Excitation Functions of Neutron-Induced Reactions of Medical Isotopes ^{32}P, ^{55}Fe, ^{74}As, ^{97}Ru, ^{103}Ru and ^{109}Pd

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Introduction

There are many stable and radioactive isotopes, each having their own physical and chemical properties, perform important roles in technology and actually existing in the field of research. The most common application is the use of radioisotopes in the medicine [1]. The medical radioisotopes are classified as therapeutic and diagnostic radioisotopes, depending on the decaying properties. The diagnostic radioisotopes, depending on the nature of radioisotopes, are used in two types of emission tomography, i.e. single photon emission computed tomography (SPECT) and positron emission tomography (PET).

The knowledge of the excitation function is necessary, to get a governed and optimized medical radionuclide. In this regard, the theoretical model calculation is very helpful. TALYS1.9 and EMPIRE-3.2 are used to determine the excitation functions of radionuclides ^{32}P, ^{55}Fe, ^{74}As, ^{97}Ru, ^{103}Ru and ^{109}Pd produced via ^{32}S(n,p)^{32}P, ^{56}Fe(n,2n)^{55}Fe, ^{58}Ni(n,α)^{55}Fe, ^{74}Se(n,p)^{74}As, ^{98}Ru(n,2n)^{97}Ru, ^{102}Ru(n,γ)^{103}Ru, ^{103}Rh(n,p)^{103}Ru, ^{104}Ru(n,2n)^{103}Ru, ^{108}Pd(n,γ)^{109}Pd, ^{109}Ag(n,p)^{109}Pd, ^{110}Pd(n,2n)^{109}Pd, and ^{112}Cd(n,α)^{109}Pd reactions in the neutron energy range 1 – 20 MeV.

The calculated results are discussed and compared with the existing experimental data (EXFOR database) [2] as well as with the evaluated data. The excitation functions of ^{32}P, ^{55}Fe, ^{74}As, ^{97}Ru, ^{103}Ru and ^{109}Pd are medically important and widely used in bone disease treatment, heat source, in biomedical, monoclonal antibodies labelling, imaging, radio labelling and potential radio therapeutic agent [3].

Calculations

Theoretical calculations based on nuclear models play a very important role in the development of cross-section data. Calculations on the cross-sections have been carried out with TALYS-1.9 and EMPIRE-3.2 codes.

TALYS-1.9 [4] is a computer code system for the analysis and prediction of the nuclear reactions. The main purpose of the TALYS is to stimulate the nuclear reactions that involve gammas, protons, neutrons, deuterons, tritons, ^{3}He and α-particles as the projectiles over energy range $10^{-3} < E < 200$ MeV for the target nuclei for the mass ≥ 12. This code takes into account different reaction mechanisms like compound nucleus formation, pre-equilibrium and direct reactions as the function of the incident particle energy. This code uses the Hauser-Feshbach model to unify the effects of the compound nucleus reaction mechanism. The pre-equilibrium contribution has been included using the exciton model, which was developed by Kalbach.

EMPIRE-3.2 [5] is a computer code for the nuclear reactions, including different nuclear models, and designed for the calculations as a wide range of incident energies and incident particles. Photons, nucleons, deuterons, tritons, helium (^{3}He), α-particles, and light or heavy ions can be selected as projectiles. This code can be used for the nuclear data evaluation as well as for the theoretical calculations of the nuclear reactions. There are various input parameter libraries, FORTRAN codes, and experimental data library (EXFOR), which are operated through the Graphical User Interface (GUI). This statistical model is an advanced implementation of the Hauser-Feshbach theory for the compound nuclear reaction cross-section. EGSM is a default level density model used in the present calculations.

