Strål
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Swedish Radiation Safety Authority

Research

Core data Research at Uppsala University

2020:13

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SSM perspective

Background

This project is to support a research group at Uppsala University in the research field of nuclear data for applications. Nuclear data research is about measuring microscopic cross-sections and developing theoretical nuclear models to create evaluated nuclear data libraries. These nuclear data libraries are used in different applications such as, nuclear technology, nuclear safeguards, medicine, final repository etc.

This project measured different nuclear reactions and developed theoretical nuclear data models. The experiments were focused on fission reactions. The experiments were performed in different facilities in Europe such as the IGISOL-facility in Jyväskylä (Finland) for proton induced and neutron induced fission.

In the report," Grunden för en långsiktig kompetensförsörjning inom strålsäkerhetsområdet", a task on the behalf of the government, it is shown that nuclear technology is a critical research area that needs more funding. Nuclear data is a sub area within nuclear technology that is identified as a critical research area. This research project is to support the national competence in that area.

Results

This project contributed to collaborations between Swedish universities, international research facilities and international organizations such as IAEA and OECD/NEA. This project contributed to 19 publications in international peer reviewed journals, two PhD's, one new PhD project, 6 master theses, 32 conference papers, multiple national and international meetings. The funding has enabled 5.2 million SEK in funding (including the research funding from this project). This project has contributed to support the national competence within the nuclear data area and areas that are dependent on nuclear data.

Relevance

SSM needs to maintain a national competence within nuclear technology, including nuclear data. The research group at Uppsala University received funding for research within nuclear fission data which are part of SSM's competence area. The funding has resulted in new competences such as PhD's, master theses and published articles that contribute to maintain the national competence within nuclear data.

Need for further research

There are needs for further research to maintain the competence within nuclear fission data as stated in the report" Grunden för en långsiktig kompetensförsörjning inom strålsäkerhetsområdet". The project was finished during 2019, but was not continued in SSM's research plan 2020. It is recommended to propose a new research project to support the competence within nuclear fission data for 2021 and beyond, as part of the long term support of the national competence in this field.

Project information

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Content

Summary

The 2-year project ”Nuclear data for application” started in spring 2018 and continues until the end of 2019. It concerns research in the domain of nuclear data.

The objectives are

(1) to obtain experimental nuclear physics data, in particular for light-ion production and the fission process, and

(2) to continue the development of Total Monte Carlo (TMC) methods and the TALYS-based evaluated nuclear data library TENDL.

The project is a lead towards better knowledge of microscopic nuclear physics observables and the impact of their uncertainties on macroscopic systems within areas like radiation effects in materials and electronics, nuclear medicine, dosimetry, and standards, reactor safety, and the nuclear fuel cycle. The project has led to competence building within the group, transcending to our research environment in Sweden and internationally.

Main achievements during the project period:

1) Two PhD students, Petter Helgesson and Vasileios Rakopoulos, have presented and successfully defended their thesis.
2) Fission studies at IGISOL/JYFLTRAP, Finland, have been expanded with a new experimental campaign, efficiency studies, development of improved analysis methods, and model development.
3) The preparation of an experimental setup, Medley, for light-ion production and fission measurements at the Neutrons For Science facility at GANIL, France has continued. The Medley setup will be shipped to GANIL before the end of 2019.
4) Preparation for experiments to study neutron emission in fission at the new MONNET facility at EC_JRC, Belgium.
5) Experimental studies at the TANDEM facility at Ångström laboratory in Uppsala to study detectors that will be used in the VERDI setup at JRC for fission yield and neutron emission measurements.
6) Work on modelling of fission using the state-of-the-art nuclear model codes TALYS and GEF has continued, leading to a dedicated research visit at IAEA in the beginning of 2020.
7) The work on uncertainty propagation methods has resulted in an improved understanding of the impact of nuclear data on applications; led to improved nuclear data; and enhanced calibration methods in the domain of nuclear engineering.
8) Development of methods to handle model defects using Gaussian processes. This activity has also resulted in improved data analysis methods in the experimental projects.
9) Started activity to implement methods from machine learning in the field of nuclear data.

10) Macroscopic reactor aging parameters have been connected to the fundamental nuclear physics processes by using the nuclear model code TALYS and the Total Monte Carlo method (TMC)
11) Continued collaboration with key institutions and organisations in the field of nuclear data (e.g., IAEA, OECD/NEA/WPEC, PSI, CEA, EC-JRC, GANIL, JYFL) and joined two large experimental collaborations (n_TOF@CERN and FRS Ion Catcher at GSI, Germany).
12) The above mentioned activities resulted in a large number of publications in refereed international journals and conferences, invited talks and seminars.

Populärvetenskaplig sammanfattning

Strålningsvetenskapen berör flera samhällsviktiga tillämpningsområden. Exempel är den medicinska strålningsvetenskapen och kärntekniken med dess besläktade områden. Gemensamt för dessa är behovet av kärnfysikalisk kunskap, som exempelvis tas fram inom kärndataforskningen. Kärndataforskning handlar om att genomföra mätningar av mikroskopiska storheter (t.ex. tvärsnittsdata eller fissionsyielder), utveckla teoretiska kärnreaktionsmodeller som beskriver mätdata samt tillåter interpolering och extrapolering i områden där mätdata saknas, samt samspel mellan teoretiska och experimentella resultat för att skapa evaluerade kärndatafiler. Dessa kärndatafiler används sedan i en rad olika tillämpningsområden, till exempel inom kärnteknik och nukleärmedicin. En central aspekt för samtliga tillämpningar är osäkerhetskvantifiering. Det är därför ett viktigt delområde inom kärndataforskning att utveckla (helst automatiserade) metoder för osäkerhetspropagering från mikroskopiskt skala till de makroskopiska tillämpningarna. Exempel på det senare är behovet att inte bara ange isotopsammansättningen i ett bränsleknippe efter flera års körning i reaktorn, men även osäkerheterna i den. Det kan tilläggas att informationen om just isotopsammansättnigen är viktiga för både reaktorn under drift, kärnämneskontroll, samt slutförvaret.

Inom projektet genomförs grundläggande mätningar av nukleära reaktioner, tester och studier av teoretiska modellkoder. Detta för att utveckla koderna och utveckling av metoder som använder modellkoder för att framställa kärndatabaser.

I den experimentella delen av projektet genomfördes olika studier kopplade till fissionsprocessen. Experimenten gjordes vid olika anläggningar i Europa, ofta med stöd från andra projekt, t.ex. EU projektet CHANDA.

Ett exempel på de experimentella arbeten är studierna som görs vid IGISOL-anläggningen i Jyväskylä, Finland. Vid IGISOL kan både protoninducerad och neutroninducerad fission studeras i en unik anläggning. Klyvningsprodukterna kan transporteras till en s.k. Penningfälla där deras massa kan mätas med stor noggrannhet. Mätmetoden möjliggör att bestämma den relativa andelen bland olika isotoper som bildas under fissionsprocessen. Andra metoder har mycket svårt att ge samma resultat. De mer klassiska mätmetoderna tillåter antingen inte en isotopsspecifik mätning då osäkerheten i massbestämningen är för stort, eller ger bara (genom gammaspektroskopi) information för begränsade isotoper med lämpliga halveringstider och signaturer. Detta sker dessutom normalt relativt lång tid efter fissionshändelsen så att de ursprungliga produkterna redan sönderfallit till mer långlivade produkter.
Utöver detta bedrevs forsknings- och utvecklingsarbeten kopplade till experiment vid flera andra anläggningar i Europa, till exempel vid Europeiska Kommissionens Joint Research Centre i Geel, Belgien.

Projektet handlar även om utveckling och tester av kärnmodeller vilket är nära kopplat till analys av och jämförelse med experimentella data. Modellkoderna som kom till användning är främst GEF och TALYS. TALYS-koden är den ledande kärnmodellkoden i världen och utvecklas numera vid IAEAs kärndatasektion. TALYS är en central del för skapandet av kärndatabasen TENDL och kopplar till den delen av projektets som handlar om metoder för osäkerhetskvantifiering.

