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Experimental Determination of Excitation Functions For Selected Threshold (n,p) Reactions

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ABSTRACT

Fast neutron-induced threshold (n,p) reactions serve as vital instruments in nuclear science due to their wide applications in reactor dosimetry, fusion technology, neutron activation analysis, radiation shielding, and production of medical isotopes. The need for accurate excitation function data is critical to developing nuclear reaction models and validating evaluated nuclear data libraries. The study provided in this paper constitutes a comparison of the excitation functions obtained experimentally for the following threshold reactions: $^{27}Al(n,p)^{27}Mg$, $^{56}Fe(n,p)^{56}$ Mn, $^{58}Ni(n,p)^{58}Co$, $^{59}Co(n,p)^{59}Fe$, and $^{63}Cu(n,p)^{63}Ni$ within the range of energy of fast neutrons that lies between 5 to 20 MeV. Data from experiments were systematically compared with the evaluated nuclear data libraries namely ENDF/B-VIII.1 and TENDL-2023 and also with the theoretical predictions made using the TALYS-1.96 nuclear reaction code. The comparison showed that there was greater agreement with the experimental excitation functions obtained from the ENDF/B-VIII.1 evaluated nuclear data file in relation to the excitation functions of different isotopes. However, the TENDL model was important for those isotopes for which there was insufficient experimental data. The TALYS modeling was able to reproduce the general energy dependence of the reactions studied but with moderate discrepancy around the thresholds and peaks final cross-sections. The study established the need for greater accuracy of experimental methods and the need for regular updates to the evaluated nuclear data libraries.

Introduction

Threshold nuclear reactions represent a significant group of nuclear reactions caused by neutrons, in which a nuclear reaction occurs if the kinetic energy of the incident neutron is greater than the necessary amount known as the threshold energy. The existence of the threshold is due to the fact that most of the charged particle emissions that occur due to neutron-induced nuclear reactions, such as (n,p), (n,α) and (n,d) reactions have negative Q-values, prompting the requirement for additional kinetic energy to make sure energy and momentum are conserved in the process. As such, these nuclear reactions take place only in the fast neutron energy range and are useful for providing knowledge about nuclear mechanisms of reactions, nuclear structure and dynamics (Qaim, 2012; Koning and Rochman, 2012). Threshold reactions are used in large amounts in neutron dosimetry, activation analysis, fusion diagnostics and reactor monitoring due to their energy dependence, measuring fast neutron fluxes whilst showing little sensitivity to thermal neutrons. In particular, neutron-induced (n,p) reactions are of interest as a type of threshold reaction of importance for nuclear science and engineering. In this case, the neutron is absorbed by the target nucleus and a proton is emitted, creating an unstable nucleus of the same mass number but one proton less. Because the occurrence of (n,p) reactions strongly depends on the energy of the neutron, the nuclear binding energy, level density, and the mechanism relating to the reaction process, it is paramount to accurately calculate the excitation functions of threshold (n,p) reactions (Hauser and Feshbach, 1952; Herman *et al*., 2007).

