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CHANDA

SOLVING CHALLENGES IN NUCLEAR DATA FOR THE SAFETY OF EUROPEAN NUCLEAR FACILITIES

SEVENTH FRAMEWORK PROGRAMME

Contents

NeuLAND time of flight detector for 200-1000 MeV neutrons read out by fast photosensors

D. Bemmerer[1] for the R3B collaboration

[1]Helmholtz-Zentrum Dresden Rossendorf, Bautzner Landstr. 400, 01328 Dresden, Germany

A new setup for kinematically complete reaction experiments for beams of radioactive nuclei far from the valley of stability is under construction at FAIR Darmstadt, Germany. NeuLAND, a highly efficient (>90%) neutron time of flight detector made of fast plastic scintillators is included in the setup. In order to reach proper resolution in the reconstructed energy spectrum, a time resolution of sigma < 150 ps is required. Using the ELBE picosecond electron beam as a time reference, it is currently being studied whether semiconductor-based photosensors (SiPMs) can be used for the readout of the NeuLAND scintillator bars.

Understanding the response of liquid xenon to nuclear recoils at low energies - MainzTPC and nELBE

B. Beskers, M. Scheibelhut, P. Sissol, R. Othegraven, U. G. Oberlack

Johannes Gutenberg University Mainz

Institute of Physics & PRISMA Cluster of Excellence

55099 Mainz, Germany

Experiments based on liquid xenon TPC technology have set the pace of progress in direct searches for Dark Matter in recent years, and excluded cross-sections for spin-independent WIMP-nucleon scattering at unprecedented levels. Reported signals of other experiments at ~keV nuclear recoils, tentatively interpreted as resulting from interactions of low mass (< 10 GeV/c^2) WIMPS and in conflict with exclusion limits reported by XENON100 and LUX, have reinforced the necessity to measure the response of liquid xenon to nuclear recoils at these low energies.

Dual phase liquid xenon TPCs are position-sensitive detectors that can measure all energy deposits above a low energy threshold of few keV. Existing direct measurements on scintillation and charge yield in liquid xenon suffer from large systematic errors, or don't extend down to sufficiently low energies.

The Mainz group wants to systematically improve on the knowledge of the low-energy (1-10 keV) response for both electronic and nuclear recoils. This comprises light yield, charge yield, and primary scintillation pulse shape, as well as the dependency of those quantities on the electric drift field. For this purpose, we built a small TPC (the so-called MainzTPC), optimized for single scatters, providing 3D position resolution and a minimal amount of passive material. The MainzTPC will initially be used in a Compton scatter setup to study response to electronic recoils, which is not only relevant for background discrimination but also for axions and exotic Dark Matter candidates. To study the response of liquid xenon to nuclear recoils, we have simulated a neutron scattering experiment at the nELBE facility.

In this talk, we will show first commissioning results of the MainzTPC and report on simulation results and requirements for the neutron scattering setup.

Inelastic scattering measurements at nELBE

Beyer, R.[1], Junghans, A.R.[1], Schwengner, R.[1]

[1]*Helmholtz-Zentrum Dresden Rossendorf, Bautzner Landstr. 400, 01328 Dresden, Germany*

[2]*Technische Universität Dresden, 01062 Dresden, Germany*

The neutron time-of-flight facility nELBE at the Helmholtz-Zentrum Dresden-Rossendorf was built to deliver cross section data of neutron induced nuclear reaction in the fast energy range. The combination of the very defined time structure of the electron beam of the superconducting accelerator ELBE, a very small photo-neutron production target and detectors with time resolutions below 1 ns enables time-of-flight measurement with flight path in the order of 6 to 10 meters with reasonable energy resolution and intensity. The usable neutron energy spectrum reaches from about 10 keV up to 10 MeV with an integral flux of about 10^4 n/s/cm^2.

Measurements of the inelastic scattering from ^{56}Fe have been performed with a double-time-of-flight setup detecting the scattered neutron and photon in coincidence. By this method the cross section for the excitation of a single nuclear level can be determined even above the threshold of higher lying states without any corrections for branching and feeding. The energy dependence of the results shows nice agreement with previous measurements but a discrepancy in the absolute scale may give hints to unknown angular correlation effects. However, measurements of the photon-production using a single high purity germanium (HPGe) detector show a slightly higher cross section compared to evaluated data bases.

In a recent experiment the angular distribution of the emitted photons by the inelastic scattering from a natural zirconium sample was measured using a set of HPGe and $LaBr_3$ detectors. Preliminary data will be presented.

This work is supported by the EURATOM FP7 project CHANDA and by the German Federal Ministry of Education and Research (03NUK13A).

Neutron-nucleus calculations with Coupled Channels Hamiltonians

Luciano Canton
Istituto Nazionale Fisica Nucleare Sezione di Padova, Italy

It will be presented an overview of calculations of neutron-nucleus scattering made with coupled-channel methods. The focus is on the MCAS (Multi-Channel-Algebraic-Scattering) approach which allows treatment of both background and resonance physics. Resonance states and sub-threshold (bound) states can be reproduced when the effects of the Pauli principle are taken into account using the Orthogonalizing Pseudo-Potential. Neutron scattering is described mainly in Carbon and Oxygen isotopes. With light nuclei, the description turns out to be quite satisfactory, but when we turn the study into systems more and more complex, the current description becomes quite problematic.

