Measurement of the Neutron Radiative Capture Cross Section and Resonance Parameter Analysis of 93Nb Using White Neutron Source

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Abstract

In this study, the neutron radiative capture cross-section of 93Nb was measured using the GTAF at the Back-n beamline of the China Spallation Neutron Source (CSNS), with the time-of-flight (TOF) method being employed. A comprehensive data processing procedure was implemented, including background subtraction, neutron flux normalization, dead time correction, and yield spectrum calculation. Uncertainties were evaluated based on statistical counting, neutron flux, sample thickness, and flight path correction. The excitation function of 93Nb was determined up to 2 keV. Resonance parameters below 200 eV were analyzed using the SAMMY code. Good consistency was obtained between the SAMMY fitting results and the experimental data, although discrepancies remained in the extracted resonance parameters. These discrepancies are attributed to relatively large uncertainties in the low-cross-section region, the presence of 181Ta impurities, and possible variations in the resolution broadening of the RPI neutron source. This study is therefore expected to serve as a useful reference for future measurements and resonance parameter evaluations of 93Nb over an extended energy range.

Full Text

Preamble

Measurement of the Neutron Radiative Capture Cross-Section and Resonance Parameter Analysis of 93Nb Using White Neutron Source

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In this study, the neutron radiative capture cross-section of 93Nb was measured using the Gamma Total Absorption Facility (GTAF) at the Back-n beamline of the China Spallation Neutron Source (CSNS), employing the time-of-flight (TOF) method. A comprehensive data processing procedure was implemented, including background subtraction, neutron flux normalization, dead time correction, and yield spectrum calculation. Uncertainties were evaluated based on statistical counting, neutron flux, sample thickness, and flight path correction. The excitation function of 93Nb was determined up to 2 keV. Resonance parameters below 200 eV were analyzed using the SAMMY code. Good consistency was obtained between the SAMMY fitting results and the experimental data, although discrepancies remained in the extracted resonance parameters. These discrepancies are attributed to relatively large uncertainties in the low-cross-section region, the presence of 181Ta impurities, and possible variations in the resolution broadening of the RPI neutron source. This study is therefore expected to serve as a useful reference for future measurements and resonance parameter evaluations of 93Nb over an extended energy range.

Keywords: Neutron capture reaction cross-section, Resonance parameter, White neutron source, Gamma total absorption facility

Introduction

Neutron reaction cross-sections are significant in both nuclear astrophysics and nuclear energy applications. In nuclear astrophysics, elements heavier than iron are primarily synthesized through rapid (r-process) and slow (s-process) neutron capture reactions [1, 2]. The s-process occurs over years and accounts for more than half of the elements between Fe and Bi [2, 3], while the r-process happens within milliseconds and is also essential for heavy element formation. The neutron radiative capture cross-section, as an important parameter in the simulation of these two processes, plays a significant role in the study of cosmic element abundances and the origin of elements [4].

In nuclear energy, precise control of reactor reaction rates is critical. Control rods regulate the neutron flux by absorbing neutrons, making accurate neutron radiative capture cross-section data for control rod and cladding materials essential [5]. 93Nb, a stable isotope with 100% natural abundance, is employed as a structural and cladding material in reactors. Accurate assessment of the impact of cladding materials on the neutron flux requires detailed knowledge of their radiative capture cross-section. Such data are essential for optimizing moderators and reflectors and for improving neutron economy, thermal efficiency, and fuel utilization in advanced nuclear systems [5]. During reactor operation, 93Nb in the cladding undergoes neutron capture to form 94Nb. Precise knowledge of the capture cross-section of 93Nb is therefore critical for fuel management, cladding performance evaluation, and post-irradiation processing [6].

Figure 1 [Figure 1: see original paper] shows that the available EXFOR data for the neutron radiative capture cross sections of 93Nb are sparse and carry large uncertainties in the resolved resonance region. Discrepancies among different datasets underscore the need for high-precision measurements. The inherently small neutron radiation capture cross-section of 93Nb further poses significant experimental challenges, requiring detection systems of exceptionally high sensitivity and accuracy.