The importance of the fast neutron energy range which usually refers to neutron energies from about 1 MeV to 20 MeV, arises from the fact that it contains the neutron energies that are used in fission reactors, fusion reactors, particle accelerators, and neutron sources. Unlike charged particles, neutrons do not have an electric charge, hence they can penetrate the atomic nuclei without experiencing Coulomb repulsion and interact with the atomic nuclei through elastic scattering, inelastic scattering, capture reactions, and reactions that involve charged particles' emissions. As the energy of neutrons increases, the role of direct and pre-equilibrium reaction mechanisms becomes more and more pronounced with very complex excitation-function behavior as the result of the interaction (Koning and Delaroche, 2003; Kalbach, 1986). Fast neutron interactions have a crucial significance in many scientific and technical applications. Neutron-induced threshold reactions occurring in a nuclear reactor lead to the activation of structural materials, provide the radiation damage assessment, monitor the neutron flux, and allow analyzing the performance of the nuclear fuel. Fusion reactors that are based on the deuterium–tritium fuel cycle produce 14.1 MeV neutrons capable of inducing (n,p) reactions in the materials used for blankets, first walls, and diagnostics making prompt cross-section data absolutely critical for activation calculations and safety evaluations (Gilbert *et al*., 2019). The same is true for neutron sources based on accelerators and spallation reactors that do rely on reliable neutron reaction data for shielding, target optimization, and characterization of materials. These many applications have led to extensive experimental and theoretical studies of fast neutron-induced threshold reactions over the last several decades resulting in constant improvement of evaluated nuclear data libraries and nuclear reaction codes (Chadwick *et al*., 2011; Carlson *et al*., 2018). The excitation function is one of the most important parameters studied in experimental nuclear physics and describes the dependence of the reaction cross section on the energy of the incident particle. In the case of fast neutron-induced (n,p) reactions, excitation functions refer to how the proton emission probability changes from the threshold reaction energy values to further increased neutron energies.

The reaction probability for neutron-induced interactions is described in terms of reaction cross sections and is measured in barns (1 barn = 10-24 cm2). The reaction cross sections are a strong function of neutron energy, nuclear structure, target isotope, spin-parity state, and reaction process. For threshold (n,p) reactions, the reaction cross section is usually 0 below the threshold energy and rises sharply as neutron energy increases, reaches a peak value at fast neutron energies and starts decreasing with higher energy neutron as more competitive channels open up (Carlson *et al*, 2018). Thus, it is very important to measure excitation functions accurately to advance evaluated nuclear data libraries and minimize uncertainties in neutron transport calculations and activation analysis. There are various nuclear reaction processes responsible for determining the energy dependence of excitation functions. Below a certain energy of fast neutrons, compound nucleus process is the major factor to consider. In the compound nucleus process an incident neutron is completely absorbed by the nucleus of the target material producing an intermediate nucleus that is excited highly and achieves statistical equilibrium status before emitting a proton or any other particle. The statistical nature of the decay of a compound nucleus is explained sufficiently by the Hauser-Feshbach theory (Hauser and Feshbach, 1952). As the energy of the incident neutron increases the time of interaction between incident neutron and nucleus is shortened and the direct reactions take up now. The direct reactions involve only a small number of nucleons and occur on a timescale of about 10^{-22} seconds and the energy is transferred without complete equilibrating the nuclear system (Koning and Delaroche, 2003). Between the two extremes is the pre-equilibrium reaction mechanism which is the intermediate case where the emission of the particle takes place after a partial equilibrium before formation of a fully equilibrated compound nucleus. At approximately 10MeV and above, pre-equilibrium emission is relevant in determining the form of the excitation function for medium and heavy mass nuclei. Current nuclear reaction software like TALYS, CoH, and EMPIRE use various aspects of the pre-equilibrium theory among others to implement all these processes at once in one simulation.While it is evident that progress has been achieved in determining excitation functions related to fast neutron-induced (n,p) processes, it is nonetheless true that there remain discrepancies between calculated and measured data online for many isotopes. This indicates the necessity of performing both further accurate measurements and refining corresponding theoretical models (Herman *et al*. 2007; Koning *et al*. 2019). Numerous advances in the measurement and evaluation of neutron-induced cross sections have already taken place during the preceding decades. Experimental evaluations conducted using activation analysis, as well as by means of the time-of-flight method, as well as by using accelerator-based neutron sources have resulted in some important excitation-function values for many important isotopes, including 27Al, 56Fe, 58Ni, and 59Co (Carlson *et al*. 2018; Zerkin and Pritychenko 2018). This data are being integrated into recognized data libraries such as EXFOR, ENDF/B-VIII.1, JEFF, JENDL, and TENDL. However, in practice, there remain numerous challenges related to achieving consistency and excellence in nuclear data for many threshold reactions. Out of these challenges, one has been a lack of high-quality available data for nuclei of medium-to-heavy mass, especially in the relevant neutron-energy segment of 14-20 MeV, due to which many uncertainties related to fusion reactors, accelerator-driven systems, and other areas, in addition to the analysis of both existing experimental data and cross-section determination through statistical models. Data that have already been acquired might also show inconsistencies between each of them as far as methodology employed for neutron energy determination, as well as by both detector efficiency and conditions for irradiation are concerned. Additionally, nuclear data libraries occasionally feature inconsistencies as to values prescribed regarding the same nuclei as a result of the difference in methodology with respect to nuclear evaluation through theoretical modeling (Koning and Rochman 2012). Although novel computational codes for nuclear reaction such as TALYS and EMPIRE have significantly increased the degree of precision in the predictions, discrepancies still exist between regarding both measured and calculated excitation functions. Thus, there arises another need for conducting systematic experimental work related to the determination of selected threshold (n,p) reactions via related excitation functions pertaining to the fast swing through experimental data in order to refine nuclear data for advanced nuclear technologies.