Results and Conclusions

In the paper, the calculations on the excitation functions of $^{32}S(n,p)^{31}P$, $^{56}Fe(n,2n)^{55}Fe$, $^{58}Ni(n,\alpha)^{55}Fe$, $^{74}Se(n,p)^{74}As$, $^{98}Ru(n,2n)^{97}Ru$, $^{102}Ru(n,\gamma)^{103}Ru$, $^{103}Rh(n,p)^{103}Ru$, $^{104}Ru(n,2n)^{103}Ru$, $^{108}Pd(n,\gamma)^{109}Pd$, $^{109}Ag(n,p)^{109}Pd$, $^{110}Pd(n,2n)^{109}Pd$ and $^{112}Cd(n,\alpha)^{109}Pd$ reactions in the 1–20 MeV energy range are presented. The calculated results are compared and discussed with the experimental as well as evaluated data.

Generally, the nuclear reaction cross-sections first increases with the increasing of neutron energy and get the maximum value and then decreases as a function of neutron energy in the case of (n,p), (n,2n) and (n,α) reactions. But in case of (n,γ) reactions, the cross-section values are higher at ~1 MeV neutron energy due to the contribution of compound nucleus as compared to the pre-equilibrium mechanism and direct reaction.

The shape of the theoretically predicted excitation functions for ^{32}P, ^{55}Fe, ^{74}As, ^{97}Ru, ^{103}Ru and ^{109}Pd radionuclides produced by (n,p), (n,2n), (n,α) and (n,γ) channels show a similar trend with the existing experimental data. It should also be noted that there is only one experimental data present for $^{102}Ru(n,\gamma)^{103}Ru$ reaction and for $^{108}Pd(n,\gamma)^{109}Pd$ reaction, no experimental data is present in this energy range. The data obtained by using EGSM model of EMPIRE-3.2 code can be used as a reference cross section and it is hoped that they can help in enterprising a well-controlled and optimized production of medical radionuclides in the energy range 5 – 20 MeV.

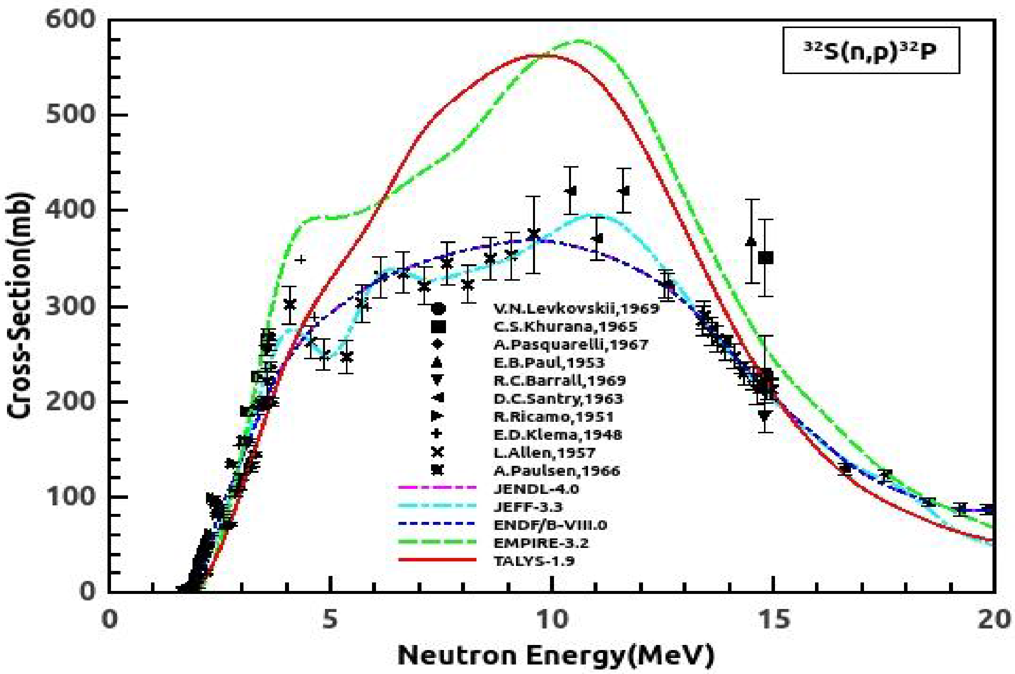

Fig.1. Theoretically predicted and experimentally measured as well as evaluated excitation functions for ^{32}P radionuclide.

