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INVESTIGATION OF REACTION CROSS SECTIONS OF $^{10,11}B$ WITH PROTONS AND NEUTRONS OF 0 – 30 MEV INCOMING ENERGY USING NUCLEAR MODELS

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Abstract: Boron, plays an extremely important role in nuclear technology, comprised of 20% ^{10}B and 80% ^{11}B abundance rate in nature. Abundance of Turkey's boron reserves makes these isotopes valuable in science and economy. In this work, for neutrons and protons in the 0 – 30 MeV energy range, cross section calculations of nuclear reactions with target ^{10}B and ^{11}B were obtained using different nuclear reactions codes as TALYS1.2, ALICE-ASH and CEM03. In preequilibrium calculations, Cascade Exciton Model is used. In equilibrium calculations, Weisskopf-Ewing model is used. Nuclear model calculation results were compared with experimental cross sections taken from Experimental Nuclear Reaction Data (EXFOR/CSISRS) library.

INTRODUCTION

Boron is a highly regarded technological element and has numerous applications in various fields. It is widely used in the semiconductor industry as a dopant for Si and Ge substrates, and it is also an essential ingredient of hard coatings on the walls of thermonuclear plants [1]. The walls of thermonuclear fusion experiments are coated with boron layers (boronization) to reduce the influx of high Z impurities into the fusion plasma [2]. Except for those applications, there is quite a keen interest to boron in astrophysics lately. Boron plays an important role in big bang and nucleosynthesis model testing.

Natural boron is comprised of approximately 20% ^{10}B and 80% ^{11}B. There are studies done in the past for p + ^{10,11}B nuclear reactions. In these studies, the authors claimed that the experimental error was 30%, but they also recognized the discrepancy between the proton backscattering yield and the Rutherford cross section was as large as 50% [3]. However, in recent theoretical works such as Trojan Horse Method (THM) [4] and some experimental works such as activation, elastic backscaretting spectroscopy (EBS), ion beam analysis (IBA) techniques [1,2,5,6,7] are undertaken. The understanding of stellar structure and mixing mechanisms in stars has been increased in the last years thanks to the amount of work regarding the problem of depletion of light elements lithium, beryllium and boron (LiBeB) in low-mass main sequence stars [8]. These elements are mainly destroyed in the stellar interior by (p,α) reactions.

Cross section data about neutron reactions with natural boron are very important in nuclear science and technology such as radiation protection, neutron flux determination and boron neutron capture therapy. Although the ^{10}B(n,α)^{7}Li reaction cross section from thermal energy to 200 keV has been adopted as the standard neutron reaction cross-section, there are large discrepancies among different measurements and evaluations in the MeV neutron energy region. To our knowledge, there are only four groups of experimental data in this energy region [9-12] with large disagreements. A relatively new work, Zhang et al. [13] gives measured cross sections of ^{10}B(n,α)^{7}Li reaction at 4.0 and 5.0 MeV using gridded ionization chamber.

CALCULATIONS AND METHODS

TALYS [14] is a computer code system for analysis and prediction of nuclear reactions. The basic objective behind its construction is the simulation of nuclear reactions that involve neutrons, photons, protons, deuterons, tritons, ^{3}He- and alpha-particles, in the 1 keV - 200 MeV energy range and for target nuclides of mass 12 and heavier. To achieve this, we have implemented suitable nuclear reaction models into a single code system. This enables us to evaluate nuclear reactions from the unresolved resonance range up to intermediate energies. The evaluations described in this paper are based on a theoretical analysis that utilizes the optical model, compound nucleus statistical theory, direct reactions and pre-equilibrium process, in combination with databases and models for nuclear structure.

The ALICE/ASH code [15] is an advanced and modified version of the ALICE code. The modifications concern the implementation in the code of models describing the pre-compound composite particle emission, fast γ-emission, different approaches for the nuclear level density calculation and the model for the fission fragment yield calculation. The ALICE/ASH code can be applied for the calculation of excitation functions, energy and angular distribution of secondary particles in nuclear reactions induced by nucleons and nuclei with the energy up to 300 MeV.