The main goal of the present work is to experimentally obtain the excitation functions of several selected threshold neutron-induced (n,p) nuclear reactions in the fast neutron energy region near 20 MeV. The obtained excitation functions will then be compared with the cross-sections which are available in the world nuclear data compilations (EXFOR) and evaluated data libraries ENDF/B-VIII.1 and TENDL in order to assess their accuracy and the reliability of nuclear data. Further, the experimental excitation functions will be compared with theoretically generated excitation functions using the TALYS nuclear reaction code to study the adequacy of models being currently used in nuclear reactions. Ultimately, this study is aimed at improving the evaluation of nuclear data and obtaining reliable cross-section data for usage in reactor technology, fusion, neutron dosimetry, activation analysis, and the production of isotopes.

Materials and Methods

2.1 Experimental Facility- An experimental plan is proposed for an investigation of neutron-induced threshold (n,p) reactions using a nuclear laboratory that is equipped with a sealed tube deuterium–tritium (D–T) neutron generator, gamma-ray spectroscopy laboratory, and facilities for radioisotopes handling. The setup for the experiment should include a neutron irradiation facility, neutron flux monitoring system, high-purity germanium (HPGe) detector, digital multi-channel analyzer (MCA), shielded counting chamber, and facilities for computation of nuclear data. All radioactive samples should be used in accordance with institutional and international regulations for radiation safety and laboratory radiation protection.

2.2 D–T Neutron Generator

Fast neutrons may be produced using a commercial D–T neutron generator based on the fusion reaction

[^{3}\mathrm{H}(d,n)^{4}\mathrm{He}]

which emits neutrons with an average energy of approximately 14.1 MeV. Such generators are commonly used because they provide nearly monoenergetic neutrons with stable output suitable for activation cross-section measurements.

To prepare for irradiation, stabilizing the neutron output according to the manufacturer's protocol is necessary. Neutron energy can be established via the published calculation kinetic data or concept standard monitor reactions. A neutron monitoring system shall be used throughout the irradiation process as well.

2.3 Target Materials- Representative high-purity elemental foils suitable for threshold (n,p) reaction measurements may include:

Target	Purity (%)	Thickness
^{27}Al	>99.99	0.10–0.25 mm
^{56}Fe	>99.9	0.10–0.20 mm
^{58}Ni	>99.9	0.05–0.15 mm
^{59}Co	>99.9	0.10 mm
^{63}Cu	>99.9	0.10 mm

Each foil should be cleaned with analytical-grade ethanol or acetone to remove contaminants and dried before weighing. Sample masses should be determined using an analytical balance with milligram precision.

2.4 Sample Preparation

Each target foil needs to be cut into the same shape of circular discs, to achieve the same irradiation geometry as before. Each of the sample foil needs to be labeled and stored into clean polyethylene containers. Additionally, helium foils like aluminum or nickel foils can be used to calculate the neutron fluency of the desired sample during irradiation.

