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Reaction Cross–Section Calculations for the Structural Reactor Materials ^{58,60,61,62,64}Ni with Different Level Density Models

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Abstract. In this study, reaction cross–section calculations of ^{58}Ni(d,n)^{59}Cu, ^{60}Ni(d,n)^{61}Cu, ^{60}Ni(d,2n)^{60}Cu, ^{61}Ni(d,n)^{62}Cu, ^{62}Ni(d,2n)^{62}Cu, ^{64}Ni(d,2n)^{64}Cu reactions have been done with TALYS 1.6, EMPIRE 3.1 and ALICE/ASH computation codes for reactor structural materials ^{58,60,61,62,64}Ni. Two Component Exciton and Equilibrium models of TALYS 1.6 and Exciton model of EMPIRE 3.1 have been used while Geometry Dependent Hybrid and Weisskopf Ewing models of ALICE/ASH have been selected for calculations. Also, by using Constant Temperature Fermi Gas, Back Shifted Fermi Gas and Generalized Superfluid models of TALYS 1.6, level density calculations for the selected reactions have been completed. All computations have been compared with the experimental values exist in the literature.

Keywords: Reaction cross–section, Level density, GEANT4, Stopping power, Nickel, EXFOR

Reaktör Yapı Malzemeleri ^{58,60,61,62,64}Ni için Farklı Seviye Yoğunluğu Modelleri ile Reaksiyon Tesir Kesiti Hesaplamaları

Özet. Bu çalışmada, ^{58}Ni(d,n)^{59}Cu, ^{60}Ni(d,n)^{61}Cu, ^{60}Ni(d,2n)^{60}Cu, ^{61}Ni(d,n)^{62}Cu, ^{62}Ni(d,2n)^{62}Cu, ^{64}Ni(d,2n)^{64}Cu reaksiyonları için TALYS 1.6, EMPIRE 3.1 ve ALICE/ASH hesaplama kodları kullanılarak reaktör yapı malzemelerinden olan ^{58,60,61,62,64}Ni için reaksiyon tesir kesiti hesaplamaları yapılmıştır. TALYS 1.6'nın İki Bileşenli Eksiton ve Denge modelleri ile EMPIRE 3.1'in Eksiton modelleri kullanılırken ALICE/ASH'in Geometri Bağımlı Hibrit ve Weisskopf Ewing modelleri hesaplamalar için seçilmiştir. Ayrıca, TALYS 1.6'nın Sabit Sıcaklık Fermi Gaz, Geri Kaymalı Fermi Gaz ve Genelleştirilmiş Süperakışkan modelleri ile seviye yoğunluğu hesaplamaları seçilen reaksiyonlar için tamamlanmıştır. Tüm hesaplamalar, literatürde mevcut olan deneysel değerler ile karşılaştırılmıştır.

Anahtar Kelimeler: Reaksiyon tesir kesiti, Seviye yoğunluğu, GEANT4, Durdurma gücü, Nikel, EXFOR

1. INTRODUCTION

Nickel is one of the lead materials used in reactors due to its high ferrite and resistance to corrosion. Nickel is the fundamental element in the stainless steel alloys which used in the reactors to provide strength to the reactor. The stainless steel alloys are formed from chrome-nickel and/or chromium-nickel-molybdenum mixtures. The composite material located in the center of the reactor core is consistent of up to 20-35 % nickel to be able to stand high temperature and pressure influence. The composite materials that consists nickel and chrome are able to stand the temperatures above 1000 °C. Since the nickel element is a structural material used in the reactor core, it interacts with the thermal neutrons in the reactor.

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Nuclear reaction codes give us simplicity to investigate phenomena of nuclear physics. There exist many computer programs such as TALYS, EMPIRE, ALICE/ASH, PCROSS, FLUKA and GEANT4. The stopping power of deuteron in ^{58,60,61,62,64}Ni materials is acquired as it has helpful applications of reactor construction material and choosing the proper thickness of the target [1]. Level density is very important to understand the nuclear reaction mechanism. The knowledge of level density for reaction cross–section calculations is required for various applications such as accelerator driven sub-critical systems, fission and fusion reactor design [2]. In this study, the cross–sections of ^{58}Ni(d,n)^{59}Cu, ^{60}Ni(d,n)^{61}Cu, ^{60}Ni(d,2n)^{60}Cu, ^{61}Ni(d,n)^{62}Cu, ^{62}Ni(d,2n)^{62}Cu and ^{64}Ni(d,2n)^{64}Cu reactions have been calculated using TALYS 1.6 [3], EMPIRE 3.1 [4] and ALICE/ASH [5] codes. Also, stopping power and penetrating distance have been calculated for deuteron, taking into consideration all possible reactions in Ni for incident energies of 0–21 MeV using GEANT 4 [6] calculation code. The obtained reaction cross–sections results have been compared with the each other and against the experimental nuclear reaction data existing in EXFOR database [7].

