SKC Annual Report 2018

Swedish Centre for Nuclear Technology

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SKC 18-01

SKC, KTH / AlbaNova, Roslagstullsbacken 21, **SE-106 91 STOCKHOLM**
www.swedishnuclear.se, dwestlen@kth.se +46 (0)73 819 53 96

2018 – A summary

In 2018, especially in the autumn, a shift in the view on nuclear power around the world could be noticed. Nuclear energy was increasingly seen as an important part of the solution to climate change. Not the least, this view was strengthened when the IPCC 1.5-degree pathways report was published. IPCC presents four scenarios, all four with a massive expansion of nuclear power globally ranging from +60 % to +100 % for 2030 and +100 % to +500 % for 2050. Also the European Commission points out nuclear power as, together with wind and photovoltaics, as the backbone of the future European energy system.

The recent difficulties to construct new reactors on time and at a competitive cost in France, the UK, Finland, and the US indicate that there is a need for innovation in nuclear design and construction. But in combination with the need to expand nuclear it also stresses that the efforts to keep the existing reactors online should be intensified. SKC contributes to this effort e.g. by supporting research in materials science aimed at ageing effects in reactor construction materials necessary for long-term operation of the existing plants, and also by supporting research on nuclear fuels.

During 2018 nine new reactors were connected to the grid globally, seven reactors closed permanently. On New Years Eve, 450 reactors were in operation, and 55 more were under construction. The total installed capacity globally was just under 400 GWe.

In Sweden the eight reactors in operation had a good year. Nuclear power was Sweden's main source of electricity, surpassing hydro for the first time in many years.

SKC activities in 2018

The Swedish Centre for Nuclear Technology (SKC) aims at contributing to a safe, efficient and reliable nuclear energy production. The importance of a well-functioning nuclear power production to the wealth of the Swedish society is fundamental. Ensuring nuclear safety is a prerequisite while e.g. making life time extension for the reactors possible has major impacts on the economy of reactor operation and on the economy of society as a whole. Several research groups funded by SKC are involved in research to allow long-term operation of the reactors, the activities at Chalmers, KTH and Uppsala University are further described under the respective sections in this report.

The nuclear business depends on structures in academia to address research needs arriving from the operation of the reactors, from the desire to continue operating the reactors beyond their original design-lives, and from other associated fields such as dismantling of reactors and waste management. The business and its associated authorities, suppliers, and also the political environment has a never ending need for skilled staff trained in the principles of nuclear power. The structures in academia also have the role to provide high quality education that interests students and attract them to the field of nuclear engineering. SKC has the task of supporting the universities in developing teaching and courses, and also in establishing collaboration to make good use of the geographically distributed resources.

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

During 2018, SKC participated in the student fairs at Chalmers (Charm) during two days, at Uppsala University (Utnarm) which lasts one day, and at KTH (Armada) for two days. There is large interest from students in our industry. The SKC stand at all three universities was manned by employees from the powerplants, supported by the SKC director and one person from the host university. This was a successful setup as it made it possible to have relevant discussions both with students in their last years having an interest in the opportunities our industry offers, as well as with students in their first years interested in courses in nuclear technology.

The interest at the student fairs signals that more activities aimed at students should be developed. The SKC financers could become more involved in the courses. Likewise, the researchers should be deeper involved in the activities of the financers to get a better understanding of which areas involve research needs.

The Sigvard Eklund Prize to the best Ph. D. thesis of the year was awarded to Klas Jareteg from Chalmers for his Development of fine-mesh methodologies for coupled calculations in Light Water Reactors. Anna Benarosch, KTH, received the prize for the best masters' thesis for her work on U_3Si_2 pellets for LWR applications. Daniel Karlsson, KTH, received the price for the best bachelor thesis for his software to speed up simulations of radiation damage in materials. The prize ceremony was held at the SKC annual symposium, October 16.

SKC changed director on 2018-09-01 when Hans Henriksson was replaced by Daniel Westlén. Also Tysse Nordlindh Falk who has been managing the administration left SKC in the late autumn.

SKC is well prepared for its role to support Swedish research and education in nuclear technology. The end of 2018 marks 26 years of fruitful collaboration between the industrial and regulatory stakeholders and the academic environment.

Stockholm 2019-03-29,

Daniel Westlén, SKC Director

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SKC-Partners, Tasks and Goals

The Swedish Centre for Nuclear Technology – (Svenskt Kärntekniskt Centrum, SKC) was originally founded in 1992 under the name of KTC, Kärntekniskt Centrum, at KTH. Later, the centre was expanded to include also Uppsala University and Chalmers. The centre is a collaboration administrated at the School of engineering sciences at KTH (KTH/SCI). The SKC collaboration follows a three-year contract. The resent contract expires 2019-12-31.
The partners in the SKC collaboration are, from the nuclear industry (financing parties):

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

And from academia:

- Chalmers University of Technology
- KTH Royal Institute of Technology
- Uppsala University

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 areas:

- 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 2018 have been to: 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 2017-01-01. 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 2018, 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 2018 by Anna Alvestav as observer. The director have acted as secretary of the meetings.

During 2018, the SKC Board consisted of:

- Karl Bergman, Chairman, Vattenfall AB
- Peter Wedin, Forsmarks Kraftgrupp AB
- Pontus Tinnert, replaced by Jan Karjalainen 2018-10-16, both at Oskarshamns Kraftgrupp AB
- Henric Lidberg, Ringhals AB
- Anders Andrén, Westinghouse Electric Sweden AB
- Leif Kari, KTH Royal Institute of Technology
- Olof Karis, Uppsala University

- Leif Åhman, Chalmers University of Technology
- Anna Alvestav, Strålsäkerhetsmyndigheten – observer
- Dag Svensson, Vattenfall AB – observer (until 2018-11-30)

SSM was represented in the Board according to the SKC contract that allows an observer status for the regulator. Also the head of human resources from Vattenfall's Business Area Generation has been invited to the meetings as an observer.

Four board meetings were held in 2018. The Director of SKC attends the Board meetings, reports the progress as well as presents proposals to the board.

The Director also has an observer position in the SSM Research Board.

SKC Financial statements 2018

SKC – Income (SEK)

Payment Forsmarks Kraftgrupp AB	2 380 000
Payment Oskarshamns Kraftgrupp AB	793 333
Payment Ringhals AB	3 173 333
Payment Westinghouse Electric Sweden AB	2 116 667
Total payments	8 463 333

SKC – Expenditures (SEK)

Payment Chalmers	- 2 500 000
Payment KTH	- 2 200 000
Payment UU	- 2 800 000
Payment SKC administration	- 963 333
Payments total	- 8 463 333

French laboratory exercises (SEK)

Balance 2018-01-01	3 751 231
Laboratory exercises (1)	- 1 185 810
Travel costs student exercises (2)	- 475 775
Support to university collaboration in France (3)	- 459 000
SKC administrative fee	- 250 000
Balance 2018-12-31	1 380 646

(1) Concerns 2017

(2) The travel expenses concern trips for student exercises during both 2017 and 2018.

(3) The SKC board made the decision in its meeting 2018-03-22 to recommend KTH to allocate funds from the French account to strengthen the research. This was seen as complimentary to the student exercises. The payments would be made in 2018 as well as in 2019. Payments to UU for 2018 (164 000 SEK) are still pending and not included in the figure.

SKC Symposium

The 2018 version of the SKC symposium was held 16-17 October at the Albanova University Centre, hosted by KTH. University activities and the SKC sponsored projects were presented. Eero Vesaoja, head of nuclear research and development at Fortum held a key note presentation on the trends Fortum see that affect research in the field of nuclear technology.

A poster session proceeded the dinner which was held at Syster och Bror. The acapella group Barbercue provided the entertainment.

The second day of the seminar was focused on presentations of the PhD-projects. This provided an insight into the progress of the individual projects and also gave the PhD-students and faculty members a better understanding for the research performed at the three universities.

Rauli Partanen, author of several books on climate change and the role of nuclear energy in curbing it, held a keynote speech to introduce the panel discussion. The panel elaborated on how nuclear technology may contribute to solve the major challenge of our time and what nuclear research can do to make the solutions possible.

The Sigvard Eklund Prize

Every year, SKC rewards the best PhD thesis, Master thesis, and Bachelor thesis within the field of nuclear technology in Sweden. The prize is awarded in the memory of Sigvard Eklund, most well known for being the Secretary General of the IAEA 1961-1981.

Fig. 1.The Sigvard Eklund Prize Winners, from the left: Daniel Karlsson, Klas Jareteg, Daniel Westlén (Director SKC), and Anna Benarosch

The Sigvard Eklund Prize to the best Ph.D. thesis of the year, 50 000 SEK, was awarded to Klas Jareteg from Chalmers for his Development of fine-mesh methodologies for coupled calculations in Light Water Reactors. Anna Benarosch, KTH, received the prize for the best masters' thesis, 35 000 SEK, for her work on U3Si2 pellets for LWR applications. Daniel Karlsson, KTH, received the price, 25 000 SEK for the best bachelor thesis for his software to speed up simulations of radiation damage in materials.

CHALMERS
UNIVERSITY OF TECHNOLOGY

Chalmers

Overview of Activities in 2018

The following Chalmers divisions/departments are engaging actively in research 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.

The nuclear research environments are very active, in particular within international research projects. Several EU-funded projects are in progress with Chalmers involvement (both as coordinators and participants). Thus, Chalmers has contributed strongly to attracting international funding for supporting the Swedish nuclear competence base and nuclear research infrastructure.
Much of the strategic nuclear research is coordinated in the national centre SAINT (Swedish Academic Initiative in Nuclear Technology Research). The centre 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

Use of the SKC funding

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

Subatomic and Plasma Physics, Dept. of Physics. 500 kkr, (463 kkr: salaries and overhead for C Demaziére, A Nordlund and P Vinai, 37 kkr: travels and guest researchers)

Nuclear Chemistry, Dept. of Chemistry and Ch. Engineering: 250 kkr, (233 kkr: salaries and overhead for A Herman and C Ekberg) (Not all base funding for 2018 used up due to parental leave A Herman, will be used during 2019)

Materials Microstructure, Dept. of Physics. 250 kkr, (232 kkr: salary and overhead for K Lindgren, 18 kkr travels)

In addition, two of the groups above are active in and receive funding within the MÅBiL project.

A project for e-learning, with separate funding, is also in progress together with Uppsala University.

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 60Co and 137Cs 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 2018:

- Effects of Irradiation and Thermal Ageing on the Nanoscale Chemistry of Steel Welds, Kristina Lindgren, PhD December 2018, supervisor Mattias Thuvander.
- Accident tolerant nitride based fuel, Aneta Herman; supervisor: Christian Ekberg.

Some noteworthy accomplishments during 2018:

- Klas Jareteg received the 2018 Sigvard Eklund Prize from SKC in the PhD category
- Lars G. Larsson was nominated and elected as a Chalmers Honorary Doctor in 2018.
- Our former PhD student, Elter Zsolt, became the first recipient of the newly established "ENS High Scientific Council PhD Award" for his PhD work which he did at our Department in co-operation with the French CEA.

- Grants
  - Short summer CORTEX course on “Fundamentals of reactor kinetics and theory of small space-time dependent fluctuations in nuclear reactors”, with 16 on-site registered participants and 26 off-site registered participants, June 18-21, 2018 (the course was a hybrid and flipped course).
  - Eureka/Eurostars-funded project SEALION “Seaborg External multiphysics Architecture for Licensing and Ip development Of Nuclear reactors” in collaboration with Seaborg Technologies, DTU and DAES
  - SKC-funded project on “Validation Experiments for Coupled Reactor Physics Simulations” in collaboration with CEA Cadarache
  - Framework Grant on Strategic Energy Research "Research for future fusion reactors: using and avoiding impurities" (VR-grant 2014-5392, PI Tünde Fülöp)
  - International Career Grant "Integrative modelling of transport barriers in fusion reactors" (VR-grant 2014-6313, PI Istvan Pusztai).
  - Project grant "Runaway electrons in fusion plasmas" (VR-grant 2014-5510, PI Tünde Fülöp)
  - Marcus Hedberg got VR international post doc for investigation of nitride fuels
  - SSF approved the SAFETY project including one PhD student and one Post Doc for ATF nitride fuel manufacturing and recycling, supervisors Christian Ekberg and Teodora Retegan.
  - The next stage of the project "Ringhals Diagnostics and Monitoring 2018", which runs from mid-2018 to mid-2019, was granted and work is in progress.

- The Area of Advances "Energy" granted 100 kkr for translation of Imre Pazsit's popular science book "The discovery of nuclear fission - women scientists in highlight" to Japanese. The Japanese version was printed in November 2018 and a book release event will take place at the Swedish Embassy in Tokyo on 9 May 2019.

- Completed projects
  - Effects of Irradiation and Thermal Ageing on the Nanoscale Chemistry of Steel Welds, Kristina Lindgren, PhD December 2018, supervisor Mattias Thuvander.
  - NKS-project HYBRID “Development of a hybrid neutron transport solver in 2 energy groups”

- Visiting researchers
  - Sandor Zoletnik, Head of Research Unit for the Hungarian Fusion Association, visited 18-19 December and gave a talk with the title Filamentary turbulence (blobs) in the Wendelstein 7-X stellarator on 19 December.
  - Luke Stagner from UCI visited 12-23 November.
  - Gergely Papp from IPP Garching visited 10-14 September
  - Elizabeth Paul from UMD visited 9-15 June and she gave a talk on "Adjoint methods for neoclassical stellarator calculations" on 12 June.
  - Eva Macusova from Institute of Plasma Physics, Prague visited us 26 Feb - 9 March.
  - Oliver Linder and Gergely Papp from Max-Planck IPP Garching visited us 22-26 January.
  - Paavo Niskala from Aalto University visited us 12 January. He gave a talk with the title "Interplay of turbulence and flows in gyrokinetic simulations of tokamak plasmas".
  - Prof. Tomoko M. Nakanishi, The University of Tokyo, Japan, 24 - 27 January and 11 - 17 November 2018
  - Dr. Yasunori Kitamura, Kyoto University Institute for Integrated Radiation and Nuclear Science (KURNS), between 1 December 2017 - 30 May 2018, with Japanese financing, research collaboration on neutron fluctuations
  - Prof. Tsuyoshi Misawa, KURNS, 25 - 29 May 2018
  - Assoc. Prof. Máté Szieberth, Budapest University of Technology and Economics, Institute of Nuclear Techniques, 18 - 21 November 2018 (ERASMUS STA assignment, gave a minicourse on Monte-Carlo methods)

Education

E – learning

The purpose of the e-learning project is to lift the e-learning competence level among the project participants (Chalmers and Uppsala University) and to create educational material within the area of nuclear technology, aiming to inspire students at late high school/early university level to further studies within the field.