Experiments for Benchmarking Elastic and Inelastic Neutron Scattering Evaluations of ^{238}U and ^{Nat}Fe

A.M. Daskalakis, E.J. Blain, and Y. Danon

Rensselaer Polytechnic Institute, Gaerttner LINAC Center, 110 8th St., Troy, NY 12180, USA

G. Leinweber, D.P. Barry, J.A. Burke, M.J. Rapp, and R.C. Block

Bechtel Marine Propulsion Corp., Knolls Atomic Power Laboratory P.O. Box 1072, Schenectady, NY 12301-1072, USA

The Rensselaer Polytechnic Institute (RPI) Linear Accelerator, located at the Gaerttner LINAC Center, was used to produce a pulsed neutron beam. A neutron beam with a burst width of 5 nanoseconds interacted with a scattering sample located 30 m from the neutron-producing tantalum target. The neutron signal was recorded as a function of time-of-flight (TOF) by eight EJ-301 liquid scintillator proton recoil fast neutron detectors. The detectors were positioned at a distance of 0.5 m from the scattering sample at seven angles. Neutrons from elastic scattering, inelastic scattering, and fission were discriminated from gamma events using pulse shape classification (PSC). Additional correction for gamma events that were initially misclassified as neutron events was included in the analysis. The RPI neutron scattering system was modeled in MCNP in order to calculate the response from several evaluated nuclear data libraries. A figure-of-merit (FOM) was used to compare the MCNP calculations in order to find the library that provided the best agreement with the experimental data. Two scattering samples were recently measured, ^{238}U and ^{nat}Fe. For both measurements, the JENDL-4.0 evaluation had the closest fit to the experimental data. The ^{238}U experiment had a unique role in the on-going development of the IAEA ^{238}U nuclear data library. ^{238}U experimental data were used as a benchmark to assess the performance of the new IAEA ^{238}U evaluation. The IAEA ^{238}U evaluation's FOM was calculated and compared with the FOM from other evaluated ^{238}U libraries. A new method was developed and incorporated into the analysis of the ^{nat}Fe experimental data to determine the inelastic-to-elastic scattering ratio. The inelastic-to-elastic scattering ratio was measured for a spectrum of incident neutron energies at seven scattering angles. MCNP was used to calculate several ^{nat}Fe nuclear data libraries' inelastic-to-elastic ratios. The calculated inelastic-to-elastic scattering ratios were compared with experimental data. Results can be used by evaluators to constrain nuclear data models.

Microscopic description of direct neutron emission in neutron induced reaction on actinides

M. Dupuis, E. Bauge, S. Hilaire, S. Péru, P. Romain* and T. Kawano†

*CEA, DAM, DIF

†Los Alamos National Laboratory

Stellar nucleo-synthesis models and nuclear energy applications require an accurate estimation of cross-sections for nucleon induced reactions for a large variety of target nuclei. As a medium energy nucleon hits a nucleus, three main mechanisms are clearly identified : a direct fast reaction, an intermediate pre-equilibrium reaction and a slow compound nucleus reaction. The fission process has also to be considered for actinides. Numerous nuclear reaction models have been developed to calculate the contributions to a particular exit channel stemming from these different reaction mechanisms. However, these models are usually built from phenomenological ingredients and may also contain one or several parameters that are directly fitted to match a selected set of experimental data. Consequently, any extrapolation to mass and energy regions where measurements are missing could be uncertain. Furthermore, some measurements on actinides are hardly reproduced by the nuclear reaction models commonly used as they lack of nuclear structure experimental information to constrain them well.

In order to improve the modeling of the neutron emission mechanisms, a microscopic model has been implemented to describe the direct emission mechanism : this direct emission includes the direct excitation of low energy discrete states and giant resonances, as well as the direct pre-equilibrium emission. This model is based on a microscopic description of the target states and does not rely on any adjustable parameters. It also provides compound nucleus reaction models with initial conditions, such as the direct component of (n,n') cross-sections and the spin distribution of the residual nucleus.

Calculations for axially deformed targets such as actinides are performed within a coupled channel framework. The semi-microscopic JLM convolution model [2] is used together with microscopic QRPA wave functions [3] to build the relevant optical and transition local potentials. This QRPA nuclear structure method, implemented with the Gogny D1S interaction, is suitable to describe collective excitations, low energy surface vibrations and giant resonances, that are needed to account for the direct emission cross sections, as it was demonstrated in a former study with the ^{90}Zr and ^{208}Pb targets [1].

A comparison between predictions and available data will be presented for (n,*x*n) inclusive cross sections, and (n,n'), (n,2n), (n,n'γ) and (n,2nγ) cross sections for neutron induced reactions below 20 MeV on ^{239}*Pu*, ^{238}U and ^{232}Th targets. We will discuss improvements in the description of (n,*x*n) reactions and examine how the initial conditions feeding CN models and provided by our microscopic modeling of direct reactions impact on observables.

