ARIEL - H2020 Final Workshop

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New cross section measurements on Fe performed at the GELINA facility

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Studies of neutron induced reactions are of great interest, not only for their importance to fundamental research in Nuclear Physics but also for practical applications. Iron is a major structural material, widely used in nuclear technology applications, especially in nuclear reactors where it can be found in several places, from the core structures to reflectors, etc. For this reason, accurate neutron data are indispensable for the design and reliable operation of such facilities. Solving the observed discrepancies between the current evaluated nuclear data libraries of iron thanks to new experimental results in the fast neutron energy range constitutes an important objective for simulating advanced reactor systems, such as Generation-IV reactors.

New cross section measurements on Fe were carried out at the neutron time-of-flight facility GELINA. On the one hand, a scattering experiment was performed to determine the differential cross section of neutron elastic and inelastic scattering on 56Fe in the fast neutron energy region, using an enriched sample. For the detection of the scattered neutrons, the ELISA (ELastic and Inelastic Scattering Array) spectrometer was used. The array consists of 32 liquid organic scintillators and a 235U fission chamber for the measurement of the neutron flux. On the other hand, transmission experiments on natFe were performed at the 50 m measurement station of flight path 4. The moderated flux configuration (MFC) provided a neutron spectrum with energies from a few eV to hundreds of keV. The neutrons were detected by a Li-glass scintillator enriched in 6Li. Two natural iron metallic discs of 1.2 cm and 4.5 cm thickness were used.

In this presentation, the analysis procedure along with the results of each experiment are presented.

Session 3 / 3

The Double-Energy Double-Velocity fission spectrometer VERDI

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The particle spectrometer VElocity foR Direct particle Identification (VERDI) allows measurements of fission fragment (FF) mass distributions with a resolution from 1 to 2 mass units, by means of the detection of two fragment velocities and two fragment energies. VERDI consists of two arms with up to 32 Passivated Implanted Planar Silicon (PIPS) detectors and a Micro Channel plate (MCP) each. The MCPs provide the start signal used to trigger the time-of-flight (ToF) measurement, and the Si

detectors are used both for energy detection and for providing the stop signal. The main challenge to achieving accurate fragment velocities is the so-called plasma delay time (PDT) phenomena in the PIPS detectors.

In this talk, we will first present the results of a dedicated experimental campaign at the LOHENGRIN fragment-recoil spectrometer, designed to determine the PDT characteristics of PIPS detectors. The PDT effect was systematically investigated as a function of mass and energy, using a dedicated time-of-flight setup. In addition, the pulse height defect (PHD) was determined, simultaneously. The studies were conducted for five PIPS detectors, with kinetic energies and mass numbers ranging from 20 to 110 MeV and 85 to 149, respectively. Using digital signal processing, an excellent timing resolution was achieved, reaching as low as 60 ps (one σ) for the heavy ions. We will present the complete set of PDT and PHD data for all detectors used in the experiment campaign, and we will discuss the mass- and energy-dependent trends of the PDT and PHD. Furthermore, the inter-detector comparison of the PDT and PHD data will be presented. We will conclude on the plasma delay studies by presenting the newly developed two-dimensional parameterisation of the PDT.

In the second part of the talk, we will shed light on the recent progress of the spectrometer at JRC Geel. The challenges and achievements in the re-operation and upgrade of VERDI will be highlighted. This includes the characterization of the performance of the PIPS detectors mounted on a new flange employing new pre-amplifiers. Moreover, we will present the upgrade of both MCPs of VERDI, including the installation of a new position-sensitive MCP. The results of the position-sensitivity analysis and the optimal operation of the MCP will be discussed. Another aspect is the use of a new DAQ framework, called Acquisition and Broadcast of Collected Data (ABCD). ABCD has been coupled to new digitizer cards with superior sampling frequency and number of bits, to assure optimal energy and TOF resolutions. All these successful developments facilitate new fission experiments with VERDI, that will be performed in 2024.

Session 2 / **4**

First experiments at the Neutrons For Science Facility

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The neutrons for science (NFS) is the running facility of SPIRAL-2 located at GANIL (France). Its unique neutron beams in the 1-40 MeV range, produced by the interaction of proton or deuteron beams with lithium or beryllium converters, make NFS a perfect facility for fast neutron induced reaction studies. NFS is one of the installations of the ARIEL project. Several experiments have been performed since 2020 covering a large number of physics cases, from fundamental research to industrial applications. After a description of the facility, physics cases studied at NFS and some of the already performed experiments will be presented.