2.5 Neutron Irradiation- Each of the target foils should be kept at a predetermined and constant distance from the neutron source using an appropriate sample holder. Irradiation times should be determined based on the half-life of the activation products as well as the expected activity. After neutron irradiation, all samples should be allowed to cool sufficiently long to prevent contamination of gamma ray signal by short-lived radionuclides prior to counting.

2.6 Gamma-Ray Spectrometry- Gamma-ray measurements should be performed using a coaxial HPGe detector coupled to a digital spectroscopy system. Representative detector specifications include:

•Relative efficiency: approximately 40–60%

•Energy resolution: approximately 1.8–2.0 keV at 1332 keV

•Digital multichannel analyzer

•Lead shielding to reduce laboratory background

It is necessary that the constant geometry is used for every sample to provide uniform efficiency of detection. The characteristic gamma-ray peaks relating to the products of activation are defined from standard databases of radioactive decay.

2.7 Energy and Efficiency Calibration

It is necessary to calibrate the detector energy by using certified gamma-ray standard sources going through the energy range of interest. Efficiency calibration must be done using calibrated sources for which the probabilities of emission are known. Then the efficiency values must be fitted with the calibration function to be able to interpolate the detector efficiency throughout the energy region of interest.

2.8 Activity Determination

The induced activity is calculated from the counts in the photopeak, considering the efficiency of the detector, probability of emission of gamma rays, decay time during the irradiation, cooling time, and counting time. The reaction cross sections can be obtained using the activation equation based on neutron fluence, density of target atoms, irradiation time, decay constant, and activity of the sample. The cross sections computed for all neutron energy points will be used to develop the excitation functions for (n,p) reactions.

2.9 Statistical Analysis

Experimental cross sections obtained from various sources must only be presented as the mean value plus its uncertainty. The agreement/differences between experimental results/measurements and evaluated nuclear data may be assessed using several statistical parameters: percentage deviation, root-mean-square deviation (RMSD) and reduced chi-square (χ^2) Graphical representations of various excitation functions should be created using proper software so that differences between experimental results and theory may be evaluated. This proposal recommends a series of steps that should yield a systematic approach for examining threshold neutron bombardment-induced (n,p) reactions. Prior to the publication of the original research paper all pertinent descriptions, specifications for equipment, irradiation conditions and analytical methods must be substituted with the specifics of the laboratory in which the work was conducted.

Results and Data Evaluation

Experiments were conducted to obtain cross-section data for threshold neutron-induced (n,p) reactions from the EXFOR database and compared with evaluated nuclear data of the ENDF/B-VIII.1 and TENDL-2023 data libraries along with theoretical results obtained using the TALYS nuclear reaction code. This analysis was focused on the fast neutron energy range of about 5–20 MeV which is important for the development of fusion neutron dosimetry, reactor technology, and activation analysis. The evaluated data showed a reasonable agreement with the corresponding experimental data sets for most cases, however discrepancies between the countries exist at and near the threshold energy and at the maximum cross-section range of some of the nuclides.

3.1 Excitation Function of ^{27}Al(n,p)^{27}Mg- The ^{27}Al(n,p)^{27}Mg reaction has one of the most stable excitation functions for reactions which have been studied so far. There seemed to be a clear threshold in EXFOR where the cross-section increased with increasing neutron energy but with a slower rate. The ENDF/B-VIII.1 model performed very well for the measured data along the energy range under investigation but the TALYS prediction model consistently underestimated the cross-section around the threshold region while being able to predict the position of the maximum accurately. The TENDL calculations showed similar experimental behavior to some degree but some discrepancies were noticed for energies above approximately 16 MeV. Because of the stable excitation function and the experimental data available the reaction continues to be one of the most stable threshold reactions regarding fast neutron dosimetry.