Activities and milestones

- For each of the nine radiation science related subject areas covered in this project, approximately 30 minutes och lectures have been recorded and videos have been produced.

- All video material has been posted on YouTube and a playlist containing all videos can be found at https://www.youtube.com/playlist?list=PLod1umE-ZizoaQ92ndSjWdRbJmEXV0Y3M

- Quiz questions related to each of the subject areas have been produced as pdf forms.

- An introduction to the material has been written, including review questions to be answered by some test users.

- Contact has been established with six high school teachers intending to use all or parts of the material in their education. These have been provided with the introduction and the quiz questions. Efforts to establish contact with more teachers are ongoing.
- Discussions have been had with high school teachers on how to develop/complement the material. There is an interest in video recorded laboratory demonstrations.
- A meeting has been held with Chalmers Professional Education, who could provide the material in the form of an e-course to nuclear professionals, given that there is an expressed interest from the industry.
- A meeting has been held with NKS, who expressed an interest in offering the material as an e-course for nuclear industry professionals.
- A plan for marketing of the material towards high school teachers and studenta has been developed in collaboration with Språng Kommunikation (who recorded the lectures), including communications with:
    - Svenska fysikersamfundet
    - Lärarförbundet, lärarnas riksförbund
    - Nationellt resurscentrum för fysik på Lunds Universitet
    - Social media
- Some home exercises related to the covered subject areas have been finalized

Plans for 2019

- Finalize home exercises for all subject areas
- Carry out the marketing strategy in collaboration with Språng Kommunikation.
- Develop a course plan for an e-course in collaboration with NKS and assist in giving the course, to desired extent.
- Record laboratory demonstrations.
- Further development of course material according to results of evaluations.

Deviations from plans (timetable and goals)

The project proceeds according to plan, except that the work with constructing home exercises has been paused awaiting decisions on which group to target and what is needed for this target group. The planned “winter school” for high school students has been replaced with classroom testing within normal teaching hours. Thereby, we avoid the problem that the only pupils likely to voluntarily participate in a “winter school” would not be representative of the average high school pupil.

Master education

Chalmers students are offered a broad range of nuclear energy related courses, of which most have been given to students during 2018, 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 has continued until the end of 2018. Work is in progress to see the different possibilities to replace the program with an alternative MSc program in collaboration with the department of radiation physics at Gothenburg University.

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

100 students have taken the full master's program in nuclear science and technology, and in addition approximatively 150 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.

A few highlights for 2018:

- The master program was presented to students both at CHARM and later at information sessions preparing the students for selecting master programs.

- 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 went 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.

- The course "Modelling of nuclear reactors" was offered, for the sixth time in a row, as a flipped course. In addition, the course was offered on-line, combining on-site and off-site students. The remote attendees were from other universities in Sweden and other European countries. The course is also offered through Chalmers Professional Education as a professional education course.

SKC- relevant courses

The following SKC-relevant courses were given.

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 †
- Modelling of nuclear reactors TIF205 †
- Applied nuclear engineering TIF195, 7.5 ECTS †
- Nuclear reactor safety TIF250, 7.5 ECTS †
- Sustainable energy futures FFR170, 7.5 ECTS
- In-service inspection technologies MTT065, 7.5 ECTS
- Nuclear chemistry II KBT168, 7.5 ECTS
- Radioecology and radioanalytical chemistry KBT216, 7.5 ECTS
- Chemistry of Lanthanides, Actinides and Super-Heavy Elements KBT171, 7.5 ECTS
- Solvent Extraction KBT196, 7.5 ECTS
- Radiofarmaceutical chemistry KBT221, 7.5 ECTS
- Computational fluid dynamics MTF072, 7.5 ECTS

- 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:

- Nuclear chemistry I KBT192, 7.5 ECTS
- Noise techniques in nuclear systems TIF245, 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 2018:

- Huaiqian Yi, Development of transport-based neutron noise modelling capabilities, supervisor: Paolo Vinai.
- Johan Eriksson, Zirconium alloys, supervisor Mattias Thuvander.
- Andrea Fazi, ATF, supervisor Mattias Thuvander.
- Lajos Nagy, double degree PhD student, jointly with the Budapest University of Technology and Economics, supervisor Paolo Vinai
- Stefan Buller, Particle transport in the edge region of fusion plasmas, supervisor Tünde Fülöp
- Linnea Hesslow, Fast electron beam dynamics in fusion plasmas, supervisor Tünde Fülöp
- Mathias Hoppe, Analysis of radiation from fast electrons in fusion plasmas, supervisor Tünde Fülöp
- Ola Embréus, Kinetic modelling of fast electrons in fusion plasmas, supervisor Tünde Fülöp
- Thea Authen (Nuclear Chemistry, separation for transmutation)
- Fredrik Espegren (Nuclear Chemistry, source term research on tellurium)
- Anna-Elina Pasi (Nuclear Chemistry)
- Niklas Hansson (Nuclear Chemistry, radiolytic fuel dissolution)
- Aneta Herman (Nuclear Chemistry, accident tolerant uranium nitride fuels)
- Luis Gonzalez (Nuclear Chemistry, enhanced accident tolerant fuel, e.g. Coated Uranium Nitride)

A specific Doctoral School in Nuclear Engineering is available at Chalmers. The Doctoral School was designed in such a way that students with various backgrounds could be accepted to the Doctoral

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

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

Complete theses

In SKC-related subjects, the following master theses were successfully presented during 2018:

- Axel Hallenbert, Multiscale Modelling of Large-Amplitude Fluctuations in Tokamak Edge Plasmas" (performed at Subatomic and Plasma Physics)

In SKC-related subjects, the following Licentiate theses were successfully presented during 2018:

- Lajos Nagy, Generalised Campbell formulae for compound Poisson processes with applications in nuclear safeguards

- Linnea Hesslow, Effect of partial screening on runaway-electron dynamics

In SKC-related subjects, the following PhD theses were successfully presented during 2018:

- Jenny Halleröd: On a solvent extraction system for recycling of used nuclear fuel using CyMe4-BTBP and TBP as extraction agents

- Artem Matyskin: Solubility and crystal structure of radium sulfate and carbonate

Publications

Publications from 2018, which were published within SKC-financed projects (including senior staff with SCK-funding and MÅBiL), are listed below.

- Cluster formation in in-service thermally aged pressurizer welds, K. Lindgren, M. Boåsen, K. Stiller, P. Efsing and M. Thuvander J. Nucl. Mater. 504 (2018) 23-28

- The effect of iron on dislocation evolution in model and commercial zirconium alloys M. Topping, A. Harte, P. Frankel, G. Sundell, M. Thuvander, H.-O. Andrén, D. Jädernäs, P. Tejland, J. Romero, E. Darby, S. Dumbill, L. Hallstadius and M. Preuss

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- Vidal-Ferràndiz A., González-Pintor S., Ginestar D., Demazière C., and Verdú G., Pin-wise homogenization for SPn neutron transport approximation using the finite element method. Journal of Computational and Applied Mathematics, 330, 806-821 (2018).

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- Matyskin, A., Brown, P. L., Ekberg, C., ” Weak barium and radium hydrolysis using an ion exchange method and its uncertainty assessment ”, J. Chem. Therm., Vol 128, pp 362-371, 2918

- Halleröd, J., Ekberg, C., Authen, T., Bertolo, L., Lin, M., Gruner, B., Svelhla, J., Wagner, C., Geist, A., Aneheim, E.,” On the Basic Extraction Properties of a Phenyl Trifluoromethyl Sulfone-Based GANEX System Containing CyMe4-BTBP and TBP ”, SXIX, Vol, 36, pp 360-372, 2018

- Ekberg, C., Costa, D. R., Hedberg, M., Jolkkonen, M., ”Nitride fuel for Gen IV nuclear power systems”, Radioanal and Nucl Chem, Vol 318, pp. 1713 – 1725, 2018

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• S Buller, HM Smith, P Helander, A Mollén, SL Newton and I Pusztai: Collisional transport of impurities with flux-surface varying density in stellarators, In Journal of Plasma Physics 84 (2018) 905840409 . https://arxiv.org/abs/1805.00972, https://doi.org/10.1017/S0022377818000867

• AR Tinguely, R Granetz, M Hoppe, O Embréus: Measurements of runaway electron synchrotron spectra at high magnetic fields in Alcator C-Mod, In Nuclear Fusion 58 (2018) 076019. https://doi.org/10.1088/1741-4326/aac444, https://arxiv.org/abs/1805.05412

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• M Hoppe, O Embréus, R A Tinguely, R S Granetz, A Stahl and T Fülöp: SOFT: A synthetic synchrotron diagnostic for runaway electrons, In Nuclear Fusion 58 (2018) 026032. https://doi.org/10.1088/1741-4326/aa9abb, https://arxiv.org/abs/1709.00674

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• E G Highcock, N R Mandell, M Barnes and W Dorland; Optimisation of confinement in a fusion reactor using a nonlinear turbulence model, In Journal of Plasma Physics 84 (2018) 905840208. https://doi.org/10.1017/S002237781800034X, https://arxiv.org/abs/1608.08812

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- Pázsit I. and Dykin V. The role of the Eigenvalue Separation in reactor dynamics and neutron noise theory. J. Nucl. Sci. Techn. 55, Issue 5, 484 - 495 (2018), doi:10.1080/00223131.2017.1412366

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KTH

Overview of activities in 2018

KTH has four research groups involved in nuclear-engineering-related research (Nuclear Engineering, Solid Mechanics, Nuclear Chemistry and Nuclear Power Safety), and three of them (Nuclear Engineering, Solid Mechanics and Nuclear Chemistry) received a direct financial support from SKC during 2018. Both the theoretical and experimental research is pursued at KTH. The Centre for Nuclear Engineering at KTH (CEKERT) is the platform to coordinate nuclear-engineering-related research and education, and it included 10 faculty members during 2018. As one of these coordinated activities, KTH/CEKERT is running the Master's Programme in Nuclear Engineering, which is one of the largest nuclear engineering programmes in the world in terms of the number of students and courses. The program attracts students from countries all around the world and is typically joined by students in three different ways: either directly, or through the EMINE programme, or via dual diploma and double degree agreements that KTH has signed with many other universities in Europe and Asia. During years 2007-2016, 21 KTH and 155 international students were admitted to the Programme. In 2018 the number of enrolled students was 25. Current statistics shows that over 60% of the Programme's all alumni work in the nuclear engineering field and about 26% of all alumni (both KTH and international) have gotten a job in Sweden. A more detailed information of the research and education activities in 2018 is provided below.

Staff directly involved in SKC activities

Nuclear Engineering group:

- 4 Professors - Pär Olsson (Head of Division, teacher), Waclaw Gudowski (former Director of TNEEM retired in September, teacher), Janne Wallenius (teacher) and Henryk Anglart (Director of CEKERT, teacher)
- 2 Associate Professors – Jan Dufek (Director of TNEEM Master Program, teacher) and Pavel Kudinov (teacher)
- 2 Ph.D. students – Mattia Bergagio (graduated in December), Elin Toijer (70% SKC, 30% EU; in cooperation with the Nuclear Chemistry group)
- 5 Researchers – Vasily Arzhanov (teacher), Michael Jolkkonen (teacher), Haipeng Li (teacher), Dmitry Grishchenko (teacher) and Sara Bortot (teacher)

Solid Mechanics group:

- 2 Professors - Bo Alfredsson and Jonas Faleskog (member of SSM:s research council)
- 1 Adj Professor – Pål Efsing
- 4 Ph.D. students – Michel Sedlak (80% SKC), Magnus Boåsen (25% SKC, 50% SSM, 5% NKSS) and André Tengstrand (40% SKC, 40% SSM) are full time students, and Martin Bjurman (RAB/OKG/FKA/SSM/Studsvik) is Industrial Ph. D. student on 70%
- 2 Researchers - Carl Dahlberg and Martin Öberg

Nuclear Chemistry group:

- 1 Professors - Mats Jonsson
- 1 Ph.D. students – Elin Toijer (together with the Nuclear Engineering group)

Highlights and major research outcome

Journal publications

Mickus, Ignas, and Jan Dufek. 2018. 'Optimal Neutron Population Growth in Accelerated Monte Carlo Criticality Calculations'. Ann. Nucl. Energy 117: 297–304. doi:https://doi.org/10.1016/j.anucene.2018.03.046.

M. Sedlak, B. Alfredsson and P. Efsing, "A cohesive element with degradation controlled shape of the traction separation curve for simulating stress corrosion and irradiation cracking", Engineering Fracture Mechanics, vol. 193, pp. 172-196, 2018.

K. Lindgren, M. Boåsen, K. Stiller, P. Efsing, M. Thuvander, "Cluster formation in in-service thermally aged pressurizer weld", J of Nuclear Materials, Vol 504, pp. 23-28, 2018.

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A. N. Chernyshev, M. Jonsson and K. Forsberg, Characterization and degradation of a polyaryl ether based superplasticizer for use in concrete barriers in deep geological repositories, Applied Geochemistry, vol. 95, pp. 172-181, 2018.

Z. Li, I. Soroka, F. Min, M. Jonsson, pH-Control as a way to fine-tune the Cu/Cu2O ratio in radiation induced synthesis of Cu2O particles, Dalton Transactions, 2018, 47, 16139-16144.

B. Seashore-Ludlow, H. Axelsson, H. Almqvist, B. Dahlgren, M. Jonsson, T. Lundbäck, "Quantitative Interpretation of Intracellular Drug Binding and Kinetics Using the Cellular Thermal Shift Assay," Biochemistry, 2018, 57, 6715-6725.