Session 3 / **5**

Isomeric yield ratio measurements of Th(α,f) at 32 MeV

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The mechanism responsible for the generation of the large angular momenta observed in fission fragments 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 yield ratio between spin isomers produced in a fission reaction. For this reason, the isomeric yield ratios of twenty-one FFs were measured for Th(α,f) at 32 MeV. To do so, we applied the phase-imaging ion-cyclotron-resonance (PI-ICR) technique using the JYFLTRAP double Penning trap at the IGISOL-4 facility at the University of Jyväskylä. This reaction was chosen in order to compare the newly measured IYR with results from earlier campaigns from U(p,f) at 25 MeV and data in the literature to investigate, e.g., the impact of the initial spin of the compound system on the IYR. In the measurement, isomers are separated with a high mass resolving power, allowing e.g. to resolve the Sn-129 isomeric pair, with a mass difference corresponding to 35 keV. The separated ions are then projected onto a position sensitive detector (MCP). The images produced are then analyzed to calculate the number of ions detected for each state, using angular projection and clustering methods. The measured IYRs 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 the half-lives. In addition, a newly commissioned multi-reflection time-of-flight mass spectrometer was used to measure eight mass spectra of different isobars. Preliminary results for several measured IYR will be presented and discussed.

Session 6 / 6

Neutron and photon yields for the 51V(p,n)51Cr reaction near threshold

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The characterization of the neutron and photon yields of reaction 51V(p,n)51Cr at energies close to the threshold have been performed at JRC-MONNET on October 2023.
To ensure a thorough measurement, we employed the time-of-flight technique to measure angle-energy neutron yields at various angles. The primary outcomes of our experiment include Time-of-Flight (TOF) spectra at different angles, followed by deconvolution into energy spectra at those angles. This presentation will encompass dN/dE for each angle, along with the corresponding neutron yields. Our experiment has also encompassed the determination of the 51V(p,n)51Cr reaction threshold through activation by measuring the decay of 51Cr. In addition, we performed a photon yield measurement of our reaction to comprehensively understand the whole production process.
Complementary measurements were undertaken to glean more insights into the reaction and the experiment. First, we measured the energy neutron yield of the 7Li(p,n)7Be reaction at 1912 keV, a well-established neutron field with available angle-energy spectra and yields at each angle, serving as a valuable reference. Second, we conducted an energy threshold sweep of the Vanadium reaction to ensure accuracy in our values.
During the experiment, we observed significant resonance effects of vanadium in the considered thick target. This realization prompted an unplanned transmission measurement using vanadium. Employing lithium as a neutron source, we examined how the known neutrons at 1912 keV proton energy transmitted through our vanadium thick target. This additional step yielded valuable insights into transmission characteristics within the scope of our experiment.
The primary goal of this characterization is to utilize the vanadium neutron source due to a scarcity of data on angle-energy yields. Potential applications include monoenergetic neutron beams, validation of nuclear data, and neutron capture therapy. The complete experiment, with time-of-flight and activation measurements, is intended to be part of the training of Antònia Verdera. Since, the study of the 51V(p,n)51Cr reaction is the major part of her PhD Thesis. Ariel has granted funding

for the experiment and for a 12-week stay in the JRC-Geel to Antònia Verdera as PhD student. Ariel has also supported the attendance of the Spokesperson of the experiment (Javier Praena) and thesis supervisor of Antònia.

Session 2 / 7

Shedding new light on the structure of ^{56}Ni using (n,3n) reaction at NFS

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Systematic studies of nuclear reactions are essential to the development of modern nuclear physics. Understanding and predicting the evolution of nuclear structure and the formation of novel phenomena in atomic nuclei can be improved by studying atomic nuclei in the phase space of Shell structure, magic numbers, angular momentum, and excitation energy. Prompt γ-ray spectroscopy of discrete states is a powerful method to achieve this goal. We want to re-investigate the nuclear structure of the doubly magic nuclei ^{56}Ni using the (n,3n) reaction from ^{58}Ni. The nuclei near ^{56}Ni are of particular interest as they are amenable to different microscopic theoretical treatments while studying the competition between single-particle and collective excitation. The collective states in ^{56}Ni involve multiparticle multi-hole excitations across the $N = Z = 28$ shell gap from the 1f$_{7/2}$ shell to the 2p$_{3/2}$, 1f$_{5/2}$, and 2p$_{1/2}$ orbits. Excitation to the higher lying 1g$_{9/2}$ orbit are necessary to explain the observed rotational bands in Cu and Zn. At high excitation energies, reaction studies have revealed evidence for hyper-deformed resonances in the ^{56}Ni compound. While the structure of ^{56}Ni has been intensively investigated using charged particle or heavy ions collisions, the pure neutron probe was never used. The (n,xn) reactions are a long standing reaction mechanism used in the nuclear data evaluation but rarely used in the framework of nuclear structure. For the first time, using the unprecedented neutron flux at $\sim$20 - 30 MeV at the NFS facility of GANIL-Spiral2, ^{56}Ni can be populated from ^{58}Ni in a (n,3n) reaction with a cross-section of 2 mb opening a new probe and possibly new aspect of the nuclear structure of this doubly magic nucleus. Co isotopes are also produced involving (n,p/d/t) reaction and comparison with pure neutron channels can be studied. In this project, we propose to perform a prompt gamma spectroscopy of ^{56}Ni using the EXOGAM array at NFS using the (n,3n) reaction. Such new spectroscopic information is also relevant for nuclear reaction mechanism formalism (like TALYS) and nuclear data evaluation. For nuclear structure, the main motivation is the search for low spin (J=2 or 4) states from 3 to 10 MeV excitation energy possibly populating the 0^+ states at 3956 keV, 6654 keV and 7903 keV observed only in ^{58}Ni(p,t)^{56}Ni reactions. The TALYS cross-section calculation as a function of incident neutron energy is shown in Fig. 1.

