THE FEASIBILITY STUDY OF CSNS BACK-N USING FOR TEMPERATURE MEASUREMENT BY RESONANCE NEUTRONS

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Abstract: The temperature measurement using neutron resonance spectrum can be used for temperature measurement of shockwave, but a pulsed white neutron source with high intensity is needed. The back-streaming white neutron beam line (Back-n) of the China Spallation Neutron Source (CSNS) was built and started running since the beginning of 2018. The white neutron source can provide neutrons from 1eV up to hundreds of MeV by impinging 1.6 GeV protons onto a thick tungsten target. There are two experimental halls along the Back-n beam line which respectively has a flight path of ~55 meters (Hall 1) and ~76 meters (Hall 2). The resonance sample (such as ^{181}Ta) was placed at Hall 1 and measured the neutron transmission spectrum at Hall 2. The neutron transmission spectrum through the resonance sample was simulated by MCNP. The 4.28 eV and 10.36 eV resonance drop of ^{181}Ta can be seen from the transmission spectrum. CSNS Back-n may be applied for temperature measurement by neutron resonance spectrum in the future.

Key words: Temperature measurement, Resonance neutron, CSNS Back-n, Monte Carlo simulation

Introduction

The Doppler broadening of the lower energy neutron absorption resonances of some metals, such as natural hafnium, tantalum, iridium and rhenium, have been studied for the purpose of measuring temperature in remote or isolated environments[1-3]. This new method of temperature measurement using neutron resonance spectrum can be also applied to some experimental studies of dynamic system, such as detonation, explosion, shock, and so on.

In order to apply this method, a pulsed neutron source which has plenty of low energy neutrons with high intensity is needed. The back-streaming white neutron beam line (Back-n) of the China Spallation Neutron Source (CSNS) was built and started running since the beginning of 2018. The white neutron source can provide neutrons from 1eV up to hundreds of MeV by impinging 1.6 GeV protons onto a thick tungsten target[4].

The feasibility of CSNS Back-n beam line using for temperature measurement by resonance neutron will be discussed in this paper.

Principle

It is proposed that the sample temperature be determined from transmission data by a methodology which directly appeals to the equations of the governing physics rather than employing empirical methods. This offers the considerable benefit over such empirical methods that a calibration experiment is not required prior to the acquisition of the desired data. In order to accomplish this, it is necessary to calculate the absorption cross-section as a function of neutron energy in the vicinity of the resonance including the contributions from the intrinsic line shape of the resonance and the Doppler broadening.

The reaction cross-section, $\sigma_f(E)$, for the capture of a neutron, with kinetic energy, E, by a stationary nucleus close to the energy of an isolated resonance, E_R, may be adequately described by the single-level Breit–Wigner formula[5].

$$\sigma_{\mathrm{r}}(E)=\pi\lambda\!\!\!^{-}{}^2 g_J \frac{\Gamma_n\Gamma_r}{(E-E_R)^2+(\Gamma/2)^2}, \qquad (1)$$

Where $\lambda\!\!\!^{-}$ is the de Broglie wavelength of the incident neutron, Γ is the resonance width, Γ_n is the neutron width, Γ_{r} is the partial width for the reaction and g_J is a statistical spin factor for the formation of a compound state with angular momentum, J.

Because practical investigations seldom encounter stationary nuclei and it is necessary as such to accommodate the velocity distribution of the target nuclei to obtain an effective cross-section. The effective cross-section can then be obtained from the convolution of the Breit–Wigner formula (Eq.1), with an energy transfer function, accounting for the velocity distribution of the target nuclei.

In the simplest case, for a mono-atomic free gas or classical solid, by taking a Maxwellian distribution of velocities for the target nuclei corresponding to a temperature, T, the Doppler width of the resonance absorption peak is given by

$$\Delta=\sqrt{\frac{4mME_RkT}{(M+m)^2}}, \qquad (2)$$

where m and M are the neutron and nuclei masses respectively and k is Boltzmann constant.

Let $\mathrm{A}=M/m$, if $\mathrm{A}>>1$, then from Eq.2, the absolute temperature of the target nuclei is given as

$$T=\frac{\mathrm{A}\Delta^2}{4kE_R}. \qquad (3)$$

Obviously, if the Doppler width could be measured by experiments, then the temperature is obtained.

Calculation

There are two experimental halls along the Back-n beam line which respectively has a flight path of ~55 meters (Hall 1) and ~76 meters (Hall 2)[6]. The resonance sample (such as Ta-181) can be placed at Hall 1 and the neutron transmission spectrum could be measured at Hall 2. The layout of the Back-n beam line is shown as Figure 1.