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Z. Wei, J. Edin, A. E. Karlsson, K. Petrovic, I. L. Soroka, I. Odnevall Wallinder, Y. Hedberg. Can gamma irradiation during radiotherapy influence the metal release process for biomedical CoCrMo and 316L alloys? Journal of Biomedical Materials Research. Part B - Applied biomaterials, 2018, 106, 2673-2680

S. Xia, C. M. Lousada, H. Mao, A. C. Maier, Nonlinear Oxidation Behavior in Pure Ni and Ni-Containing Entropic Alloys, FRONTIERS IN MATERIALS, 2018.

M. Jonsson, Roles of the Active Species Generated during Photocatalysis, in Visible Light-Active Photocatalysis: Nanostructured Catalyst Design, Mechanisms, and Applications. Ed. S. Ghosh, Wiley, 2018

A. Barreiro Fidalgo, Y. Kumagai, M. Jonsson, The role of surface-bound hydroxyl radicals in the reaction between H2O2 and UO2, J. Coord. Chem. 2018, 71, 1799–1807.

Spirzewski, M. and Anglart, H., "An improved phenomenological model of annular two-phase flow with high-accuracy dryout prediction capability," Nuclear Engineering and Design, vol. 331, pp. 176-185, 2018.

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Anglart, H., Li, H. and Niewinski, G., “Mechanistic modelling of dryout and post-dryout heat transfer,” Energy, vol. 161, pp. 352-360, 2018.

Janne Wallenius, Staffan Qvist, Ignas Mickus, Jesper Ejenstam, Design of SEALER, a very small lead-cooled reactor for commercial power production in off-grid applications, Nuclear Engineering and Design 338 (2018) 23.

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.

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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 148 (2018) 116.

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S Galushin, P Kudinov, Sensitivity and Uncertainty Analysis of the Vessel Lower Head Failure Mode and Melt Release Conditions in Nordic BWR using MELCOR Code, Annals of Nuclear Energy (accepted 2019)

C Geffray, A Gerschenfeld, P Kudinov, I Mickus, M Jeltsov, K Kööp, et al, Verification and validation and uncertainty quantification, Thermal Hydraulics Aspects of Liquid Metal Cooled Nuclear Reactors (2019) 383.

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I Gallego-Marcos, P Kudinov, W Villanueva, R Kapulla, S Paranjape, et al, Pool stratification and mixing induced by steam injection through spargers: analysis of the PPOOLEX and PANDA experiments, Nuclear Engineering and Design 337 (2018) 300.

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Fan, W., Li, H. and Anglart, H., "Numerical investigation of spatial and temporal structure of annular flow with disturbance waves," Int. J. of Multiphase Flow, vol. 110, pp. 256-272, 2019.

H. Anglart, "Progress in understanding and modelling of annular two-phase flows with heat transfer," Nuclear Engineering and Design, vol. 345, pp. 166-182, 2019.

E. Toijer, M. Jonsson, Radiation Physics and Chemistry (accepted 2019).

Conference presentations

M. Boåsen, K. Lindgren, J. Roudén, M. Öberg, J. Faleskog, M. Thuvander, P. Efsing, "Thermal ageing of low alloy steel weldments from a Swedish nuclear power plant – a study of mechanical properties", In proceedings from Fontevraud 9, 2018, Avignon, France

K. Lindgren, M. Boåsen, K. Stiller, P. Efsing, M. Thuvander, "Thermal ageing of low alloy steel weldments from a Swedish nuclear power plant – the evolution of the microstructure", In proceedings from Fontevraud 9, 2018, Avignon, France

M. Bjurman, M. Thuvander, K. Lindgren, P. Efsing, "Thermal aging and irradiation of cast and welded stainless steels and the influence on LTO", In proceedings from Fontevraud 9, 2018, Avignon, France

Björn Dahlgren, Lorena Anna Ditta, Maria Antonietta Sabatino, Clelia Dispenza, and Mats Jonsson, Numerical Simulations of the Kinetics Of Pulsed Electron Beam Induced Synthesis Of Nanogels In Dilute Aqueous Polymer Solutions, The Ionizing Radiation and Polymers symposium, Moscow, August 26-31, 2018

Björn Dahlgren, Lorena Anna Ditta, Maria Antonietta Sabatino, Clelia Dispenza, and Mats Jonsson, Understanding large-scale e-beam synthesis of biomedical nanogels: preliminary experimental results and process simulation using a novel approach, 7th Asia-Pasific Symposium on Radiation Chemistry, Shanghai, November 4-8, 2018

Valentina Leandri and Mats Jonsson, Comparison of Chemical Probes for Quantification of Photocatalytic Activity, The 24th International Conference on Advanced Oxidation Technologies for Treatment of Water, Air and Soil (AOTs-24). Shanghai, November 5-8, 2018.

Fan, W., Li, H. and Anglart H., "Disturbance wave characteristics in two-phase annular flows," 8th European-Japanese Two-Phase Flow Group Meeting, the Watson Hotel, Manhattan, New York, USA, 22-26 April, 2018.

M. Zemła, J. S. Wróbel, M. Muzyk, T. Wejrzanowski, D. Nguyen-Manh, S.L. Dudarev, L. Messina, P. Olsson, C. Domain, Properties of interstitials in concentrated Fe-Cr alloys from first principles, MMM-2018, Osaka, 28 Oct-1 Nov 2018.

E. Toijer, N. Sandberg, P. Olsson, Ab initio study of point defect interactions with grain boundaries in fcc nickel, NuMat-2018, Seattle , 14–18 Oct 2018.

S.C. Middleburgh, A. Claisse, D.A. Andersson, R.W. Grimes, P. Olsson, S. Mašková, The solubility of hydrogen in U3Si2 accident tolerant fuel candidate - impact on fuel manufacturing and operation, NuMat-2018, Seattle , 14–18 Oct 2018.

P. Olsson, D. Karlsson, Quantum mechanical simulations of displacement cascades in metals, NuMat-2018, Seattle , 14–18 Oct 2018.A. Claisse, S. Middleburgh, D. Nanopoulos, P. Olsson, A DFT study of burnupinduced volume changes in

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J-C. Dumas, M. Lainet, K. Samuelsson, B. Sundman, Modeling volatile fission products transport into the

germinal v2 fuel performance code by coupling to thermochemical software, NuMat-2018, Seattle , 14–18 Oct 2018.

K. Samuelsson, J-C. Dumas, B. Sundman, C. Guéneau, Validation of TAF-ID thermodynamic database

based on post irradiation examinations of high burnup MOX fuel in fast reactors, NuMat-2018, Seattle , 14–18 Oct 2018.

P. Olsson, Multi-scale modelling of microstructural evolution in Ringhals RPV welds, BRUTE seminar, VTT, 31 Oct, Espoo.

S Galushin, G Grishchenko, P Kudinov, Risk Analysis Framework for Decision Support for Severe Accident Mitigation Strategy in Nordic BWR, Probabilistic Safety Assessment and Management PSAM 14, 2018.

S Galushin, L Ranlöf, O Bäckström, Y Adolfsson, D Grishchenko, et al, Joint Application of Risk Oriented Accident Analysis Methodology and PSA Level 2 to Severe Accident Issues in Nordic BWR, Probabilistic Safety Assessment and Management PSAM 14, 2018.

S Galushin, P Kudinov, Sensitivity Analysis of the Vessel Lower Head Failure in Nordic BWR using MELCOR Code, Probabilistic Safety Assessment and Management PSAM 14, 2018.

S Galushin, D Grishchenko, P Kudinov, Surrogate Model Development for Prediction of Vessel Failure Mode and Melt Release Conditions in Nordic BWR based on MELCOR code, ICONE-27, 27th International Conference on Nuclear Engineering, Tsukuba 2019.

S Galushin, D Grishchenko, P Kudinov, The Effect of the Uncertainty in Prediction of Vessel Failure Mode and Melt Release Conditions on Risk of Containment Failure due to Ex-Vessel Steam Explosion in Nordic BWR, ICONE-27, 27th International Conference on Nuclear Engineering, Tsukuba 2019.

Poster presentation

Alexandre Barreiro Fidalgo, Yuta Kumagai, Björn Dahlgren and Mats Jonsson, The role of surface-bound hydroxyl radicals in radiation induced dissolution of UO2, 2nd International Conference on Ionizing Processes, Annapolis, Maryland, July 22-27, 2018.

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	357 kkr
Professor position in thermal-hydraulics	357 kkr
Associate professor position in reactor physics	286 kkr

The fixed funding has been used according to the planned budget for year 2018.

Education

Status of the TNEEM master programme at KTH

Programme Director Jan Dufek.

Admission of students

This analysis considers students that follow majority of courses offered in the Nuclear Energy Engineering TNEEM programme; such students include:

- students admitted through KTH own admission (internal and external, marked as TNEEM in analysed data),
- students 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 ENSTA - University Paris-Saclay, Paris or Grenoble Institute of Technology, Grenoble-INP,
- Dual Diploma students in Nuclear Energy Engineering in cooperation with Tsinghua University, Beijing (marked as TNEEM in analysed data),
- students of the Dual Diploma Programme between KTH and Korean Advanced Institute for Science and Technology (KAIST) (marked as TNEEM in analysed data),
- Double Degree students in the frame of KTH's Double Degree agreement in Civil Engineering and within the ERASMUS program (marked as Double Degree in analysed data).

Number of admitted students

In 2018, 25 new students were admitted to our master programme. Fig. 1 gives the number of students enrolled in 2014 – 2018. The growing trend lasted till 2017, while a drop-in number of enrolled students occurred in 2018. This was primarily caused by a sharp decrease in the number of Double

Degree French students (15 French DD students were enrolled in 2017, while only 1 French DD student was admitted in 2018). The reason to this drop is not obvious.

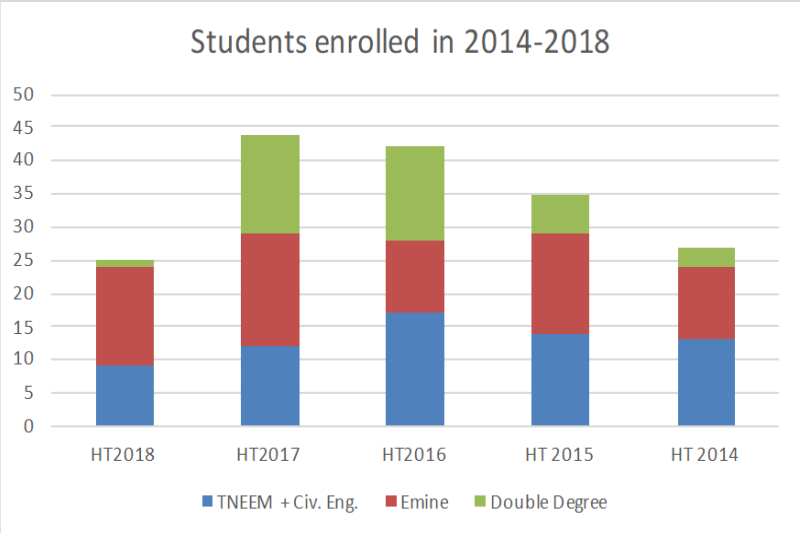

Figure 2: Enrolled students in 2014-2018

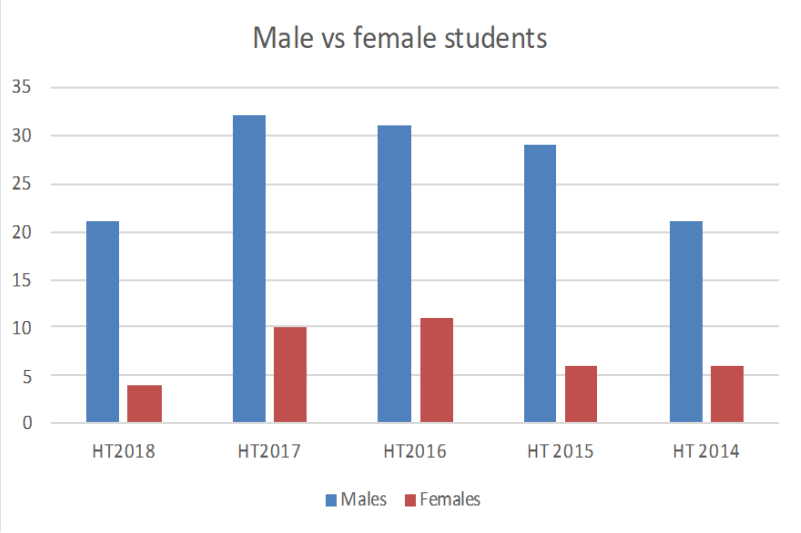

Figure 3: Number of male and female students admitted from 2014 to 2018

Another reason of the overall smaller admission of students is a decrease in the number of students from the Dual Diploma Programme between KTH and Tsinghua University (10 students in 2016 and 2017, and only 5 students in 2018). This drop is due to a KTH self-imposed limit to admission of TU students due to an imbalance of the flow of students between KTH and Tsinghua University.
The numbers of students admitted through KTH own admission has been poor in 2018 (only 1 external and 2 internal students). Nevertheless, the admission of EMINE students remains strong at 15 students per year, and we anticipate similar numbers in the coming years. Currently, EMINE represents the most significant source of our students.
Gender-wise, majority of students are males, see Fig. 2. In 2018, 4 female and 21 male students were admitted. Percent-wise, the ratio of females-to-males has dropped from about 25% in previous years to 16%. This may be attributed to the larger statistical fluctuation of females in the overall smaller number of admitted students.