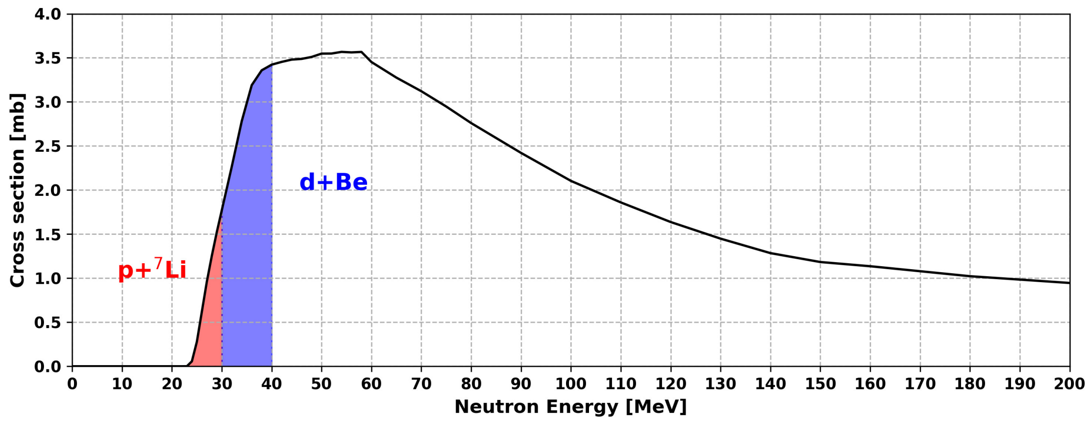

Figure 1: ^{56}Ni cross section as a function of neutron energy from ^{58}Ni. The red area shows the neutron beam energy covered by p-induced reaction at NFS and the blue area corresponds to d-induced reaction.

The maximum cross section is predicted to be at 40 MeV, slightly higher than the end-point of NFS. p+Li/Be allows to reach up to the [20-30] MeV range, whereas d+Be up to a broader [25-40] MeV range.The experiment was performed in October 2023. During 2 weeks, a high energy neutron beam produced by a primary beam of 10 μAmps of ^{2}H, bombarded a 1mm thick Ni target. The prompt gamma rays selected on the fastest neutron using the Time of Flight information have been detected by 12 EXOGAM clovers placed at 15 cm off the beam axis. About 1.6×10^{10} $\gamma\gamma$ coincidences have been sorted after the AddBack procedure. ^{56}Ni decay was observed and a large amount of $\gamma\gamma$ coincidences Co have been sorted. The very preliminary analysis of the experiment will be presented. Limitation of the use of large germanium volume detector with fast neutron will be also shown.

This experiment is a pioneering work in the study of the nuclear structure studies using large gamma-array and fast neutron and is only possible at GANIL-Spiral2 today. If successful, this program will open new opportunity at the NFS facility.

Session 5 / 8

Towards improvement of the 238U level scheme using gamma-spectroscopy of the (n, n'gamma) reaction