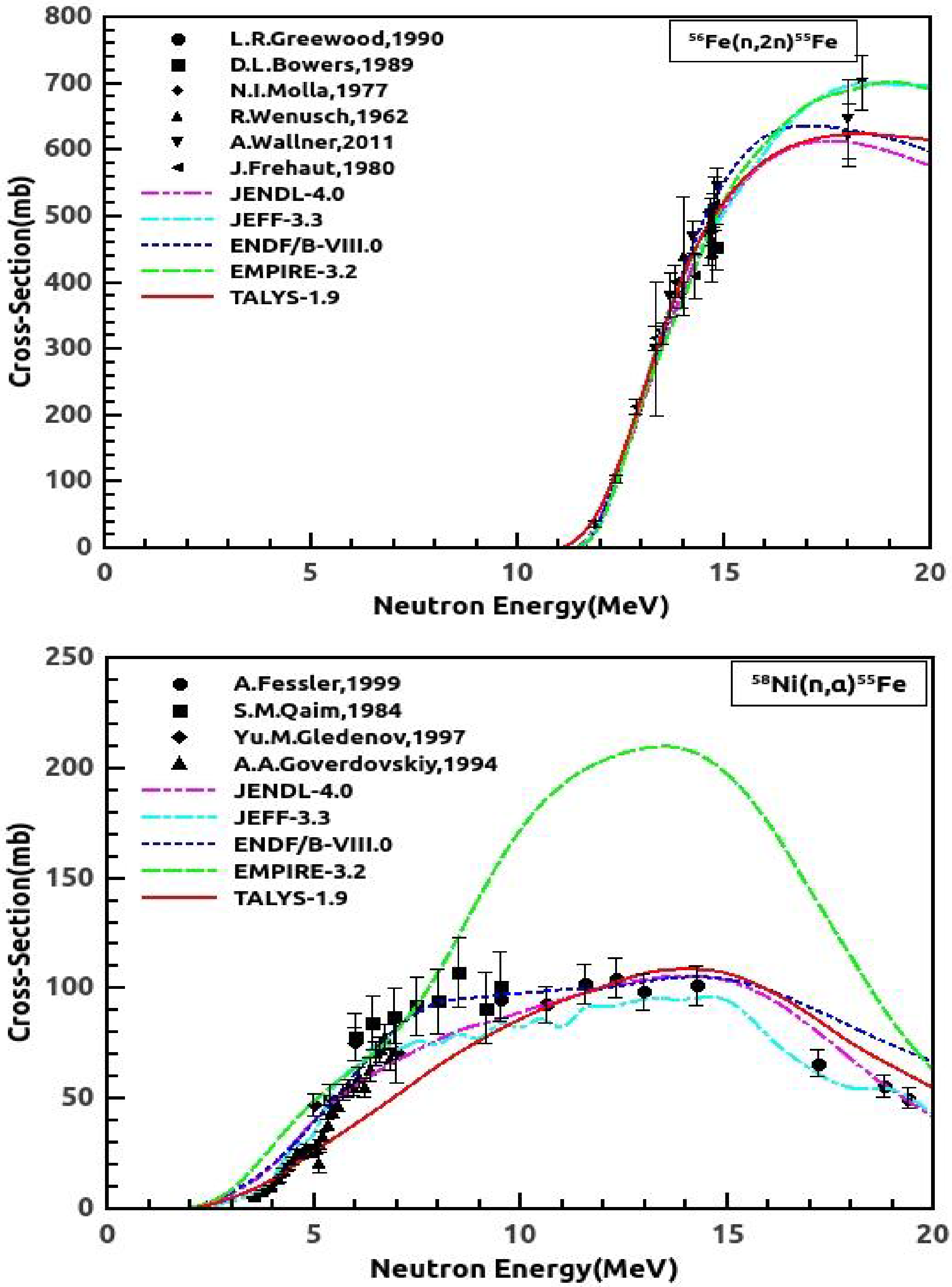

Fig.2. Theoretically predicted and experimentally measured as well as evaluated excitation functions for ^{55}Fe radionuclide.

