Compound-Nuclear Reactions and Related Topics (CNR*24)

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Book of Abstracts

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Semi-classical treatment of photon cascades in nuclei

Author: Jorgen Randrup[1]

Co-author: Thomas Dossing [1]

[1] *Lawrence Berkeley National Laboratory*

Corresponding Author: jrandrup@lbl.gov

A simple semi-classical treatment of photon cascades has been developed. The basic assumption is that a nucleus with a classical spin vector $\boldsymbol{J}$ can be represented by the maximally aligned quantum state $|J,M = J>$ with the quantization axis being the spin direction $\boldsymbol{J}/J$. It is furthermore assumed that a photon emission yields a daughter state of a similar form, $|J',M' = J'>$, but with its alignment direction having been modified as a consequence of the angular momentum recoil. The overall good quality of the treatment is illustrated for a variety of *E1* and *E2* two-photon cascades for which non-trivial angular correlations emerge. The method is suitable for use in nuclear fission simulation codes, making it possible to address photon-photon correlation observables quantitatively.

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Observational Consequences of Angular Momentum in Fission

Author: Ramona Vogt[1]

Co-author: Jorgen Randrup [2]

[1] *LLNL and UC Davis*

[2] *Lawrence Berkeley National Laboratory*

Corresponding Author: vogt2@llnl.gov

The role of angular momentum in fission has been the subject of intense recent attention. Published data showed that, while the fission fragment spins may be generated by highly correlated processes, the final, measured, fragment spins appeared to be largely uncorrelated. This talk will summarize advances made with the fission simulation model FREYA to study the role of angular momentum in fission. FREYA can easily simulate a variety of scenarios for generating fragment spin and determine the observational consequences.

Acknowledgements
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Nuclear reactions relevant to nuclear astrophysics, status and perspectives.

Author: Stephane Goriely[1]

[1] *ULB*

Corresponding Author: sgoriely@astro.ulb.ac.be

Though the origin of most of the nuclides lighter than iron is now quite well understood, the synthesis of the heavy elements (i.e. heavier than iron) remains puzzling in many respects. The major mechanisms called for to explain the production of the heavy nuclei are the slow neutron-capture process (or s-process), occurring during the hydrostatic stellar burning phases, the rapid neutron-capture process (or r-process) believed to develop during the explosion of a star as a supernova or the coalescence of two binary neutron stars. In addition, the origin of the neutron-deficient nuclides observed in the solar system is attributed to the so-called p-process taking place in supernovae. Recently, the intermediate neutron-capture process (or i-process) has been called for to explain the surface enrichment of specific metal-poor stars. The stellar production of heavy elements requires a detailed knowledge not only of the astrophysical sites and physical conditions in which the processes take place, but also of accurate and reliable nuclear data.
The present talk will critically review the different astrophysical models as well as the enormous theoretical challenges in nuclear physics. These include, in particular, nuclear models needed to estimate reaction rates, namely nuclear masses, level densities, photon strength functions, as well as fission properties. New progress based on mean-field models will be described and their impact on nucleosynthesis processes illustrated.

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Isomeric yield ratio measurements in the alpha-particle induced fission of Thorium at 32 MeV

Author: Simone Cannarozzo[1]

Co-authors: Stephan Pomp [1]; Andreas Solders [1]; Ali Al-Adili [2]; Gao Zhihao [1]

[1] *Uppsala University*

[2] *Department of Physics and Astronomy, Uppsala University*

Corresponding Author: simone.cannarozzo@physics.uu.se

The mechanism generating fission fragments'large angular momenta is still a heavily discussed question in nuclear physics. Since they are not directly measurable, experimentally accessible observables are used to derive the angular momenta using nuclear model codes. One of these observables is the ratio between the yields of spin isomers produced in a fission reaction, the so-called isomeric yield ratio. The isomeric yield ratio is also relevant to test nuclear models and in technological applications, since, *e.g.*, the fraction of nuclei in the excited state may affect the decay heat of spent fission fuel.

For these reasons, the isomeric yield ratio of fifteen fission products in the high mass region was measured for Th(α,f) at 32 MeV. The α-induced fission of Th was chosen in order to investigate the impact of the initial spin of the compound system on the yield ratio and eventually the corresponding angular momenta. To do so, the newly measured isomeric yield ratios can be compared with data from different fissioning systems, such as ^{233}U and ^{235}U, where, in principle, compound nuclei similar to those of Th(α,f) are formed.

The measurements were performed at the University of Jyväskylä using the phase-imaging ion-cyclotron-resonance (PI-ICR) technique at the IGISOL-4 facility. Through PI-ICR, isomers are separated with a high mass resolving power, allowing *e.g.* to resolve the ^{129}Sn isomeric pair, with an

energy difference corresponding to 35.1 keV. The separated ions are then projected onto a position sensitive detector. The images produced are then analyzed to calculate the number of ions measured for each state. The measured ratios are then corrected to account for the MCP efficiency and the decay and feeding effects from eventual precursors in the beam, as the time from extraction to measurement can be comparable to their half-lives.
The analysis procedure and results of the measurement campaign will be presented.

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Nuclear reaction models and codes: Building bridges between nuclear structure and nuclear reaction communities

Author: Jutta Escher[1]

Co-authors: Aaina Thapa [1]; Cole Pruitt [2]; Emanuel Chimanski [3]; Eunjin In [1]; Gregory Potel [1]; Jeff Berryman [1]; Kostas Kravvaris [1]; Marc Dupuis [4]; Oliver Gorton [5]; Salvatore Simone Perrotta [2]; Sophie Péru [4]; Walid Younes [1]

[1] *Lawrence Livermore National Laboratory*

[2] *Lawrence Livermore National Lab*

[3] *Brookhaven National Laboratory*

[4] *CEA DAM DIF*

[5] *Lawrence Livremore National Laboratory*

Corresponding Author: escher1@llnl.gov

The past couple of decades have seen tremendous advances in nuclear structure and reaction theory. Innovative theory frameworks for describing the nuclear many-body system, increasingly powerful computers, and opportunities for confronting theory predictions with data on unstable nuclei, have been driving the field. An important goal is to move from phenomenological ingredients in reaction calculations to predictive theories based on microscopic frameworks. I will discuss ongoing efforts aimed at integrating microscopic descriptions of nuclear structure into reaction predictions for medium-mass and heavy nuclei. I will highlight areas where Eric Bauge, a champion for building bridges, has made important contributions by encouraging and enabling collaborations between communities with complementary expertise.

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CEA-LANL efforts on nuclear reaction theories and their application to nuclear data

Author: Toshihiko Kawano[1]

[1] *Los Alamos National Laboratory*

Corresponding Author: toshihiko.kawano@gmail.com

For more than a decade CEA Bruyeres-le-Chatel and LANL theoretical division have been cooperating on the development of nuclear theories and their application to the nuclear data. Dr. Eric Bauge of CEA had vigorously participated in the collaborative efforts to promote ideas in fundamental theoretical physics to the basis of scientific and/or technological achievements in the applied area. Our joint efforts include incorporation of theoretical nuclear structure models into reaction theories, implementation of advanced nuclear reaction theories into computer codes that are widely used in nuclear data production, quantifying nuclear data uncertainties by considering nuclear reaction models, exchanging ideas for improvement of evaluated nuclear data, and so on. This talk summarizes

the CEA-LANL collaborative activities on the development of nuclear theory and data, and demonstrates how the efforts have been expanded into the wider nuclear science community.

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Building bridges - International Collaboration

Author: Mark Chadwick[1]

[1] *Los Alamos National Laboratory*

Corresponding Author: mbchadwick@lanl.gov

In this talk in honor of Eric Bauge's leadership in nuclear data collaborations, I describe the CIELO international collaboration that we ran, from 2013-2018. I set this up through the auspices of the OECD/NEA/WPEC in 2013, with much help from Eric. Numerous labs from the US, Europe and Asia collaborated on new measurements and new evaluations. The results of the collaboration positively impacted both ENDF and JEFF databases. Subsequently, the collaborative efforts were taken over via the IAEA/INDEN project, with continued successes. I will also talk about a different topic related to this conference on compound reactions: the A=5 system with its 3/2+ Bretscher resonance that enhances DT fusion, and its enduring role in modern fusion technologies.

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Introduction

Corresponding Author: stephane.hilaire@cea.fr

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Contrasting phenomenological models: my experience with Eric

Author: Roberto Mario Capote Noy[1]

[1] *IAEA NAPC-NDS*

Corresponding Author: roberto.capotenoy@iaea.org

A short overview of the interaction with Eric within the RIPL project will be given. Calculations performed with the semi-microscopic Lane-consistent folding model (SMOM) potential of Bauge et al. [1] extended to coupled channels [2] will be compared with dispersive coupled-channel optical model potentials for ²³²Th and ²³⁸U [3,4].

References

(1) E. Bauge, J. P. Delaroche, M. Girod, Phys. Rev. C63, 024607 (2001).
(2) F. S. Dietrich, J. D. Anderson, R. W. Bauer, S. M. Grimes, R. W. Finlay, W. P. Abfalterer, F. B. Bateman, R. C. Haight, G. L. Morgan, E. Bauge, J. P. Delaroche, P. Romain, Phys.Rev. C67, 044606 (2003).
(3) R. Capote, S. Chiba, E. Sh. Soukhovitskii, J. M. Quesada and E. Bauge, "A Global Dispersive Coupled-Channel Optical Model Potential for Actinides", J. Nucl. Sci. & Techn. 45, p. 333–340 (2008)
(4) E. Sh. Soukhovitskii, R. Capote, J. M. Quesada, S. Chiba, and D. S. Martyanov, "Nucleon scattering

on actinides using a dispersive optical model with extended couplings", Phys. Rev. C94, 064605 (2016)

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Building bridges between nuclear reactions and statistical methods

Author: Dimitri Rochman[1]

[1] *PSI*

Corresponding Author: dimitri-alexandre.rochman@psi.ch

In modern nuclear data evaluations, nuclear reactions and statistical methods cannot be separated. Whereas the first one is continuously improved for many decades, the second one is now benefiting from large computer power.
Ahead of its time, our colleague Eric Bauge had understood the advantage of linking them together. He developed modern Bayesian methods, and helped many of us to move in this direction. I will present two examples of the work that we did together, following his vision: the application of BFMC, and the evidence of correlation between nubar, chi and fission cross section.
Finally, he was not only a bridge builder, he was also able to jump from fundamental physics to very applied aspects, making him a frontier crosser.

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Microscopic nuclear reaction models: building bridges between microscopic theory and nuclear data

Author: Marc Dupuis[1]

[1] *CEA, DAM, DIF*

Corresponding Author: marcodup@yahoo.fr

As a former student and long-time collaborator of Eric Bauge, I am honored to discuss the advancements in microscopic reaction models aimed at enhancing the reliability of nuclear data. Eric Bauge' s work has been instrumental in fostering close collaborations between nuclear structure physicists and reaction physicists. His encouragement and guidance have inspired me and many others to pursue these interdisciplinary connections.

In this session, I will highlight the numerous collaborations that Eric initiated and developed at CEA/DAM, bringing together international experts in reaction models. These efforts have significantly advanced our understanding and capabilities in the field. Eric's contributions have had a lasting impact on our research community, and this presentation will showcase the critical initiatives he supported.

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Status of TALYS

Author: Arjan KONING[1]

[1] *IAEA*

Corresponding Author: a.koning@iaea.org

TALYS is a software package for the simulation of nuclear reactions below 200 MeV. It is used worldwide for the analysis and prediction of nuclear reactions and is based on state-of-art nuclear structure and nuclear reaction models.
We will present the overall status of the code, in particular the recent TALYS-2.0 release.
Next, a global validation of the latest photon strength functions and level density models using relevant experimental databases will be given. Finally, we will share some possible TALYS development plans for the next decade.

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Eric's impact on the r-process nucleosynthesis

Author: Stephane Goriely[1]

[1] *ULB*

Corresponding Author: sgoriely@astro.ulb.ac.be

The rapid neutron-capture process, or r-process, is one of the major nucleosynthesis processes called for to explain the origin of about half of the elements heavier than iron in the Universe. From the nuclear physics side, the r-process requires the knowledge of the neutron capture cross section by exotic neutron-rich nuclei, hence of the neutron-nucleus optical model potential. Eric has played a key role to review the Jeukenne-Lejeune-Mahaux (1977) microscopic potential in the late 90's, in particular by renormalizing the isoscalar and isovector contributions to both its real and imaginary components. The resulting JLMB potential has proven to be of great importance to determine the neutron-capture rate of astrophysical interest in r-process simulations. It also represents today the largest uncertainty potentially affecting the nucleosynthesis predictions. The evolution of the JLMB potential, Eric's contribution to its development and its impact on r-process abundance predictions will be discussed.

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Studies on neutron-induced reaction with Medley at GANIL

Authors: Lucas de Arruda Serra Filho[1]; Diego Tarrio[2]; Stephan Pomp[2]; Xavier Ledoux[3]; Diego Ramos[3]

Co-author: MEDLEY TEAM

[1] *GANIL / Uppsala University*

[2] *Uppsala University*

[3] *GANIL*

Corresponding Author: dearruda@ganil.fr

Neutron induced reactions remain as a subject of great interest for both theory and applications, especially at medium energy range (20 MeV - 40 MeV), where particle emission is mostly described by

"pre-equilibrium processes"and nuclear structure effects start to wash out. The current theoretical nuclear models still lack the capability to predict cross sections for any nucleus in an arbitrary energy range with reasonable accuracy for practical applications. These models, implemented within codes like TALYS [1], still rely on experimental data, which are necessary for a correct choice of their free parameters.
In this scope, this project aims at obtaining double differential cross-sections measurements of light charged particles (p, d, t, He, and α) for ^{nat}C, ^{nat}Cr and ^{nat}Fe in neutron-induced reactions. The latter two elements are the primary components of Eurofer steel, which will be extensively explored in fusion technologies, such as in the upcoming DONES facility [2]. Reliable data on radiation damage in structural material are essential for making suitable predictions regarding the longevity and performance of these materials.
In the last few years, three experiments have been conducted at the Neutrons For Science (NFS) facility at GANIL with the Medley setup to study production of light ions in those elements. This setup, designed and assembled in Uppsala [3], comprises eight telescopes, each containing two silicon detectors and one CsI, for detection and identification of light-ions using the ΔE-ΔE-E technique. The first objective of this series of experiments is to measure the NFS neutron spectrum, using neutron-proton elastic scattering in a CH_2 target. Medley has shown to provide good particle identification with enough energy resolution to distinguish between the individual isotopes of H and of He, and the required resolution for time of flight measurements in the whole energy range available at the facility.
In this contribution, we will present the preliminary values of the NFS neutron spectrum, along with the perspectives regarding the analysis of light-ion emission on the aforementioned nuclei.

[1] A. Koning, S. Hilaire, and S. Goriely, Eur. Phys. J. A, 59 6 (2023) 131
[2] Y. Qiu, Fusion Engineering and Design, 201 (2024) 114242
[3] Pomp, S., et al., EPJ Web of Conferences, 8 (2010) 07013

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Constraining and Calculating Nuclear Reactions on Unstable Fission Products

Authors: Adriana Sweet[1]; Andrea Richard[2]; Andrew Ratkiewicz[1]; Artemis Spyrou[3]; Barbara Alan[1]; Caleb Mattoon[1]; Darren Bleuel[1]; Gregory Potel[1]; Jutta Escher[1]; Matthew Mumpower[4]; Nicholas Scielzo[1]; Sean Liddick[3]; Stephanie Lyons[5]; Steven Pain[6]

[1] *Lawrence Livermore National Laboratory*

[2] *Ohio University*

[3] *Michgian State University/Facility for Rare Isotope Beams*

[4] *Los Alamos National Laboratory*

[5] *Pacific Northwest National Laboratory*

[6] *Oak Ridge National Laboratory*

Corresponding Author: ratkiewicz1@llnl.gov

Nuclear reactions on unstable fission products are of interest to nuclear non-proliferation efforts and basic science. While these reactions have historically been extremely difficult to measure, new experimental facilities are beginning to make beams of fission products available for the first time, enabling exciting experiments. The opening of this new area of the nuclear chart for measurements presents the opportunity to test, refine, and expand theories developed to explain behavior closer to stability, deepening our knowledge of the fundamental physics at play. We will present a summary of our white paper on the work needed, and the investments required to enable this work, to make measurements of nuclear reactions away from stability and the theoretical developments required to understand the underlying physics.

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DICER: A new instrunent at LANSCE to constrain neutron capture rates on radionuclides

Author: Thanos Stamatopoulos[1]

[1] *Los Alamos National Laboratory*

Corresponding Author: thanos@lanl.gov

With very few exceptions, direct measurements of neutron capture rates on radionuclides have not been possible. A number of indirect methods have been pursued such as the surrogate method [1], the γ-ray strength function method [2,3], the Oslo method [4-7] and the β-Oslo method [8]. Substantial effort has been devoted to quantify the usually large systematic errors that accompany the results from these techniques. A new instrument has been recently developed at the Los Alamos Neutron Science Center (LANSCE) to provide more accurate data on several radionuclides relevant to nuclear criticality safety, radiochemical diagnostics, astrophysics, nuclear forensics and nuclear security, by measuring the transmission of neutrons through radioactive samples and studying resonance properties. The Device for Indirect Capture on Radionuclides (DICER) [9-11] and associated radionuclide production at the Isotope Production Facility (IPF) [12, 13], both at LANSCE, as well radioactive sample fabrication, have been under development the last few years. A description of the new apparatus, data on a few mid-weight stable isotopes and efforts on radionuclide measurements will be presented.

References

1. J. E. Escher et al., Phys. Rev. Lett. 121, 052501 (2018)
2. H. Utsunomiya et al., Phys. Rev. C 82, 064610 (2010)
3. H. Utsunomiya et al., Phys. Rev. C 88, 015805 (2013)
4. M. Guttormsen et al., Nucl. Instrum. Meth. A, 374 (3) (1996)
5. M. Guttormsen et al., Nucl. Instrum. Meth. A, 255 (3) (1987)
6. A. Schiller et al., Nucl. Instrum. Meth. A, 447 (3) (2000)
7. A. C. Larsen et al., Phys. Rev. C 83, 034315 (2011)
8. A. Spyrou et al., Phys. Rev. Lett. 113, 232502 (2014)
9. P.E. Koehler, Springer Proceedings in Physics, 254 (2021) p. 187
10. P.E Koehler, LA-UR-18-22995 (2018)
11. A. Stamatopoulos et al., Nucl. Instrum. Meth. A, 1025 (2022) 166166
12. K.F. Johnson et al., LA-UR-04-4570 (2004)
13. https://lansce.lanl.gov/facilities/ipf/index.php

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Ab initio investigation of the 12C(n,p)12B charge-exchange reaction

Authors: Petr Navratil[1]; Matteo Vorabbi[2]; Sofia Quaglioni[3]; Guillaume Hupin[4]

[1] *TRIUMF*

[2] *University of Surrey*

[3] *LLNL*

[4] *Université Paris-Saclay*

Corresponding Author: navratil@triumf.ca

Neutron-induced charged-particle reactions are ubiquitous in nature and their understanding is needed for a variety of applications, ranging from fundamental Nuclear Physics to energy production and medical applications. Motivated by recent measurements at CERN n-TOF facility, we have

performed calculations of the charge-exchange 12C(n,p)12B reaction within the ab initio no-core shell model with continuum (NCSMC).

The NCSMC method [1,2] can describe both bound and unbound states in light nuclei in a unified way. With chiral two- and three-nucleon interactions as the only input, we can predict structure and dynamics of light nuclei and, by comparing to available experimental data, test the quality of chiral nuclear forces.

After correcting the ab initio NCSMC calculations for experimental thresholds and energies of known resonances, we obtain a quite satisfactory description of the neutron-12C total, elastic and inelastic cross sections and predict the 12C(n,p)12B cross section where limited data are available. We calculate integrated and differential cross sections for the ground state and excited states of 12B, and for neutron energies up to 20 MeV, where high level densities in the compound 13C nucleus are reached. Our calculations demonstrate NCSMC capability in a regime where statistical compound nuclear reaction methods are typically applied.

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[1] S. Baroni, P. Navratil, and S. Quaglioni, Phys. Rev. Lett. 110, 022505 (2013); Phys. Rev. C 87, 034326 (2013).
[2] P. Navratil, S. Quaglioni, G. Hupin, C. Romero-Redondo, A. Calci, Physica Scripta 91, 053002 (2016).