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Spatial asymmetry of heavy nuclei as essential feature for predictions of compound nuclear cross sections and decay rates

E. Grosse[1], A.R. Junghans[2], and R. Massarczyk[1,2]
1) Institute of Nuclear and Particle Physics, Technische Universität Dresden,
Zellescher Weg 19, D-01069 Dresden, Germany
2) Institute of Radiation Physics, Helmholtz-Zentrum Dresden-Rossendorf,
Bautzner Landstrasse 400, 01328 Dresden, Germany

Nuclear level densities $\rho(E_x,J^\pi)$ are a very important input for various predictions of compound nuclear cross sections and decay rates. Here parameters extracted from differing experimental situations may enter and theory based calculations are needed. For the Fermi gas phase of nuclear matter the level density parameter 'a' is fixed by the Fermi energy [1] and for lower energies the situation is governed by pairing and the condensation energy [2,3]. To account for shell and surface effects in finite nuclei a respective adjustment of 'a' as well as a modification of the backshift energy were investigated. Whereas the influence of shells is controlled quite well by comparing mass formulae [4] to data, we treat the surface addition to 'a' as a global fit parameter. Actually this is the only free parameter we need to well describe average level distances $1/\rho$ of neutron capture resonances as observed for 146 even-even target nuclei with $51<A<253$ – leading to $½^+$-resonances. Avoiding any 'ad hoc' assumption about spherical or axial symmetry of nuclei excited to many MeV a significant enhancement of $\rho(E_x,J^\pi)$ results even if the deviation from symmetry is small. This ansatz and a factor for $\mathcal{R}$-symmetry [1,5] replace the proposed [8,9] collective enhancement factors. For low spins a simple approximation can be derived without explicit inclusion of moments of inertia; they play a role only for higher angular momenta to quantify the spin cut-off. The energy dependence of the state density is assumed to be exponential [3] in the pairing dominated phase below the phase transition point.
Admission of the breaking of axial symmetry, albeit often rather weak, also improves the consistency of a global description of Giant Dipole Resonance (IVGDR) shapes by the sum of 3 Lorentzians (TLO) [6]. These add up to the TRK sum rule, when theoretical predictions for the A-dependence of pole energies and spreading widths are used. Thus a combination of the corresponding photon strength to the abovementioned approximation for level densities seems intriguing. A comparison on absolute scale to cross section data for neutron capture in the range of unresolved resonances – including Maxwellian average cross sections compiled recently for $\langle E_n\rangle$=30 keV [7] – indicates three points:

(1) The *ad hoc* assumptions on shapes and collective enhancement in previous [8,9] calculations of compound nuclear rates should be replaced to directly account for broken symmetries.

(2) The low energy tail derived from the global triple Lorentzian (TLO) fit to IVGDRs does not have to be modified to obtain a value for the electric dipole strength, which agrees to data.

(3) Photon scattering and other experiments show that additional 'minor' de-excitation dipole strength may significantly contribute to capture yields.

The derived global parameterization is expected to allow predictions for radiative neutron capture also outside the valley of stability − important for nuclear astrophysics and for the transmutation of nuclear waste. Information on higher spins and excitation energies may be obtained from data resulting from fast neutron scattering. Looking at some of the rare respective investigations agreement to the parameterization proposed by us as well as interesting differences are found.

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Measurement of (n, xn γ) reaction cross section in W isotopes

Greg Henning[1,2,*], A. Bacquias[1,2], C. Borcea[3], O. Capdevielle[1,2], P. Dessagne[1,2], J.C. Drohé[4], M. Kerveno[1,2], A.J.M. Plompen[4], A. Negret[3], M. Nyman[4], A. Olacel[3] and G. Rudolf[1,2].

[1]*Université de Strasbourg, IPHC, 23 rue du Loess 67037 Strasbourg, France*

[2]*CNRS, UMR7178, 67037 Strasbourg, France*

[3]*Nat. Inst. Of Phys. And Nucl. Eng., Bucharest, Romania*

[4]*EU/ JRC-IRMM, Geel, Belgium*

Most of nuclear reactor developments are using evaluated data base for numerical simulations. However, the considered databases present still large uncertainties and disagreements. To improve their level of precision, new measurements are needed, in particular for (n, xn) reactions, which are of great importance as they modify the neutron spectrum, the neutron population, and produce radioactive species.

Tungsten is not an active element in nuclear reactors, but, because of its chemical and mechanical properties, it is used in many alloys. The interaction of neutrons with tungsten is therefore of importance for reactor physics, in particular for fusion reactors in which tungsten is one of the most exposed material to high energy neutrons.

From a theoretical point of view, tungsten isotopes are easier to describe than actinides as they do not present a neutron-induced fission channel, all the while being deformed, as for actinides. Experimental data on these nuclides would provide constraints on nuclear models as well as on the involved reaction mechanisms. Still, there are only a few measurements available today to test evaluations.

The IPHC group started an experimental program to measure (n, xn gamma) reaction cross sections using prompt gamma spectroscopy and neutron energy determination by time of flight [1-3]. Measurements of (n, xn gamma) cross section have been performed for $^{nat,182,183,184,186}W$. The experimental setup is installed at the neutron beam at GELINA (Geel, Belgium). The setup and the analysis will be presented, along with the first results for natural tungsten isotopes, which will be compared to the latest predictions from the TALYS code.

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Inelastic Neutron Scattering Cross Sections from Gamma-Ray Production Cross Sections in ^{54}Fe and ^{56}Fe

S. F. Hicks[1], J. R. Vanhoy[2], B.P. Crider[3], A.J. French[1], T.J. Howard[1], S.H. Liu[3], M.T. McEllistrem[3], R. L. Pecha[1], E.E. Peters[3], F.M. Prados-Estévez[3], T.J. Ross[3], Z.C. Santonil[1], and S.W. Yates[3].

