldsymbol{\beta}\right)$ is the model, **x**, is the vector of the independent variable, $\boldsymbol{\beta}$is the parameter vector, $\boldsymbol{\varepsilon}\left(\mathbf{x}\right)$ is the measurement uncertainty, $\boldsymbol{\varepsilon}_{\mathbf{m}}\left(\mathbf{x}\right)$ is the model defect:

$$\boldsymbol{\varepsilon}_{\mathbf{m}}\left(\mathbf{x}\right) = \left(\varepsilon_m\left(x_1\right), \varepsilon_m\left(x_2\right), \varepsilon_m\left(x_3\right), \varepsilon_m\left(x_4\right) \ldots\ \varepsilon_m\left(x_n\right)\right),$$

where, in turn, $\varepsilon_m\left(x\right) : \ GP\left(0, k(x,x')\right)$, prior to observing the data for some choice of the covariance function $k(x,x')$. By model the model defect using a GP, and fit the model parameters and the GP to the experimental data simultaneously, it is possible to both reproduce experimental data, and obtain a good description of the underlying physics. It is possible to work with the GP both in the parameter and observable domain.

Reached milestones for the project

1. One of the main goals was to publish methods that better takes into account the experimental differential data to calibrate the nuclear data and its uncertainties and to apply these methods to reactor-relevant structural materials. Articles in Nuclear Data Sheet [3] (2014), Progress of Nuclear Energy [4] (2017), and Nuclear Inst. and Methods in Physics Research A [5] (2016) have addressed these issues as well as [ISRD16] and [Non-linear] (2017). During 2017 the GP (see [Non-linear], [PRAGUE]) have been developed, in order to be able to apply them to Fe-56 before the end of the project.

2. In reference [4] (2017) uncertainties in the effectiveness of using so-called "shielding assemblies" aiming to extend the life of pressurized water reactors was reported. The uncertainty was determined to be 2%, but there are some indications that the uncertainty might be bigger and consequently, we will continue to work with this application. See above.

[2] Boldface for vector notations.

3. To improve the He production prediction and to provide nuclear data uncertainty estimates, new ^{59}Ni cross section data has been produced. The work is accepted for JEFF3.3 and published [6] (2017).

4. One of the goals was to publish methods to better take into account the use of integral data. This has been done [7] and also improved during 2017 [PRAGUE2]. However, the methods need to be applied to material relevant problems.

5. The impact of Nuclear Data on different fuel configurations was thoroughly studied in Ref [6], including also fission yield uncertainties.

6. In respect to fission gas uncertainties, some preliminary work has been performed [9], and the new work in [Non-Linear] addresses fission yield determination, in particular.

As mentioned in previous reports, the work within MÅBiL has shifted away from SiC to structural materials (e.g., Fe and Ni).

Activities during 2017

During 2016 a new evaluation of Ni59 was completed. Beginning 2017 final preparation and submission of *"Uncertainty driven nuclear data evaluation including thermal (n,α): applied to 59Ni.* " was completed and accepted. The Ni59 file was also finally accepted in the JEFF3.3 library.

In respect to the challenges with calibrating damage metrics to large experimental databases, most of the challenges were outlined in Ref [4], where the consequences concerning model defects, too rigid co-variance matrix and inconsistent experimental data is described. To address different calibration methods, we have continued to work with synthetic-data resembling the prompt fission neutron spectrum which can be important for different damage metrics. In this work, Monte Carlo methods based on Unified Monte-Carlo (UMC-B), classical Generalized Least Squares (GLS) and novel methods based on using the Levenberg Marquardt (LM) method with a prior were tested. The results were presented at Sixteenth International Symposium on Reactor Dosimetry in Santa Fe, NM, together with colleagues from Los Alamos and IAEA and were well received. A conference paper was also prepared and submitted [ISRD16]. We have found that LM and UMC-B perform worse when model defects are present, which makes sense since the model is never abandoned. When there are no models defects, LM and UMC-B perform better both in precision and accuracy compared to GLS when the distribution is non-Gaussian. However, the GLS method seems to estimate the uncertainty better. As seen, there is no silver-bullet yet found for damage metrics calibration. The work also indicated that GP could be advantageous in treating the model defects.

GP together with a non-linear Generalized least square fitting routine [Non-linear] were subsequently used to address the problems of model defects. The problem addressed was fission yield determination at IGISOL. The corresponding paper [Non -linear] was chosen *Editors pick*. The work showed that the use of GP and realistic prior information could substantially improve the analysis of the data.