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Progress in the measurement of the neutron-induced fission cross-section at CSNS Back-n

Author: Yonghao Chen[1]

[1] *Institute of High Energy Physics, Chinese Academy of Sciences*

Corresponding Author: chenyonghao@ihep.ac.cn

China Spallation Neutron Source (CSNS) is a newly built large scale facility in 2018. It is generating neutrons by bombarding 1.6 GeV protons into a tungsten target for multidisciplinary research. A back-streaming neutron beamline (Back-n) at CSNS is built at the reverse direction regarding to the proton beam mainly for the nuclear data measurement. Back-n is characterized by its wide energy range (from thermal to 300 MeV), high flux (up to 10^7 n/cm^2/s at 77 m) and good energy resolution (less than ~1% below 1 MeV), which stands as one of the state-of-the-art white neutron source in worldwide. Fission cross-section of a series of isotopes, such as ^{232}Th, ^{235}U, ^{236}U, ^{238}U, ^{239}Pu, has been measured in wide energy ranges since 2018, and more isotopes (such as minor actinides) are planned to be measured in the near future. In this presentation, the CSNS Back-n facility and the campaigned fission cross-section measurement will be reviewed. Then the challenges and perspectives of the fission cross-section measurement at CSNS Back-n will be highlighted.

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The SANDA and APRENDE European nuclear data projects

Author: Daniel Cano Ott[1]

[1] *CIEMAT - Centro de Investigaciones Energéticas, MedioAmbientales y Tecnológicas*

Corresponding Author: daniel.cano@ciemat.es

Accurate nuclear data (ND) are necessary for the conception, development, optimization, and safety evaluation of nuclear energy applications (both fission and fusion) and non-energy applications such as radiation protection, radionuclide production, health, geosciences, space research, security, and industry.

In Europe, the ND activities have been funded so far by national funding agencies and diverse Euratom programs of the European Commission (EC). The EC has supported nuclear data activities almost continuously since 1999. An overview of the research work carried out during the ongoing Euratom nuclear data project SANDA (Supplying Accurate Nuclear Data for Applications) will be provided, together with the activities proposed for the recently approved project APRENDE (Addressing PRiorities of Evaluated Nuclear Data in Europe).

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Status and current activities for neutron-induced cross-section measurements in ANNRI·MLF·J-PARC

Author: Atsushi Kimura[1]

[1] *Japan Atomic Energy Agency*

Corresponding Author: kimura.atsushi04@jaea.go.jp

For detailed technical designs and safety evaluations of innovative nuclear reactor systems, accurate cross-sections are required. Especially, in the field of nuclear systems such as the transmutation of radioactive waste and various innovative reactor systems, neutron-capture cross sections of minor actinides (MAs) and long-lived fission products (LLFPs) are quite important to estimate the production and the transmutation rates [1-3]. However, accurate measurements of these cross sections are very difficult due to high radioactivity of these samples.

The Accurate Neutron-Nucleus Reaction measuring Instrument (ANNRI) was constructed to overcome this problem through a collaboration between Hokkaido University, Tokyo Institute of Technology, and JAEA in 2008.
ANNRI is located on Beam Line No. 04 of the Materials and Life science experimental Facility (MLF) at the J-PARC. There are three detector systems in ANNRI [4]. At flight lengths of 21.5 and 28 meters, an array of Ge detectors and a NaI(Tl) spectrometer were installed. These two gamma-ray spectrometers are used to determine the capture cross-section.
For total cross-section measurements, Li-glass detectors were installed at a flight length of 28.5 m. Since 2008, measurements of neutron-induced cross-sections of the MAs and LLFPs with high-intensity pulsed neutrons have been conducted. Neutron capture and/or total cross sections of ^{244}Cm, 246Cm, ^{241}Am, ^{243}Am, ^{237}Np, ^{99}Tc, ^{107}Pd, ^{129}I, and many stable isotopes were reported [5-9]. These results will make significant contributions to the field of developing innovative nuclear systems. A brief overview of ANNRI and its current activities are reported in this presentation.

[1] M. Salvatores et al., A Report by the Working Party on International Evaluation Co-operation of the Nuclear Science Committee **Vol. 26** (2008).
[2] T. Sugawara et al., JNST, **47**, 521 (2010).
[3] H. Iwamoto et al., JNST, **50**, 856 (2013).

[4] K. Kino et al., NIM-A, **626**, 58 (2011).
[5] A. Kimura et al., JNST, **49**, 708 (2012).
[6] S. Kawase et al., JNST, **58**, 764 (2021).
[7] G. Rovira et al., JNST, **59**, 110 (2022).
[8] K. Terada et al., JNST, **55**, 1198 (2018).
[9] A. Kimura et al., JNST, **56**, 479 (2019).

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Neutron induced capture and fission gamma measurements in the resolved resonance region

Author: Yaron Danon[1]

Co-authors: Katelyn Cook [1]; Ian Parker [1]; Devin Barry [2]

[1] *Gaerttner LINAC Center, Rensselaer Polytechnic Institute, Troy, NY, 12180, USA*

[2] *Naval Nuclear Laboratory, Schenectady, NY 12301-1072, USA*

Corresponding Author: danony@rpi.edu

Measurements are routinely performed at the Rensselaer Polytechnic Institute (RPI) Gaerttner Linear Accelerator (LINAC) Center to generate nuclear data for different neutron reactions in multiple energy ranges. These measurements use neutrons generated by a 60 MeV pulsed electron LINAC and various neutron and gamma detection systems at different flight path lengths. A new project was developed to assess the accuracy of capture gamma-rays generated from nuclear structure evaluations when used for different applications [1]. To achieve the project goal, a new simulation method was developed based on MCNP 6.2 [2] to more accurately model and transport neutron capture gamma-ray cascades. The results of this new method were compared with recent experimental neutron capture gamma-ray data generated at the RPI LINAC. Methods are also under development for actinides such as U-235 where fission and capture gammas are both emitted.

The recent neutron capture gamma-ray measurements were performed using the RPI 16-segment NaI multiplicity detector [3] and the neutron time-of flight method. This detector is located at a flight path of about 25.5m and is useful in the energy range from 0.01-3000 eV. The detected gamma-ray pulses are digitized, streamed to a computer, and saved for multidimensional post processing. The neutron capture gamma-ray spectra for different energy ranges and observed multiplicities were derived for comparison with simulations. The neutron capture gamma-ray spectra for a single resonance in a particular material can be analyzed to determine spin dependence. In the case of U-235, this information was used to simultaneously measure the capture and fission cross sections.

The Monte Carlo codes DICEBOX [5] and a modified version of MCNP 6.2 were used along with pertinent nuclear structure evaluations found in ENSDF [4], to calculate the neutron capture gamma-ray cascade spectrum and validate against the RPI LINAC experiments. A modification of the MCNP code allowed for reading gamma-ray cascade data generated by DICEBOX and subsequent transport of these gamma-rays through the RPI detector geometry. The resulting output was an event-by-event list of gamma-ray energy deposition in each of the 16 segments in the detector system. The simulation output is similar in form to the experiment results thus direct comparison was possible. It was demonstrated than when the neutron capture gamma-ray cascade is well known, such as in the case of Fe-56, the experiment and simulation are in very good agreement with respect to the individual detector spectrum as well as the coincidence spectrum (from all detectors) generated by thermal neutrons. Therefore, the simulation methodology was validated for the RPI experimental capture data. The system was used for a variety of materials including F-56, Ta-181, U-238 and U-235.

References

[1] Cook at al., EPJ Web of Conf., vol. 284, pp. 06001, 2023, DOI:10.1051/epjconf/202328406001.
[2] Werner, C.J., Los Alamos National Laboratory, LA-UR-17-29981, 2017.
[3] Danon et al., Nucl. Sci. Eng., vol. 187, no. 3, pp. 291-301, 2017, DOI:10.1080/00295639.2017.1312937.

[4] Bhat, M.R., In: Qaim, S.M. (eds) Nuclear Data for Science and Technology. https://doi.org/10.1007/978-3-642-58113-7_227, 1992.
[5] F. Bečvář, Nucl. Instr. Meth. Phys. Res. A, Vol 417, Issues 2–3, 1998.

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Neutron inelastic scattering

Author: Maëlle Kerveno[1]

[1] *CNRS/IPHC, Strasbourg*

Corresponding Author: maelle.kerveno@iphc.cnrs.fr

Neutron inelastic scattering is an important process involved in many applications but also for background studies supporting more fundamental research area. In the fast energy range, it is one of the major nucleon-nucleus interactions and its cross section constantly increases above the threshold energy of the first excited state up to a few MeV. In the field of nuclear energy applications or security and safeguard purposes, accurate nuclear data are required. However, despite significant advances in modeling and experimental efforts, using different experimental techniques, during these last decades, such cross section calculations still pose a major challenge to nuclear theory to reach predictions at the level of the required accuracy by applications.
In this context, this contribution will first present the issues linked to the current state of evaluated nuclear data in the particular field of nuclear energy. Then, the experimental effort made over more than 30 years will be compared to the progress made in modeling the neutron inelastic scattering. Indeed, as experimental information available for evaluating the inelastic scattering cross sections is rather limited (and often parcel), theoretical knowledge is needed to infer the total cross section. The last part of the contribution will be devoted to evoking the possible future of this topic and challenges to tackle in view of providing accurate neutron inelastic cross section.

Measurements I / 96

Capture-to-fission ratio measurements at LANSCE

Author: Esther Leal Cidoncha[1]

Co-authors: Aaron J. Couture [1]; Amy Lovell [2]; Cathleen Fry [2]; Evelyn M. Bond [2]; Gencho Rusev [2]; Ingrid Knapova [1]; Ionel Stetcu [1]; John L. Ullmann [1]; Luiz Leal [3]; Marco Pigni [4]; Todd A. Bredeweg [2]; Toshihiko Kawano [2]

[1] *Los Alamos National Laboratory*

[2] *LANL*

[3] *ORNL*

[4] *Oak Ridge National Laboratory*

Corresponding Author: iknapova@lanl.gov

Capture-to-fission cross section ratios are used as an alternative to absolute cross section measurements. This is due to the simplification on the calculations and the reduction of the uncertainties with respect to an absolute measurement of the cross section by eliminating experimental complications like self-absorption, beam/target overlap and non-uniformities. Different capture-to-fission reactions have been measured through the years at the Los Alamos Neutron Science Center (LANSCE) at Los Alamos National Laboratory (LANL) using the Detector for Advanced Neutron Capture Experiments (DANCE) combined with different fission detectors. Some of these are a Parallel Plate Avalanche Counter (PPAC) to detect fission fragments (FF), and the NEUtron detector array at dANCE (NEUANCE) to detect fission neutrons. As DANCE detects the γ-rays produced in capture and fission reactions, the fission instrument placed inside the DANCE cavity is used to tag the fission γ-rays for background identification and subtraction. Some examples of capture-to-fission

ratio measurements performed with DANCE in the last years are the ^{233}U, ^{235}U and ^{239}Pu. The measurement technique, the different setups, and other potential applications of the instruments will be explained.

Measurements II / 66

The neutron-induced fission cross section on 235U measurement at the n_TOF facility at CERN

Author: Alice Manna[1]

[1] *University of Bologna*

Corresponding Author: alice.manna@cern.ch

The neutron time-of-flight facility, n_TOF, at CERN, offers the possibility to study neutron-induced reactions thanks to the extremely wide neutron energy spectrum available in its experimental area, from thermal up to GeV. Already since the year 2001, the n_TOF Collaboration has been producing relevant nuclear data for fundamental nuclear physics, technology and astrophysics.
In particular, an extensive programme of neutron-induced fission measurements has being carried out on major and minor actinides, as well as on few lighter elements characterised by a high fission threshold. Together with the features of the neutron beam, the measurements have benefited from high performance detection and acquisition systems specifically developed at n_TOF.
Among these activities, given its importance as main reference, the 235U(n,f) cross section is still deeply studied in different energy regions and using several detector concepts. At n_TOF, this cross section was measured, as a function of the energy, as ratios to 238U(n,f), 10B(n,a), 6Li(n,t) cross sections. More recently, a dedicated measurement campaign was carried out to provide accurate and precise cross section data of the 235U(n,f) reaction in the high energy region from 10 MeV to 440 MeV relative to the neutron-proton elastic scattering cross section.

The experimental apparatus used for this measurements, which involved the effort of several research institutions (INFN, PTB and IPN, in addition to CERN), consisted of three flux detectors and two fission detectors. This allowed to simultaneously record the number of neutrons impinging on the 235U samples (incident neutron flux), as well as fission events. The neutron flux measurement is based on the neutron-proton elastic scattering reaction and it exploits the detection of the recoil protons from a polyethylene target using three Proton Recoil Telescopes. The fission events have been recorded with a fission ionization chamber, as well as by a parallel plates avalanche counters (PPAC) detectors, specifically designed for operation at n_TOF [1,2].

An initial introduction to the _TOF fission program will be followed by a focus on the 235U(n,f) measurement in the high-energy region. The experimental apparatus and data analysis and the results will be presented [3]. In addition, a comparison with current model descriptions of the fission process at high neutron energies will be included in the comparison with the experimental results obtained at n_TOF.

[1] A. Manna, on behalf of the n_TOF Collaboration, Journal of Instrumentation 18 (04), P04024
[2] E. Pirovano, on behalf of the n_TOF Collaboration, Journal of Instrumentation 18 (11), P11011.
[3] A. Manna, E. Pirovano, submitted for publication (2024)

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The ^{239}Pu neutron capture and fission cross-section measurements at n_TOF, CERN

Author: Adrian Sanchez Caballero[1]

[1] *CIEMAT*

Corresponding Author: adrian.sanchez@ciemat.es

The NEA/OECD included the cross-section of neutron capture and neutron-induced fission reactions for ^{239}Pu in its High Priority Request List, in response to the demands for more accurate and reliable nuclear data essential for the design and operation of nuclear technologies. Recent efforts have been concentrated on meeting these data needs by means of a new measurement utilizing ^{239}Pu samples in the n_TOF time-of-flight facility at CERN. This activity forms part of the scientific program approved by the European Commission H2020 Supplying Accurate Nuclear Data for energy and non-energy Applications (SANDA), and aims to improve the current knowledge and reduce existing uncertainties on the ^{239}Pu neutron capture and fission cross-sections, along with the α-ratio. Ten thin samples of 1 mg each were deposited within a novel ionization chamber, specifically designed for the challenging conditions of high counting rates coming from the α-decay of ^{239}Pu. This fission fragment detector was operated in combination with the n_TOF Total Absorption Calorimeter to highly suppress the γ-ray fission background in the measurement of the capture reaction cross-section, employing the so-called fission tagging technique. To extend the measurement of the capture cross-section, a thicker ^{239}Pu sample of 100 mg was also used. In addition to the cross-section data, the measurement will also provide valuable information on the distribution of the γ-rays cascades emitted in ^{239}Pu(n,γ) and ^{239}Pu(n,f) reactions, as experienced in previous experiments performed with the TAC. This contribution to the CNR*24 workshop will provide a description of the experimental activities of the ^{239}Pu measurement at n_TOF and will also show the latest updates on the data analysis, including preliminary results of the experimental reaction yields.

Measurements II / 37

The CERN n_TOF facility: high accuracy measurements of neutron induced cross sections

Author: Michael Bacak[None]

Corresponding Author: michael.bacak@cern.ch

Based on an idea by Carlo Rubbia, the n_TOF facility at CERN has been built and has been operating for over 20 years. It is a neutron spallation source, driven by the 20 GeV/c proton beam from the CERN PS accelerator. Neutrons in a very wide energy range (from GeV, down to sub-eV kinetic energy) are generated by a massive Lead spallation target feeding two experimental areas. EAR1, horizonal with respect to the proton beam direction is set at 185 meters from the spallation target. EAR2, on the vertical line from the spallation source, is placed at 20 m. Neutron energies for experiments are selected by the time-of-flight technique (hence the name n_TOF), while the long flight paths ensure a very good energy resolution.

Over one hundred experiments have been performed by the n_TOF Collaboration at CERN, with applications ranging from nuclear astrophysics (synthesis of the heavy elements in stars, big bang nucleosynthesis, nuclear cosmo-chronology), to advanced nuclear technologies (nuclear data for applications, nuclear safety) to basic nuclear science (structure and decay of highly excited compound states).

During the planned shutdown of the CERN accelerator complex between 2019 and 2021, the facility went through a substantial upgrade with a new target-moderator assembly, refurbishing of the neutron beam lines and experimental areas. An additional measuring and irradiation station (the NEAR Station) has been envisaged and its capabilities for performing material test studies and new physics opportunities are presently explored.

An overview of the facility and of the activities performed at CERN will be presented, with a particular emphasis on the most relevant experiments for nuclear astrophysics.

NLD and PSF I / 91

20 years of microscopic Nuclear Level Densities from drip lines to drip lines

Author: Stéphane Hilaire[1]

Co-authors: Sophie Péru [1]; Stephane Goriely [2]

[1] *CEA, DAM, DIF*

[2] *ULB*

Corresponding Author: stephane.hilaire@cea.fr

Nuclear reaction models, and in particular compound nucleus reactions, require the knowledge of nuclear level densities (NLDs), among other ingredients. For decades, analytical expressions have been used in nuclear reaction codes, due to the freedom they offer to the user to modify their associated parameters in order to fit cross sections.
The development of computational resources has opened a new era, roughly 20 years ago, by allowing the systematic calculation of NLDs from more microscopic approaches and their use in reaction codes through tables stored in databases.
During this 20 year period, several approaches have been developed to improve step by step the physical description of NLDs. We will review all these efforts and will show where we are now and what we foresee as future improvements.

NLD and PSF I / 67

The measurement of the level densities of neutron-rich ^{68}Cu and ^{65}Ni using the evaporation technique with a white neutron beam, and the improved neutron capture rates of ^{67}Cu and ^{64}Ni that are relevant for nucleosynthesis in low neutron exposure conditions.

Author: Georgios Perdikakis[1]

Co-authors: Hye Young Lee [2]; Nikolaos Dimitrakopoulos ; Panagiotis Gastis [2]; Pelagia Tsintari ; Sean Kuvin [2]

[1] *Department of Physics, Central Michigan University*

[2] *Los Alamos National Laboratory*

Corresponding Author: perdi1g@cmich.edu

We employ a new method to extract the level densities of neutron-rich isotopes by utilizing (n,p) and (n,α) reactions and the evaporation technique to analyze the emitted particle spectra. This level density extraction method is particularly suited to nucleosynthesis at low neutron exposures that typically proceeds by neutron captures along a path extending within a few neutrons away from the valley of stability. In this region, a direct measurement of the relevant reaction rates still remains out of the grasp of experiments. Our method allows for the statistical properties of several relevant isotopes to be studied experimentally to constrain the reaction modeling. In this work, I will present the details of the method and the level densities we extracted for the isotopes ^{68}Cu and ^{65}Ni during our recent experimental campaign at Los Alamos National Laboratory. I will also present improved Hauser-Feshbach calculations of the neutron capture reaction rates on ^{67}Cu and ^{64}Ni for the relevant nucleosynthesis scenarios.We employ a new method to extract the level densities of neutron-rich isotopes by utilizing (n,p) and (n,α) reactions and the evaporation technique to analyze the emitted particle spectra. This level density extraction method is particularly suited to nucleosynthesis at low neutron exposures that typically proceeds by neutron captures along a

path extending within a few neutrons away from the valley of stability. In this region, a direct measurement of the relevant reaction rates still remains out of the grasp of experiments. Our method allows for the statistical properties of several relevant isotopes to be studied experimentally to constrain the reaction modeling. In this work, I will present the details of the method and the level densities we extracted for the isotopes ^{68}Cu and ^{65}Ni during our recent experimental campaign at Los Alamos National Laboratory. I will also present improved Hauser-Feshbach calculations of the neutron capture reaction rates on ^{67}Cu and ^{64}Ni for the relevant nucleosynthesis scenarios.

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Comparing Nuclear Level Densities: Particle Evaporation vs. Neutron Resonance Data

Author: Alexander Voinov[1]

[1] *Ohio University*

Corresponding Author: voinov@ohio.edu

All level density models currently used in nuclear reaction codes are based on experimental data on absolute values of nuclear level density which are basically coming from two data sets: discrete level scheme at low excitation energies and the s-wave neutron resonance spacing (D0) at the neutron separation energy. These data are known in very limited ranges of excitation energies and spins. This restriction poses a challenge in effectively constraining level density models, resulting in significant uncertainties when modeling reaction cross-sections for various applications.
The experimental technique based on measuring the shape of emitted particle spectra from compound nuclear reactions (also referred to as evaporation spectra) allows for obtaining independent absolute level density information at higher excitation energies (up to the neutron separation energies) using only known discrete level scheme for the absolute normalization. This allows for independent cross-check of level densities obtained from particle evaporation technique and neutron resonances for their consistency, which will help with understanding the cause of possible difference. Understanding this difference is very important for constraining level density models and improving accuracy of reaction cross-section calculations. Also, it is critical for understanding systematical uncertainties of the experimental techniques based on the Oslo method of extracting level densities and gamma-strength functions, which uses D0 data for absolute normalization.
In this presentation, experimental information on level densities from particle evaporation and neutron resonance data will be compared for the range of nuclei and the difference and possible causes will be discussed.