2. CALCULATION METHODS

TALYS 1.6, EMPIRE 3.1 and ALICE/ASH are three most used and reliable codes among the others which scientists have developed to compute reaction cross–section, spectrum of out-going particles and dose calculations including many theoretical nuclear models. All three mentioned calculation codes includes many theoretical nuclear reaction models inside them yet in this study some of them have been employed for comparisons with experimental results. The Two Component Exciton (TCE) Model and Equilibrium Model from TALYS 1.6 have been used for pre-equilibrium and equilibrium reaction calculations [3]. Among EMPIRE 3.1 models, Exciton Model has been selected [4]. For the calculations performed with ALICE/ASH code, Geometry Dependent Hybrid (GDH) Model and Weisskopf Ewing (WE) Model have been employed [5]. All these models have been used as previously mentioned pre-equilibrium and equilibrium reaction calculations. All the obtained results for reaction cross–section calculations with the specified models have been compared with the experimental values in Figures 1-6. On the other hand, as a next part of this study, selected reactions cross–section computations have been completed with different level density models to observe the differences and agreements among them. For these calculations, Constant Temperature Fermi Gas Model, Back Shifted Fermi Gas Model and Generalized Superfluid Model among the all models exist in TALYS 1.6 have been employed [3]. Obtained results comparisons with experimental values have been given in Figures 7-12.

In addition to the cross–section calculations for the selected reactions with the given computation codes and models, in this study another simulation code named GEANT 4 has been used too. GEANT 4 is a free simulation and calculation code that can be used to investigation of high-energy physics, medical physics, space and radiation physics. GEANT 4 is an abundant set of physics models to handle the interactions of particles with matter across a large energy range. Data and expertise have been drawn from many sources around the world and in this respect, GEANT4 acts as a repository that incorporates a large part of all that is known about particle interactions. In the view of given scientific clues, the penetration distance and stopping power calculations have been done via GEANT 4 software with high accuracy and the results are given in Figure 13.

3. RESULTS AND DISCUSSION

The cross–section calculations for ^{58,60,61,62,64}Ni materials using TALYS 1.6, EMPIRE 3.1 and ALICE/ASH codes for mentioned pre-equilibrium and equilibrium reaction models have been given in the Figures 1-6.

Among all that given figures for pre-equilibrium and equilibrium reaction calculations, it can be expressed that the more accuracy has been observed for EMPIRE 3.1 Exciton model calculation results. Also, for the energy range lower than 10 MeV the experimental values and equilibrium calculation results show some differences.

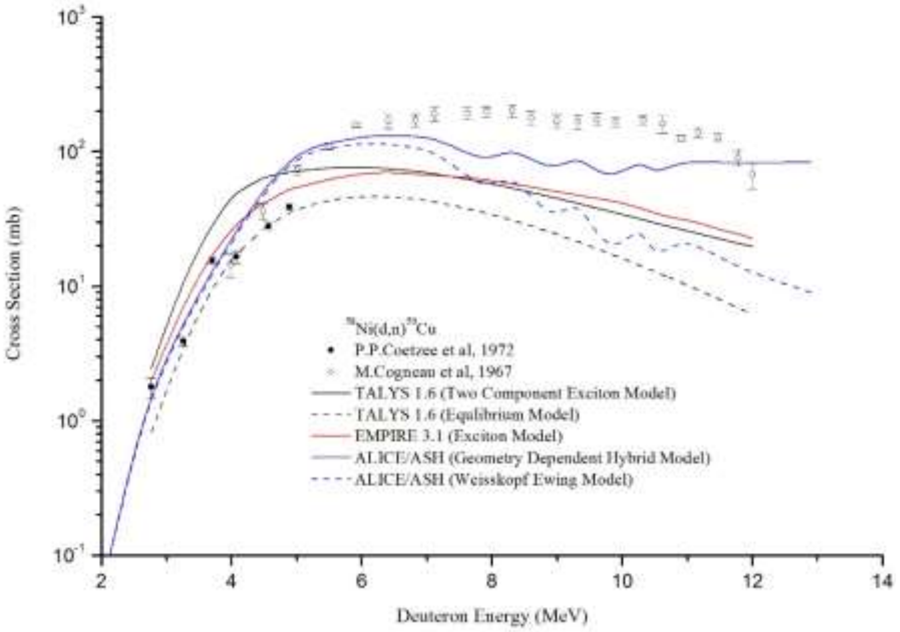

Figure 1. Comparisons of experimental data and ^{58}Ni(d,n)^{59}Cu reaction cross–section calculations