Since the 1960s, the time-of-flight (TOF) method combined with prompt gamma-ray detection has been widely adopted internationally for measuring neutron radiative capture cross-sections [7–10]. Early detection systems, such as large-volume liquid scintillators [8, 11] and Moxon-Rae detectors [12], contributed significantly to the development of this technique. However, their high neutron sensitivity and interference from cascade gamma rays limited measurement precision.

To overcome these limitations, research institutions such as CERN and ORNL developed detection systems based on C6D6 liquid scintillators [13, 14]. These detectors feature low neutron sensitivity and good gamma-ray energy resolution, significantly enhancing measurement accuracy. The Back-n beamline is equipped with a C6D6 detector, which has yielded numerous experimental results in recent years [15–17]. However, their low detection efficiency and limited solid-angle coverage make them less suitable for measuring the capture cross-section of low-cross-section isotopes, small samples, or radioactive nuclides.

BaF2 scintillators, developed in the early 1980s, offer low neutron sensitivity, excellent timing resolution, and easy fabrication, making them well-suited for precise neutron capture cross-section measurements. Today, several major research institutions have established 4π total absorption detector systems based on BaF2 arrays. Notable examples include the n_{TOF} facility at CERN [18] and the DANCE array at the LANCE beamline of Los Alamos National Laboratory (LANL) [19], both of which have produced significant results in measuring neutron capture cross-sections of various isotopes. Compared with C6D6 detectors, BaF2 detectors offer advantages in measuring neutron radiative capture cross-sections of samples with small cross sections, limited quantities, or spontaneous fission characteristics.

In this study, neutron radiative capture cross-section measurements of 93Nb were conducted using the Gamma Total Absorption Facility (GTAF), developed by the China Institute of Atomic Energy (CIAE) [20]. Resonance parameters from 1 eV to 200 eV were extracted using the SAMMY code. The experimental results and fitted parameters were compared with evaluated nuclear data libraries. This work provides new experimental data for the resonance region of 93Nb, offering valuable reference information for both nuclear physics research and reactor engineering applications.

Subject-Specific Metadata

Parameter	Description
Subject area	Nuclear physics
Data format	Analyzed ROOT files
Type of data	Neutron capture reaction cross-section and resonance parameter
How data were acquired	Measurements were performed using GTAF
Parameters for data collection	Trapezoidal shaping of detector pulses from the detector was performed
Description of data collection	Data were collected by saving list-mode detector data during acquisitions
Data source location	Institution: China Institute of Atomic Energy, Country: China
Data accessibility	Repository name: Science Data Bank, Data identification number: https://cstr.cn/31253.11.sciencedb.26661, Direct URL: https://doi.org/10.57760/sciencedb.26661

Experimental Design, Materials and Methods

A. Brief Introduction of Back-n Beamline

The China Spallation Neutron Source (CSNS) [21], completed in 2018 in Dongguan, Guangdong Province, is China's first high-power pulsed spallation neutron facility. It operates at 140 kW with a 25 Hz pulsed proton beam, generating neutrons over a broad range of energies and emission angles. After deflection by a magnetic system, protons strike the target at a 15° angle, creating spatial separation between the incident beam and the emitted neutrons. In the backward direction opposite the proton beam, the neutrons form a continuous energy spectrum, commonly known as white neutrons [22]. Along this direction, the Back-n beamline has been constructed (Fig. 2 [Figure 2: see original paper]) [20, 23]. It delivers a neutron spectrum from thermal to MeV energies, making it well suited for radiative capture cross-section measurements across a wide energy range.

The Back-n beamline has two experimental halls: Hall 1 with a 55 m flight path and Hall 2 with a 76 m flight path. A neutron shutter together with Collimators #1 and #2 is used to control the beam spot size [21]. By adjusting the shutter status and collimator apertures, different spot sizes can be obtained. The corresponding configurations and spot sizes are listed in Table 1 .