Sist men inte minst behandlar projektet frågeställningen om hur osäkerheterna från de experimentella data, samt möjliga brister i deras teoretiska beskrivning, bäst hanteras inom de skapade kärndatabaserna. Syftet är att förbättra möjligheten att på ett säkert och reproducerbart sätt kvantifiera osäkerheter resulterande från de grundläggande mätningarna och fysikaliska modeller till makroskopiska system, t ex bränslet i bränslecykeln, men även olika material. Här handlar det om utvecklingen och användning av matematiska metoder för att kunna automatisera processen så långt möjligt. Målsättningen är att skapa en väldefinierat och kvalitetssäkrat process där datorkluster regelbundet kan skapa uppdaterade kärndatabaser med realistiska osäkerheter.
Sammanfattningsvis bidrog projektet inte bara till dem målsättningar som nämndes inledningsvis, men även till samarbeten mellan svenska universitetsbaserade forskare och internationella forskningsanläggningar och organisationer som IAEA och NEA, och resulterade i ett flertal publikationer i internationella refereegranska tidskrifter och en nationell och internationell närvaro på vetenskapliga möten och konferenser. Genom att stödja den nämnda forskningen bidrog projektet till utbildningen av två doktorander, och till kompetenssäkring och kompetensuppbyggnaden inom kärndataområdet och de områden som är beroende av kärndata; den tillämpade kärnfysiken, kärnteknik och kärnsäkerhet.

1. Research projects

1.1. Experimental activities

1.1.1. Cross section measurements (NFS, GANIL, France)

We are working in the development of an experimental setup to perform different measurements of cross-sections of neutron-induced reactions at the future Neutrons For Science (NFS) facility at GANIL (Caen, France) [6, 34]. Those experiments will focus on the study of two topics: one is the production of light-ions induced by neutrons[1]. For this topic, we have been granted beam time for studying the light-ion production on Carbon, of interest for topics such as dosimetry in aerospace and medical applications, radiation-induced failures in silicon carbide electronic devices, and for materials used in nuclear technologies. The other topic of interest are the fission reactions, where our focus is on the improvement of the neutron standard cross sections. In addition to these two topics, our setup will be also used for characterizing the neutron beams of the facility.

The NFS facility is still not operative because of several delays with the license of operation from the authorities. A very first test beam has finally been run in October 2019. Further test towards the neutron production area are scheduled for November 2019. Commissioning will then start in spring 2020 and experimental runs are expected to start in 2021. We have been working further in the development of the experimental setup. In particular, the works about the characterization of Silicon detectors have led to a Master project [59] (ended in June 2019). The development of PPACs (Parallel Plate Avalanche Counters) for fission fragment detection has also continued during this time, resulting into another Master project [60] (ended in June 2018) and, more recently, into a presentation at the International Conference in Nuclear Data 2019 (Beijing, China), whose proceedings will be published in 2020 [53].

1.1.2. Fission studies at IGISOL/JYFLTRAP, Jyväskylä, Finland

The long-term goal of the project is to measure isotope-specific independent fission-yields in neutron-induced fission of various actinides and in different neutron fields. This can be done at the IGISOL facility at the Accelerator lab of the University of Jyväskylä, Finland [32,62]. At this facility fission product can be separated by mass at resolving power of more than 10^6 (see Fig 1). This is enough to separate not only the different elements in an isobar, but in many cases also ground states from long-lived excited states of the same nucleus.

[1] K. Jansson et al., "Designing an upgrade of the Medley setup for light-ion production and fission cross-section measurements", Nucl. Inst. and Methods in Phys. Research A **794**, 141-150 (2015).

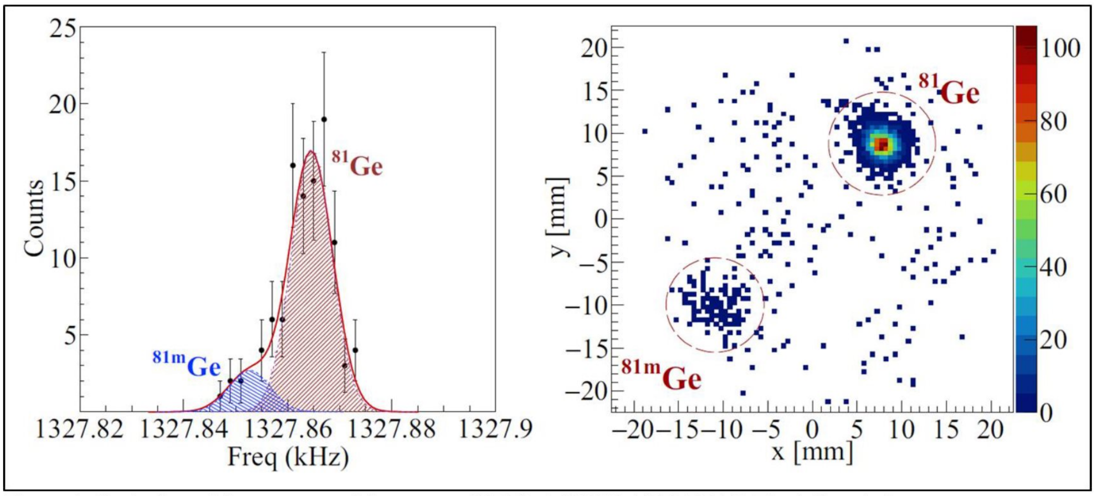

Figure 1: Illustration of the mass resolving power (MRP) at IGISOL/JYFLTRAP. The left part shows a measurement of the ^{81}Ge and its isomer using the sideband cooling technique. Although this technique offers an MRP in excess of 10^5, the excited state with an energy of 679 keV can barely be resolved. The right part of the figure shows a measurement for the same fission product but using the newly implemented phase imaging technique. With this technique, a MRP of more than 10^6 can be achieved and the two states are clearly separated.

At IGISOL fission is routinely achieved by impinging high energy proton beams on fissionable targets. To facilitate neutron induced fission a Be(p,n) converter and a dedicated ion guide has been developed and commissioned on site in 2016. First studies using gamma spectroscopy have been done [7]. However, to achieve high enough count rates of fission products for the measurements with the Penning trap that we want to perform, it is necessary to use the high current cyclotron MCC30 which still is not in commission.

The focus of the research as of lately has been the study of isomer production in proton induced fission [11,12]. The population of high spin isomers in fission provides insight into the distribution and generation of angular momentum of the fission fragments at scission. This, in turn, is valuable information for the understanding of the fission process and in the development of fission models. Such models can be used to predict fission observables in systems that are difficult to study experimentally, for example the fission of minor actinides in Generation IV reactors or the fission of extremely neutron rich nuclei in interstellar matter.

A first run dedicated to measurements of isomer production in fission was performed in January of 2017 and resulted in values of isomeric yield ratios (IYR) of 12 nuclei [12]. Most importantly a systematic study was made of the IYR in odd-A indium and cadmium isotopes. From the measured values of the IYR we derived the average angular momentum of the corresponding fragments, which revealed an interesting correlation with the quadrupole moment of the fission products. The result was published in 2019 and was part of the PhD defence of V. Rakopoulos in December 2018 [58].

In October 2018 a new doctoral student, Zhihao Gao, was recruited. His main task in the first year has been to benchmark a simulation model of the ion guide for neutron induced fission [25]. This has been done using gamma spectroscopy data of implantation foils from the commissioning run in 2016. The result was presented at the Nuclear Data conference (ND2019) in Beijing this year and a paper for the proceedings has been submitted. The next step will be to use this model to optimize the performance of the guide. Our hope is that this will facilitate neutron induced measurement also with the lower proton current of the facility-standard K130 cyclotron.

In August a second campaign with measurements of IYR in proton induced fission was performed. This time the focus was to measure yield ratios at and around the shell closures of the doubly magic ^{132}Sn. The purpose is to study how the population of high spin isomers and the angular momenta behaves as the neutron and/or proton shell approach closure. The analysis is ongoing and will be part of the thesis of Z. Gao.

Work is also ongoing to improve our estimates of the angular momentum distributions of fission fragments from the obtained values of the IYR. To this end, a Master diploma student, Dany Gabro, has been recruited. The result of this work will be presented in his theses, to be defended in January 2020.