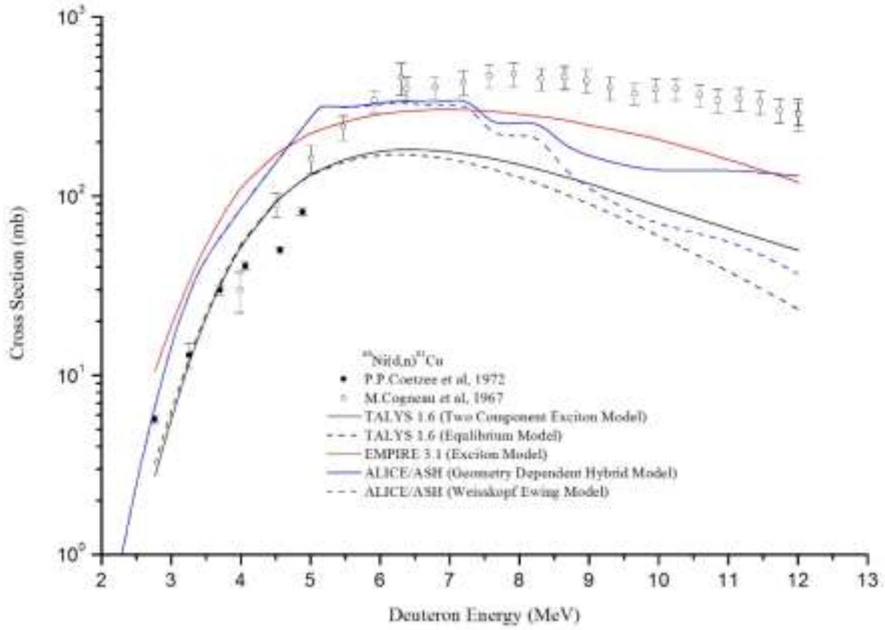

Figure 2. Comparisons of experimental data and ^{60}Ni(d,n)^{61}Cu reaction cross–section calculations

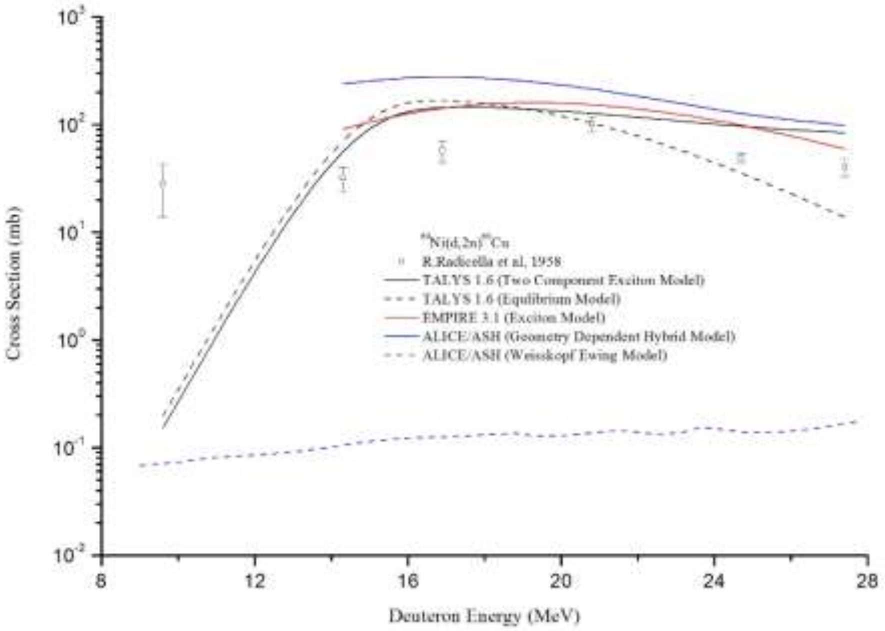

Figure 3. Comparisons of experimental data and ^{60}Ni(d,2n)^{60}Cu reaction cross–section calculations