B. Time-of-Flight Method

The capture cross-section can be calculated using equation (1):

$$\sigma_{n,\gamma}(E_n) = \frac{C(E_n)}{A \cdot \phi_n(E_n)}$$

Here, $\sigma_{n,\gamma}(E_n)$ (barn) denotes the neutron radiative capture cross-section at neutron energy E_n (eV). $C(E_n)$ (/s) is the total count rate of capture events occurring in the sample. $\phi_n(E_n)$ (neutrons/cm^2/s/eV) represents the neutron flux passing through the sample. A (atoms/barn) is the areal density (atomic thickness) of the sample. According to the time-of-flight (TOF) method, the energy of the incident neutron can be determined as shown in equation (2) [24, 25]:

$$E_n = \left(\frac{72.2977 \cdot L}{T_{\gamma n} - T_{\gamma f} + L_0/c} \right)^2$$

Where $T_{\gamma n}$ (ns) denotes the time at which cascade γ-rays from the neutron radiative capture reaction reach the detector. $T_{\gamma f}$ (ns) represents the arrival time of the γ-flash at the detector. L (m) is the neutron flight path, approximately 75.9 m. L_0 (m) is the distance traveled by the γ-flash from the spallation target to the detector crystal (also approximately 75.9 m). c (m/s) is the speed of light. Accordingly, by measuring the neutron time-of-flight, the count rate of capture events, and the neutron beam intensity provided by the accelerator, the neutron radiative capture cross-section can be determined.

C. Gamma Total Absorption Facility

High-precision measurements of neutron radiative capture cross-section require detectors with excellent timing resolution, low neutron sensitivity, and efficiency independent of γ-ray cascade characteristics. BaF2 scintillators satisfy these requirements, providing fast timing and low neutron sensitivity. They emit two scintillation components: a fast component (~0.6 ns) and a slow component (~630 ns) [26]. The GTAF detector system, based on BaF2 crystals, is installed in Experimental Hall 2 of the Back-n beamline at CSNS. It consists of 40 crystals —28 hexagonal and 12 pentagonal—arranged in a spherical shell with an inner diameter of 10 cm and an outer diameter of 25 cm, covering 95.2% of the solid angle [27] (Fig. 3 [Figure 3: see original paper]).

Four samples were used in the experiment: 197Au for cross-section normalization, 93Nb as the target, natural carbon (natC) for background estimation, and an empty holder for environmental and system background. The detailed sample parameters are summarized in Table 2 .

D. Sample Measurement Time

Absolute cross-section measurements at the Back-n beamline are challenging due to the difficulty in precisely determining the neutron flux, which can introduce significant systematic uncertainties. To minimize errors, a relative measurement method was employed, using 197Au as the standard sample. The experiment was performed at a beam power of 140 kW, with a neutron beam spot diameter of 30 mm. Samples were mounted inside a vacuum pipeline to reduce background from scattered neutrons.

The Back-n beamline is equipped with several neutron absorbers, including Cd, Ag, and Co. To evaluate background contributions, two configurations were used: a single Cd filter and a combination of Cd, Ag, and Co. The full experimental setup, including absorber arrangements and sample combinations, is summarized in Table 3 .

E. Data Acquisition System

The data acquisition system consists of three Pixie-16 boards, each with 12-bit resolution and a 500 MHz sampling rate [28]. The overall architecture of the GTAF detection system and the DAQ system is shown in Fig. 4 [Figure 4: see original paper]. It operates in conjunction with GDDAQ firmware, enabling real-time data analysis, encoding, and storage [29, 30].