1.1.3. Fission studies at JRC-EC (Geel, Belgium)

In addition to the activities at IGISOL, we have also conducted experiments at the Joint Research Centre of the European Commission in Geel, Belgium. For the full width of activities and results, we refer to the publications. Here, only a brief summary is given.

The first set of experimental campaigns were devoted to the so-called "2E-2v" method and the development of the VERDI (VElocity foR Direct particle Identification) spectrometer [4,22,27]. Fission fragment energies and velocities are measured simultaneously to extract precise fission yields with a mass resolution better than 2 atomic mass units. The method provides another important observable, namely the average prompt neutron multiplicity (nubar). Through our Ph.D. student Kaj Jansson (finished 2017) we were able to improve the setup by completing the second time-of-flight arm and measure the yields of ^{252}Cf(s,f).

During the project we worked on improving calibration and characterization of our detectors to further improve the critical goal of optimizing time and energy resolution. To this end we have been performing dedicated calibration experiments on the VERDI detectors, at the TANDEM facility at Uppsala University. The data are currently being analyzed and further campaigns at the TANDEM facility are planned for 2020. The development and investigation on VERDI that could be done so far resulted in a successful application to VR, and Ali Al-Adili received a grant (etableringsbidrag) for the VERDI project, allowing for hiring a new Ph.D. project.

The second set of experimental campaigns were devoted to the so-called "2E" method were the kinetic energies of fragment are detected in a Frisch Grid Ionization chamber, in conjunction with prompt fission neutron detection in liquid scintillators (see Fig. 2). The aim was to measure the average neutron multiplicity, which was successfully done for ^{252}Cf(s,f) and ^{235}U(n_{th},f). The data were presented in several conference proceedings but are now being prepared for a final peer-reviewed publication. Recently a new experimental campaign was granted at the MONNET facility at JRC Geel in Belgium. This time we will measure the average neutron multiplicity at higher excitation energies, to investigate the energy dependence. The MONNET facility is still in commissioning phase, but beam can be expected during 2020.

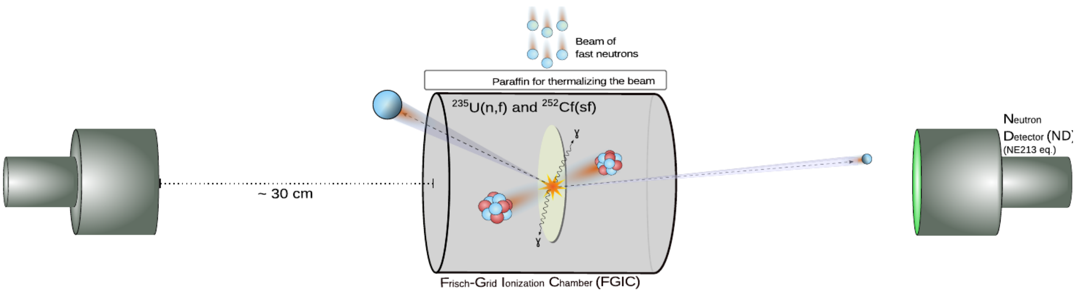

Figure 2: Illustration of the experimental setup used to study the energy dependence of neutron emission on the energy of the incoming particle. The fission products and their angular distribution are measured in a Frisch-Grid ionization chamber (center). The emitted neutrons are detected by two liquid scintillator detectors.

It should be mentioned that ongoing changes in the personnel and philosophy at JRC in Geel, with a strong push to transform MONNET and GELINA to user facilities, i.e., strongly reducing the local, much valued physics support provided by JRC thus far, puts larger responsibilities on the outside users, in order to run successful experimental campaigns and data analysis.

1.2. Studies of model codes

Within the framework of the IGISOL/JYFLTRAP research program, we developed a calculation method for fission fragment de-excitation using the TALYS [11,12]. The goal was to perform iterative calculations were pre-cursors are de-excited from highly excited fragments to ground state fission products, for different initial populated angular momenta distributions, P(J) (see illustration in Fig 3). The P(J) influences the isomeric state population and therefore, we try to match the measured IYR values by finding the right set of parameters in energy and spin J. The amount of angular momentum of the fission fragment strongly influences the relative fraction of the de-excitation energy going to neutron or gamma emission, respectively. Good modeling of this parameter is thus of importance for consistent description of prompt neutron and prompt gamma spectra.

We recently benchmarked our method with literature values for isomeric yield ratios from other reactions, and with other fission codes (GEF). We found that our method is rather robust and reproduced many earlier reported angular momentum values. It was also compatible with GEF. We found outliers in the literature values, deviating from both the TALYS and GEF codes, and we called for a second review of these data sets [2,23].

Currently we have master student working on the model, trying to implement more realistic excitation energy distributions. We have also initiated a collaboration with the TALYS developers (Arjan Koning, section head at IAEA) to improve our model further. Ali Al-Adili received a travel grant from Liljewahls to (three months at IAEA) to further develop the model together with the TALYS developers. He will spend in total three months at IAEA during 2020 to work on this topic.

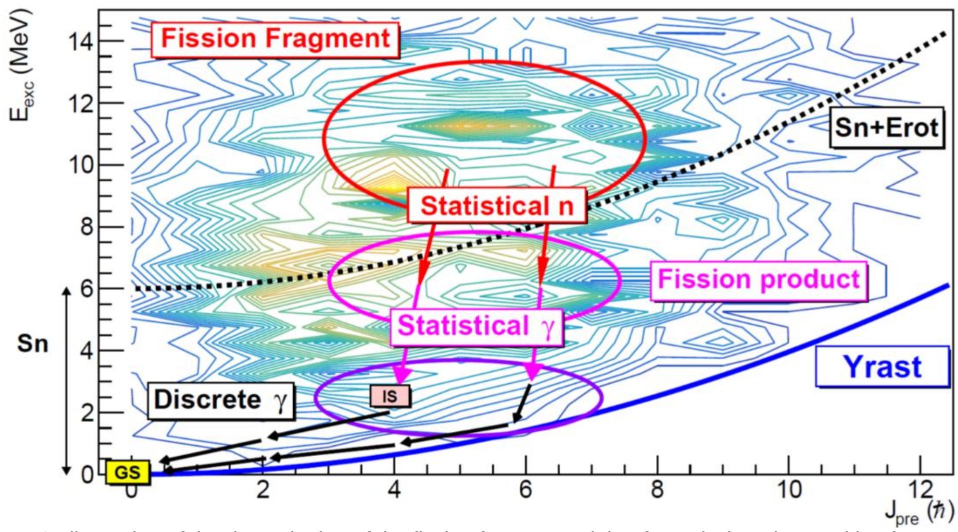

Figure 3: Illustration of the de-excitation of the fission fragment. Right after scission, the resulting fragments are highly excited. The excess energy is reduced via emission of neutrons and gammas. These emission processes compete with each other and the angular moment of the fragment (x-axis) sets limits on the neutron emission. The figure thus illustrates the interplay between the fundamental fission dynamics, and key observables for fission (neutron multiplicity and energy spectra, as well as gamma emission)

1.3. Uncertainty propagation and TENDL

This project connects fundamental nuclear data to different applications using state-of-the-art calibration methods. The outcome of the project is three-fold: an improved understanding of the impact of nuclear data on applications; improved nuclear data; and enhanced calibration methods in the domain of nuclear engineering. Consequently, this project contains three sub-projects during the reporting period: *Nuclear data for materials*; *Use of integral data for rector physics* and *Calibration and Uncertainty quantification methods*. Below is a list of the progress of the different projects.

1.3.1. Calibration and Uncertainty quantification methods

The main aim has been to improve calibration methods by addressing model defects and unrecognized systematic uncertainties, USUs. When a model defect is present, underlying physics cannot be reproduced independent of the choice of the model parameters (see Figure 1 as an example).

