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Rensselaer Polytechnic Institute

Book of Abstracts

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Fast neutron inelastic scattering from 7Li

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The inelastic scattering of fast neutrons from ^{7}Li nuclei was investigated at the nELBE neutron-time-of-flight facility.
This process has technological implications in fusion and fission reactors. In the former it could create an intense γ-ray field causing heating and radiation damage, in the latter it could strongly influence the neutron energy spectrum and therefore the neutronics of e.g. novel reactor concepts like the molten salt reactor. Furthermore the γ-ray production cross section of ^{7}Li is a very good case to be used as an alternative for neutron fluence determination to enable relative measurements of neutron-induced reactions. Inelastic neutron scattering on ^{7}Li leads to the production of a 478 keV γ-ray from the first excited state of ^{7}Li. The next higher lying state in this nucleus at 4630 keV already undergoes break up into an α-particle and a triton. The angular distribution of the γ-rays after inelastic neutron scattering is isotropic and has negligible internal conversion. The threshold energy is low enough to be able to cover a large range of neutron energy and the cross section of about 0.2 barn is reasonably high to enable good statistics within a feasible measurement time.
At nELBE the photon production cross section was determined by irradiated a disc of LiF with neutrons of energies ranging from 100 keV to about 10 MeV. The target position was surrounded by a setup of 7 $LaBr_3$ scintillation detectors and 4 high-purity germanium detectors to detect the 478 keV de-excitation γ-rays. A ^{235}U fission chamber was used to determine the incoming neutron flux. All details of the experiment and the data analysis will be explained. The final results will be compared to previous measurements.

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GAINS - Twenty Years After

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The GAINS spectrometer, an integral part of the GELINA neutron source of EC-JRC Geel, has played a pivotal role in advancing neutron inelastic scattering measurements and contributing to significant scientific inputs. For more than 20 years, GAINS allowed us to perform very reliable and high precision neutron inelastic cross section measurements on various low-to-medium mass nuclei. This talk explores the rich history of this spectrometer, from its inception to the present day, highlighting its key achievements and emphasizing its importance in nuclear data research.

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Back on the iron throne: A new measurement of the 56Fe(n,inl) and 56Fe(p,inl) cross sections

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New measurements of the nucleon inelastic scattering cross sections was proposed in response to the concerns raised by the evaluators community with regard to the previous experiments, including our measurement published in 2014 [1].
The current experimental campaign includes a measurement of the proton inelastic scattering at the 9-MV Tandem accelerator of IFIN-HH, Romania and one of the neutron inelastic cross sections at the GELINA neutron source of JRC-Geel, Belgium.
We will report on the current status of the two experiments scheduled in 2022.
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Neutron inelastic cross sections on 40Ca

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In this talk we will present preliminary results associated to the neutron-induced inelastic channel on 40Ca. The data were measured at the GELINA neutron source of EC-JRC-Geel using the GAINS spectrometer. This is a HPGe-detector-based spectrometer that uses gamma spectroscopy coupled with the neutron time-of-flight technique to extract angle-integrated gamma-production cross sections for the most intense transitions following neutron inelastic scattering. We were able to extract inelastic data for the two main transitions in 40Ca, at 3736 and 3903 keV. After a very short description of the setup and experimental technique associated to our measurements at GAINS, we will then proceed to comparing our results with previously measured data and with TALYS theoretical calculations performed using the default settings of the code.

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Cross sections for inelastic scattering of neutrons on 14N using the GAINS spectrometer

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The inelastic scattering of neutrons on 14N was investigated using the (n,n'g) technique. The g-production cross sections were measured at the GELINA (Geel Electron Linear Accelerator) neutron source of European Commission –Joint Research Centre. The radiation of interest was detected using the GAINS (Gamma Array for Inelastic Neutron Scattering) spectrometer, located on flight path 3, 100-m measurement cabin. The incident neutron fluence rate was monitored by a 235U fission chamber. Making use of the excellent neutron energy resolution of GELINA, we are able to provide state-of-art g -production cross sections up to 20 MeV incident neutron energy. Using these primary-extracted quantities and information about the level scheme of the target nucleus, we can determine level and total inelastic cross sections. Preliminary results for the 2312.5 keV and 1635.2 keV transitions will be presented and compared with previously reported data for this isotope.

