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An experimental cross-section measurement of $^{10}B(n,\alpha)^{7}Li$ reaction on counting alpha particles track density

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Abstract

The present work determines the particle size based only on the number of tracks detected in a cluster created by a hot particle on the CR-39 solid state nuclear track detector and depending on the exposure time. The mathematical model of the cross section developed here gives the relationship between alpha particle emitting from the (n, α) reaction and the number of tracks created and distribution of tracks created on the surface of the track detector. In an experiment performed during this work, disc of boron compound (boric acid or sodium tetraborate) of different weights were prepared and exposed to thermal neutron from the source. Chemical etching is processes of path formation in the detector, during which a suitable etching solution attacks the detector at a sufficient speed and the damaged regions along the ion trails (latent track) are preferentially dissolved, removed and get transformed into a hollow channel. The most common etching for plastics is the aqueous solutions of NaOH and temperatures in between 50˚C - 80˚C.The program (CR-39) processing counting and calculations only take place depending on the number of tracks.

Key words
Chemical etching, ^{241}Am-Be neutron source, Track Etching Parameters, $^{10}B(n,\alpha)^{7}Li$, CR-39 detectors.

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حساب المقطع العرضي للتفاعل النووي $^{10}B(n,\alpha)^{7}Li$ تجريبيا من عد كثافة اثار جسيمات الفا

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الخلاصة

يستند عمل البحث على اظهار عدد جسيمات الفا الناتجة من تفاعل (n, α) الساقطة على الكاشف الصلب CR-39 بالاعتماد على وقت التعرض. الانموذج الرياضي المستخدم لحساب المقطع العرضي يعطي العلاقة بين جسيمة الفا الناتجة من تفاعل نيترون-الفا التي تمثل عدد المسارات المتولدة على سطح الكاشف. تم تحضير قرص من مركب حامض البوريك او تترات الصوديوم باوزان مختلفة بتعريضه للنيوترون الحراري من المصدر النيوتروني. المعالجة الكيميائية المتمثلة بعمليات القشط بمحلول هيدروكسيد الصوديوم NaOH ذو العيارية 6.25N بدرجة حرارة من C˚ 50-80. يقوم البرنامج الحاسوبي بلغة الماتلاب باجراء عمليات المعالجة الصورية لاثار جسيمات الفا الساقطة على مادة الكاشف. وذلك من خلال استخدام كاميرة رقمية متصلة بمجهر. يقوم البرنامج بقياس اقطار الاثار كل على حده وتسجيل قيمة كل قطر على الصورة الرقمية وحساب معدل الاقطار و انحرافاتها المعيارية ضمن المشهد الواحد.

Introduction

The two stable isotopes of natural boron consists of ^{11}B(80.1%) and ^{10}B(19.9%). Only the ^{10}B in (n,α) reaction has a high thermal neutron capture cross section 3840 barns for 0.025 eV neutron [1]. Boron and thermal neutrons interact in two possible ways; (Q value = 2.792 MeV, ground state; **γ**-ray Q value of 0.48 MeV; Q value = 2.310 MeV, excited state) [2-5]. Isotope ^{11}B has absorption cross-section for thermal neutrons about 0.005 barns (for 0.025 eV neutrons) [6]. Most of (n,α) reactions of thermal neutrons are $^{10}B(n,\alpha)^{7}Li$ reactions accompanied by 0.48 MeV γ-ray emission. The^{10}B component, which can exist in gas, liquid, solid states are exceedingly used for neutron shielding, detection and absorption out of the $^{10}B(n,\alpha)^{7}Li$ reaction, one of the more significant nuclear reactions in implementation of research of nuclear physics and nuclear engineering and for biomedical applications [6-8].

