SDU Journal of Science (E-Journal), 2010, 5 (2): 211-215

# Investigation of Proton Emission Spectra of Some Nuclear Reactor Materials for (p,xp) Reactions

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Received: 31 August 2010, Accepted: 5 October 2010

**Abstract:** Proton-emission spectra produced by (p,xp) reactions for some nuclear reactor and particle accelerator material $^{56}Fe$ and $^{60}Ni$ target nuclei have been investigated by a proton beam up to 50 MeV. In these calculations, the pre-equilibrium effects have been investigated. The calculated results are compared with the experimental data taken from literature.

***Key words***: (p,xp) reactions, Weisskopf-Ewing model, Full- Exciton model

# Bazı Nükleer Reaktör Materyallerinin (p,xp) Reaksiyonlarının Proton Yayınım Spektrumunun İncelenmesi

**Özet:** Parçacık hızlandırıcıları ve nükleer reaktör materyallerinden olan $^{56}Fe$ ve $^{60}Ni$ hedefler ile enerjileri 50 MeV'e kadar olan proton demetlerinden elde edilen proton-yayınım spetrumları incelendi. Bu hesaplamalarda denge öncesi etkiler araştırıldı. Hesaplama sonuçları literatürden elde edilen deneysel sonuçlarla karşılaştırıldı.

***Anahtar kelimeler:*** (p,xp) reaksiyonları, Weisskopf-Ewing model, Full Exciton model

## 1. Introduction

Nuclear reactors can be one of the attractive systems as cheap and constant energy sources and minimal environmental impact. Increasing of energy needs, global warming and decreasing of fuel reserves make necessary nuclear reactors. Therefore investigation behaviors of nuclear reactor materials with radiation are important. Central in the goal of designing a safe, environmentally benign, and economically competitive power system is the requirement for high performance, low activation materials. The general performance requirements for such materials have been defined and it is clear that materials developed for other applications (e.g. aerospace, nuclear energy, fossil energy systems) will not fully meet the needs of fusion [1].

Accelerators underpin every activity of the Office of Science and, increasingly, of the entire scientific enterprise. From biology to medicine, from materials to metallurgy, from elementary particles to the cosmos, accelerators provide the microscopic information that forms the basis for scientific understanding and applications. The combination of ground and satellite based observatories and particle accelerators will advance our understanding of our world, our galaxy, our universe and ourselves [2]. Thus reactions of nuclear reactors and particle accelerators materials, Fe and Ni, with protons are very important for efficiently work of these systems.

## 2. Calculation Methods

The compound nucleus reactions occur on a very much longer time scale ($\cong 10^{-16}$ to $10^{-18}$ s). Weisskopf-Ewing sufficiently described this process. Equilibrium emission is calculated according to Weisskopf-Ewing and Full exciton model [3] by neglecting angular momentum. In the evaporation model contains the basic parameters; binding energies, inverse reaction cross-section, the pairing, and the level-density parameters. Light projectiles with incident energies above about 8-10 MeV induce nuclear reactions and pre-equilibrium processes are important agency for these reactions. The description of Pre-equilibrium reactions started a series of semi classical models of varying complexities have been developed for calculating and evaluating particle emissions in the continuum. A first model to treat intermediate process is the intra nuclear cascade model (INC), where classical nucleon trajectories are followed, assuming that nucleons collide pair wise with rate and angular distributions given by the measured free nucleon-nucleon scattering results [4] the partition in energy that results of nucleon-nucleon scattering process is considered in the exciton model of Griffin [5]. A hierarch of configurations following one, two or three, etc., nucleon-nucleon scattering events is followed, each described by the exciton number $n = p+h$, where $p$ and $h$ are the numbers of excited particles above the Fermi energy and below it, respectively. It was also shown that with some freedom in the choice of parameters, these models for high energy process could give reasonable fit to the observed energy and angular distributions of the emitted particles [4,6,7]. The pre-equilibrium and equilibrium emission spectrum in accordance with [8],

$$\frac{d\sigma_{ab}}{d\varepsilon_b}(\varepsilon_b) = \sigma^r_{ab}(E_{inc})\, D_{ab}(E_{inc}) \sum_n W_b(E, n, \varepsilon_b)\, \tau(n), \qquad (1)$$