Cascade-Exciton Model (CEM) [16] of nuclear reactions was proposed 25 years ago at Laboratory of Theoretical Physics, Joint Institute of Nuclear Research, Dubna, USSR. It was extended to consider photonuclear reactions and to describe fission cross sections using different options for nuclear masses, fission barriers and level densities. The CEM03.01 code calculates nuclear reactions induced by nucleons, pions, and photons. It assumes that the reactions occur generally in three stages. The first stage is the Intra Nuclear Cascade (INC), in which primary particles can be re-scattered and produce secondary particles several times prior to absorption by, or escape from the nucleus. When the cascade stage of a reaction is completed, CEM03.01 uses the coalescence model to “create” high energy d, t,

^{3}He, and ^{4}He by final-state interactions among emitted cascade nucleons, already outside of the target. The emission of the cascade particles determines the particle-hole configuration, Z, A, and the excitation energy that is the starting point for the second, preequilibrium stage of reaction. The subsequent relaxation of the nuclear excitation is treated in terms of an improved version of the modified exciton model of preequilibrium decay followed by the equilibrium evaporation/fission stage of the reaction. Generally, all four components may contribute to experimentally measured particle spectra and other distributions. But if the residual nuclei after the INC have atomic numbers with $A \leq 12$, CEM03.01 uses the Fermi break-up model to calculate their further disintegration instead of using the preequilibrium and evaporation models. Fermi break-up is much faster to calculate and gives results very similar to the continuation of the more detailed models to much lighter nuclei.

CONCLUSIONS

In this work, we have calculated cross sections of ^{10,11}B with protons and neutrons of 0–30 MeV incoming energy range with the equilibrium and preequilibrium reaction models. These calculations were obtained using different nuclear reaction programs such as TALYS1.2, ALICE/ASH and CEM03.01. Obtained cross section values were compared with experimental cross section values taken from Experimental Nuclear Reaction Data (EXFOR/CSISRS) library and were shown Figs. 1, 2, 3, 4, 5, 6, 7 and 8.

In all figures, the vertical axis is semi-logarithmic and cross section is in milibarn, and horizontal axis is incoming proton or neutron energies in MeV. The three theoretical calculations are generally in close agreement with each other. For all reactions, the calculated reaction cross sections by using CEM03.01 and TALYS codes for preeqilibrium model parameters and ALICE/ASH code for the equilibrium with Weisskopf-Ewing model calculations are generally in agreement with the experimental data. Especially, these results are of great importance to the data estimation and shell model, in the development of nuclear reaction theories.

The purpose of this work was to calculate the cross sections of these reactions and to compare them with experimental values. For ^{10}B(n,p)^{10}Be reaction, the model calculations are compatible with each other. TALYS calculations are very good agreement with the experimental data at 0-5 MeV energy range for ^{10}B(n,α)^{7}Li reaction as shown Figure 2. Although the model calculations for ^{10}B(p,n)^{10}C are above experimental values, they have approximately the same shape. In Figure 4, TALYS and CEM are in good agreement with experimental values but the calculated cross sections by using ALICE/ASH code for the equilibrium with Weisskopf-Ewing model are less than those of the other calculations. In 12-20 MeV energy range, TALYS and CEM results show that calculated cross sections for ^{11}B(n,α)^{8}Li reaction are in excellent agreement with experiment data. In 14–17 MeV energy range, all of the calculations for ^{11}B(n,p)^{11}Be have good agreement with experimental values. As to ^{11}B(p,n)^{11}C reaction, three models calculations and experimental data are very good agreement with each other. For ^{11}B(p,α)^{8}Be reaction, while TALYS and CEM results are compatible with each other, ALICE/ASH results are not in agreement with them. Moreover, all of the model calculations are in very good agreement with the experimental data for this reaction. Consequently, TALYS, ALICE/ASH, CEM codes are mostly in good agreement with both each other and experimental data.

