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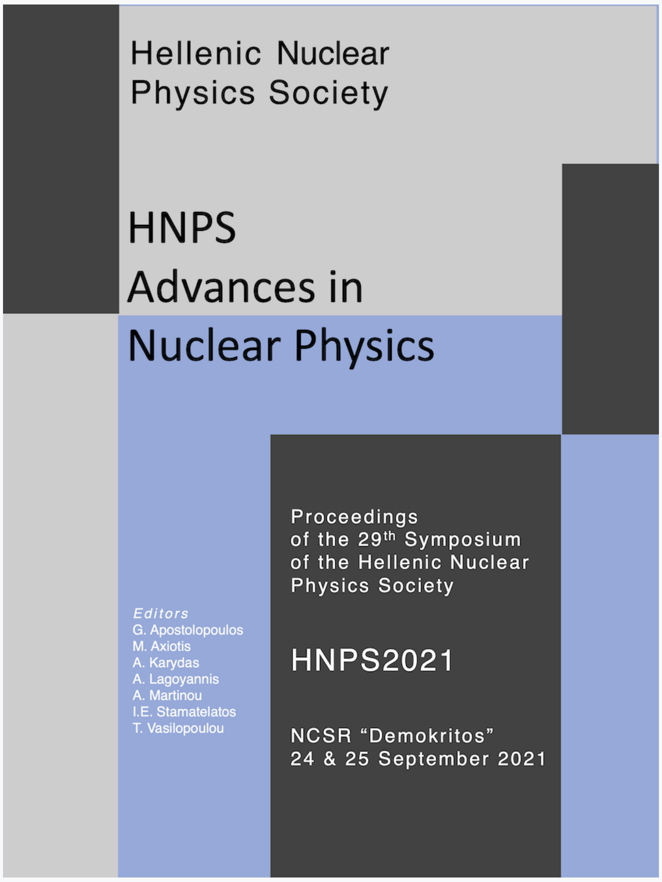

A new approach for indirect capture measurements: The DICER neutron transmission station at LANSCE

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A new approach for indirect capture measurements: The DICER neutron transmission station at LANSCE

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Abstract Direct (n,γ) measurements on radioactive nuclei can often be challenging. Substantial effort has been devoted to developing indirect techniques and perform measurements on short-lived radionuclides of astrophysical interest. A new indirect technique is being explored at the Los Alamos Neutron Science Center (LANSCE) which enables the calculation of average neuron capture properties from neutron transmission data. A station for neutron transmission, has been under commissioning during the last two years at LANSCE. The Device for Indirect Capture Experiments on Radionuclides (DICER) is currently capable of carrying out measurements on stable cylindrical samples with a diameter as small as 1 mm and mass as low as a few mg. The first year of operation indicate that the DICER instrument is ready to perform its first measurement on a radioactive sample (^{88}Zr, $t_{1/2}$=83.4 days) which is planned for the winter of 2021. A brief description of the apparatus and details on the latest DICER results will be presented.

Keywords neutron transmission, time-of-flight, DICER, resonance analysis, random matrix theory

INTRODUCTION

The accurate knowledge of (n,γ) cross sections is essential in various applications such as nuclear forensics, radiochemical diagnostics and nuclear astrophysics. Several direct measurements have been performed on many stable nuclei but only a few on radionuclides, mainly long-lived ones [1]. Studies on short-lived nuclei is far more challenging, hence, a number of indirect methods have been developed (i.e. surrogate [2], γ-ray strength function [3], Oslo [4] and β-Oslo [5]), however, the associated results are often quite uncertain.

On the other hand, neutron transmission measurements are less affected by radioactive-decay backgrounds because of long sample-to-detector distances, which are typically of the order of tens of meters. Those types of measurements can tightly constrain capture cross sections and in some cases even accurately quantify them, through Nuclear Statistical Model (NSM) calculations. This approach technique is presented in detail in Ref. [6].

In summary, a neutron transmission spectrum can provide the level spacing (D_0, distance between successive transmission dips), the total width (Γ, width of the transmission dip) and neutron width (Γ_n, depth of the transmission dip) of each resolved resonance. In some cases the radiation width (Γ_γ) is not significantly smaller than Γ_n, so it can be calculated using $\Gamma = \Gamma_n + \Gamma_\gamma$. At the same time Γ_γ distributions do not appreciably fluctuate, therefore only a relatively small number of resonances is practically needed to calculate the average radiation width ($<\Gamma_\gamma>$) with sufficient accuracy.