During 2017 GP was also developed for the parameter domain to address model defects in TALYS. This was done by un-constraining the parameters in the energy domain (See figure 1). I.e., the parameters are allowed to become energy dependent around a parameter β.

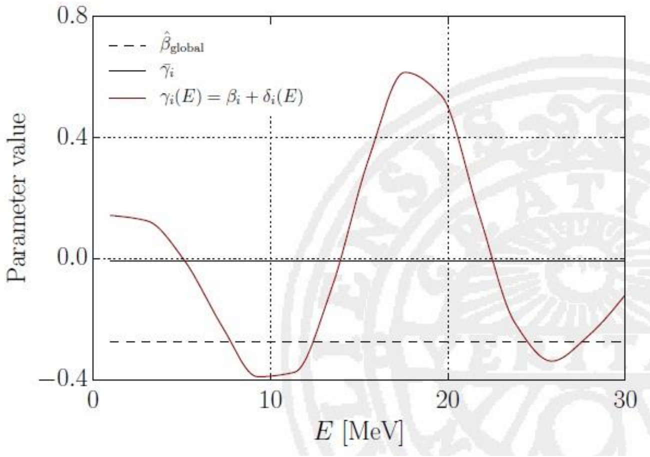


Fig. 26. Illustration of the use of GP in the parameter domain. Normally the parameters are energy independent, but here we allow the parameters to vary with using a GP.

This will allow for addressing model defects for multi-channel physics (i.e., the reactions in iron). The first results were presented at a TENDL workshop [Prague]. The results, so far are very promising, and it seems as if the use of GP in the parameter domain can address the problem of model defects in TALYS. Figure 2 illustrates the deviation between a fit to an assumed truth from a synthetic data study using a TALYS like model. As can be seen, the use of GP (red) substantially improves the result.

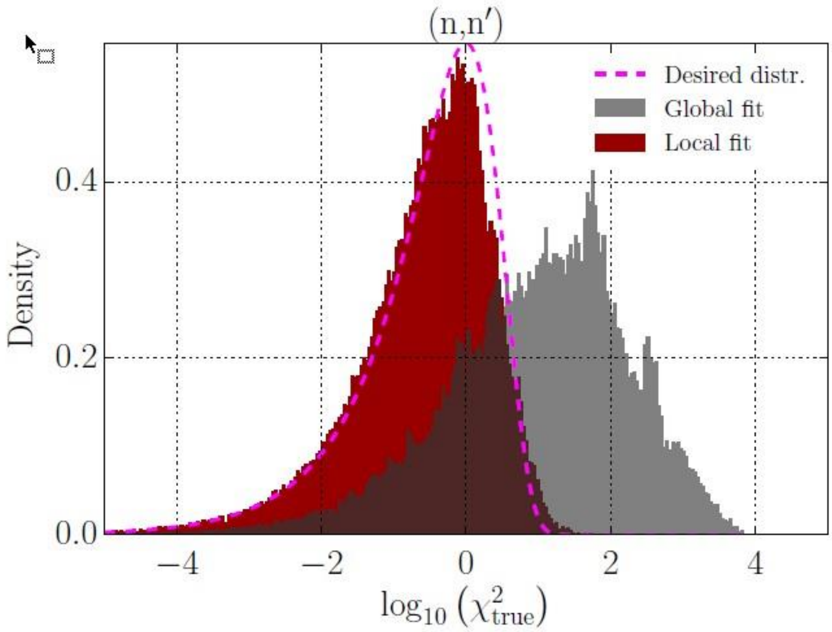


Fig. 27. Results on a synthetic data study (140 000 points). Allowing the parameters to be energy dependent using GP (red) or using classic fits (grey). The example here is the inelastic cross-section of Fe56, important for damage calculations.

In addition, during the year the methods to calibrate nuclear data using integral experiments were also improved [Prague 2]

Plans

By integrating and expanding on the findings from this and previous quarter to the TALYS code package, we intend to produce well calibrated DPA, including covariances, for iron to be used by the material damage community.

In addition, the PhD-thesis is planned to be presented in Q2 of 2018.

References

[1] A. Koning and D. Rochman, Nucl. Data Sheets 113,2841 (2012).

[2] https://www-nds.iaea.org/CRPdpa/.

[3] P. Helgesson, H. Sjöstrand, A.Koning, D.Rochman, E.Alhassan, S.Pomp Incorporating experimental information in the TMC methodology using file weights Nuclear Data Sheets, Volume 123, 214–219, 2015.

