ORNL Neutron Cross-Section Measurements in the Resolved Resonance Range for the NCSP

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INTRODUCTION

Nuclear criticality simulations test the quality and the consistency of the existing nuclear evaluated data libraries such as ENDF/B, JEFF, or JENDL. In some cases, the cross-section evaluations of those libraries are found insufficient to describe accurately criticality benchmarks. The US Nuclear Criticality Safety Program (NCSP) collaborates with the Joint Research Center (JRC) in Geel, Belgium, to perform high-resolution neutron-induced cross section measurements at the Geel Linear Accelerator (GELINA) to resolve deficiencies in nuclear data that have been emerging in criticality calculations. Problems with nuclear data include insufficient neutron energy range, missing covariances, and problems with previous experiments. For example, the use of the ENDF/B-VII.1 neutron cross section data for vanadium, cerium and zirconium in nuclear criticality safety calculations shows discrepancies between benchmark calculations and measurements, and demonstrates the need for reliable covariance data. For new covariances of existing data, a reevaluation of the old cross section data is needed. However, these data are in many cases no longer available. This deficit can be overcome only by obtaining new experimental data to serve as the basis of a new evaluation.

Recent measurements were made of the neutron total and capture cross sections of natural vanadium and natural zirconium in the neutron energy range from 100 eV to several hundred keV. These measured data will be used to improve representation of the cross sections since most of the available evaluated data rely on old measurements.

EXPERIMENTS AT GELINA

Neutron capture and transmission experiments were performed at the GELINA high-resolution time-of-flight (TOF) facility [1]. Neutrons are produced using a rotating depleted uranium target via Bremsstrahlung from a stopped electron beam. To moderate the neutrons, two beryllium canned water containers are mounted above and below the uranium target. The pulsed electron beam of the GELINA is compressed to a 1 ns pulse using a special bunching magnet in the target hall. By combing the short pulse and long flight paths (up to 400 m), excellent TOF and hence neutron energy resolution can be achieved, facilitating resolving individual resonances in the neutron cross sections.

Four deuterated benzene (C_6D_6) detectors [2] located at the 60 m flight station were used to record gamma rays after the neutron was captured in the sample. The pulse-height weighting method was applied to this detector system [2]. The TOF and gamma ray energy were recorded for each event. Neutron flux was determined by utilizing a ^{10}B-loaded ionization chamber located 80 cm upstream of the sample. The capture and transmission experiments were preformed using metallic disks of natural zirconium and vanadium. Samples with different thicknesses were measured to perform a correct resonance analysis. This ensures that the peak of strong resonances in the total cross section can be determined, and in many cases the spin of the resonance can be deduced. Capture cross sections on isotopically enriched samples of zirconium will be measured in forthcoming experiments. However, new measurements are not needed for the transmission of enriched Zr isotopes since high quality data are available from ORELA experiments, including data for the long-lived fission product ^{93}Zr.

The neutron capture experiments at GELINA were performed at an 800 Hz repetition rate with a 1 ns pulse width. Additional measurements included runs using an empty sample holder and a ^{208}Pb sample in the beam to determine the level of background originating from the sample holder and sample scattered neutrons. Supplementary background measurements were performed using black resonance filters in the neutron beam; a ^{10}B slab served as a frame overlap filter. The obtained neutron capture data were normalized to the 1.15 keV resonance in ^{56}Fe.

As an example of neutron capture data generated from this experiment, Fig. 1 shows the experimental neutron capture cross section for natural V compared to the cross section calculation using resonance parameters

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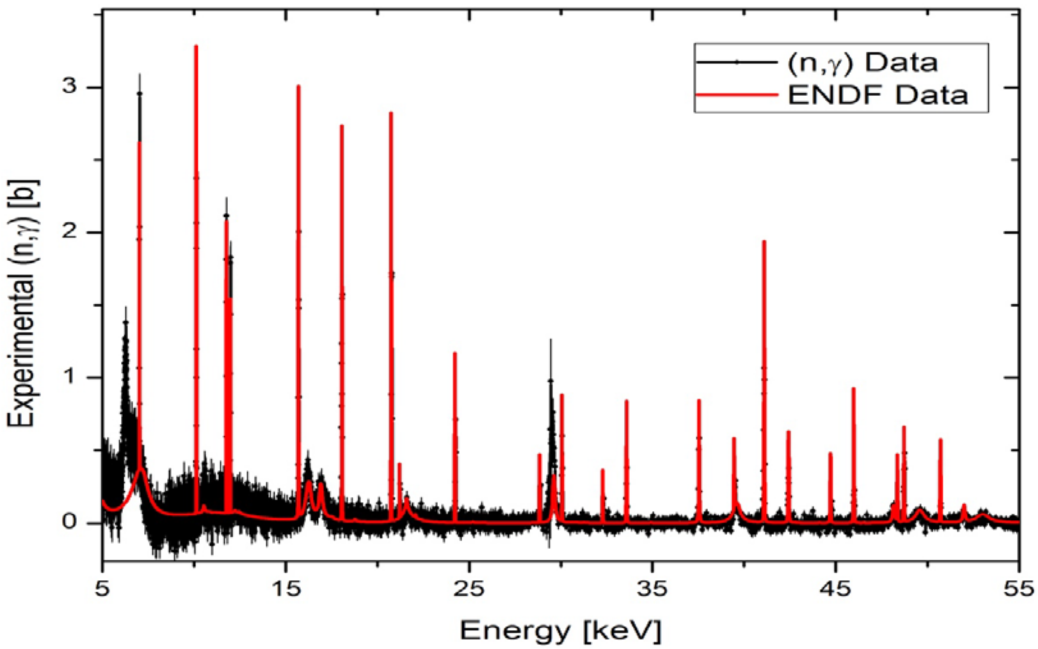

Fig. 1. Detailed view of neutron capture for natural V compared to ENDF/B-VII.1 evaluation. The resonance parameters do not describe the capture cross section accurately.

from the ENDF/B-VII.1 evaluation. This calculation included all experimental effects.