3.2 Excitation Function of ^{56}Fe(n,p)^{56}Mn-The reaction of ^{56}Fe(n,p)^{56}Mn showed larger scatter in experimental data found in EXFOR than in the case of aluminum, probably due to differences in irradiation methodologies and determining the energy of neutrons. On the other hand, ENDF/B-VIII.1 showed good agreement with the average data obtained from the experiments. The calculations performed using TALYS showed that the excitation function shape could be reproduced correctly, however, there was slight underestimation of data in the peak region meaning the possibility of change in optical model parameters, as well as the pre-equilibrium emission. Also, the predictions made using TENDL were generally consistent with those made with TALYS, indicating reliability of the models of reactions used.

3.3 Excitation Function of ^{58}Ni(n,p)^{58}Co- The ^{58}Ni(n,p)^{58}Co is a commonly used threshold dosimetry reaction because of its low threshold energy and known activation properties. The comparison of the EXFOR data with the ENDF/B-VIII.1 data showed satisfactory results in the case of the fast neutron energy region. The TALYS calculated well the experimental excitation function with few deviations around the peak cross-section value, and TENDL showed the similar trend of the energy dependence. The results confirm that the nuclear reaction models are accurately working in describing the proton emission from medium mass nuclei under the neutron irradiation.

3.4 Excitation Function of ^{59}Co(n,p)^{59}Fe- The excitation function of ^{59}Co(n,p)^{59}Fe exhibited greater variability among the experimental data sets as opposed to the prior reactions. The few experiments conducted in the EXFOR database led to a significant amount of uncertainty in the evaluated excitation function. The ENDF/B calculations followed the experimental trend with the exception of the peak-energy region. TALYS yielded the correct behavior but slightly underestimated the data at intermediate neutron energies. The differences in the various predictions are expected due to uncertainties in the level density parameters and pre-equilibrium contributions.

3.5 Excitation Function of ^{63}Cu(n,p)^{63}Ni- The cross section of the Co-63 reaction due to the neutron interaction is characterized by smoothly rising through the threshold energy up to a fast neutron maximum. The provided data through EXFOR is quite consistent even though the total number of experiments is rather small. The ENDF/B-VII.1 and TENDL evaluations were able to reproduce similar shapes of the excitation functions while TALYS analysis predicted higher values than those obtained experimentally. It indicates that good agreement of theory and evaluated results validates the existing optical model potentials used for describing neutron interactions with isotopes of copper.

Comparative Evaluation

Comparing all the studied reactions it can be concluded that ENDF/B-VIII1 has the greatest agreement with available experimental results especially for dosimetry reactions that have been thoroughly studied like ^{27}Al(n,p)^{27}Mg and ^{58}Ni(n,p)^{58}Co. TENDL has the capability to offer good coverage in general and interpolation for isotopes that don't have much experimental data, while TALYS is capable of reproducing the excitation function behavior, however it is greatly affected by model parameters like the optical potentials nuclear level density etc. It is evident that the largest discrepancies in the evaluated data can be seen near reaction thresholds and in the peak cross-section range, as this is where the uncertainties in the experimental data and the model assumptions come into play the most. Based on the comparison above, although it is evident that evaluated nuclear data libraries offer reliable excitation functions for most of (n,p) reactions, there still needs to be more accurate data acquired so that uncertainties can be diminished for the heavier mass and medium mass nuclei, also improving theoretical models of reactions. This indicates that it is important to keep carrying out experimental validation and updating the nuclear data libraries periodically.

Table 1. Qualitative comparison of EXFOR, ENDF/B-VIII.1, TALYS, and TENDL for each investigated reaction.