Courses offered in the TNEEM programme

Tbl. 1 gives compulsory courses and Tbl. 2 gives elective courses that are offered by Nuclear Engineering, Power Safety and Nuclear Physics divisions for the TNEEM programme (Teachers' names are stated in the brackets):

Table 1: Compulsory courses in Year 1 of the TNEEM programme

Code	Teacher	Course Name	ECTS
SH2603	T. Bäck.	Radiation, Protection, Dosimetry and Detectors	6
SH2600	J. Dufek.	Nuclear Reactor Physics, Major Course	9
SH2706	H. Anglart	Sustainable Energy Transformation Technologies	9
SH2702	H. Anglart	Nuclear Reactor Technology	8
SH2773	W. Ma	Nuclear Power Safety	6

Table 2: Elective courses in Year 1 of the TNEEM programme

Code	Teacher	Course Name	ECTS
SH2610	Inv. speakers	Leadership for Safe Nuclear Power Industry	6
MJ2411	A. Martin	Renewable Energy Technology	6
SH2701	H. Anglart	Thermal-Hydraulics in Nucl. Ene. Engineering	6
SH2302	B. Cederwall	Nuclear Physics	8
SH2605	P. Olsson	Radiation Damage in Materials	6
SH2704	J. Dufek.	Monte Carlo Methods and Sim. in Nucl. Technol.	6
SH2705	S. Ghias	Compact Reactor Simulator	6
SH2774	V. Arzhanov	Numerical Methods in Nuclear Engineering	6
SH2604	S. Bortot	Generation IV Reactors	6
SH262V	Inv. speakers	Elements of Back-end of Nucl. Fuel Cycle	7.5
SH2703	J. Dufek	Nuclear Reactor Dynamics and Stability	6

Table 3: Compulsory courses in Year 2 of the TNEEM programme

Code	Teacher	Course Name	ECTS
AK2030	J. Berg	Theory and Methodology of Science	4.5
SH2614	J. Wallenius	The Nuclear Fuel Cycle	6
SH2007	Olsson, Bäck	Research Methodology in Physics	6
SH204X	T. Bäck	Degree Project in Physics, Second Cycle	30

Table 4: Elective courses in Year 2 of the TNEEM programme

Code	Teacher	Course Name	ECTS
EF2200	M. Ivchenko	Plasma Physics	6
SH2610	Inv. speakers	Leadership for Safe Nuclear Power Industry	6
SH2615	V. Arzhanov	Neutron Transport Theory	6
SH2772	M. Jolkkonen	Chemistry and Physics of Nuclear Fuels	8
SH2611	J. Wallenius	Small Reactors	6
ED2235	H. Bergsåker	Atomic Physics for Fusion	6

Graduation from the programme

Students in the nuclear energy engineering program have generally a good study discipline and a high rate of completion of their study (over 90%). Over 60% of students graduate within 2.5 years after admission to the programme. Nevertheless, since a large proportion of students is in the Dual Diploma and Double Degree programmes it is not straightforward to get exact time-dependent statistics.

Master theses defended in 2018

Tbl. 5 summarises the master theses completed and successfully defended in 2018.

Table 5: Master theses defended in 2018

TRITA	Name of the student	Examiner	Title of the thesis
2018:057	Yuyu Bai	H. Anglart	Numerical Analysis of Local Flow and Heat Transfer Characteristic in a Regular Arranged Pebble Bed Reactor
2018:058	Jingdan Cui	W. Ma	The Inlet Passageway optimization research of Intermediate Heat Exchanger in HTGR
2018:059	Hua Guo	M. Jolkkonen	Study on the Compatibility of 15-15Ti with Simulated Fission Products and Lead Coolant
2018:063	Jing Yuan	W. Ma	LBM simulation of bubble behavior and CHF prediction of pool boiling in narrow channels under different body forces
2018:064	Baorui Zhang	J. Dufek	Preliminary Neutronic and Thermal-Safety Analysis for CFETR HCCB-TBM
2018:065	Yifan Zheng	M. Danielsson	Research on the material discrimination method by cosmic ray muon tomography
2018:066	Kaixin Zhu	H. Anglart	Nuclear Reactor Seismic Analysis Considering Soil-Structure Interaction
2018:067	Elias Vandermeersch	H. Anglart	Study of sensitivities of Monte Carlo simulations to nuclear resonance parameters
2018:070	Manon Dieuaide	W. Gudowski	SAMOFAR Molten Salt Fast Reactor reprocessing unit design
2018:218	Benjamin Coppere	W. Gudowski	Quantification of the uncertainty on the secondary sodium activation due to uncertainties on nuclear data
2018:322	Yulia Mishcehnko	J. Wallenius	Composite UN-UO2 fuels
2018:366	André Ramirez	W.Gudowski	Alternative Calculation of Real Price Changes
2018:394	Simon Wakter	P. Kudinov	Technological Feasibility of Water Desalination using SMRs

Alumni

A majority of our students come from abroad, mainly from other European countries, but a significant number of students also come from Asia. Therefore, we have decided to evaluate the success rate of our alumni at finding jobs in Sweden. This is for the first time we have data of this kind at hand available for interested parties (such as SKC that contributes to funding of our programme).
During the years 2007-2016, we admitted 21 Swedish and 155 international students. Out of the 21 Swedish students, we could track online 19 students and out of them 18 got jobs in Sweden. Out of the 155 international students, we could track 104 students, and out of these 28 got jobs in Sweden. Moreover, 60% of all alumni work in nuclear engineering field (whether in Sweden or abroad). Hence, we can see that our international students are a very significant source of employees for the Swedish industry; in fact, the number of international students getting jobs in Sweden exceeds that of Swedish students by a large margin.

Conclusions

The number of enrolled students has dropped to 25 from about 40 in the previous two years. This was caused by a smaller number of Double Degree students from French universities and a smaller KTH limit for admission of Dual Diploma students from Tsinghua University. The strongest source of our students represents the KIC Innoenergy admission for European Master in Nuclear Energy (EMINE) that sits at stable 15 students per year.
Ours students have a high rate of completion their studies, over 90%. Practically all graduated Swedish students find job in Sweden, 60% of them in nuclear engineering. Almost 30% of our international students find jobs in Sweden and 60% of them in nuclear engineering. In absolute numbers, our international graduated students represent a larger source of employees for the Swedish industry than Swedish students (due to a larger admission number of international students and a relatively large success rate at finding jobs in Sweden).

TNEEM programme quality development

Development of Technology Empowered Education

Since 2017 we have put significant efforts into developing our “Technology Empowered Engineering Education” framework that teachers can use in order to enrich the learning environment with the following E-learning elements:

Personalised electronic home assignments

The electronic home assignments are provided via the Möbius platform that is integrated into the Learning Management System CANVAS. CANVAS is now a standard electronic platform for teacher-student interaction; it handles the distribution of materials and serves as a platform for following the students’ progress. The Möbius platform is, on the other hand, a specialised tool suitable for teaching and training students via quizzes and exercises. Parameters in assignments can be made different for each student, so a simple copying of results is not possible. Students have multiple trials to get the answers right, which goes well with the pedagogic approach of giving a feedback without punishment. Students know right away whether the answer is correct or not. After the deadline, students learn immediately the correct derivation of the answers.
So far, we have used Möbius in two courses: Nuclear Reactor Physics and Sustainable Energy Transformation Technologies. In the coming period, we will use Möbius in other courses, such as Nuclear Reactor Dynamics and Stability.

Personalised electronic exams.

The same electronic platform, Möbius, is used for personalised electronic exams. Nevertheless, we set up the platform differently. Students cannot learn immediately whether the answer they provide are right or wrong. They will learn this only after the exam. Immediately after the exam, students will be

informed about their success rate, and they have the option to communicate the outcome with the teacher who may override the points that were assigned to the student automatically.

Video recording of whole lectures.

Many courses have being recorded and made available for students at the dedicated internet site accessible via KTH's Learning Management System CANVAS.

Development and changes of courses

The following changes in courses have been done in 2018 (or they are planned in the near future):

SH2706 Sustainable Energy Transformation Technologies

Is a new course developed by H. Anglart, and given in 2018 for the first time. The course substitutes an older course MJ2405 Sustainable Power Generation that was not well aligned with the goals of our programme.

SH2600 Nuclear Reactor Physics course

Includes reactor exercises that have been done at the ISIS reactor in Saclay in last years. In December 2018, we have sent 29 students + 4 KTH instructors for the exercises at ISIS. Similarly as in previous years, the exercises could be done only with the SKC financial support, which was crucial for these exercises.
The ISIS reactor has been closed down in January 2019, right after our exercises were completed, and it will not be available for training any more. For the coming years, we need to locate another training reactor for our students. In March 2019, a very promising negotiation was done with the representatives of the Dep. of Nuclear Reactors in Prague to secure the VR-1 training reactor for our students in December 2019. Significantly more favourable financial conditions can be foreseen for the overall exercise in comparison to the exercises in Saclay.

SH2610 Leadership for Safe Nuclear Power Industry

Was executed in 2018 in the same fashion as in the previous years, with the help of invited experts. Unfortunately, all the experts are over 67 years old now, and their involvement in the coming years is, due to KTH regulations, very unlikely. New negotiations to secure younger experts are currently ongoing.

SH262V Elements of Back-end of Nuclear Fuel Cycle

Undergoes turbulent times due to a diminishing support from SKB. The course has been designed and organized by 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). In the previous years, SKB provided experts and organised trips at no cost for the course. Nevertheless, for this and the coming years, SKB will participate in the summer course only when compensated for the services. Negotiations are currently being conducted to secure SKB participation in a smaller extent. The funding for selected SKB services could be covered from our EMINE budget this year; nevertheless, this will likely not be possible in the coming years. A long-term solution is needed.

Research Project funding and outcome during 2018

Experimentla and analytical study of thermal mixing at reactor conditions

- Ph.D. student: Mattia Bergagio

Supervisor: Henryk Anglart

Funds spending

The project has been partially supported by SKC in previous years and entirely by KTH in 2018.

Activities within the project under 2018

Mattia Bergagio completed his PhD studies and defended his thesis (ISBN 978-91-7873-001-8, full text available at http://www.diva-portal.org/smash/get/diva2:1257426/FULLTEXT02.pdf) on December 6, 2018. Prof. H.-M. Prasser from ETH, Zurich, served as the opponent. M. Bergagio's major achievements during 2018 include two journal papers. The first paper was on "An iterative finite-element algorithm for solving two-dimensional nonlinear invers heat conduction problem", published in the *International Journal of Heat and Mass Transfer*, vol. 126, pp.281-292, 2018, and the second paper on "Large eddy simulation of thermal mixing with conjugate heat transfer at BWR operating conditions", submitted to Nuclear Engineering and Design.

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 kSEK. Funding from SKC ended in 2017 and 855 kSEK from KTH was in-kind. No deviation from budget.

Activities within the project under 2018

Manuscript 1, with title A cohesive element with degradation-controlled shape of the traction separation curve for simulating stress corrosion and irradiation cracking, was published in Engineering Fracture Mechanics, v. 193, pp. 172-196, 2018. Manuscript 2 is finalized. It describes a simulation of IGSCC including diffusion, corrosion and crack growth with focus on the effect of different yield stress and crack tip load K_I on the crack growth rate. Experiments in the literature are predicted. The manuscript has received review comments from an international journal. It is currently being revised.

An autoclave for accelerated experiments of IG-SCC at increased temperature and pressure has been manufactured. Experiments on IG-SCC are ongoing.

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 80% and Bo Alfredsson 10% of respective annual time in the project. Total cost of salary was 855 kSEK. Budget funding was 400 kSEK from SSM, 200 from SKC and 255 kSEK from KTH in-kind. No deviation from budget.

Activities within the project under 2018

The PhD student André Tengstrand started work on WP1: determining crack load for temperature load in experimental version of pilot; determining material model and crack growth parameters in environment. Verifying material testing was done and preparations were made for environmental testing. An agreement was reached with Studsvik to borrow an autoclave with servo-hydraulic test machine for fracture mechanics testing in environment. A LVDT was purchased for the testing. Simulations of stresses have commenced using the CFD results of Mattia Bergagio from the Nuclear Engineering group.

At the end of 2018 André Tengstrand decided to end his PhD studies for another employment. The remaining budget was too small for employing a new PhD student. Therefore, the project was terminated and outstanding funding at SKC and SSM remained with the respective sponsor. New application will be submitted to the sponsors for a new start in 2020.

Influence of thermal and irradiation induced ageing in Low Alloy Steels

- Ph.D. student: Magnus Boåsen
- Supervisor: Pål Efsing

Funds spending

Magnus Boåsen spent 80% of his annual time at the project, which is 25% supported by SKC and 75% by SSM. Supervising by Pål Efsing is provided through the agreement between KTH – Hållfasthetslära and Ringhals AB regarding Efsing time participation and activity at KTH. Total cost of salary was 855 kSEK, 171 kSEK from KTH in-kind. No deviation from budget. The SKC funding was used as partial cover of the salary cost of the Ph. D. student.

Activities within the project under 2018

Boåsen has actively participated in the development of a material test scheme for the continued work within the BREDA/BRUTE-projects. The aim of the project is to perform mechanical testing o material harvested form the retired Barsebäck 2 Reactor Pressure Vessel. Samples where extracted in 2018 and the actual testing is foreseen to start in the latter part of Q3 of 2019.

As part of the preparatory work for this a methodology to numerically estimate the effect of constraint on the mechanical properties and the effect of ageing on the constraint has been developed. Further a methodology regarding pre-fatigue of shallow cracks in 2-point bend specimens has been developed and tested at sample materials.

Boåsen and Efsing participated in the international conference “Fontevraud 9”, devoted to contribution of materials investigations and operating experience to Light water NPP’s safety, performance and reliability in Avignon, September 2018. Boåsen presented a paper on mechanical properties of in-service thermally aged material collected from a retired components at Ringhals NPP. The paper was a collaboration between KTH and CTH, where CTH presented the microstructural evolution of the material in a companion paper.

During 2018 mechanical tests have been performed in order to study the evolution of the transition temperature between cleavage and ductile fracture of the thermally aged material. The testing is based on fracture mechanical testing in accordance to the Mast.cruve methodology. The work is a base-line work for both coming testing at the Barsebäck material, and for a future envisaged shift in the testing programs related to the regulatory demanded surveillance tests for the Swedish Nuclear Power Plants from the current impact test methodology to direct fracture toughness determination.

Studies of irradiation assisted stress corrosion cracking

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

Funds spending

The project was funded partly by SKC and by H2020 projects GEMMA and IREMEV.

Activities within the project under 2018

During 2018, Elin Toijer completed a manuscript on radiation and H2O2-induced corrosion of stainless steel. The manuscript was submitted and accepted for publication in Radiation Physics and Chemistry (to be published in 2019). Experiments aiming at elucidating the detailed mechanism of the reaction between the aqueous radiolysis product H2O2 and metal oxide surfaces (using ZrO2 as a model) have been carried out during 2018 and Elin Toijer started writing a manuscript based on these experiments late in 2018.

Elin Toijer is finalizing a manuscript on solute – point defect interactions in fcc Ni in collaboration with colleagues from France (EDF and Univ Lille). She has completed most of a second study of the effect of solute interactions and diffusion to grain boundaries in fcc Ni. Elin has finished almost all courses for her PhD and has completed the last of her teaching activities. Elin participated in the NuMat 2018 conference in Seattle and presented her work there.

