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DESCRIPTION OF EVALUATION FOR $^{58,60,61,62,64}Ni$ PERFORMED FOR ENDF/B-VI

D. C. Larson, D. M. Hetrick, and C. Y. Fu
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831-6356

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DESCRIPTION OF EVALUATIONS FOR $^{58,60,61,62,64}Ni$ PERFORMED FOR ENDF/B-VI*

D. C. Larson, D. M. Hetrick, and C. Y. Fu
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831-6356
U. S. A.

ABSTRACT

Isotopic evaluations for $^{58,60,61,62,64}Ni$ performed for ENDF/B-VI are briefly reviewed. The evaluations are based on analysis of experimental data and results of model calculations which reproduce the experimental data. Evaluated data are given for neutron induced reaction cross sections, angular and energy distributions, and for gamma-ray production cross sections associated with the reactions. File 6 formats are used to represent energy-angle correlated data and recoil spectra. Uncertainty files are included for the major cross sections. Detailed evaluations are given for $^{58,60}Ni$, and results of calculations for the major reactions are used for evaluations of the minor isotopes.

1. INTRODUCTION

Separate evaluations have been done for each of the stable isotopes of nickel. In this report, we briefly review the structure of the evaluations, describe how the evaluations were done, and note the major pieces of data considered in the evaluation process. Experimental data references were obtained primarily from CINDA, but also from the literature and reports. The data themselves were mostly obtained from the National Nuclear Data Center at Brookhaven National Laboratory and, occasionally, from the literature and reports. The TNG nuclear model code (FU80,SH86), a multistep Hauser-Feshbach code which includes precompound and compound contributions to cross sections, angular, and energy distributions in a self-consistent manner, calculates gamma-ray production, and conserves angular momentum in all steps, was the primary code used for these evaluations. Extensive model calculations were performed with the goal of simultaneously reproducing experimental data for all reaction channels with one set of parameters. This ensures internal consistency and energy conservation within the evaluation. In the case of reactions for which sufficient data were available, a Bayesian analysis using the GLUCS code (HE80) was frequently done, using ENDF/B-V or the TNG results as the prior. In cases where insufficient data were available for a GLUCS analysis, and the available data were deemed to be accurate, but in disagreement with the TNG results, a line was drawn through the data and used for the evaluation. A hand-drawn line was also used for cross sections where resonant structure was felt to be important, but resonance parameters were not included. The final evaluation is thus a combination of TNG results (used where extrapolation and interpolation was required and where data sets were badly discrepant), GLUCS results (used where sufficient data existed to do an analysis), and hand-drawn curves.

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In Section 2 the resonance parameters are discussed; Section 3 contains a description of the major cross sections included in the evaluation; Section 4 is devoted to angular distributions; and Section 5 to energy-angle correlated distributions. Section 6 describes the uncertainty files.

Much of this information is abstracted from Ref. HE87, a report devoted to a description of the calculations for ^{58,60}Ni. As of this writing, the various pieces of the evaluations are being reviewed, modified if necessary, and assembled into full evaluations using the ENDF/B-VI formats, and will be submitted by May 1988 to the Cross Section Evaluation Working Group (CSEWG) for inclusion in ENDF/B-VI.

2. RESONANCE PARAMETERS

Resonance parameters for ^{58}Ni from 10 to 810 keV were taken from a recent SAMMY analysis (PE87) of ORELA transmission, scattering, and capture data. Sixty-two ℓ=0 and 410 ℓ>0 resonances were identified and are included, using the Reich-Moore formats. Resonance parameters for ^{60}Ni cover the energy range from 1 to 450 keV and were also taken from a SAMMY analysis of ORELA transmission and capture data (PE83). Thirty ℓ=0 and 227 ℓ>0 resonances were identified and included in the ^{60}Ni evaluation. For the ^{61,62,64}Ni evaluations, the resonance parameters were taken from the compilation of Mughabghab (MU81).

3. CROSS SECTIONS

In this section we briefly describe the contents of the files containing cross sections for the more important reactions. The total cross section for ^{58}Ni above the resonance region was taken from a high-resolution measurement (PE87) up to 20 MeV. For ^{60,61,62,64}Ni the total cross section above the resonance region was taken from a high-resolution measurement of natural nickel (LA83). Cross sections for inelastic scattering to discrete levels in ^{58,60}Ni were taken from the model calculations which compared favorably with numerous data sets available for these levels. Direct interaction contributions were included for many of the levels. Agreement with experimental data is generally favorable; however, the experimental uncertainties are often rather large. Figures 1 and 2 show a comparison of the TNG results with experimental data for the total inelastic scattering cross section for ^{58,60}Ni, respectively. For ^{61,62,64}Ni the cross sections for the lowest few levels were included from the calculations, and a continuum was used to represent the remainder of the inelastic scattering cross section.