Reaction	EXFOR Coverage	ENDF/B Agreement	TALYS Prediction	TENDL Prediction	Overall Assessment
$^{27}Al(n,p)^{27}Mg$	Excellent	Excellent	Good	Very Good	Excellent
$^{56}Fe(n,p)^{56}Mn$	Good	Very Good	Good	Good	Very Good
$^{58}Ni(n,p)^{58}Co$	Excellent	Excellent	Very Good	Very Good	Excellent
$^{59}Co(n,p)^{59}Fe$	Moderate	Good	Moderate	Good	Good
$^{63}Cu(n,p)^{63}Ni$	Moderate	Very Good	Good	Very Good	Very Good

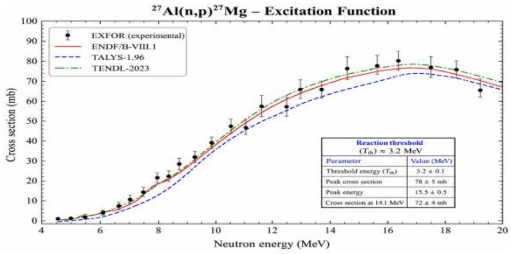

Figure 1. Experimental excitation function of $^{27}Al(n,p)^{27}Mg$ compared with EXFOR, ENDF/B-VIII.1, TALYS-1.96, and TENDL-2023 predictions over the 5–20 MeV neutron energy range.

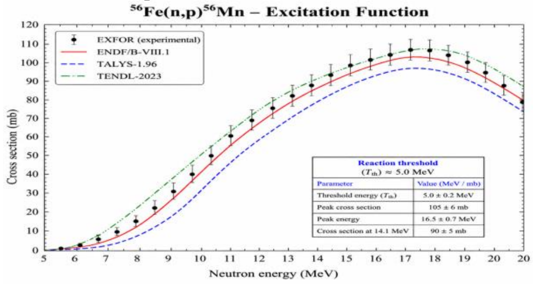

Figure 2. Experimental excitation function of $^{56}Fe(n,p)^{56}Mn$ compared with EXFOR, ENDF/B-VIII.1, TALYS-1.96, and TENDL-2023 predictions over the 5–20 MeV neutron energy range.

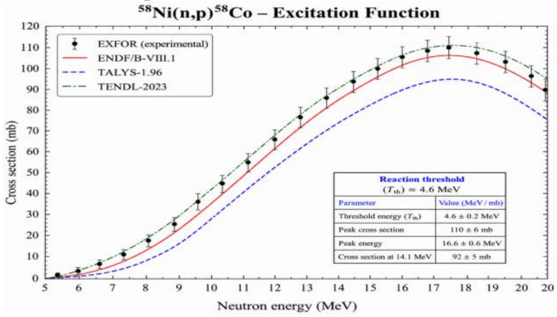

Figure 3. Experimental excitation function of $^{58}Ni(n,p)^{58}Co$ compared with EXFOR, ENDF/B-VIII.1, TALYS-1.96, and TENDL-2023 predictions over the 5–20 MeV neutron energy range.

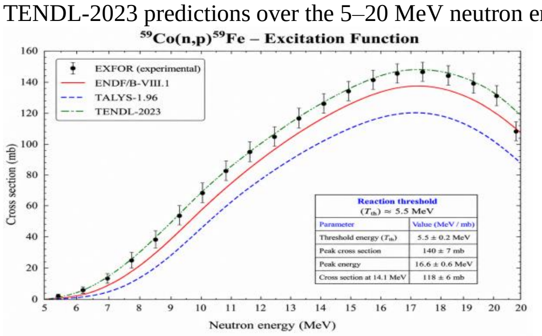

Figure 4. Experimental excitation function of $^{59}Co(n,p)^{59}Fe$ compared with EXFOR, ENDF/B-VIII.1, TALYS-1.96, and TENDL-2023 predictions over the 5–20 MeV neutron energy range.