where $\sigma^r_{ab}(E_{inc})$ is the cross-section of the reaction $(a, b)$, $W_b(E, n, \varepsilon_b)$ is the probability of the emission of a particle type $b$ with energy $\varepsilon_b$ from a state with $n$ excitons and excitation energy $E$ of the compound nucleus, $\tau(n)$ is the solution of the master equation which represents the time during which the system remains in a state of $n$ excitons. $D_{ab}(E_{inc})$ is a coefficient which takes into account the decrease in the available cross-section due to the particle emission by direct interactions with low excitation energy levels of the target nucleus.

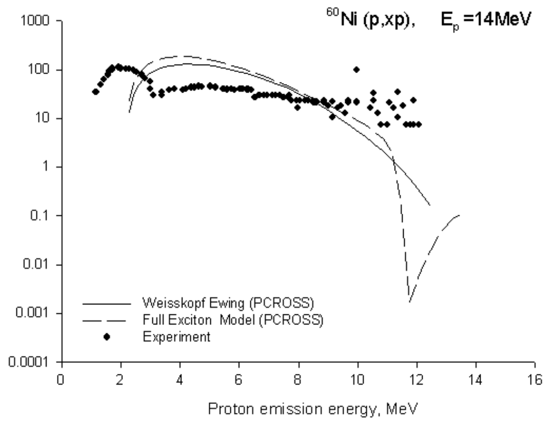


**Fig.1.** The comparison of calculated proton emission spectra of (p,x*p*) reactions with the values reported in literature for $^{60}Ni$ at 14 MeV. The experimental values were taken from [9].

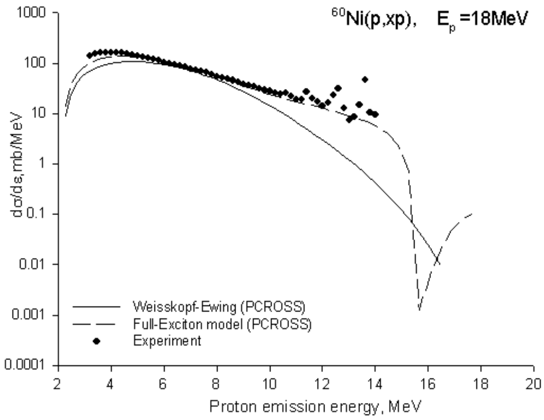


**Fig.2.** The comparison of calculated proton emission spectra of (p,x*p*) reactions with the values reported in literature for $^{60}Ni$ at 18 MeV. The experimental values were taken from [9].

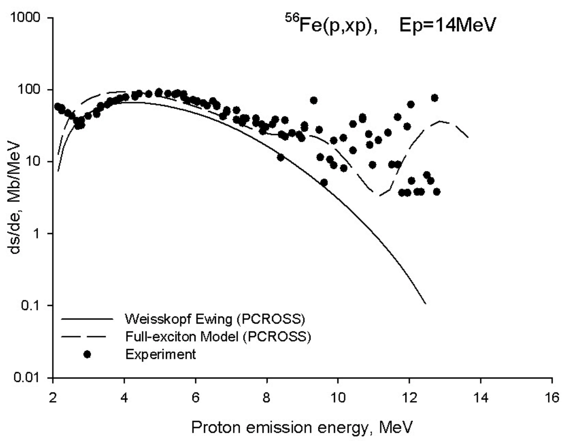


**Fig.3.** The comparison of calculated proton emission spectra of (p,x*p*) reactions with the values reported in literature for $^{56}Fe$ at 14 MeV . The experimental values were taken from [9].