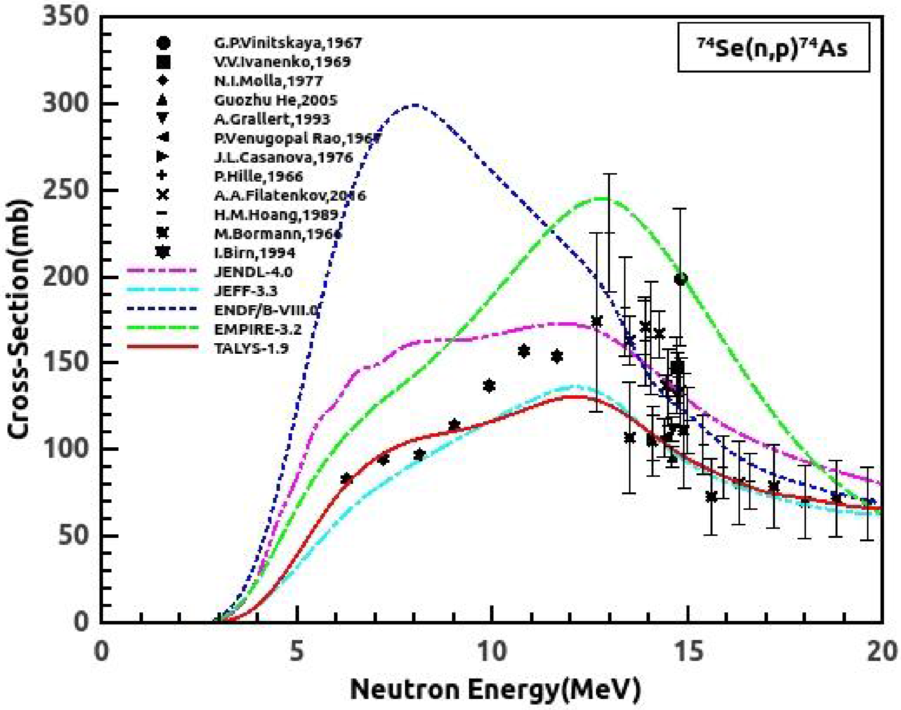

Fig.3. Theoretically predicted and experimentally measured as well as evaluated excitation functions for ^{74}As radionuclide