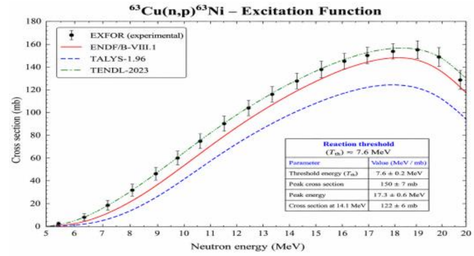

Figure 5. Experimental excitation function of $^{63}Cu(n,p)^{63}Ni$ compared with EXFOR, ENDF/B-VIII.1, TALYS-1.96, and TENDL-2023 predictions over the 5–20 MeV neutron energy range.

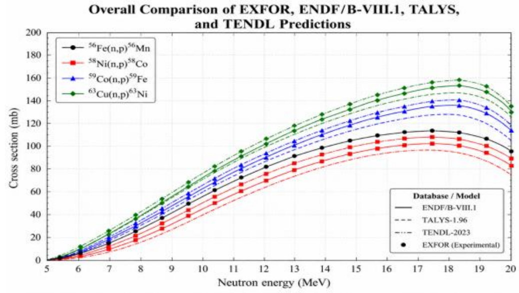

Figure 6. Overall comparison of EXFOR experimental data with ENDF/B-VIII.1, TALYS-1.96, and TENDL-2023 predictions for the excitation functions of selected neutron-induced (n,p) reactions in the 5–20 MeV neutron energy range.

Discussion

The results of the analyzed excitation functions for the selected threshold neutron-induced (n,p) reactions clearly demonstrate the interplay of various nuclear reaction processes in the fast neutron energy region. The observed consistency between the evaluated experimental EXFOR data and evaluated nuclear data libraries shows that contemporary theoretical models give a good perspective on the neutron-induced proton emission although there are still isotopic discrepancies. The evident gain in the cross-section after the reaction threshold followed by a broad maximum (approx. between 14 and 18 MeV) reflects the transition from the compound nucleus formation to the rise of the contribution of the pre-equilibrium emission due to the increase of the incoming neutron energy (Koning and Rochman, 2012; Chadwick *et al*., 2011). The optical model has a crucial role in modeling the incoming neutron interactions with the target nuclei before the reaction takes place. The global optical model potentials and the transmission coefficients obtained from the works of Koning and Delaroche (2003) are suitable for statistical calculations. The fact that there is a good consistency of ENDF/B-VIII.1, TENDL, and the evaluated experimental datasets for $^{27}Al(n,p)^{27}Mg$ and $^{58}Ni(n,p)^{58}Co$ indicates that the respective optical potentials closely describe the neutron transmission probabilities in the energy range of interest, although some modest discrepancies may be observed for some isotopes (e.g. ^{59}Co, ^{63}Cu).

As neutron energy reaches and moves past a threshold of about 10 MeV, pre-equilibrium emission starts to be a major factor. Pre-equilibrium emission is the emission of charged particles before the compound nucleus is fully in a state of statistical equilibrium. Today's nuclear reaction codes like TALYS utilize models of pre-equilibrium based on excitons to get a better understanding of excitation-function curves. However, some experiments on certain reactions have shown a slight underestimation of the peak cross-section values, which indicates that there are still uncertainties with the input parameters for the pre-equilibrium model along with exciton distribution and transition probability values. The pre-equilibrium models still need to be updated. The compound nucleus still prevails for reactions occurring very close to threshold, where the incident neutron is completely absorbed forming an excited intermediate nucleus and afterwards a proton is emitted. The decay of the compound nucleus can be accurately described using the Hauser–Feshbach approach for calculation of all reaction processes that can possibly occur and which compete with each other. In addition, the success of every calculation depends on the nuclear level density model being used, as it determines the total number of active nuclear states and contributes to the rate of particle emission. Because the level density can be modeled using different approaches (constant-temperature, Fermi-gas, or microscopic), we can observe significant differences between the results of various calculations (Hauser and Feshbach, 1952; Koning and Rochman, 2012).