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Improving the knowledge of the neutron population of actual and future reactors is required to improve the accuracy of neutronics simulations. Among others, this population is driven by (n, xn) reactions, including inelastic scattering, these reactions changing the number of neutrons in a reactor core and their speed. Their cross sections are however, still nowadays, not precisely known. That is why the neutron inelastic scattering cross section of ^{238}U, main nucleus of a nuclear reactor cores fuel, features in the High Priority Request List 1.
The prompt γ-ray spectroscopy coupled to time-of-flight measurements is one method to measure the (n, xn') cross section. The total (n, xn') cross sections can be inferred from the measured (n,xnγ)

cross sections and the level scheme information [2]. However, the ^{238}U level scheme knowledge is still very incomplete: the discrete states are assumed to be fully known up to 1.3 MeV only [3] and the average uncertainties on branching ratios in ENSDF [4] are of 8%. Moreover, sensitivity calculations performed with the TALYS code [5] showed that modifying the branching ratios of 10% in the input's code can have an impact of up to 4% on (n, n'γ) cross sections [2].
It has therefore become of high importance to improve the level scheme knowledge. An initiative to experimentally reinvestigate the ^{238}U nucleus structure has been launched with the γ-γ coincidences method thanks to the coupling between the ν-Ball γ-spectrometer [6] and the LICORNE neutron source [7, 8] of the ALTO facility. Indeed, the LICORNE source allows the production of a pulsed quasi-mono-energetic kinematically focused neutron flux thanks to the p(^{7}Li, n)^{7}Be inverse reaction, the produced ^{7}Li beam impinging on a ^{1}H-gas cell. The neutron flux impinged then on the ^{238}U target. The γ produced have been collected by the ν-Ball γ-spectrometer thanks to the two rings of 12 HPGE-Clover detectors composing it.
Two ν-Ball campaigns have been led in 2018 and 2022. The analysis of the γ-γ coincidences matrix obtained during the first ν-Ball campaign with a neutron flux of a mean energy of 2.1 MeV has been performed thanks to the Radware software [9]. The data obtained during the second ν-Ball campaigns, with a much higher statistics and much clearer, are now used to double-check the obtained level scheme. In total, 91 γ and 51 levels registered in ENSDF have been confirmed and 125 new γ and 51 new levels have been found.

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Session 5 / 9

Radiative capture study of silver γ-decay spectra using γγ-coincidences

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Determination of the accurate values for gamma transitions, level scheme, nuclear level density and radiative strength functions is crucial in low-energy nuclear physics. Accurate experimental values of those parameters are very important for both fundamental and applied research. The two-step gamma cascades method, involving the detection of gamma coincidences following thermal (cold) neutron capture, i.e. the $(n_{th}, 2\gamma)$ reaction, is a highly suitable technique for obtaining spectroscopic

data and insights into level density and radiative strength functions. The experiment using an enriched ^{107}Ag target was conducted at the PGAA station of the Budapest Neutron Centre, Budapest, Hungary, with thermal neutron beam, 3 HPGe detectors with appropriate shielding and acquisition system for coincidence measurements. In this talk, a brief overview of the method, some of the previous results, as well as the spectroscopic results for ^{108}Ag nuclei obtained through ^{107}Ag(n_{th},2γ) reaction will be presented.

Session 2 / 10

Neutron-induced light-ion production experiments with Medley at GANIL-NFS

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New and reliable data for neutron-induced light-ion production (p, d, t, ^{3}He, and α) is essential to improve theoretical models and enhance our understanding of nuclear-reaction mechanisms. It has significant consequences on developing future technologies and on several applications, such as for single-event effects in electronics, neutron dosimetry, and fusion energy development. In this last topic, for example, the neutron irradiation of structural materials leads to the formation of isotopes of H and He, producing gas bubbles that affect their mechanical properties, mainly by producing embrittlement. In order to make reliable predictions on this damage, accurate experimental data on these nuclear reactions are required.

Despite their importance, these kinds of measurements are still scarce, especially above 14 MeV neutron energy. Therefore, reaction codes such as TALYS, and evaluated nuclear data libraries will benefit from newer experimental data.

The Medley setup, now installed in the Neutrons For Science (NFS) facility at GANIL, consists of a set of eight telescopes, each of them including two silicon detectors and one CsI. It is designed to detect and identify light-ions using the ΔE-ΔE-E technique so that it is capable of measuring double-differential cross-sections of light-ion production. As it will be shown in this contribution, the setup has demonstrated to have enough energy resolution to distinguish between the different isotopes of H and of He (p, d, t, ^{3}He, and α). Moreover, the time resolution is enough to provide data as a function of neutron energy, measured using the time of flight technique, in the whole energy range of the NFS facility, that extends between 2 MeV to 40 MeV,

In this workshop, the first preliminary experimental results for the last campaigns of 2022 and 2023,funded by ARIEL will be presented. These results comprise measurements for ^{nat}C, ^{nat}Cr, and ^{nat}Fe targets in the neutron energy range previously mentioned.

Session 7 / 11

Effects of MgF2 on neutrons along the keV energy range and study of the neutron capture on fluorine.