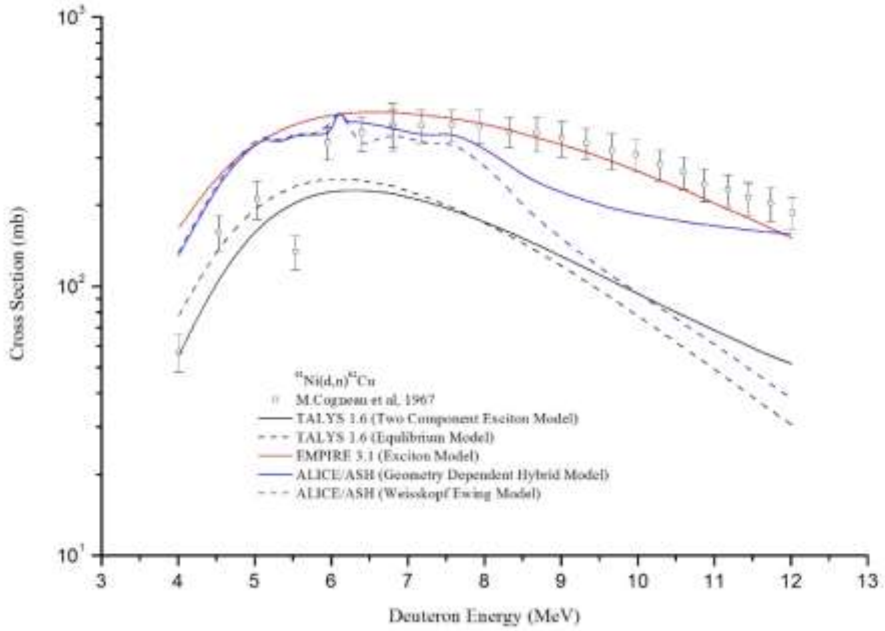

Figure 4. Comparisons of experimental data and ^{61}Ni(d,n)^{62}Cu reaction cross–section calculations

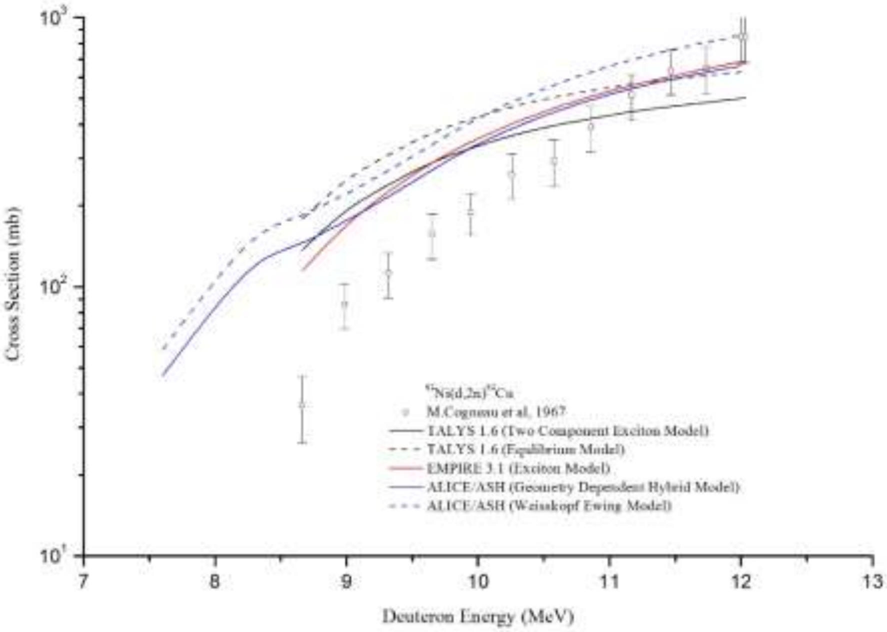

Figure 5. Comparisons of experimental data and ^{62}Ni(d,2n)^{62}Cu reaction cross–section calculations