Data Analysis

A. Pulse Shape Discrimination (PSD)

BaF2 scintillators contain trace amounts of radium (Ra), which emits α particles and generates intrinsic background. However, because γ-rays primarily excite the fast scintillation component while α particles mainly excite the slow component, this background can be effectively suppressed using pulse shape discrimination (PSD). The PSD calculation method is given in equation (3):

$$PSD = \frac{ET_{long} - ET_{short}}{ET_{long}}$$

Where ET_{long} denotes the energy obtained from the long-gate integration, while ET_{short} denotes the energy obtained from the short-gate integration. Figure 5 [Figure 5: see original paper] shows the two-dimensional PSD versus total energy spectrum obtained with a 22Na calibration source. The region enclosed by the red contour corresponds to α-induced events, which can be identified and removed to effectively suppress the intrinsic α background.

B. Total Gamma Energy Discrimination

The total γ-ray energy of each event was obtained by summing the shaped signals from all detector units using trapezoidal filtering. Environmental background, such as X-rays, typically appears below 2 MeV, while high-energy backgrounds, including cosmic rays, are mostly above 10 MeV. By restricting the summed energy to a region near the Q-value of the (n, γ) reaction, background contributions can be effectively suppressed.

Figure 6 [Figure 6: see original paper] presents the summed energy spectra for 197Au, 93Nb, natC and a blank sample. Compared with the blank, 197Au and 93Nb exhibit pronounced count increases in the 4–9 MeV range, whereas signals from neutron scattering off the natC sample are concentrated between 8–10 MeV. According to evaluated nuclear data, the Q-values of the (n, γ) reactions for 197Au and 93Nb are 6.51 MeV and 7.22 MeV, respectively. Considering detector resolution and peak broadening, the total γ-ray energy was restricted to 4.5–7.8 MeV during data processing, effectively reducing background from environmental radiation and scattered neutrons.

C. Crystal Multiplicity Discrimination

In neutron radiative capture reactions, de-excitation occurs via the emission of multiple cascade γ-rays, which deposit energy across different scintillation crystals. The number of crystals responding to a single physical event is defined as the crystal multiplicity. Capture events generally produce a multiplicity greater than one, whereas background from environmental radiation or electronic noise typically triggers only a single detector. In this experiment, a 100 ns coincidence window was applied to group signals from the same event, and the crystal multiplicity was recorded. As shown in Fig. 7 [Figure 7: see original paper], excluding events with a multiplicity of one effectively suppresses accidental coincidences and environmental background.

D. Proton Beam Normalization and Dead Time Correction

Due to differences in measurement durations for each sample and fluctuations in the number of neutrons emitted during each cycle, normalization is required for accurate comparison. At CSNS, the proton beam operates at 25 Hz, and the number of protons per pulse is recorded. Since neutron yield is proportional to the number of incident protons, the total proton count during each sample' s measurement serves as the normalization basis. Using the total proton count for the 197Au sample as a reference, correction factors $f_{proton,sample}$ for other samples are calculated as shown in equation (4):

$$f_{proton,sample} = \frac{C_{proton,sample}}{C_{proton,197Au}}$$

Here, $C_{proton,sample}$ refers to the total proton beam counts recorded during the measurement of the sample under investigation, while $C_{proton,197Au}$ denotes the total proton beam counts recorded during the measurement of the 197Au sample.

During data acquisition, system dead time—the period during which new events cannot be recorded while previous ones are being processed—can lead to event losses and affect measurement accuracy. To account for this, a dead-time correction is applied using the correction factor defined in equation (5):

$$f_{dead,sample} = e^{-1\times R_{sample}\times\tau}$$

Where R_{sample} (/s) denotes the counting rate of the sample, and τ (ns) is the system dead time, which is 200 ns in this experiment. The dead time correction factors for the 197Au and 93Nb samples are shown in Fig. 8 [Figure 8: see original paper].