The development of the Device for Indirect Capture Experiments on Radionuclides (DICER) was based on this technique and was developed at the Los Alamos Neutron Science Center (LANSCE). Many radionuclides relevant to radiochemical diagnostics, nuclear forensics, nuclear astrophysics [7-9] are expected to be studied at DICER. Finally, DICER is designed to study small samples (~10 μg,

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0.1-1 mm in diameter) with half-lives as small as tens of days and level spacings as big as tens of eV.

BRIEF DESCRIPTION OF THE DICER INSTRUMENT

DICER is located at LANSCE at the Manuel Lujan Jr. Neutron Scattering Center. Source-to-detector distances of 31 and 64 m are available, however, only results from the 31 m station, shown in Fig. 1, will be presented. A detailed description of the first DICER generation is provided in Ref. [10].

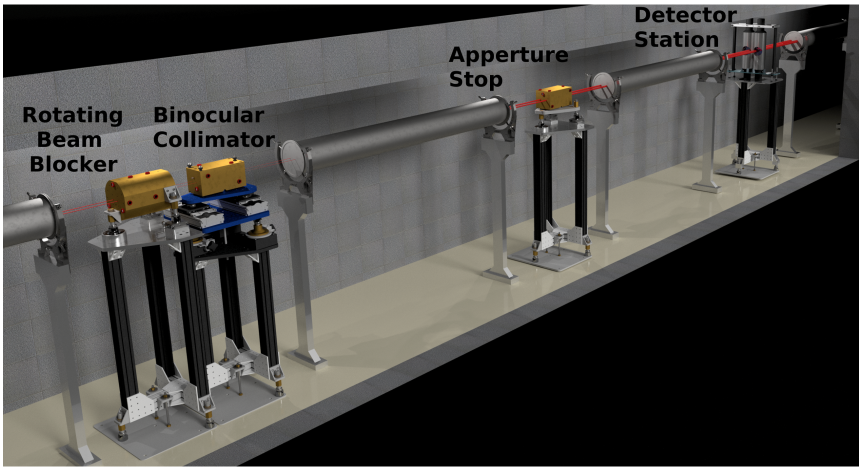

Fig. 1. *Schematic representation of the 31 m DICER station. The red lines indicate the neutron beam.*

The neutrons delivered at DICER are spallation products from an 800 MeV proton beam, pulsed at 20Hz [11] which impinges on a split, 10 cm in diameter, cylindrical tungsten target. Each pulse has an 125 ns FWHM and average intensity of ~100 μA. Neutrons are then moderated in a liquid hydrogen moderator and as a result the DICER neutron spectrum spans from 0.2 meV up to 100 keV, as shown in Fig. 2.

The collimation system developed for DICER allows to perform simultaneous measurements of the sample (sample in) and its envelope (sample out). Standard neutron transmission set-ups require a periodic sample insertion/removal which can cause repositioning errors; therefore the samples are larger than the beam size. The DICER approach allows the measurement of small samples and reduces the measuring time by a factor of 2 by utilizing two beam lines, which spot at the same area on the liquid hydrogen moderator.

The first collimation component, consists of a cylindrical shell of brass (Rotating Beam Blocker, Fig. 1), with a length of 30.5 cm and a diameter of 21.5 cm. This collimator is installed 14.35 m from the spallation target. A rotating cylindrical brass piece, 10 cm in diameter, is inserted within the cylindrical shell and is equipped with three 0.8 cm in diameter holes. The holes, depending on the arrangement, provide four different beam line configurations: (a) two beam lines, (b) no beam lines, (c) a beam line to the left and (d) a beam line to the right.

The second and main stage of collimation, takes place at a 14.85 m distance from the neutron source, where a right rectangular brass prism (Binocular Collimator, Fig. 1), 30 cm long and 15 cm wide, is installed. This component serves both as a sample holder and a collimator and provides two beam lines of 1mm diameter.

The last stage of collimation takes place 18.5 m from the tungsten target where a rectangle brass collimator (aperture stop, Fig. 1) 30 cm long and 15 wide, is located. The aperture stop cleans up the beam halo from the sample collimator and ensures two well defined beam spots at the detector position.

