Neutron activation research activities of NTUA at the neutron facility of NCSR “Demokritos”

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Studies of neutron induced reactions are of considerable importance as they provide significant information in the field of Nuclear Physics and Astrophysics as well as in practical applications like nuclear technology, dosimetry, medicine and industry. These tasks require improved and high accuracy cross section data for neutron induced reactions on various isotopes.

At the 5.5 MV tandem T11/25 Accelerator Laboratory of NCSR "Demokritos" (Athens) quasi-monoenergetic neutron beams can be produced in the energy ranges ~ 15-20 MeV by means of the $^{3}H(d,n)^{4}He$ reaction, ~ 4-11 MeV via the $^{2}H(d,n)^{3}He$ reaction and ~ 2.0-5.3 MeV using the $^{3}H(p,n)$ reaction. The maximum flux is of the order of 10^{5}-10^{6} n/cm^{2}s, implementing reference reactions (such as $^{27}Al(n,\alpha)^{24}Na$, $^{197}Au(n,2n)^{196}Au$ and $^{93}Nb(n,2n)^{92m}Nb$), while the flux variation of the neutron beam is monitored by a BF_3 detector. The neutron beam has been characterised using the multiple foil activation technique as well as extensive simulations.

The neutron beam has been used over the past 20 years by the NTUA group, for the measurement of (n,2n) and occasionally (n,3n), (n,p), (n,α) reaction cross sections on several isotopes of Am, Hf, Ir, Au, Tl and Ge, using the activation technique. After the end of the irradiation the induced γ-ray activity of the samples and the reference targets are measured off- line by HPGe detectors of 80%, 50% and 16% relative efficiency. The absolute efficiency of the detectors is deduced using a calibrated ^{152}Eu source, placed at the same distance as the sample. Furthermore, the experimental set up is always simulated with the use of the MCNP (Monte Carlo N-Particle) code, for the estimation of the neutron flux, the self-absorption of the γ-rays in the sample, the effect of parasitic neutrons which accompany the beam etc. In addition, statistical model calculations using the codes EMPIRE and TALYS are usually performed on a wide energy range for the measured data as well as for the data available in literature.

An overview of the neutron activation campaign at this facility will be presented.

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The n_TOF fission programme

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Neutron-induced fission reaction cross sections are essential in many areas of nuclear science and applications. Experimental data from neutron-induced fission reactions play a fundamental role in understating nuclear processes at high excitations, ultimately leading to the creation and refinement of models that can characterize spallation and nuclear fragmentation, in addition to the binary fission process. At the same time, the availability of cross section data is decisive in a wide range of technology applications. In fact, on the one hand, new data maximise the safety and performance of the present nuclear reactors; on the other hand, new generation of nuclear reactors, like the Accelerator Driven Systems-ADS and the Generation IV Fast Neutron Reactors, require high-accuracy data for a wide range of neutron-induced reactions at energies ranging from thermal up to several tens of MeV for their design, feasibility, and sensitivity studies. The (n,f) cross sections are generally used as reference to monitor neutron beams in experimental facilities, in parallel or alternative to other neutron-induced reactions. For these reasons and more, calls for the continuous improvement of neutron-induced fission cross section data, to increase their accuracy and reliability, are in order.

The neutron time-of-flight facility n_TOF at CERN offers the possibility to study neutron-induced reactions in an extremely wide energy domain, from sub-meV to GeV neutron kinetic energies. Since the start of operation in 2001, fission measurements are a key component of the n_TOF physics program. The main features of the facility, such as the high energy resolution and instantaneous intensity of the neutron beam, make n_TOF ideal for high-resolution high-accuracy fission cross section measurements. An extensive programme of neutron-induced fission measurements has been carried out on major and minor actinides as ^{245}Cm, ^{243}Am, ^{232}Th, ^{237}Np and ^{233,234,235,238}U as well as on few lighter elements characterized by a high fission threshold. This resulted in a significant improvement of nuclear data for reactions that were previously poorly known, sometimes only from nuclear explosion or from low-resolution measurements.

In recent years, a dedicated measurement campaign was carried out to provide accurate and precise cross section data of the ^{235}U(n,f) reaction in the full energy range, from thermal to the MeV region and at high energy region from 10 MeV to 440 MeV. The experimental apparatus used in the measurement at high neutron energies, which involved the effort of several research institutions (INFN, PTB and IPN, in addition to CERN), consisted of three flux and two fission detectors, allowing to simultaneously record the number of neutrons impinging on the ^{235}U samples (incident neutron flux), as well as fission events, as a function of the neutron energy.

A review of the n_TOF fission programme will be presented, focusing on the most significant measurements made over the years. Among these, a description of the measurement of the high-energy ^{235}U(n,f) cross section will lead us to the conclusion of the talk with a description of future prospects.