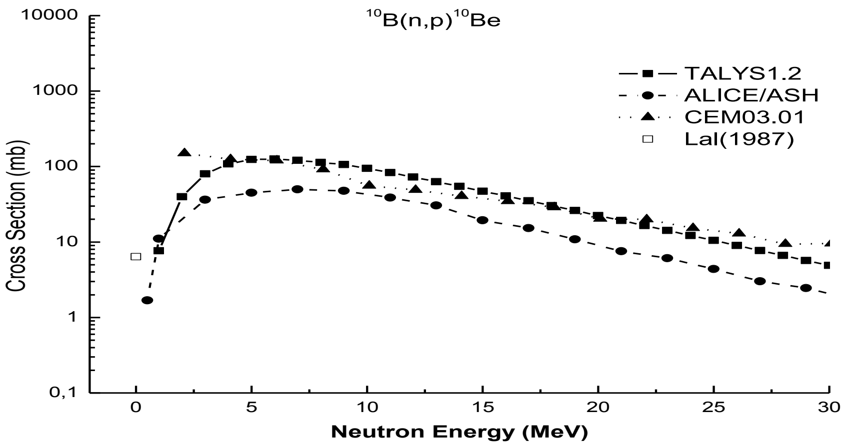

Figure 1. Comparison of calculated $^{10}B(n,p)^{10}Be$ cross section for different reactions codes with experimental data.

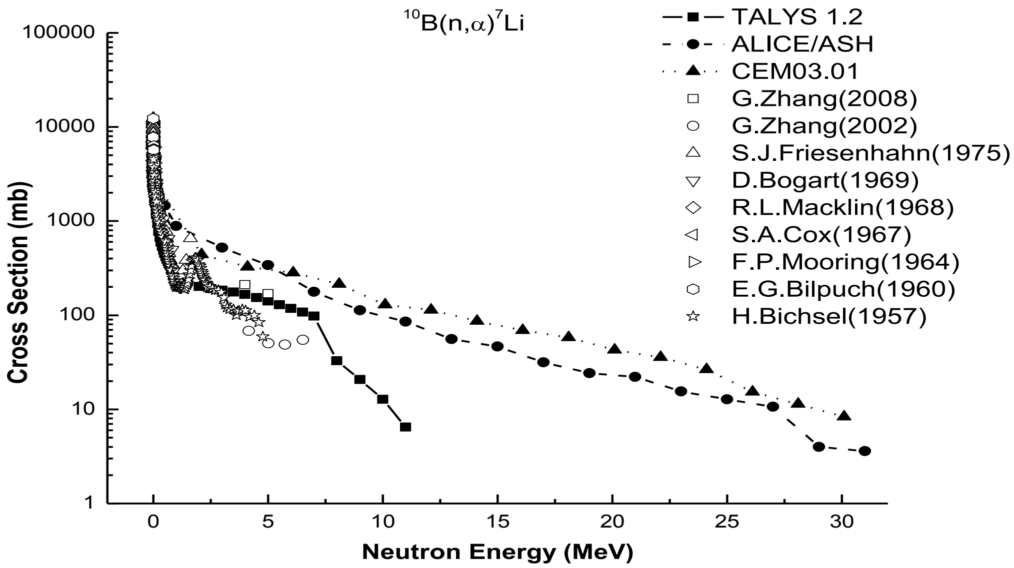

Figure 2. Comparison of calculated $^{10}B(n,\alpha)^{7}Li$ cross sections for different reactions codes with experimental data.

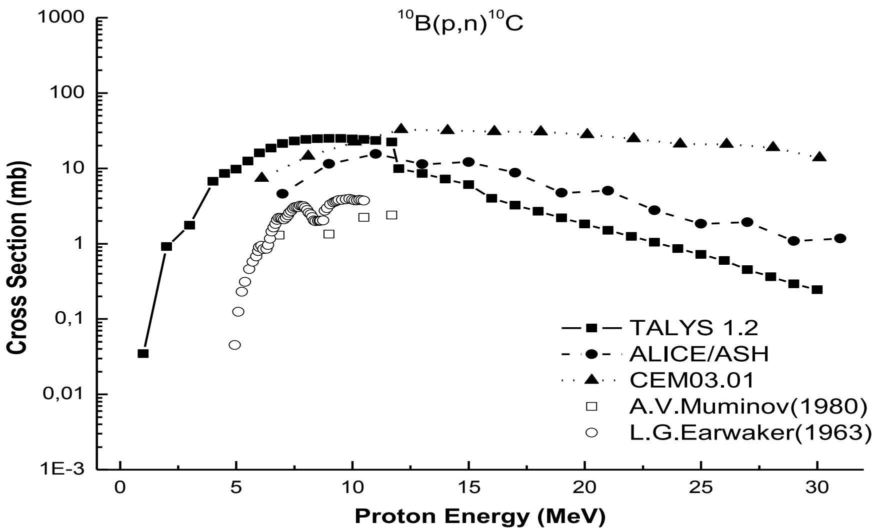

Figure 3. Comparison of calculated $^{10}B(p,n)^{10}C$ cross-sections for different reactions codes with experimental data.