[1]*University of Dallas, Irving, Texas 75062, USA*

[2]*U.S. Naval Academy, Annapolis, Maryland 21402, USA*

[3]*University of Kentucky, Lexington, Kentucky 40506, USA*

Neutron cross sections for scattering to excited levels in ^{54}Fe and ^{56}Fe have been deduced from γ-ray production cross sections following the ^{54,56}Fe(*n*,*n*'γ) reaction. Measurements were performed at the University of Kentucky Accelerator Laboratory using the neutron production and γ-ray detection facilities located there for incident neutron energies between 1.5 and 4.7 MeV. The total inelastic neutron scattering cross sections, as well as the cross sections for scattering to individual levels in ^{54,56}Fe, were determined at each incident neutron energy. Additional measurements were made on ^{nat}Al, ^{nat}Ti, and ^{nat}V to investigate procedures for normalizing absolutely the Fe cross sections. Absolute normalization is a challenge for these measurements, as ^{56}Fe is typically used as the cross section standard when deducing neutron scattering cross sections from γ-ray production cross sections. Results for ^{54,56}Fe will be presented, as well as the results from the Al, Ti, and V study of the absolute normalization procedure. Our results will also be compared to data-base evaluations and previously measured cross sections.

This research was supported by a grant from the U.S. Department of Energy - Nuclear Energy Universities Program: NU-12-KY-UK-0201-05 and the Cowan Physics Fund at the University of Dallas.

Introduction to the nELBE facility

A. R. Junghans, R. Beyer*, E. Grosse*, R. Hannaske, T. Kögler*, R. Massarczyk*, R. Schwengner, A. Wagner

Helmholtz-Zentrum Dresden-Rossendorf, Postfach 510119, 01314 Dresden, Germany

** also at Technische Universität Dresden, Dresden, Germany*

The compact neutron-time-of-flight facility nELBE at the superconducting electron accelerator ELBE of Helmholtz-Zentrum Dresden-Rossendorf has been rebuilt. A new enlarged experimental hall with a flight path of up to 10 m is available for neutron time of flight experiments in the fast energy range from about 100 keV to 10 MeV. As the neutron radiator consist only of a liquid lead circuit no moderated neutron are produced and also the background from capture gamma rays is very small [1]. As the electron bunch length is only a few ps the energy resolution in the MeV range is dominated by the timing resolution of the detectors. nELBE is intended to deliver cross section data of fast neutron nuclear interactions e.g. for the transmutation of nuclear waste and improvement of neutron physical simulations of innovative nuclear systems and also for fundamental research. The experimental programme consists of transmission measurements of neutron total cross sections, elastic and inelastic scattering cross section measurements, and neutron induced fission cross sections.

This work is supported by the EURATOM FP7 project CHANDA and by the German Federal Ministry of Education and Research (03NUK13A).

Neutron elastic scattering angular distribution in the resolved and unresolved resonance regions

Toshihiko Kawano, LANL
Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM 87545, U.S.A.

David A. Brown, BNL
National Nuclear Data Center, Brookhaven National Laboratory, Upton, NY 11973, U.S.A.

We derive a simple relationship between observed total cross sections and elastic scattering angular distributions for neutron induced reactions in the fast energy range by combining resonance theory and the optical model. This relationship enables us to estimate the anisotropy in the scattering angular distribution when experimental total cross section data are available. We apply this method to the angular distributions of Ni58 and Fe56 and compare with the evaluated values which are based on the experimental data. We also explore the method with Zr90 for which Multi-level Breit-Wigner resonance parameters are given [LA-UR-13-28335].

Status of (n,xnγ) reaction cross section measurements on actinides with the GRAPhEME set-up at GELINA

M. Kerveno[1], A. Bacquias[1], C. Borcea[3], O. Capdevielle[1], Ph. Dessagne[1], G. Henning[1], A. L. Negret[3], M. Nymann[2],A. Olacel[3], A. Plompen[2], G. Rudolf[1]

1) CNRS, Université de Strasbourg, UMR7178, IPHC, 23 Rue du Loess, 67037 Strasbourg, France

2) European Commission, Joint Research Centre, Institute for Reference Materials and Measurements, Retieseweg 111, B-2440 Geel, Belgium

3) National Institute of Physics and Nuclear Engineering "Horia Hulubei", Reactorului 30, 077125 Bucharest-Magurele, Romania

maelle.kerveno@iphc.cnrs.fr

For several years, our collaboration has developed an experimental set-up, named GRAPhEME (GeRmanium array for Actinides PrEcise MEasurements), dedicated to the studies of (n,xn) reactions on actinides. This device is installed at the GELINA Time of Flight facility (IRMM, Geel, Belgium) and uses the prompt γ spectroscopy method to measure (n,xn) reaction cross sections. The WINS workshop is the opportunity to present, every two years, the progresses of our work. In 2014, we would like to present last results on ^{238}U and ^{232}Th and to highlight the theoretical improvements performed in the description of such nuclear data but also the challenges which still exist in this field.

Measurement system of the neutron total cross section at J-PARC/ANNRI

K. Kino[1#], F. Hiraga[1], T. Kamiyama[1], Y. Kiyanagi[2], H. Harada[3], A. Kimura[3], F. Kitatani[3],

S. Nakamura[3], M. Igashira[4], T. Katabuchi[4], M. Mizumoto[4], and J. Hori[5]

[1]Graduate School of Engineering, Hokkaido University, Sapporo 060-8628, Japan
[2] Graduate School of Engineering, Nagoya University, Nagoya 464-8603, Japan
[3] Japan Atomic Energy Agency, Tokai, Ibaraki 319-1195, Japan
[4] Research Laboratory for Nuclear Reactors, Tokyo Institute of Technology, O-okayama, Meguro-ku, Tokyo 152-8550, Japan
[5] Research Reactor Institute, Kyoto University, Kumatori, Osaka 590-0494, Japan