UPPSALA UNIVERSITET

Uppsala

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, safe nuclear power operation 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 2018.

In the wake of the energy agreement (Energiöverenskommelsen), we experience a renewed interest for nuclear power in Sweden; the nuclear industry has created a substantial outreach through e.g. social media, the political sphere has initiated serious discussions regarding the nuclear option and the surrounding society increasingly requests viewpoints from the academy. In this context, the industry's outreach 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 on all levels. Altogether we can conclude that the various initiatives taken during 2018 has vitalised our working atmosphere considerably.

An important activity for us during 2018 was our engagement in the reference groups issued by SSM. These groups supplied the authority with input in response to the governmental request to investigate the competence supply within, among others, nuclear technology. The result of this effort was published by SSM in a report in autumn 2018, which exposed several aspects having direct impact on the academy. For example: the need for coordinating research and education as well as the need for a coordinated governmental approach for research funding within the field in Sweden was addressed. The aspect of coordination of research and education is completely in line with our long-lasting strategy in Uppsala, which has manifested itself through, for example, our MÅBiL initiative within SKC a couple of years ago, our engagement to create the complementary collaborative platform SAINT and the Nordic Academy for Nuclear safety and Security (NANSS).

Furthermore, we are especially satisfied with that the notion of coordinated state funding was highlighted in the SSM report because, during the process, Uppsala University emphasised the inadequate governmental funding of nuclear research and education within the academy as an issue and in particular the lack of adequate base funding. The nuclear industry has, by all means, taken a responsibility beyond its core to secure academic research and education. However, for the academy to be able to further secure research and, in particular, nuclear education in a long-term perspective, it is necessary to initiate a national undertaking where governmental bodies canalize adequate and relevant

funding to the academy in a coordinated way. Although outside our reach, we strongly support a development where also the Ministry of Education and Research, on some level, is engaged in such an undertaking. If such a process results in a larger base funding in absolute terms, the academy would be in a considerably better position to fulfil the essence of the SSM report.

Finally some words about the OECD Halden Reactor Project. The Halden reactor was closed summer 2018. This unfortunate event has implication to our research in several ways. Of course it marks the end of a successful international programme of fuel testing in which our expertise in instrumentation and analysis methodology has been a part of. It has also influenced our bilateral collaboration with colleagues at IFE. During many years, this collaboration has implied exchange of research ideas and occasionally of staff and we are now in a position where we need to adjust to the new situation. We are quite optimistic, however, that the good relationship we have with the Institute of Energy Technology is the determining factor for us to find new paths to step on in order to continue our research aiming at safe and secure nuclear power operation.

With these introductory words, we hereby submit the Annual Report from Uppsala University for the year 2018.

Education

During 2018 Uppsala University has continued its efforts to provide high-quality teaching and education within the fields of nuclear technology. The objective is to providing primarily engineering students with knowledge about and understanding of nuclear energy systems to the benefit of Swedish society in general and the nuclear industry in particular. Staff from the Division of applied nuclear physics remains in positions as managers of three education programmes. These are:

- The Master Programme in Energy Systems Engineering, (Civilingenjörsprogrammet i energisystem, ES)
- The Bachelor Programme in Physics, (Kandidatprogrammet i fysik),
- The Bachelor Programme in Nuclear Engineering, (Högskoleingenjörsprogrammet i kärnkraftteknik, KKI).

Henrik Sjöstrand, Matthias Weiszflog and Michael Österlund, respectively, are coordinators for the three educational programmes. Cecilia Gustavsson, 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 division is also managing the UU competence centre NANSS (Nordic Academy for Nuclear Safety and Security), which presently functions as a hub and portal for organizing contract education within the field of nuclear technology.

Swedish Radiation Safety Authority (SSM) government remittance on long-term competence supply within radiation safety

In 2018 SSM was commissioned by the Swedish government to investigate the conditions for maintaining national competence within radiation safety related fields and also to suggest a plan for how this competence should be maintained and developed in a long-term perspective. UU participated in an advisory reference group formed by SSM and was one of the official referral bodies for the final SSM report (SSM2017-134-23). Much of this work was delegated by UU to staff from the Division of Applied nuclear physics.

One important conclusions of the SSM report is that the system for maintaining radiation safety competence is at present very vulnerable and that it needs to be strengthened. The report states that it is of great importance to maintaining academic research within fields such as nuclear technology, reactor physics, nuclear data, safeguards etcetera to ensure that education, relevant for radiation safety can be provided in the long-term perspective. This applies to education on undergraduate and graduate levels as well as continued education of professionals, i.e., contract education.

Master Programme in Energy Systems Engineering,

(Civilingenjörsprogrammet i energisystem, ES)

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

The track generates students who are well prepared to perform their master thesis in nuclear engineering work, and master theses are conducted annually. The support from SKC is crucial for offering this broad track to our students. The programme Manager for the Energy Systems programme is Henrik Sjöstrand, who is also the track manager for the nuclear power track.

During 2018 the following courses with relevance for nuclear power were given by teachers from the Division of applied nuclear physics within UU engineering and physics programs:

- Introduktion till kärnfysik och dess tillämpningar
  - Kandidatprogram i fysik
  - 5 hp, grundnivå, 3 studenter

- Energifysik I
  - Teknisk fysik, kandidatprogram fysik, masterprogram fysik
  - 5 hp, grundnivå, 36 studenter

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

- Kärnkraft – teknik och system
  - Energisystem
  - 10 hp, avancerad nivå, 7 studenter

- Framtida nukleära energisystem
  - Energisystem
  - 5 hp, avancerad nivå, 7 studenter

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

- Energisystemfysik
  - System i teknik och samhälle
  - 10 hp, grundnivå, 28 studenter

- Tillämpad reaktorfysik
  - Fristående kurs
  - 5 hp, avancerad nivå, 11 studenter
- Komplexa system för teknik och samhälle
  - System i teknik och samhälle
  - 10 hp avancerad nivå, 28 studenter

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

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

Bachelor of Science in engineering with a specialisation in nuclear engineering (Högskoleingenjörsprogrammet i kärnkraftteknik, KKI)

Following a two-year hiatus the Education board of the Faculty of natural sciences and technology at UU has decided to re-establish the Bachelor's programme in nuclear technology (KKI), commencing in autumn 2019. The decision was taken following discussions with industry stakeholders about future demand for technical staff at the nuclear power plants, envisioned staff turnover and in the light of concerns about the need for base load power plants in the Swedish grid to ensure a secure and stable supply of electric energy.
Presently an agreement has been made between UU, FKA and RAB, who are actively supporting the program.

The program will remain in more or less in its previous one-year format with students from Bachelor's programs in primarily mechanical and electrical engineering. From 2019 onwards, students with a prior education background in 'civilingenjör' programs will also be admitted to the KKI program, the objective being to broaden the recruitment base.

For the autumn semester 2020 the plan is to admit students to the UU Bachelor's programme in electrical engineering with a new specialisation in nuclear technology. Recently, the Bachelor's program in electrical engineering has been revised with a stronger emphasis on electrical power systems and the inclusion of a specialisation in nuclear technology is considered a natural next step. Students who choose to follow the nuclear technology specialisation will take a selection of KKI courses mainly during their 3rd year and will graduate with a Bachelor's degree in electrical engineering with a specialisation in nuclear technology. In this framework, discussions are ongoing about new courses and development of a new course, Power electronics, 5 hp, on the bachelor's level has started.
This course is also expected to be made available in a format that can be used for contract education of NPP professionals.

Contract education directed to the industry

Contract education continues to be a focus area and during 2018 courses have being provided both in Uppsala and on-site at nuclear power plants. 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. 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 continues 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 2018 the Uppsala University provided industry with 12,5 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.

Course	Credits (hp) or equivalent duration (weeks)
Tillämpad reaktorfysik	5 hp
Fördjupad strålskyddsutbildning (FS1)	6 hp
Aktivitetsmätning m. Ge-detektorer	1 w
Värme- och strömningslära (ROP/TOP-utbildning)	2 w (FKA) 1,5 w (RAB)
Reaktorfysik fördjupad (ROP/TOPutbildning)	1,5 w (FKA) 1,5 w RAB
Man-Technology-Organisation/Human Factors for Nuclear Safety including Virtual Reality Resources as part of Safety Culture	6 hp

Table 1: Contract education courses provided on one or more occasions during 2018.

Development of teaching education in the nuclear field

E-learning development (SKC –funded project)

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. The principal objective is to create study materials suitable for e-learning with the objective of stimulating student interest for applications of nuclear physics in general and nuclear energy in particular. Another consideration is that the course material should be made available to teachers at other universities and upper secondary schools who wish to incorporate one or more modules into their own course curriculums.

Chalmers and Uppsala University have had a very interesting and fruitful collaboration during 2018, producing a series of e-learning videos on different nuclear subjects. The work will continue during 2019 producing further study materials, development of quizzes and hand-in exercises and also

organize the material in a form that is suitable for distribution to teachers and students. This work described in more detail in the Chalmers annual report.

Hitherto, the following subjects have been treated in the video productions by UU, with other subjects being covered by Chalmers.

- Icke-spridning och kärnämneskontroll (Sophie Grape)
- Kärnkraftens historia (Ane Håkansson)
- Kärnfysik för nyfikna (Stephan Pomp)
- Kärnbränslecykeln (Michael Österlund)

Presently the movies are available on YouTube. Search for 'SAINT Radiation Science'

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 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, which is coordinated by the European Nuclear Education Network (ENEN) was started in 2017 will end in 2019. Within the project UU are responsible for the development of two courses:

- The ANNETTE Course on Nuclear Safeguards

collaboration with SCK•CEN, Mol, Belgium and FZJ, Jülich, Germany)

- MTO/HF for Nuclear Safety including Virtual Reality Resources as part of Safety Culture (6 ECTS)

(collaboration with IFE, Halden, Norway)

The well-established ESARDA course on nuclear safeguards where UU is involved since several years is also included within the ANNETE project.

The ANNETTE safeguards and MTO/HF courses were given for the first time as pilots (prepaid by the ANNETTE project) in early 2019 and late 2018, respectively. The outcome of the courses was very positive and it is planned to offer the courses on a regular basis, primarily as contract education courses.

Student's theses during the calendar year 2018

- Benjamin Eriksson

o "Monte Carlo simulations of a back scatter time-of-flight neutron spectrometer for the purpose of concept testing."

o Master Programme in Physics, 10 HE credits

o Benjaminas Marcinkevicius (supervisor)

o Finished 2018-08-21

- Benjamin Eriksson
  - ”Simulations of a back scatter time of flight neutron spectrometer for the purpose of concept testing at the NESSA facility.”
  - Master Programme in Physics, Master Thesis, 30 HE credits
  - Anders Hjalmarsson (supervisor)
  - Göran Ericsson (subject reader)
  - Finished 2018-09-07

- Anastasios Anastasiadis
  - ”Calculation of γ-ray mass attenuation coefficients (μ/ρ) for different burnup values of UO2 nuclear fuels in a PWR simulated by Serpent 2 Monte Carlo code”
  - Master Programme in Physics, 10 HE credits
  - Peter Andersson (supervisor)
  - Finished 2018-05-23

- Markus Björklund
  - “Utveckling av beräkningsmodell för värmepumpstillsats i avfuktarsystem”
  - Master Programme in Energy Systems Engineering, Master Thesis, 30 HE credits
  - Jacob Eriksson (subject reader)
  - Finished 2018-06-26

- Linus Hägg
  - “Plasma diagnostics for particle confinement studies in magnetic fusion devices”
  - Master Programme in Engineering Physics , Master thesis, 30 HE credits
  - Marco Cecconello (subject reader)
  - Finished 2018-11-15

- Matthias Carlsson
  - “Development and Characterization of Parallel-Plate Avalanche Counters for Nuclear Physics Experiments”
  - Master Programme in Engineering Physics , Master thesis, 30 HE credits
  - Alexander Prokofiev, Diego Tarro (supervisors)
  - Cecilia Gustavsson (subject reader)
  - Finished 2018-06-22

- Albert Linder
  - o "Impact of thermal equilibriumassumption on modelling of coreuncovery in FIX-II experimentby APROS"
  - o Master Programme in Engineering Physics , Master thesis, 30 HE credits
  - o Michael Österlund (subject reader)
  - o Finished 2018-08-21

- David Nordman
  - o "Cs-137 i Svamp: Dataanalysrutiner för gammaspektroskopi"
  - o Bachelor Programme in Physics, Bachelor thesis, 15 HE credits
  - o Erik Andersson Sundén (supervisor)
  - o Cecilia Gustavsson (subject reader)
  - o Finished 2018-07-26

- William Lindberg
  - o "Characterization of an HPGe detector for experiments on radioactive mushrooms"
  - o Bachelor Programme in Physics, Bachelor thesis, 15 HE credits
  - o Mattias Lantz (supervisor)
  - o Cecilia Gustavsson (subject reader)
  - o Finished 2018-06-26

- Fredrik Jonasson & Björn Sparresäter
  - o "Monte Carlo-simuleringar av germaniumdetektor för gammaspetroskopi"
  - o Bachelor Programme in Physics, Bachelor thesis, 15 HE credits
  - o Mattias Lantz (supervisor)
  - o Ali Al-Adili (subject reader)
  - o Finished 2018-09-01

- Sofie Thorell
  - o "Examination of laboratory work on heat radiation performed at university : Video analysis of the lab to examine the students' work with the lab and its purpose"
  - o Upper Secondary School Teacher Education Programme, Thesis, 15 HE credits
  - o Matthias Weiszflog (supervisor)
  - o Cecilia Gustavsson (subject reader)
  - o Finished 2018-10-26

- My Löfberg

o "Understanding of heat radiation : A qualitative interview study that examines whether a laboratory at a university level increases the understanding of the relationship between the phenomena of heat radiation."

o Upper Secondary School Teacher Education Programme, Thesis, 15 HE credits

o Matthias Weiszflog (supervisor)

o Cecilia Gustavsson (subject reader)

o Finished 2018-10-26

- Carl Näslund

o "LEED Accreditation and Comparison of Conventional and Green Building Methods for a Single Family Home"

o Master Programme in Energy Systems Engineering, Project work, 10 HE credits

o Henrik Sjöstrand (supervisor)

o Finished 2018-06-25

Research projects

The following research projects represent activities of high relevance for reactor operation and nuclear fuel performance and with project support from SKC.