Using an CR-39 solid state nuclear track detector (SSNTD) enables the registering of the α-charged particles, which induce damage along their interaction path resulting from the reaction $^{10}B(n,\alpha)^{7}Li$. The damaged regions produced by radiation charged particles on the surface of CR-39 detector are developed and amplified for visualization through an optical microscope with magnifications ranging from 400-1000X [9-12]. In this study the cross section is calculated for the $^{10}B(n,\alpha)^{7}Li$ reaction with thermal neutrons by preparing of different disc thickness and using different weight of boric acid. For incident neutrons with the energy of 0.025 eV the experimental data are of interest as new experimental investigations by using CR-39 detector, which increases drastically with lower neutron energy. A boron doped SSNT CR-39 detector has an important advantage of high geometric factor for alpha particle registration because (n,α) nuclear reactions take place in the plastic [13]. The accurate measurement of ^{10}B distributions in samples with a ppm-concentration is important for evaluating the potential usefulness of different boron-containing compounds for BNCT [14-17]. One of the main parameters that govern track formation is the bulk etch rate V_B dependences on different parameters such as the preparation procedures, etching conditions, irradiation before etching etc. and are examined property. A review of existing methods for determination of the bulk etch rate and track etch rate V_T is also given. Examples of V_T functions for some detectors are presented. Some unsolved questions related to V_T and some contradictory experimental results published in the literature are also summarized in the references [5, 18-20].

The thermal neutrons interact with boron in two possible ways;

$$^{10}B+n_{th}(0.025eV)\rightarrow{}^{4}He^{2+}+{}^{7}Li^{3+}+2.79\ MeV\ \ (6\%) \quad (1)$$

$$^{10}B+n_{th}(0.025eV)\rightarrow{}^{4}He^{2+}+{}^{7}Li^{3+}+2.31\ MeV+\gamma(0.48MeV)\ \ (94\%) \quad (2)$$

The Q value of the both reaction in Eqs. (1) and (2) is very large compared to the incident neutron energy, which represented the kinetic energy of the products [11]. $^{10}B(n,\alpha)^{7}Li$ cross sections were obtained by using the formula [5,15-24]:

$$\sigma = 4\rho/CB{*}N{*}\ \varphi{*}(R_{\alpha}.\cos^{2}\theta\alpha+R_{Li}\cos^{2}\theta_{Li}) \quad (3)$$

where ρ; nuclear track density, CB fraction of boron atoms equal to 0.198; σ a thermal neutron capture cross section; φ neutron flux (1.67 × 10^7 n/cm^2.s); N atom density of the sample, (1.7 × 10^4 for boron standard) ; $R_{\alpha}\cos^{2}\theta_{\alpha}+R_{Li}\cos^{2}\theta_{Li}$ in that R_{α} and

R_{Li} are the ranges of alpha particles and lithium ions respectively.

Experimental method and material
1. Neutron source
All samples were irradiated with neutron at ambient temperature with a ^{241}Am-Be neutron source was supplied by Radio-Chemical, Ltd, England, with the flux of 10^7 neutron. cm^{-2}. sec^{-1}. All neutrons obtained from these sources may be thermalized (i.e. 0.025 eV) with paraffin thermal neutron beam was obtained by placing petroleum wax around the source, such a way the distance of samples from the source is 5.0 cm [8, 21, 23]. CR-39 detectors, cut from a 500μm thickness sheet, were irradiated with incident alpha particles from $^{10}B(n,\alpha)^7Li$ nuclear reaction. The irradiated detectors were etched in 6.25 N solution of NaOH in a bottle without stirring, at a temperature of 70 $^{\circ}$C, in water bath at a constant temperature ±1°C, to keep of NaOH concentration due to evaporation and moisture shown in the Fig. 1.