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The main goal of this proposed experiment is to study the interaction of neutrons with magnesium fluoride (MgF2). These neutrons are produced at MONNET in the Joint Research Centre-European Comission at Geel, Belgium, using a lithium fluoride target (LiF), via 7Li(p,n) reaction. There are three main goals for the experiment:
1.-Characterization of the angular and energetic distribution of the neutron production via protons onto 7Li at 2.1 MeV, to be made using Time-of-Flight technique with the measurements of a 6-Lithium-glass detector. An energy of 2100 keV for the accelerated protons and a flight path of around 70 cm is intended to be used, in conjunction with gamma monitors (sodium iodide, NaI, and cerium bromide, CeBr3, detectors).
2.-Secondly, transmission measurements through pure magnesium (Mg) and magnesium fluoride samples shall be performed, in order to determine the total cross section. It is of special interest the keV range, due to discrepancies and lack of data for Mg and F isotopes (24Mg, 25Mg, 26Mg and 19F). In order to have a better result around the resonances, as well as at other energies at which the cross section is lower, two sets of samples have been collected: thin samples (1 mm of Mg and 1.4 mm of MgF2) and thick samples (6 mm of Mg, 8.5 mm of MgF2).
3.-Measurements of the moderation capabilities of MgF2 with the aim of building a Beam Shaping Assembly for future clinical applications of Boron Neutron Capture Therapy, which are to be compared with simulated results using Monte Carlo methods. To this end, several samples of MgF2 (similar to the ones used in the transmission part, stacked to reach 4 cm of thickness) were surrounded by other MgF2 samples to compare the neutron spectra obtained after them.
Due to the temporal proximity between the date of the meeting and the experiment (which is expected to be performed in December 2023), only preliminary results will be presented.

Session 4 / 12

The 243Am(n,f) cross-section campaign at the n_TOF facility at CERN

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The 243Am(n,f) reaction is very important both for basic Nuclear Physics and Nuclear Technology. However, the available data in literature for the 243Am(n,f) reaction are scarce, especially in the sub-threshold region presenting many discrepancies and/or poor energy resolution. To this end, a challenging measurement of this cross section was organized and performed at the n_TOF facility at CERN in order to produce, for the first time, a high-accuracy and high-resolution dataset of the 243Am(n,f) reaction, covering the neutron energy range of 10 orders of magnitude from thermal up to hundreds of MeV.
This challenging measurement lasted ˜3 months and needed a very long preparatory phase with long and frequent stays at CERN and has been strongly supported by ARIEL. The involved PhD, PostDoc and Staff members have benefited a) through the mobility support for education and training visits for Early-Stage Researchers and b) through Transnational Access for beam time at the CERN n_TOF facility. An overview of this campaign will be given in this presentation.

Session 4 / 13

Cross-Section Measurements Using Enriched Ge samples at the IRSN AMANDE facility

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Cross-section measurements of neutron induced reactions on Ge isotopes are very important for practical applications including dosimetry, nuclear medicine, astrophysical projects and reactor technology, but also from a fundamental research point of view. Some neutron-induced reactions produce residual nuclei in high-spin isomeric states, the de-excitation of which is heavily dependent on the spin distribution of the continuum phase space and the spins of the involved discrete levels. The study of such reactions can play a very important role in the study of the residual nucleus. Furthermore, the several available reaction channels that can be studied via the activation technique can reveal interesting systematics, while the simultaneous reproduction of all reaction channels with the same set of input parameters acts as a very important constraint in statistical model calculations. In this work, experimental cross-section values were calculated for a total of nine reaction channels on the five natural occurring isotopes of Ge ($^{70,72,73,74,76}Ge$) via the activation technique. Quasi-monoenergetic neutron beams were produced via the $^3H(d,n)^4He$ (D-T) reaction at the neutron beam facility of AMANDE, IRSN (France) at 14 MeV by placing the targets at a 100 degree angle with respect to the axis of the neutron beam, completing a set of cross-section measurements performed at NCSR "Demokritos"(Athens, Greece), where quasi-monoenergetic neutron beams were produced via the D-T reaction in the energy range between 15-20 MeV. Monte-Carlo simulations were performed for the neutron flux determination via the combined use of MCNP6 and NeuSDesc codes. Five isotopically enriched samples were used for the cross-section measurements, provided by the n_TOF collaboration (CERN). Enriched samples produce more accurate cross-section results, because when natural targets are used, the studied residual nuclei can be produced not only from the measured reaction, but also from other reaction channels on neighboring isotopes found in the target, acting as contaminants. Theoretical corrections are then needed that suffer from their own uncertainties. Following the experimental measurements, a theoretical study was performed via the EMPIRE 3.2.3 code, reproducing all the experimental results, implementing the same set of input parameters.