E. Other Background Subtraction

After the above corrections, three primary background components remain in the experimental data: (1) beam-related but sample-independent background, such as γ-rays from neutron capture in the sample holder or surrounding materials; (2) environmental background from natural radioactivity; and (3) background from neutron-induced activation. These three types of background are represented by equation (6):

$$B(t_n) = B_{beam}(t_n) + B_{active}(t_n) + B_{scatter}(t_n)$$

Scattered neutrons from the beamline can interact with surrounding materials, producing γ-rays that contribute to the beam-related background $B_{beam}(t_n)$. This component is measured using an empty sample holder, and by subtracting the normalized empty holder data from the 197Au, 93Nb, and natC sample data, the beam-related but sample-independent background can be effectively removed.

Long-lived radioactive isotopes in the environment emit γ-rays, contributing to a flat background component $B_{active}(t_n)$. A cadmium absorber was used throughout the experiment to block neutrons below 0.3 eV, ensuring that counts in this energy region originate solely from background and remain stable. According to the time-of-flight relationship, neutron flight time is proportional to the square root of energy. By dividing the counts in each energy bin by the square root of its width, the flat background appears as a horizontal line. Its average value, multiplied by the square root of the bin width, yields the background level for each sample.

Scattered neutrons from the sample can activate surrounding materials, generating γ-rays that contribute to background. This component is difficult to suppress using conventional methods such as energy filtering, PSD, or crystal multiplicity, and therefore requires quantitative analysis using absorbers. Given that natC has a much higher neutron scattering cross-section than capture cross-section, measurements with natC are used to assess the influence of scattered neutron background. To further evaluate this background, 197Au and 93Nb samples were measured with Cd, Ag, and Co absorbers. The Ag absorber exhibits a resonance peak at 5.1 eV. After subtracting the flat and empty-holder backgrounds, aligning the natC data with the absorber' s resonance enables a quantitative estimation of the scattered neutron background, as illustrated in Fig. 9 [Figure 9: see original paper].

F. Neutron Beam Normalization

The neutron flux in the Back-n beamline varies across different energy regions, which affects the shape of the TOF spectra. The neutron energy distribution can be monitored using a Li-Si detector, as shown in Fig. 10 [Figure 10: see original paper]. Dividing the background-subtracted spectrum by the neutron spectrum measured by the Li-Si detector effectively removes the influence of neutron flux variations on the experimental spectrum. The yield spectra are then obtained by normalizing the samples under test using the saturated resonance peak of 197Au, as illustrated in Fig. 11 [Figure 11: see original paper].

G. Uncertainties

The experimental uncertainties can be categorized into the following components: statistical uncertainty, neutron flux uncertainty, sample thickness and mass uncertainty, and TOF correction uncertainty. Statistical uncertainty can be calculated based on the raw counts of the sample using equation (7):

$$\varepsilon_{statistic} = \frac{\sqrt{C + C_b}}{C_n} \times 100\%$$

Here, C represents the total counts measured, C_b represents the background counts, and C_n represents the net counts after background subtraction. These quantities satisfy the relationship $C_n = C - C_b$. The uncertainty calculated per energy bin from the experimental data shows that the statistical uncertainty is below 10% in the resonance peak region. However, in regions with lower cross-section, the statistical uncertainty is significantly higher, reaching up to 100%, primarily due to the small cross-section of the 93Nb sample and the limited experimental time.

The neutron energy spectrum in this experiment was measured using a Li-Si detector. The associated uncertainty primarily arises from the statistical uncertainty of the Li-Si detector, calculated using equation (8):

$$\varepsilon_{Li-Si} = \frac{1}{\sqrt{n}} \times 100\%$$

Here, n represents the counts within each energy bin. Using this method, the neutron flux uncertainty is found to be less than 10% within the energy range from 1 eV to 2 keV.

The mass of the 93Nb sample was measured using a precision balance with a scale division of 0.001 g, resulting in a thickness measurement uncertainty of less than 0.005%. The flight path correction was performed using a linear fit, which exhibited good linearity with a fitting error of less than 0.1%. In summary, based on the error propagation formula, the experimental uncertainties are listed in Table 4 .