The neutron transmission spectrum through the resonance sample was simulated by MCNP. But before the simulation, the effective cross-section must be obtained. In this work, the effective cross-sections of Ta-181 at different temperatures were calculated by the NJOY

Nuclear Data Processing System (NJOY 99.0)[7,8]. Two of them are shown as Figure 2.

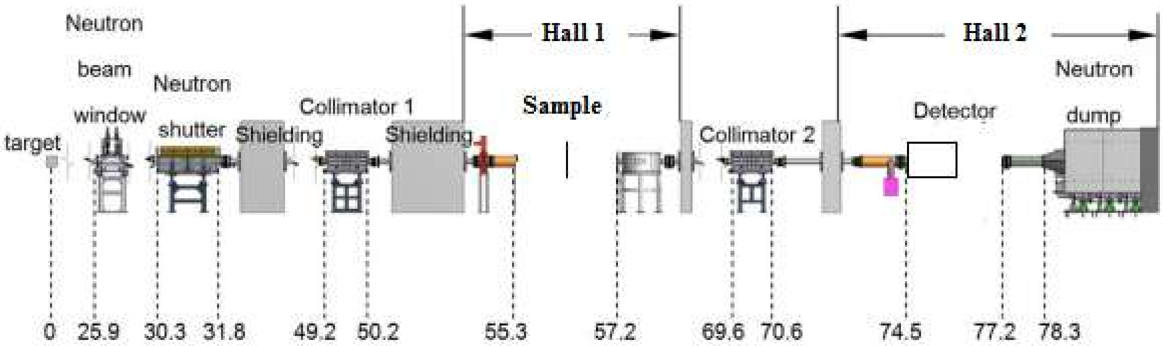
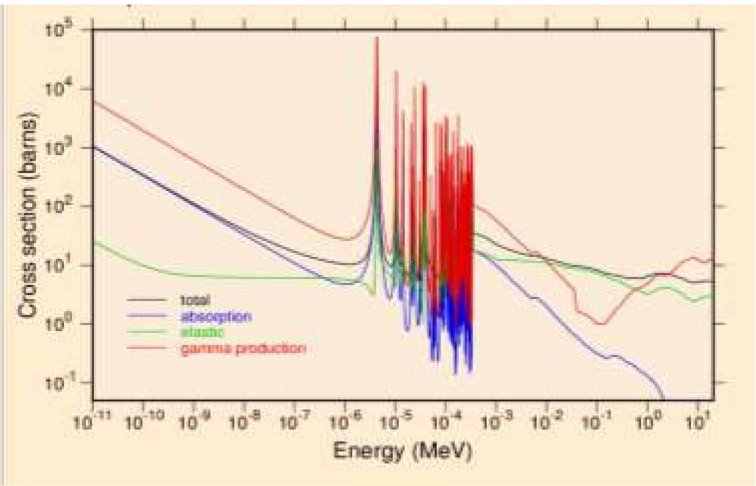
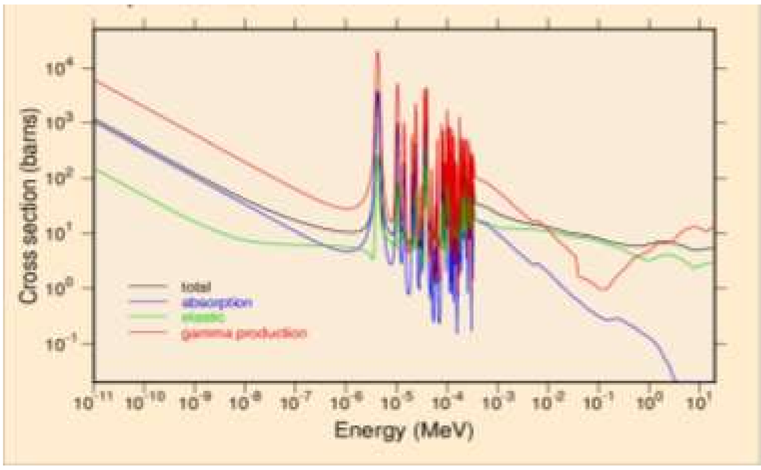


Figure 1. Layout of the Back-n beam line (distances are given in meters)



(a)T=273 K



(b) T=1E4 K

Figure 2. The effective cross-section of Ta-181 at different temperatures

It can be seen from Figure 2 that the resonance peaks are becoming lower and wider when the temperature is higher. The size of tantalum we used here is Ø60 mm×1 mm. The input neutron energy spectrum is provided by Dr. H.T. Jing[9], shown as Figure 3.