 #) corresponding author: E-mail k-kino@eng.hokudai.ac.jp

ANNRI at J-PARC is the beamline for neutron capture cross-section measurements by the combination of an intense pulsed neutron beam and prompt gamma-ray spectrometers (Ge and NaI(Tl)). It is used for the nuclear data, nuclear astrophysics, microanalysis, etc. On the other hand, the neutron total cross-section is another method to obtain resonance parameters. We have constructed the measurement system of the neutron total cross-section. Fig. 1 shows the cross section of ANNRI. There is the Ge spectrometer at 21.5 m from the neutron source and the NaI(Tl) spectrometer at 27.9 m. We set a rotary sample changer at 25 m. This instrument reduces the systematic uncertainty by changing samples periodically. There is a Li-glass neutron detector at 28.5 m, which detect transmitted neutrons of the sample. We obtained preliminary data of Tc-99, which is one of the LLFPs (Long-Lived Fission Products) and observed resonances on the time-of-flight spectrum. In this presentation, we introduce the measurement system and preliminary experimental data. This work was supported by JSPS KAKENHI Grant Number 22226016.

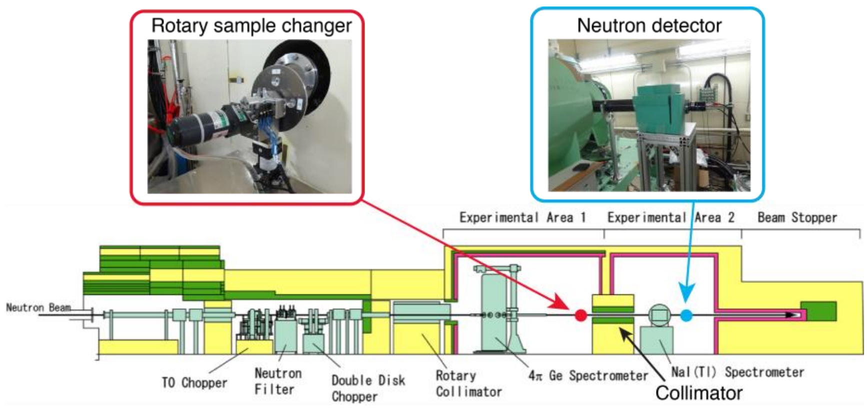

Fig. 1 Cross section of ANNRI.

R-matrix Evaluation of ^{56}Fe Including Elastic, Inelastic, and Angular Dependent Cross Sections

L. Leal,[1] A. Daskalakis,[2] Y. Danon,[2] and A. Plompen[3]

1) Oak Ridge National Laboratory, P. O. Box 2008, Oak Ridge, TN, USA
2) Gaerttner LINAC Center, Rensselaer Polytechnic Institute (RPI), Troy, NY, USA
3) European Commission, Joint Research Centre, Institute for Reference Materials and Measurements (IRMM)

leallc@ornl.gov

A resolved-resonance evaluation of the ^{56}Fe+n isotope performed with the computer code SAMMY has recently been proposed for testing in the Collaborative International Evaluated Library Organization (CIELO) project. New features in this evaluation are 1) the extension of the resonance range up to 2 MeV using the R-matrix limited formalism, 2) use of high-resolution transmission experimental data measured at the RPI linear accelerator, 3) inelastic data measured at the Geel Electron Linear Accelerator (GELINA) at IRMM and 4) a representation of the double-differential elastic and inelastic cross sections from resonance parameters. Below the threshold energy of the first inelastic state (~ 847 keV), there exists double-differential elastic measurements performed at the Oak Ridge Linear Accelerator (ORELA) that permit resonance spin assignments leading to a better fit of the double-differential cross-section data. However, above the first inelastic threshold, very few measurements are available for the double-differential elastic experimental cross section and essentially no measurements for the inelastic cross section. Recently, an effort has been taken at RPI to address the lack of angular elastic and inelastic data for ^{56}Fe (abstract presented at this workshop). The objective of this workshop presentation is to show the accomplishments achieved by using the resonance parameters to represent the existing experimental data. The recently measured RPI data will be included in the resonance-parameter evaluation that is presented during the workshop.

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Neutron induced background for neutrinoless double beta decay experiments

A. Negret[1], C. Borcea[1], A. Olacel[1] and A.J.M. Plompen[2]

[1] *IFIN-HH, Romania*
[2] *EC-JRC-IRMM, Belgium*

The double beta decay of a nucleus (A,Z) occurs when the conventional beta decay towards the (A,Z+1) nucleus is energetically impossible while the decay towards the (A,Z+2) nucleus is allowed. 35 natural isotopes can undergo such decay. The process can be regarded as a succession of two β-decays: two neutrons are converted into two protons while two electrons and two antineutrinos are emitted. However, if the neutrino is a Majorana particle (i.e. if it is its own antiparticle) then the double beta decay should also occur without neutrino emission. The process, unconfirmed experimentally up to now, would violate the conservation of the lepton number and, according to theoretical predictions would have a very long halflife.

Nevertheless the confirmation of neutrinoless double beta decay would have profound implications in Astrophysics and in the mass theories. Therefore a significant experimental effort is currently spent towards an experimental proof of this decay mode. Basically, the experiments are based on the idea of increasing as much as possible the number of parent nuclei while keeping the whole measurement completely shielded from any sources of background. One measures the energy deposited in the large mass of the parent isotope trying to identify the specific value of the neutrinoless double beta decay. In case of ^{76}Ge this is $Q_{\beta\beta}(^{76}Ge)$ = 2039.06 keV while for ^{130}Te this is $Q_{\beta\beta}(^{130}Te)$ = 2527.51 keV.