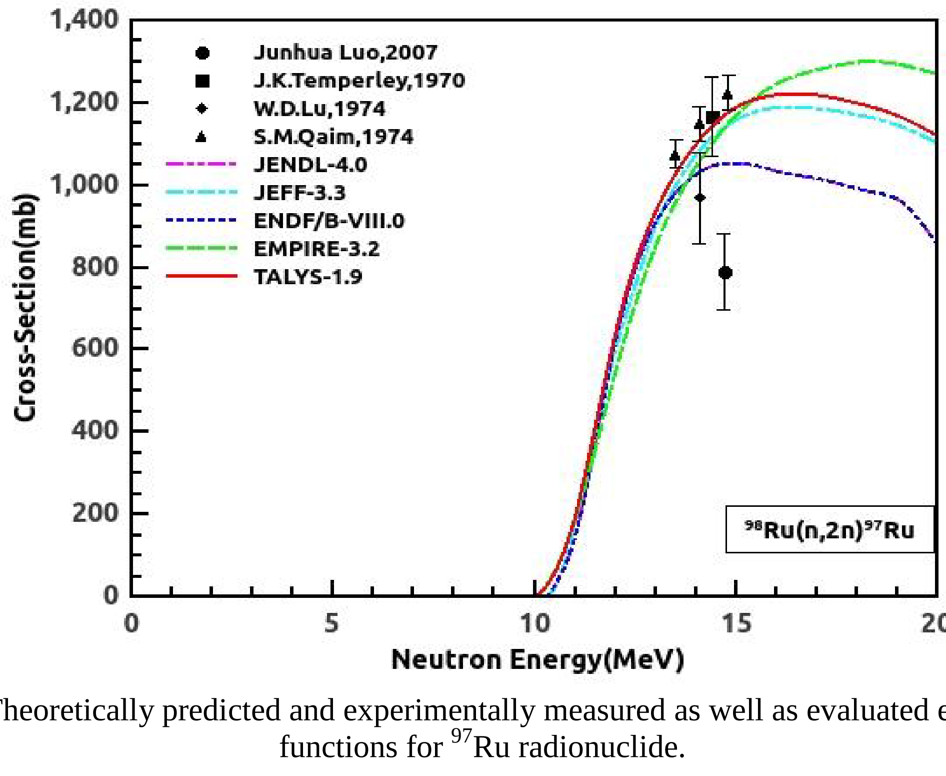

Fig.4. Theoretically predicted and experimentally measured as well as evaluated excitation functions for ^{97}Ru radionuclide.