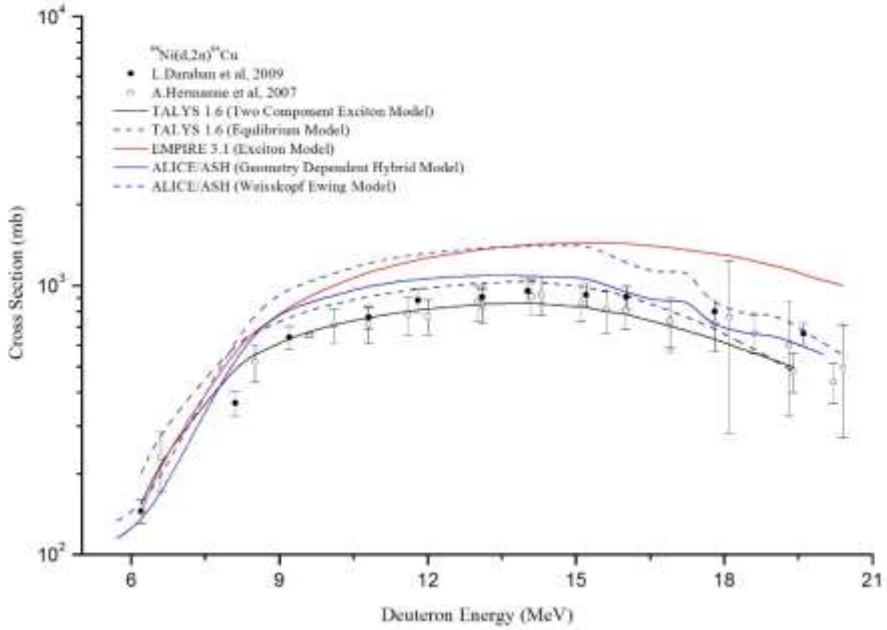

Figure 6. Comparisons of experimental data and ^{64}Ni(d,2n)^{64}Cu reaction cross–section calculations

The cross–section calculations for ^{58,60,61,62,64}Ni materials using selected level density models of TALYS 1.6 code have been given in the Figures 7-12.

From the obtained and graphed results, it is clear to see that TALYS 1.6 level density model calculations have in agreement with each other and the experimental data for ^{558}Ni(d,n)^{59}Cu, ^{60}Ni(d,n)^{61}Cu, ^{60}Ni(d,2n)^{60}Cu, ^{61}Ni(d,n)^{62}Cu, ^{62}Ni(d,2n)^{62}Cu and ^{64}Ni(d,2n)^{64}Cu reactions and in the cases of unavailability of the experimental data or etc. the level density model calculations could be chosen.

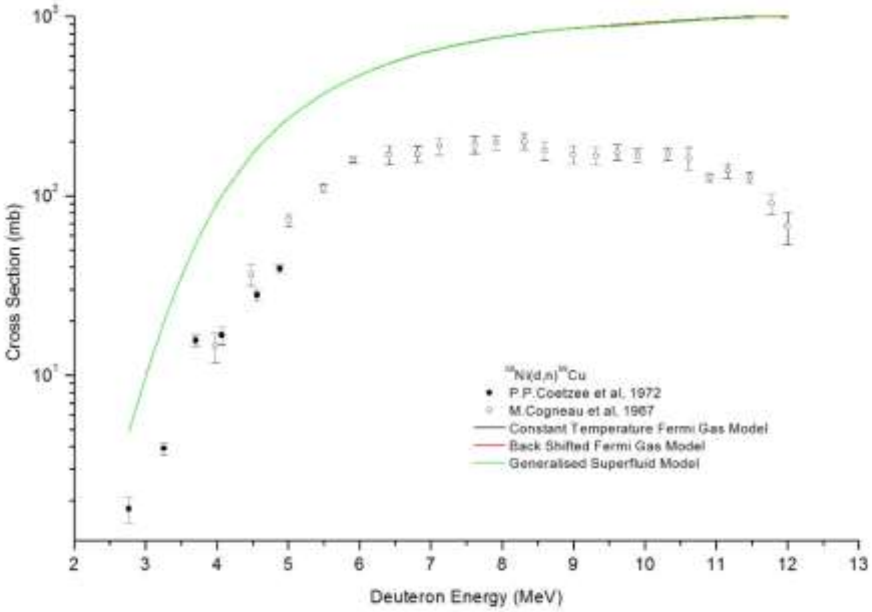

Figure 7. Comparisons of experimental data and ^{58}Ni(d,n)^{59}Cu reaction cross–section calculations obtained by using level density models.