NLD and PSF II / 52

The Shape Method and Status of the Photon Strength Function Database

Author: Mathis Wiedeking[None]

Corresponding Author: mwiedeking@lbl.gov

Nuclear data in the quasi-continuum have increasingly garnered attention due to their central role in a vast array of applications spanning fields such as isotope production, fission and fusion reactor technologies, non-proliferation, and the fundamental sciences of nuclear astrophysics and nuclear structure. These data are characterized by the photon strength function (PSF) and nuclear level density (NLD), and their measurements have and will continue to play a central role as these are inputs for the statistical Hauser-Feshbach model. This facilitates the extraction of neutron-capture cross-section data even for nuclei where direct measurements are not feasible. Now, PSF and NLD measurements in previously inaccessible regions of the nuclear chart have become possible due to many facilities worldwide offering enhanced or new state-of-the-art research infrastructure. In parallel, several new experimental and analytical techniques have been developed, enabling more reliable PSF and NLD studies. Recognizing the pivotal role of PSFs and NLDs, the International Atomic Energy Agency (IAEA) launched a Coordinated Research Project in 2016 aimed, in part, at establishing a PSF database, an initiative that encompasses measured PSF data and recommended theoretical models.

This presentation will focus on two aspects:
1) I will provide an overview of the recently developed Shape method, which provides an alternative approach to determine the slopes of the PSFs and NLDs extracted from the Oslo-type methods. The Shape method was developed specifically to provide a prescription when s-wave neutron resonance spacing data is unavailable. It utilizes branches of primary γ-ray transitions from a specific excitation-energy region to different low-lying discrete levels. Information about the functional form of the PSF is contained in the measured intensities of these primary branches, allowing for an independent normalization of the slope of PSFs and by extension NLDs [1,2].
2) I will provide an update on the current status, challenges, and perspectives of the PSF database [3], which was initially released in 2019. Numerous new measurements of the PSF have become available since, prompting a substantial update of the PSF database. This updated version is scheduled to be made available in 2024.

[1] M. Wiedeking et al., Phys. Rev. C 104, 014311 (2021).
[2] D. Mücher et al., Phys Rev C. 107, L011602 (2023).
[3] S. Goriely et al., Eur. Phys. J. A 55, 172 (2019).

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NLD and PSF II / 69

The dipole photon strength of uranium isotopes

Authors: Frank Gunsing[1]; Javier Moreno-Soto[1]; Michael Bacak[2]; Stanislav Valenta[3]; n_TOF Collaboration[None]

[1] *CEA Irfu, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France*

[2] *European Organization for Nuclear Research (CERN), Geneva, Switzerland; Technische Universität Wien, Austria; CEA Irfu, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France*

[3] *Charles University, Prague*

Corresponding Author: stanislav.valenta@matfyz.cuni.cz

The photon strength functions (PSFs) and nuclear level density (NLD) are vital ingredients for the calculation of the photon interaction with nuclei, in particular, the reaction cross sections via the Hauser-Feshbach approach \1. These cross sections are important, especially in nuclear astrophysics \[2,3] and in the development of advanced nuclear technologies \[4,5].

The role of the scissors mode in the *M1* PSF of well-deformed actinides was investigated by several experimental techniques, see e.g. Refs. \[6,7]. The analyses of these experiments show significant differences, especially on the strength of the mode. The shape of the low-energy tail of the giant electric dipole resonance is uncertain as well. In particular, some works proposed a presence of the *E1* pygmy resonance just above 7 MeV. Because of these inconsistencies, additional information on PSFs in this region is of great interest.

The γ-ray spectra from neutron-capture reactions on the ^{233}U, ^{234}U, ^{236}U, and ^{238}U nuclei have been measured with the total absorption calorimeter of the n_TOF facility at CERN \8. The background-corrected sum-energy and multi-step-cascade spectra were extracted for several isolated *s*-wave resonances.

The experimental coincident γ-ray spectra were compared with their simulated counterparts using Monte-Carlo code DICEBOX \9. This approach allowed us to test different models of NLD and PSFs. Our results for odd compound nuclei were published in Ref. \10. I want to highlight the main results from this study and show the first results from the capture on ^{233}U. The integrated strength of the scissors mode was found to be significantly higher compared to values in Refs. \[6,7]. The comparison of PSFs shall be discussed in detail.

\1[W. Hauser and H. Feshbach, Phys. Rev. **87**, 366 (1952).]1

\2[M. Arnould and S. Goriely, Prog. Part. Nucl. Phys. **112**, 103766 (2020).]2

\3[J. J. Cowan *et al.*, Rev. Mod. Phys. **93**, 015002 (2021).]3

\4[D. A. Brown *et al.*, Nucl. Data Sheets **148**, 1 (2018), Special Issue on Nuclear Reaction Data.]4

\5[A. J. M. Plompen *et al.*, Eur. Phys. J. A **56**, 181 (2020).]5

\6[M. Guttormsen *et al.*, Phys. Rev. C **89**, 014302 (2014).]6

\7[J. L. Ullmann *et al.*, Phys. Rev. C **96**, 024627 (2017).]7

\8[n_TOF Collaboration, C. Guerrero *et al.*, Eur. Phys. J. A 49, 1 (2013).]8

\9[F. Bečvář, Nucl. Instr. Methods A **417**, 434 (1998).]9

\10[n_TOF Collaboration, J. Moreno-Soto *et al.*, Phys. Rev. C **105**, 024618 (2022).]10

NLD and PSF II / 117

Photon strength function modelling, status and perspectives.

Author: Sophie PERU[1]

Co-authors: Stéphane hilaire [1]; Stephane Goriely [2]

[1] *CEA, DAM, DIF*

[2] *ULB*

Corresponding Author: sophie.peru-desenfants@cea.fr

The present contribution will give an overview of the photon strength function models developed to compensate for the lack of data for experimentally non-accessible nuclei. During this overview, phenomenological and microscopic approaches will be presented in light of their respective strengths. We will discuss more particularly the added value of microscopic approaches and the progressive reduction of phenomenological ingredients introduced in their post-treatment.

Among microscopic methods, the quasi-random phase approximation (QRPA) has been extensively used for the past decade due to its ability to be applicable to all nuclei.
Focussing on this approach, we will present the Gogny-based QRPA approach 1 which can be applied to spherical as well as to axially deformed nuclei, from light (i.e. oxygen) to superheavy elements 2. Despite the intensive computational effort it represents, large-scale calculations of dipole strength functions can be performed with limited phenomenological ingredients [3,4,5]. The resulting photon strength functions have been shown to reproduce the bulk of experimental data with a high level of accuracy 6.

We will also present other observables obtained within the standard QRPA framework 7 and its extension, with a special emphasis on the 4^- isomeric states in the $N = 100$ isotonic chain 8.
This study requires the calculation of the transition probabilities between excited QRPA states, which have also been consistently applied to the microscopic description of the low-energy component of the dipole strength function, known as the upbend and as observed in Oslo data 6.
We will therefore return to the definition of the photon strength function and its application to reaction calculation. Particular attention will be paid to the differences and similarities between photon absorption and de-excitation strength functions.

As perspectives, new theoretical results including these transition probabilities between excited states will be presented and commented.

1 S. Péru and H. Goutte, Phys.Rev. C 77, 044313 (2008);
2 S. Péru *et al.*, Phys.Rev. C 83, 014314 (2011);
3 M. Martini, S. Péru *et al.*, Phys.Rev. C 94, 014304 (2016);
4 S. Goriely *et al.*, Phys.Rev. C 94, 044306 (2016);
5 S. Goriely *et al.*, Phys.Rev. C 98, 014327 (2018);
6 S. Goriely *et al.*, The European Physical Journal A 55, 172 (2019);
7 S. Péru and Martini, Eur. Phys. J. A 50: 88 (2014);
8 L. Gaudefroy, S. Péru *et al.*, Phys.Rev. C 97, 064317 (2018).

NLD and PSF II / 2

Constraining experimentally photon strength functions using real photons at the HIGS/TUNL facility

Author: L. Adriana Banu[1]

[1] *James Madison University*

Corresponding Author: banula@jmu.edu

This presentation brings into focus ^{78,80}Kr(γ,γ'), ^{93}Mo(γ,n) and ^{90}Zr(γ,n) cross section measurements carried out using real photons at the HγGS/TUNL facility. The overarching physics motivation for these experimental investigations is to advance knowledge on a forefront topic in nuclear astrophysics –the nucleosynthesis beyond Fe of the rarest *stable* isotopes naturally occurring on Earth (the origin of p-nuclei) by constraining the statistical models that are used to calculate unknown stellar reaction rates. In particular, these stellar reaction rates are highly sensitive to the low-energy tail of the nuclear photon strength function (pSF).
Due to its high selectivity for dipole excitations, real photon scattering via nuclear resonance fluorescence (NRF) is the method of choice to extract experimentally, with high accuracy and model independently, the dipole pSFs in stable nuclei. The quasi-monochromatic and linearly polarized photon beam of very high flux available at HγGS makes this facility ideal for investigation of photoabsorption reaction cross section with p-nuclei as targets.
The NRF measurements on ^{78,80}Kr will provide for the first time information for the low-energy part of the E1-pSF in ^{78,80}Kr, as direct input into the p-process nucleosynthesis modeling. In this presentation, we will report on the status of data analysis of these very recent measurements.
The cross sections for ^{94}Mo(γ,n) and ^{90}Zr(γ,n) reactions were measured with high precision, from the respective neutron emission thresholds up to 13.5 MeV. In order to constrain the dipole pSFs in the A $\approx$ 90 mass region, the measured cross sections were compared with predictions of Hauser-Feshbach statistical model calculations using two different dipole pSF models. Since these models are based on fundamentally different physics, they can reflect the existing uncertainties affecting the pSF and also the impact of such uncertainties on reaction cross sections and corresponding astrophysical reaction rates. In this presentation, we will showcase our final results that show how sensitive the ^{94}Mo(γ,n) and ^{90}Zr(γ,n) stellar reaction rates can be to the corresponding measured cross sections, as discussed in detail in our recent publication, Phys. Rev. C 99, 025802 (2019).

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Nuclear Level Densities and Strength Functions: measurements

Author: Sunniva Siem[1]

[1] *University of Oslo*

Corresponding Author: sunniva.siem@fys.uio.no

NLD and PSF III / 23

Photon strength functions and nuclear level densities: Recent developments in photonuclear reaction studies

Author: Johann Isaak[1]

[1] *Institut für Kernphysik, TU Darmstadt*

Corresponding Author: jisaak@ikp.tu-darmstadt.de

Photons provide a particularly clean probe for studying a wide range of nuclear structure phenomena 1. Their interaction with the nucleus is described by the electromagnetic interaction, so that the nuclear response can be separated almost model-independently from the details of the reaction mechanism. Thus, photon-induced reactions are important tools in nuclear physics for determining the properties of low-spin excited states in atomic nuclei.

Important quantities for the modeling of nuclear and stellar reaction rates are photon strength functions (PSF) and nuclear level densities (NLD). Systematic studies of PSFs and NLDs across the nuclear chart are an important testing ground for benchmarking microscopic and macroscopic models, allowing extrapolation from mostly stable isotopes to experimentally unreachable exotic neutron-rich isotopes.

Many different experimental approaches and nuclear reactions are used to investigate PSFs, either by studying photoabsorption cross sections or by observing the γ-decay behaviour of excited nuclear states 2. One advantage of photo-induced nuclear reactions is the selectivity towards nuclear levels with predominantly J=1 spin quantum numbers. Hence, in contrast to reactions with hadronic probes, the spin quantum numbers of the populated nuclear levels are explicitly known and well defined in scattering experiments with real photons. Using γ-γ coincidence spectroscopy following photoexcitations, PSFs can be determined in both the absorption and emission channels independently. This new experimental technique makes it possible to test the Brink-Axel hypothesis directly and model-independently over a wide excitation energy range in a single experiment 3.

In addition to the study of PSFs, the nuclear self-absorption method offers a completely new approach to the determination of NLDs of J=1 states in the energy range below the neutron separation energy. The idea of this measurement method is based on the fact that for a given excitation energy range the strength of nuclear self-absorption depends only on the number of nuclear levels present, i.e. NLD, and their strength distribution. This requires experimental conditions with intense photon beams, the possibility to vary the energy of the photon beams and very low background radiation. All these conditions are met by the use of quasi-monochromatic photon beams [4,5].

In this contribution, recent results for PSFs and a pilot experiment for the determination of NLDs conducted at the High Intensity γ-Ray Source 6 at Duke University are presented and discussed.

1 A. Zilges, D. L. Balabanski, J. Isaak, and N. Pietralla, Prog. Part. Nucl. Phys. 122, 103903 (2022).
2 S. Goriely, P. Dimitriou, M. Wiedeking et al., Eur. Phys. J. A 55, 172 (2019).
3 J. Isaak et al., Phys. Lett. B 788, 225 (2019).
4 D. Savran and J. Isaak, Nucl. Instr. Meth. A 899, 28 (2018).

5 D. Savran, J. Isaak et al., Il Nuovo Cimento 47 C, 57 (2024).
6 H. R. Weller et al., Prog. Part. Nucl. Phys. 62, 257 (2009).

NLD and PSF III / 26

Approaching the pygmy dipole resonance in Sn isotopes with the Oslo method

Author: Maria Markova[1]

Co-authors: Ann-Cecilie Larsen [1]; Frank Leonel Bello Garrote [1]

[1] *University of Oslo*

Corresponding Author: maria.markova@fys.uio.no

The pygmy dipole resonance (PDR) is a feature commonly appearing in the low-lying electric dipole response of nuclei on top of the tail of the giant dipole resonance (GDR). Despite the ongoing debates regarding its origin, its emergence is commonly associated with the presence of the neutron excess and might potentially affect the neutron-capture rates and, thus, abundances of elements produced in heavy-element nucleosyntehsis 1. A systematic investigation of the evolution of the PDR in different isotopic chains with different theoretical approaches and experimental methods is therefore required for both general nuclear structure studies and large-scale astrophysical calculations.

This work presents a systematic study of the evolution of the low-lying electric dipole strength in eleven Sn isotopes, $^{111-113,116-122,124}$Sn, using the dipole γ-ray strength functions (GSF) below the neutron separation energy extracted from particle-γ coincidence data with the Oslo method 2. These GSFs were compared with the strengths from relativistic Coulomb excitation in forward-angle inelastic proton scattering below the neutron threshold 3, where they were found to be in excellent agreement within the uncertainties. The Coulomb excitation data cover a wide energy range of both the PDR and the GDR and provide the dipole magnetic part of the response. Together with the Oslo data, they were used to extract the low-lying electric dipole strength in all eleven Sn isotopes. It appears to exhaust $\approx 2\%$ of the classical Thomas-Reiche-Kuhn (TRK) sum rule and to be nearly constant throughout the whole chain of stable Sn isotopes. This is in contradiction with the majority of theoretical approaches (e.g., relativistic quasiparticle random-phase and time-blocking approximations), which predict a steady increase in the PDR strength with neutron number. Moreover, a presumably isovector component of the PDR was extracted for $^{118-122,124}$Sn. Its strength was found to increase almost linearly with neutron number, reaching up to $\approx 0.5\%$ of the TRK sum rule in ^{124}Sn.

The nuclear level densities of Sn isotopes, also extracted with the Oslo method, were employed together with the corresponding GSFs as inputs for calculations of neutron-capture cross sections and rates within the Hauser-Feshbach approach with the reaction code TALYS. The obtained cross sections and rates are in excellent agreement with other experimental data and evaluations from the KADoNiS, JINA REACLIB, and BRUSLIB libraries. Even though the low-lying electric dipole strength in Sn isotopes is limited to $\approx 2\%$ of the TRK sum rule, it contributes up to 20% of the estimated total cross sections. Moreover, the new experimentally constrained rates of the $^{121,123}\mathrm{Sn}(n,\gamma)^{122,124}$Sn reactions were found to affect the production of ^{121,123}Sb in the i-process simulations and limit the available theoretical uncertainties considerably.

1 S. Goriely, Phys. Lett. B 436, 10-18 (1998).
2 A. C. Larsen, et al., Phys. Rev. C 83, 034315 (2011).
3 S. Bassauer, et al., Phys. Rev. C 102, 034327 (2020).

NLD and PSF III / 1

Evidence for a toroidal electric dipole mode in nuclei and implications for the pygmy dipole resonance

Author: Peter von Neumann-Cosel[1]

[1] *Institut für Kernphysik, Technische Universität Darmstadt*

Corresponding Author: vnc@ikp.tu-darmstadt.de

I present first experimental evidence for a low-energy toroidal electric dipole mode in the nucleus ^{58}Ni based on a combined analysis of high-resolution (p,p'), (γ,γ') and (e,e') experiments 1. Large transverse electron scattering form factors are identified as a unique signature of the toroidal nature of E1 transitions. Although ^{58}Ni is a nucleus with N ≈ Z, these results bear important implications for the nature of the pygmy dipole resonance (PDR) in heavy nuclei with neutron excess. The toroidal excitations carry the same experimental signatures as the states forming the PDR 2: large isovector response (on the scale of low-energy E1 strength), strong isoscalar response and large ground-state branching ratios. QRPA models successfully describing the toroidal mode in ^{58}Ni predict the PDR in heavy nuclei to be of toroidal nature 3 and also reproduce the specific form of transition densities approximately isoscalar in the interior with a pronounced peak of the neutron density on the surface 4. Furthermore, a recent study of the systematics of the low-energy dipole strength in the Sn isotope chain reveals much smaller B(E1) strengths of the PDR than previously thought 5. These findings challenge an interpretation of the PDR as neutron skin oscillations implying a relation of the isovector strength to the neutron skin thickness and to the density dependence of the symmetry energy 6.

1 P. von Neumann-Cosel et al., arXiv:2310.04736.
2 A. Bracco, E.G. Lanza and A. Tamii, Prog. Part. Nucl. Phys. **126**, 360 (2019).
3 A. Repko et al., Eur. Phys. J. A **55**, 242 (2019).
4 E.G. Lanza et al., Prog. Part. Nucl. Phys. **129**, 104006 (2023).
5 M. Markova, P. von Neumann-Cosel and E. Litvinova, arXiv:2311.14525.
6 N. Paar, D. Vretenar, E. Khan and G. Colò, Rep. Prog. Phys. **70**, 671 (2007).

Nuclear Data I / 115

IAEA Neutron Data Standards

Author: Georg SCHNABEL[1]

[1] *IAEA*

Corresponding Author: g.schnabel@iaea.org

Most neutron cross section measurements are made relative to cross sections that are referred to as the Neutron Data Standards (NDS). The conversion to absolute cross sections requires precise knowledge of the NDS, as any bias or uncertainty in the NDS will impact the quality of the resulting absolute cross sections. Moreover, the NDS uncertainties constitute a lower limit for these absolute cross sections. Due to this significant role of the NDS, both the rigorous assessment of experimental uncertainties and the statistical evaluation procedure are crucial aspects in the Neutron Data Standards project. This talk will present development activities towards the next NDS release undertaken since the last NDS release in 2017. Particular emphasis will be placed on a newly introduced Monte Carlo-based methodology for the rigorous consideration of non-linearities and unrecognized sources of uncertainty in the evaluation procedure.

Nuclear Data I / 65

Informing Nuclear Data Evaluations by combining ML/AI and CoH Sampling, and Integrating the New Model into CGMF.

Authors: Fanta Diaby[1]; Denise Neudecker[1]; Amy Lovell[1]

[1] *Los Alamos National Laboratory*

Corresponding Author: fdiaby@lanl.gov

Fission cross-sections are crucial in understanding nuclear reactions, for instance, in designing and analyzing nuclear reactors, applications in nuclear criticality safety, etc.

Current challenges stem from inherent biases and uncertainties within existing fission models, limiting their predictive capabilities, and unknown systematic biases in experimental data. For model predictions we used the Hauser-Feshbach method implemented in the LANL code CoH code. CoH connects fission cross-sections with other reaction channels, and it also correlates fission cross-sections with prompt fission observables through CGMF, a fission-event generator.