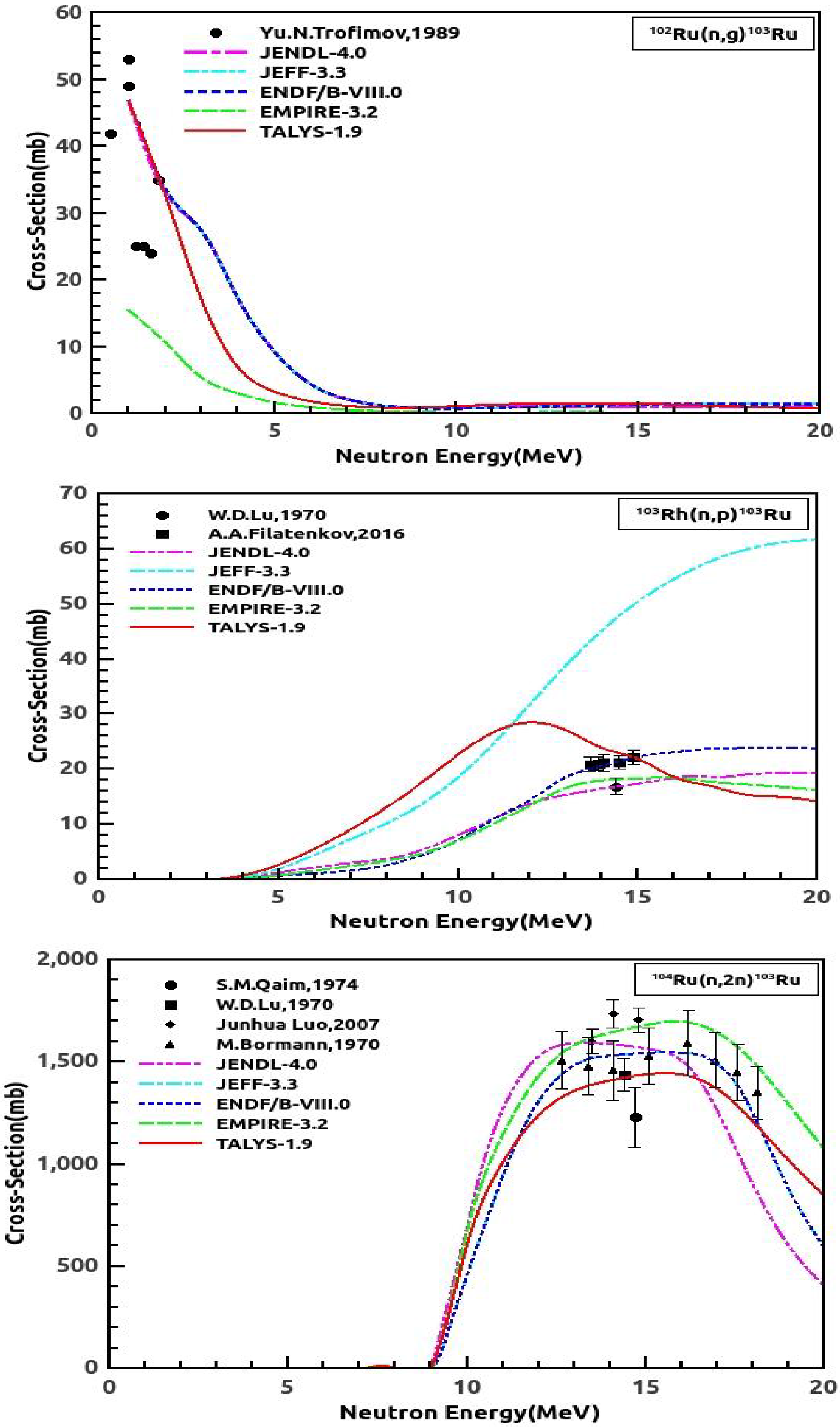

Fig.5. Theoretically predicted and experimentally measured as well as evaluated excitation functions for ^{103}Ru radionuclide.