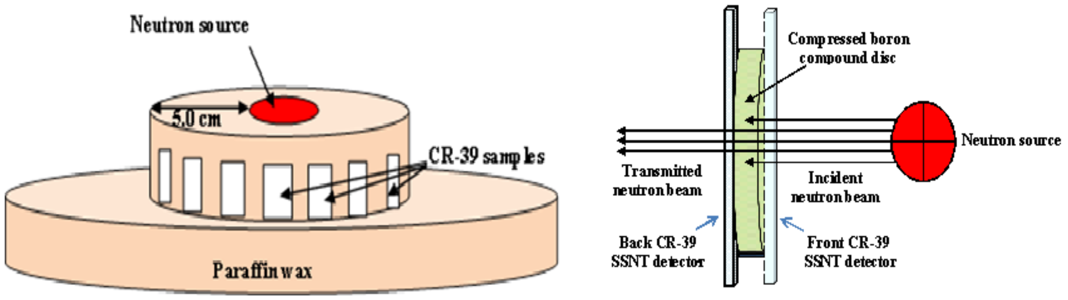

Fig.1: The design represents the neutron source and sample sites used to study variables related to the disk method.

2. Preparation methods
Boron samples were prepared and exposed to the thermal neutron beam in two methods.

2.1 The disc method
In this method, boron samples were pressed as uniform disc by using mechanical press supplied with stainless steel dye of 10 mm diameter with a pressure 4.0 Ton. The following variables were studied, to find the best adjustment to obtain good reproducibility for the concentration of boron. Preparation of different disc thickness was prepared by using the following weight of boric acid: 75.0, 100.0, 125.0 150.0, 175.0, 200.0 and 225.0 mg. SSNTD was fixed at the front and back of the detector, irradiated with neutron beam for 24 hours. The number of tracks of the produced alpha particle were counted by the microscope at amplification power of 400 and plotted against the neutron capture cross section of boric acid or sodium tetraborate in the disc.

2.2. Solutions preparation
Seven boron samples containing gelatin were prepared and applied to the surface of SSNTD and left overnight to dry. Weight accurately 2.6540 g of boric acid or sodium tetraborate, $Na_2B_4O_7.10H_2O$ using and dissolve it in 500 mL volumetric flask containing ~ 100 mL distilled water, and the volume completed to the mark with distilled water. The concentration of this solution is 290 ppm of boron. Different volumes of standard solution of 290 ppm of boric acid or sodium tetraborate (0, 5, 10, 20, 30, 40, 50, 60, 70, 80, and 90 µL) were transferred by a pipette to 100 mL volumetric flasks and then diluted with distilled water to

the mark. The detectors were left overnight in a well-ventilated cabinet. The prepared detectors were irradiated with thermal neutron beam for 96 hours removed from the neutron source.

3. Track observation and computer image processing

CR-39 used in this study obtained from Moulding Ltd, UK with 500 μm thickness and density of 1.3 g/cm^3 [17]. The most common method of viewing and making quantitative measurements of the observable track parameters like number, length, diameter, etc. is through an optical microscope with calibrated eye pieces and mechanical stages under transmitted light and with magnifications ranging from 400-1000X. Advanced and automatic track counting systems based on new optical devices coupled with microprocessors have also been employed to count the tracks. In one such device, images of the tracks focused under the microscope scanned through a camera to an image digitizer in the PC. These digital images are subsequently analyzed by a software called Image [23, 26]. The size and characteristics of the alpha particle tracks depended upon the energy and direction of motion in connection with NSSTD. Energy dependence is related to the position of the reacted nuclei in contact with the detector surface or as a matrix. In the former case the angle of interaction will possess a critical value [16-18]. The data on the capture cross sections are needed in several applications of nuclear physics. This work is concerned with the design and test CR-39 computer algorithm capable of performing image processing operations on digital images of alpha particles tracks on CR-39 detectors. The software measures the diameters of individual tracks separately and registers the measured value of each diameter on the digital picture. It also calculates the mean and standard deviation for all tracks within any particular view. The software saves a great deal of manual effort compared with the method currently being used for the study of nuclear tracks [23, 26].