In the present work, we discuss recent results utilizing the machine learning algorithm elastic net to explore potential biases in experimental 235U and 239Pu fission cross sections. Experimental uncertainties are then enlarged based on those potential biases found by elastic net that are also deemed realistic by expert judgment. Then we calibrate CoH calculations against this experimental data. Subsequently, model parameters derived from fitting experimental datasets are informed by neural networks, uncovering inadequacies in the parameter space and guiding future model extension. We will integrate this improved model fit of fission cross sections into CGMF and pair it with experimental databases on prompt-fission neutron spectra and multiplicities to further explore inconsistencies within the model and experimental data.

Nuclear Data I / 100

Nuclear data evaluation, status and perspectives

Author: Helmut Leeb[None]

Corresponding Author: helmut.leeb@tuwien.ac.at

The knowledge of nuclear reaction data is an important requisite for the development and advances in nuclear technologies, but also for several fields of basic sciences such as nuclear astrophysics, nuclear medicine and material sciences. Nuclear data evaluation aims to reveal the best knowledge of nuclear reactions combining available experimental data, theoretical knowledge and mathematical constraints. In this presentation a short introduction into the concept of Bayesian evaluation techniques and an overview of the status and advances of recent and upcoming nuclear data libaries will be given. Especially, the generation of reliable uncertainty information will be discussed which is one of the most important demands from the user community. In this context the difficulties of a unique treatment of the resolved resonance range and the range of intermediate energies will be addressed. Furthermore specific problems of evaluations of light nuclear systems will be outlined. In the outlook of the presentation there will be a focus on methods and proposals taking advantage of the availability of increased storage and computational power which enable a more streamlined generation of updates of evaluations.

Nuclear Data II / 36

Neutron and Gamma Nuclear Reaction Data Calculations in CENDL

Author: Ruirui Xu[1]

[1] *China Institute of Atomic Energy*

Corresponding Author: xuruirui@ciae.ac.cn

Neutron and gamma induced reaction data are the important elements in diversified nuclear applications. The complete nuclear reaction information includes the nuclear reaction cross sections, angular distributions, energy spectrum et al. The study of nuclear reaction data and the relevant covariance in China have been carried out for decades under the joint collaboration of China Nuclear Data Center (CNDC) and the Chinese Nuclear Data Cooperation Network (CNDCN).
Restricted by experimental measurement conditions, theoretical model calculations are the unique way to provide complete and consistent nuclear reaction data. The optical models, the equilibrium and pre-equilibrium models for the compound nuclei, principle of detailed balance and so on jointly built a nuclear reaction platform to produce the nuclear data. Some representative theoretical methods and methodologies are studied in Chinese theoretical calculations for neutron and gamma data, which will be introduced in this work.
As for the neutron induced data, the hybrid approach with the R matrix and the statistics models are built for light nuclei on the 1s and 1p shells; the unified Hauser-Feshbach model and exciton models are developed and adopted in the middle-heavy mass region, and these models are recently being developed at the neutron incident energy from 20 to 30MeV; moreover, the program MINUIT et al. is added in the system to accelerate the optimization process. The large-scale calculations are feasible for the next sub-library of nuclear reaction data, and more than 400 nuclei will be released in the next CENDL. In addition, the more fundamental theories from the Classical Density Functional Theory (CDFT) and the calculation based on the ab initio theory are also applied in the nuclear structures, the multi-fission chambers and optical models et al. to improve the calculation environment of nuclear reactions. Besides, the methodologies of covariance are built for the cross sections based on the deterministic and random approaches.
As for the gamma induced data, the nuclear reaction models with multi-particle emission below 200 MeV are built in CNDC both for light nuclei and heavier. The photon absorption in the giant dipole resonance region is considered both with the various empirical Lorentz functions and the quasiparticle random-phase approximation for the spherical nucleus and deformed nuclei. Also, the optimized method is compiled with the main nuclear reaction codes, which help us to generate more data in the scheme. We also systematically investigate the measured photon nuclear data in Table and add machine learning method to analyze the data. More than 200 nuclei have been achieved using this scheme.

Nuclear Data II / 46

State of the EMPIRE: progress, issues, and future

Authors: Brett Carlson[1]; Michal Herman[2]; Nobre Gustavo[3]; NOY, Roberto Capote[4]; Toshihiko Kawano[5]; Hirokazu Sasaki[5]; Mihaela Sin[6]; Andrej TRKOV[7]

[1] *ITA*

[2] *Los Alamos National Laboratory*

[3] *BNL*

[4] *IAEA*

[5] *LANL*

[6] *University of Bucharest*

[7] *Josef Stefan Institute*

Corresponding Author: mwherman@lanl.gov

We will briefly summarize changes in the EMPIRE code since the last CNR meeting in 2018. Then we will discuss the fundamental issue of gradual absorption in the Multistep Compound mechanism that has been hindering its use in evaluation work. A new attempt at solving the problem will be presented. We will also mention the advanced treatment of gamma emission in the MSC that, albeit implemented a long time ago, is not well known within the community. Finally, we will indicate open problems and possible improvements along with the guidelines for the intended vast modernization of the whole code, including the use of Artificial Intelligence.
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Nuclear Data II / 48

Fission Product Yield Modeling and Evaluation

Authors: Amy Lovell[1]; Patrick Talou[2]; Toshihiko Kawano[2]

[1] *Los Alamos National Laboratory*

[2] *LANL*

Although independent and cumulative fission product yields have been a part of evaluated libraries for decades, there have been few updates over the years. The fission product yield sub-library in the ENDF/B-VIII.0 library is still largely based on the evaluation of England and Rider from the mid-90's 1, with only more recent updates to the energy dependence of ^{239}Pu below 2 MeV 2 and fixes to isomeric states and missing fission products 3. This previous evaluation depends strongly on phenomenological parameter variations and can include robust incident-energy dependence only where enough experimental data are available. However, over the past several years, there have been a wealth of new measurements of independent and cumulative fission product yields, particularly those with short half-lives, and there have been significant improvements in the modeling of prompt and delayed fission observables.

In this talk, we describe recent progress in the improvement of fission product yield calculations, using the BeoH code and the underlying Hauser Feshbach Fission Fragment Decay (HF^{3}D) model, developed at Los Alamos National Laboratory [4,5]. BeoH is a deterministic fission fragment decay code that uses the Hauser-Feshbach statistical model to follow the de-excitation of initial fission fragments through the emission of prompt neutrons and gamma rays, starting from phenomenologically parametrized fission fragment initial conditions. After this emission, a time-independent method, combined with decay data (branching ratios, half-lives, etc.) is used to calculate the cumulative fission product yields. This model, while still relying on phenomenologically parametrized inputs, models the multi-chance fission process without approximations, and therefore, energy-dependent calculations can be performed, even where experimental data are scarce.

We will describe our recent calculations for consistent prompt and delayed fission observables for major and minor actinides, including new work investigating isomeric ratios. We will detail the ongoing evaluation process for energy-dependent fission product yields from thermal up to 20 MeV incident energy and some validation work that has been performed for these new fission product yield calculations. Additionally, we will discuss future perspectives of this work, including highlighting the need for additional data.

LA-UR-24-22531

1 T.R. England and B.F. Rider, LA-UR-94-3106 (1994)
2 M.B. Chadwick, T. Kawano, et al., NDS 111, 2923 (2010)
3 A. Mattera and A. Sonzogni, BNL-220804-2021-INRE (2021)
4 S. Okumura, et al., JNST 55, 1009 (2018)
5 A.E. Lovell, et al., PRC 103, 014615 (2021)

Nuclear Fission I / 31

Properties and Dynamics of Fission Fragment Spins

Author: Ibrahim Abdurrahman[1]

Co-authors: Aurel Bulgac [2]; Guillaume Scamps [3]; Ionel Stetcu [4]; Kyle Godbey [5]; Matthew Kafker [2]

[1] *Los Alamos National Lab*

[2] *University of Washington*

[3] *Laboratoire des 2 Infinis - Toulouse*

[4] *Los Alamos National Laboratory*

[5] *FRIB*

Corresponding Author: ia4021@lanl.gov

In recent times, new theoretical and experimental results made it clear that the generation and dynamics of fission fragment (FF) intrinsic spins and their correlations were not well understood. During this period, we investigated various aspects of FF spins for compound nuclei 236U, 240Pu, and 252Cf using time-dependent density functional theory (TDDFT) extended to superfluid systems. We performed the first extraction of the FF spins distributions, as well as found the first evidence for all collective angular momenta modes, within a microscopic framework. Soon after we investigated the role of the relative angular momenta between FFs and extracted the opening angle distribution between the FF spin vectors, which vastly differed from leading phenomenological approaches at the time. Most recently, the role of the K quantum number, or projection of the spin along the fission axis, was carefully investigated, showing that the FF intrinsic spin dynamics is explicitly three-dimensional.

Nuclear Fission I / 94

Non-Equilibrium Aspects of Fission Dynamics within the Time Dependent Density Functional Theory

Author: Aurel Bulgac[None]

Corresponding Author: aurel.bulgac.phys@gmail.com

In the first microscopic description of induced fission, based on a full implementation of the Time-Dependent Density Functional Theory (TDDFT) extended to superfluid fermion system, using only 8 well known parameters (energy and density of symmetric nuclear matter, nuclear surface tension, symmetry energy and its density dependence, strength of the spin-orbit and pairing interactions, and proton charge), without any fitting or unchecked assumptions, and with controlled approximations, it was demonstrated that the fission dynamics from saddle-to-scission has a strongly non-equilibrium character. This is the apparent behavior of a viscous fluid and the use of the widely used adiabatic hypothesis is invalid. Within this theoretical framework the need for a collective potential energy surface and for a collective inertia become both superfluous and irrelevant and the role of the pairing correlations is crucial. A very good agreement was obtained with the experimental data for total kinetic energy of the fission fragments, their average masses, charges, excitation energies, intrinsic fission fragment angular momenta and their correlations. The dependence of these properties with excitation energy of the formed compound nucleus was studied and general features observed in experiments were also observed.

In more recent developments we have shown that the fission dynamics is unexpectedly non-Markovian in character, an aspect at odds with many phenomenological treatments of various aspects of fission dynamics such as Langevin, Smoluchowski, Brosa, Fokker-Planck, Boltzmann-Uehling-Uhlenbeck/Boltzmann-Nordheim frameworks. The solution of the TDDFT equation for superfluid systems is identical to the exact solution of the time dependent Gorkov equations for a superconductor in non-equilibrium. A theoretical prediction by Bohr and Wheeler in 1939, almost as old as Meitner and Frisch's nuclear liquid drop fission model from 1939, that a nucleus at scission should produce smaller droplets, now

identified as scission neutrons, remained an unsolved problem both theoretically and experimentally. The clear evidence of non-equilibrium scission neutrons has been demonstrated now and their number and wide energy spectrum have been predicted within the TDDFT framework. In another demonstration of the power of TDDFT we have simulated the induced fission of odd-mass and odd-odd nuclei within TDDFT, a process notorious for its theoretical complexity and difficulty of accurate treatment due to the presence of time-symmetry breaking terms in the density functional. All these developments became possible now due to the availability of very powerful supercomputers.

Nuclear Fission I / 95

Theory of Nuclear Fission

Author: Dario Vretenar[1]

[1] *University of Zagreb*

Corresponding Author: dvret.phy@pmf.hr

The process of spontaneous or induced fission, by which an atomic nucleus breaks into two or more fragments, presents, more than eight decades after its discovery, a very interesting research topic in the field of low- and medium-energy nuclear physics. From a modern perspective, nuclear fission can be considered a representative example of large-amplitude collective motion in a self-bound mesoscopic system, that exhibits both classical and quantal characteristics. In addition to important technological applications, primarily in energy production, fission is also relevant for the stability of superheavy elements, production of short-lived exotic nuclides far from stability, nuclear astrophysics, and the mechanism of nucleosynthesis.

A wealth of experimental results on nuclear fission have been accumulated, and a basic understanding of the mechanism gained. Several successful phenomenological approaches and methods have been developed that reproduce, to various degrees of accuracy, low- and medium-energy fission observables. Recently, significant advances in the microscopic description of various aspects of the fission process have been reported. These include studies of nuclear shell effects on fission observables, dynamical pairing correlations, symmetry restoration, fission in odd-mass nuclei, the energy dissipation mechanism and total kinetic energy distribution, neck dynamics, properties of fragments beyond scission, generation of fragment angular momentum, fragment distributions and their impact on r-process nucleosynthesis, element production, fission in compact stars, etc. Even though microscopic methods have been very effective in modelling specific observables, a unified framework for the description of the entire fission process remains a formidable challenge for nuclear theory.

Optical Model / 90

The Optical Potential in direct and compound nuclear reactions

Author: Gregory Potel Aguilar[1]

Co-authors: Grigor Sargsyan [2]; Jutta Escher [1]; Kostas Kravvaris [1]

[1] *Lawrence Livermore National Laboratory*

[2] *FRIB*

Corresponding Author: potelaguilar1@llnl.gov

The nucleon-nucleus optical potential (OP) is one of the essential ingredients in both direct and compound reaction calculations. Phenomenological parametrizations based on fits to elastic scattering data are widely used for many applications in astrophysics, basic nuclear science, and nuclear data.

However, the explicit connection of the OP with the underlying nuclear structure has always been an active line of research since the seminal papers of Feshbach were published in the 50's. This connection contributes to a better microscopic understanding of nuclear collisions, to a more transparent extraction of structure information from reaction experiments, and to a better controlled extrapolation to scarcely explored regions of the nuclear chart. We will present a brief overview of the status of the field of OPs, as well as of the open lines of investigation.

Optical Model / 93

Nucleon-Nucleus Optical Potentials for Soft Deformed Nuclei

Author: Dmitry Martyanov[1]

Co-authors: Roberto Mario Capote Noy [2]; José Manuel Quesada Molina [3]

[1] *JIPNR-Sosny, NAS of Belarus*

[2] *IAEA NAPC-NDS*

[3] *Universidad de Sevilla, Seville, Spain*

Corresponding Author: martyanov@gmail.com

This work presents the current state of a consistently developing dispersive Lane-consistent coupled channels optical model. The model considers the optical potential of a soft deformed target nucleus as an axially deformed potential with linear corrections corresponding to the softness and non-axiality of a nucleus 1. A soft rotator model was used to calculate the "effective" deformations –matrix elements of quadrupole and octupole deformation operators –with Hamiltonian parameters derived from the low-lying excitation spectrum of a nucleus 2. While the soft rotator model describes only even-even nucleus excitations, the suggested approach allows the evaluation of these values for odd-A nuclei for levels in rotational bands that share the same single-particle state 3. Additional corrections arising from nuclear volume conservation and the immobility of the center of mass are also taken into account.

In this model, levels from 5 rotational bands are coupled for even-even actinides, and up to 3 rotational bands for odd-A nuclides. The softness of a target affects the calculations even when levels from only one rotational band are coupled. New regional potentials are obtained for actinides and the tungsten region. It is shown that the new model provides a lower predicted compound nucleus cross-section in a weakly constrained incident energy region of 100 keV-1 MeV compared to the rigid rotor model.

References:

1 E. S. Soukhovitskiĩ, R. Capote, J. M. Quesada, S. Chiba, and D. S. Martyanov, Phys. Rev. C 94, 064605 (2016).
2 D. Martyanov, E. Soukhovitskii, R. Capote, J. M. Quesada, and S. Chiba, EPJ Web Conf. 146, 12031 (2017).
3 D. Martyanov, E. Soukhovitskiĩ, R. Capote, J. M. Quesada, and S. Chiba, EPJ Web Conf. 239, 03003 (2020).

Optical Model / 51

Deuteron-induced reaction cross sections for 93Zr up to 200 MeV

Author: Marilena Avrigeanu[1]

[1] *Horia Hulubei National Institute for Physics and Nuclear Engineering (IFIN-HH)*

Corresponding Author: marilena.avrigeanu@nipne.ro

Description of the deuteron-nucleus interaction is still a challenge for the basic research, while the accurate activation cross sections are highly requested by several on-going strategic research projects (ITER, IFMIF, SPIRAL-2). Actually, evaluation of the deuteron-induced activation data for IFMIF has pointed out a ratio of ~70 for the deuteron- and neutron-induced activities over the same decay times, showing the great importance of deuteron-induced reactions 1. However, in opposition to the case of neutrons, the systematic of deuteron activation cross sections is yet modest.
While recent advancements in deuteron reaction modeling in the TALYS code [2,3] are taken into account to provide more reliable data, to be reviewed and integrated step by step in the future 4, current discrepancies between experimental and calculated data follow the incomplete theoretical frame of deuteron interactions requesting, besides pre-equilibrium emission (PE) and fully equilibrated compound nucleus (CN) decay, consistent inclusion of breakup mechanism (BU) and direct reactions (DR) contributions. Furthermore, the consideration of the deuteron BU has to take into account two opposite effects, namely the important BU leakage of initial flux as well as the BF enhancement brought by the BU-nucleon interactions with the target nucleus (e.g., [3,5]). Thus, an extended analysis of the deuteron interaction with the target nuclei common in the alloys of candidate materials for ITER and IFMIF installations already concerned the stable isotopes of Al, Cr, Mn, Fe, Co, Ni, Zr, Nb, and Mo for deuteron energies ≤60 MeV (3 and Refs. therein).
An amazing opportunity to extend the incident energy range of the above-mentioned analyses is provided by recent experimental studies which were performed for deuteron-induced reactions by inverse-kinematics studies using radioactive ion (RI) beams across 50–210 MeV (6 and Refs. therein). Thus, the most recent 93Zr+d production cross sections of Nb and Zr isotopes at ~50 MeV are quite well reproduced by TALYS, showing qualitative improvement 6 with the recent BU model 3. However, the case is different for Y-isotope production, where the alpha emission channels for Y-isotope production are dominant but still underestimated up to a factor of 3. It is the object of this work to continue the efforts to better describe these new results and improve models of deuteron-breakup mechanisms across the widest possible energy range. We have used in this respect the experience leading already to the suitable account of all reaction cross sections induced by deuteron on 93Nb 7 and 90-92,94,96Zr 8 within the energy range ≤60 MeV.

1 R.A. Forrest and I Cook, Fus. Eng. and Des. **82**, 2478 (2007)
2 U. Fischer et al., Fus. Eng. and Des. **136**, 162 (2018)
3 M. Avrigeanu et al., Eur Phys J A **58**, 3 (2022)
4 G. Schnabel et al., Nucl. Data Sheets **139**, 1 (2024).
5 M. Avrigeanu et al., Phys. Rev. C **92**, 021601(R) (2015)
6 T. Chillery et al., Prog. Theor. Exp. Phys. **2023**, 121D01.
7 M. Avrigeanu et al., Phys. Rev. C **88**, 014612 (2013)
8 E. Simeckova et al., Phys. Rev. C **104**, 044615 (2021)

Poster Session / 4

Accuracy Evaluation of the Available Fission Yields in the ENDF/B-VII.1, ENDF/B-VIII.0 and JEFF 3.3 data libraries

Authors: Nader Mohamed[1]; Mohamed Elsaied[2]

[1] *Egyptian Atomic Energy Authority, ETRR-1, Cairo, Egypt*

[2] *Reactors Department, Egyptian Atomic Energy Authority, Cairo, Egypt*

Corresponding Author: mnader73@yahoo.com

The presentation presents a part of the work carried out in the research contract No. 24284 titled "accuracy evaluation of available fission yield data and updating"under the umbrella of the Coordinated Research Project (CRP): "updating fission yield data for applications"organized by the International Atomic Energy Agency (IAEA). One of the main objectives of this project is to evaluate the accuracy of the available fission yield data by simulation of a series of benchmarks in the areas of nuclear reactors calculations.

In this research, the latest ENDF/B-VIII.0 and JEFF3.3 data libraries that released on 2018 and 2017, respectively, as well as the ENDF/B-VII.1 data library were tested on two research reactors (ETRR-2 and OPAL) using two different classes of computational codes: MCNPX V2.7.0 and WIMS-5B/CITVAP codes. Since the reactor criticality calculations are very sensitive to the data library accuracy, criticality benchmarks were selected in the work for the evaluation of these data libraries.

The Results showed that MCNPX V2.7.0 computational code is more accurate than WIMS-5B/CITVAP codes in the multi-cycles core calculations. Criticality calculations of multi-cycles core based on ENDF/B-VII.1, ENDF/B-VIII.0, or JEFF 3.3 data libraries gave good agreements with the measurements. ENDF/B-VIII.0 library resulted in higher accuracy than the other two data libraries. Considerable differences in the concentrations of Xe-135 and Sm-149 (the dominant generated poisons) were resulted from the three data libraries. ENDF/B-VIII.0 gave higher concentrations of the two poisons than the other two Data libraries while ENDF/B-VII.1 resulted in higher concentrations of the two poisons than that of JEFF 3.3.