Abundant data are available to define the ^{58,60}Ni(n,p) reaction cross sections. Figure 3 shows a comparison of the available data, and the TNG and GLUCS results for the ^{58}Ni(n,p) cross section. The evaluated ^{58}Ni(n,p) cross section was taken from a Bayes' simultaneous analysis of several correlated cross sections (FU82), while the ^{60,61,62,64}Ni(n,p) cross sections were taken from the model calculations. Data for the (n,α) reactions are sparse, and the evaluations are based on calculated results, which were compared with available experimental data. Total proton and alpha emission cross sections for ^{58,60}Ni were also taken from the model calculations and agreed well with the integrated data at 14 MeV of Grimes et al. (GR79) and Kneff et al. (KN86), and with the data of Qaim et al. (QA84) at lower energies.

There is abundant cross section data for the ^{58}Ni(n,2n) reaction, but no data for the (n,2n) cross section on any of the other isotopes. Results of the TNG model calculations were in good agreement with the available (n,2n) data, as well as the neutron emission spectra for natural Ni; thus results of the model calculations were used for the (n,2n) cross sections for all of the isotopes. It should be noted that the (n,2n) cross sections are large for the minor isotopes ^{61,62,64}Ni, and were explicitly included in the reactions for these minor isotopes.

Cross sections for all significant binary and tertiary reactions are given for each isotopic evaluation. See the detailed description in Ref. (HE87) for ^{58,60}Ni.

4. ANGULAR DISTRIBUTIONS

Calculated elastic scattering angular distributions using the Wilmore-Hodgson optical model potential (WI64) are in good agreement with abundant experimental data and are given as Legendre coefficients in File 4/2. Disagreements in experimental angular distribution data sets for inelastic scattering to discrete levels are often outside rather large uncertainties. Model calculations including direct interaction and compound reaction contributions were compared with available data and used for the evaluations. These data are also entered as Legendre coefficients in File 6/51-90 in each evaluation for as many levels as discrete information is available. Only the few lowest levels were used for the minor isotopes, and isotropic angular distributions were assumed.

5. ENERGY-ANGLE CORRELATED DISTRIBUTIONS (FILE 6)

Often, neutron, proton, alpha, and gamma-ray emission spectral data are measured as a function of outgoing particle angle, and this correlation of outgoing angle with measured spectra can now be represented in File 6. However, generally these distributions have only been measured at one or at most a few incident energies, thus we rely upon the TNG model calculations to reproduce the available data as a function of outgoing energy and angle, and then extrapolate to other incident neutron energies. Figure 4, taken from Ref. HE87, shows a comparison of the experimental data with the calculated results for the natural Ni(n,xn) cross section, and Figure 5 (HE87) shows a comparison of the measured and calculated angular distributions for three outgoing neutron energy bins. These calculated energy-angle distributions have been taken from the TNG calculations and entered in File 6 for the ^{58,60}Ni evaluations for a number of incident energies between 1 and 20 MeV. Cross sections associated with these distributions are given in File 3.

Figures 6 and 7 (HE87) show comparisons of calculated results with experimental data for the ^{58}Ni(n,xp) and ^{60}Ni(n,xα) reactions near 14 MeV, respectively. These energy distributions, with isotropic angular distributions assumed, have been entered in File 6. Recoil spectra for the heavy residual nuclei have also been included in File 6. Since the angular distributions are given as isotropic, File 5 could have been used for all charged particle spectra with the exception of the recoil spectra, but for ease of energy balance and KERMA calculations, a consistent File 6 usage is desirable. Cross sections associated with these distributions are given in File 3.

File 6 was also chosen to represent the gamma-ray production energy distributions, for consistency with the neutron and charged particle distributions. Isotropic angular distributions were used for the gamma rays. Figure 8 (HE87) shows a comparison of measured gamma-ray spectra around 14 MeV with the TNG calculation at 14.5 MeV. Note that without use of the calculated results, a significant amount of cross section below about 1-MeV gamma-ray energy would be missing. Calculated distributions are given in File 6 for several incident neutron energies from 1 to 20 MeV. Cross sections associated with these distributions are given in File 3.