Result and discussion

As shown in Fig.2 the samples after 24 hours of thermal neutron irradiation followed alkali treatment with NaOH, and recorded alpha particles tracks, Images of the tracks focused under the microscope, scanned through a camera to an image digitizer in the PC, these digital images are subsequently analyzed by software called Image. The Fig. 3 show when the temperature increase the bulk etch rate is also increased. The bulk etch rate is one of the most important parameters that control the formation and the number of tracks, which is depend on many factors such as the preparation and chemical composition of the detector, the type of etching solution and the etching conditions, they have an extra effect. The range of the alpha particle should be at least 2.8 μm, which requires minimum 400 keV kinetic energy and depends on dE/dx [14, 26]. In this case, the transfer of the linear energy deposition is quite enough, ~ 200 keV/μm, to provide enough damage to be visualized which is typically ranging in diameter from 3 nm to 10 nm, too small to be visible with an optical microscope [20, 21]. The cross section for boron capturing neutrons increases drastically with lower neutron energy, reaching to 3797 barn for boric acid or 3172 barn for sodium tetraborate of different weights at thermal energy level ~ 0.025 eV, When thermal neutrons interact with boron, the reaction leads to ^{7}Li in the excited state 94% of the time, while the remaining 6% are ground state ^{7}Li.

In both cases, since the Q value of the reaction is very large compared to the incoming neutron energy, the kinetic energy of the products (α and Li) is almost equal to the Q value. This can be estimated by the Eq. (3) [6, 14, 24]. The earliest experimental result of the nuclear cross section close to the International Atomic Energy Agency IAEA [20], experimental data obtained is the use of Eq. (3) and Neutron flux as shown in the Tables 1 and 2 as can be seen, the Figs. 4 and 7 show there is a difference in the density of nuclear track number on both the front and back surfaces where we note that the density of nuclear track number on the front surface more than on the back surface for boric acid and sodium tetraborate. In both cases boric acid and sodium tetraborate, by increasing the thickness, the cross section of the reaction (n,α) is reduced because by increasing the thickness it leads to the absorption of alpha particles, as shown in Fig. 5 and 8, where the cross section (n,α) reaction is directly proportional to track number density, as the Figs. 6 and 9 show the gradual growth of the track number density on the detector surface by increasing cross section [23, 25].