Poster Session / 9

Microscopic calculations with noniterative finite amplitude methods and the application to neutron radiative captures and inelastic scatterings

Author: Hirokazu Sasaki[1]

Co-authors: Ionel Stetcu [1]; Toshihiko Kawano [1]

[1] *Los Alamos National Laboratory*

Corresponding Author: hsasaki@lanl.gov

We derive the fully self-consistent quasiparticle random-phase approximation (QRPA) equations with noniterative finite amplitude methods and calculate the transition strengths of giant resonances. Then, we apply the QRPA results to both neutron radiative capture calculations based on the statistical Hauser-Feshbach theory and inelastic scattering calculations based on distorted-wave Born approximation (DWBA). We compare the calculated results with available experimental data and demonstrate how our approach can reproduce giant resonances and various nuclear reactions.

Poster Session / 14

History, development and main achievements in sixteen years of the Neutron Activation Analysis based method used for the establishment of the nuclear database at CNESTEN Morocco.

Author: Bounouira Bounouira[1]

[1] *CNESTEN-Maroc*

Corresponding Author: bounouira2000@gmail.com

History, development and main achievements in sixteen years of the Neutron Activation Analysis based method used for the establishment of the nuclear database at CNESTEN Morocco.

Hamid. Bounouira1*, Hamid. Amsil1, Abdessamad. Didi1, Iliasse. Aarab1, and Abdelwahab. Badague1

1 National Center of Energy, Sciences and Nuclear Techniques (CNESTEN), Morocco
*E-mail: bounouira2000@gmail.com

Keywords: Neutron activation analysis, Comparative method, k0-standardization method, TRIGA reactor

Neutron Activation Analysis is a technique used to determine the chemical elemental composition of materials from various matrices. Since the start-up of the Moroccan TRIGA Mark II research reactor in 2007, it has been used by the neutron activation laboratory at the National Centre for Nuclear Energy, Science and Technology (CNESTEN-Morocco). Different approaches of this technique, such as the comparative method utilizing the NADA programme and the k0-standardisation method, were developed and enhanced at CNESTEN in 2009 and 2013, respectively, for determining multielemental concentrations. The outcomes of proficiency testing revealed which unacceptable data supplied by the NAA technique should be improved throughout time.
This study discusses the history of the NAA technique's development in our NAA laboratory as well as its major accomplishments.

Poster Session / 24

Hauser-Feshbach Analysis of Fast Neutron-Induced Reactions on Chlorine

Author: Kenneth Hanselman[1]

Co-authors: Heshani Jayatissa [1]; Hye Young Lee [1]; Lukas Zavorka [2]; Matthew Wargon [3]; Panagiotis Gastis [1]; Scott Essenmacher [1]; Sean Kuvin [1]; Tommy Cisneros [3]; Toshihiko Kawano [1]

[1] *Los Alamos National Laboratory*

[2] *Oak Ridge National Laboratory*

[3] *TerraPower LLC*

Corresponding Author: khanselman@lanl.gov

Neutron-induced reactions on chlorine isotopes have recently been analyzed in a Hauser-Feshbach framework at Los Alamos National Laboratory. Particular focus has been applied to the "fast" energy range above 100 keV, where these reactions become important for applications like CLYC detector characterization and the development of molten chloride fast reactors (MCFRs). However, challenges to applying a purely statistical analysis to this mass range have presented themselves in the form of cross section fluctuations and deviations due to low-mass structure. In this presentation these challenges and their current solutions will be highlighted, representing improved agreement with available data over the current databases. Comparison will also be made between ^{35}Cl and ^{37}Cl in terms of valence shell structure and compound system level density. Finally, extensions to nearby ^{39}K will be discussed with astrophysical implications.

Poster Session / 40

Photonuclear reaction cross-section evaluation of ^{181}Ta, ^{197}Au, and ^{209}Bi considering experimental double differential cross-section data

Author: Thuong Nguyen Thi Hong[1]

Co-authors: Nobuyuki Iwamoto [2]; Toshiya Sanami [3]

[1] *Graduate University for Advanced Studies, SOKENDAI*

[2] *JAEA*

[3] *KEK, SOKENDAI*

Corresponding Author: ngthuong@post.kek.jp

Photonuclear reaction cross-section data are required for wide-range applications, such as electron accelerator shielding design and possibly nuclear transmutation. So far, the nuclear data libraries, such as JENDL 1, TENDL 2, and ENDF 3, of various target materials have been prepared up to a photon energy of 200 MeV. To establish the libraries, almost all evaluations have been conducted only the experimentally obtained reaction cross-section data, i.e., cross-sections of photon absorption and photo-particle yield. However, data libraries have not been validated for the energy spectra of secondary particles because this type of experimental data was scarce when the libraries were established.

Recently, the double differential cross-sections (DDXs) on the medium and heavy targets have been measured using monoenergetic, polarized photons at energies of 13 and 17 MeV [4–6]. Using the DDX data of ^{181}Ta, ^{197}Au, and ^{209}Bi, we have been implementing evaluation for these relatively heavy nuclei, similar in mass to those used as targets and beam stoppers, but different in nuclear structures and forms. We conducted the evaluation using the CCONE code system 7, which is used for JENDL.

The main task of the evaluation was to increase the photoneutron emission from the preequilibrium process described by the two-component exciton model. For this purpose, modifications of the multiplying factor for the state density in the exciton model were made in comparison with the DDX data. The results obtained by our evaluation for reaction cross-sections and DDXs were compared with the results from JENDL-5, as well as experimental data. The evaluation shows better reproduction of photoneutron emission than JENDL-5 for DDXs at 13 and 17 MeV photon energies while maintaining consistency on the total photoneutron cross-section data.

References

1 O. Iwamoto et al., J. Nucl. Sci. Technol., 60(1), (2023), 1-60.
2 A.J. Koning et al., Nuclear Data Sheets 155, (2019), 1-55.
3 D.A. Brown et al. Nucl. Data Sheets 148, (2018), 1.
4 T. Nguyen et al., J. Nucl. Sci. Technol., 61(2), (2024), 261-268.
5 T. Nguyen et al., EPJ Web Conf., 292, (2024), 07004.
6 Tuyet T.K et al., Nucl. Inst. and Meth. in Phys. A, 989, (2021), 164965.
7 O. Iwamoto et al., Nuclear Data Sheets, 131, (2016), 259-288.

Poster Session / 53

Low energy excitations in nuclei and their implication for nucleon-nucleus inelastic scattering

Author: Eun Jin In[1]

Co-authors: Aaina Thapa [1]; Emanuel Chimanski [2]; Jutta Escher [1]; Sophie P´eru [3]; Walid Younes [1]

[1] *Lawrence Livermore National Laboratory*

[2] *Brookhaven National Laboratory*

[3] *CEA, DAM, DIF (France)*

Corresponding Author: in2@llnl.gov

The properties of nuclear excitations, particularly collective excitation modes such as the giant resonance (GR) and pygmy resonance (PR), can reveal important characteristics of the underlying nuclear structure. The successful description of the nuclear excitations will enable the complete modelling of transitions between their ground and excited states and, furthermore, produce inputs for scattering calculations. We perform fully consistent calculations of excited states using the Quasi-particle Random Phase Approximation (QRPA) built on Hartree-Frock-Bogoliubov (HFB) states, offering valuable insights into the collective excitation characteristics. We integrate microscopic structure of nuclei with reaction theory for nucleon-nucleus scattering. We utilize the nucleon-nucleus effective interaction to proton-induced inelastic scattering, which are applicable as surrogate reaction method. In this presentation, we present characteristics of low energy electric excitations in spherical molybdenum isotopes and elastic and inelastic scattering cross sections.

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Measurement of the production branching ratio following nuclear muon capture

Author: Megumi Niikura[1]

Co-authors: Takeshi Saito [1]; Teiichiro Matsuzaki [1]; Katsu Ishida [2]; Adrian Hillier [3]

[1] *RIKEN*

[2] *KEK*

[3] *SFTC RAL-ISIS*

Corresponding Author: niikura@riken.jp

The energy distribution of compound states populated by nuclear muon capture can facilitate understanding the reaction mechanism. We developed a new method, called the in-beam activation method, to measure the production probability of residual nuclei by muon capture. In the method, decaying γ rays are measured simultaneously with beam irradiation by exploiting the time structure of the pulsed muon beam. Combining in-beam and ordinary offline activation methods enables the measurement of most of the β-decaying states with a wide range of half-lives from milliseconds to years. For the first application of the new method, we have measured the muon-induced activation of five isotopically enriched palladium targets of ^{104,105,106,108,110}Pd 1.

The experiment was performed at the RIKEN-RAL muon facility of the Rutherford Appleton Laboratory (RAL) in the UK 2. The pulsed muon beam impinged on the enriched palladium targets, and γ rays from the β and isomeric decays from the reaction residues were measured using high-purity germanium detectors. The production branching ratios of the residual nuclei of muon capture for five palladium isotopes were obtained.

The experimental results were compared with a model calculation using the particle and heavy ion transport system (PHITS) code 3. The model calculation reproduced the general trend of the obtained branching ratio rather well. In the workshop, we will present the details of the experiment and discuss the properties of compound states produced by muon capture.

1 M. Niikura et al., Phys. Rev. C 109, 014328 (2024).
2 T. Matsuzaki et al., Nucl. Instrum. Methods A 465, 365 (2001).
3 S. Abe and T. Sato, J. Nucl. Sci. Tech. 54, 101 (2017).

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Incomplete Fusion Dynamics in Reactions Induced by Alpha and Non-Alpha Cluster Projectiles at Low Energies

Author: AVINASH AGARWAL[1]

Co-authors: A K Chaubey [2]; Anuj Kumar Jashwal [3]; Harsh Vardhan [3]; I A Rizvi [2]; Kamal Kumar [4]; Munish Kumar [5]; S Dutt [6]

[1] *Bareilly College, Bareilly*

[2] *Department of Physics, Aligarh Muslim University, Aligarh 202 002, Uttar Pradesh, India*

[3] *Department of Physics, Bareilly College, MJP Rohilkhand University, Bareilly 243 006, Uttar Pradesh, India*

[4] *Department of Physics, Hindu College, MJP Rohilkhand University, Bareilly 243 006, Uttar Pradesh, India*

[5] *Department of Physics, Khandelwal College of Management Science & Technology, Bareilly (UP) -243002*

[6] *Key Labortory of High Precision Nuclear Spectroscopy, Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, People's Republic of China*

Corresponding Author: avibcb@gmail.com

In the reactions induced by weakly bound, tightly bound heavy ions and radioactive ion beams, Incomplete fusion (ICF) dynamics has been an issue of prime interest among nuclear physicists over past decade. The studies with projectiles having alpha structure like 12C, 16O and 20Ne has established the onset of ICF dynamics at energy as low up to Coulomb barrier. Exclusive entrance channel systematics has also been presented by number of researchers. In recent past our group has published the measurements with alpha structure projectile for Vanadium (51V) target that follow the systematics of ICF dynamics, based on various entrance channel parameters, including projectile energy, mass asymmetry (μA) of interacting partners, Coulomb factor (ZpZT), neutron skin thickness of target, and target deformation. In the preset report we have made an effort to have the same measurements for the same target (51V) with a non- alpha cluster beam i.e.,19F. The stacked foil activation technique has been used. The measured excitation functions (EFs) for several reaction residues produced in the interaction of 19F+51V system have been studied at energies above the Coulomb barrier and to our knowledge are presented for the first time. The measured EFs are compared with the theoretical estimations obtained from the statistical model code. To comprehend the ICF dynamics in a decisive way, the ICF fraction has been deduced and explored its reliance on various entrance channel parameters. It may be concluded that ICF probability is greatly influenced by various parameters of entrance channel and not only a single parameter is able to explain the systematic of ICF dynamics in a decisive way.

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New measurements of 63Cu(α,γ)67Ga reaction compared with improved calculations

Authors: Maria Peoviti[1]; Michail Axiotis[2]; Nikolaos Patronis[3]; Paraskevi Dimitriou[4]; Varvara Foteinou[5]; Sotirios V. Harissopulos[2]; Fotios Maragkos[6]; Detlef Rogalla[5]

[1] *Tandem Accelerator Laboratory, Institute of Nuclear Physics, NCSR "Demokritos" and Department of Physics, University of Ioannina*

[2] *Tandem Accelerator Laboratory, Institute of Nuclear Physics, NCSR "Demokritos"*

[3] *Department of Physics, University of Ioannina*

[4] *Nuclear Data Section, International Atomic Energy Agency*

[5] *Central Unit for Ion Beams and Radionuclides, Ruhr-University Bochum*

[6] *Central Unit for Ion Beams and Radionuclides, Ruhr-University Bochum and Department of Physics, National Technical University of Athens*

Corresponding Author: marpeoviti@gmail.com

One of the challenges of nuclear astrophysics is understanding the observed abundances of the p-process nuclei. Nucleosynthesis simulations typically employ an extended reaction network involving tens of thousands of reactions and thousands of isotopes. As it is impossible to directly measure such a vast number of reactions, simulations rely heavily on calculated cross-sections derived from the Hauser-Feshbach (HF) theory. To improve the predictive power of the HF theory, it is important to develop global models for the ingredients of the theory, validated against experimental data 1.

In this paper, we report on a new measurement of the ^{63}Cu(α,γ)^{67}Ga reaction cross-section, at energies relevant to the p-process nucleosynthesis. The purpose of the measurement was to further constrain the global α-nucleus Optical Model Potential (αOMP). HF calculations were performed with the TALYS code (version 1.96) 2 for both ^{63}Cu(α,γ)^{67}Ga and ^{65}Cu(α,γ)^{69}Ga reactions 3 probing the sensitivity to all the important ingredients of the calculations including the Optical Model Potentials (OMP), Nuclear Level Densities (NLD), and γ-ray Strength Functions (γSF). New optimized parameters are proposed for the global semi-microscopic αOMP for both Cu isotopes. The results are preliminary.

References
1 Sotirios V. Harissopulos, Eur. Phys. J. Plus 133, 332 (2018)
2 Koning, A., Hilaire, S. & Goriely, S. TALYS: modeling of nuclear reactions. Eur. Phys. J. A 59, 131 (2023). https://doi.org/10.1140/epja/s10050-023-01034-3
3 Sotirios V. Harissopulos, EPJ Web of Conferences 227, 0 (2020), https://doi.org/10.1051/epjconf/202022701008

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A Total Monte Carlo study in the modelling of nuclear de-excitation

Author: ali Al-Adili[1]

Co-authors: P. Karlsson ; Z. Gao ; A. Göök ; S. Pomp ; H. Sjöstrand ; A. Solders ; Arjan KONING [2]

[1] *Department of Physics and Astronomy, Uppsala University*

[2] *IAEA*

Corresponding Author: ali.al-adili@physics.uu.se

In this study, we utilized the Total Monte Carlo (TMC) methodology to simulate the de-excitation process of primary fission fragments in GEF and TALYS. Our primary goal was to establish a framework for evaluating model deficiencies and parameter sensitivities in fission models. As a proof-of-principle we systematically varied the input fission fragment data in TALYS using the GEF code, generating 10,000 random files by altering the 94 model parameters that influence fission yields and excitation energy distributions. This parameter variation, amounting to a 3% change, resulted in significant deviations across various aspects of fission evaporation data, encompassing the multiplicities of γ rays, prompt neutrons, and their corresponding spectra. Furthermore, our study shed light into the impact of angular momentum population on the de-excitation data derived from both GEF and TALYS. Finally, we attempt to optimise the parameter files by benchmarking against evaluated nuclear data files, aiming to establish a parameterisation scheme for enhanced accuracy in future simulations.

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Optical model potential parameter optimization for nucleon-40Ca induced reactions: Implications on γ-ray production cross sections for residual Argon nuclei.

Author: Walid Yahia Cherif[1]

Co-authors: Smail Damache [1]; Saad Ouichaoui [2]; Jürgen Kiener [3]; Elena A. Lawrie [4]; Jacobus J. Lawrie [5]; Vincent Tatischeff [3]; Amel Belhout [2]; Djamel Moussa [2]; Paul Papka [6]; Hinda Benhabiles-Mezhoud [7]; Daphney T. Bucher [6]; Azzedine Chafa [2]; Mohammed Debabi [2]; Isabelle Deloncle [3]; J. L. Easton [5]; Clarisse Hamadache [3]; Faïrouz Hammache [8]; Pete Jones [4]; Vincent B. Kheswa [6]; Nontobeko Angel Khumalo [5]; T. Lamula [5]; Siyabonga N. T. Majola [4]; J. Ndayishimye [4]; Dinesh Negi [9]; Sive P. Noncolela [4]; Nicolas De Séréville [8]; John Francis Sharpey-Schafer [5]; Obed Shirinda [4]; Mathis Wiedeking [4]; S. Wyngaardt [6]; Souhila Ouziane [10]

[1] *CRNA*

[2] *University of Sciences and Technology Houari Boumediene (USTHB), Laboratory of Nuclear Sciences and Radiation-Matter Interactions (SNIRM-DGRSDT)*

[3] *Centre de Sciences Nucléaires et de Sciences de la Matière (CSNSM)*

[4] *iThemba LABS*

[5] *Department of Physics, University of the Western Cape*

[6] *Department of Physics, Stellenbosch University*

[7] *Université M'Hamed Bougara, Institut de Génie Electrique et Electronique*

[8] *Institut de Physique Nucléaire (IPN)*

[9] *Department of Nuclear and Atomic Physics, Tata Institute of Fundamental Research*

[10] *University of Sciences and Technology Houari Boumediene (USTHB)*

Corresponding Author: w.yahiacherif@crna.dz

We have optimized the optical model potential (OMP) parameters for nucleons (protons and neutrons) induced reaction on 40Ca using the OPTMAN code 1 available on the RIPL-3 data library 2. The potentials, geometrical and nuclear deformation parameters were extracted via fitting angular distribution data for protons/neutrons elastic and inelastic scattering (Ep,n = 0 –200 MeV) taken from the EXFOR data library 3. Our results demonstrate imporvement in the prediction of the angular distribution cross sections compared to the Koning-Delaroche OMP 4. We have, then, calculated the γ-ray production cross sections of the most intense transitions emitted by 38Ar (Eγ = 2167,47 keV) and 36Ar (Eγ = 1970,38 keV) residual nuclei produced in 40Ca(p,xγ)(38,36)Ar, using both our OMP parameters and TALYS build-in OMP parameters. The results of the calculations were compared with preliminary cross section data extracted in the analysis of 40Ca(p,xγ2168 keV)38Ar, and 40Ca(p,xγ1970 keV)36Ar for incident proton energies ranging from 30 –125 MeV. Theses data were obtained in the analysis of p+40Ca γ-ray spectra recorded in experimental compaigns [5, 6] performed on the AFRODTE array of iThemba LABS (Cape-Town, South Africa) using eight Compton-suppressed HPGe clover detectors. The results and implications are discussed.

References

1 E. S. Soukhovitski, S. Chiba, R. Capote, J. M. Quesada, S. Kunieda, and G. B. Morogovskij, OPTMAN code v1.
2 RIPL-3, https://www-nds.iaea.org/RIPL-3/
3 Experimental Nuclear Reaction Data (EXFOR), https://www-nds.iaea.org/exfor/exfor.htm
4 A. J. Koning, S. Hilaire, and M. C. Duijvestijn. Talys-1.9 Nuclear Reaction code.
5 W. Yahia-Cherif, S. Ouichaoui, J. Kiener, et al., Phys. Rev. C, 102, 025802 (2020).
6 Y. Rahma, S. Ouichaoui, J. Kiener, et al., Nucl. Phys. A, 132, 122622 (2023).