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T^6LYC vs C^6LYC: Comparison of Fast Neutron and γ-Ray Detector Performance for In-Beam Neutron Scattering Measurements

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Neutron and γ-ray dual mode sensitivity is a widely utilized detector capability for nuclear security applications and fundamental nuclear physics measurements, such as neutron scattering and β-delayed neutron emission. In particular, the pulse-shape discrimination (PSD) technique exploitable with $Cs_2{}^6LiYCl_6$:Ce (C^6LYC) scintillators permits simultaneous measurements of neutrons and γ rays from inelastic neutron scattering reactions. C^6LYC also provides a relatively broad dynamic range in neutron energy that usually requires multiple detector types to attain. Recent developments of new elpasolite scintillators has led to $Tl_6{}^6LiYCl_6$:Ce (T^6LYC), a variant of C^6LYC with thallium replacing cesium ions for higher effective $Z(Z_{eff} = 69)$. This work focuses on characterizing the properties of T^6LYC using standard γ-ray calibration sources, an unmoderated ^{252}Cf fission chamber, and in-beam neutron scattering on ^{12}C. Performance comparisons of T^6LYC relative to C^6LYC detectors from the Correlated Gamma-Neutron Array for sCattering (CoGNAC) at Los Alamos National Laboratory will be presented.

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Last news from GRAPhEME @ GELINA and future measurements @ GANIL/SPIRAL2/NFS facility

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GRAPhEME is a g-spectrometer developed by CNRS/IPHC Strasbourg (France), in collaboration with EC-JRC/Geel (Belgium) and IFIN-HH Bucharest (Romania). With its 6 High Purity Planar Germanium detectors, GRAPhEME, installed at the EC-JRC GELINA facility, was optimized for measurements of accurate (n,xn g) cross sections on actinides. The experimental methodology is based on prompt gamma-ray spectroscopy coupled to time of flight measurements. In a first configuration, involving 4 HPGe, several measurement campaigns have produced numerous sets of data for 235U , 238U , 232Th and 183,182,184,186,natW isotopes. An update of the setup in 2016, with a segmented (6x6 pixels) HPGe has opened the way for measurements with very active targets. A first campaign

on 233U has been performed and a second one, on 239Pu is ongoing. Beyond the experimental work, a strong collaboration with theoreticians from CEA, LANL and IAEA has emerged allowing the use of the data produced with GRAPhEME to test and constraint nuclear reaction codes like TALYS, CoH and EMPIRE.
In this contribution, an overview of the last results (on 232Th, 233U, 238U) obtained with GRAPhEME since the last WINS workshop in 2018 will be presented.
The next challenge tackled by our collaboration is the completion of (n,2ng) and (n,3ng) cross sections measurements at the new GANIL/SPIRAL2/NFS facility in Caen, France. The results of first tests performed in 2022 at NFS during which we have verified that the experimental conditions are suitable for prompt g-ray spectroscopy method, will be presented. The first measurement case will concern 238U and is planned in fall 2024. The status of the preparation of this measurement will be discussed.

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Using Neural Networks for Inelastic Neutron Scattering Cross-Sections Interpretation

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The necessary improvement of evaluated nuclear data for nuclear applications development is possible through new and high quality experimental measurements.
In particular, improving (n, n') cross-section evaluations for faster neutrons than in current reactors is a goal of interest for new reactor fuels.

Our group at CNRS-IPHC has been running an experimental program to measure (n, n' γ) cross-section using prompt gamma-ray spectroscopy and neutron energy determination by time-of-flight, recording and analyzing data for 182,184,186W, 232Th, 233,235,238U [1,2].

From the partial transition measurements, the total (n, n') cross-section has to be inferred, either by summing individual contributions [3] (a method usually valid only up to a certain neutron energy), or by constraining reaction models [4,5]. This interpretation work is made difficult in (the usual) cases when not all the transitions going to the ground state could be measured. If that happens, one has to rely on **filling** the missing information by models or guess, reducing the accuracy of the final computed cross-section.

