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Complete files of neutron- and proton-induced nuclear data to 1 GeV for ^{208}Pb target

Oleg Grudzevich[1,a], Julia Martirosyan[1], and Sergey Yavshits[2]

[1] State Technical University, Obninsk, Russia
[2] Khlopin Radium Institute, St. Petersburg, Russia

Abstract. Nuclear data for high projectile energies are needed to design an Accelerator Driven System (target, material activation, heating, shielding, etc.). The files of evaluated neutron and proton nuclear data were created in ENDF-6 format for the projectile particle energies from 20 MeV to 1000 MeV. The evaluated data of the files are based mainly on the modern theoretical model calculations with MCFx code. Three mechanism of nuclear reaction were modeled in computing: i) intranuclear cascade; ii) preequilibrium exciton multiparticle emission and iii) statistical decay of excited nuclei. The experimental data available were used to benchmark of the model calculation results. The data on neutron total and reaction cross sections were used to create and to check the set of the optical model parameters in wide energy region. The experimental spectra of ^{208}Pb(p,xn) reaction for projectile energies up to 160 MeV were described with one set of the model parameter. The measured fission cross sections of ^{208}Pb by protons and neutrons were described without fitting practically. The files contain total cross sections, fission cross sections, elastic scattering cross sections and angular distributions, proton- and neutron energy-angular distributions.

1 Introduction

The development of modern nuclear technologies requires a large amount of nuclear data to supply needs for the conceptual design of different fields of applications: the technology of radioactive waste transmutation and power production, radiotherapy, shielding problems and so on.

There are two ways of nuclear data supply for practical goals – to include the nuclear data generator into the transport codes or to produce nuclear data files outside. We guess the second way is more reliable due to the possibility of modern and sufficiently complicated codes applications. The development of the nuclear data libraries as well as corresponding computer codes has to be done for nuclear reactions induced by proton and neutron beams in projectile energy region 20 MeV–1 GeV.

2 Theoretical model and code

The MCFx code [1] is based on a detailed description of all stages of nuclear reaction induced by the intermediate energy nucleons. It uses well-checked and reliable models for the entrance channel simulation (coupled channels method), direct processes (intranuclear cascade model), pre-equilibrium particle emission (exciton model with multiple particle emission [2]), and compound nuclear decay (statistical model).

At the first stage for the files creation the optical model parameter (OMP) set for wide region of projectile energies and for the target form ^{208}Pb to ^{239}Pu was generated. We used ECIS code with relativistic corrections to calculate total, elastic and reaction cross sections. The experimental data available were included into the model calculations testing. So KRI-2006 OMP set was prepared. The examples of the comparison of experimental data and results of calculations are presented in figures 1–4. It can be seen from the figures that generally speaking all experimental data available in the library [3] are described reasonably good simultaneously for wide projectile energy region.

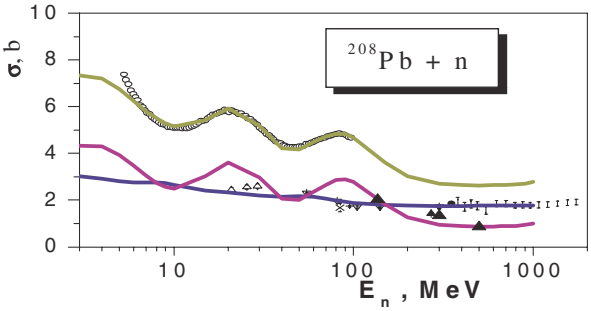

Fig. 1. Total, elastic and reaction cross sections for the interaction of neutrons with ^{208}Pb target. The symbols are the experimental data, the lines are the results of optical model calculations.

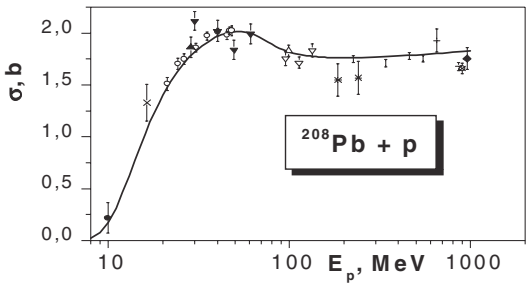

Fig. 2. Reaction cross section for the interaction of protons with ^{208}Pb target. The symbols are the experimental data, the line is the results of optical model calculations.