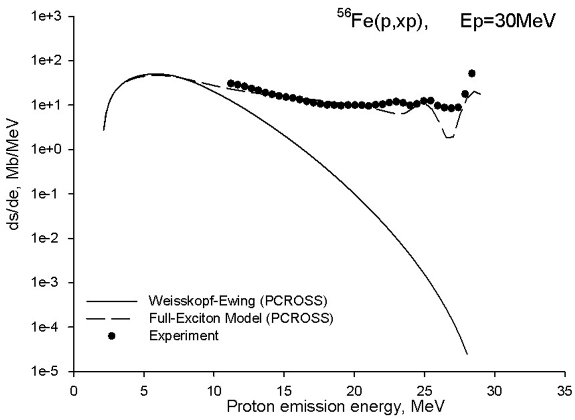


**Fig.4.** The comparison of calculated proton emission spectra of (p,x*p*) reactions with the values reported in literature for $^{56}Fe$ at 30 MeV. The experimental values were taken from [9].

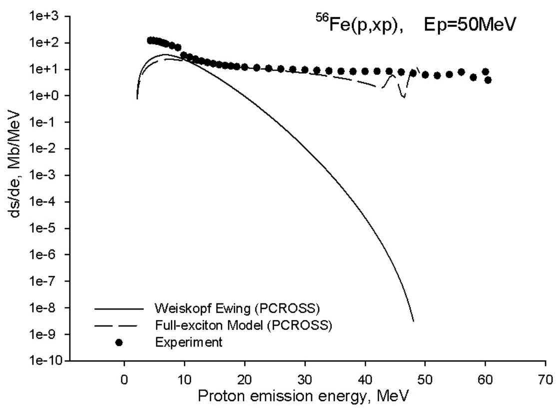


**Fig.5**. The comparison of calculated proton emission spectra of (p,x*p*) reactions with the values reported in literature for $^{56}Fe$ at 50 MeV. The experimental values were taken from [9].

## 3. Results and Discussion

In this study, the proton-emission spectra produced by (p,xp) reactions for some structural nuclear reactor materials as $^{56}$Fe, $^{60}$Ni have been calculated with the equilibrium and pre-equilibrium reaction models in Fig. 1. It is clear that the compound process dominates at the low proton emission energy up to 8-10 MeV. Generally for all reactions, the calculated proton emission spectra by using PCROSS codes for the equilibrium with Weisskopf-Ewing model and Full-exciton model calculations are in agreement with the experimental data at low energy region up to 8-10 MeV. Above 10 MeV, the Weisskopf-Ewing model can not calculate emission spectra (even if all the calculation parameters are changed).

The equilibrium calculations with Weisskopf-Ewing model don't include angular momentum effects. In this theory, compound nucleus wave function is very complicated, involving a large number of particle-hole excitations to which statistical considerations are applicable, the spectra of the emitted particles are approximately Maxwellian, and the angular distributions of emitted particles are symmetric about 90 degrees.

The pre-equilibrium and equilibrium level density parameters have been investigated using the full exciton model and Weisskopf-Ewing model for the proton emission spectra produced from $^{56}$Fe, $^{60}$Ni (p,xp) reactions at 14-50 MeV incident proton energy. The calculated results using the PCROSS code of the full exciton model and Weisskopf-Ewing model have been given in Fig. 1, Fig. 2, Fig. 3, Fig. 4, Fig. 5.

The mean free path $k_{m\,\mathrm{f\,p}}$ parameter allows an increase in mean free path, with simulation of effects, which are not considered in the calculations, such as conservation of parity and angular momentum in intra nuclear transitions. As the direct excitations of levels of a collective nature are considered in the PCROSS code, the hard part of emission spectrum can be described satisfactorily with a global value of $k_{m\,\mathrm{f\,p}} = 1$, which is smaller than reported earlier [9]. We have investigated the multiple pre-equilibrium matrix element constant from internal transition for $^{60}$ Ni (p,xp) neutron emission spectra at 14 MeV and 18 MeV and $^{56}$Fe (p,xp) at 14 MeV, 30 MeV and 50 MeV proton incident energies for the full exciton and (Fig. 1).

When more experimental data for the proton scattering and emission differential cross sections become available by using new technology, more reliable results can be obtained and more nuclear reaction mechanisms can be developed. These experimental cross–section data can be used for better understanding the basic nucleon–nucleus interaction, the binding energy systematics, nuclear structure, and for development of refined nuclear models. Improved predictions can guide the design of the target/blanket configurations and can reduce engineering over design costs.

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