[4] P. Helgesson, H. Sjöstrand, A.J. Koning, J. Rydén, D. Rochman, E. Alhassan, S. Pomp, Combining Total Monte Carlo and Unified Monte Carlo: Bayesian nuclear data uncertainty quantification from auto-generated experimental covariances, Progress in Nuclear Energy, Volume 96, Pages 76-96, April 2017.

[5] P. Helgesson, H. Sjöstrand, A.J. Koning, J. Rydén, D. Rochman, E. Alhassan, S. Pomp, Sampling of systematic errors to estimate likelihood weights in nuclear data uncertainty propagation, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 807, 21 January 2016, Pages 137-149, ISSN 0168-9002, http://dx.doi.org/10.1016/j.nima.2015.10.024.

[6] Helgesson P., Sjöstrand H., Rochman D.; "Uncertainty driven nuclear data evaluation including thermal (n,alpha): applied to Ni-59"; Journal: Nuclear Data Sheets; Vol: 145; DOI: 10.1016/j.nds.2017.09.001; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-315678; (2017).

[7] E. Alhassan, H. Sjöstrand, P. Helgesson, M. Österlund, S. Pomp, A.J. Koning, D. Rochman, On the use of integral experiments for uncertainty reduction of reactor macroscopic parameters within the TMC methodology, Progress in Nuclear Energy, Volume 88, April 2016, Pages 43-52, ISSN 0149-1970, http://dx.doi.org/10.1016/j.pnucene.2015.11.015.

[8] P. Dimitriou, F.-J. Hambsch, **S. Pomp** FISSION PRODUCT YIELDS DATA, Current status and perspectives, Summary report of an IAEA Technical Meeting,IAEA Headquarters, Vienna,23 – 26 May 2016.

[9] [ISRD16] Helgesson P, Neudecker D, Sjöstrand H, Grosskopf M, Smith DL, Capote R. Assessment of Novel Techniques for Nuclear Data Evaluation. Presented at 16th International Symposium on Reactor Dosimetry (ISRD16). Available from: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-322558.

[10] Helgesson P, Sjöstrand H. Fitting a defect non-linear model with or without prior, e.g., to distinguish nuclear reaction products. Submitted to Review of Scientific Instruments. Available from: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-326313.

[11] Helgesson P., Sjöstrand H.; "Treating model defects with a Gaussian Process prior for the parameters"; Conference: Workshop on TALYS/TENDL developments, 13-15 November 2017, Prague; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-339285; (2017).

[12] Sjöstrand H., Helgesson P., Alhassan E.; "TENDL adjustments using integral benchmarks"; Conference: Workshop on TALYS/TENDL developments, 13?15 November 2017, Prague; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-339210; (2017).

Amorphous alloys for the nuclear industry

Ph.D. student: **Maciej Kaplan**
Main supervisor: Prof. Björgvin Hjörvarsson

Finances

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Co-financed by the materials physics research programme.

Background

Amorphous alloys (or metallic glasses) lack long range periodicity compared to their crystalline counterparts. The disordered (amorphous) atomic structure gives rise to many useful properties, such as lack of dislocations and grain boundaries. The latter, of which is believed to play a major role for diffusion of interstitials, influences corrosion in a profound way. High temperature application of amorphous alloys is still a challenge due to the limited thermal stability of the known materials. The properties of amorphous alloys are strongly dependent on their chemical composition, which is both a challenge and a possibility: It is possible to strongly alter the thermal stability through changes in composition. Amorphous alloys are not well understood and there is a significant lack of theoretical predictive power with respect to material properties.

We have chosen a quaternary system, Zr-Nb-Cr-Mo as the next step in the exploration of the stability of amorphous alloys. A thermodynamic database was constructed and calculations were made using the Calphad method (Calculations of Phase Diagrams). Calphad relies on data from Density Functional Theory (DFT) and experiments which then allows calculating the Gibbs energy of phases in alloy systems with respect to composition and temperature. Calphad is an excellent tool for assessing phase diagrams of alloy systems. It can be used for predicting phase equilibrium, which can be used to capture the crystallisation of amorphous alloys. The aim is to increase the predictive power of these tools using a combined experimental and model based approach. This we do by making amorphous alloys using combinatorial sputtering synthesis, evaluation of the thermal stability of the samples and by thermodynamic calculations of the expected phase stability. By this approach we both develop the understanding of amorphous materials as well as building the required knowledge base for utilising this class of materials for nuclear applications.