MÅBiL

Project title: **ICEWATER**

Research leader: Prof. Mattias Klintenberg, Division of Materials Theory, Department of Physics and Astronomy, Uppsala University

Ph.D. student: Erki Metsanurk

Finances: SKC funding has been used for 50% of salary (E.M.) only

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. Instead of neutrons, the irradiation will be performed using protons. This on one hand allows for much quicker, cheaper and safer experiments, but on the other hand introduces several engineering challenges due to high energy and short stopping range of the particles. However, when solutions are found for these problems, the equipment could be used for more systematic studies behind the underlying mechanisms of IASCC.

The goals for 2018 were to:

- 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.

New cell design

Together with SmartStuff OÜ from Estonia we have designed a new high pressure high temperature cell for the device. Whereas still work in progress, it incorporates possible solutions majority of the problems associated with the high energy and short stopping range of the protons in steel. Most notable of those are:

- The possibility to remotely control the distance between the sample and the stainless steel window through which protons enter the cell. This is important in order to ensure that the gap is maximized during experiments while still allowing for protons to reach the sample. In addition it makes it easier to gather data for estimating the heating effect of the protons.

- Since the sample material will be a thin foil, it is important that the pressurization of the cell does not induce prohibitively high stress in the sample which could break it even before the experiment begins. This is mitigated mainly by using pull rods that pass through the cell thereby zeroing out the differential pressure.

- In order to estimate the local heating, wires will be connected to the sample to perform four-terminal sensing of its resistance.

- Water inlet and outlet are placed as close to the sample as possible in order to maximize the flow around it. The overall water volume in the cell is minimized in order to limit the amount of steam generated if the window should break.

- For low temperature experiments the lid of the cell can be easily changed to a transparent one in order to perform visual monitoring.

In addition, emphasis is put on the manufacturability of the cell, i.e. to minimize the amount and complexity of the components. The first and second iterations of the design are shown on the following figures.

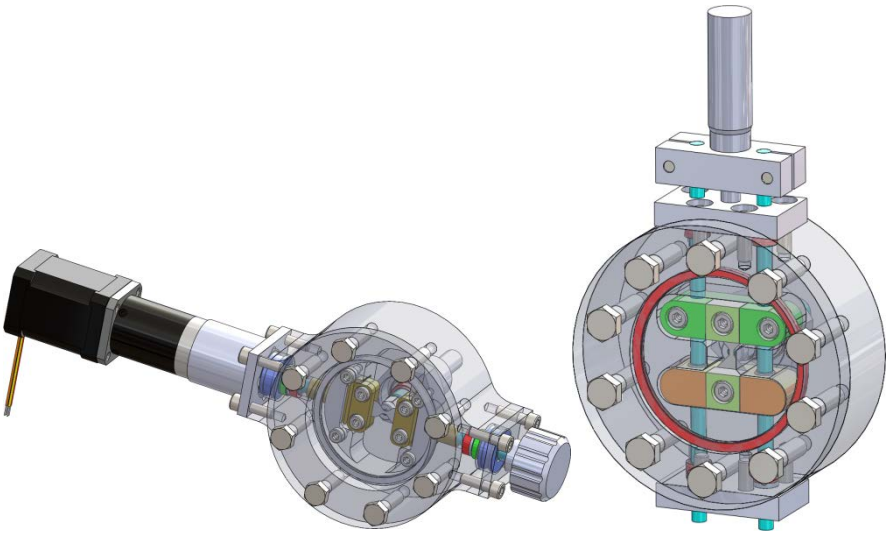

Fig. 4.

Making and testing the window holder

The first component built and tested for the design described above was the window holder. As the name suggests, its purpose is to hold the thin stainless steel sheet that contains the pressure of the cell and allows for protons to pass through. Attempts to use welding were unsuccessful due to the very small (50 μm for the prototype) thickness of the sheet. Instead a mechanical holder was designed and built. Our tests showed that with some modifications it is possible to use this type of holder in the device.

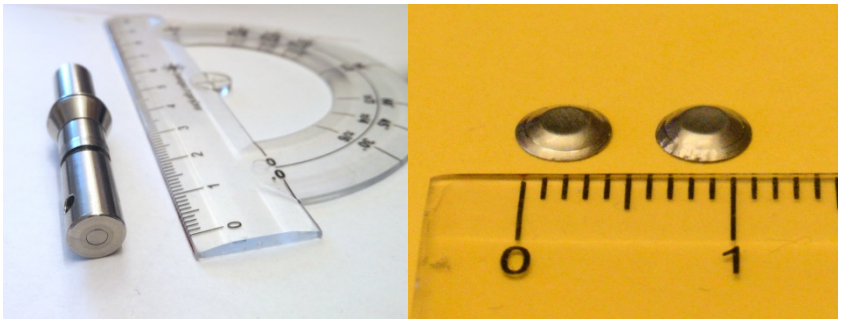

Fig. 5.

In addition, we acquired 30 μm thick 11R51 strip steel from Sandvik. The tensile strength of the sheet is 2050 MPa which could be increased to 2300 MPa through heat treatment, and elongation at break 0.5%. There are several benefits to using thinner window. It makes possible to reduce the energy of protons which in turn reduces activation and increases the damage rate in the sample.

Other

In order to simplify the design and accommodate it for using a thinner window material, we have decided to reduce the target temperature in the cell from 320 °C to 280 °C. This nearly halves the pressure at the boiling point which changes from 113 bar to 64 bar and therefore significantly reduces the risk of the window breaking.

We have acquired funding for the fast valves that are necessary to protect the beamline vacuum in case of window failure.

Future plans

We expect to finalize the design in the first quarter of 2019 after which it can be built, installed to the accelerator together with the fast valves, and first experiments be performed. The results of those will then be used to make modifications and improvements.

Amorphous alloys for the nuclear industry

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

Finances

Salary for one Ph.D. student provided
Co-financed by Materials Physics research programme

Overview

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 influences corrosion in a profound way, since it is believed to play a major role for diffusion of interstitials. High temperature applications of amorphous alloys are still a challenge due to 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 influence 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.

In 2016 the ternary Mo-Si-Zr system was chosen for a thermal study, which was finalised in the in 2017, resulting in a master thesis published on DiVA portal (“Thermal stability of amorphous MoSiZr thin films”). The alloy showed a reasonably high thermal stability for a three component alloy – the structure remained amorphous up to 800 °C. A new system was then chosen; the quaternary Zr-Nb-Cr-Mo system. Deposition of films started shortly thereafter.

In 2017 the region of amorphicity in the Zr-Nb-Cr-Mo system was mapped at room temperature conditions by X-ray diffraction on thin films (~ 100 nm). Depositions of thicker films (~ 1 µm) were also performed to allow corrosion and mechanical measurements. Additionally, powder samples were produced to enable differential thermal analysis or calorimetry (DTA/DSC). Furthermore, Calphad, a tool for assessment of thermodynamic properties and phase stabilities, was identified as a possible tool to complement the predictive power with regard to amorphous alloys.

Project activities in 2018

2018 started with DTA measurements at RWTH University in Aachen. A total of 13 compositions were analysed, crystallisation is found to occur from 610 to 770 °C. Slightly lower than the previous system, however, without use of metalloid elements (Si) which often times significantly enhances thermal stability. The samples also oxidised in protective Ar atmosphere (likely due to oxygen and/or water contaminations), indicating poor corrosion properties even at moderate temperatures (with ATF

standards measured), at crystallisation. However, it can be confirmed that crystallisation and oxidation do occur simultaneously and self-passivation possibilities of the material has not been investigated up to this point.

A significant portion of 2018 has been used to make in-situ thermal X-ray measurements operational. Many challenges (water cooling, vacuum, temperature measurement/control etc.) along the way have been solved and at the very end of the year everything was up and running. Measurements of samples are planned to take place early 2019.

Simultaneously, the work on predictive calculations has been constantly progressing. As mentioned above Calphad will be a part of it, contributing with equilibrium phases, enthalpies, Gibbs energies and/or melting points of alloys. Additionally, a topological model has been identified and fully implemented as a possible second contributor. Based on analytical expressions of efficient packing of atoms giving compositions likely to form glasses. These are planned to be complemented with construction of structures and Density functional theory (DFT) and/or molecular dynamics (MD) calculations of for instance binding energies. Little to no efforts to combine calculations/modelling methods have currently been found in the literature. The aim is to combine these methods into one framework that can take into account multiple parameters in order to speed up the process of alloy design.

Following up on the annual SKC symposium, conversations with Mathias Thuvander on ATF coatings were initiated. Contact with Westinghouse was established and a meeting in early 2019 has taken place. Discussions on possibilities of loss of coolant accident (LOCA) and wear tests of metallic glasses were the two main topics. Collaborations and further discussions are already planned.

Plans for 2019

- Bench marking and developing knowledge on data collection and interpretation of the X-ray reflectivity/diffraction (XRR/XRD) with in situ heating. Assessment of viability as a high throughput screening method.
- Finalising the thermal study of the Zr-Nb-Cr-Mo system.
- As suitable calculations have been found for a predictive framework are found, production of data and compiling the results into guidelines for alloy design remain.
- Selecting a new system, containing both metals and metalloids, screening through compositions and in collaboration with Westinghouse perform LOCA tests. Conversations with Tribology group at Uppsala University to perform wear studies on selected alloys are planned as well.

Outlook

The understanding of the physical properties of amorphous alloys is still in its infancy. Development of primarily predictive tools is of significant importance, closely followed by the need of experimental verification, that is, high throughput screening methods. Both these aspects are expected to increase and accelerate due to increased interest in amorphous alloys in general. However, while it is foreseeable for a protective amorphous fuel cladding coating to remain chemically and structurally stable at elevated temperatures even above 1300 °C, it is high time to expand the horizon. It is easy to find potential application areas for amorphous alloys mainly due to the lack of grains, grain boundaries and dislocations. In order to stay at the very front of reactor development, assessments of feasibility for amorphous alloys should be performed for various parts of the reactor environment. For instance;

- stress corrosion cracking (SCC) and/or
- He embrittlement of reactor pressure vessels

may be possible to erase by definition – lack of grains and grain boundaries. As stated in the last annual report, use of additive manufacturing (AM) for production of reactor components may unlock new solutions to various challenges. The synergetic effects of close collaboration with amorphous alloy development and the AM project at the Ångström laboratory are therefore undeniable. Mainly due to AM currently being the only viable method of manufacturing components at length scales which were earlier impossible due to insufficient cooling rates in conventional methods.

Research project

A number of research projects have been carried out within the division during 2018 that are funded from other sources than SKC. A short account of some major research projects are described below.

Fuel diagnostics

Research leader: Dr. Peter Andersson

Other participants: Dr. Scott Holcombe (IFE), Dr. Terje Tverberg (IFE), Dr. Wolfgang Wiesenack (IFE), Prof. Ane Håkansson (UU) and Ass. Prof. Staffan Jacobsson Svärd (UU)

The former MÅBiL Fuel diagnostics project has continued with the support from other financing sources. Within this project, two PhD students have recently been employed using funding from VR New Nuclear Technology and SSF SAFETY. The current focus in the fuel diagnostics project is the development of Gamma Emission Tomography for nuclear fuels. The aim is to create a versatile non-destructive inspection tool for irradiation tested nuclear fuel in research reactors. Thereby, our developments may enable faster and less costly validation data generation from irradiation tests of nuclear fuel.

Building on the experience from the previous GET instrument developed in collaboration between the Halden reactor, Westinghouse and Uppsala University, we are currently examining improved detector concepts for higher efficiency in the gamma ray detection. Such improvements may in principle be used to shorten measurement times for the same quality of the data, but instead the main intention is to trade it for more measured data in the inspection, and thereby offering higher spatial resolution (to give a more detailed image of the fuel interior). While the existing tomography setup at the Halden reactor offers spatial resolution down to 1 mm, the aim is to improve this by an order of magnitude to the range of 102 microns.

In 2018, a new detector concept has been conceptually designed using segmented germanium detectors, and the performance such detectors has been investigated using Monte Carlo simulation of the radiation interaction in the detector system. In addition, detector concepts from other existing or previously proposed tomographic designs have been evaluated based on review of the literature. Preliminary results indicate that our new detector concept can offer a better trade-off between the conflicting objectives of short measurement time and high spatial resolution, while simultaneously offering unmatched energy resolution, and therefore we will continue on the developments using our proposed detector type.

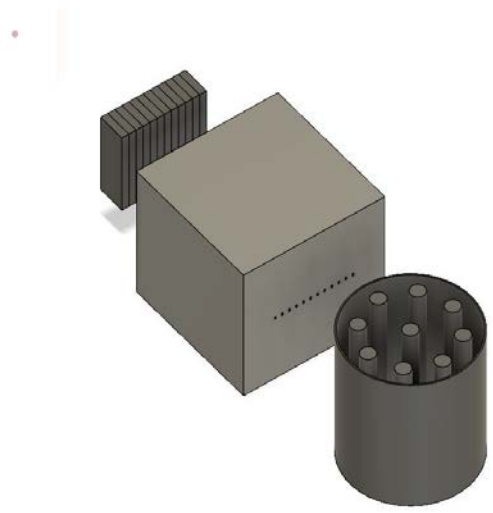

Fig. 6. One of our detector concepts under evaluation. Upper left: Segmented detector, middle: shielding with collimator slits, right: Fuel rig for irradiation test rods.

Strålande Jord – a citizen science project

Participants from Applied Nuclear Physics: Cecilia Gustavsson, Erik Andersson-Sundén, Mattias Lantz, Anders Hjalmarsson

In a collaboration between the Department of Physics and Astronomy and the Department of Earth Sciences at Uppsala University, and the Department of Forest Mycology and Plant Pathology at the Swedish University of Agricultural Sciences, an interdisciplinary "mass experiment" has been carried out with a focus on radioactivity in fungi. The invitation to participate in data collection and analysis was sent out to 250 school classes from all over Sweden with the help from the unit for communication and school collaboration at the Faculty of Science and Technology, Uppsala University. The school classes were equipped with a “research box” containing tools, containers and instructions and their primary task was to forage for mushroom and at the same time collect associated soil samples and search for animal droppings.