Here we propose a new method, involving training a Neural Network on a calculated data set and using it to predict the (n, n') cross-section from the experimental (n, n' γ) ones. This allows a quick combination of models and experimental data.
After detailing the method and checks performed for consistency, some test cases will be presented. Potential benefits, as well as the identified weakness, and future application will be discussed.

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Study of (n, xn γ) Reactions on Tungsten Isotopes : Retrospective and perspectives

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To improve the accuracy of numerical simulations used in the development of nuclear reactors, over the past decade we studied (n, xn) reactions on tungsten isotopes. As this element, because of its physical and chemical properties, is widely used in modern nuclear reactors (and foreseen as a key component in fusion ones).

The IPHC group carried out an experimental program to measure (n, xn gamma) reaction cross sections using the GRAPhEME setup at the JRC-Geel with the GELINA neutron beam facility. The measurements were performed on natural, 182, 183, 184, and 186W targets.

The obtained experimental data, the only available of their kind, provide a comprehensive and constraining test for the predictability of nuclear reaction models. These latter need to accurately describe the reaction mechanism, the nuclear de-excitation process, and the nuclear structure to correctly reproduce the experimental (n, n' γ) cross-sections [1,2].

Preliminary results for even-even isotopes have already been published and discussed [3,4]. Additionally, a glimpse into the study of 183W was provided at the ND 2022 conference [5].

A near future publication will detail the definitive experimental results, compare these to existing models, and identify which ingredients play key roles in these reactions, in particular consider the role of spin distribution in the pre-equilibrium part of the reaction, the description of the discrete levels and continuum, and their coupling.

Building on this work, the next focus will be on the reactions 183W(n, n' γ) and (n, 2n γ). Preliminary results suggest that the recorded data will allow the extraction of almost a dozen cross section. The studied reactions could provide further insights into the reaction mechanism and the predictability of models.

Finally, a future analysis of isotopic targets data will yield information on (n, 2n g) reactions on even-even isotopes. In particular, we will be able to "bridge the gap" from 184 to 182W with (n, n') and (n,2n) cross section on 184W, 183W and 182W. To that end, our goal is to publish the data quickly following the availability of the results with 183W.

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Quasi-Differential Neutron Scattering Measurements of 181Ta and Teflon from 1.75 to 20 MeV

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To better understand the accuracy of current evaluated nuclear data, measurements of the neutron emission spectrum from the 181Ta, 19F, and 12C nuclei were conducted using the time-of-flight technique at the Gaerttner Linear Accelerator Laboratory at Rensselaer Polytechnic Institute. An array of eight EJ-301 organic liquid scintillator detectors coupled to photomultiplier tubes were used to detect neutrons and photons resulting from nuclear interactions between the pulsed white neutron source and the nuclei of interest. These detectors were positioned at angles from 28 to 150 degrees relative to the incident neutron beam, and recorded radiation interactions concurrently throughout the experiment. The experimental system electronics were upgraded to utilize an SIS-3305 10-bit analog-to-digital converter that converted raw electrical signals to digital waveforms for these experiments. Each digitized waveform underwent postprocessing routines and pulse shape analysis to determine whether it originated from a neutron or photon interaction in the scintillator. The resulting neutron emission spectra were compared to detailed Monte Carlo neutron transport simulations using MCNP6.2. Integral normalized results from the 12C validation measurements agreed within 2% of neutron transport simulations using ENDF/B-VIII.0 data; thus, allowing the 181Ta and 19F nuclei results to be examined. Preliminary investigation of the 181Ta experiment highlighted large disagreements between the experimental data and the JEFF-3.3 evaluation at all angles below 12 MeV.