One key point of all experiments is the background. Deeply underground where the experiments are conducted the neutrons represent the most significant source of background. They are created either by high energy cosmic muons or from fission and (a,n) reactions occurring in the surrounding rocks. Further, inelastic scattering of neutrons can produce gamma rays that represent sources of background in the energy regions of interest.

During the last years we collected very precise neutron inelastic cross section data on various structural materials using the GAINS spectrometer at the GELINA neutron source of EC-JRC-IRMM. A scan of all these data in the gamma energy region around $Q_{\beta\beta}(^{76}Ge)$ and $Q_{\beta\beta}(^{130}Te)$ can produce significant results for the background estimation for the neutrinoless beta decay experiments. We present here the result of our investigation on ^{206}Pb, ^{56}Fe, ^{28}Si, ^{24}Mg and ^{12}C identifying the cases where neutron inelastic scattering may represent a matter of concern and determining the values of cross section as a function of neutron energy.

Neutron Inelastic Measurements at LANSCE for Applications and Science

R.O. Nelson

Los Alamos Neutron Science Center (LANSCE)
Los Alamos National Laboratory

Accurate inelastic scattering cross sections for neutrons are important for a wide range of applications. Recently, coordinated efforts have begun through the CIELO collaboration[1] to improve the accuracy of the international evaluated database libraries with first efforts focusing on the priority nuclei, ^{1}H, ^{16}O, ^{56}Fe, $^{235,238}U$, and ^{239}Pu. Previous inelastic gamma-ray measurements at LANSCE have provided data on ^{16}O, ^{56}Fe, and ^{238}U, and further work may help to refine uncertainties. Current neutron inelastic gamma-ray measurements at LANSCE include efforts to define improved neutron-induced gamma-ray reference cross sections for more accurate relative cross section measurements. These measurements focus on LiF(n,n'$\gamma\gamma$) for the ^{7}Li(n,n'γ=478 keV) cross section and Ti(n,n'γ) for the ^{48}Ti(n,n'$\gamma\gamma$ =984 keV) cross section. Measurements relative to Fe(n,n'$\gamma\gamma$) have been made as well as those using the ^{238}U(n,f) cross section as a reference. In addition, gas samples have been measured, such as ^{86}Kr providing new spectroscopic information as well as cross section data. ^{86}Kr is one of a number of nuclei that is a candidate detector for neutrinoless-double-beta-decay searches. The high-energy ($1 < E_n < 400$ MeV) neutrons at LANSCE provide a check of gamma-ray backgrounds produced by cosmic-ray produced neutrons that penetrate deep underground where such experiments are carried out to reduce backgrounds. Also, at LANSCE, the Chi-Nu experiment to measure prompt fission neutron spectra consists of large arrays of neutron detectors. These arrays provide an alternate means of studying inelastic neutron scattering using high-resolution gamma-ray tagging that has been demonstrated previously. Recent results of LANSCE experiments will be presented and plans for measurements will discussed.

1) https://www.oecd-nea.org/science/wpec/sg40-cielo/SG40.pdf

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γ-ray production cross sections of inelastic neutron scattering on natural molybdenum

M. Nyman[1], **A. Plompen[1]**, **C. Rouki[1]**

[1]*European Commission, Joint Research Centre, Institute for Reference Materials and Measurements, Retieseweg 111, B-2440 Geel, Belgium*

γ-ray production cross sections of inelastic neutron scattering have been measured for molybdenum using the (n,n'γ)-technique. The experiment was performed at the GELINA facility at the Institute for Reference Materials and Measurements (IRMM) with the Gamma Array for Inelastic Neutron Scattering (GAINS) setup. GAINS consisted of eight high purity germanium detectors at the time of this experiment. The sample was made of natural molybdenum, which includes seven isotopes (*A* = 92, 94, 95, 96, 97, 98, 100). The presence of so many isotopes in the sample leads to overlapping peaks in the spectra, which limits the amount of data that can be extracted from the analysis. Nevertheless, a total of 31 γ rays from the seven isotopes were analysed and γ-ray production cross sections were determined. Comparisons to other experimental results were made when such data was available. Also comparisons with model calculations made with the TALYS code will be shown. In a publication by Garrett *et al*. [1] a normalization of experimental data was done using a calculated gamma-production cross section for the 1510 keV $2^+ \rightarrow 0^+$ transition in ^{92}Mo. A difference of about 40% between the present data for the 1510 keV γ ray and that reported in [1] was found.

[1] P. E. Garrett *et al*., Phys. Rev. C 62, 054608 (2000).