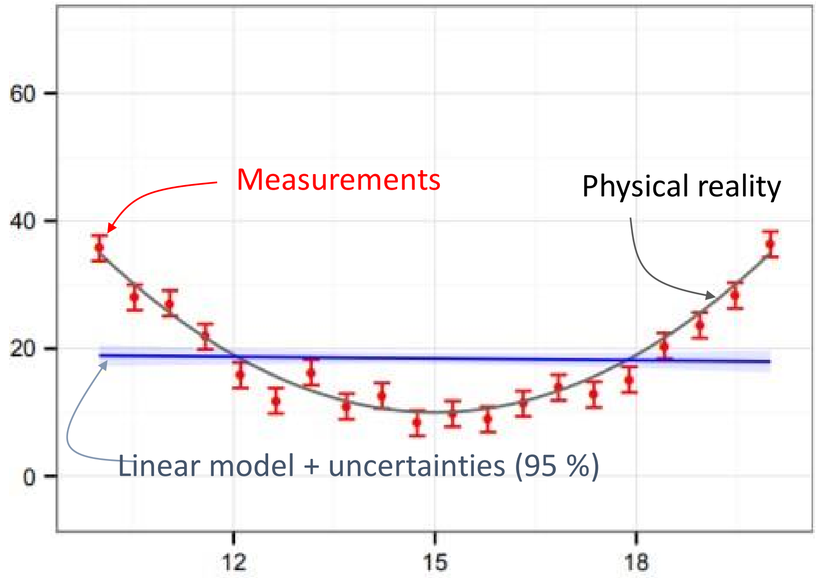

Figure 4: An example of where a Linear model severely underestimates the uncertainties (at a given point) when the true underlying physics is described by a quadratic model.

This typically leads to a severe underestimation of the resulting uncertainties. We address model defects by using Gaussian Processes. We have shown that the model defect can be treated either in the parameter domain or in the observable domain. We have demonstrated that we obtain both better best-estimates of the model-parameters, as well as more well-founded uncertainties by including a treatment of the model-defect [3, 13, 28, 36, 37, 43, 44, 50, 51, 54, 55, 57].

In the presence of USUs, there is again a risk that the obtained uncertainties in the model calibration are underestimated. We have used the method of marginal likelihood optimization (MLO) to estimate the magnitude of these USUs. The technique has been proven very powerful and adapted to numerous different applications (see below) [15,20, 36-38,45-49,52,55,57].

The results have been disseminated both through an active collaboration with IAEA, as well as active participation in *OECD/NEA Working Party on International Nuclear Data Evaluation Co-operation (WPEC), Investigation of Covariance Data in General Purpose Nuclear Data Libraries (SG44)* and SG46 (see below). The resulting codes have been published under open-source licenses, are well documented, and available to the community [55].

1.3.2. Nuclear data for materials

In this project, we connect macroscopic reactor aging parameters to the fundamental nuclear physics processes by using the nuclear model code TALYS and the Total Monte Carlo method (TMC). The TENDL and JEFF libraries are improved to address material parameters (such as flux at the reactor vessel, gas production, and DPA) coupled to monitoring of aging in nuclear reactors. The goal is to quantify these parameters including their uncertainties. One of the most critical parts of this work is to calibrate the model input parameters and their uncertainties by using experimental data. For this we have used the methods listed above. We have particularly worked with Fe-56, and an example evaluation of Fe-56 has been produced [54, 55, 56]. The project has been a part of the IAEA Coordinated Research Project: Primary Radiation Damage Cross-Sections (https://www-nds.iaea.org/CRPdpa/), which came to a successful completion with the review article: "Neutron-induced damage simulations: Beyond defect production cross-section, displacement per atom and iron-based metrics" [17]. Work with Fe-56, and other isotopes important for structural materials is foreseen to continue with support from, e.g., the Euratom research and training program.

1.3.3. Use of integral data for reactor physics

Nuclear data is used in designing of various nuclear applications and can be improved by using integral experiments. This is often done by adjusting the nuclear data so that a good agreement between simulation and experiments are obtained. Together with CEA France, UU has worked to improve the use of integral data for calibration (adjustment) of nuclear data. This has been done by investigating the influence of different nuclear model parameters on the adjusted data. For this, indicators such as the concept of Cook’s distance; and Akaike, Bayesian, and deviance information criteria; were developed and tested within the CEA-CONRAD platform. The results are yet not conclusive and should be seen as a basis for further research [5, 29].

In addition, UU has worked together with EPFL and PSI within WPEC subgroup 46: *Efficient and Effective Use of Integral Experiments for Nuclear Data Validation* to treat USUs in integral data using MLO (see 1.3.1.). This has proven to be a more robust method (than traditional methods) to handle the disagreements between different experiments[15, 45-48].The results so far are promising and have been well received by the community. The problem of overfitting and unrealistic small posterior uncertainties seems to be addressed by the method. As an outlook we foresee to better integrate this work with the work presented in 1.3.1, and for example include integral adjustment directly in our code pipeline [55].

1.3.4. Dissemination and research education

The project has resulted in one Ph.D. thesis [57] and training of two individuals at post-doc stage of their careers. The results are disseminated through seven journal publications (accepted or submitted), 19 international talks, and two published code packages. The work has been performed and disseminated in collaboration with IAEA, OECD/NEA/WPEC, EFPL, PSI, and CEA.

1.3.5. Outlook

The goal is to continue to develop methods for model calibration in the domain of nuclear engineering in general and nuclear data in particular. Model calibration is a sub-domain of machine learning; this is a fast-growing field, and there is a continued development of new techniques and algorithms that can be implemented and developed to fit our applications. By doing so, we will ensure that we can provide both justified best-estimates and well-founded uncertainties within our domain as well as to branch to new areas within nuclear technology.

2. Other activities and developments

2.1. Environmental radioactivity studies at UGGLA

The nuclear reactions group, in collaboration with other researchers from UU and SLU, has become engaged in activities related to the detection and monitoring of radioactivity in the environment. The activities, under the internal project name UGGLA (Uppsala Generic Gamma detection LAb), has recently focused on gamma spectroscopy measurements of different kinds of environmental samples. The main infrastructure for the activities is two detectors from the former radioecology laboratory at Swedish University of Agricultural Sciences (SLU).

During 2018-19 the main activity has been the citizen science project ”Strålande jord”[2], where pupils, aged 12-15, from more than 200 Swedish schools were involved in gathering samples of mushroom, soil and animal droppings. The project aimed to measure the radioactive content in mushrooms. A total of 250 mushroom samples with related soil samples and 50 animal droppings were sent in from all over Sweden for measurements of Cs-137, K-40 and radionuclides from the uranium and thorium decay chains. The analysis is still ongoing but preliminary results have been presented [30,64]. One interesting result is that only two of the mushroom samples have levels of caesium-137 above the 1500 Bq/kg limit, and in general, the levels are quite low in comparison with what would be expected, based on available data in “Cesiumdatabasen” at SSM[3]. An investigation is ongoing on whether there is a bias in how the samples were gathered, or if there could be other reasons.

In addition to the measurement of the radioactive content in mushrooms, we aim to investigate how the cesium content spreads in the biological system including mushroom, soil, and animals that are prone to eating mushrooms.

The citizen science aspect of Strålande Jord has also been analyzed. In this project we, the researchers, are not in control of the collection of samples. We are analyzing how this aspect affects our possibilities to draw conclusions and how well the pupils can determine the fungal species. Furthermore, we are analyzing how the project affects the pupils. Both the school teachers and the pupils have answered surveys. The answers to these surveys are being analysed together with researchers from the Center for Gender Research at UU. We are interested in how the pupils perceive the project and how it affects their interest in natural sciences as well as how they identify themselves in relation to science and research. [26].

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[2] http://teknat.uu.se/samverkan/skola/massexperiment/stralande-jord/

[3] https://www.stralsakerhetsmyndigheten.se/omraden/miljoovervakning/sokbara-miljodata/cesiumdatabasen/

The group is presently looking into if we can identify low energy gamma transitions originating from lead-210 in sediments from the bottom of lakes. The plan is to initiate a collaboration with researchers in limnology who are studying methane production in sediments. The gamma measurements will be an important tool for dating the sediment layers.

Presently the long term plan is to develop our skills in these kinds of measurements, and we see many possibilities to contribute to competence building and emergency preparedness. Three student theses have so far been completed within the project [61,62,63] and several more are going on or will start up soon.