H. Resonance Analysis

The neutron radiative capture cross-section and resonance parameters were obtained using the SAMMY code developed by Oak Ridge National Laboratory [31]. SAMMY is based on the R-matrix formalism and is widely used for analyzing neutron-induced reactions. In the evaluation of neutron radiative capture experiments, SAMMY employs the multi-level, multi-channel Reich-Moore formalism, which depends only on the excitation levels of the nuclide and is characterized by the ground-state spin I, incident particle spin s, orbital angular momentum l, channel spin, and total spin J. The spin groups for 93Nb are listed in Table 5 .

The SAMMY code incorporates various experimental corrections, including Doppler broadening, multiple scattering broadening, and self-shielding effects. These corrections require the use of experimental conditions and CSNS Back-n resolution as input parameters [32]. The input information and experimentally obtained yield data were processed using the SAMMY code, with the fitting range set to 0–200 eV. Bayesian fitting was enabled in the program, and the resonance energy, neutron width, and gamma width were sequentially fitted. Table 6 lists the resonance parameters obtained from SAMMY. The fitted resonance energies agree well with those in the experimental database. Using the fitted gamma and neutron resonance widths, the ratio of the capture kernel to that in the database was calculated. Considering the relatively small cross-section of 93Nb and the high experimental uncertainties, these ratios fall within a reasonable range.

Figure 12 [Figure 12: see original paper] shows the comparison of fitting results with experimental data. Figure 13 [Figure 13: see original paper] shows the comparison of reconstructed cross-section with evaluated nuclear data libraries. From these figures, the following conclusions can be inferred:

(1) In metallurgy, Nb and Ta commonly occur as associated minerals, and due to their similar chemical properties, they are difficult to separate [33]. As a result, Nb samples often contain Ta impurities. The five resonance peaks indicated by the arrows cannot be matched with any of the 93Nb resonance results in the evaluated libraries. However, a review of the ENDF/B-VIII.0 library reveals that they correspond precisely to the resonance peaks of

181Ta. These findings provide clear evidence for the presence of 181Ta impurities in the sample [34].

(2) Figure 12 shows that the SAMMY fits reproduce the experimental data, but the resonance parameters in Table 6 differ from those in ENDF/B-VIII.0. The reconstructed cross sections (Fig. 13) exhibit additional discrepancies in the low-cross-section region and near several resonance peaks. These deviations are mainly due to the small cross-section of 93Nb and the limited measurement time, which reduce the signal-to-background ratio and increase the statistical uncertainty, thereby affecting the low-energy fits. Variations in the resolution function of the RPI neutron source during CSNS upgrades may also contribute by modifying the apparent resonance broadening. These effects together account for the observed differences between the fitted parameters and the evaluated libraries.

(3) A resonance near 55 eV aligns with JENDL-5 and TENDL-2023, but deviates from ENDF/B-VIII.0.

(4) Some additional resonance-like structures are present in the experimental data, which also appear in the measurements of 197Au. These are presumed to originate from structures in the neutron energy spectrum.

Conclusion

This study presents the measurement of the neutron radiative capture cross-section of 93Nb using the GTAF detection system at the Back-n beamline of the China Spallation Neutron Source (CSNS). A time-of-flight method was applied, supported by a systematic data processing procedure involving multiplicity filtering, time-window coincidence selection, background modeling, and subtraction of beam-related and environmental backgrounds. To ensure the accuracy of the experimental results, neutron flux normalization was carried out using the proton charge information of each beam pulse. Multiple sources of uncertainty, including statistical uncertainty, neutron flux fluctuation, sample thickness measurement, and flight path corrections were carefully evaluated and incorporated into the results.

The experimental yield of 93Nb in the energy range of 0–200 eV was obtained and fitted using the SAMMY code, which applies the Bayesian R-matrix method. The resulting resonance parameters were compared with evaluated nuclear data libraries such as ENDF/B-VIII.0, JENDL-5, and TENDL-2023. Good agreement was achieved between the fits and the experimental data, but deviations from the evaluated libraries were observed in the resonance parameters. Discrepancies in the reconstructed cross-section were seen in the low-cross-section region and in the form of broadened resonance peaks, which are attributed to the low signal-to-background ratio in the 93Nb measurements and to possible variations in the RPI resolution function.