Overall, the ENDF/B-VIII.1 (β2) and JENDL-5.0 evaluations best match the current experimental results. Upon investigating the results of the 19F experiment, large discrepancies were also observed between the experimental data and the ENDF/B-VIII.0 and JEFF-3.3 evaluations above 2 MeV. Across all angles the JENDL-5.0, ENDF/B-VIII.1 (β2), and INDEN 2022 evaluations trend similarly and are observed to overpredict backscattering between 3.5 and 7 MeV. Furthermore, all evaluations were observed to poorly predict the 2.25 MeV, and the 2.6 MeV 19F resonance structure at 150 degrees. Work is ongoing at RPI to improve the pulse shape discrimination methods used for the analysis of these experiments to enhance statistical accuracy and expand the region of results of these experiments to 500 keV.

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Zirconium Scattering Sensitivity in Neutron Transport Calculations of Multiplying Systems

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The ability for neutron transport methods to correctly represent the behavior of physical systems is directly related to the accuracy of the evaluated nuclear data. Most legacy differential and integral nuclear data measurements of high importance nuclei studied the total and radiative neutron capture cross sections to solve the neutron diffusion equation. Modern computational resources however make solving the neutron transport equation using Monte-Carlo methods feasible and are employed in MCNP, Serpent, and OpenMC. Contrary to the diffusion equation, the neutron transport equation is heavily dependent on the double differential scattering cross section of a given nuclei. Zirconium' s (Zr) presence in the nuclear industry, as fuel rod cladding or a reflector, was used to study the impact of perturbations to the double differential scattering cross sections when predicting the time independent eigenvalue of a multiplying system using MCNP6. Manual perturbations to the double differential elastic and inelastic scattering cross sections and radiative neutron capture cross sections using ENDF/B-VIII.0, JEFF-3.3, and JENDL-5.0 nuclear data were performed for stable Zr isotopes in a suite of accepted integral nuclear data experiments from the International Handbook of Evaluated Criticality Safety Benchmark Experiments (ICSBEP). System Keff values were observed to be most sensitive to the double differential elastic scattering cross section of 90Zr, 92Zr, and 94Zr in energy range of 100 keV to 5 MeV. Predicted system Keff values for ICSBEP cases were observed to differ by up to 700 PCM between the JEFF-3.3, JENDL5.0, and ENDF/B-VIII.0 evaluations with over 500 PCM contributions to ΔKeff attributable to differences in the double differential elastic scattering cross sections. The contribution of the elastic scattering angular distributions to the observed 500 PCM difference was higher than that of the differential elastic scattering cross section for all cases. Differences in the differential inelastic scattering cross sections of these isotopes also contributed over 100 PCM to the observed ΔKeff of 700 PCM in certain cases. In addition, disagreements were observed between these evaluated nuclear data libraries and high energy quasi-differential neutron scattering measurements of elemental Zr performed at Rensselaer Polytechnic Institute (RPI). These findings were identified by the Nuclear Criticality Safety Program (DOE-NCSP) as a criticality safety issue and an integral measurement campaign (IER:516 ZTA) was funded to create more highly sensitive critical systems to validate current and future evaluated Zr nuclear data. Preliminary design efforts for the experiments emphasized the importance of the Zr scattering reactions by creating more sensitive systems. System Keff values predicted for certain configurations using different evaluated nuclear data for the double differential elastic scattering cross section were observed to differ by over 5000 PCM. Ultimately, new measurements of the double differential elastic and inelastic scattering cross sections of the 90Zr, 92Zr, and 94Zr isotopes in the energy range of 500 keV to 5 MeV are recommended to compliment the current integral measurement campaign to enhance future Zr evaluations.

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Validation and Evaluation Uses for Quasi-Differential High Energy Scattering Data