Project activities

Mapping the amorphous zone in the Zr-Nb-Cr-Mo system was finalised in early 2017. We used the so called combinatorial approach: The samples consist of thin films with composition gradients, thus each sample contain a wide range of compositions. By measuring properties, such as atomic order, locally, we obtain information on the thermal stability in a highly efficient manner which accelerates the exploration of the available phase space significantly. The sputtering process was optimised to allow production of films which are thick enough (without cracking and delamination) for characterisation of mechanical and electrochemical properties. The films were successfully grown in mid-2017 and the evaluation of mechanical and electrochemical properties were initiated later in 2017. The earlier planned resistivity setup for evaluation of thermal stability has been partly replaced by differential scanning calorimetry (DSC). Evaluation of thermal stabilities in the Zr-Nb-Cr-Mo system using DSC will be performed in early 2018. Sample preparation for such measurements is time consuming, hence a combination of DSC and X-ray reflectivity (XRR) will be used in the planned studies. In-situ XRR heat treatments will be performed to efficiently screen through compositions in an alloy system.

A thermodynamic database for the Zr-Nb-Cr-Mo system was created. This enabled prediction of the high melting points using Calphad, which are otherwise difficult to access experimentally. It is also likely that equilibrium crystalline phases play a role for thermal stability (and formation) of amorphous alloys, these can now be assessed. The following step is to relate precipitating phases to thermal stability: some phases nucleate and grow slower than others, which could be used to increase the thermal stability.

The project has developed significantly during 2017 as we have developed an approach that provides compositional screening with high throughput. Furthermore, the access to literature data allowed the construction of a database for the Zr-Nb-Cr-Mo system, which enabled calculations of melting points and phase fractions. These can also to some extent be verified by experiments when evaluating thermal stability. The next step is to evaluate Calphad as a tool for alloy design by drawing conclusions from precipitating crystalline phases in amorphous materials. Designing new alloys could then start by looking into Calphad databases and choosing a system depending on its equilibrium behaviour. A well described system could possibly point toward favourable compositions.

Milestones

Fig. 28. Milestones and tasks for 2017-2018

Task	Milestone	Status
Microstructure evaluation at room temperature	Mapping of compositional region for amorphicity	Finished Q1
Constructing a thermodynamic database for Zr-Nb-Cr-Mo	Evaluation of Calphad as a predictive tool for amorphous alloys	Q2
Optimising sputtering process	Manufacturing samples without cracking/delamination	Finished Q2/Q3
Manufacturing samples for mechanical/electrochemical measurements	Enabling later experiments	Finished Q3
Sample preparation for DSC	Enabling experiments	Finished Q4
Nano-indentation measurements	Finding properties of the material	Started Q4
Electrochemical measurements	Finding properties of the material	Started Q4
DSC measurements	Finding thermal stability of alloys in Zr-Nb-Cr-Mo	Start first weeks of Q1 (2018)
Evaluation of in-situ XRR as screening method	Efficient compositional screening of combinatorial samples	Start early Q1 (2018)

Outlook

The understanding of the physical properties of amorphous alloys is still in its infancy. Substantial development is required for obtaining materials suitable for high-temperature applications in reactor environment. The increased interest for amorphous materials will certainly accelerate the process and the use of amorphous materials as a protective coating for fuel cladding stable above 1300 °C is therefore foreseeable. The combination of amorphous oxides and metals are most likely the first obtainable step in that direction. The use of Additive Manufacturing (AM) for fabrication of the metallic part, with a post processing for obtaining the oxide layers, are realistic in this context. Substantial synergy effects are therefore obtained with the close collaboration with the development of amorphous materials for AM, which takes place within a SSF project at the Ångström laboratory. The up-scaling of the production can be performed by AM, which will allow a rapid turnaround concerning the test of the materials in nuclear environment.

PhD student in Influence of thermal and irradiation induced ageing in Low Alloy Steels

- Ph.D. student: Magnus Boåsen
- Supervisor: Pål Efsing, Jonas Faleskog

Funds spending

Cost of salaries: Covered by funding from SSM and NKS. No deviation from the budget. Supervision by Efsing was funded by agreement between KTH and Ringhals AB.

Activities within the project under 2017

Magnus has participated in the development of specifications for material extraction from the reactor pressure vessel at Barsebäck 2. The report has been distributed via NKS.

Magnus has been part of further publications published as a collaboration between CTH (Lindgren/Thuvander) and KTH (Boåasen/Efsing) regarding mechanical and microstructural properties of thermally and irradiation aged materials.

Milestones achieved during the period: Analysis of the material requirement for the implementation of fracture mechanics assessment of reactor pressure vessel at Barsebäck 2.