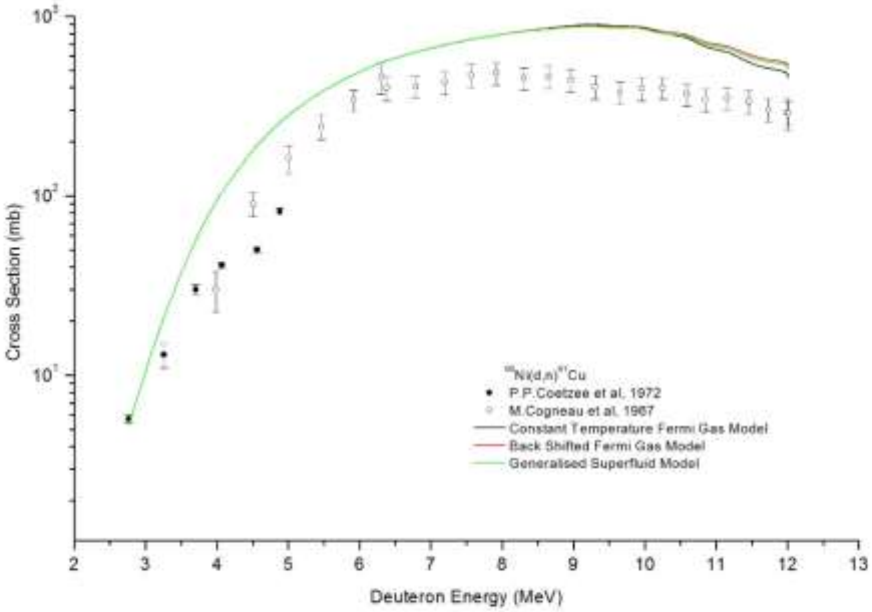

Figure 8. Comparisons of experimental data and ^{60}Ni(d,n)^{61}Cu reaction cross–section calculations obtained by using level density models.

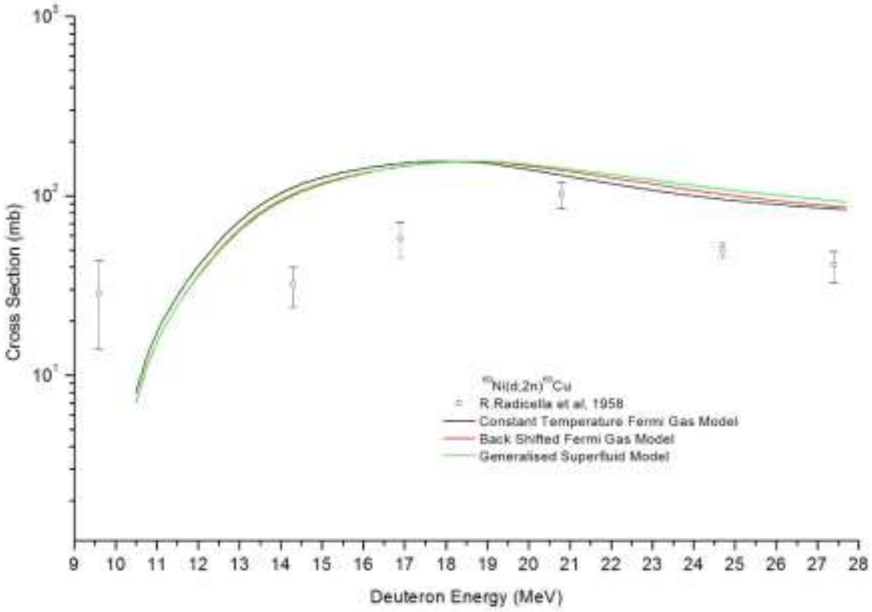

Figure 9. Comparisons of experimental data and ^{60}Ni(d,2n)^{60}Cu reaction cross–section calculations obtained by using level density models.

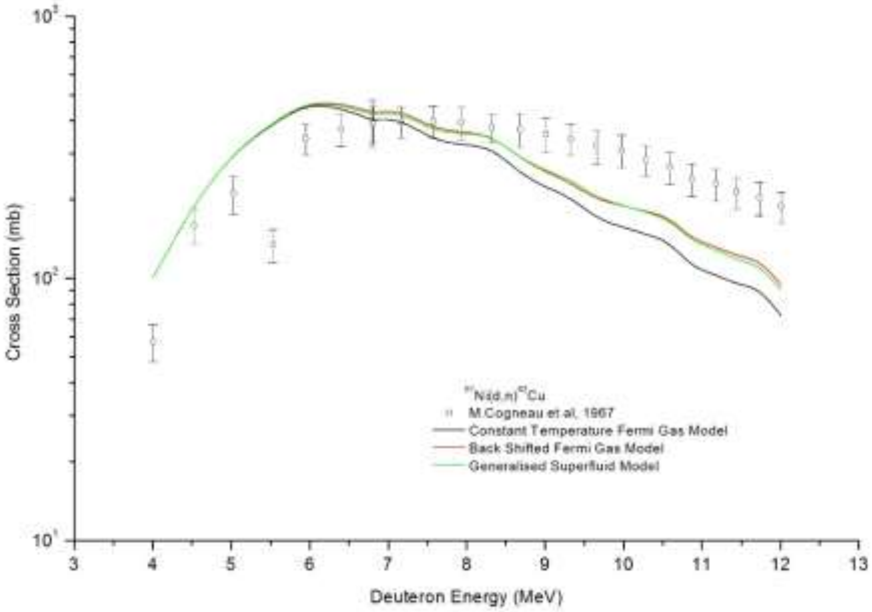

Figure 10. Comparisons of experimental data and ^{61}Ni(d,n)^{62}Cu reaction cross–section calculations obtained by using level density models.