Neutron irradiation of slate samples from the West of Scotland

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The irradiation of materials with neutrons and the subsequent radioactive decay of the neutron-capture products can be used to determine the amount of a given stable isotope present in a sample. The sensitivity of this technique depends mainly upon the neutron flux, the efficiency and resolution of the radiation detector(s) used, and nuclear properties such as the neutron-capture cross section and half-life. In general, careful characterisation of the experimental environment (e.g. source geometry and attenuation) is necessary to reduce systematic uncertainties [1, 2]. In the current work, neutron irradiation coupled with high-resolution gamma-ray spectroscopy will be used to analyse slate samples from historic sites in the West of Scotland, and the results compared to samples from slate quarries. Sample activity due to the presence of trace amounts of other long-lived radioactive nuclei (e.g. ^{40}K and nuclei produced via the uranium and thorium decay series) may also be observed.

Slate quarried in the West of Scotland, for example at Ballachulish and Easdale [3], was supplied to sites throughout Scotland as a building (e.g. roofing) material. Slate is a metamorphic rock [4] formed from layered sediments comprised of silicate, alumina, and other oxides incorporating trace elements with low atomic number (Z) $\lesssim$ 26 [5]. The aim of the current work is to investigate the selectivity of this technique with regards to the geo-location of the original slate deposits used to source slates incorporated in historic buildings. Details of preparatory experiments performed at the University of the West of Scotland using a moderated Am-Be neutron source and a high-purity germanium detector will be presented.

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Preliminary results on the first transmission measurement at n_TOF on a gas target: The Argon physics case

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Neutron propagation and capture in argon are fundamental processes, significant in a variety of particle and nuclear physics applications. Recently, the n_TOF [1] and the ARTIE [2] Collaborations teamed up aiming to improve the understanding of these neutron-induced reaction channels, by developing experiments involving liquid (LAr) and gaseous Argon (GAr). Despite the growing use of liquid Argon as a detector material for neutrinos and dark matter, yet its nuclear interactions are not well-studied. In particular, the neutron-induced total cross section of Ar-40 in the energy range between 50-100 MeV has not been measured at all, whereas data at low energies and above 100 MeV show large uncertainties. Therefore, a significant effort is required to improve the nuclear data for neutron interactions with Argon.

Within the framework of the Multiple Argon Experiments (MArEX) initiative, a first set of test measurements was performed for the first time at n_TOF, to conduct the feasibility study of the total cross section (or transmission) measurement on gaseous Argon based on two independent experimental setups. The transmission measurement was carried out in the first experimental area (EAR-1) of the n_TOF facility. Neutron detection across a broad energy spectrum, ranging from eV to several hundred MeV, was performed using the ^{235}U(n,f) and ^{10}B(n,a) neutron conversion reactions.

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Opportunities for High-energy Neutron-induced Measurements for Fusion Technology at the Soreq Applied Research Accelerator Facility (SARAF)

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The second phase of the Soreq Applied Research Accelerator Facility (SARAF Phase II) is currently under construction at the Soreq Nuclear Research Center in Yavne, Israel [1,2]. This facility will be one of the brightest sources of neutrons in the world and is planned to start running in 2025. Access to such large neutron flux allows for the measurement of neutron-induced yields and, in particular, the cross-sections that constitute the "damage cross-section" for a given material [3]. Knowledge of these cross-sections is limited by the scarcity of nuclear data on high-energy neutron-induced cross-sections and is vital for the planning of future fusion facilities [4].

To produce this high flux of neutrons, a 5 mA continuous wave beam of deuterons is accelerated to 40 MeV and impinged on a gallium-indium (GaIn) liquid-jet target [5]. This will produce a neutron spectrum with energies as high as approximately 45 MeV with a neutron rate of around 10^{15} n/sec. A thin sheet of target material will be placed in a cryogenic stopping cell (CSC) close to the neutron-generating target. The isotopes produced in the neutron reactions are thermalised in the CSC and are then unambiguously identified using multiple-reflection time-of-flight mass spectrometers (MR-TOF-MS), see [6] for a recent example of thermalised isotope identification in an MR-TOF-MS. The advantage of this technique is that it does not rely on detecting radiation but instead directly measures reaction yields of all channels simultaneously. Detailed estimations have been made for iron [7].

The talk will discuss the novel technique for measuring neutron-induced reactions. We show by sophisticated GEANT4 Monte Carlo simulations that it will be possible to improve the sensitivity to neutron-induced cross-sections by three orders of magnitude with respect to present experimental data. We also show that by varying the energy of the initial deuteron beam, the neutron energy dependence of the yields could be deduced.

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