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Open issues on scattering kernels of compound nuclear reactions

Authors: Ron Dagan[1]; Yaron Danon[2]; A. Konobeev[1]

[1] *KIT-Karlsruhe Institute of Technology*

[2] *Rensselaer Polytechnic Institute*

Corresponding Author: ron.dagan@kit.edu

Scattering kernels are more complicated to evaluate than absorption processes due to the fact that scattering procedures involve not only the internal structure of the target nuclei but also the free "classical"particle interacting and emitted from the target. Strictly speaking, the interaction within the nucleus is based on quantum mechanical considerations whereas the emitted particle (neutron) is being treated in a classical manner obeying the classical momentum and energy conservation laws. The scattering kernel procedure that was recently adopted by a lot of Monte Carlo codes, uses the DBRC method which was validated experimentally by dedicated measurements done in RPI.
The theory behind the numerical treatment of DBRC method is based on Doppler broadening of the resonances for scattering kernels which is an extension of the Broadening of the cross section themselves. However, the DBRC approach includes a double differential treatment of the angular and energy distribution as independent variables. The azimuth angle is a dependent variable of the polar angle. This model, which was validated for S-wave resonances is not consistent the Optical Model (OM) and the Blatt Biedenharn (BB) scattering kernels, both based upon the angular momentum numbers and spin. In those latter treatments the scattered energy is a function of the angular polar angle, taken mostly at 0° K, while the azimuth angle is being a free parameter taken to be isotropic. Main cause for those differences is the explicit appearance of the temperature and hence a Doppler Broadening approach, which does not exist in the OM nor in the BB formalism.
In the higher resonance range above 9 KeV and in particular for p wave resonances the BB approach adopts the spin obtained by measurement of integral scattering cross sections. Further, at energies where a resonance structure is not clearly resolved one usually uses optical model potential theory. However, based of development in one can extract from the OM (via S- Matrix) the needed parameters for the BB angular distribution treatment.
Further, in the low thermal energy range the impact of the chemical binding replaces usually replaces the free gas model, albeit neglecting the fact that the integral temperature dependent cross section is mostly being broadened with a free gas approach. Consequently, in several codes like MCNP the scattering cross section itself depends on which model is used in the input, new scattering table -(S(a,b))- or free gas model.
This work deals with comparison of different approaches of scattering kernels experimentally and numerically. In particular the validity range of different scattering models are discussed, as well as the planned measurements in RPI for the angular distribution in the resolved energy range and above. In parallel, the impact of the temperature and the doppler effect, discussed above, is being investigated in dedicated experiments in the GALINA facility in Geel.

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What can we say about the dipole photon strength in ^{57}Fe compound from the $(n_{\rm th},\gamma)$ data?

Authors: Ivo Tomandl[1]; Jiri Kopecky[2]; Milan Krtička[3]; Stanislav Valenta[3]

[1] *Nuclear Physics Institute, Czech Academy of Sciences, \v{R}e\v{z}, Czech Republic*

[2] *JUKO Research*

[3] *Charles University, Prague*

Corresponding Author: stanislav.valenta@matfyz.cuni.cz

Decay properties of nuclear states in the domain of high nuclear level density (NLD) are usually described within the statistical model of the nucleus using the NLD and photon strength functions (PSFs). In some nuclei with mass $A \sim 30 - 100$, the NLD might still be insufficiently low even near the neutron separation energy S_n. Despite this, the statistical model is used to describe the decay of these nuclei.

In the mentioned mass range, information on PSFs for γ-ray energies well below S_n comes mainly from charged-particle-induced reactions, analyzed using the Oslo method \1. Data analyzed with this method show that the PSFs should significantly decrease with E_γ for E_γ $lesssim 3$ MeV. This feature is known as a low-energy enhancement (LEE) and was, for the first time, reported in Fe nuclei \2. This result was supported by two-step γ cascade data following thermal neutron capture measured at Budapest \2. However, these data can easily be contaminated by soft bremsstrahlung induced by extremely intense primary transitions \3 that may mimic the effect of LEE.

In practice, the LEE has been reported only from a limited number of techniques other than the Oslo method. Any independent experimental confirmation of LEE is thus desired, especially as data from radiative thermal neutron capture in Mo isotopes – where the LEE was also reported from Oslo data – seem inconsistent with any strong enhancement \[4-6].

An almost complete decay scheme of ^{57}Fe was recently published from radiative capture of thermal neutrons on ^{56}Fe \7. In this contribution, we present tests of the compatibility of these experimental data with several PSFs and NLD models. The main limitations of analysis come from expected fluctuations of individual transition intensities – believed to follow the Porter-Thomas distribution (PTD) around an E_γ-dependent expectation value \8. The PTD predicts many transitions with low intensities, which may escape detection, and a threshold for observation of transitions thus has to be considered in any analysis within the statistical model. Several different observables from $^{56}\mathrm{Fe}(n,\gamma)$ reaction can be checked against predictions from simulations.
Particular interest is paid to primary transitions that are relevant for the radiative cross section.

In addition, a new detailed analysis of two-step γ cascade spectra from $^{56}\mathrm{Fe}(n,\gamma\gamma)$, re-measured at Nuclear Physics Institute at Řež, has also been made. A comparison of the results from this experiment will be presented, too.

\1[A. Schiller *et al.*, Nucl. Instr. Methods A **447**, 498 (2000).]1
\2[A. Voinov *et al.*, Phys. Rev. Lett. **93**, 142504 (2004).]2
\3[F. Bečvář *et al.*, Nucl. Instr. Methods B **261**, 930 (2007).]3
\4[M. Krtička *et al.*, Phys. Rev. C **77**, 054319 (2008).]4
\5[S. A. Sheets *et al.*, Phys. Rev. C **79**, 024301 (2009).]5
\6[C. L. Walker *et al.*, Phys. Rev. C **92**, 014324 (2015).]6
\7[R. B. Firestone *et al.*, Phys. Rev. C **95**, 014328 (2017).]7
\8[C. E. Porter, R. G. Thomas, Phys. Rev. **104**, 483 (1956).]8

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The study of shape evolution in Mo isotopes with photon strength function

Author: Yuan Tian[None]

Corresponding Author: tiany@ciae.ac.cn

The charge radii in neutron-rich isotopes of Mo, Sr, and Zr have been experimentally shown to suddenly increase at N=58-60 due to a prolate-to-oblate transition, indicating a significant shape evolution. The giant resonance structure has been observed in photonuclear reaction experiments and in measuring the photo-absorption cross sections. For spherical nuclei, a single Lorentzian curve is sufficient to fit the experimental photon absorption cross section. However, for deformed nuclei, the cross-section curve splits into two components due to the breaking of rotational symmetry. These components correspond to the frequencies of oscillation along the long and short axes, respectively. In this paper, the evolution of the shape of Mo isotopes is studied by the use of photon power functions.

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Study of 209Bi(g,xn) photonuclear reactions

Authors: Nikola Jovancevic[1]; Rade Smolovic[2]

[1] *University of Novi Sad*

[2] *Faculty of Natural Sciences, University of Novi Sad*

Corresponding Author: radesmolovic9@gmail.com

Authors: Miodrag Krmar 1, Rade Smolović 1 , Nikola Jovančević 1
1 Faculty of Science, University of Novi Sad, Novi Sad, Serbia

The cross section values for the 209Bi(γ,xn) nuclear reactions are calculated using the different models for the level density and the radiation strength function by the TALYS code 1. Based on the obtained data, the yields of nuclear reactions are determined. The results of this theoretical calculation are compared with experimental data in the range up to 60 MeV.

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Statistical gamma decay and pygmy resonance in ^{204}Tl measured at DANCE

Author: Ingrid Knapova[1]

Co-authors: Aaron J. Couture [1]; Milan Krtička [2]; John L. Ullmann [1]; Stanislav Valenta [3]

[1] *Los Alamos National Laboratory*

[2] *Charles University, Prague*

[3] *Charles University*

Corresponding Author: iknapova@lanl.gov

Electromagnetic response of the nucleus is characterized by level density and photon strength functions –two key ingredients for modeling statistical gamma decay. Knowledge of these quantities is crucial for our understanding of neutron capture reactions occurring in stars, responsible for nucleosynthesis of heavy elements. The so-called pygmy resonance in photon strength function has emerged as a critical component for description of neutron-rich nuclei, interpreted as a neutron-skin oscillation outside the nuclear core. Yet, there still remain questions about its nature and systematic properties \1. One of the regions where pygmy resonance has been observed are nuclei with mass number $A \approx 200$, such as gold or thallium \2.

Detector for Advanced Neutron Capture Experiments (DANCE) \3, located at the Los Alamos Neutron Science Center \4, has been used to measure neutron capture cross sections for a broad range of nuclei, reaching from nickel \5 to actinides \[6,7]. Due to its high efficiency and high granularity, DANCE is an ideal instrument to detect complete gamma cascades, which presents unique capability to study level density and photon strength functions.

This work is focused on studying statistical gamma decay in ^{204}Tl –an isotope of particular interest in nuclear astrophysics, as ^{204}Tl is a branching point in the *s*-process reaction chain. The experimental coincident gamma-ray spectra were compared with their simulated counterparts using Monte-Carlo tool DICEBOX \8. This allowed us to test different models of level density and photon strength functions, with an emphasis on studying properties of the pygmy resonance. Our findings can help to accurately model neutron capture cross sections using Hauser-Feshbach theory, as the pygmy resonance is usually not reflected in the widely used photon strength functions models.

\1[E.G. Lanza *et al.*, J. Phys.: Conf. Ser. **2586**, 012084 (2023)]1

\2[E. D. Earl *et al.*, Can. J. Phys. **52**, 989 (1974)]2

\3[M. Heil *et al.*, Nucl. Instrum. Methods A **459**, 229 (2001)]3

\4[S. F. Nowicki *et al.*, Physics Procedia **90**, 374 (2017)]4

\5[A. M. Alpizar-Vicente *et al.*, Phys. Rev. C **77**, 015806 (2008)]5

\6[M. Jandel *et al.*, Phys. Rev. C **78**, 034609 (2008)}]6

\7[J. L. Ullmann *et al.*, Phys. Rev. C **89**, 034603 (2014)]7

\8[F. Bečvář, Nucl. Instr. Methods A **417**, 434 (1998)]8

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Cross Section Calculations of (n, p) reaction on 175Lu for the production of medically important radioisotope 175Yb

Author: Muhammad Nadeem[1]

Co-authors: Muhammad Atta [1]; Syed Hameed Qaiser [1]; Tayyab Mahmood MAlik [1]; Muhammad Sajjaad [1]

[1] *Pakistan institute of Nuclear Science and Technology*

Corresponding Author: dearmnadeem@hotmail.com

Among the prospective nuclear reactor-produced radionuclides, ytterbium-175 (175Yb) is found to be suitable for the preparation of therapeutic radiopharmaceuticals due to its decay characteristics (T1/2 (4.18d), Emax (480 keV)). It is an important metal that belongs to the rare earth metal family. However, a major constraint for its production via the (n, γ) reaction is the presence of lutetium-177 (177Lu) impurity alongside the 175Yb, which is co-produced upon irradiation of a natural ytterbium (Yb) target 1. In this study, the reaction cross-section via the (n, p) reaction is calculated using lutetium-175 (175Lu) as the target material. We have considered neutron energies ranging from the threshold value to energies where the compound nuclear reaction mechanism has a significant contribution. This energy range corresponds to the maximum yield of 175Yb production. For the production of 175Yb, the Q-value for the neutron-induced reaction is 312 keV and, its half-life makes it feasible for easy transportation to remote locations from production sites to nuclear medicine sites. Among the two natural lutetium (Lu) isotopes, 175Lu has the highest abundance (97.40%). The produced 175Yb is then converted back to the parent stable nuclei 175Lu through beta decay (100%), leaving no co-produced impurities behind during the production of 175Yb. Therefore, it is feasible to prepare a radiotherapeutic agent with easily recoverable 175Yb via the studied reaction, and waste generation is also minimized. In the study, deterministic codes EMPIRE 2 and TALYS 3 were utilized with their default input parameters as well as with optimized input parameters. Experimental data [4-6] were taken for comparison from the EXFOR library 7. Using both codes, calculations were performed based on the Hauser Feshbach statistical model, including width fluctuation corrections (WFC) with different expressions for the compound nuclear reaction mechanism. This study aims to enhance the nuclear data bank and its quality for further development to meet the increasing demand for medically important radionuclides 8. For comparison, major evaluated nuclear data libraries, ENDF, JEFF, and TENDL, were also consulted. The calculated results, available experimental data, and evaluated results were found to be comparable with some discrepancies.

1 R. Chakravarty, et al., Radiochimica Acta. 4, 100 (2012)
2 M. Herman, et al., EMPIRE-3.2 Malta Modular system for nuclear reaction calculations. Tech. Rep. INDC (NDS)-0642, BNL
3 A.J. Koning, D. Rochman, Modern nuclear data evaluation with the TALYS code system. Nucl. Data Sheets
4 Z. Zhang, et al., Measurement of cross-sections for 14 MeV neutron interaction with 175Lu. Applied Radiation and Isotopes. 1, 132 (2018)
5 J. Luo, et al. Measurements of activation cross sections for 175Lu (n, x) reactions induced by neutrons around 14 MeV. Annals of Nuclear Energy. 8,38 (2011)
6 N. Dzysiuk, et al. Cross sections for fast-neutron interaction with Lu, Tb, and Ta isotopes. Physical Review C. 1,81 (2010)
7 Experimental Nuclear Reaction Data (EXFOR), https://www-nds.iaea.org/exfor/

8 M. Qaim, Development of novel radionuclides for medical applications. Journal of labelled compounds and radiopharmaceuticals. 3, 61 (2018)

Poster Session / 12

Reaction parameter study of the 51V beam onto deformed targets: 51V+159Tb reaction

Author: Pierre Brionnet[1]

Co-authors: Daiya Kaji [1]; Hideyuki Sakai [1]; Hiromitsu Haba [1]; Kouji Morimoto [1]; Satoshi Sakaguchi [2]; Sota Kimura [3]; Toshitaka Niwase [2]

[1] *RIKEN NISHINA Center*

[2] *Department of Physics, Kyushu University*

[3] *KEK wnsc*

Corresponding Author: pierre.brionnet@riken.jp

With the syntheses of elements up to oganesson (Z = 118), all the fusion evaporation reactions using the 48Ca beams on deformed actinide targets have already been performed. Due to the lack of target material beyond the californium, the use of 50Ti, 51V, and 54Cr is now becoming mandatory to access elements beyond the oganesson (Z = 118). In the SHE mass region, these beams have only been used in reaction on spherical Pb and Bi targets to produce neutron deficient Sg, Db, and Rf isotopes. In addition, the cross-section predictions for SHE elements past Oganesson are currently extrapolated from the reaction performed with 48Ca beams, resulting in a wide range of predictions depending on the model used.

Thus, in addition to reaction parameter measurements [1,2], the precise systematic measurements of excitation functions of lighter systems based on deformed targets around lanthanide nuclei provide a suitable training dataset for training and improving the predictive power of existing models. These lighter systems are good substitutes for the deformed actinide targets used in the current search for new elements above Oganesson. They have similar deformation parameters, but at a much higher production rate (μb range). In addition, the simultaneous measurement of the barrier distribution and the excitation function allows for the direct correlation between the barrier distribution and the maximum cross-section of production. This correlation is an important part of the discussion in the selection of the optimal beam energy for the synthesis of superheavy elements [1,2].

The search for the new element Z = 119 is currently underway at RIKEN using the reaction 248Cm(51V,xn)299-x119 on the GARIS-III experimental setup 3. The goal of this work is thus to extend the systematic study of reaction parameters with deformed targets using the 51V beam to see if the behavior observed in [1,2] can be reproduced with lighter surrogate systems. In this work, the effects of the beam energy and nuclear deformation in the reaction 159Tb(51V,xn)210-xRa have been studied by measuring both the barrier distribution and the detailed excitation functions. The goal is to extend the systematic study of the quasielastic (QE) barrier distribution with 51V and to compare it with the results obtained in [2,3] as well as theoretical prediction using the Couple Channel Calculation (CCFULL 4). In addition, the production of the full and detailed excitation function for the xn, pxn and αxn, also allowed us to study the correlation between the barrier distribution and the maximum cross-section of production and compare it with prediction made using the Fusion-By-Diffusion model 5. The experimental setup, analysis and preliminary results of both studies will be presented in this presentation.

1 M. Tanaka et al., J. Phy. Soc. Jpn, 91, 084201 (2022).
2 T. Tanaka et al., Phys. Rev. Lett. 124, 052502 (2020).
3 H. Sakai, H et al., Eur. Phys. J. A 58, 238 (2022).
4 K. Hagino et al., Comput. Phys. Commun. 123, 143 (1999).
5 T. Cap, M. Kowal, K. Siwek-Wilczy´nska, Eur. Phys. J. A (2022) 8:5231

Poster Session / 42

Development of R-matrix formulations for three-body systems

Authors: Felix Willibald Wuehrleitner[None]; Helmut Leeb[None]; Thomas Srdinko[None]; Tobias Wojta[None]

Corresponding Author: e11741272@student.tuwien.ac.at

The R-matrix formalism provides an elegant tool for the description of resonant reaction cross sections. Albeit not microscopically based it is widely used because it satisfies conservation rules and yields consistent sets of reaction cross sections. However, R-Matrix theory is limited to two-body channels, while approximations are frequently required for the description of capture and breakup channels. In this presentation we revisit the status of developments of R-matrix formalisms suited for three-body channels. Especially, we consider the extension of the Glöckle formalism based on general R-matrices. The key of the improved method is the introduction of a generalized Bloch operator, suggested by Baye, which restores hermiticity of the Hamiltonian in the inner region. In addition we propose the R-matrix Faddeev method which promises a straightforward combination with standard R-matrix analyses. First applications of both methods will be presented.

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A Microscopic Compound Nucleus in the Time-dependent Mean-field Theory

Author: Paul Stevenson[1]

[1] *University of Surrey*

Corresponding Author: p.stevenson@surrey.ac.uk

Modern time-dependent density functional theory (TDDFT) codes (see e.g. Comput. Phys. Commun. 229, 211 (2018)) can be used to describe the excited states of nuclei via a number of reaction mechanisms: Through external multipole field excitation, Coulomb scattering, as fission fragments, in heavy ion collisions from around the Coulomb barrier up to deep-inelastic regimes, and via mechanisms such as quasi-fusion and multi-nucleon transfer.

The physics input to the method is a microscopic (at the level of individual nucleons) effective interaction, along with the approximation that the dynamics are driven by a time-varying mean potential.

In this work we present an overview of the theory, highlighting how quantities such as gamma strength functions can be extracted through Fourier analysis, and discuss the successes and limitation of the method as a description of the compound nucleus.

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Study of fission dynamics at low excitation energies with the Langevin approach

Author: Lile Liu[None]

Co-authors: Caiwan Shen ; Krzysztof Pomorski ; Nengchuan Shu ; Xizhen Wu ; Yongjing Chen ; Zhigang Ge ; Zhuxia Li

The three-dimensional Langevin model is used to study the fission dynamics for uranium and plutonium isotopes at low excitation energies. Within the macroscopic-microscopic model, the potential

energy surface is obtained by two methods which are that based on the two-center shell model and the finite range liquid drop model, and that based on the Fourier shape parametrization, the LSD model and the Yukawa-folded potential. The Werner-Wheeler approximation is used to calculate the inertia tensor and the wall-and-window model is applied to calculate the friction tensor. With the Langevin approach based on the two-center shell model, the influences of the nuclear dissipation and the neck parameter on the fission dynamics are studied, and then the mass distributions and the TKE distributions of the fission fragments for major actinide nuclei fission induced by neutron are calculated and the overall mass distributions are in agreement with the evaluated data from ENDF/B-VIII.0, which shows the predictive power of the model in the fission fragment mass distributions. In addition, the Langevin approach is extendedly applied to study the dynamical process of nuclear fission within the Fourier shape parametrization. The mass distributions and the TKE distributions in 14 MeV n + 233,235,236,238U and 239Pu fission are well described. Furthermore, the behavior of the correlation of the distance between the centers of mass of two fragments with the heavy fragment mass at the scission point is found to be consistent with that of the TKE distribution where the shortest R12 locates around Ah = 135 due to the influence of the shell effects.

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SHE facility at RIKEN, construction, commissioning and present status

Author: Hideyuki SAKAI[1]

[1] *RIKEN Nishina Center*

Corresponding Author: hidesakai@riken.jp

To synthesize a new superheavy element, Z=119, the RIKEN Nishina Center (RNC) upgraded the existing heavy ion linac system (called RILAC) by partially replacing the superconducting linear accelerator (SRILAC) to increase the final beam energy from 5.5 MeV/u to 6.5 MeV/u, enabling a hot fusion reaction of 51V+248Cm. The new Superconducting Electron Cyclotron Resonance Ion Source (SC-ECRIS), operating at a higher RF frequency to increase beam currents, was constructed. The new gas-filled recoil ion separator GARIS-III, suitable for hot fusion reaction residues, was also built. This upgrade project, the "SHE Project", was completed in 2020. The project and its commissioning are described in detail in ref. 1.

After the commissioning of SRILAC, the first step was to measure the Coulomb barrier distribution for the 51V+248Cm system to select the optimal bombard energy of the 51V beam. The Coulomb barrier distribution was obtained using the quasi-elastic (EQ) backscatter cross sections at θ = 180◦ with GARIS-III, which provided the mean Coulomb barrier height B0. The resulting B0 value is 225.6 ± 0.2 MeV for the 51V+248Cm system 2.