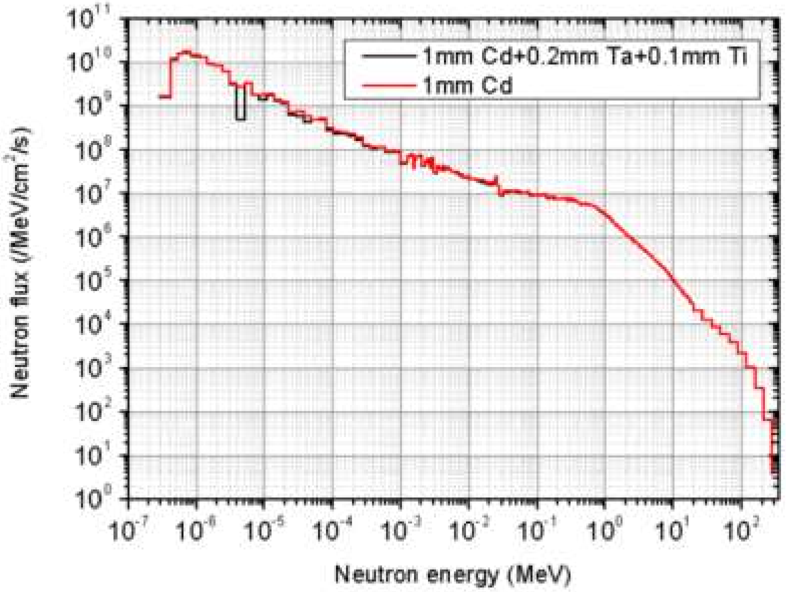


Figure 3. Neutron spectrum of CSNS back-n

The neutron intensities spectra after the neutrons passed through the sample were recorded according to different temperatures. The results are shown as Figure 4.

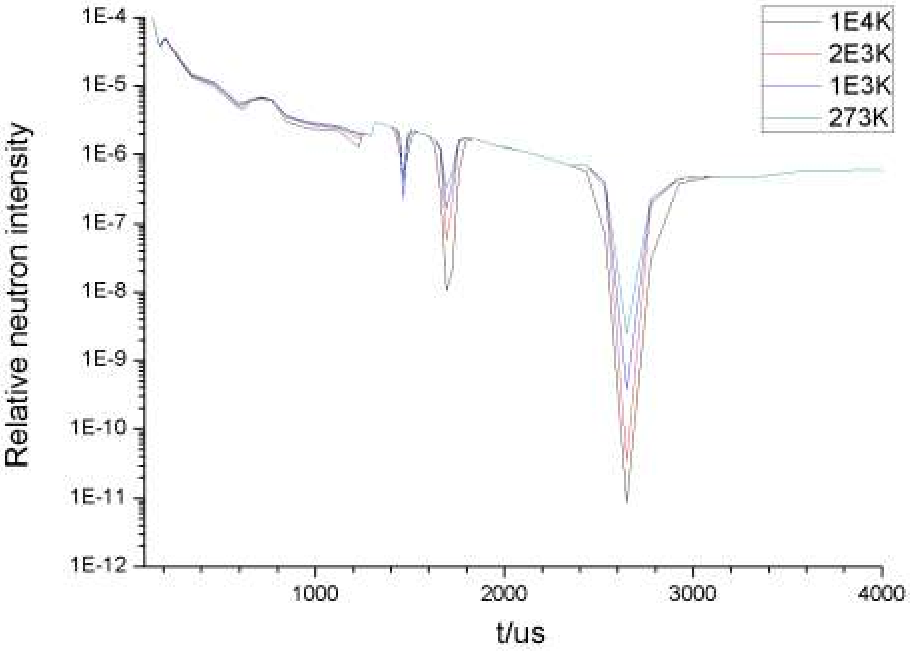


Figure 4. Neutron transmission spectrum at Hall 2

The 4.28 eV and 10.36 eV resonance drops of Ta-181 can be seen clearly from the transmission spectrum. The width of the absorption peak could be obtained and it was broaden when the temperature was changed to a higher temperature.

We can use TOF methods to measure the Doppler Broadening at Hall 2 by fast timing technique. The current neutron beam of CSNS Back-n can be used for stable temperature measurement by using neutron resonance spectrum; but for a dynamic system, the intensity of low energy neutron for single pulse is not enough high.

Discussion

1. On the one hand, the effective cross-section of the sample is important to this method. Different models and assumptions may give different results. On the other hand, the calculation results of this work may have a relative bigger uncertainty because the input neutron energy spectrum must be corrected by measured results.

2. A ^{6}Li glass scintillation detector with flat energy response for low neutron energy neutrons is planning to use. Fission chamber with SiC detector is also a good choice. An appropriate sample is also important.

3. In order to escape from gamma flash and high energy neutrons, the gating photomultiplier is recommended. The signal from another fast scintillation detector which monitors the gamma flash can be used as a triggered signal for the gating photomultiplier.

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