Capture gamma-ray cross sections and spectra are given in File 13 and 15, respectively, and are based on a combination of experimental data and calculation.

As an example of the usage of File 6, consider the ^{58}Ni(n,$n\alpha$) reaction. In File 6/22, constant yields are given for the outgoing neutron, alpha and ^{54}Fe residual, and an energy dependent yield is used for the gamma rays associated with the (n,$n\alpha$) reaction. Normalized energy distributions are given for each outgoing product, but only the outgoing neutron has a non-isotropic angular distribution. The cross section to be used for normalization is taken from File 3/22.

6. UNCERTAINTY INFORMATION

Uncertainty files are given only for the cross sections in File 3 and not for the resonance parameters, energy distributions or angular distributions. Fractional and absolute components, correlated only within a given energy interval, are based on scatter in experimental data and estimates of uncertainties associated with the model calculations.

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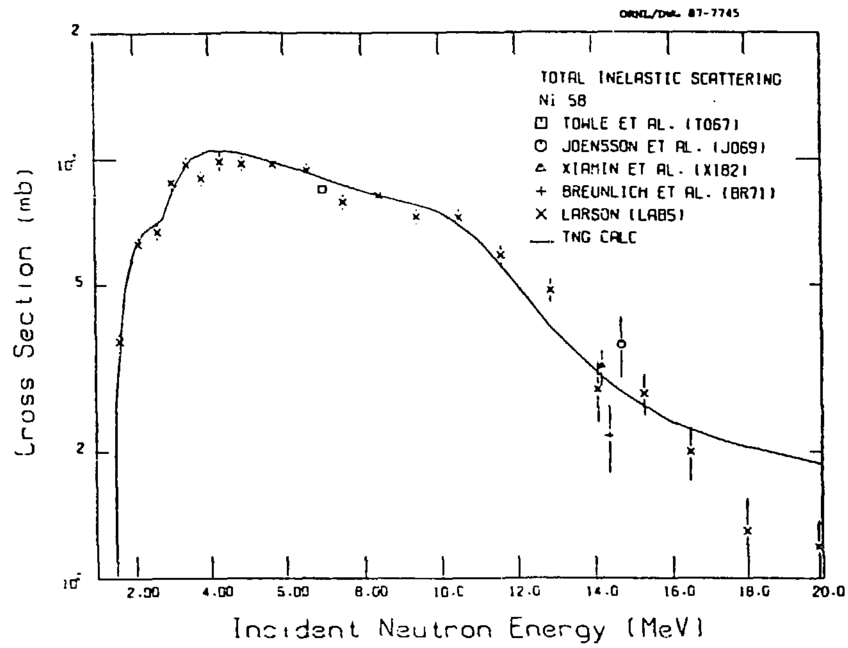

Fig. 1. Comparison of calculated and experimental total inelastic scattering cross sections for ^{58}Ni.

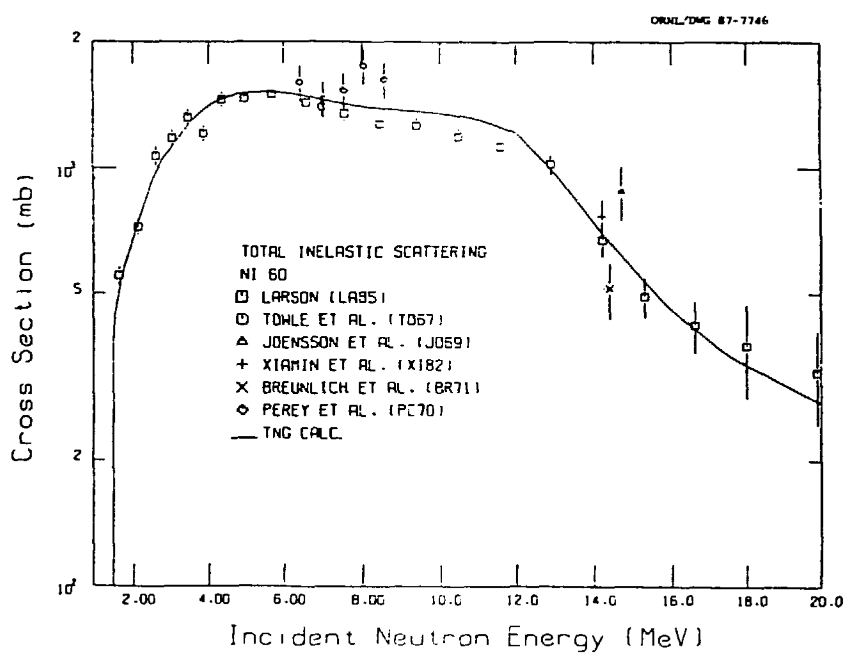

Fig. 2. Comparison of calculated and experimental total inelastic scattering cross sections for ^{60}Ni.