Neutron inelastic cross section measurements for ^{24}Mg

A.Olacel[1, 2], C. Borcea[1], A. Negret[1], P. Dessagne[3], M. Kerveno[3], A.J.M. Plompen[4]

[1] Horia Hulubei National Institute for Physics and Nuclear Engineering, Reactorului 30, 077125 Bucharest-Magurele, Romania
[2] University of Bucharest, Faculty of Physics, Atomistilor 405, 077125, Bucharest-Magurele, Romania
[3]CNRS, Universite de Strasbourg, UMR7178, IPHC, 23 rue du Loess 67037 Strasbourg, France
[4] European Commission, Joint Research Center, Institute for Reference Materials and Measurements, B-2440 Geel, Belgium

The neutron inelastic scattering measurement of ^{24}Mg was performed at GELINA (Geel Linear Accelerator), the neutron source operated by EC-JRC-IRMM, Belgium, using GAINS (Gamma Array for Inelastic Neutron Scattering) spectrometer with 7 large volume HPGe detectors placed at 110^{o} and 150^{o} with respect to the beam direction. The setup is installed at 200 m from the neutron source. The neutron flux was determined with a ^{235}U fission chamber. The gamma production cross sections, the level cross sections and the total inelastic cross section were calculated. The gamma production cross sections and the level cross sections were compared with the theoretical calculations performed with the TALYS 1.6 code using the default parameters. The total inelastic cross section was compared with the theoretical calculations performed with TALYS 1.6 code, with the ENDF/B-VII evaluations and previous experimental results. TALYS calculations using the default parameters describe fairly well our experimental data. The total uncertainty on the gamma production cross-section of the main transition and on the total inelastic scattering cross section was around 5% up to 7 MeV and less than 15% up to 18 MeV.

Neutron Elastic Scattering with a New Scintillator Array

E. Pirovano, A.J.M. Plompen, M. Nyman, R. Wynants, G. Alaerts

European Commission, Joint Research Center, Institute for Reference Materials and Measurements, B-2440 Geel, Belgium

A new setup for the study of neutron elastic scattering is being developed at the GELINA (GEel LInear Accelerator) facility, the pulsed white neutron source operated by the EC-JRC-IRMM. The setup consists of an array of eight EJ301 liquid scintillation detectors, which will be used to investigate the distribution of neutrons scattered from samples irradiated with the neutron beam of GELINA. The scintillators are installed at specific angles with respect to the direction of the beam; these are chosen so that the total elastic cross-section can be obtained by numerical integration of the measured differential cross-section, by applying the Legendre-Gauss quadrature method.

The status of development of the setup will be shown, including the establishment of a new beam line with a fast spectrum, characterisation of the beamline and the detectors and first test measurements with carbon. The tests carried out up to the present day mainly consist in calibration measurements with different gamma sources. The objective is to characterise the response and the efficiency of the scintillators, and to tune the settings of the data acquisition system. For each detector, the resolution function and the light output functions for electrons and protons are determined by fitting with a least square method the theoretical response of the detectors folded with the resolution function to the experimental pulse height spectra. To model the scintillators and calculate their theoretical response, the MCNP transport code from Los Alamos National Laboratory is being used.

The plan for the forthcoming months is to test the whole setup by measuring cross-section of carbon-12. The purpose of this experiment is to refine the experimental procedure, and to validate and consolidate the data analysis method. Following successful characterisation, the new setup will be used for the study of cases of interest such as Fe and Na.

The need and new developments for improved scattering data for energy applications.

Arjan Plompen

European Commission, Joint Research Center, Institute for Reference Materials and Measurements, B-2440 Geel, Belgium

Neutron scattering, both elastic an inelastic, is important in fission energy applications and beyond. A summary will be given of recent interests that emerged from the high priority request list for nuclear data and subgroups of WPEC, as well as from various national and collaborative projects.

A short summary of the activity of the European CHANDA project in this field will be presented with an emphasis on the outstanding points that will be tackled. The presentation aims at starting a discussion among the participants at the workshop to develop new collaborative efforts.

Sensitivity to scattering cross sections in the simulations of quasi-differential and integral experiments

A. Trkov and R. Capote

NAPC-Nuclear Data Section, International Atomic Energy Agency, Vienna, Austria

Neutron scattering properties of materials are important parameters that affect shielding and reflective properties of materials in nuclear reactor design. They are of importance for safety aspect, as well as for the economy of operation (fuel mass, shielding thickness and composition, etc.).

The Working Party on Evaluation Cooperation of the OECD set up a subgroup WPEC-SG40 (alias CIELO) to focus on the evaluated nuclear data of the major nuclides in reactor technology, namely ^{1}H, ^{16}O, ^{56}Fe, ^{235}U, ^{238}U and ^{239}Pu. Different research groups in various parts of the world are working on improved evaluated nuclear data and their uncertainties for these nuclides; the ultimate test of improvement is the performance of the data in simulating integral experiments.

The focus of the present work is on the analysis of (quasi) integral experiments that are sensitive to the scattering properties of ^{238}U, ^{56}Fe and ^{16}O. However, one must be aware of the sensitivity to the neutron source; hence the prompt fission neutron spectrum of ^{235}U is also mentioned.

Recently, a series of experiments were performed at the Rensselaer Polytechnic Institute (RPI), USA in which short pulses of neutrons with a broad spectrum were directed onto a target at some distance to provide the incident energy resolution. Neutron yields were measured by a system of detectors placed at different angles. Simulations of these experiments for ^{238}U helped us to fine-tune the inelastic cross section and demonstrated the importance of proper treatment of the anisotropy in the compound-elastic cross section. A similar analysis will be performed for ^{56}Fe.

The form of the R-Matrix resonance theory is available in the ENDF-6 Format for resonance parameter representation that allows elastic (and inelastic) scattering angular distributions to be reconstructed from the resonance parameters. Such a data file for ^{56}Fe was submitted by the research group from the ORNL to the CIELO project. The detailed energy resolution of the angular distributions results in very large data files that can be difficult to handle. Our analysis shows that replacement of the angular distributions of ^{56}Fe from ENDF/B-VII.1 library with those reconstructed from the resonance parameters has a significant impact on some criticality benchmarks. Work is in progress to resolution-broaden the resonant angular distribution and check if the differences come from the detailed structure or from the inherent differences in the averaged angular distributions.