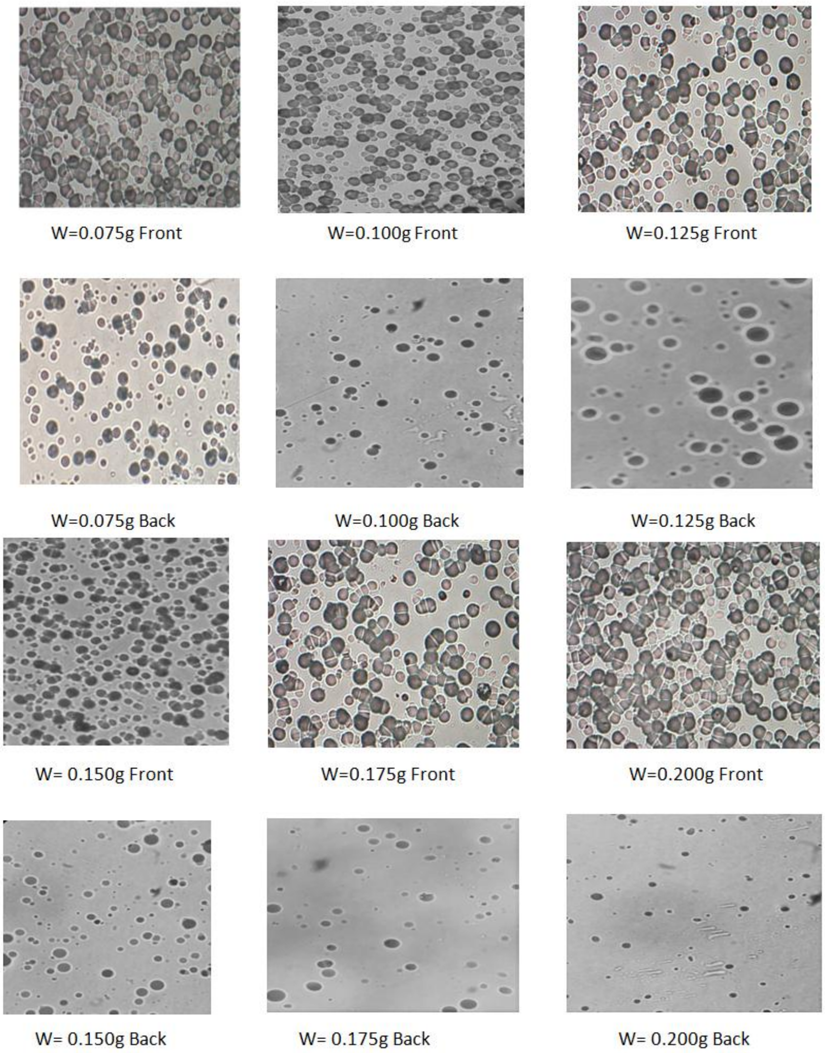

Fig. 2: Images of alpha particles tracks of boric acid on CR-39 detector of different disc thickness and weight; 0.075, 0.10, 0.125, 0.150, 0.175, and 0.200 g).

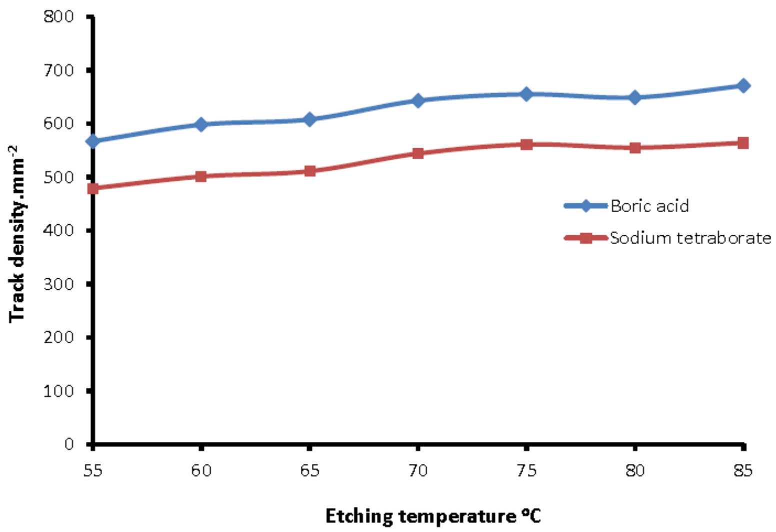

Fig.3: The track density of alpha particle recorded for different CR-39 SSNT detectors coated with 100 µL of 100 ppm boron compound loaded on gelatin film, irradiated for 24 hour, then developed with strong alkali at different etching temperature.

Table 1: Number of alpha particles track and cross-section for different disc thickness was prepared by using the following weight of boric acid (0.075, 0.10g, 0.125, 0.150, 0.175 and 0.200 g) on CR-39 detectors.

Disc weight (g)	No. of track per field of view		No. of track/cm^2		Total No.	σ_{Front} (barn)	σ_{Back}(barn)	σ_{tot}(barn)
	Front	Back	Front	Back				
0.050	2175	1974	1103512	1005178	2108690	5366	4888	10254
0.075	2168	1753	1103512	1001200	2104712	1991	1806	3797
0.100	2168	1496	1103512	892277	1995789	1991	1206	3197
0.125	2168	1183	1103512	761464	1864976	1991	828	2819
0.150	2168	816	1103512	602147	1705659	1991	544	2535
0.175	2168	526	1103512	415344	1518856	1991	321	2312
0.200	2168	219	1103512	267734	1371246	1991	182	2173