Session 6 / 14

Assessment of the feasibility of measuring neutron-induced reactions at a laser-driven neutron beam

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The fast development of high-power lasers (> 10ˆ19 W/cm2) with ultrashort pulses (˜ fs), and their applications as compact particle accelerators, are emerging as a promising alternative to conventional accelerators for producing neutron beams. Laser-driven neutron sources (LDNS) are especially attractive for nuclear physics applications based on the time-of-flight technique due to their short pulse length and high instantaneous flux. However, the feasibility of carrying out nuclear physics experiments with laser-driven neutron beams is subject to the response of the detectors currently used in conventional neutron sources.

Recently, the neutron beams user community has been focusing its attention on developing small-scale and compact neutron sources as a complement to major facilities to fully exploit all the possibilities of these techniques. In this context, laser-driven ion sources are garnering the interest of the nuclear physics community due to the fast development of ultra-short (˜ fs) and ultra-high power lasers and their applications as compact particle accelerators. Laser-driven neutron sources (LDNS) are particularly attractive for nuclear physics applications based on the time-of-flight technique thanks to their short pulse length and high instantaneous flux.

There are several recent works about neutron production by laser reaching fluxes per pulse competitive to those of conventional neutron sources, but there is a lack of studies in terms of their application
to nuclear physics experiments. There has been a lot of effort aimed at mitigating the impact of the harsh prompt radiation and the electromagnetic background in sensitive neutron diagnostics, mostly based on single-shot PW-class and TWclass lasers at high repetition rates. However, the typical current-mode operation of neutron detectors in LDNS experiments is not suitable to carry out neutron-induced nuclear reaction experiments, since those require the detection of single signals corresponding to the observables from the individual reactions and processes involved.

In 2021, an experimental campaign was carried out in the complex environment of an LDNS at the DRACO laser facility of the Helmholtz Center Dresden-Rossendorf (HZDR) in Dresden, Germany, producing neutron shots at 0,02 Hz in a high-power system in stable conditions. In addition to conventional scintillators and bubble detectors operated in current/integrated mode, multi-shot neutron production made it possible to use a neutron and charged particle detector with low efficiency, i.e. diamond detector, to measure individual signals from fast neutron interactions. The characterization of the neutron source resulting from two different nuclear reactions, Cu(p,n) and LiF(p,n), by means of the individual signals and the time-of-flight technique, has been positively validated against Monte Carlo simulations, confirming the feasibility of measuring single fast neutron interactions at an LDNS.

Session 6 / 15

Detection of neutron induced nuclear reactions in a silicon photodiode at the HISPANoS faclity

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We will present a main experiment and an auxiliary one. The main experiment got signals of neutron induced nuclear reactions in the silicon bulk of a commercial thin photodiode. We used the HISPANoS neutron beam facility at CNA, Sevilla, Spain. The signal dataset is useful to reproduce the signals using femtosecond pulsed lasers, a more easily tool in the industrial environment. The auxiliary experiment tested the new MAX10 FPGA from Intel/Altera under a neutron beam to look for Single Event Effects. In both experiments we used the 9Be(d,n)10B production reaction, giving a neutron spectra up to 10 MeV.

Session 7 / 16

Neutron characterization of scintillators for neutron metrology from 100 keV to 22 MeV

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The Laboratory for micro-irradiation, neutron metrology and dosimetry (LMDN) is responsible for establishing metrological references in France for neutron fluence energy distributions and associated dosimetric quantities. The LMDN has acquired four 2"x2" scintillators for these metrological purposes; two stilbenes and two EJ309. The aim of this work is to characterize these scintillators, which are coupled to a digital acquisition system. The total energy range is 100 keV and 22 MeV, although the energy range of each scintillator is limited. Response times are fast enough to use the time-of-flight (ToF) measurement technique.
Stilbenes are crystalline organic scintillators with good energy resolution and sensitivity, capable of detecting neutrons up to 100 keV. In fact, new methods for manufacturing stilbene crystals have made it possible to reduce the energy threshold to 100 keV and improve discrimination between neutrons and gammas. However, stilbene has an anisotropic response, and EJ309 scintillators are also chosen by the LMDN because, although their measurement threshold starts at a neutron energy of 1 MeV, their response is isotropic. These two types of scintillator were chosen because they have no safety restrictions.
Response function shapes are determined from white neutron fields at Neutron For Science (NFS) between 100 keV and 22 MeV using ToF. Neutron fluence references are determined at the Physikalisch-Technische Bundesanstalt (PTB) on the main monoenergetic component of neutron fields at several neutron energies (1.2, 2.8, 5.0, 14.8, 17.0 and 19.0 MeV). For measurements at 5.0, 17.0 and 19.0 MeV, the beam is pulsed to enable for scintillators to select in a time window the main monoenergetic component.
These measurements provide a complete characterization of neutrons between 1 MeV and 22 MeV. The 100 keV - 1 MeV decade is measured a stilbene and is largely understudied. A specific study needs to be carried out to determine neutron fluence using the PTB fluence reference at 1.2 MeV.
To complete the neutron field characterization, the photon response function has also been established.
Full characterization of these scintillators will enable the LMDN to determine the energy distribution of the neutron fluence and the associated photon field.