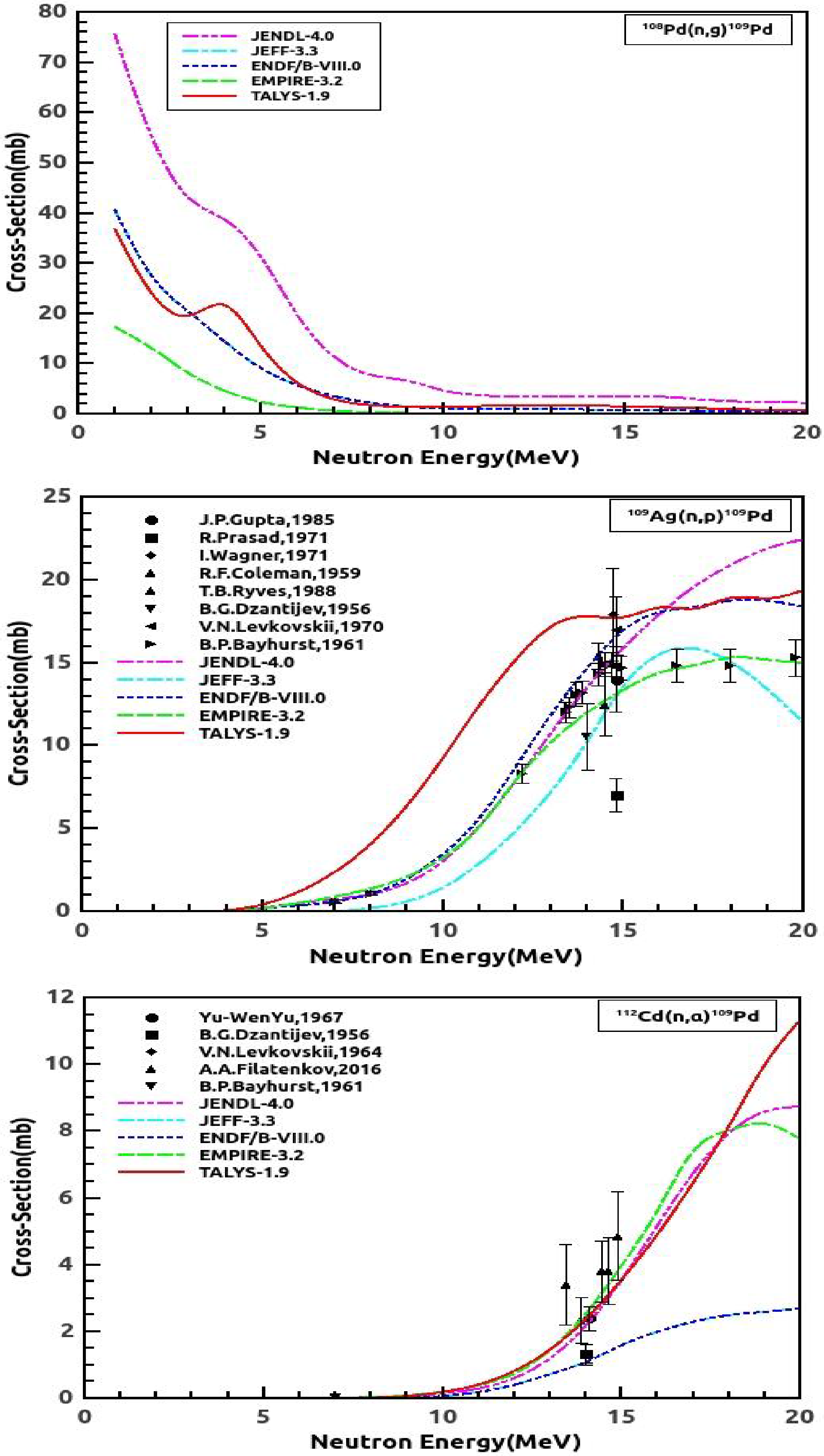

Fig.6. Theoretically predicted and experimentally measured as well as evaluated excitation functions for ^{109}Pd radionuclide.

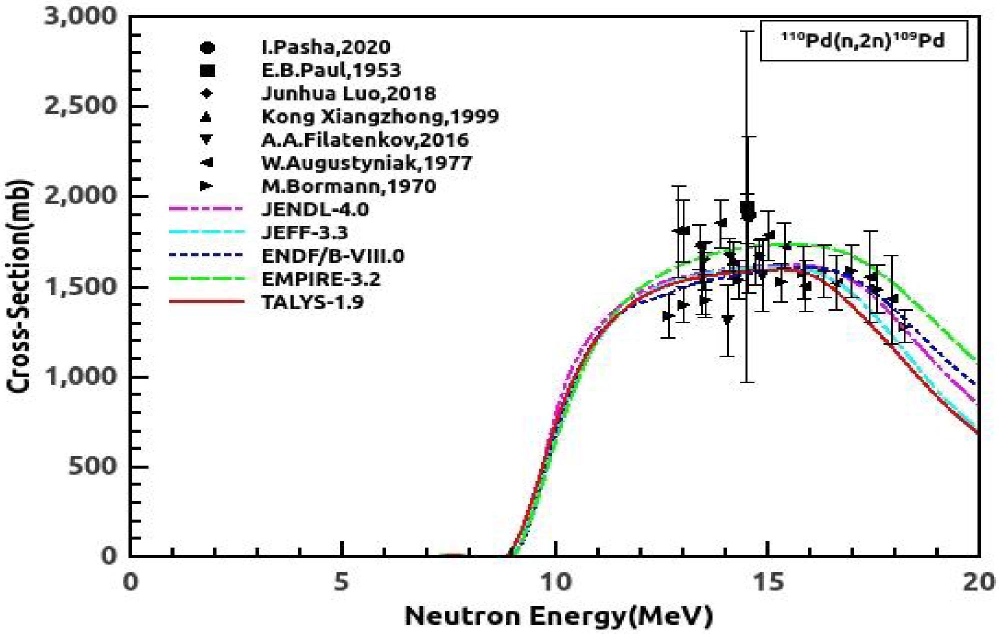

Fig.7. Theoretically predicted and experimentally measured as well as evaluated excitation functions for ^{109}Pd radionuclide.

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