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Natural lead evaluations have been performed at RPI [1] to address concerns in deficient cross sections for fast spectrum applications [2]. As lead is a primarily scattering material, the quasi-differential scattering measurements done at RPI providea great basis for validating natural lead [3]. MCNP [4]simulations of the experiment with current lead evaluations[5] [6] [7] alluded to the understanding that elastic scattering angular distributions (ESAD) were a major problem in lead. Using the Blatt-Biedenharn formalism [8] implemented into NJOY[9], ESAD from resonance parameters were calculated and showed great promise in addressing the current problems with replicating natural lead. A novel method, encompassing SAMMY [10], NJOY, and MCNP connected with Python, proved useful in extending the resolved resonance region of 208Pb when coupled with differential transmission data [11]. This method relies on the premise of the domination of the scattering data to isolated resonances, the spin of which, should produce radically different signals in scattering calculations. Further studies into the ESAD derived for 208Pb highlighted potential for constraining the P1 moment uncertainty of evaluated nuclear data angular distributions (MF-34). The outcome of updating the elastic scattering distributions of lead isotopes greatly increased the agreement between MCNP simulations and experimental data. Long held as a tool for validation, with the ESAD fitting methodologies developed here, quasi-differential scattering data can be used as part of the evaluation tool set to adjust model parameters and provide uncertainties.

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Recent Results from CoGNAC Neutron Scattering Measurements at LANL

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As the leading contributor to the total neutron cross section of nearly every nucleus, neutron scattering nuclear data are relevant for a wide variety of fundamental and applied fields of physics. While heavy element and actinide scattering cross sections are particularly poorly known, there exist major gaps in our understanding of cross sections and both neutron and γ-ray angular distributions from scattering reactions with no measurements of correlated n-γ distributions on any nucleus except ^{12}C. Elements in structural materials, such as Al and Fe, and those that commonly appear in compounds, like C and O, are of particular importance for active interrogation scenarios, nuclear reactor studies, and more.

A new detector system for measuring neutron elastic and inelastic scattering cross sections termed the Correlated Gamma Neutron Array for sCattering (CoGNAC) is being developed for use at the fast, white neutron source at the Weapons Neutron Research (WNR) facility, which is part of the Los Alamos Neutron Science Center (LANSCE). This array utilizes a combination of liquid scintillator and C^{6}LYC detectors to measure n-γ data from reactions on nuclei ranging from light elements up through actinides. In this talk, the analysis and covariance techniques developed for use on CoGNAC data will be discussed in the context of recent results for neutron scattering cross sections and angular distributions on C, O, Al, and Fe targets.

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Deployment of Gaussian Surrogate Model for Ad-Hoc Adjustments to Elastic Scattering Angular Distributions

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Neutron scattering reactions, specifically elastic scattering angular distributions, are an often neglected aspect of nuclear data evaluations. Difficulties in representing scattering distributions from both theoretical as well as formatting perspective and a lack of validating experiments leaves a largely unconstrained physics space that has proven to contribute significantly to critical integral experiments. To bypass the traditional evaluation pipeline, empirically fit angular distributions based on Gaussian surrogate models have been explored as an alternative method for adjustments to angular distributions. Monte Carlo neutron transport simulations of the RPI Quasi-Differential Scattering Experiment formed the basis of analysis with the goal of minimizing the difference between simulation and experiment. Design variables are the Legendre polynomial coefficients, an, and the objective function is a chi-square figure of merit between the experimental and simulated data. Due to the inherent noise of Monte Carlo calculations and processing procedures for tallies, a surrogate model built in MATLAB was deemed the simpler approach over common optimization algorithms such as Steepest Descent or Genetic Algorithms. Likelihood maximization utilized in the surrogate model development ensured an accurate recreation of the objective's hyper surface. After model construction, a gradient optimization using MATLAB's fmincon performed the minimization of the objective function and therefore shrunk the distance between simulation and experimental data. Validation of the method was demonstrated using the 814 keV resonance in 208Pb and further adapted to fix angular distributions at the energy threshold for (n,2n) reaction for 9Be. Results show that this method works for well isolated resonances where elastic scattering is the dominant component. Future work includes expanding the surrogate model to fit multiple regions at once or training neural networks to recognize the needed adjustments to angular distributions.