2.2. NEutron Source in uppSAla, NESSA

An important activity in the division of applied nuclear physics (ANP) and the nuclear reaction research group has been the development of a local neutron facility, NEutron Source in uppSAla, NESSA. This has been originally motivated by the closure of the neutron facility housed at The Svedberg Laboratory in Uppsala. After the closing of other facilities and research reactors in the Nordic countries, access to neutrons has become scarce. Central goals are to provide local options for education, competences building, research and development.

In more detail, ANP plans to use NESSA to:

1) Develop and characterize a number of neutron fields (e.g. thermal and fast-reactor like fields), including measurements of flux and energy spectra.
2) Benchmark and validate transport codes applied to different neutron and gamma-ray fields and shielding options.
3) Develop, test, and calibrate detectors (proton-recoil telescopes, diamond detectors, liquid and solid scintillators, silicon detectors, self-powered neutron detectors, fission chambers, parallel-plate avalanche counters, and thin-film breakdown counters), detector materials, and experimental setups used by research groups of the department at large-scale infrastructures such as JET, ITER, GANIL, GSI, n_TOF, future ESS, etc.
4) Develop neutron measurement techniques relevant for nuclear power plants such as radiographic and tomographic techniques, allowing for checks of boron content in control rods and for studies of hydrodynamic phenomena in fuel assemblies.
5) Develop laboratory exercises for education of undergraduate and PhD students as well as for contract education in radiation protection and reactor technology.
6) Collaborate with research groups studying radiation effects in electronics, e.g. at KTH as well as in the framework of the Horizon-2020 EU project RADSAGA and subsequent projects in this field.
7) Perform research projects in nuclear physics and nuclear data on neutron-induced fission of actinides, production of isomers, light-charge-particle production, neutron activation, etc.

8) Find external collaborations and develop joint projects in, e.g., material physics, geology, biology, and radioecology.
9) Provide irradiation possibilities for authorities and industry: detector calibrations, electronics testing, material analysis, etc.

The NESSA facility will house neutron generators (NG) capable of producing neutrons with energy up to 14 MeV. We prepare for installation of two NGs, with total neutron rates (yields) of 10^8 and $5 \cdot 10^{10}$ neutron/s, respectively. Both NGs will utilize the DT nuclear reaction. The stronger NG, which is crucial for many applications (see above), will provide a 14-MeV neutron flux up to ~10^9 cm^{-2} s^{-1}, with possibilities to decrease it to any lower value by altering the settings of the NG and/or the distance to the object under irradiation. Both the NGs are capable of delivering neutrons in continuous mode as well as in pulses with programmable temporal structure. Furthermore, using a flexible collimation system, users will be able to ”tailor” the resulting neutron beam spot to a size and a shape suitable for each specific experiment. The features described above will put the NESSA facility among the top facilities in its class in Europe. The NG will be delivered and commissioned in autumn 2020. The submission of the Safety Analysis Report to SSM is ongoing, as well as the preparation of an application for the trial-operation permit. Currently significant work and resources are spent on preparation of the bunker in the FREIA hall at Ångström laboratory, housing the NG, in particular installation of shielding etc.

The nuclear reactions group and ANP are looking forward to start using NESSA for education and research in 2021 and we are currently working on establishing partnerships and attracting users to the facility from various institutes.

2.3. Outreach

Our research group has a strong record in participating in a series of different outreach activities. The “Strålande jord” project [26,30,64] mentioned above is but one example. We regularly participate in SciFest[4] [71-72], organised by the faculty and held on a yearly basis. Here we meet both school classes and the general public, talking mostly about radiation and the environment. In 2019, we participated in Kulturnatten[5], informed the public about radiation, and gave a number of public lectures about our research [67-70]. We also participate in the political debate, trying to add some scientific perspectives to questions related to nuclear power [73-76].

[4] https://www.scifest.uu.se/ and https://www.scifest.uu.se/allmanheten/
[5] https://www.gustavianum.uu.se/kalendarium/evenemang/?eventId=45800

3. Collaboration and Outlook

The group continues to act within the international community of the field. Besides the above-mentioned activities and collaborations, we have had some involvement with the n_TOF collaboration at CERN, Switzerland [8,9,10,21,24]. Upon invitation, we have now formally joined this collaboration during 2019. To this end, a Memory of Understanding between CERN/n_TOF and UU has been signed. The n_TOF collaboration consists of 46 institutes, mostly from Europe and now with UU as the only partner from Scandinavian countries, and runs experiments at the two experimental areas of the white neutron beam of CERN[6]. The collaboration has a successful history of nuclear data measurements and a competitive programme of future activities, not the least within the new experimental area 2, located only 20 m from the neutron production target[7]. Support for this new collaboration received from SSM in the form of payment of the annual fee for two permanent members in the collaboration is gratefully acknowledged. Further support has been received via the infrastructure fund of the Department of Physics and Astronomy.

As an extension of the very successful measurement campaigns at IGISOL/JYFLTRAP, we have also been invited to join the FRS Ion Catcher collaboration at GSI Helmholtz Centre for Heavy Ion Research, Darmstadt, Germany. This collaboration less formal than the n_TOF collaboration and opens the way for us to perform fission and nuclear data research at another world leading facility and possibly the future FAIR project at GSI within the Super-FRS collaboration.

As mentioned above in Section 3.2, we have also initiated a collaboration with IAEA on development of fission model codes. The current head of the Nuclear Data Section of IAEA, Arjan Koning, is the main developer of the state-of-the-art nuclear model code TALYS. Koning was earlier associated professor in our group and we have earlier collaborated related to light-ion production studies, and implementation of an early version of another fission model code (GEF) into TALYS. This collaboration is supported by a stipend of Liljewalch travel scholarship for Ali Al-Adili.

Last not least, our collaboration within projects funded by the European Commission continues. The CHANDA project finished in 2018 and applications called SANDA (research) and ARIEL (education and access to facilities) have been approved by the European Commission and have formally started in autumn 2019.

In sum, we can conclude that the activities of the nuclear reaction group are at the forefront of nuclear data research, well anchored in international research programmes and collaborations at the leading European facilities.

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[6] see, e.g., E. Chiaveri, et al., EPJ Web of Conferences **146**, 03001 (2017).
[7] F. Gunzing et al., EPJ Web of Conferences **146**, 11002 (2017).

Publications 2018 - 2019

Published articles

1. Acciarri R., Adams C., Asaadi J., Baller B., Bolton T., Bromberg C., Cavanna F., Church E., Edmunds D., Ereditato A., Farooq S., Ferrari A., Fitzpatrick R., Fleming B., Hackenburg A., Horton-Smith G., James C., Lang K., Lantz M., Lepetic I., Littlejohn B., Luo X., Mehdiyev R., Page B., Palamara O., Rebel B., Sala P., Scanavini G., Schukraft A., Smirnov G., Soderberg M., Spitz J., Szelc A., Weber M., Wu W., Yang T., Zeller G.; "Demonstration of MeV-scale physics in liquid argon time projection chambers using ArgoNeuT"; Journal: Physical Review D: covering particles, fields, gravitation, and cosmology; Vol: 99; No: 1; Publisher: AMER PHYSICAL SOC; DOI: 10.1103/PhysRevD.99.012002; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-375223; (2019)
2. Al-Adili A., Rakopoulos V., Solders A.; "Extraction of angular momenta from isomeric yield ratios : Employing TALYS to de-excite primary fission fragments"; Journal: European Physical Journal A; Vol: 55; No: 4; DOI: 10.1140/epja/i2019-12731-5; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-383514; (2019)
3. 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)
4. Jansson K., Al-Adili A., Andersson Sundén E., Göök A., Stephan O., Pomp S.; "The impact of neutron emission on correlated fission data from the 2E-2v method"; Journal: European Physical Journal A; Vol: 54; DOI: 10.1140/epja/i2018-12544-0; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-355518; (2018)
5. Kumar D., Alam S., Sjöstrand H., De Saint Jean C.; "Influence of nuclear data parameters on integral experiment assimilation using Cook's distance"; Journal: EPJ Web of Conferences; Vol: 211; Publisher: EDP Sciences; Conference: 5th edition of the International Workshop On Nuclear Data Evaluation for Reactor Applications (WONDER-2018), Aix en Provence, France, October 8-12, 2018; DOI: 10.1051/epjconf/201921107001; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-378672; (2019)
6. Ledoux X., et al. "The Neutrons for Science Facility at SPIRAL-2"; Journal: Radiation Protection Dosimetry; Vol: 180; No: 1-4; Publisher: OXFORD UNIV PRESS; Conference: 13th Symposium on Neutron and Ion Dosimetry (NEUDOS), MAY 13-19, 2017, Polish Acad Sci, Inst Nucl Phys, Krakow, POLAND; DOI: 10.1093/rpd/ncx257; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-364997; (2018)