This work demonstrates the capability of the GTAF system in high-precision neutron capture measurements and provides valuable data and methodology for future studies on 93Nb and other isotopes over broader energy ranges. The following improvements can be made in future experiments:

(1) In the current data analysis approach, the neutron scattering background is estimated using experimental measurements from a natC sample. However, the actual neutron scattering cross-section of 93Nb differs from that of the natC sample, resulting in discrepancies between the estimated and true scattering background. This discrepancy affects the accuracy of the experimental data. To improve measurement precision in future work, Monte Carlo simulations can be employed to quantitatively assess the differences in neutron scattering backgrounds between the 93Nb sample and the natC sample across different energies. This approach will enable more accurate background subtraction and enhance overall data quality.

(2) Structures in the neutron spectrum significantly affect the measurements. As the spallation source is upgraded, the spectrum changes, making real-time monitoring with Li-Si essential. Currently, the low Li-Si count rate results in high spectral uncertainty, leaving residual structures in the data. Extending spectrum measurement time in future experiments can reduce these effects.

Usage Notes

This work provides neutron radiative capture cross-section data for 93Nb. The data have significant applications across various fields:

(1) 93Nb and its radioactive isotope 92Nb serve as important tools in astrophysics for studying nucleosynthesis and the early solar system. The 93Nb/92Nb ratio records timing information of early solar system materials. 92Nb originates from supernova explosions, reflecting stellar nuclear processes. Its decay helps reveal neutrino-induced reactions in the early solar nebula, providing insights into galactic chemical evolution and element formation.

(2) Stable 93Nb acts as a reference isotope in accelerator mass spectrometry for measuring 92Nb. Proton-induced reactions on niobium targets offer data crucial for radioactive isotope production and accelerator target design. Understanding 93Nb nuclear reactions improves accelerator efficiency and safety, facilitating applications in nuclear medicine and industry.

(3) 93Nb nuclear magnetic resonance is widely employed to investigate niobium-based superconductors such as Nb3Sn. This technique reveals the microscopic electronic structure and magnetic response of superconductors, supporting the design of high-performance superconducting magnets. These studies help optimize critical current and stability, advancing superconducting technologies in particle accelerators and

medical devices.

Code Availability

The DAQ firmware and data decoding software used in this system have been publicly released. Those interested in the data processing methodology are encouraged to contact Luo Haotian for further discussion. Resonance parameters were obtained using the SAMMY code, which is open-source and publicly available on its official website.

In the dataset, the experimental data spans from 0.1 eV to 2000 eV, divided into 2000 bins, matching the binning of the neutron energy spectrum collected by Li-Si for ease of data processing. The time-of-flight (TOF) for capture events is calculated using the t0 signal from the CSNS Back-n facility as the start time. TOF calibration is performed based on the second to fifth resonance peaks of a 197Au sample. Due to the large size of the raw experimental data, the dataset provides files where the raw data have been organized into capture events, including information such as TOF, neutron energy, crystal multiplicity, and raw count rates. Users can re-bin and process the data according to their specific interests. The dataset also contains energy and pulse shape discrimination (PSD) calibration information for 40 detectors, measured using a 22Na calibration source. Background subtraction results are saved progressively as histograms within ROOT files. For further data details, please contact the authors.

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Author Contributions Statement

The experiment was conceived and designed by Zhang QW, Luan GY, and Wu HY. The measurements were performed by Zhang QW, Luan GY, Wu HY, Luo HT, and Chen XB. Luo HT conducted the data analysis and wrote the manuscript. Ruan XC and Ren J contributed to data interpretation and manuscript revision. Jiang W and Fan RR supported the experimental procedures.

Competing Interests

This study utilized the Pixie-16 data acquisition system, generating approximately 20 TB of raw experimental data. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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