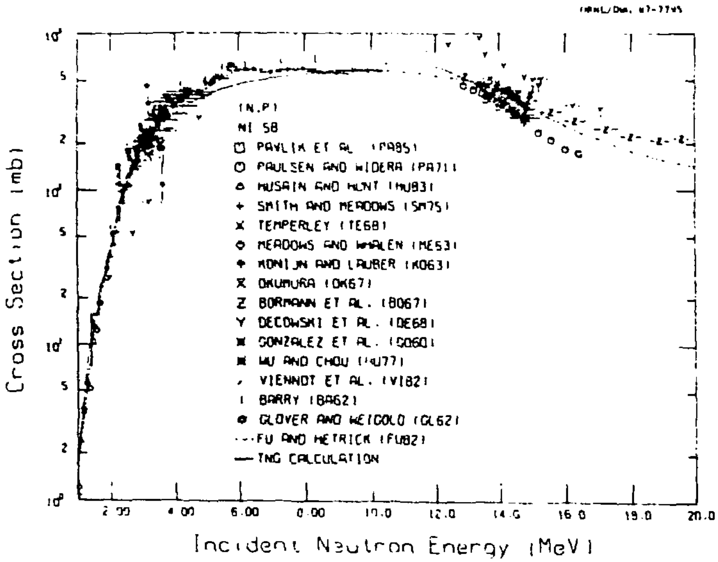

Fig. 3. Comparison of ^{58}Ni(n,p) cross sections with TNG results (HE87) and GLUCS results (FU82). (See Ref. HE87 for references.)

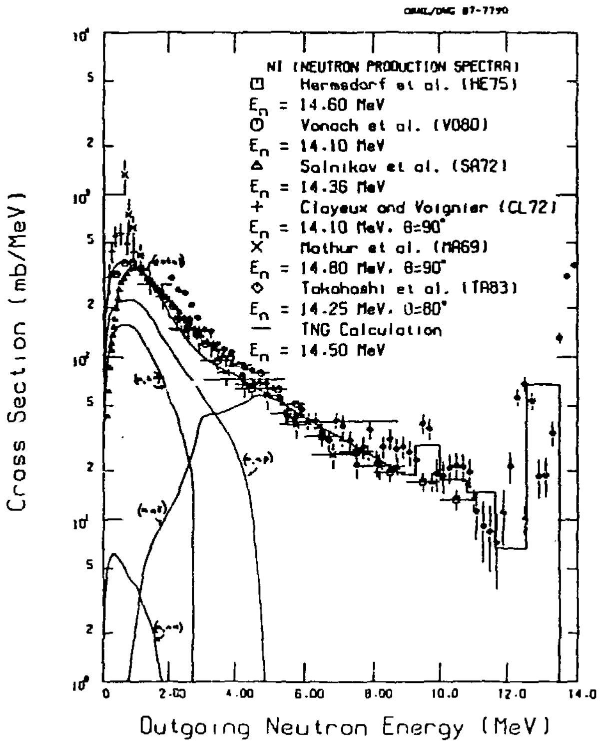

Fig. 4. Neutron emission spectra for the TNG calculation compared with experimental data. The data of Clayeux and Voignier (CL72) and Mathur et al. (MA69) were taken at 90°, the data of Takahashi et al. (TA83) were taken at 80°, and the other measured data sets shown (HE75, VO80, and SA72) are angle integrated. Contributions from the various neutron-producing components are shown (they sum to the total). The curves labeled (n,np) and ($n,n\alpha$) include the (n,pn) and ($n,\alpha n$) components, respectively.