[a] Presenting author, e-mail: grudzevich@iate.obninsk.ru

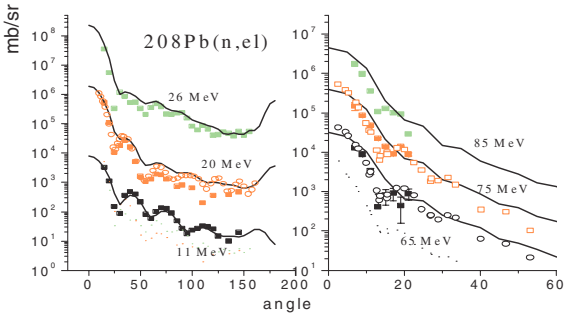

Fig. 3. Angular distributions of the neutron elastic scattering on ^{208}Pb for projectile energies from 11 MeV up to 85 MeV. The symbols are the experimental data, the lines are the results of optical model calculations.

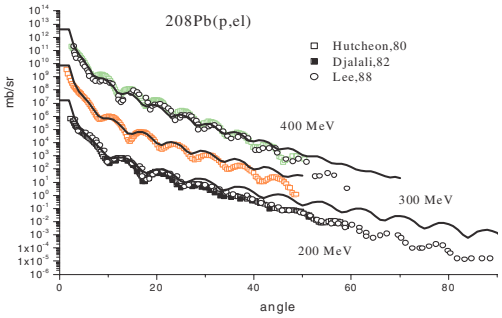

Fig. 4. Angular distributions of the proton elastic scattering on ^{208}Pb for projectile energies 200, 300 and 400 MeV. The symbols are the experimental data, the lines are the results of optical model calculations.

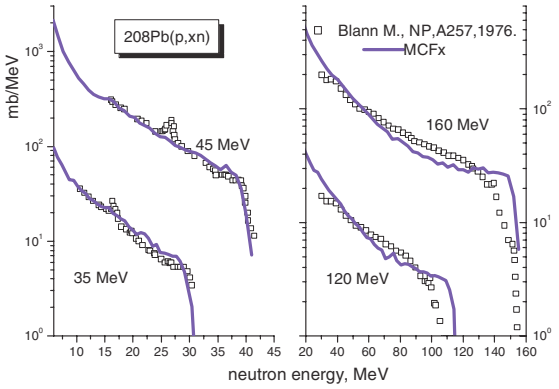

Fig. 5. Comparison of calculated and experimental neutron spectra [4] for ^{208}Pb(p,xn) reaction at 35, 45, 120 and 160 MeV proton energies.

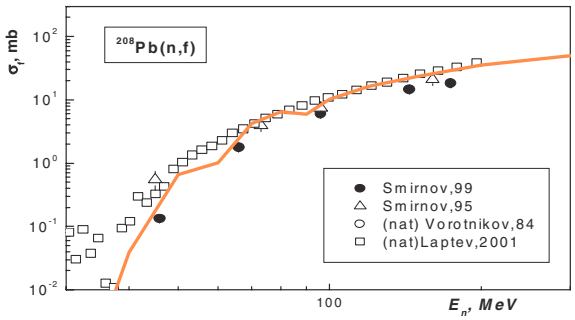

Fig. 6. Fission cross section for ^{208}Pb+n. The experimental data are shown by the symbols, MCFx results is line.

Figure 1 shows neutron total, elastic and reaction cross section for ^{208}Pb target. Agreement is good, except 300 MeV for elastic cross section. The next figure 2 demonstrates proton reaction cross section for ^{208}Pb target. Unfortunately, modern experimental data for proton are absent in time and the testing of our OMP set KRI-2006 against measured data for total and elastic cross sections is impossible. On the other hand, there are a lot of resent and old data for comparison and OMP set checking on neutron and proton elastic scattering angular distributions.

One can see from figure 3 that all data for neutron projectile energies from 11 MeV to 85 MeV are described by OM calculations good. For example, all structures of 11 MeV data are reproduced. But more helpful to file creation is agreement for higher energies (26–85 MeV).

We have compiled and analysed experimental data from [3] on proton elastic scattering angular distributions. It should be mentioned the information abundance for ^{208}Pb target for projectile energies from 20 MeV to 1 GeV. Different author's data practically in all cases are in good agreement. Typical descriptions of experimental angular distributions for the intermediate energy are shown in figure 4. Agreement is good for angles to 30 degrees and bad for higher angles. The discrepancies have no practical importance because the cross sections at these angles are one million times lower then at forward angles, so they are practically negligible.