The first part of the project is now finished. 135 school classes participated and together contributed with 248 samples of dried mushroom, the same number of soil samples and ca 50 samples of animal droppings, mainly deer and wild boar. All mushroom samples have been measured with a HPGe detector resulting in gamma spectra where we have analysed the activity of Cs-137. GEANT 4 simulations have been performed to correct for geometrical effects in samples of different mass (and thereby height and geometry).

The preliminary results on 137-Cs in mushrooms has been reported to participating schools and can be found in a google database:

https://www.google.com/maps/d/viewer?mid=1d5qHyozVSQ8htgsNhrjLs8rmd67i0pBw&ll=60.801484287476725%2C16.63973699999997&z=5

In summary, only two mushroom samples had activities above 1500 Bq/kg, which is the threshold value for selling mushroom in Sweden. Both samples were collected in northern Sweden in areas that received a relatively large amount of fallout from the Chernobyl accident. The overall distribution was

in large as expected from the fallout maps. Preliminary results have been reported to SSM (Swedish Radiation Safety Authority) and SLV (National Food Agency).

After having delivered the preliminary results, there is a lot of interesting research to pursue. Presently we are working on DNA sequencing of soil samples (together with our partner at Forest Mycology and Plant Pathology) to establish which competing species exist in the same environment as the individual fungi samples. Together with the sampling of fungi species themselves, this can give important information about how different fungi species in different surroundings take up radiocaesium. In parallel, we are developing methods for radioactivity measurements of the soil samples, which are much denser and gamma-absorbing than mushroom tissue. In this work we have collaboration with the Department of Earth Sciences at UU and an ongoing bachelor project. Following these activities will be a survey (DNA sequencing and activity measurement) of animal droppings to map the transfer of caesium in food chains.

We believe that the citizen science part of this project has been an important effort to bring interest and knowledge about science to a young audience. The effects of this will be investigated through analysing a questionnaire that has been answered by 600 school pupils and 42 teachers.

This project has been widely reported in media and the researchers have featured in several radio and newspaper interviews. We have also reported the activities at two workshops; the Swe-Rays workshop in Uppsala and the Environmental radioactivity workshop in Gothenburg organized by the Japan Society for the Promotion of Science. Two abstracts have been sent to the Nuclear Data International Conference in Beijing in May 2019. Both were accepted, one as invited talk.

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 (Bill) Rakopoulos joined the division in spring 2012 to work on the AlFONS project. AlFONS is co-financed by SSM and SKB and 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. Bill has been involved in tests and characterization measurements of the converter and the ion guide. However, his main focus has been on measurements of isomeric yield ratios (IYR), the production rate of metastable states (isomers) relative to the ground state in fission, and the comparison of experimental data with theoretical calculations using TALYS and GEF.

In December 2018, Rakopoulos defended his doctoral thesis entitled Isomeric yield ratio measurements with JYFLTRAP. In his thesis he presents data on more than 20 isomeric yield ratios on proton induced fission of uranium and thorium. He also developed a methodology to estimate the angular momentum of the fission fragment just after scission from the measured yield ratios.

Measurements of prompt fission neutron multiplicities

Research leader: Dr. Ali Al-Adili

Participant researchers: B. Becherini, D. Tarrío, S. Pomp, A. Göök, S. Oberstedt

The goal of this project is to perform systematic measurements on the average prompt fission neutron multiplicity (nubar) in correlation to fission yields. This is important as it reveals how excitation energy is shared in fission. Our instruments are a Twin Frisch grid ionization chamber and two liquid scintillators.

Reached milestones: We have performed one measurement on both Cf-252(sf) and U-235(nth,f) which resulted in 3 proceedings.

- EPJ Web Conf., 146:04056, (2017) – ND 2016 – Ali Al-Adili et al.
- EPJ Web of Conferences 169, 00002 (2018) – Theory 4 – Ali Al-Adili et al.
- Web of Conferences, 122:01007, (2016) – CNR*15 - Ali Al-Adili et al.

Outlook: We have granted beam-time application at the MONNET facility at JRC for making another measurement at higher excitation energy. The aim is to study the excitation energy dependence of nubar(A).

Measurements of fission yields with the VERDI 2e-2v setup

Ph.D. student: Bernardo Becherini

Research leader: Dr. Ali Al-Adili

Participant researchers: D. Tarrío, S. Pomp, A. Göök, S. Oberstedt

The aim of this project is to develop a state-of-the-art instrument (VERDI) to investigate the properties of fission fragments (mass and energy distributions). Accurate fission yields are to be measured to enhance fission modelling and to improve the inventory of precise nuclear data of relevance for nuclear applications. VERDI stands for VElocity foR Direct particle Identification and is a collaborative project between Uppsala and EC-JRC Geel.

Reached milestones: We have developed VERDI by including a second Micro Channel Plate detector and performing the first measurements on Cf-252(sf) which resulted in two proceedings. Our Ph.D. student Kaj Jansson finished his thesis partly on the VERDI data. We also developed the methodology itself by a simulation work. We discovered some flaws with the central assumptions in the technique and also presented the remedy for the problem, which resulted in one peer-reviewed article.

- EPJ Web of Conferences 146, 04016 (2017) - ND2016 - Kaj Jansson et al.
- EPJ Web of Conferences 169, 00002 (2018) – Theory 4 – Ali Al-Adili et al.
- Eur. Phys. J. A (2018) 54: 114 – Kaj. Jansson et al.

Outlook: We have enrolled a new Ph.D. student (Bernardo Becherini) on this project. Currently we are performing dedicated experiments at the TANDEM facility in Uppsala, to solve some pending instrumental challenges with VERDI. Once solved, we will move on to a first measurement using a neutron beam. Probably at a nuclear reactor (Budapest and ILL, Grenoble are two options).

Characterization of Spent Fuel in connection to Encapsulation and Disposal

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. In early 2018, collaboration intensified with Pacific Northwest National Laboratory and Lawrence Livermore National Laboratory, USA, for gamma-ray transport calculations in the context of gamma emission tomography of nuclear fuel. During 2018, a work package entitled "Spent Fuel Characterisation and Evolution until Disposal" was developed as a part of a proposal to a European Joint Programme ("EURAD") in the field of radioactive waste management and disposal. (The proposal was accepted by the European Commission in February 2019).

Development of statistical methods for the quantitative assessment of a validation domain in modern neutronics calculations

Participants: Dr. Henrik Sjöstrand, Dr. Georg Schnabel, Dinesh Kumar.

In collaboration between Uppsala University and CEA- France we are developing methods to improve the use of integral data for ASTRID, a CEA French prototype sodium-cooled reactor that is planned to be built. The project is a joint VR-financed project between Uppsala University and CEA, where the postdoc Dinesh Kumar is employed by Uppsala University and is stationed at CEA Cadarache.

During 2018 methods to account for the influence of different inputs into reactor calculations have been analyzed using the concept of Cook's distance. JEZEBEL integral experiment was considered for data assimilation, and then the transposition of results on ASTRID fast reactor concept was tested. [1]

In addition, improved methods for including discrepant integral experiments into a data assimilation scheme were presented during 2018. [2]

References

[1] Kumar D., Alam S., Sjostrand H., De Saint Jean C.; "Influence of nuclear data parameters on integral experiment assimilation using Cook's distance"; Journal: EPJ Web of Conferences; (2018)

[2] Sjöstrand H., Schnabel G.; "Monte Carlo integral adjustment of nuclear data libraries – experimental covariances and inconsistent data"; Journal: EPJ Web of Conferences; (2018).

Measurements of neutron-induced reactions at GANIL-NFS

Research leader: Prof. Stephan Pomp

Participants: Alexander V. Prokofiev, Diego Tarrío, Cecilia Gustavsson.

Master student: Matthias Carlsson

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 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. The facility has not started-up yet.

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 2018, different design and service works on the Medley chamber have been performed in order to ensure its proper installation at the NFS experimental area.

In particular, 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 2018 at our premises in Uppsala. A new set of preamplifiers built at GANIL have been received and successfully tested at our laboratory, 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. New PPAC prototypes have been built using very thin electrodes, so that they are transparent to fission fragments. The development and characterization of these new PPACs has been the main subject of a master thesis. Some preliminary results on the PPAC characterization, as well as on the general development of the aforementioned projects, have recently been presented at different scientific meetings and conferences:

- Final meeting of the EU project “CHANDA” (“Solving CHAllenges in Nuclear DAta”). Madrid (Spain), April 2018.

- Swedish Nuclear Physics Meeting. Uppsala, October 2018.

A diploma student, Matthias Carlsson, has been working in the group in the first half of 2018. He successfully defended his master thesis entitled “Development and Characterization of Parallel-Plate Avalanche Counters for Nuclear Physics Experiments” in June 2018. The work was co-supervised by Alexander Prokofiev and Diego Tarrío.

Our group has hosted a visiting Ph.D. student (Keita Nakano) from Kyushu University (Japan) between September and December 2018. The student has worked in the characterization of the PPAC detectors, under supervision of Alexander Prokofiev and Diego Tarrío.

Multi variate analysis within nuclear safeguards

Multivariate analysis for nuclear safeguards purposes

Postdocs: Dr. Li Caldeira Balkeståhl and Dr. Zsolt Elter

Other participants: Ass. Prof. Sophie Grape

Within this project, the goal was to study how and to what extent multivariate analysis (MVA) algorithms can be used within the field of nuclear safeguards. The purpose for this has been both to investigate the possibility to determine initial enrichment, burnup, and cooling time of spent fuel assemblies independently of operators’ declarations, and to identify partial defects where a fraction of the fuel material has been diverted.

In the project, nuclear fuel assemblies have been modelled using Serpent2 and the passive high-resolution gamma spectroscopy signatures as well as a neutron signature were simulated. When possible, the early die-away τ, as determined by the Differential Die-Away Self Interrogation (DDSI) Instrument, was used in the analysis. This parameter is a reflection of the fissile content in the fuel assembly, as well as the content of neutron-absorbing fission products. In order to compute the passive gamma spectra, the in-pool passive gamma measurement station at the central interim storage facility for spent nuclear fuel (Clab) in Oskarshamn (Sweden) was considered. The gamma measurement station was modelled with a dedicated point-kernel code named FEIGN, which provides

a fast way of simulating the detector response, which is more favourable when training multi variate data analysis models which require a vast amount of samples.

For the fuel parameter determination of PWR 17x17 fuel assemblies, the modelled gamma signature was combined with the modelled early die-away time from the DDSI instrument. Earlier work has shown promising results for cooling times up to 20 years, and now cooling time was expanded to 70 years. Using Partial Least Squares (PLS) regression on the gamma response of Cs-137 and Eu-154 and τ, the results showed that all three fuel parameters could be determined. However, using the known CT gives a better accuracy in the IE and BU determination.

An attempt was also done to determine the determine initial enrichment, burnup and cooling time for intact 8x8 BWR fuel assemblies (with cooling times up to 30 years). The most important nuclides to classify BWR and PWR fuels were presented and compared with results from the literature. The axial density profile of the coolant void was modelled, together with its average value with is often used. The signatures used in the MVA to determine the fuel parameters were Cs-134, Cs-137, Eu-154 and the geometry independent k-infinity value (used instead of the DDSI signature). Several different MVA algorithms were tried, and the Random Forest regression was finally selected. The results showed that he model did a great job with predicting cooling time. However, for BU other MVA methods may be more accurate. We observed that the inclusion of the neutron signature results in a significant improvement on the root mean squared error of the IE predictions, thus combining gamma and neutron signatures for safeguards verifications is strongly advised.

For the partial defect studies of 17x17 PWR fuel assemblies, only the gamma response to fuel assemblies with cooling times up to 30 years was studied. A partial defect level of 30% was selected and the removed fuel rods were replaced with steel dummies. Substituting fuel rods with non-radioactive material will affect the source of the gamma rays, and thereby the resulting gamma spectrum. Three different partial defect configurations were modelled, and the gamma response from Cs-134, Cs-137 and Eu-152 was analysed and visualized using Principal Component Analysis (PCA). The results showed that the data points cluster according to the partial defect configuration, but that at longer cooling times the clusters are less well separated. This can be expected, as the fission product concentration is reduced with cooling time. The spread of the clusters is a consequence of the different BU and CT in the samples.

In the continuation of the work, it is necessary to further optimize the models to avoid overfitting, and to assess the sensitivity to measurement noise. It is also planned to both include the Cherenkov light intensity as an additional signature, and to create a combined methodology using multiple MVA techniques. A next step is also to validate models using experimental measurement data.

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

In October 2018 Erik Branger successfully defended his PhD thesis titled “Enhancing the performance of the Digital Cherenkov Viewing Device: Detecting partial defects in irradiated nuclear fuel assemblies using Cherenkov light”. The thesis summarizes the work done on further enhancing the performance of the Digital Cherenkov Viewing Device (DCVD), used to verify spent nuclear fuel assemblies in wet storage based on the Cherenkov light produced.

During 2018, Erik has been working on investigating the background found in DCVD measurements, to quantify its effect and to propose methods for removing it. Based on measurements made at Clab it was concluded that the background removal method implemented in the DCVD may not always completely remove the background, and that this could be a problem when verifying low-intensity assemblies. The background was found to mainly originate from the instrument itself, and it was proposed to use a standard dark-frame calibration to more accurately identify and remove this component. Due to the lighting conditions at Clab, background originating from facility lighting could not be detected, and its potential impact on DCVD measurements could not be assessed.

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. Simulated DCVD images has been used to investigate how different top plates and other top structures in a PWR 17x17 assembly affects the DCVD measurements, and have identified ways to compensate for the difference. This will allow assemblies with different physical designs to be compared with better accuracy, where today the assemblies would either not be compared, or compared knowing that there are systematic errors in the comparison.

While the PhD student project is finished, Erik will continue working with DCVD-related questions as a postdoc. This work will involve further investigations regarding how to improve the DCVD performance, such as by studying various partial defects in greater detail, to better characterize the DCVD partial defect detection performance, and by analysing methods to extract more information from DCVD measurements. The project will also collaborate with the multivariate analysis for partial defect verification project underway, to investigate if the combination of gamma, neutron and Cherenkov light signals will provide a more detailed description of the assembly than any one signal by itself.