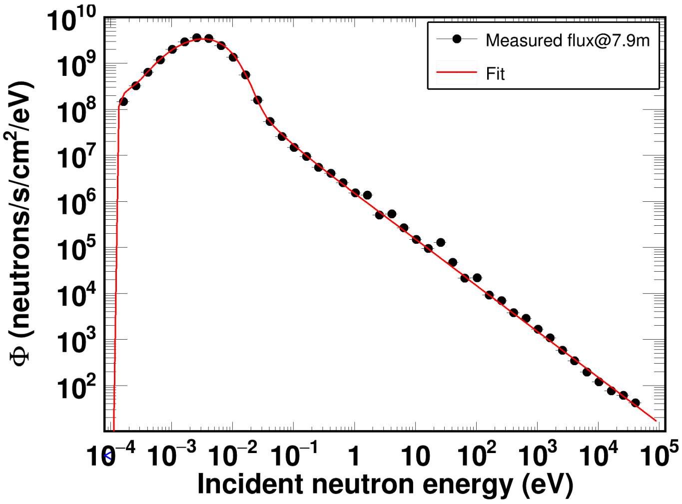

Fig. 2. *The neutron spectrum at DICER spans from 0.2 meV up to 100 keV. The flux was measured at 7.9 m from the spallation target with a ^{235}U-loaded fission detector.*

Finally, the main detection system of DICER consists of two ^{6}Li-glass disks, 10 cm in diameter and various thicknesses (1, 2, 4, 6.3, 12.7 mm). Each disk is coupled to dual photomultipliers (PMTs) which are perpendicular to the neutron beam in order to minimize backgrounds, as shown in Fig. 3.

FIRST DICER RESULTS

DICER is in commissioning phase from the fall of 2019 up to this date. However, many studies of stable isotopes have been performed. A few examples include ^{147,149}Sm, ^{191,193}Ir, ^{95}Mo, ^{209}Bi, ^{197}Au, ^{nat}Cd and ^{nat}Gd. In this section, a few results will be presented mainly as evidence of the per-design-operation of DICER.

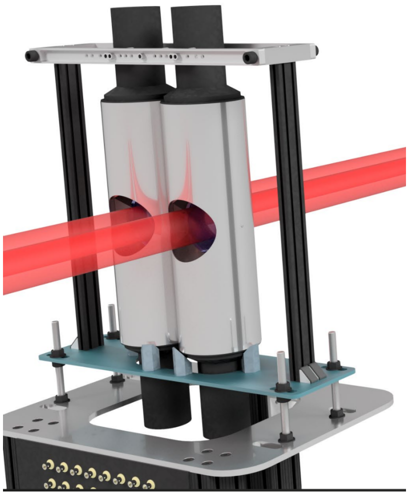

Fig. 3. *The main neutron detection system of DICER consists of two dual PMT detectors coupled to a ^{6}Li-glass disk, each. The red transparent lines correspond to the neutron beam line envelope.*

^{209}Bi has isolated s-wave resonances and well-known resonance parameters, therefore it is an excellent benchmarking tool. As shown in Fig. 4, the reproduction of DICER data using resonance parameters from ENDF/B-VIII.0 [12] is satisfactory.

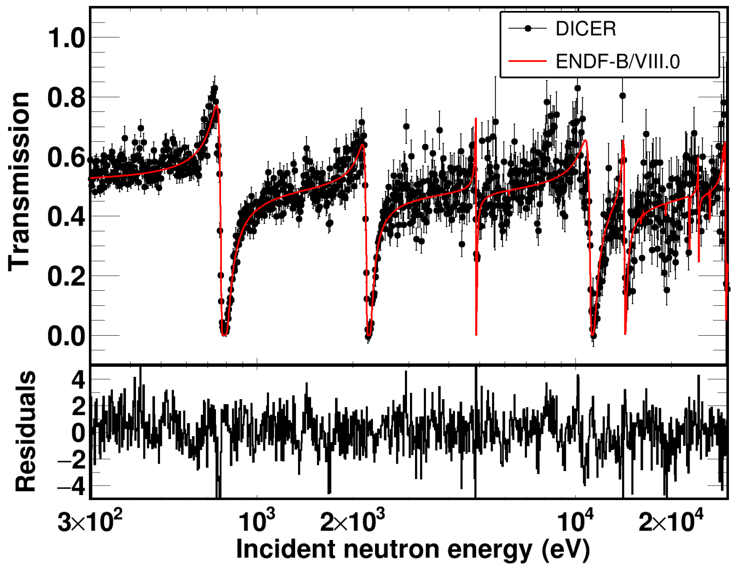

Fig. 4. *DICER data in comparison with ENDF/B-VIII.0 in the 300 eV – 30 keV energy region. A satisfactory reproduction was achieved.*

Similarly, cadmium is a material that is frequently used to filter neutron beams below 0.5 eV. In addition, resonance parameters of ^{nat}Cd are adequately known, therefore it can be considered as a test case to pinpoint any issues with the understanding of DICER operation and data reduction scheme. As shown in Fig. 5, the ENDF/B-VIII.0 resonance parameters can adequately reproduce the data taken with DICER.