The measurement of the synthesis of Z=119 was then started and is still ongoing.

This poster gives an overview of the SHE project and describes the current status of the facility operation and the problems encountered during the measurements.

1 H. Sakai et al., Eur. Phys. J. A 58, 238 (2022).
2 M. Tanaka et al., J. Phy. Soc. Jpn, 91, 084201 (2022).

Poster Session / 43

FAST NEUTRON FISSION OF 236Pu NUCLEUS

Author: Cristiana Oprea[1]

[1] *ANCS Romania, National Department of Education Bihor*

Corresponding Author: coprea2007@yahoo.co.uk

Plutonium isotopes are produced in nuclear reactors by neutron-induced fission of 235,238U nuclei and by (n,2n), (gamma,n) processes of Neptunium isotopes. Among the Plutonium isotopes, 236Pu nucleus is a trace element of interest for studies of the environmental impact of fuel cycles. Development of new type of fast neutron nuclear reactions destined for scientific researches based on 237Np fuel, implies the analysis of the influence of different fission products such as 236Pu.
Fission variables of fast neutron-induced of 236Pu nucleus like cross-sections, fission fragment mass and charge distributions, emitted neutron spectra, isotope production of interest for applications in medicine, electronics and nuclear technology was investigated. The contribution of different reaction mechanisms to fission and production of 236Pu were examined. In the incident and emergent fission channels level density and Wood-Saxon potential parameters were extracted.
Experimental data from the literature were compared with theoretical evaluations of fission observables. It is necessary to note that in the case of fast neutron-induced fission of 236Pu nucleus there are very few experimental data regarding fission observables and therefore their evaluation is of great importance for both fundamental and applicative researches.

References
1 G. Audi, O. Bersillon, J. Blanchot, A. H. Wapstra, Nucl. Phys. A, v. 729, issue 1, p. 3-128 (2003)
2 F.G. Kondeev, M. Wang, W.J. Huang, S. Naimi, G. Audi, Chinese Physics C, v. 45, No. 3 030001 (2021)
3 H. Yamana, T. Yamamoto, K. Kobayashi, T. Mitsugashira, H. Moriyama, Journal of Nuclear Science and Technology, v. 38, No. 10, p. 859-865 (2001)
4 C. Oprea, M. Ayaz Ahmad, I. A. Oprea, J. Hassan Baker, N. Amrani, International Journal of Scientific and Engineering Research, vol. 1, p. 83-92 (2020)
5 E. P. Shabalin, V. L. Aksenov, G. G. Komyshev. A. D. Rogov, Preprint JINR Dubna, P-13-2017, p. 1-18 (2017)

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Evaluation of Transmission Coefficients in Nuclear Processes

Authors: Cristiana Oprea[1]; Ioan Oprea[1]

[1] *ANCS Romania, National Department of Education Bihor*

Corresponding Author: coprea2007@yahoo.co.uk

Transmission coefficients describe the probability that a micro-particle will pass through a potential barrier. Using a quantum mechanical approach, the reflection factor is used to calculate the transmission coefficients for charged and neutral particles. Logarithmic derivative is calculated using a rectangular potential in the internal region. With a computer code developed by the authors, and based on Hauser-Feshbach formalism, cross-sections of fast neutron-induced reactions followed by the emission of charged particles are evaluated. When discrete states of residual nuclei are considered, the realized codes agree with experimental data. The present quantum approach can be extended to continuum states of residual nuclei using the integral form of penetrability coefficients, including nuclear density states described by nuclear Fermi-gas model.

References
1. A. Foderaro, The Neutron Interaction Theory, The MIT Press, Cambridge, Massachusetts and London, England (1971)

2. David. J. Griffiths, Introduction in Quantum Mechanics (Second Edition), Cambridge University Press, New York (2016)
3. G.A. Gamow, Z. Phys. 51, 204 (1928)
4. E.U. Condon, R.W. Guerney, Nature, 122, 439 (1928)
5. 5 V. Hauser, W. Feshbach, Phys. Rev., 87, 2, 366 (1952)
6. P. A. Moldauer, Rev. Mod. Phys., 36, 1079 (1964)
7. C. Oprea, A, Mihul, A.I. Oprea, CERN-Proceedings-2019-001, 125 (2019)

Poster Session / 70

Study of the ^{169}Tm(n,γ) reaction using DANCE facility at LANSCE

Authors: Aaron J. Couture[1]; C. J. Prokop[1]; Frank Gunsing[2]; G. Rusev[1]; Ingrid Knapova[1]; J. M. O'Donnell[1]; John L. Ullmann[1]; K. J. Kelly[1]; Kamila Špringlová[3]; Milan Krtička[3]; R. Reifarth[1]; Stanislav Valenta[3]

[1] *Los Alamos National Laboratory*

[2] *CEA Irfu, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France*

[3] *Charles University, Prague*

Corresponding Author: kamcaspringlova@gmail.com

The reason for studying the neutron capture reaction on the mono-isotopic element thulium is twofold. Its only stable isotope, ^{169}Tm, is often used as a neutron-flux activation monitor. The neutron capture cross-section in the relevant energy range has been measured several times \[1-4] in the past and more recently at CSNS \5. While these data show rough agreement, there are significant differences. Moreover, the uncertainties are often not quoted. These two motivate a state-of-the-art measurement and analysis of the neutron capture cross-section in the keV energy range.

The neutron capture cross-section can also be calculated via the Hauser-Feshbach approach \6, for which the key ingredients are the photon-strength-functions (PSFs) and nuclear level density (NLD). These quantities can be inferred from the γ-ray spectra of *s*-wave resonances by comparing them to the simulated spectra.

The neutron-capture reactions on the ^{169}Tm nuclei have been measured with the DANCE calorimeter \[7,8] at LANSCE \9. The background-corrected sum-energy and multi-step-cascade spectra were extracted for a number of strong isolated *s*-wave resonances. These experimental coincident γ-ray spectra are compared with their simulated counterparts using Monte-Carlo code DICEBOX \10 to obtain information about PSFs and NLD. In particular, we investigate the scissors-mode (SM) role in the *M1* PSF. Previously, SM parameters of well-deformed rare-earth nuclei were obtained by several experimental techniques, see e.g. Refs. \[11-13] and review \14. They show significant differences, especially in the strength of the mode. The shape of the low-energy tail of the giant electric-dipole resonance is uncertain too. Because of these inconsistencies, additional information on PSFs in this region is of great interest.

The neutron capture cross-section is deduced from the experimental data in the usual fashion, i.e. by subtracting backgrounds, determining the neutron flux using several flux monitors, and normalizing to the standard cross-section. The analysis steps, internal consistency of our data, preliminary results on PSFs, and neutron capture cross-sections will be presented.

\1[R. C. Block *et al.*, Conference proceedings, "Time of Flight Methods,"Saclay, 1961.]1
\2[J. Gibbons *et al.*, Phys. Rev. **122**, 182 (1961).]2
\3[R. L. Macklin *et al.*, Nucl. Sci. Eng. **82**, 143 (1982).]3
\4[Y.-J. Xia *et al.*, Chinese Nucl. Phys. **11**, 75 (1989).]4
\5[J. Ren *et al.*, Chin. Phys. C **46**, 044002 (2022).]5
\6[W. Hauser and H. Feshbach, Phys. Rev. **87**, 366 (1952).]6
\7[M. Heil *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **459**, 229 (2001).]7
\8[R. Reifarth *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **531**, 530 (2004).]8
\9[M. Mocko and G. Muhrer, Nucl. Instrum. Methods Phys. Res., Sect. A **704**, 27 (2013).]9
\10[F. Bečvář, Nucl. Instr. Methods A **417**, 434 (1998).]10

\11[U. Kneissl, H. H. Pitz, and A. Zilges, Prog. Part. Nucl. Phys. **37**, 349 (1996).]11
\12[I. Knapová *et al.*, Phys. Rev. C **107**, 044313 (2023).]12
\13[E. Melby *et al.*, Phys. Rev. C **63**, 044309 (2001).]13
\14[S. Goriely *et al.*, Eur. Phys. J. A **55**, 172 (2019).]14

Poster Session / 76

First results of the measurement of the Ta(n,γ) cross-section at n_TOF, CERN

Author: Victor Alcayne[1]

Co-authors: Adrian Sanchez Caballero [1]; Alberto Pérez de Rada Fiol [1]; Daniel Cano Ott [2]; Emilio Mendoza Cembranos [1]; Enrique González Romero [1]; Roberto Mario Capote Noy [3]; Trino Martinez Perez [1]; n_TOF Collaboration

[1] *CIEMAT*

[2] *CIEMAT - Centro de Investigaciones Energéticas, MedioAmbientales y Tecnológicas*

[3] *IAEA NAPC-NDS*

Corresponding Author: adrian.sanchez@ciemat.es

V. Alcayne1, D. Cano-Ott1, E. González-Romero1, T. Martínez1, E. Mendoza1, A. Pérez de Rada Fiol1, A. Sánchez-Caballero1, J. Balibrea-Correa2, F. Calviño3, R. Capote4, A. Casanovas3, C. Domingo-Pardo2, J. Lerendegui-Marco2 and the n_TOF collaboration.

1 Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Spain
2 Insituto de Física Corpuscular, CSIC - Universidad de Valencia, Spain
3 Universitat Politècnica de Catalunya, Spain
4 International Atomic Energy Agency, Vienna-A-1400, PO Box 100, Austria

victor.alcayne@ciemat.es

Metallic alloys or metals with high melting points such as tantalum are being considered for the development of nuclear reactors for space. In recent critical experiments using highly enriched uranium or plutonium fuels, moderators and tantalum, large discrepancies have been found between the predicted and measured keff (i.e. needed critical masses). These observed discrepancies have been attributed to larger than reported uncertainties in the nuclear data of the materials involved, mainly tantalum, plutonium and graphite. The Ta(n,γ) cross section has also been reported as an important contributor to the uncertainty in the activation and heating of magnets used in large fusion reactors. The different measurements of the Ta neutron capture cross sections used in the evaluations are discrepant and affected by important experimental corrections like the self-shielding or angular correlations between γ-rays.
For these reasons, a new measurement of Ta(n,γ) cross section in the energy range from 0.1 eV to 500 keV has been performed at the n_TOF facility. The use of C6D6 detectors at different angles and samples of different thicknesses have allowed us to overcome the limitations of the previous measurements. This abstract presents the experiment conducted at n_TOF. It outlines the methodology employed for measurements and highlights the recent advancements in data analysis. In particular, the compatibility of the measurements made with different samples and different detectors will be presented as well as the preliminary comparison with the previous measurements and the most recent evaluations.

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Possible evidences for Giant Quadrupole Resonances within neutron-induced alpha-particle emission

Author: Vlad Avrigeanu[1]

[1] *Horia Hulubei National Institute for Physics and Nuclear Engineering (IFIN-HH)*

Corresponding Author: vlad.avrigeanu@nipne.ro

The first measurement of 91Zr(n,a)88Sr reaction cross sections 1, performed in the 3.9–5.3 MeV incident–energy range, followed the need of reliable nuclear data for the isotopes of zirconium used in the blanked and first wall of fusion reactors while the related evaluated data changed by up to 6.4 times were found in widely used libraries. The alpha-particle optical model potential (OMP) was thought to be the reason behind this variance, other parameters of the corresponding statistical model (SM) and pre-equilibrium emission (PE) predictions having only a marginal influence at these incident energies. However, the TALYS default alpha-particle OMP 2 has recently been proved to describe well the neutron–induced alpha emission in the mass range A~90 including all Zr stable isotopes 3. Thus, a further discussion should concern the analysis of the new (n,a) reaction data, while several issues could be of interest also for the related nuclear processes understanding.
First, the alpha-nucleus OMP 2 was finally obtained by analysis of alpha-particle elastic scattering at energies ≤50 MeV, and induced reactions below and around the Coulomb barrier, on A~45–209 nuclei. More recently, also alpha-emission description by the same potential 2 has become possible by additional consideration of (i) the pickup direct reaction, and (ii) eventual isoscalar giant quadrupole resonance alpha-decay [3,4].
Second, the following key demands supported these results. (i) Consistent SM parameter sets were formerly validated by analysis of independent data, other than the concerned reaction cross sections. (ii) Hence, no further empirical rescaling factors of the gamma and nucleon widths were needed. (iii) Thus, compensation effects of less accurate model parameters were prevented. (iv) Due consideration was given to the correlation between the accuracy of the above–mentioned independent data, the input parameters determined by their fit, and the corresponding final uncertainties of the calculated reaction cross sections. (v) Suitable description of all competitive reaction channels was also concerned, for parameter sets validation. (vi) The analysis included the available data for whole isotopic chains as well as neighboring elements.
Third, there are singular conditions 1 supporting a significant reaction modeling challenge on far better terms than usual. The feeding, basically, of the only one final state reduces essentially the model parameters which could affect the results correctness. Moreover, following the suitable account of the other reaction channels of neutrons incident on 91Zr and the use of a consistent SM+PE parameter set already fixed [3,5], the alpha-particle OMP remains the only constraint on the calculated (n,alpha) reaction cross sections. Therefore, comparison of the new measured and calculated (n,alpha) cross sections is aimed to either check this OMP or reveal the weight of the non–statistical processes that have to be additionally considered.

1 G. Zhang et al., Phys. Rev. C **106**, 064602 (2022)
2 V. Avrigeanu et al., Phys. Rev. C **90**, 044612 (2014)
3 M. Avrigeanu et al., Phys. Rev. C **107**, 034613 (2023)
4 V. Avrigeanu et al., Eur. Phys. J. A **57**, 54 (2021); ibid. **58**, 189 (2022)
5 V. Avrigeanu et al., Phys. Rev. C **96**, 044610 (2017)

Poster Session / 68

Width Fluctuation Correction Factor for Beta-delayed Neutron Emission

Author: Oliver Gorton[1]

Co-author: Jutta Escher [2]

[1] *Lawrence Livremore National Laboratory*

[2] *Lawrence Livermore National Laboratory*

Corresponding Author: gorton3@llnl.gov

Porter-Thomas fluctuations of neutron widths are known to skew compound nuclear decay probabilities away from their statistical, Hauser-Feshbach values. For Hauser-Feshbach codes, the common remedy is to apply the width-fluctuation correction factor of Moldauer, or similar, which accounts for correlations between the entrance and exit channels. For more exotic reactions like beta-delayed neutron emission, the effect is subtler, arising due to statistical fluctuations of the total neutron widths rather than correlations between channels. Some authors have tackled the problem by Monte Carlo simulations, where individual levels and partial widths are simulated from the appropriate random distributions, with statistics chosen to reproduce the usual level density, photon strength function, and neutron transmission coefficients. The disadvantage of this is increased compute time. I demonstrate a simpler, alternative method for taking Porter-Thomas fluctuations into account for one-neutron decay near threshold using a method analogous to the width fluctuation correction factor of Moldauer.

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Measuring fission fragment mass distributions of 252-Cf with VERDI using a novel plasma delay correction procedure

Author: Ana Gomez L.[1]

Co-authors: Alf Göök [1]; Ali Al-Adili [1]; Andreas Oberstedt [2]; Andreas Solders [1]; Diego Tarrio [1]; Stephan Oberstedt [3]; Stephan Pomp [1]

[1] *Uppsala University*

[2] *Extreme Light Infrastructure - Nuclear Physics (ELI-NP), Horia Hulubei National Institute for Physics and Nuclear Engineering (IFIN-HH)*

[3] *European Commission, Joint Research Centre*

Corresponding Author: ana.gomez@physics.uu.se

The VElocity foR Direct particle Identification (VERDI) is a fission-fragment spectrometer based on the detection of velocities as well as energies of fission fragments (2E-2v method). It aims at determining fission yield mass distributions with a resolution of at least $A/\Delta A = 100$. VERDI includes two time-of-flight (TOF) sections, each equipped with a micro-channel plate (MCP) and up to 32 passivated implanted planar silicon (PIPS) detectors. One of the main challenges in achieving the desired mass resolution mentioned above, is the accurate determination of the fragment velocities with the PIPS detectors, which is affected by the so-called plasma delay time (PDT). The PDT distorts the PIPS signals, which alters the fission fragments'velocity spectra.

In the process of analyzing fission data taken with VERDI, the PDT needs to be modeled and applied, in order to determine correct fission fragment velocity distributions. However, previous models have fallen short in terms of producing reliable fission data that aligns with reference data. One reason could be that the PDT models proposed in the literature are detector-specific, and some of them present quite different functional dependencies with respect to the fission fragments' mass and kinetic energy.

To mitigate this problem, an experimental campaign was conducted at the LOHENGRIN recoil fission-fragment spectrometer, aimed at overcoming the PDT-related challenges faced by VERDI. This effort led to the development of a new PDT model, expressed as $PDT = 0.2A^{0.02}E^{0.5}$. The PDT model has been applied to the analysis of previous measurements taken with VERDI using ^{252}Cf. In this presentation, we will discuss the preliminary results of the mentioned data analysis.

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Measurement of charged particle spectra emitted following muon nuclear capture in Si nuclei

Author: Shoichiro Kawase[1]

Co-authors: Teppei Kawata [1]; Kentaro Kitafuji [1]; Yukinobu Watanabe [1]; Megumi Niikura [2]; Rurie Mizuno [3]; Katsuhiko Ishida [4]; Dai Tomono [5]; Adrian Hillier [6]; Futoshi Minato [1]

[1] *Kyushu University*

[2] *RIKEN*

[3] *University of Tokyo*

[4] *High Energy Accelerator Research Organization*

[5] *Osaka University*

[6] *ISIS Neutron and Muon Facility*

Corresponding Author: kawase@aees.kyushu-u.ac.jp

When a negative muon stops in matter, it is captured into an atomic orbit, and subsequently, it is captured by the atomic nucleus at a certain probability through the weak interaction 1. This process is known as muon nuclear capture (μNC). In this process, most of the muon's rest energy is carried away by a muon neutrino and the remainder is used to excite the residual nucleus. This excited nucleus may emit charged particles such as protons, deuterons, and alpha particles, in addition to gamma rays and neutrons. The low-energy spectra of these emissions reflect the evaporation process from the compound nucleus formed after μNC. Conversely, the spectral shape in the high-energy region is considered to reflect the details of the pre-equilibrium process.

The study of μNC in silicon, a primary material in semiconductor devices, is particularly relevant for understanding how cosmic-ray muons can induce soft errors, which are temporary malfunctions in semiconductor devices. Charged particles emitted following μNC can generate electron-hole pairs in semiconductors, potentially flipping the data stored in memory and causing what is known as a single event upset (SEU). The risk of cosmic-ray muon-induced soft errors is considered significant, especially with the ongoing trend of die shrinkage and reduced operation voltage2. Thus, measuring the energy spectra of charged particles is essential for evaluating the soft error rate for advanced semiconductor devices induced by cosmic-ray muons.

We conducted measurements of the energy spectra of light charged particles emitted after μNC at the RIKEN-RAL muon facility3. Negative muons were irradiated and stopped in thin silicon targets. The energy of emitted charged particles was measured using telescopes comprised of silicon detectors and CsI scintillators. Particle identification for low-energy particles that do not penetrate the Si detectors was performed using the pulse shape analysis method4, while for penetrating particles, the ΔE-E method was used.

This presentation will report on the details and results of the experiment. The obtained energy spectra will be compared with theoretical calculations.

1 D.F. Measday, Phys. Rep. 354, 243 (2001).
2 W. Liao et al., Proc. IEEE Int. Rel. Phys. Symp., 5A. (2019).
3 A.D. Hillier et al., Phil. Trans. R. Soc. A377, 20180064 (2018).
4 S. Kawase et al., Nucl. Instrum. Meth. Phys. Res. A 1059, 168984 (2024).