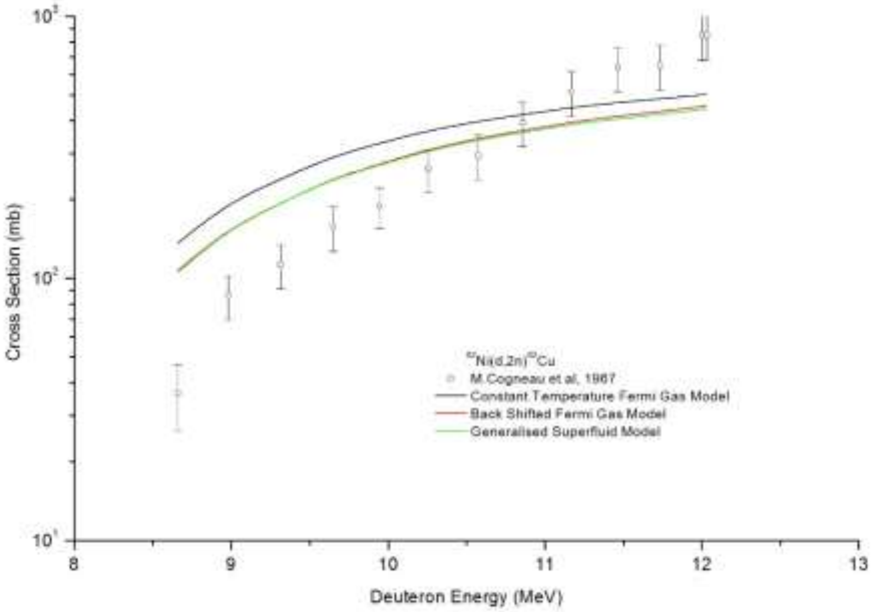

Figure 11. Comparisons of experimental data and ^{62}Ni(d,2n)^{62}Cu reaction cross–section calculations obtained by using level density models.

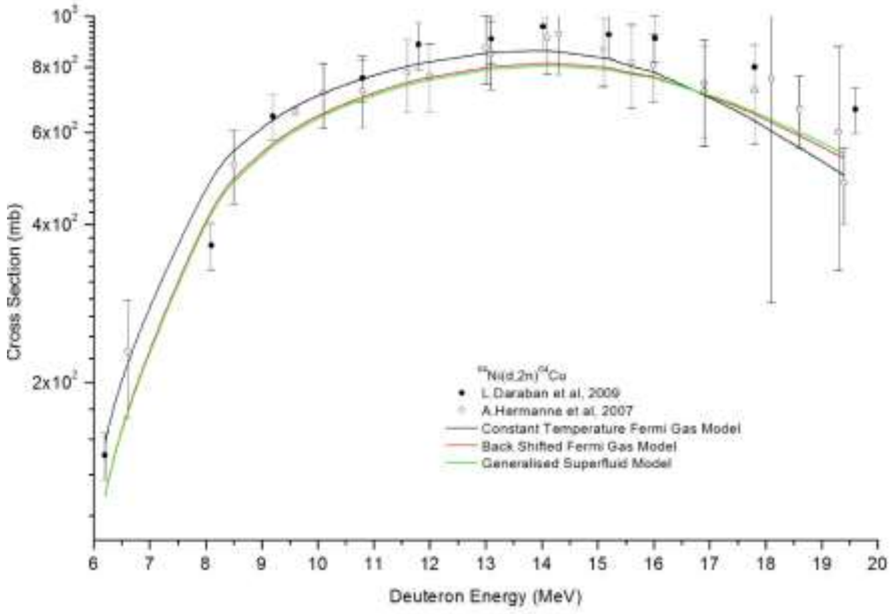

Figure 12. Comparisons of experimental data and ^{64}Ni(d,2n)^{64}Cu reaction cross–section calculations obtained by using level density models.

The stopping power and penetrating distance calculations of deuteron particles for Nickel material have been given in Figure 13. The results are obtained as expected and both theoretically and experimentally proved before.