Session 5 / 17

Photoactivation of ^{209}Bi with laser induced bremsstrahlung using DRACO

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Nuclear Physics experiments are usually carried out in large accelerators, whose reduced number restricts the access to these facilities. For this reason, there is a growing interest in developing complementary facilities capable of hosting Nuclear Physics experiments, even at smaller size, to further extend the nuclear data available. In this context, high-power, high-repetition-rate lasers become an appealing complement due to the reduced footprint and lower running costs.

As a proof-of-concept, a photoactivation experiment of ^{209}Bi was carried out using the 150 TW arm of the DRACO laser (HZDR, Germany). Electron bunches of ˜0.1 nC and energy up to 450 MeV were accelerated at 0.1 Hz via the laser wakefield acceleration (LWFA) mechanism and propagated into a thin tantalum converter to obtain the high energy bremsstrahlung photons that were used for photoactivation. After 1 hour of irradiation, corresponding to 370 shots, a short-lived activity of 10-100 Bq was produced, and photoactivation reactions below the pion threshold of up to at least ^{209}Bi(γ,9n)^{200}Bi were observed, with activation levels in agreement with numerical simulations. Further analysis regarding the direct production of lighter elements, such as Pb, will also be presented.

These results show not only the potential of laser-driven accelerators as a useful tool in Nuclear Physics, but also show the possibility of measuring offline the high-energy photon spectrum from the activation yield, with the advantage of being insensitive to pulse pile-up and the strong electromagnetic pulse accompanying the laser shots.

Session 1 / 18

Measurement of the 35Cl(n,p)35S cross section in the energy range 0.5 –5 MeV

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Molten salt reactors (MSR) is a GEN-IV technologies using fuel in the form of very hot fluoride or chloride salt. There are many benefits associated to this technology, but a major drawback is the fuel sensitivity to neutron transmutation. In the case of molten chloride reactors, chlorine is the carrier salt with the fuels being, for example, UCl3-NaCl or PuCl3-NaCl. In these cases, neutron sensitivity is linked to the 35Cl(n,p) and 35Cl(n,α) reactions. The other naturally occurring isotope of chlorine, 37Cl, contributes negligibly to the problem having a higher reaction threshold.
Sensitivity studies have shown that in case of fast reactors, the uncertainty of the 35Cl(n,p)35S reaction cross section contributes very significantly to criticality calculations. For this reason, a new

measurement of the cross section is currently included in the NEA high priority request list. Accuracy of near 2% in the 35Cl(n,p) cross section is required to achieve the desired neutron multiplication factor keff uncertainty of 300 pcm. An uncertainty of 5-8% is however requested as a minimal requirement.
A collaboration between the University of Granada, the University of Manchester and NPL is carrying out the 35Cl(n,p)35S and 35Cl(n,α)32P cross section measurements at the NPL neutron monoenergetic facility. The measurement is conducted by activation, with 35S and 32P that will be detected by liquid scintillation counting. The neutron energies planned for the measurement are 0.565, 1.2, 2.5, 4, and 5 MeV, which will be generated using 7Li(p,n), 3H(p,n), and 2H(d,n) reactions.
This contribution will present the experimental setup and the preliminary result of the irradiation.

Session 4 / 19

Overview of the activities of the University of Ioannina (UoI) supported by ARIEL

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In this contribution an overview of the activities carried out over the last years by the research group of the University of Ioannina (UoI) and supported by ARIEL initiative will be discussed. The beneficiaries of ARIEL were supported through a) the mobility for training of early-stage researchers and scientific visits and b) the transnational access for beam time to the n_TOF/CERN and ILL/Grenoble facilities. Status reports will be presented on the research projects concerning: the neutron induced fission cross section measurement of 243Am at EAR-1 and the neutron capture measurements at NEAR of the n_TOF facility at CERN, the development of the new annular double-sided silicon detector at n_TOF and the investigation of pulse shape discrimination capabilities of silicon detectors performed at ILL Lohengrin spectrometer.