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Examining and Modeling Gamma Emission from Quasi-Differential High Energy Scattering Measurements

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Quasi-differential neutron measurements performed at Rensselaer Polytechnic Institute with the high-energy scattering (HES) system have been used to collect energy-angle information from samples-of-interest. Data from those measurements were used with MCNP to validate various evaluated nuclear data libraries, such as ENDF/B-VIII.0 and JENDL-5. In addition to total quasi-differential measurements methods were developed to isolate the contribution from elastic scattering, inelastic scattering, and fission based on the HES system's response to neutrons. To further expand the HES system's capabilities the gamma-ray response was modeled by coupling MCNP calculations with analytical methods. Data presented walkthrough initial steps to fully utilize all data collected during a quasi-differential scattering measurement.

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Examination of C, Be, Mo, U-238, Fe-nat using the RPI HES Data with Current ENDF, JEFF, and JENDL Evaluations

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Quasi-differential scattering measurements were performed at the RPI Gaerttner Linear Accelerator (LINAC) Center with the High Energy Scattering (HES) System, which relies on the time-of-flight method to determine the incident neutron energy. The HES system relied on eight proton recoil fast neutron liquid scintillators detectors to collect neutron data. Each detector was optimized to measure neutrons with energies between 0.5 and 20 MeV, and their locations about the scattering samples were predetermined based on where significant discrepancies between evaluated nuclear data libraries were observed. Data collected from these measurements contain single and multiple scattering collisions from elastic collisions, various inelastic states, and fission. The measurement data were compared to simulations of the experiment using OpenMC and MCNP models using reaction probabilities found in evaluated nuclear data files. This work examines how the current nuclear data library evaluations, ENDF/B-VIII.1, JEFF-3.3, and JENDL-5.0, perform with HES quasi-differential measurements of carbon, beryllium, molybdenum, uranium-238, and iron.

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Gaussian orthogonal ensemble model for low-energy neutron-induced reaction to excite weakly overlapped compound nucleus states

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The Gaussian Orthogonal Ensemble (GOE) model for the compound nucleus reaction includes a random matrix in the scattering matrix, which allows us to evaluate average properties of fluctuating cross sections. The GOE model has been successfully applied to study the relation among the channel transmission coefficients, the decay width, and the cross section. It is a powerful tool when many overlapped resonances are involved in the excited compound nucleus. However, since the model itself is so abstract in dimensionless space that no attempt has been made to implement it into the nuclear reaction codes to generate stochastic cross sections. A neutron interaction with a nucleus often shows isolated resonances at very low energies, and they start overlapping as the neutron energy increases. To study the smooth transition from the isolated to overlapped resonance cases, we extend the GOE model to more general circumstances. In this talk, we develop a technique to incorporate the GOE model into realistic nuclear reaction calculations, and discuss calculations of cross sections when the excited compound state includes weakly overlapped resonances.

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Using OpenMC to Model Time-of-Flight Quasi-Differential Scattering Experiments

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The Gaerttner Linear Accelerator (LINAC) Center at Rensselaer Polytechnic Institute (RPI) utilizes its High Energy Scattering (HES) system to perform quasi-differential scattering measurements. This apparatus uses the time-of-flight (ToF) method for determining neutron energies and has a useful energy interval of 0.5 to 20 MeV. Monte Carlo simulations of the HES system are used in the experiment design phase, allowing for the identification of discrepancies between different nuclear data libraries. Experimental results are then compared to the simulations to identify discrepancies between each library and with the measured data, which provides valuable validation information to the nuclear data evaluators. Traditionally, MCNP has been used to perform these simulations; however, effort is being devoted to investigate the use of the open-source Monte Carlo code, OpenMC, to perform these simulations. This is the first time that OpenMC has been used to perform ToF simulations for measurements at the RPI LINAC. This work showcases the HES system at the LINAC modeling scattering from carbon and iron with both MCNP and OpenMC. These simulations are also compared to experimental data to validate OpenMC for the HES system.