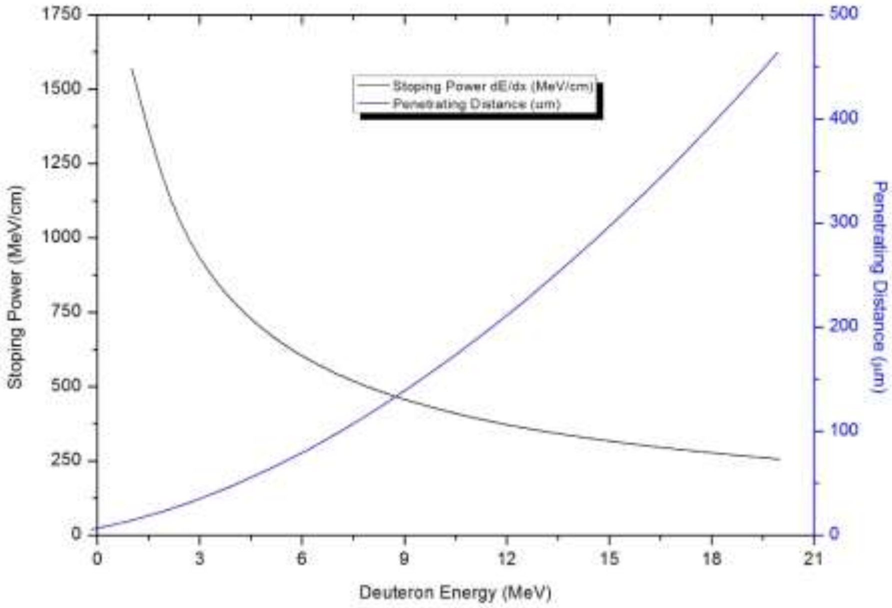

Figure 13. Stopping power and penetrating distance of deuteron particles in Nickel.

4. SUMMARY AND CONCLUSIONS

In this study, reaction cross–section calculations of the structural reactor materials ^{58,60,61,62,64}Ni have been calculated using the TALYS 1.6, EMPIRE 3.1 and ALICE/ASH codes. Also, calculations have been performed with different level density models of TALYS 1.6. The theoretical calculation results have been also compared with the obtainable experimental data in the EXFOR database. In addition to the cross–section calculations, stopping power and distance of penetrating in Nickel target using by GEANT 4 have been simulated. The results can be summarized and concluded as follows:

1. Generally the calculated reaction cross–sections of ^{58,60,61,62,64}Ni reactions are in agreement with the experimental data for the TALYS 1.6 level density models and EMPIRE 3.1 Exciton model results.
2. The equilibrium model calculations show some disparateness with the EXFOR values for all reactions investigated in this study under 10 MeV energy range.
3. The level density models for ^{58,60,61,62,64}Ni (d,n) reaction cross–section calculations can be chosen, if the experimental data are unavailable or are improbably to be produced because of the experimental troubles.
4. The obtained Nickel material's stopping power and penetrating distance results for the projectile charged particles can be used in several applications such as reactor design.

REFERENCES

1. Özdoğan H., Çapalı V., Kaplan A. Reaction Cross–Section, Stopping Power and Penetrating Distance Calculations for the Structural Fusion Material ^{54}Fe in Different Reactions, J. Fusion Energ. 2015; 34 (2), 379-385.
2. Kaplan A., Sarpün İ. H., Aydin A., Tel E., Çapalı V., Özdoğan H. (g,2n) Reaction Cross Section Calculations of Several Even–Even Lanthanide Nuclei Using Different Level Density Models, Phys. Atom Nucl. 2015; 78 (1), 53-64.
3. Koning A., Hilaire S., Goriely S. TALYS–1.6 A Nuclear Reaction Program, User Manual (NRG, The Netherlands), First Edition: December 23, 2013.
4. Herman M., Capote R., Carlson B.V., Obložinský P., Sin M., Trkov A., Wienke H., Zerkin V. EMPIRE: Nuclear reaction model code system for data evaluation. Nucl. Data Sheets 2007; 108 (12), 2655-2715.
5. Broeders C. H. M., Konobeyev A. Yu., Korovin Yu. A., Lunev V. P., Blann M., ALICEIASH - Precompound and evaporation model code system for calculation of excitation functions, energy and angular distributions of emitted particles in nuclear reactions at intermediate energies. FZK 7183 (2006).
6. Geant4 Collaboration, 2014. Geant4 User's Guide for Application Developers. (http://geant4.web.cern.ch/geant4).
7. Brookhaven National Laboratory, National Nuclear Data Center, EXFOR/CSISRS (Experimental Nuclear Reaction Data File). Database Version of October 06, 2015, (http://www. nndc.bnl.gov/exfor/)