Simultaneously to the capture experiments, transmission measurements were performed using alternating samples. A ^{6}Li loaded glass scintillator 0.635 cm thick, viewed by one photomultiplier placed outside the neutron beam, was used to detect sample-transmitted neutrons. The detector was located at flight path number 4 at a distance of 49.33 m from the neutron production target. The samples were cycled in and out of the beam with the computer-controlled sample changer. Using the transmission data and the resulting total cross section data, a complete set of resonance parameters can be obtained, which is also used to calculate the appropriate correction factors for the capture yield using a resonance analysis program like SAMMY [3].

The obtained data for transmission, capture, and flux were all stored in list mode. During data sorting, corrections for detector gain shifts were applied, and checks for stability using scalers and counts for different TOF windows were performed. The resulting spectra were processed by the Analysis of Geel Spectra (AGS) software code [4], which transforms recorded count rates into observables such as transmission data and reaction yield. AGS also corrects for backgrounds. In the final step, the vanadium and zirconium capture yields are normalized using the iron runs. At this point, the data are ready to be compared to the latest evaluations. The result for the natural V experimental capture data is shown in Fig. 1. The newly obtained capture data are not described correctly by the evaluation; many resonances have incorrect parameters.

Using different sample thicknesses and background filters, the transmission data for V and Zr were recorded applying equal measuring time for sample in and sample out. Afterwards, the data were checked for stability using scalers, which recorded all relevant information. The accepted cycles were summed to histograms for sample in and sample out. In a last step, the histograms were then normalized using neutron monitor counts. Using the histograms, transmission data were produced with the AGS code, including a full covariance matrix. By applying the black resonance filter technique, background corrections were determined for sample in and sample out. The calculated transmission data from ENDF/B-VII.1 resonance parameters for V+n are compared to the experimental transmission data shown in Fig 2. The ENDF/B-VII.1 evaluation has no resonance parameters above 200 keV, and the observed transmission is not described in detail. As shown in Fig. 2, due to the good resolution of the transmission data obtained in this experiment, the resolved resonance region can be extended to higher neutron energies.

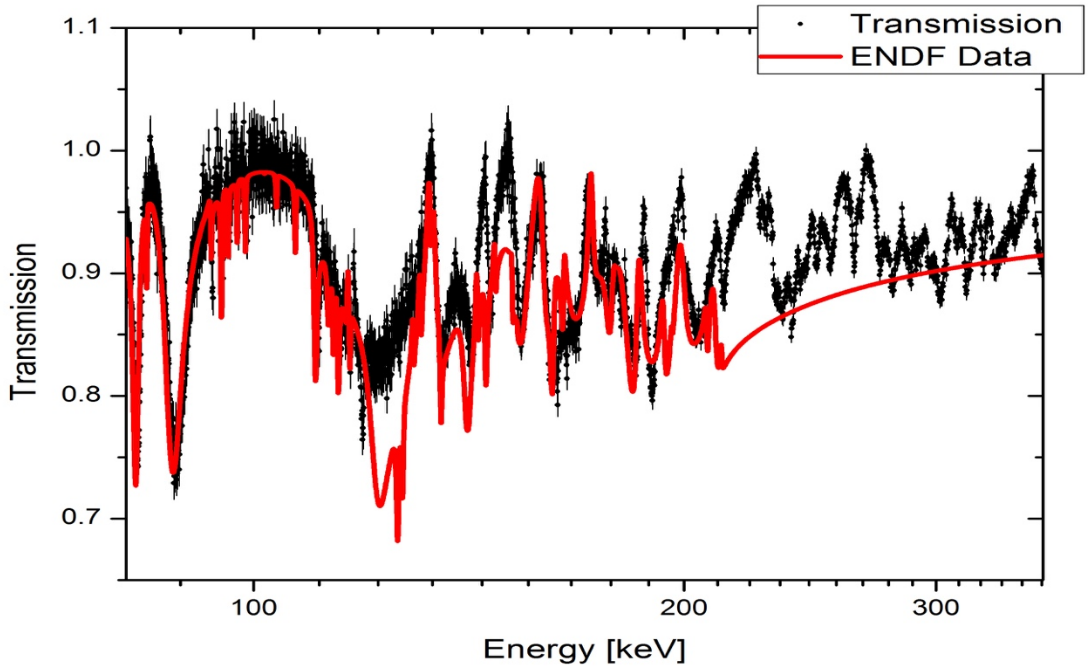

Fig. 2. Detailed view of neutron transmission data for natural V compared to ENDF/B-VII.1 evaluation.

RESULTS AND DATA ANALYSIS

Discrepancies are obvious when comparing the new results of this capture and transmission experiments for natural V to the evaluated nuclear libraries. The data clearly show that the capture widths for natural V are over- and underestimated, and resonances are missed in the nuclear data libraries. Resonances are resolved with sufficient statistics to much higher neutron energies compared to the ENDF/B-VII.1 evaluation. Thus, the resolved resonance region for V can be extended in a new evaluation which will be performed by the Nuclear Data and Criticality Safety Group of the Reactor and Nuclear Systems Division at Oak Ridge National Laboratory. The newly obtained data for natural Zr will be a necessary addition to the existing data sets to allow for a new evaluation. These data will also eventually include new neutron capture data of separated isotopes.

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