Within an IAEA project on Neutron Cross Section Standards an attempt is made to evaluate the prompt fission neutron spectrum of ^{235}U. Preliminary results indicate a decrease in the average neutron energy, which has a significant effect on small critical assemblies of highly-enriched uranium solutions with a high leakage fraction. Cancellation effects due to ^{16}O data were studied on two competing evaluations, one by Leal from ORNL and the other by Hale from LANL. By successive substitution of parts of the new evaluations the breakdown of the contributions to the reactivity change was determined.

Elastic and Inelastic Neutron Scattering Cross Sections on ^{54}Fe

S.H. Liu[1], M.T. McEllistrem[1], J.R. Vanhoy[2], S.F. Hicks[3], B.P. Crider[1], A.J. French[3], E.A. Garza[2], S.L. Henderson[3], T.J. Howard[3], S.Nigam[1], R. L. Pecha[3], E.E. Peters[1], F.M. Prados-Estévez[1], , B.G. Rice[2], T.J. Ross[1], Z.C. Santonil[3], L.C. Sidwell[3], J.L. Steves[2], B.K. Thompson[2], and S.W. Yates[1]

[1]*University of Kentucky, 40506 Lexington, Kentucky USA*
[2]*U.S. Naval Academy, 21402 Annapolis, Maryland USA*
[3]*University of Dallas,75062 Irving, Texas USA*

Neutron elastic and inelastic scattering cross sections were measured for the lowest levels of ^{54}Fe at the University of Kentucky Accelerator Laboratory (www.pa.uky.edu/accelerator/), using nanosecond pulsed beams and time-of-flight techniques. Nine angular distributions were measured for incident neutron energies between 2.0 and 8.0 MeV. An overview of neutron production and detection, data acquisition, and data analysis will be presented. Issues necessary to achieve optimum accuracy and precision of the cross sections will be described; these include measurement of the energy-dependent detection efficiency of the C_6D_6 detector and data corrections for sample-size effects of the 1.45 cm diameter, 1.5 cm height ^{54}Fe sample, including multiple-scattering and neutron-attenuation corrections. Absolute cross sections were obtained by normalizing relative ^{54}Fe cross sections to the *np* neutron scattering standard. Results are compared with data from previous measurements, data-base evaluations, and coupled-channels calculations using the code ECIS06.

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List of registered participants

Name	Affiliation	email
Daniel Bemmerer	HZDR, Dresden	d.bemmerer@hzdr.de
Bastian Beskers	Johannes Gutenberg University Mainz	beskers@uni-mainz.de
Roland Beyer	HZDR, Dresden	roland.beyer@hzdr.de
Luciano Canton	INFN, Padova	luciano.canton@pd.infn.it
Ron Dagan	KIT, Karlsruhe	ron.dagan@kit.edu
Yaron Danon	Rensselaer Polytechnic Institute, Troy NY	danony@rpi.edu
Adam Daskalakis	Rensselaer Polytechnic Institute, Troy NY	daskaa@rpi.edu
Philippe Dessagne	IPHC/CNRS Strasbourg	philippe.dessagne@iphc.cnrs.fr
Marc Dupuis	CEA/DAM/DIF, Arpajon	marc.dupuis@cea.fr
Eckart Grosse	Technische Universität Dresden	E.Grosse@tu-dresden.de
Greg Henning	IPHC/CNRS Strasbourg	ghenning@iphc.cnrs.fr
Sally Hicks	University of Dallas, TX	hicks@udallas.edu
Arnd Junghans	HZDR, Dresden	a.junghans@hzdr.de
Toshihiko Kawano	LANL, Los Alamos, NM	kawano@lanl.gov
Maëlle Kerveno	IPHC/CNRS Strasbourg	maelle.kerveno@iphc.cnrs.fr
Koichi Kino	Hokkaido University, Sapporo	k-kino@eng.hokudai.ac.jp
Toni Kögler	HZDR, Dresden	t.koegler@hzdr.de
Luiz Leal	ORNL, Oak Ridge, TN	leallc@ornl.gov
Gregory Leinweber	Bechtel Marine Propulsion Corporation Knolls Atomic Power Laboratory	leinwg@rpi.edu
Alexandru Negret	Horia Hulubei National Institute for Physics and Nuclear Engineering, Bukarest	alnegret@tandem.nipne.ro
Ron Nelson	LANL, Los Alamos, NM	Rnelson@lanl.gov
Ralf Nolte	PTB, Braunschweig	ralf.nolte@ptb.de
Markus Nyman	EC JRC IRMM, Geel	markus.nyman@ec.europa.eu
Adina Olacel	Horia Hulubei National Institute for Physics and Nuclear Engineering, Bukarest	aolacel@tandem.nipne.ro
Elisa Pirovano	EC JRC IRMM, Geel	elisa.pirovano@ec.europa.eu
Arjan Plompen	EC JRC IRMM, Geel	arjan.plompen@ec.europa.eu
Melanie Scheibelhut	Johannes Gutenberg University Mainz	scheibelhut@uni-mainz.de
Andrej Trkov	IAEA, Vienna	a.trkov@iaea.org
Jeff Vanhoy	US Naval Academy, MD	vanhoy@usna.edu
Andreas Wagner	HZDR, Dresden	A.Wagner@hzdr.de