7. Mattera A., Pomp S., Lantz M., Solders A., Rakopoulos V., Al-Adili A., Penttilä H., Moore I., Rinta-Antila S., Eronen T., Kankainen A., Gorelov D.; "Production of Sn and Sb isotopes in high-energy neutron induced fission of ^{nat}U"; Journal: European Physical Journal A; Vol: 54; DOI: 10.1140/epja/i2018-12462-1; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-328572; (2018)
8. Mendoza E., et al.,"Measurement and analysis of the 241Am neutron capture cross section at the n_TOF facility at CERN"; Journal: Phys. Rev. C; Vol: 97; Publisher: American Physical Society; DOI: 10.1103/PhysRevC.97.054616; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-394875; (2018)
9. Praena J., et al. ; "Measurement and resonance analysis of the 33S(n,alpha)30Si cross section at the CERN n_TOF facility in the energy region from 10 to 300 keV"; Journal: Phys. Rev. C; Vol: 97; Publisher: American Physical Society; DOI: 10.1103/PhysRevC.97.064603; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-394874; (2018)
10. Praena J., et al; "Preparation and characterization of 33S samples for 33S(n,alpha)30Si cross-section measurements at the n_TOF facility at CERN"; Journal: Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment; Vol: 890; DOI: 10.1016/j.nima.2018.02.055; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-394873; (2018)
11. Rakopoulos V., Lantz M., Pomp S., Solders A., Al-Adili A., Canete L., Eronen T., Jokinen A., Kankainen A., Mattera A., Moore I., Nesterenko D., Reponen M., Rinta-Antila S., de Roubin A., Vilén M., Österlund M., Penttilä H.; "Isomeric fission yield ratios for odd-mass Cd and In isotopes using the phase-imaging ion-cyclotron-resonance technique"; Journal: Physical Review C; Vol: 99; No: 1; DOI: 10.1103/PhysRevC.99.014617; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-364949; (2019)
12. Rakopoulos V., Lantz M., Solders A., Al-Adili A., Mattera A., Canete L., Eronen T., Gorelov D., Jokinen A., Kankainen A., Kolhinen V., Univ Jyvaskyla D., Moore I., Nesterenko D., Penttila H., Pohjalainen I., Rinta-Antila S., Simutkin V., Vilen M., Voss A., Pomp S.; "First isomeric yield ratio measurements by direct ion counting and implications for the angular momentum of the primary fission fragments"; Journal: Physical Review C: Covering Nuclear Physics; Vol: 98; No: 2; Publisher: AMER PHYSICAL SOC; DOI: 10.1103/PhysRevC.98.024612; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-362692; (2018)
13. Schnabel G., Sjöstrand H.; "A first sketch : Construction of model defect priors inspired by dynamic time warping"; Journal: EPJ Web of Conferences; Vol: 211; Conference: WONDER 2018: 5th International Workshop On Nuclear Data Evaluation for Reactor applications, 8-12 October 2018, Aix-en-Provence, France; DOI: 10.1051/epjconf/201921107005; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-379182; (2019)

14. Sjöstrand H., Asquith N., Helgesson P., Rochman D., van der Marck S.; "Efficient use of Monte Carlo : The Fast Correlation Coefficient"; Journal: EPJ N - Nuclear Sciences and Technologies; Vol: 4; Conference: 4th edition of the International Workshop on Nuclear Data Covariances, October 2-6 2017, Aix en Provence, France.; DOI: 10.1051/epjn/2018019; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-339229; (2018)
15. Sjöstrand H., Schnabel G.; "Monte Carlo integral adjustment of nuclear data libraries – experimental covariances and inconsistent data"; Journal: EPJ Web of Conferences; Vol: 211; No: 07007; Conference: WONDER-2018: 5th edition of the International Workshop On Nuclear Data Evaluation for Reactor Applications,Aix-en-Provence, France, 8-12 October 2018; DOI: 10.1051/epjconf/201921107007; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-378726; (2019)
16. Ström P., Petersson P., Rubel M., Fortuna-Zaleśna E., Widdowson A., Sergienko G.; "Analysis of deposited layers with deuterium and impurity elements on samples from the divertor of JET with ITER-like wall"; Journal: Journal of Nuclear Materials; Vol: 516; DOI: 10.1016/j.jnucmat.2018.11.027; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-379019; (2019)
17. Sublet J., Bondarenko I., Bonny G., Conlin J., Gilbert M., Greenwood L., Griffin P., Helgesson P., Iwamoto Y., Khryachkov V., Khromyleva T., Konobeyev A., Lazarev N., Luneville L., Mota F., Ortiz C., Rochman D., Simakov S., Simeone D., Sjöstrand H., Terentyev D., Vila R.; "Neutron-induced damage simulations : Beyond defect production cross-section, displacement per atom and iron-based metrics"; Journal: The European Physical Journal Plus; Vol: 134; No: 7; Publisher: Springer Berlin/Heidelberg; DOI: 10.1140/epjp/i2019-12758-y; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-391432; (2019)
18. Vasilopoulou T., Andersson Sundén E., Binda F., Cecconello M., Conroy S., Dzysiuk N., Ericsson G., Eriksson J., Hellesen C., Hjalmarsson A., Possnert G., Sjöstrand H., Skiba M., Weiszflog M., Zychor I.; "Improved neutron activation dosimetry for fusion"; Journal: Fusion engineering and design; Vol: 139; DOI: 10.1016/j.fusengdes.2019.01.002; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-378735; (2019)
19. Wamers F., et al. .; "Comparison of electromagnetic and nuclear dissociation of Ne-17"; Journal: Physical Review C: Covering Nuclear Physics; Vol: 97; No: 3; Publisher: AMER PHYSICAL SOC; DOI: 10.1103/PhysRevC.97.034612; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-351420; (2018)

Submitted articles

20. Capote R., Badikov S., Carlson A., Duran I., Gunsing F., Neudecker D., Pronyaev V., Schillebeeckx P., Schnabel G., Smith D., Wallner A.; "Unrecognized Sources of Uncertainties (USU) in Experimental Nuclear

Data"; Journal: Nuclear Data Sheets; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-396567; (2019)

21. Colonna N., A. Tsinganis, R. Vlastou, N. Patronis, M. Diakaki, S. Amaducci, M. Barbagallo, S. Bennett, E. Berthoumieux, M. Bacak, G. Cosentino, S. Cristallo, E. Dupont, P. Finocchiaro, J. Heyse, D. Lewis, A. Manna, C. Massimi, E. Mendoza, M. Mirea, A. Moens, R. Nolte, E. Pirovano, M. Sabaté-Gilarte, G. Sibbens, G. Smith, N. Sosnin, A. Stamatopoulos, D. Tarrío, L. Tassan-Got, D. Vanleeuw, A. Ventura, D. Vescovi, T. Wright, P. Žugec, and the n TOF Collaboration; "The fission experimental programme at the CERN n_TOF facility: status and perspectives"; Journal: European Physical Journal A; accepted for publication; Manuscript ID EPJA-105216.R1; (2019)