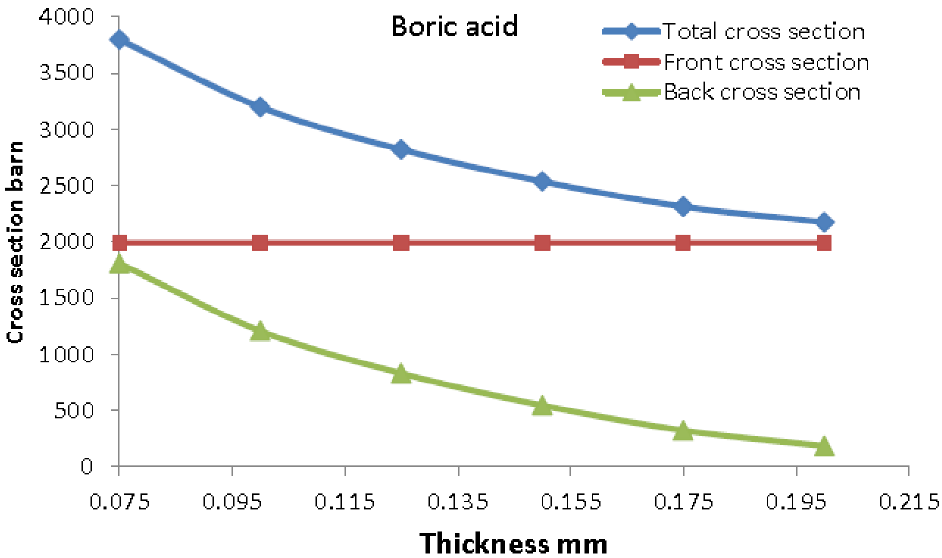

Fig. 4: Graph showing various cross sections as a function of thickness.

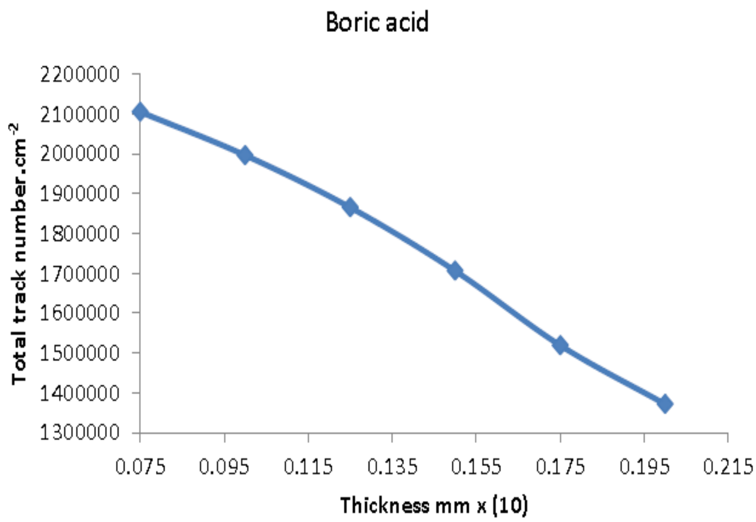

Fig. 5: Total track number, cm^2 as a function of with Thickness.

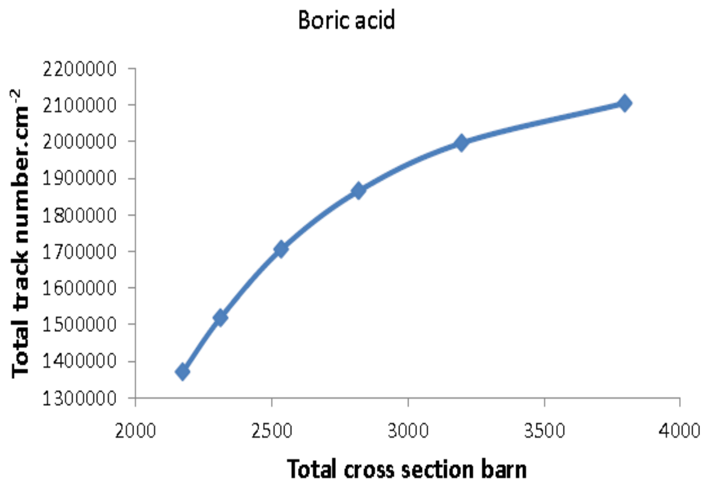

Fig. 6: Total track number, cm^2 as a function of with total cross section (barn).