Session 6 / 20

Diamond Detector Measurements at the NEAR Station of the n_TOF facility at CERN

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The new experimental area of the n TOF facility at CERN, namely NEAR 1, has been built at a very short distance from the Pb spallation target (approximately 2.5 m) in order to take advantage of the extremely high neutron fluence expected and perform various challenging measurements for numerous applications. In this experimental area, due to the high instantaneous flux, only passive techniques, such as the multiple foil activation technique, have been utilized to characterize the neutron flux. However, diamond exhibits very promising properties for in beam neutron detection,leading to the widespread usage of diamond detection systems in radiation applications, particularly
in neutron induced reaction studies and neutron fluence measurements ([2],[3]). In this work, a newly built single crystalline diamond detector and associated electronics were developed by the CIVIDEC Instrumentation [4], aiming to measure the neutron flux in the harsh environmental conditions of the NEAR station. It was essential to perform numerous experiments in order to test the

response of the detector and the electronics as well as to determine the optimized experimental set-up. One test was performed at the EAR2 and the following three at the NEAR station, where an in-beam measurement was attempted for the first time. These challenging measurements lasted 3 months, spread out in 2022 and 2023, and required frequent visits at CERN, supported by ARIEL. The preliminary results of these tests will be presented and discussed in this presentation.

Session 7 / 21

Neutron capture on Cr for criticality safety via time-of-flight at CERN n_TOF and activation at CNA HiSPANoS with 30 and 90 KeV quasi-Maxwellian spectra

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The NEA High priority Request List [Plompen:2007] features the neutron capture on 50Cr and 53Cr between 1 and 100 keV as very relevant for criticality safety. In the case of 50Cr, the product of the (n,γ) reaction is 51Cr, unstable with a half-life of 27.7 days which makes it suitable for neutron activation experiments. Although several time-of- flight experiments have been performed, including a recent one at the CERN n_TOF facility [Guerrero:2021]. Neutron activation should be in principle more accurate, but to date only one experiment has been published [Xia:2002], being the corresponding publication just a 2 pages conference proceeding.

In this work work we present an activation measurement performed last year at the CNA HISPANoS facility (Sevilla, Spain) to determine the (n,g) maxwellian-averaged cross section (MACS) of 50Cr. In addition to measure the activation to a neutron beam with a 30 keV quasi-maxwellian energy distribution -produced by the 7 Li(p,n) reaction with 1912 keV protons, and routinely employed in activation measurements- we applied a novel method to develop a quasi-maxwellian 90 keV beam, based on the superposition of the distributions produced via 7Li(p,n) reaction with different incident beam energies. The activation with a 90 keV MB distribution is of high interest for stellar nucleosynthesis studies, in particular to study the weak s-process. We will present preliminary results of the activation at 30 and 90 keV on 50Cr and 197Au, whose (n,g) cross section is well-known and its MACS at 30 keV is considered a standard.

Session 5 / 22

Investigating neutron scattering with surrogate proton induced reactions

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Investigating neutron scattering with surrogate proton induced reactions

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GRAPE: Neutron transmission experiments at GELINA for stainless steel nuclear data

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GRAPE: Neutron transmission experiments at GELINA for stainless steel nuclear data

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Summary of the ARIEL project

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The EURATOM coordination and support project "Accelerator and Research reactor Infrastructures for Education and Learning (ARIEL)" brings together the most modern and state-of-the-art European neutron beam laboratories using the full range of neutron sources from high-energy proton synchrotons to research reactors.

For the continued improvement of the safety of current and future nuclear facilities, accurate and precise nuclear data are required e.g. embedded in computer simulations. Producing these nuclear data is a complex process, which relies on neutron facilities and on highly-trained nuclear physicists.

Twenty-three partners from 14 European countries will work together for the education and training of a new generation of young scientists and technical staff.

Session 4 / 25

Experiments with SCALP@nELBE

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Experiments with SCALP@nELBE

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ARIEL Education & Training Activities

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ARIEL Education & Training Activities

Session 3 / 27

Delayed neutron data measurements for the fast neutron induced fission of 238U at the PTB Ion Accelerator Facility

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n 2023, two experimental campaigns were performed at the PTB Ion Accelerator Facility in Braunschweig (Germany), in order to measure the delayed neutron macroscopic data in the fast neutron induced fission of 238U. In total, the delayed neutron yield was measured for 15 energies between 1.5 and 19 MeV. 3 measurements of the kinetics parameters associated to the delayed neutrons emission (precursors groups abundances) were also performed. The presentation will introduce the experimental setup, give some details about the analysis methodology and show the results obtained so far for the delayed neutron yield measurements.

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ARIEL Transnational Access

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ARIEL schools

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Finalizing reporting for ARIEL

Auteur: Carola Franzen[None]

Finalizing reporting for ARIEL

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Buffet lunch

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giorgia wants a talk after cocktail