Nuclear Data Evaluation for ^{54,56,57,58}Fe Induced by Proton

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1. Introduction

Nuclear data on proton-induced reactions are needed for various applications such as the design of Accelerator-Driven System (ADS), the production of radioisotopes and surface analysis in industrial application. The reliability of the simulations carried out in those applications is directly affected by the availability of accurate nuclear data [1]. Thus, this work aims to provide the accurate nuclear data of the material induced by proton.

Iron is a common structural material for nuclear power reactors and the associated shielding. Consequently, the accurate data of iron will avoid the unnecessary conservatism in the ADS design studies, which would otherwise be needed in order to meet the shielding requirements [2]. However, the evaluated nuclear data libraries such as ENDF/B-VII.0, JENDL-HE, and JEFF-3.1 show a discrepancy with the available experiment data. In response to this situation, we evaluated the nuclear data files for Iron which naturally consists of four isotopes, such as ^{54}Fe, ^{56}Fe, ^{57}Fe and ^{58}Fe. The theoretical calculation was performed by up-to-date nuclear reaction code Talys which provide a complete and accurate simulation of nuclear reaction in the 1 KeV – 200 MeV energy range, through an optimal combination of reliable nuclear models.

We give a complete representation of nuclear reactions induced by protons with incident energies up to 160 MeV for all stable iron isotopes. The results were compared to the available experimental data and the existing nuclear data libraries such as ENDF/B-VII.0, JENDL-HE, JEFF-3.1.

2. Model Calculation

Talys is a computer code system for the prediction and analysis of nuclear reaction. The nuclear modeling calculation based on Talys is generally categorized into direct, pre-equilibrium, and compound parts. Those parts can be described by various nuclear models and their parameters. Of them, the Optical Model Potential (OMP) has a significant impact on many branches of nuclear reaction physics. The complicated interaction between an incident particle and a target nucleus can be represented by dividing the reaction flux into a part covering shape elastic scattering and a part describing all competing non-elastic channels. So, we are firstly interested in the parameterization of optical model potential (OMP) among the many model parameters such as nuclear level densities, gamma strength functions [3]. The OMP parameters used in this work were taken from Ref. [4] and adjusted to reproduce the available measurements. The OMP parameterization for the incident proton is

$$
\begin{aligned}
&V_v(E) = v_1[1 - v_2(E-E_f) + v_3(E-E_f)^2 - v_4(E-E_f)^3],\\
&W_v(E) = w_1 \frac{(E-E_f)^2}{(E-E_f)^2 + (w_2)^2},\\
&r_v = constant,\\
&a_v = constant,\\
&W_d(E) = d_1 \frac{(E-E_f)^2}{(E-E_f)^2 + (d_3)^2} \exp[-d_2(E-E_f)],\\
&r_d = constant,\\
&a_d = constant,\\
&V_{so}(E) = v_{so1} \exp[-v_{so2}(E-E_f)],\\
&W_{so}(E) = w_{so1} \frac{(E-E_f)^2}{(E-E_f)^2 + (w_{so2})^2},\\
&r_{so} = constant,\\
&a_{so} = constant,\\
&r_c = constant,
\end{aligned}
\qquad (1)
$$

where $V_{V,SO}$ and $W_{V,D,SO}$ are the real and imaginary components of the volume-central (*V*), surface-central (*D*) and spin-orbit (*SO*) potential well depths, respectively, r_i is the associated reduced radius and a_i is the diffuseness parameters, *E* is the incident energy in the LAB system in MeV, r_c is the coulomb radius and E_f is the Fermi energy. Table 1 shows the OMP parameters used for ^{56}Fe target.

Table 1. OMP parameters for protons incident on the ^{56}Fe

Parameters	p + ^{56}Fe	Parameters	p + ^{56}Fe
r_V	1.198	d_1	20.57
a_V	0.669	d_2	0.0218
v_1	59.59	d_3	11.5
v_2	0.0094	r_{so}	1.000
v_3	1.79 x 10^{-5}	a_{SO}	0.580
v_4	7 x 10^{-9}	v_{SO1}	6.10
w_1	14.44	v_{SO2}	0.0040
w_2	78.0	w_{SO1}	-3.1
r_D	1.281	w_{SO2}	160.
a_D	0.547	E_f	-7.63
r_C	1.261		

We calculated the proton-induced nuclear reaction for ^{56}Fe target with incident energies from 0.1 MeV to 160 MeV by using the OMP parameters in Table 1. Figure 1 show our result compared to experimental data and to the ENDF/B-VII.0, JENDL-HE, JEFF-3.1 evaluations for the proton non-elastic scattering cross section of ^{56}Fe. Our results, the ENDF/B-VII.0 and JEFF-3.1 evaluations are in good agreements with the measured data, while JENDL-HE is lower than them around 60 MeV and higher above 100 MeV.

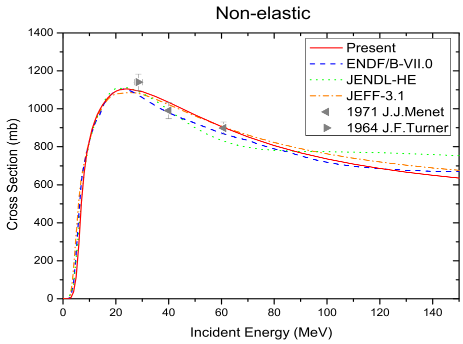

Figure 1. Non-elastic scattering cross section.

Figure 2 shows the result for the production of residual nucleus, ^{56}Co. Our results including the JENDL-HE and JEFF-3.1 evaluations reproduce the available experimental data well, while ENDF/B-VII.0 is lower than them around 10 MeV. The residual production cross section is important because it determines the production of the undesired products in a nuclear installation and also may have consequences for the shielding requirements [2].

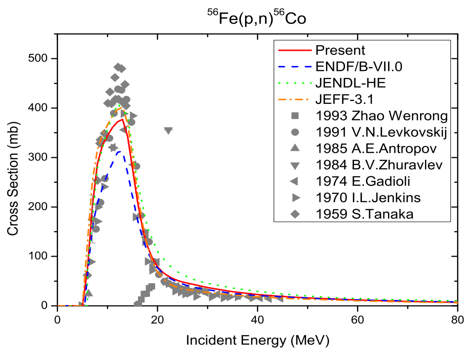

Figure 2. Residual production cross section of ^{56}Co.

Figure 3 shows the result compared to the available experimental data for emission gamma with 0.847 MeV. The gamma emission is the nuclear decay process of fluorescent emission of gamma rays from an excited state to the lower state. We took the discrete levels from RIPL-2 database [5].

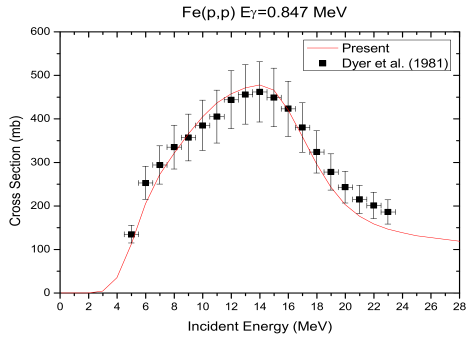

Figure 3. Gamma-ray production in proton inelastic scattering on ^{56}Fe.

3. Conclusions

We obtained the nuclear cross section data for four iron isotopes induced by proton with the incident energy range from 0.1 MeV to 160 MeV. Our calculations are in good agreements with the available experimental data. Our results were compiled into ENDF/B-6 formatted files, and subject to test runs with the code MCNPX to ensure that the files can be used in the various nuclear applications.

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