Table 2: Number of alpha particles tracks and cross-section for different disc thickness was prepared by using the following weight of sodium tetraborate (0.075, 0.100g, 0.125, 0.150, 0.175 and 0.200 g) on CR-39 detectors

Disc weight (g)	No. of track per field of view		No. of track/cm^2		Total No.	σ_{Front} (barn)	σ_{Back} (barn)	σ_{tot}(barn)
	Front	Back	Front	Back				
0.050	10564	7019	1055800	742205	1798005	5134	3609	8743
0.075	10558	6436	1055800	701912	1757712	1906	1266	3172
0.100	10569	4629	1056900	643621	1700521	1906	780	2686
0.125	10568	2994	1055800	462931	1509831	1906	503	2494
0.150	10567	1847	1056700	299423	1356123	1906	271	2177
0.175	10567	1048	1056700	184713	1241413	1906	120	2026
0.200	10568	792	1056800	104814	1161614	1906	71	1977

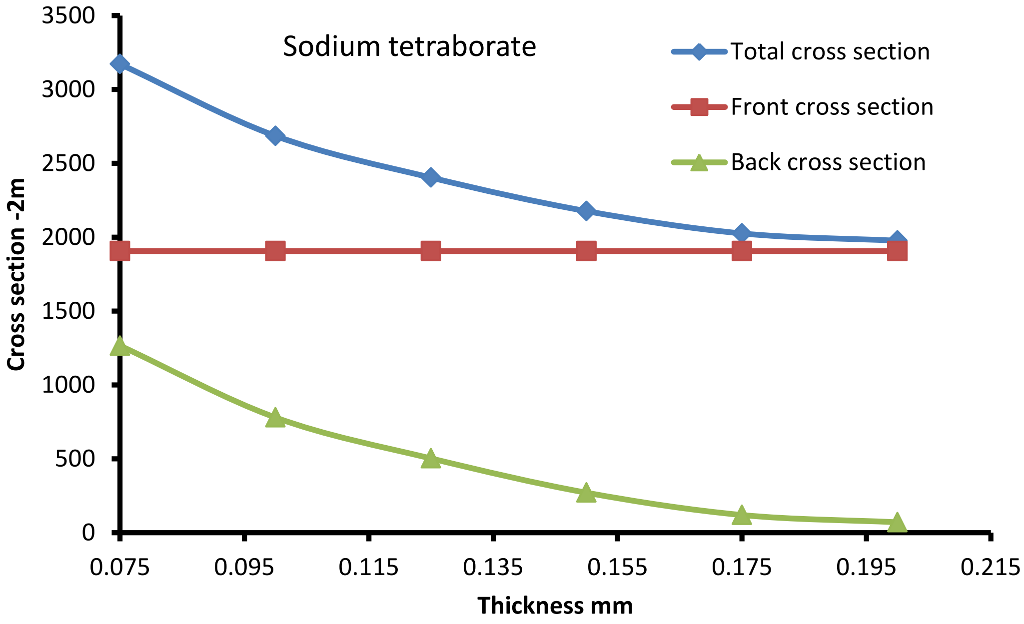

Fig. 7: Cross sections various with thickness of sodium tetraborate sample.