Conference contributions

22. Al-Adili A., Jansson K., Tarrio D., Hambsch F., Gook A., Oberstedt S., Fregeau M., Gustavsson C., Lantz M., Mattera A., Prokofiev A., Rakopoulos V., Solders A., Vidali M., Österlund M., Pomp S.; "Studying fission neutrons with 2E-2v and 2E"; ISBN: 978-2-7598-9031-6; Conference: 4th Scientific Workshop on Nuclear Fission Dynamics and the Emission of Prompt Neutrons and Gamma Rays (Theory), JUN 20-22, 2017, Varna, BULGARIA; DOI: 10.1051/epjconf/201816900002; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-361440; (2018)
23. Al-Adili A., et al.; "Isomeric yields in nuclear fission"; Invited talk; Conference: Castelvecchio Pascoli, Barga, Italy: Theory-5 Scientific Workshop on Nuclear Fission Dynamics and the Emission of Prompt Neutrons and Gamma Rays, September 24-26, (2019)
24. Diakaki M., European Org Nucl Res CERN G., Audouin L., Chen Y., Leong L., Tassan-Got L., Berthoumieux E., Dupont E., Gunsing F., Bacak M., Calviani M., Tsinganis A., Colonna N., Mastromarco M., Duran I., Leal-Cidoncha E., Guerrero C., Paradela C., Stamatopoulos A., Vlastou R., Tarrio D., Smith A., Wright T.; "Fission Activities at the CERN n_TOF Facility"; Publisher: World Scientific; ISBN: 978-981-3229-43-3; Conference: Sixth International Conference on Fission and Properties of Neutron-Rich Nuclei (ICFN6), November 6 - 12 2016, Florida, United States; DOI: 10.1142/9789813229426_0093; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-365884; (2018)
25. Gao Z., Solders A., Al-Adili A., Canete L., Eronen T., Gorelov D., Jokinen A., Kankainen A., Lantz M., Mattera A., Moore I.D., Nesterenko D.A., Penttilä H., Pohjalainen I., Rakopoulos V., Rinta-Antila S., Vilén M., Pomp S.; "Fission studies at IGISOL/JYFLTRAP: Simulations of the ion guide for neutron-induced fission and comparison with experimental data"; Conference: 2019 International Conference on Nuclear Data for Science and Technology, May 19-24, 2019, Beijing, China; (2019)

26. Gustavsson, C., Andersson-Sundén E., Barker A., Hjalmarsson A., Jacewicz M., Lantz M., Lundén K., Pomp S., Ziemann V.; "Citizen science in radiation research"; Invited talk; Conference: 2019 International Conference on Nuclear Data for Science and Technology, May 19-24, 2019, Beijing, China; (2019)
27. Hambsch F., Gamboni T., Geerts W., Gook A., Oberstedt S., Vidali M., Al-Adili A., Jansson K., Pomp S.; "Prompt Neutron Emission Correlations with Fission Fragment Properties"; Publisher: World Scientific; ISBN: 978-981-3229-43-3; Conference: Sixth International Conference on Fission and Properties of Neutron-Rich Nuclei (ICFN6), November 6 - 12 2016, Florida, United States; DOI: 10.1142/9789813229426_0090; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-365883; (2018)
28. Helgesson P., Neudecker D., Sjöstrand H., Grosskopf M., Smith D., Capote R.; "Assessment of Novel Techniques for Nuclear Data Evaluation"; Publisher: ASTM International; ISBN: 978-0-8031-7661-4; Conference: 16th International Symposium on Reactor Dosimetry, MAY 07-12, 2017, Santa Fe, NM; DOI: 10.1520/STP160820170087; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-322558; (2018)
29. Kumar D., Sjöstrand H., Bahauddin Alam S., Palau J., De Saint Jean C.; "Analysis of the Prior Nuclear Data Correlation and Its Effect on the Adjustment in Bayesian Inference"; Conference: International Conference on Nuclear Data for Science and Technology, Beijing, China, May 19-24, 2019; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-396768; (2019)
30. Lantz M., Andersson-Sundén E., Andersson P., Barker A., Cecilia Gustavsson C., Hjalmarsson A., Jacewicz M., Lundén K.,Marciniewski P., Stephan Pomp S., Rathore V., Ziemann V.; "Gamma spectroscopy methodology for large amounts of environmental samples in Sweden 30 years after the Chernobyl accident"; Conference: 2019 International Conference on Nuclear Data for Science and Technology, May 19-24, 2019, Beijing, China; (2019)
31. Oberstedt A.; "Systematic study of the de-excitation of neutron-rich nuclei produced in various fission reactions"; Conference: Castelvecchio Pascoli, Barga, Italy: Theory-5 Scientific Workshop on Nuclear Fission Dynamics and the Emission of Prompt Neutrons and Gamma Rays, September 24-26, 2019; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-396980; (2019)
32. Pomp S., Mattera A., Rakopoulos V., Al-Adili A., Lantz M., Solders A., Jansson K., Prokofiev A., Eronen T., Gorelov D., Jokinen A., Kankainen A., Moore I., Penttila H., Rinta-Antila S.; "Measurement of fission yields and isomeric yield ratios at IGISOL"; ISBN: 978-2-7598-9031-6; Conference: 4th Scientific Workshop on Nuclear Fission Dynamics and the Emission of Prompt Neutrons and Gamma Rays (Theory), JUN 20-22, 2017, Varna, BULGARIA; DOI: 10.1051/epjconf/201816900017; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-361441; (2018)
33. Pomp S.; "80 years of nuclear fission studies - Shouldn't we be done by now? : Invited presentation at Strålsäkerhetsdagar 2019"; Conference:

Strålsäkerhetsdagar, 6-7 Nov 2109, Stockholm; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-396857; (2019)

34. Pomp S.; "Nuclear reaction studies for improved nuclear data for science and technology : Invited talk"; Conference: XXIst Colloque GANIL, September 9-13, 2019, Strasbourg, France; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-396854; (2019)
35. Qi L., Wilson J., Lebois M., Al-Adili A., Chatillon A., Choudhury D., Gatera A., Georgiev G., Gook A., Laurent B., Maj A., Matea I., Oberstedt A., Oberstedt S., Rose S., Schmitt C., Wasilewska B., Zeiser F.; "Prompt fission gamma-ray emission spectral data for Pu-239(n,f) using fast directional neutrons from the LICORNE neutron source"; ISBN: 978-2-7598-9031-6; Conference: 4th Scientific Workshop on Nuclear Fission Dynamics and the Emission of Prompt Neutrons and Gamma Rays (Theory), JUN 20-22, 2017, Varna, BULGARIA; DOI: 10.1051/epjconf/201816900018; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-361442; (2018)
36. Schnabel G., Sjöstrand H., Rochman D., J. Koning A.; "Interfacing TALYS with a Bayesian treatment of model defects and inconsistent data"; Conference: International Conference on Nuclear Data for Science and Technology, 2019, Beijing, China, May 19-24, 2019; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-396398; (2019)
37. Schnabel G., Sjöstrand H.; "Recent ND developments and plans at UU"; Conference: IAEA Consultants' Meeting of INDEN International Nuclear Data Evaluation Networkon the Evaluated Nuclear Data of the Structural Materials, Vienna, Austria, Oct 29, 2018; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-396524; (2018)
38. Schnabel G.; "Bayesian evaluation method(s) with a treatment of unknown uncertainties"; Conference: IAEA meeting: Consultancy Visit on Selection of experimental data and estimate of associated uncertainties.; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-396753; (2018)
39. Schnabel G.; "Bayesian statistics with a stochastic linear model and its surprising result"; Conference: 2018 ISBA World Meeting (International Society for Bayesian Analysis), June 24-29 2018, Edinburgh, UK; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-379185; (2018)
40. Schnabel G.; "Learning from Google : About A Computational EXFOR Database for Efficient Data Retrieval and Analysis"; Conference: International Conference on Nuclear Data for Science and Technology, May 19-24, 2019, Beijing, China; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-396399; (2019)
41. Schnabel G.; "Mixture GLS with examples"; Conference: IAEA Technical Meeting on Uncertainty Quantification in Nuclear Data Evaluation; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-396526; (2019)
42. Sjöstrand H., Helgesson P., Alhassan E.; "TMC adjustment of nuclear data libraries using integral benchmarks"; Conference: WPEC meeting SG46 May 2018; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-356844; (2018)