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What's "Happ'nin"at Kentucky

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The University of Kentucky Accelerator Laboratory has achieved ˜1800 hours of beam-on-target since the last WINS meeting, and the research group has worked to upgrade our data acquisition and neutron/gamma-ray detection systems. Specifically, over the last year, angular distribution measurements of neutron elastic scattering on carbon-13 and neutron inelastic scattering on lithium-7 enriched targets were performed. CAEN V1730 and V1782 modules were incorporated into new data acquisition and analysis systems using COMPASS and ROOT. We are awaiting delivery of locally-annealable HPGe detectors in order to restore our ability to perform neutron-induced gamma-gamma coincidence measurements. The status of the new datasets, quirks of the data acquisition system, future projects, and outlook for the laboratory will be discussed

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Overview of the Gamma Rays Induced by Neutrons (GRIN) Project

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Active interrogation (AI) with neutrons is an important tool for nuclear security and nonproliferation applications, as well as for fossil fuel and space exploration. The backbone of this technique is a pattern of emitted gamma-rays which provide a distinct isotopic "fingerprint"of the material being interrogated. We aim to support AI by improving traditional and event-by-event simulation tools that can model particle-gamma and gamma-gamma coincidences. The Gamma Rays Induced by Neutrons (GRIN) project was established to improve the data supporting AI in the ENDF/B library. The GRIN project has developed improved (n, n') outgoing gamma data by synchronizing ENDF/B files with authoritative sources such as ENSDF and is developing improved methods and evaluations for outgoing gamma data from (n, g) reactions. These evaluations rely on new capabilities in the Generalised Nuclear Database Structure (GNDS) format. The GRIN project has also drafted a gap analysis detailing shortcomings in the ENDF/B-VIII.0 library. Finally, the GRIN project is adapting the Monte Carlo event generator MCGIDI to use our new evaluations in radiation transport calculations.

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On quantum entanglement and Neutron scattering

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The ongoing enhanced interest in quantum entanglement, which can be actually regarded as photon scattering, is compared with the inclusion of internal level structures (resonances) of the nucleus and its impact on the scattering process and in particular on the angular distribution. The work covers the different approaches of the elastic and inelastic scattering in view of the fundamental outcome of the Schrödinger equation and the way it is incorporated in lower S resonances for the elastic scattering and on the other hand for high energy with p or d levels and the consequent inelastic scattering within the unresolved range. Based on the measurement done in RPI during 2007-2009 for elastic scattering in the resolved resonance range different assumptions (at least as neutron are concerned) are made concerning the completeness and locality of quantum mechanics theory as argued by quantum physicists. As a conclusion a more "classical physical"oriented approach is suggested for scattering at higher energies, albeit without solid experimental proof for the presented isotopes. The design of such experiments should combine discrete angular distributions and temperature dependencies with which the existing theories could be considerably improved.

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Problem with gradual absorption in MSD/MSC calculations

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Multistep Direct (MSD) and Multistep Compound (MSC) mechanisms when combined account for emission of nucleons from a composite nucleus before it attains compound nucleus equilibrium. In spite being better founded than exciton model or other classical pre-equilibrium models, MSD and MSC were only occasionally employed in practical calculations. Initially, it was due to higher complexity of these quantum-mechanical theories and higher computational cost. Both these factors, however, are not major obstacles today since MSD (TUL) and MSC (NVWY) were implemented in the EMPIRE code by the end of the last century and modern computational capabilities make such calculations feasible on a single-processor laptop. The major cause of avoiding MSD/MSC in practical calculations (e.g., nuclear data evaluations) was the fact that these two models tend to underestimate the middle-energy range of neutron spectra.
In our recent work we were able to overcome this deficiency and obtain very good reproduction of experimentally measured neutron spectra coming from neutron interaction with Ta181 and Pu239 targets. The default MSD/MSC calculations on Ta181 are already acceptable. Similar result with exciton model requires DWBA calculations to a large number of fake levels embedded in the continuum to simulate MSD mechanism. This success comes, however, at the price of turning off gradual absorption to the MSC chain. This is at odds with the fundamental distinction between MSD and MSC mechanisms that should proceed through the chain of open (P-space) and closed (Q space) respectively. By blocking gradual absorption we allow the first stage of MSC to be fully populated from the incident channel. This ignores the fact that at high enough incident energies creation of a bound three-quasiparticle state is energetically impossible.
We will discuss various attempts of addressing the problem that, so far, remains open.