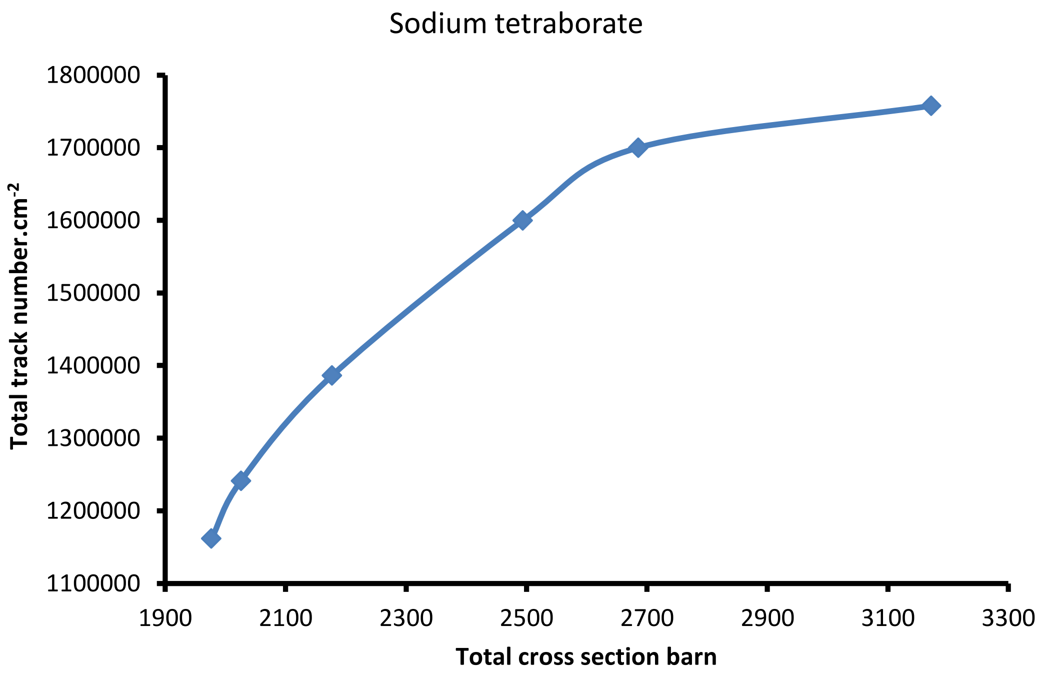

Fig. 8: The total cross section of Sodium tetraborate as a function of total track number of sample.

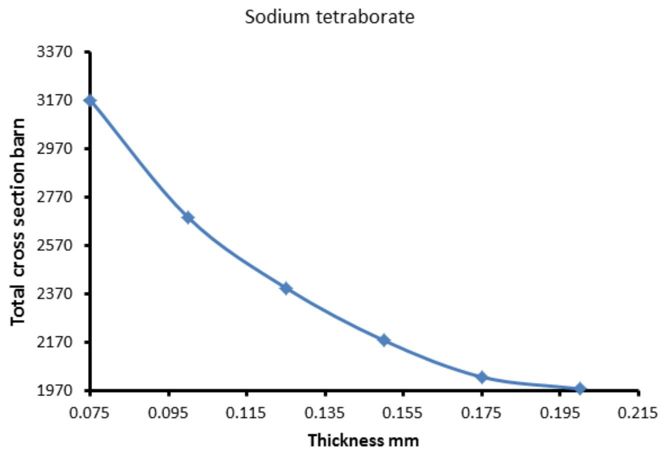

Fig.9: The total cross section of sodium tetraborate as a function of thickness of sample.

Conclusions and applications

The study of the nuclear reaction cross section of the industrial and natural element of the boron leads the researcher to study the use of Boron material for biomedical applications. In particular, chemical properties, mechanical, the intrinsic optical, and providing new opportunities for treating incurable diseases and organizing complex biological processes. This study leads us to the possibility of using boron nanomaterial's in the following applications, bio-reactions of nanomaterial's, delivery of drugs by nanomaterial's, and experimental radiotherapy that is given to a compound containing ^{10}B peer atoms and preferentially accumulated in tumor tissue. When the ^{10}B atoms contained in the tumor are irradiated by low-energy neutrons, a spontaneous nuclear reaction occurs. Neutron is absorbed, α- rays and ^{7}Li particles are produced inside the tumor, destroying cancer cells. Boron neutron capture therapy (BNCT) is a form of radiation therapy mediated by the short range (less than 10 μm) energetic alpha ^{4}He and ^{7}Li ionizing particles that result from the prompt disintegration by slow neutrons of the stable-(nonradioactive) nucleus boron ^{10}B. After being taken up by cells, the efficacy of the treatment increases and reduces the effects on the surrounding healthy tissue. So this possibility represents an actual magic bullet against tumors [23].

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