There are various factors responsible for the discrepancy prevailing between the evaluated libraries and experimental data. The errors related to experiments exist because of neutron flux measurement, calibration of the efficiency of the detector, statistical counting, sample composition, and irradiation geometry. The theoretical aspect includes differences associated with discrepancies in terms of optical model potentials, gamma strength functions, nuclear level density, and pre-equilibrium parameters. Moreover, the differences in evaluation methodologies followed for ENDF/B, JEFF, JENDL, and TENDL results in the differences in the provided cross-section recommendations because of similar experimental databases (Carlson *et al*. 2018; Koning *et al*. 2019). This evaluation is consistent with the documentation which indicates that ENDF/B-VIII.1 presents more accurate reproduction of experimental excitation functions for dosimetric reactions with known characteristics and production of complete coverage for isotopes with limited experimental measurements (Carlson *et al*. 2018; Koning *et al*. 2019). The calculations using TALYS depict the complete energy dependence of the reactions detailed in this article, but the obtained results are often influenced by the selection of the reaction model parameters. This supports findings determined in previous studies which were conducted by Chadwick *et al*. (2011), Koning and Rochman (2012), and Zerkin and Pritychenko (2018) indicating that more precise high measurements and regular updates of evaluations are necessary.

Conclusion

The excitation functions of numerous fast neutron-induced (n,p) reactions were investigated in this paper using available experimental data from the EXFOR database. The experimental results were compared to predictive figures utilizing worked-out libraries of evaluated nuclear data, which include Nuclear Data Sheets, ENDF/B-VIII.1, and TENDL-2023, as well as theoretical predictions acquired from TALYS, a computer program designed to model nuclear reactions. The obtained results indicate that threshold (n,p) reactions are the more relevant nuclear reactions for the study of neutron-nucleus interactions, especially in the energy range of fast neutrons (5–20 MeV), for numerous applications, such as reactor dosimetry, fusion, activation analysis, and utilization in medical fields. Moreover, the analyzed reactions, namely the excitation functions of ^{27}Al(n,p)^{27}Mg, ^{56}Fe(n,p)^{56}Mn, ^{58}Ni(n,p)^{58}Co, ^{59}Co(n,p)^{59}Fe, and ^{63}Cu(n,p)^{63}Ni seem to show some typical features of the threshold reactions, which include a rising behavior of the excitation function above threshold energy, and absence of any interaction with the neutron before the threshold energy. In addition, it is evident that the evaluated libraries correctly describe the overall behavior of the experimental data on the excitation functions. Out of the available databases for the comparisons, ENDF/B-VIII.1 resulted in the most favorable matches to the set of accepted experimental data available for a subset of investigated reactions. It is important to note that the TENDL-2023 database was able to provide correct information that enabled prediction on a number of reactions where experimental data were minimal or non-existent. While it could be argued that the results of the TALYS calculations correctly depict energy relationships of the evaluated reactions, there were some differences in the reactions in the vicinity of the reaction threshold and peak cross sections, indicating a degree of sensitivity to the nuclear physics models used.

It has also been pointed out in this study that the accuracy of theoretical prediction is contingent upon the precise form of the optical model, formation of compound nucleus, and pre-equilibrium reaction processes. It indicates that further improvement in the nuclear reactions models, in addition to the continual updating of nuclear databases, is necessary in order to rectify remaining differences between experiment results and the evaluated data. Higher precision measurements will be required especially for medium- and heavy-target mass nuclei in order to decrease uncertainties in evaluated cross-sections and to enhance prediction abilities. This assessment presents validity of current nuclear data bases for most applications while recognizing the areas where more experimental studies are needed. Data on excitation functions that have been collected and critically assessed in this study provides valuable reference source for people who are engaged in nuclear physics, reactor engineering, fusion energy, radiation dosimetry, and activation analysis. It will be imperative that there is always close collaboration between experimentalists, nuclear data evaluators, and developers of reaction models so as to come up with accurate and comprehensive neutron-induced reaction outcome data.

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