Research projects

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

In February 23, 2018, Matilda Åberg Lindell successfully defended her thesis: “Nuclear safeguards evaluation and analysis techniques for application to nuclear fuel material in Generation IV nuclear energy systems”. Her project was financed by Vetenskapsrådet, SSM and Uppsala University. The thesis covered a broad range of aspects, from proliferation resistance assessment for a Gen IV system to multivariate analysis (MVA) assessments using simulated nuclear fuel data.

Her research showed, among other things, that one of the most proliferation sensitive parts of the Gen IV system is the recycling facility and that the 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.

Fission yields for next generation nuclear power

Ph.D. student: Zhihao Gao

Main Supervisor: Dr. Andreas Solders

Assistant Supervisor: Dr. Mattias Lantz, Prof. Stephan Pomp, Dr. Ali Al-Adili

Zhihao Gao joined the division of applied nuclear physics in September 2019. He will continue the work by Mattera (PhD dissertation in 2018) and Rakopoulos with the aim of measuring both independent and isomeric fission yields. A first measurement campaign is planned for August 2019 and meanwhile Gao focuses on improving the design of the ion guide by comparing simulations in GEANT4 with data acquired in 2016. He will present the results of this study at the International Conference on Nuclear Data for Science and Technology in Beijing in May this year.

In addition to above, there are other ongoing education activities comprising various aspects of Gen IV systems.

Publications and conferences

PhD theses

1. Branger E.; "Enhancing the performance of the Digital Cherenkov Viewing Device : Detecting partial defects in irradiated nuclear fuel assemblies using Cherenkov light"; Publisher: Acta Universitatis Upsaliensis; ISBN: 978-91-513-0415-1; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-357578; (2018)

2. Helgesson P.; "Approaching well-founded comprehensive nuclear data uncertainties : Fitting imperfect models to imperfect data"; Publisher: Acta Universitatis Upsaliensis; ISBN: 978-91-513-0334-5; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-348553; (2018)

3. Rakopoulos, Vasileios; Isomeric yield ratio measurements with JYFLTRAP: In quest of the angular momentum of the primary fragments; Publisher: Acta Universitatis Upsaliensis; ISBN: 978-91-513-0502-8; Permalink: http://urn.kb.se/resolve?urn=urn%3Anbn%3Ase%3Auu%3Adiva-364951; (2018)

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Work published/accepted in scientific journals

The following scientific papers were published during 2018:

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4. Branger E., Grape S., Jansson P., Jacobsson Svärd S.; "Experimental study of background subtraction in Digital Cherenkov Viewing Device measurements"; Journal: Journal of Instrumentation; Vol: 13; No: 8; DOI: 10.1088/1748-0221/13/08/T08008; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-357150; (2018)

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6. Helgesson P., Sjöstrand H.; "Treating model defects by fitting smoothly varying model parameters : Energy dependence in nuclear data evaluation"; Journal: Annals of Nuclear Energy; Vol: 120; DOI: 10.1016/j.anucene.2018.05.026; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-348552; (2018)

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14. Åberg Lindell M., Andersson P., Grape S., Hellesen C., Håkansson A., Eriksson 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)

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2. Sjöstrand H., Schnabel G.; "Monte Carlo integral adjustment of nuclear data libraries – experimental covariances and inconsistent data"; Journal: EPJ Web of Conferences; Conference: International Workshop On Nuclear Data Evaluation for Reactor Applications (WONDER-2018); Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-378726; (2018)

3. Branger, E, Grape, S, Jansson, P, Jacobsson Svärd, S, On the inclusion of light transport in prediction tools for Cherenkov light intensity assessment of irradiated nuclear fuel assemblies. Journal of Instrumentation.

Conference contributions

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19. Zs. Elter, L. Caldeira Balkeståhl, S. Grape, C. Hellesen: Nuclear Safeguards Verification of Modelled Spent BWR Fuel Using A Multivariate Analysis Approach, IAEA Symposium on International Safeguards, 2019

20. L. Caldeira Balkeståhl, Z. Elter, S. Grape, and C. Hellesen. ”Application of Multivariate Analysis to Gamma and Neutron Signatures from Spent Nuclear Fuel”. In the Proceedings of the 59th Annual Meeting of the Institute of Nuclear Materials Management (INMM), July 22-26 2018, Baltimore, USA.

21. L. Caldeira Balkeståhl, Z. Elter, S. Grape, C. Hellesen, “Nuclear safeguards verification of modelled partial defect PWR fuel using multivariate analysis”. IAEA Safeguards Symposium: Building Future Safeguards Capabilities, Nov 5-8, Vienna. 2018.

Other reports, books etc.

1. Andersson P.; "Validation of axial flux profiles and development of a modified axial flux model using gamma scans of IFA-677"; Publisher: Institutt for energiteknikk; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-374362; (2019)

2. Jansson P.; "Nonproliferation and nuclear fuel cycle back-end research at Uppsala University, Sweden : Special Seminar at PNNL"; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-340081; (2018)

3. Bourva L., Jansson P.; "International Workshop on Numerical Modelling of NDA Instrumentation and Methods for Nuclear Safeguards : (NM-NDA-IMNS18)"; Publisher: European Safeguards Research & Development Association (ESARDA); Conference: International Workshop on Numerical Modelling of NDA Instrumentation and Methods for Nuclear Safeguards, Luxembourg, May 16-17, 2018; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-366710; (2018)

Networking and collaborations

- Sweden:
  - KTH
  - Chalmers
  - Stockholm University
  - Gothenburg University
  - Lund Univeristy
  - Linköping University
  - Skånes universitetssjukhus
  - Akademiska sjukhuset
  - Karolinska sjukhuset
  - Skandion-kliniken
  - SKB
  - SSM
  - 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
  - CEA
- Japan:
  - Kyushu University
    continued dialogue with Tokyo Technical Institute
- Switzerland:
  - CERN
  - PSI
- Thailand:
  - Chiang Mai University
- USA:
  - LANL

- UCB
- LBNL
- LLNL
- PNNL
- ANL
- ORNL

- Norway:
  - OECD Halden Reactor Project and IFE
- IAEA
- The World Nuclear University
- EU:
  - CHANDA
  - ENEN (European Nuclear Education Network)
  - Euratom
  - ESARDA (European Safeguards Research and Development Association)
  - RADSAGA network
  - Preparation for a project within the European Joint Programme ("EURAD")
- Nordic Academy for Nuclear Safety and Security, NANSS
- MÅBiL project with participants from Uppsala University, KTH and Chalmers
- Co-operating the Swedish Academic Initiative in Nuclear Technology, SAINT, together with Chalmers.

Outreach

General

- Dr. Sophie Grape is a member of Kärnavfallsrådet.
- Dr. Mattias Lantz is chairing Analysgruppen
- Dialogues with members of Parliament
- Meeting with MP Richard Nordin (C), energy policy spokesman and member of the energy commission.
- Dialogue with the Ministry of Education and Research

Excerpt from our activities within popularisation of science and informing the public audience about nuclear power

This activity is by far the most difficult to present because of its diverse nature, spanning from public lectures and writing debate articles to commenting on social media. Nevertheless, below is a brief sample of what we have done during 2018.

1. Ane Håkansson interviewed by P4 Västernorrland about the consequences of a nuclear war.

2. Mattias Lantz in a panel debate about the future energy mix. Arranged by the student unions of science and technology in Uppsala.

3. SciFest 2018 (Uppsala).

4. Carl Hellesen featured as an expert in ”Vetenskapens värld” (SVT) regarding Thorium-fueled reactors

5. Vetenskap och Allmänhet "Plocka svamp i forskningens tjänst!" Guest column by Cecilia Gustavsson about the citizen science project "Strålande jord"

6. Interview with Sophie Grape in “Studio Ett” (SR) about technical measures to supervise disarmament of nuclear weapons.

7. Stefan Jarl Holm och Mattias Lantz visiting ”Gräsödagen” and addressed the public about radioactivity.

8. Sophie Grape in a dialogue with fourth graders about nuclear power, P4 Uppland (SR)

9. Ane in interview by SVT regarding the restart of the nuclear power engineering programme in Uppsala.

10. Study visit by 40 pupils and teachers from Kunskapsgymnasiet Globen in Stockholm.

11. Mattias Lantz requests the journal ”Naturvetaren” to correct erroneous information about the Chernobyl accident.

Additional information and commitments during 2018

NESSA

By Dr. Alexander Prokofiev

The NESSA facility (NEutron Source in UppSAla), being developed by the Division of Applied Nuclear Physics, will be an infrastructure intended for using of neutron generators (NG) for research, education, and irradiations for industry. The research uses will comprise detector development, nuclear data measurements, as well as development of neutron-tomography techniques. Uses in education are envisioned at both graduate and post-graduate levels, the latter in particular in framework of summer schools for early-stage researchers from European and other countries.

Such first summer school, based on the NESSA facility, is planned in framework of a recently accepted EU Horizon-2020 project, called ARIEL (Availability and Use of Nuclear Data Research Infrastructures for Education and Learning), submitted by us together with 22 other universities and research centres across Europe. In framework of the same project, NESSA will become a member of a European network of neutron facilities for nuclear data research, open for transnational access by research groups.

The construction works at the facility, situated in the FREIA hall with Ångström laboratory, are now ongoing. The procurement of the neutron generator is now completed. The Site Acceptance Test (SAT) of the new facility is planned for September 2020.

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.

Vision

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 1 - 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.

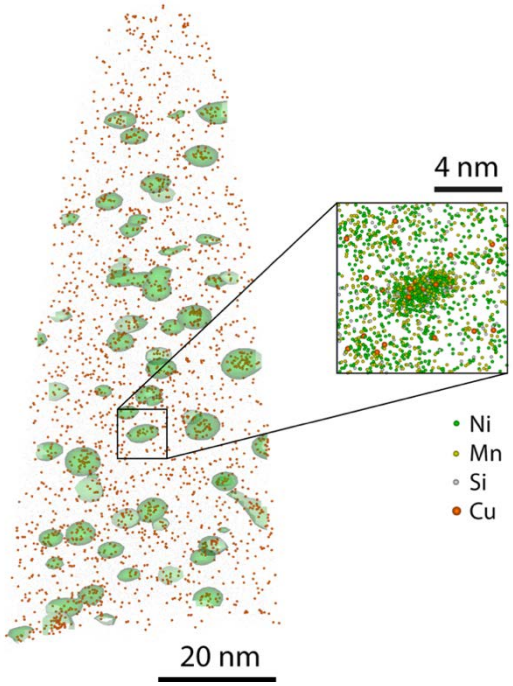


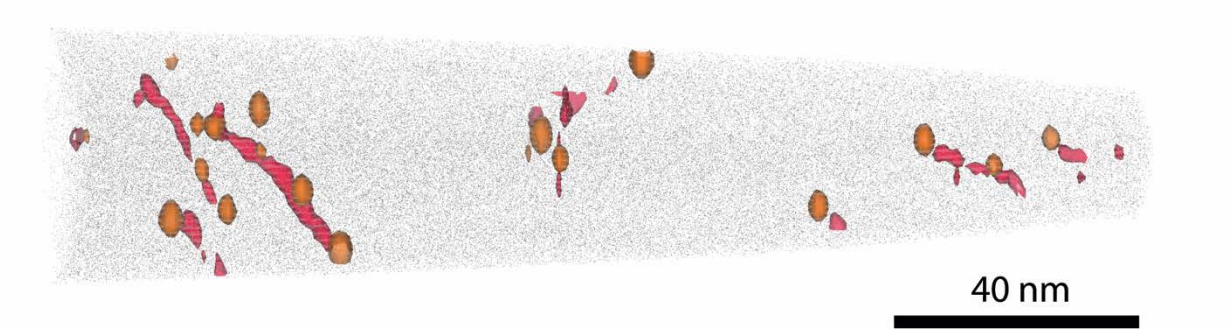
Fig. 7. An atom probe tomography reconstruction of an irradiated reactor pressure vessel steel of surveillance material. Green surfaces correspond to 12.43 at% of Ni, Mn and Si. Orange dots correspond to Cu atoms. The enlarged volume is 10x10x10nm³.

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, 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. 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.

Figure 8. 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 ast% Mo.



In 2018, the PIA experiments were continued and resulted in a manuscript (no 7) for the thesis. Before submission of the manuscript, some additional hardness measurements needs to be performed in a hotcell. In addition to two conferences (APT&M and Fontevraud) and a course (Soteria, in Valencia) attended, a visit to Manchester was done to compare the APT and TEM results. The main event of 2018 was the successful PhD defence, that took place December 11, with Sergio Lozano-Perez (University of Oxford) as opponent.

Plans

Kristina is currently employed as a post-doc at Chalmers during 2019, and will continue with the project. Material from the decommissioned Barsebäck plant is expected to arrive to Chalmers early 2019 for APT analysis.

Publications within the project

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.

4. Cluster Formation in In-service Thermally Aged Pressurizer Welds, K. Lindgren, M. Boåsen, K. Stiller, P. Efsing, M. Thuvander. Journal of Nuclear Materials 504 (2018), 23-28.

5. Thermal ageing of low alloy steel weldments from a Swedish nuclear power plant - the evolution of the microstructure, K. Lindgren, M. Boåsen, K. Stiller, P. Efsing, and M. Thuvander. Proceedings of Fontevraud 9: Contribution of Materials Investigations and Operating Experience to Light Water NPPs Safety, Performance and Reliability (2018)

6. PhD thesis: Effects of Irradiation and Thermal Ageing on the Nanoscale Chemistry of Steel Welds, 2018.

Planned publications (tentative titles and authors)

7. Post irradiation annealing of high flux irradiated reactor pressure vessel weld, K. Lindgren, M. Boåsen, P. Efsing, K. Stiller, and M. Thuvander.

8. Clustering in a decommissioned BWR RPV, K. Lindgren, M. Boåsen, P. Efsing, K. Stiller, and M. Thuvander.

Conference contributions

1. APT&M 2016, Gyeongyu, South Korea (oral presentation)

2. NuMat 2016, Montpellier, France (oral presentation)

3. APT&M 2018, NIST Washington, US (oral presentation)

4. Fontevraud 9 2018, Avignon, France (oral presentation)

Planned

5. IGRDM 21 2019, Gifu, Japan (abstract submitted)

6. Euromat 2019, Stockholm, Sweden (abstract submitted)