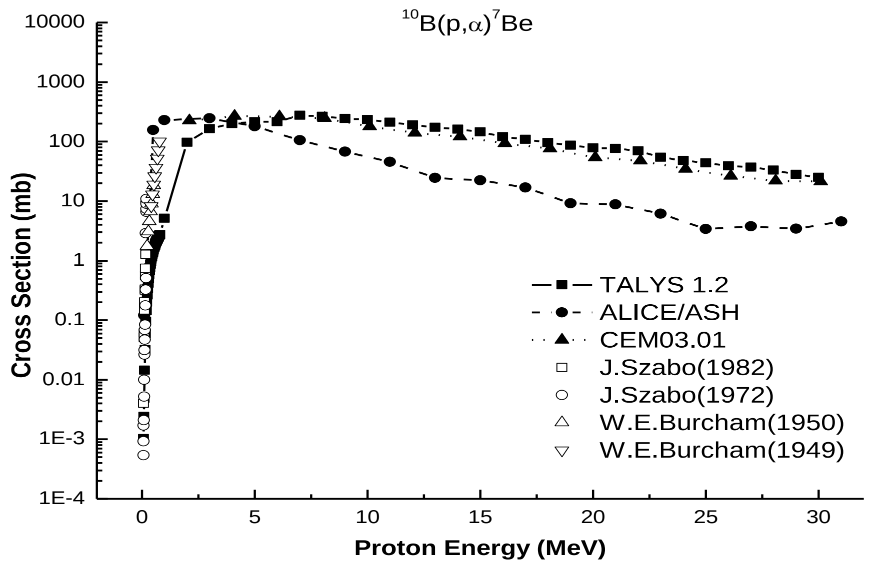

Figure 4. Comparison of calculated $^{10}B(p,\alpha)^{7}Be$ cross sections for different reactions codes with experimental data.

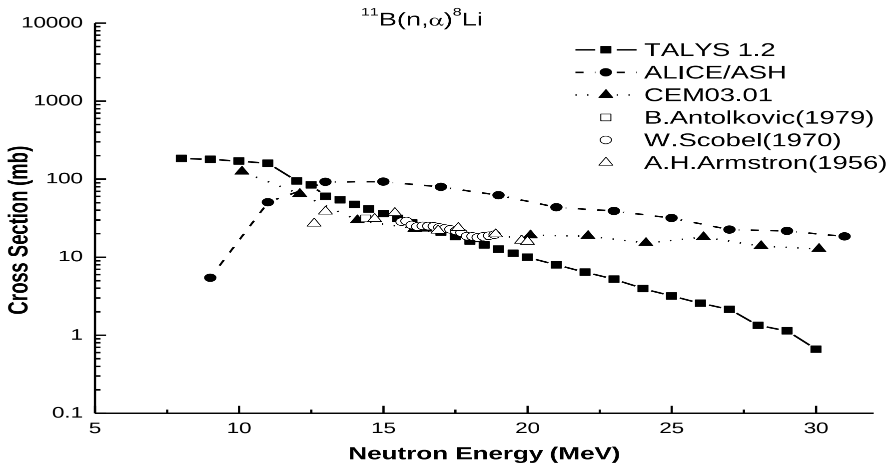

Figure 5. Comparison of calculated $^{11}B(n,\alpha)^{8}Li$ cross sections for different reactions codes with experimental data.