The next stage of data generation for the complete files was the calculations of cross sections of (p,xnyp) and (n,xnyp) reactions by MCFx code system. The main parameter of the intranuclear cascade part is the shut down energy of the cascade. We used parabolic barrier with 20 MeV height and 50 MeV width to simulate the end of intranuclear interaction. This was done for two aims: i) to get reasonably smooth particle energy spectra and ii) to avoid sharp boarder of interaction. The most important parameter of preequilibrium model is the matrix element of two particle interaction. This value was fixed for all nuclei and projectile energies on the base of neutron and proton spectra calculations at 14–20 MeV projectile energies, where the contribution of intranuclear cascade is small.

The calculated by MCFx code energy distributions of the secondary neutrons for the ^{208}Pb(p,xn) reaction at the different proton energies are demonstrated in figure 5 in comparison with the experimental data. No fitting was done. The descriptions of all measured data are more or less good.

One can see from figures 6 and 7 that the experimental data are described well. It means the contribution of direct and preequilibrium parts of the reaction mechanism was taken into account correctly.

The main goal of the complete files for ^{208}Pb target is to supply the data of transport calculations of neutrons and protons in ADS target.

Fission cross section investigation from this viewpoint has no practical importance, but it is very reliable test of the theoretical models used in evaluation of the data.

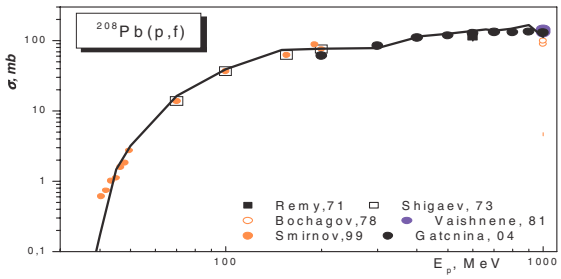

Fig. 7. Fission cross section for ^{208}Pb+p. The experimental data are shown by the symbols, MCFx results is line.

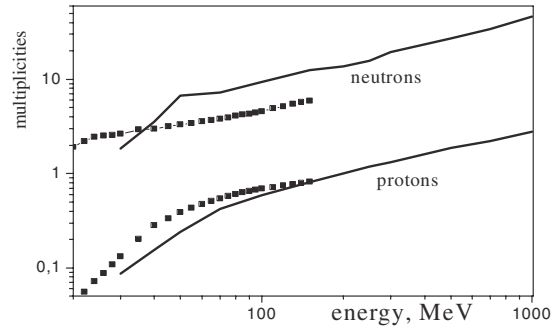

Fig. 8. Multiplicities of secondary neutrons and protons as a function of projectile energies. Symbols are LA150 data, curves are present calculations.

Two functionals have the influence on the calculated fission cross sections. They are non statistical part of interaction and the fission barriers. Comparisons of fission cross section of ^{208}Pb target by neutrons and protons are demonstrated in figures 6 and 7.

So we have benchmarked the results of neutron and proton data calculations with MCFx code system by the comparison with experimental data available for ^{208}Pb target. The data agreement analysis shows that MCFx code can be used to produce complete files with the parameter sets adopted.

3 File content

For the information representation we used three files of complete file according to ENDF-6 manual recommendations. File 1 contains general information where in very brief style the methods of data evaluation are described. File 2 was not prepared because neutron projectile energies of our evaluations start from 20 MeV. We believe it is better to insert different complete files into transport calculation separately instead of compiling one data file for energy from 10^{-5} eV to 1 GeV.

File 3 contains cross sections as a functions of incoming energy: i) total reaction cross section, ii) elastic scattering cross section, iii) fission cross section and iv) cross section of neutron/proton production. Some small corrections of calculated fission cross sections were done to reproduce measured data better.

The energy-angle distributions of secondary neutrons/protons and the multiplicities of these particles are included into file 6. We used Kalbach-Mann approach of the data presentation to save the file volume. So for each energy of the nucleon spectra the probability of emission and non-equilibrium part of reaction are presented.

The multiplicities of the secondary neutrons and protons from (p,xnyp) and (n,xnyp) reactions were calculated by MCFx code. The Monte Carlo simulation of all possible reaction chains was done to prepare input data for the code. The comparisons of our results and LA150 [4] library data for neutrons and protons are demonstrated in figure 8. It can be concluded the good agreement for proton because statistical contribution to the value is rather small and nonstatistical models are more or less analogous. One can see that for neutrons the factor of two in multiplicities takes place. The contribution of statistical mechanism into n-multiplicities is not negligible and the reason of the differences is different parameters of the statistical model of nuclear reactions.

4 Conclusions

We have generated and tested complete data files in ENDF-6 format of neutron and proton reactions to 1 GeV for ^{208}Pb target. The same files for ^{209}Bi, ^{235}U and ^{238}U are in process of format testing by standard computer codes. The date of the file release is May, 2007.

References

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