Poster Session / 87

A Platform for Measuring Neutron Capture Cross Sections in a Plasma Environment

Author: Brian Applebe[1]

[1] *Imperial College London*

The National Ignition Facility (NIF) laser at Lawrence Livermore National Laboratory is capable of producing a plasma environment with temperatures ~10 keV, particle densities ~10³² m⁻³, and neutron fluxes of up to 10³⁴ m⁻² s⁻¹. These features, combined with the advanced x-ray, neutron and radiochemistry diagnostics that are available at the NIF, make it uniquely suitable for carrying out experiments to investigate interactions between plasma physics and nuclear physics. A NIF Discovery Science experiment has recently been commissioned to measure the neutron capture cross section of Thulium-171 (¹⁷¹Tm) at a neutron energy of 2.45 MeV. This presentation will outline the main features and challenges of this experiment, predicted results, and future complementary experiments that could be carried out on the NIF.
The plasmas at the NIF are produced by using the laser to compress capsules (diameter ~1 mm) containing deuterium or deuterium-tritium fuel on timescales of ~1 ns, resulting in a neutron source of ~100 µm in diameter and duration ~100 ps. The commissioned experiment will include trace amounts of ¹⁷¹Tm and other monitor isotopes in a deuterium capsule designed to minimize the neutron scattering background in the plasma. Therefore, the ¹⁷¹Tm isotopes undergoing neutron capture will have a temperature of ~10 keV, and so a significant population of nuclear excited states of ¹⁷¹Tm will be created (first excited state is at 5.036 keV). Initial capture cross section calculations indicate that the ground state and excited state cross sections are similar. Thus the experiment will yield a combined cross section that shows little dependence on the excited-state population and will provide a baseline for future excited-state measurements where significant differences are expected. ¹⁷¹Tm and other reaction products will be recovered and counted after the experiment using NIFs radiochemistry diagnostics.
The NIF facility also includes diagnostics for accurately measuring the plasma temperature, density, size and duration. This information can be used for calculating the populations of nuclear excited states and for modelling processes, such as nuclear excitation by electron transfer and capture (NEET and NEEC), which can affect population rates. Future experiments will be designed to investigate these processes. This will support the development of a reliable platform on the NIF for measuring capture cross sections of excited state nuclei.

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A versatile R-matrix module including alternative parametrizations

Authors: Helmut Leeb[None]; Thomas Srdinko[None]

Corresponding Author: thomas.srdinko@tuwien.ac.at

The R-matrix formalism is well suited and worldwide used for the description of nuclear reactions in the resonance region. At present there exist several excellent R-matrix codes for extended analyses of nuclear reaction data (e.g. SAMMY, AZURE, AMUR, EDA, RAC et others). Recently the coupled-channel code system GECCCOS has been developed at TU Wien which includes a versatile R-matrix module. The latter serves as a platform for the test of new developments in the field.
In this contribution an overview and newly implemented features of this R-matrix module are presented. Major modifications concern the capability of R-matrix analyses with alternative parametriza-

tions. Especially, the implementation of the alternative R-matrix parametrization by Park 1 will be discussed. A first application of this feature to real data will be presented and compared with standard R-matrix analysis.
Further ongoing developments concern the improved capability of Reduced R-matrix analyses, the inclusion of polarization observables and the development of a graphical user interface.

1 T.-S. Park, Phys. Rev. C 104, 064612 (2021)

R-matrix, Reactions / 104

Applications of R-matrix Methods to Light Nuclei

Author: Carl Brune[1]

[1] *Ohio University*

Corresponding Author: brune@ohio.edu

This talk will discuss the application of phenomenological R-matrix methods to problems in light nuclei. An overview of the theoretical approaches will be presented and contemporary computer codes will be reviewed. Included here will be a discussion why R-matrix methods are often the method of choice for nuclear cross section evaluations in light nuclei. Examples of current interest to nuclear astrophysics and other applications, such as the ¹⁶O and ¹⁷O compound-nuclear systems, will be discussed. Recent progress in R-matrix methodology, including the introduction of Bayesian techniques, will be discussed. Finally, the I will comment on several open questions in this field, such as the treatment of photon channels, the inclusion of three-body channels, and the challenges of extending R-matrix methods to higher energies.

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Quantum computing for nuclear reactions

Author: Ionel Stetcu[1]

[1] *Los Alamos National Laboratory*

Corresponding Author: stetcu@lanl.gov

Description of quantum many-body dynamics is extremely challenging on classical computers, as it requires taking into account many degrees of freedom. In nuclear physics, this translates on a large number of break up channels that have to be taken into account depending on the energy of the reaction. Even using classical computing exascale capabilities will not allow a full description of dynamical processes beyond drastic approximations. On the other hand, the dynamics can be naturally implemented on quantum hardware that is designed to easily handle unitary transformations, and hence the hope that in the future we will be able to obtain reaction observables from first principles. Any application will require three major steps: (i) preparing the initial state, (ii) time evolution by applying exp(-iHt) on the initial state, and (iii) measurements and computation of desired observables. In this talk, I will provide an overview of our efforts to apply quantum computing to the nuclear many-body problem using interactions that mimic the complexity of realistic nucleon-nucleon interactions, and a first application to electron-deuteron scattering, as a case of the simplest dynamics problem in nuclear physics.

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Transitions To Door-way States And Nuclear Responses Against 2-body External Fields

Author: Futoshi Minato[1]

[1] *Kyushu University*

Corresponding Author: minato.futoshi@phys.kyushu-u.ac.jp

A nucleus is a good stage to study a many-body quantum system in nature. Excited nuclei generate a variety of vibrations, rotations, and so on, which are called nuclear collective motions. It is known that the leading-order effect of nuclear vibrational excitations is 1-particle 1-hole (1p1h) states. With increasing the excitation energy, higher-order correlations beyond 1p1h states become important. The 2 particle 2-hole (2p2h) state, the so-called doorway state, is the next leading-order effect of nuclear excitations. This configuration is important for microscopic understanding of preequilibrium states and thus high-energy particle emissions from nuclei. We recently studied 2p2h states within a second-random-phase approximation (SRPA) and found that those states are essential to describe particle emission following muon captures 1. In addition, we also confirmed that 2-body external fields that are characterized by meson-exchange current also play a significant role to reproduce experimental data, especially those of proton spectra. Since nuclear responses against 2-body external field have not studied well as compared to those against 1-body external field, we carried out the analyses by SRPA. As a result it was found that the 2p2h states show less nuclear collectivities than 1p1h ones. In addition, depending on type of 2-body external fields, nuclei show a different characteristic collectivity from usual. We will demonstrate the detail of this mechanism and discuss its impact on particle emissions from nuclear excited states.
1 F. Minato, T. Naito, O. Iwamoto, Phys. Rev. C107, 054314 (2023).

Reaction mechanisms / 101

Nuclear reaction mechanisms for incident nucleons and light composite particles

Author: Brett Carlson[1]

[1] *Instituto Tecnológico de Aeronáutica*

Corresponding Author: brettvc@gmail.com

Low-energy nuclear reaction mechanisms are frequently classified as either direct, pre-equilibrium or compound nucleus ones. Here, the role of the first two of these is examined up to the stage of the formation of a compound nucleus. Although direct reactions are often distinguished from pre-equilibrium ones, the point of view is adopted here that the latter consist, for the most part, of a sequence of direct reactions [1-3]. The characteristics of nucleon-induced reactions of this type are briefly examined and the principal models in use at present to describe them are discussed [4-6].

Attention is then turned to stripping and breakup reactions involving light composite projectiles. The discussion is concentrated on the deuteron, the simplest of these particles as well as the least bound. The principal methods used to describe stripping and breakup [7-9] are discussed and their consequences on emission spectra and on the formation of the compound nucleus are illustrated with several examples [10-11].

Pickup reactions and the models in use for their description 12 are briefly mentioned in closing.

References

1 H. Feshbach, A. Kerman, S. Koonin, Ann. Phys (N.Y.). 125 (1980) 429.
2 T. Tamura, T. Udagawa, H. Lenske, Phys. Rev. C 26 (1982) 379.

3 H. Nishioka, H. A. Weidenmüller, S. Yoshida, Ann. Phys. (N.Y.) 183 (1988) 166.
4 M. Dupuis, T. Kawano, J. P Delaroche, E. Bauge, Phys. Rev. C 83 (2011) 014602; M. Dupuis, E. Bauge, S. Hilaire, S. F. Lechaftois, S. Péru, N. Pillet, C. Robin, Eur. Phys. J. A 51 (2015) 168.
5 A. J. Koning and M. Duijvestijn, Nucl. Phys. A 744, 14 (2004).
6 M. Blann, Phys. Rev. C 54 (1996) 1341; M. Blann, M. Chadwick, Phys. Rev. C 57 (1998) 233.
7 N. Austern, Y. Iseri, M. Kamimura, M. Kawai, G. Rawitscher, and M. Yahiro, Phys. Rep. 154, 125 (1987).
8 Jin Lei and A. M. Moro, Phys. Rev. C 92, 044616 (2015); 061602(R) (2015).
9 B. V. Carlson, R. Capote and M. Sin, Few-Body Systems 57, 307 (2016).
10 F. Torabi and B. V. Carlson, J. Phys. G 50, 045107 (2023).
11 E. V. Chimanski, L. A. Souza and B. V. Carlson, Braz. J. Phys. 51, 323 (2021).
12 A. Iwamoto and K. Harada, Phys. Rev. C 26, 1821 (1982).

Structure for Reactions / 21

Evaluation of 232Th and 237Np fast neutron-induced fission cross sections by simultaneous evaluation approach

Author: VIDYA DEVI[None]

Co-author: Naohiko Otuka [1]

[1] *International Atomic Energy Agency, Wien, Austria*

Corresponding Author: vidyathakur@yahoo.co.in

The Hauser-Feshbach formalism and Hill-Wheeler formula provide a reliable framework for describing fission cross-sections, particularly for fast neutrons, integrated into various nuclear reaction model codes such as TALYS, EMPIRE, CCONE and CoH. However, predicting fission cross-sections using this method relies on parameters like barrier heights, necessitating adjustments to closely match experimental data. The EXFOR library has a large number of experimental datasets, and it enables us to perform evaluation by least-squares analysis of the EXFOR datasets without a physics model. The least-squares analysis code SOK developed for simultaneous evaluation for the JENDL project has been successfully applied to evaluation of the ^{233,235,238}U and ^{239,240,241}Pu fission cross sections for fast neutrons.

As nuclear data libraries evolve, Nuclear Reaction Data Centres (NRDCs) increasingly prioritize compiling experimental uncertainty and covariance information. To facilitate this, the EXFOR format has expanded to include correlation property flags and adopt computer-readable matrix formats, enhancing data accessibility and usability. Moreover, there is growing interest in acquiring new experimental datasets relevant to simultaneous evaluations, notably from time-of-flight facilities such as CERN n_TOF and LANSCE.

In response to these advancements, we embarked on recreating the simultaneous evaluation of the neutron-induced fission cross section of ^{232}Th and ^{237}Np in the fast neutron region. These nuclides were chosen since (1) ^{232}Th energy dependent cross section and fission neutron spectrum averaged cross section show inconsistency, and (2) ^{237}Np is sometimes used as a reference and better to be a part of our simultaneous evaluation framework. The experimental ^{232}Th and ^{237}Np fission cross sections and their ratios to fission cross sections of other nuclides such as ^{235,238}U in the EXFOR library were reviewed and analyzed. Experimental covariances were estimated for each experimental dataset and incorporated in the new evaluation. The newly evaluated cross sections were validated against spectrum-averaged cross sections measured in the ^{252}Cf spontaneous fission neutron standard field.

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Development of a Photon Strength Function Database Interface

Author: Sandile Jongile[1]

Co-authors: Ludmila MARIAN ; Mathis Wiedeking ; Paraskevi DIMITRIOU [2]

[1] *iThemba LABS*

[2] *International Atomic Energy Agency*

Corresponding Author: sandilejongile@gmail.com

We have developed a specialized web application with the purpose of managing, querying, and visualizing Photon Strength Function (PSF) data. This data is compiled in a well-defined format as an outcome of an IAEA Coordinated Research Project 1. This web application represents a significant advancement in accessibility and interaction with the data over existing platforms, particularly improving upon the capabilities of the prior resource noted in Ref 2.

Central to this application is the database structure, crucial for efficient data management and retrieval. Built using the Django framework, the web application's user interface is designed to present queried data and search results in an accessible format. It works seamlessly with the backend to fetch and display data (based on the data query from the user), detailing basic nuclear properties such as atomic number (Z) and mass number (A), multipolarity, energy range, and experimental method employed to produce the data. Additionally, the application offers functionalities for searching and sorting data by author names or publication years, facilitating a more refined navigation through the extensive PSF data repository. This is especially beneficial for tracking specific contributions or examining the evolution of PSF data over time.

A noteworthy feature is the dynamic data visualisation tool, which utilises Plotly to create interactive graphs displaying strength functions and other pertinent data points, thus enhancing the intelligibility of different datasets. Moreover, the platform features a comprehensive data processing pipeline. In the backend, this pipeline extracts, transforms, and loads information from data files and README files into the system, safeguarding data integrity and accessibility.

In this presentation, I will discuss and demonstrate the web application, which marks a substantial advancement in the management and dissemination of PSF data.

This work is based on research supported in part by the National Research Foundation of South Africa (Grant Number: 118846). We also acknowledge the financial support from the International Atomic Energy Agency.

References:

1 Goriely et al., Eur. Phys. J. A (2019) 55:172
2 International Atomic Energy Agency. "Photon Strength Functions Database." IAEA Nuclear Data Services. https://www-nds.iaea.org/PSFdatabase/

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Vortex photon induced nuclear reaction: mechanism, model, and application to the studies of giant resonance and astrophysical reaction rate

Author: Yi Xu[1]

Co-authors: Dimiter L. Balabanski [1]; Virgil Baran [2]; Cristian Iorga [2]; Catalin Matei [1]

[1] *Extreme Light Infrastructure - Nuclear Physics (ELI-NP), Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH)*

[2] *Faculty of Physics, University of Bucharest*

Corresponding Author: xuyixuyi2012@gmail.com

The vortex photon beam induced nuclear reaction is studied. The interaction formalism of nuclei with vortex photons is developed and incorporated into the statistical reaction model to calculate reaction cross-sections. For 138 nuclei of high nuclear astrophysics and structure interest, the cross-sections of γ-ray emission and neutron production from the decay of the giant resonances (GR) populated by vortex photons are computed. It is shown that for these calculated crosssections, the GR contribution of an individual L is either enhanced or suppressed depending on the parameters of vortex γ-rays, and the contribution from the GR of a specific L can be identified and deduced. To this end, a novel method to exclusively determine the γ-strength function (γSF) for the GR of a specific L is proposed considering the measurements of the emitted γ and neutron, and the feasibility studies demonstrate that the γSF for the giant quadrupole resonance can be extracted. Furthermore, the astrophysical reaction rates of the vortex photon induced reactions in p-process are investigated. It is indicated that photo-nuclear reactions induced by vortex photons will bring new insights in nuclear physics and astrophysics research.

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Surrogate Nuclear Reaction Methods

Author: Jutta Escher[1]

[1] *Lawrence Livermore National Laboratory*

Corresponding Author: escher1@llnl.gov

Cross sections for compound-nuclear (CN) reactions are important for nuclear astrophysics and other applications. Direct measurements are not always possible for the reactions of interest and calculations without experimental constraints can be quite uncertain. Thus indirect approaches, such as the surrogate reaction method (SRM), are being developed to fill the gaps. The SRM, which uses a (direct) inelastic scattering or transfer reaction to obtain information on the decay of a specific compound nucleus, has a long history of providing probabilities for fission, gamma and particle emission. While earlier implementations of the method used minimal theory to provide approximate cross sections for (n,f) reactions, better theoretical descriptions of the underlying reaction mechanisms have made it possible to also obtain (n,γ), (n,n'), and (n,2n) cross sections that agree well with benchmarks. I will discuss multiple applications of the modern implementation of the SRM, highlight theory advances that enable them, and comment on opportunities offered at new experimental facilities.

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New experimental techniques to inform neutron-induced reaction cross sections on rare isotopes with surrogate reactions.

Author: Jolie Cizewski[1]

Co-authors: Andrew Ratkiewicz [2]; Gregory Potel [2]; Harrison Sims [1]; Jutta Escher [2]; Oliver Gorton [2]; Steven Pain [3]

[1] *Rutgers University*

[2] *Lawrence Livermore National Laboratory*

[3] *Oak Ridge National Laboratory*

Corresponding Author: cizewski@physics.rutgers.edu

Understanding neutron-induced reaction rates on rare isotopes is important in fission and nucleosynthesis processes and applications in nuclear energy and forensics and stewardship science. Informing these rates requires indirect methods and rare isotope beams. The Surrogate Reaction Method (SRM) 1, where beams interact with light-element targets, has been demonstrated 2 as a valid method to inform neutron-induced reaction rates. In the SRM the same compound nucleus (CN) can be formed as in the neutron-induced reaction and differences, in particular entrance spin-parity distributions, can be accounted for with nuclear reaction calculations. To date most of the SRM applications for (n,γ) reactions have involved measuring discrete γ-ray transitions in an established level scheme, to determine the gamma-decay probabilities of the CN. Low beam intensities of rare isotope beams require high efficiency, high resolution arrays of gamma-ray detectors to detect the discrete transitions. However, even the state-of-the-art γ-ray detector arrays are only about 15% efficient, with efficiency strongly dependent on γ-ray energy. A particular challenge is when the final nucleus is odd-odd, where not only may little be known about the level scheme, but the decay of the compound nucleus is likely to fragment into many paths. Our collaboration has recently developed the techniques to measure the γ-ray decay probability of a final nucleus in a surrogate (d,p) reaction, without requiring discrete γ-ray transitions.

The Oak Ridge Rutgers University Barrel Array (ORRUBA) of position sensitive silicon strip detectors was coupled to the S800 spectrograph at NSCL to inform 84Se(n,γ) rates with the SRM (d,p) reaction 3. Beam-like reaction products were measured in the focal plane of the S800 in coincidence with (d,p) reaction protons. By measuring the S800 focal plane energy loss as a function of time of flight, the 85Se recoils could be separated from the un-reacted 84Se beam, with about 35% efficiency. The 84Se from neutron emission from the 85Se CN has sufficiently different kinematics that these ions are well separated from the 85Se desired product and can be blocked in the focal plane, along with most of the unreacted 84Se beam. By careful measurement of the proton singles in the 84Se(d,p) reaction, the (n,γ) cross sections as a function of neutron energy can be informed. The collaboration is scheduled to measure the (d,pγ) reaction with ORRUBA coupled to GRETINA and the S800 in April 2024 with 80Ge and 75Ga FRIB beams. These measurements would inform (n,γ) rates important for nucleosynthesis processes intermediate between slow and rapid neutron capture.

This talk would present the experimental techniques used in the earlier 84Se measurement of ORRUBA +S800 and how (n,γ) rates can be informed, as well as preliminary results from the Spring 2024 FRIB measurements.

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1 J.E. Escher et al., Rev. Mod. Phys. 84, 253 (2012)
2 A. Ratkiewicz et al., Phys. Rev. Lett. 122, 052502 (2019).
3 H.E. Sims, PhD Dissertation Rutgers University (2020) and to be published.

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Extending the Dispersive Optical Model to β-unstable systems

Author: Cole Pruitt[1]

Co-authors: Jutta Escher [2]; Oliver Gorton [2]; Salvatore Simone Perrotta [1]

[1] *Lawrence Livermore National Lab*

[2] *Lawrence Livermore National Laboratory*

Corresponding Author: pruitt9@llnl.gov

Optical potentials remain an indispensable ingredient for modeling many types of nuclear reaction, such as in statistical (Hauser-Feshbach) calculations of radiative capture. As with level densities and γ-ray strength functions, optical potentials for systems near the neutron dripline remain poorly known but are important for characterizing key astrophysical nucleosynthesis pathways. Recent work with dispersive optical potentials on β-stable Ca, Ni, Sn, and Pb isotopes suggests that even in the absence of scattering data to train against, bound-state observables –such as the charge radius, binding energy, particle number, and single-particle energies –can provide powerful constraints on the potential, improving the fidelity of extrapolation toward the dripline. Using a simplified dispersive optical potential equipped with uncertainty quantification, we show how single-nucleon scattering data on 40-48Ca systems can be augmented with bound-state information from 36-60Ca to provide improved neutron capture cross sections relevant for the weak r-process.

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Updates on experimental reaction studies on radioactive nuclei including astrophysical impacts and solenoidal development at LANSCE

Author: Hye Young Lee[1]

[1] *Los Alamos National Laboratory*

Corresponding Author: hylee@lanl.gov

For better understanding of reaction rates for radioactive isotopes relevant for the nu-p process, we directly measured cross sections of ^{56,59}Ni(n,p), ^{56}Co(n,p), and ^{59}Ni(n,α) using the LENZ (Low Energy NZ) instruments at the Los Alamos Neutron Science Center (LANSCE). I will discuss the impacts of updated experimental reaction rates in the nu-p process nucleosynthesis for the context of answering to heavy element production puzzles. As a continued effort of improving nuclear reaction studies on radionuclides at LANSCE, I will present the progress on the dedicated solenoidal spectrometer for directly measuring neutron induced charged particle reactions with highly radioactive targets. This development is aimed to provide improved precision than the current LENZ instruments for various nuclear application's data needs.

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