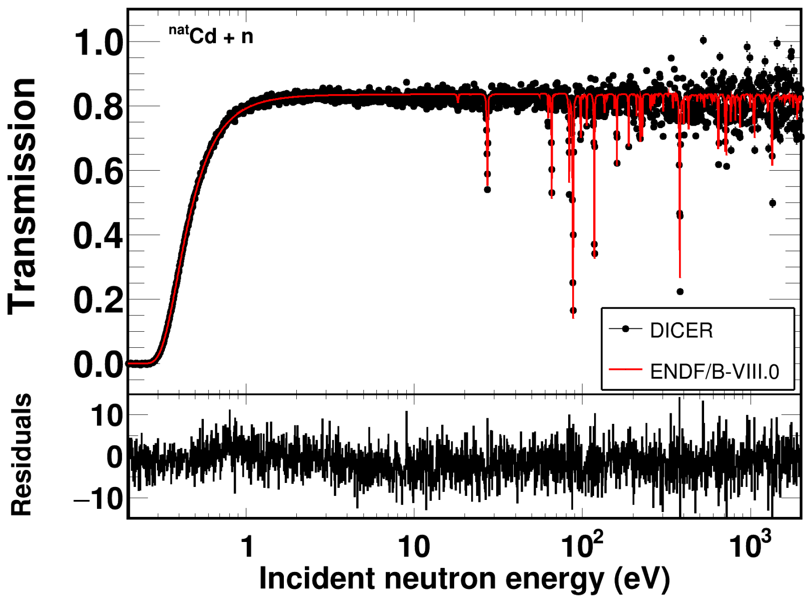

Fig. 5. *DICER data in comparison with ENDF/B-VIII.0 in the 0.5 eV – 2 keV energy region for ^{nat}Cd. A satisfactory reproduction was achieved.*

TOWARDS DICER GEN-2

The successful commissioning of DICER and the need for measuring smaller samples, lead to a redesign of the instrument. More specifically, an additional binocular collimator will be built that will define a neutron beam with a 0.1 mm diameter. Certain measurements of radionuclides that have a relatively small (n,tot) cross section, require thick samples. Sometimes these radionuclides are short-lived and difficult to produce in large amounts, therefore the minimization of their diameter is crucial for dose-rate and cost considerations. An example of such a radionuclide is ^{88}Y which is planned to be measured during the 2022 run cycle.

The alignment of such a small beam is challenging, therefore there is a need for a neutron beam imaging device. The Large Area Picosecond Photo Detector (LAPPD) [13], a Multi-Channel Plate (MCP) based detector with 64 square pixels, each 2 cm wide, was coupled to two 2 mm in thickness ^{6}Li-glass square tiles, 10 cm in size. The detector was successfully irradiated for a few days and the first beam images were reconstructed based only on the native spatial resolution of the detector (i.e. no weighting was applied). The results are encouraging, as shown in Fig. 6 and the two DICER beam spots are distinguishable.

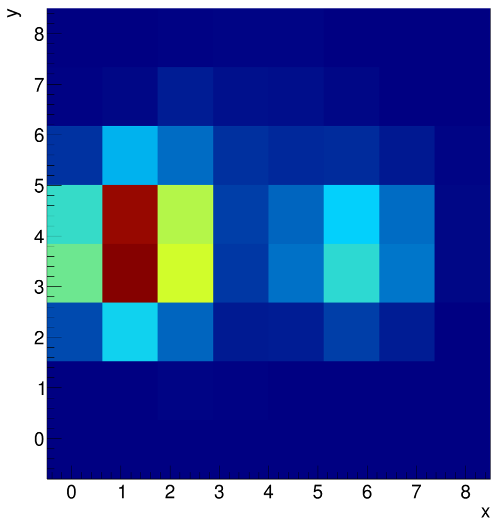

Fig. 6. *The first neutron beam image generated by the LAPPD detector. Despite the poor native spatial resolution, the two beam spots are distinguishable.*

CONCLUSIONS

A new instrument is being developed at the Manuel Lujan Jr. Neutron Scattering Center at LANSCE to study (n,γ) reactions on short-lived radionuclides in an indirect fashion, through neutron transmission measurements and resonance analysis. Great effort has been devoted to design and precisely align the instrument as well as to develop an efficient and reliable data reduction scheme. Both efforts led to a deep understanding of the instrument's performance which was demonstrated by the satisfactory reproduction of DICER data from well-known resonance parameters. Effort has also been made to develop the next DICER generation by upgrading the binocular collimator from 1 mm to 0.1 mm diameter and utilizing the LAPPD detector to image the neutron beam. Finally, DICER is getting ready to perform its first measurements on radioactive samples on ^{88}Zr and ^{88}Y.

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