43. Sjöstrand H., Helgesson P.; "Justified co-variance data by treating model defects; fitting optimized energy-dependent model parameters in Fe-56 nuclear data evaluation"; Conference: 30th WPEC Meetings SG44 meeting Paris May 2018; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-356845; (2018)
44. Sjöstrand H., Helgesson P.; "Model defect treatment for ^{56}Fe"; Conference: JEFF April 2018 Meetings; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-349852; (2018)
45. Sjöstrand H., Schnabel G., Helgesson P.; "Monte Carlo integral adjustment of nuclear data libraries – experimental covariances and inconsistent data"; Conference: WONDER-2018: 5th edition of the International Workshop On Nuclear Data Evaluation for Reactor Applications, Aix-en-Provence, France, 8-12 October 2018; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-380377; (2018)
46. Sjöstrand H., Schnabel G., Rochman D., Siefman D.; "Treating inconsistent data in integral adjustment using Marginal Likelihood Optimization"; Conference: Working Party on International Nuclear Data Evaluation Co-operation (WPEC): Efficient and Effective Use of Integral Experiments for Nuclear Data Validation WPEC subgroup 46 (SG46) NEA Headquarters, Boulogne-Billancourt, France, 25-26 June 2019; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-396806; (2019)
47. Sjöstrand H., Schnabel G., Rochman D.; "Integral adjustment of nuclear data libraries : finding unrecognized systematic uncertainties and correlations"; Conference: 2019 International Conference on Nuclear Data for Science and Technology, May 19-24, 2019, Beijing, China; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-396767; (2019)
48. Sjöstrand H., Schnabel G., Siefman D.; "Treating inconsistent data in Monte Carlo integral adjustment using Marginal Likelihood Optimization"; Conference: Working Party on International Nuclear Data Evaluation Co-operation (WPEC) - SG46 - November 2018; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-378727; (2018)
49. Sjöstrand H., Schnabel G.; "Inconsistent data and uncertainties – SG44/46"; Conference: Working Party on International Nuclear Data Evaluation Co-operation (WPEC) - SG44/46 - November2018; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-378782; (2018)
50. Sjöstrand H., Schnabel G.; "Model defect treatment for 56Fe : Model defect treatment for 56Fe Status report: UU contribution to Eurofusion2018: VR contribution to PPPT nuclear data development: Evaluation of neutron cross section data in the fast energy range"; Conference: JEFF meeting, 27-30 November 2018, NEA, Boulogne-Billancourt, France; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-378783; (2018)
51. Sjöstrand H., Schnabel G.; "Model defect treatment for 56Fe"; Conference: Joint Evaluated Fission and Fusion (JEFF) Nuclear Data Library JEFF Fusion Working Group, 25 April 2019, NEA Headquarters Boulogne-Billancourt, France; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-396807; (2019)

52. Sjöstrand H., Schnabel G.; "The identification and treatment of unrecognized uncertainties and the impact on evaluated uncertainties – SG44"; Conference: Working Party on International Nuclear Data Evaluation Co-operation (WPEC): Investigation of Covariance Data in General Purpose Nuclear Data Libraries WPEC subgroup 44 (SG44) NEA Headquarters, Boulogne-Billancourt, France, 25 June 2019; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-396805; (2019)
53. Tarrío D., Prokofiev, A. V., Nakano, K. Pomp, S.; "Characterization of PPACs' time resolution for fission studies"; Conference: 2019 International Conference on Nuclear Data for Science and Technology, May 19-24, 2019, Beijing, China; (2019)

Reports

54. Schnabel G., Sjöstrand H.; "*VR contribution to PPPT nuclear data development: Evaluation of neutron cross section data in the fast energy range* : *ENR-PRD.MAT.IREMEV.7.1-T003*"; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-396984; (2019)
55. Schnabel G.; "Prototype of a pipeline for reproducible nuclear data evaluation"; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-396808; (2019)
56. Schnabel G.; "Yet another computational EXFOR database User manual"; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-396811; (2019)

PhD Thesis

57. 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)
58. Rakopoulos V.; "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:nbn:se:uu:diva-364951; (2018)

Master thesis etc

59. L. Lehtilä, "Implementation and characterization of Silicon detectors for studies on neutron-induced nuclear reactions", M.Sc. Thesis, Uppsala Univ. (2019).

60. M. Carlsson, “Development and characterization of Parallel-Plate Avalanche Counters for Nuclear Physics Experiments”, M.Sc. Thesis, Uppsala Univ. (2018).
61. W. Lindberg, “Characterization of an HPGe detector for experiments on radioactive mushrooms”, B.Sc. Thesis, Uppsala university, 2018.
62. D. Nordman, “Cs-137 i Svamp: Dataanalysrutiner för gammaspektro-skopi”, B.Sc. Thesis, Uppsala university, 2018.
63. F. Jonasson and B. Sparresäter, “Monte Carlo-simuleringar av germanium-detektor för gammaspektroskopi”, B.Sc. Thesis, Uppsala university, 2018.
64. L. Castellanos, "Application of sub-channel thermal-hydraulic analysis to core calculations with POLCA8 and VIPRE-W", M.Sc. Thesis, Uppsala Univ. (2019). Permalink: http://urn.kb.se/resolve?urn=urn%3Anbn%3Ase%3Auu%3Adiva-393517

Other

65. Gustavsson C., Andersson-Sundén E., Barker A., Hjalmarsson A., Jacewicz M., Lantz M., Lundén K., Marciniewski P., Ziemann V.; “Citizen Science and Radioactivity”, Nuclear Physics News 29 (2) 25-28 (2019)
66. Pomp S.; "Isomeric yield ratio measurements at IGISOL/JYFLTRAP for assessing angular momenta of fission fragments : Invited talk, NUSTAR seminar series, GSI"; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-396855; (2019)
67. Lantz M.; ”Strålning och strålspöken”; Populärvetenskaplig föredrag, Kulturnatten 2019, Uppsala.
68. Pomp S.; "Jakten på nya kemiska element - Periodiska systemet 150 år: Populärvetenskaplig föredrag, Kulturnatten 2019, Uppsala"; Permalink: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-396859; (2019)
69. Solders A.; ”Hur mycket väger ett kilo?”; Populärvetenskaplig föredrag, Kulturnatten 2019, Uppsala.
70. Sundén E.A.; ”Drömmen om det exakta”; Populärvetenskaplig föredrag, Kulturnatten 2019, Uppsala.
71. SciFest 2018, Exhibition “Strålningen, se den!”, Fyrishov, Uppsala, 8-10 mars 2018
72. SciFest 2019, Exhibition “En strålande upplevelse”, Fyrishov, Uppsala, 7-9 mars 2019
73. M. Lantz, “Kan kärnkraften rädda klimatet”, PI-samtal, Kulturhuset, Stockholm, 3 okt 2019.
74. M. Lantz: “Klimatförvirring i miljökrönika”, Alingsås Tidning, debatt, 20 mars (2019).
75. A. Håkansson and M. Lantz: “Hylander och Sidén blandar ihop effekt och energi”, DN Debatt, 13 maj (2019).
76. C. Ekberg and M. Lantz: “Miljörörelsen behöver bli mer konstruktiv”, SvD Brännpunkt, 27 juli (2019).

Summary of performance indicators

Related to the present project we have, during the project period, completed:

1. PhD thesis: **2**
2. PhD projects initiated: **1**
3. Licentiate thesis: **0**
4. Master thesis: **6**
5. Published articles: **19**
6. Conference contributions: **32**
7. Conference participations: **11**
8. International projects: **4**
9. International meetings: **8**
10. National projects: **3**
11. National meetings: **5**
12. Swedish grants (MSEK): **4.6 MSEK** (including the present project)
13. Total grants (MSEK): **5.2 MSEK**
14. Applied grants: **10**

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The Swedish Radiation Safety Authority works proactively and presentively to protect people and the environment from the harmful effects of radiation, now and in the future. The Authority issues regulations and supervises compliance, while also supporting research, providing training and information, and issuing advice. Often, activities involving radiation require licences issued by the Authority. The Swedish Radiation Safety Authority maintains emergency preparedness around the clock with the aim of limiting the aftermath of radiation accidents and the unintentional spreading of radioactive substances. The Authority participates in international co-operation in order to promote radiation safety and finances projects aiming to raise the level of radiation safety in certain Eastern European countries.

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