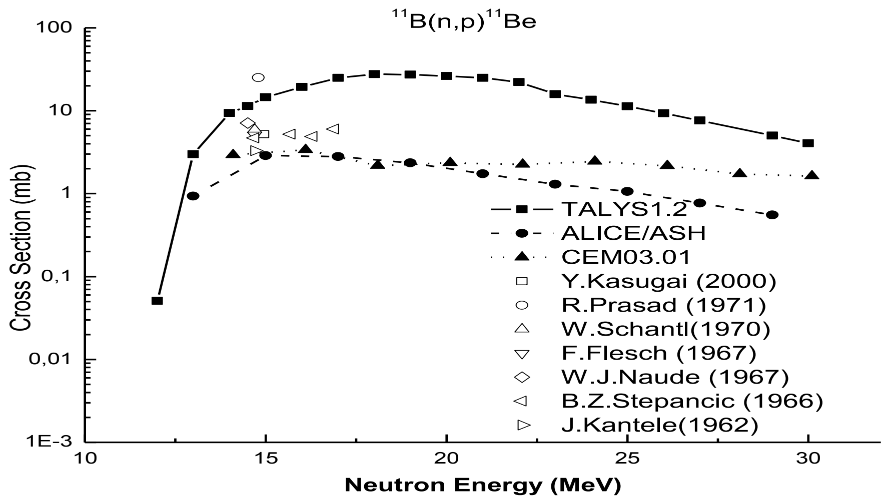

Figure 6. Comparison of calculated $^{11}B(n,p)^{11}Be$ cross sections for different reactions codes with experimental data.

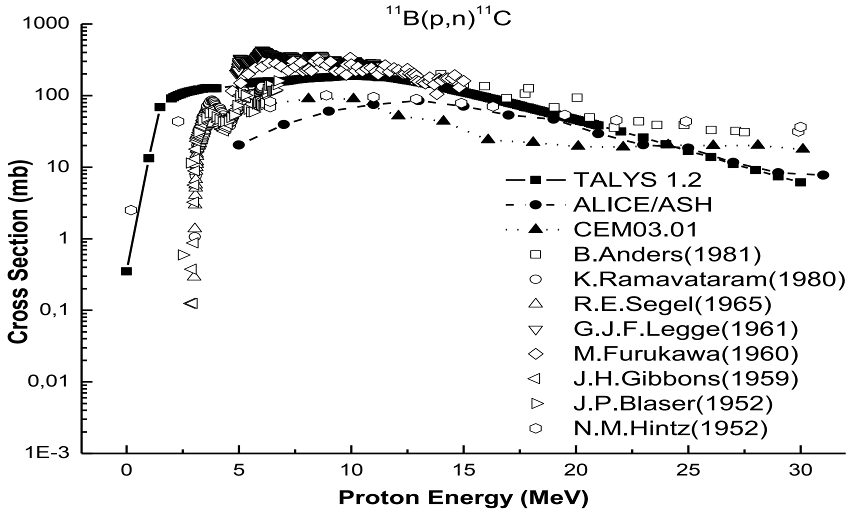

Figure 7. Comparison of calculated $^{11}B(p,n)^{11}C$ cross sections for different reactions codes with experimental data.

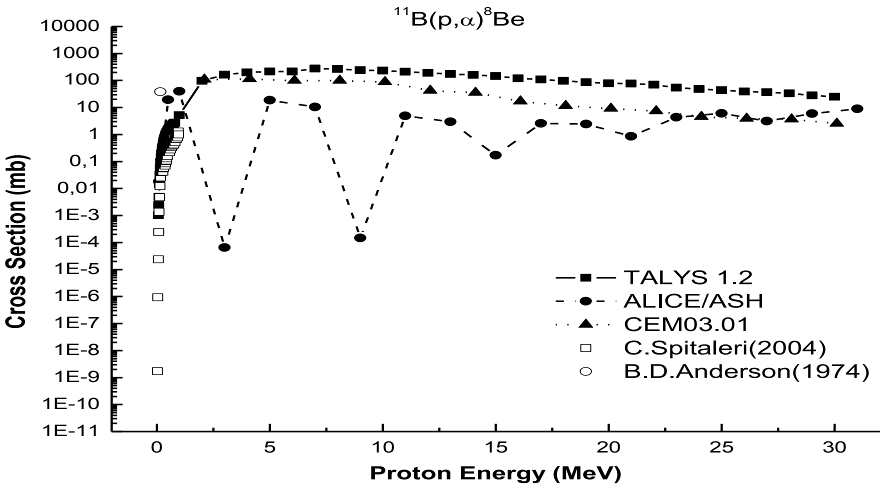

Figure 8. Comparison of calculated $^{11}B(p,\alpha)^{8}Be$ cross sections for different reactions codes with experimental data.

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