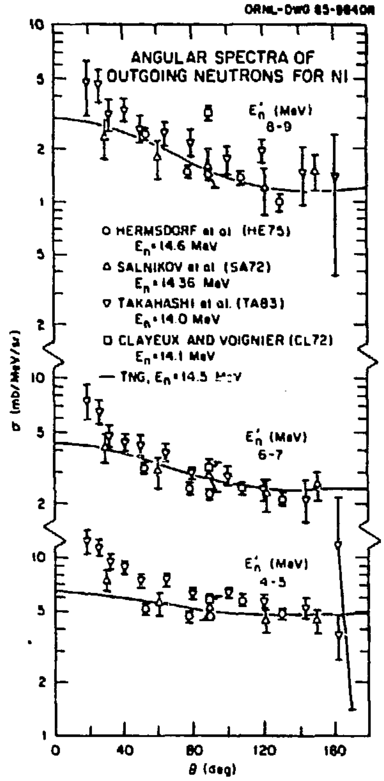

Fig. 5. Comparison of calculated and experimental neutron production cross sections.

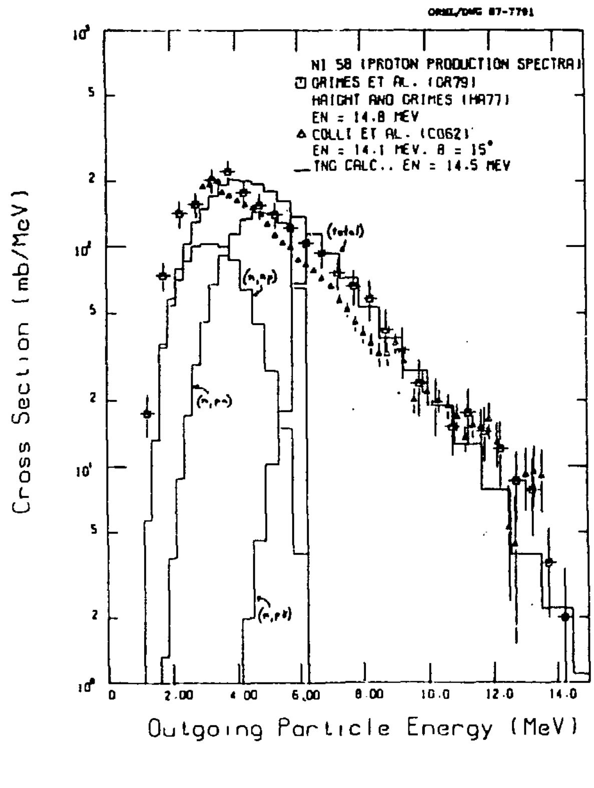

Fig. 6. Comparison of calculated experimental proton production spectra for ^{58}Ni. The measurements were taken at incident energies of 14.8 and 14.1 MeV; the TNG calculation was for E_n = 14.5 MeV. The data of Grimes et al. (GR79, HA77) are angle integrated; the data of Colli et al. (CO62) were taken at 15°.

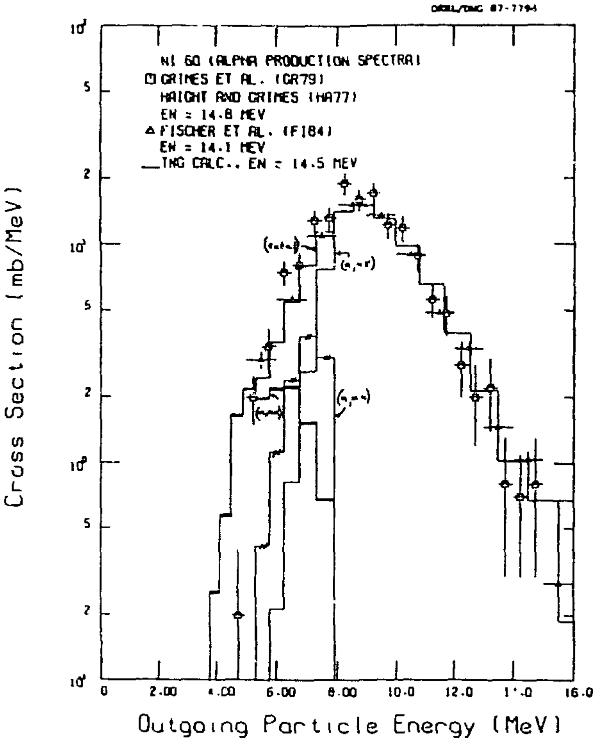

Fig. 7. Comparison of calculated and experimental alpha production spectra for ^{60}Ni. The measurements were taken at incident energies of 14.8 and 14.1 MeV and are angle integrated; the TNG calculation was for E_n = 14.5 MeV.

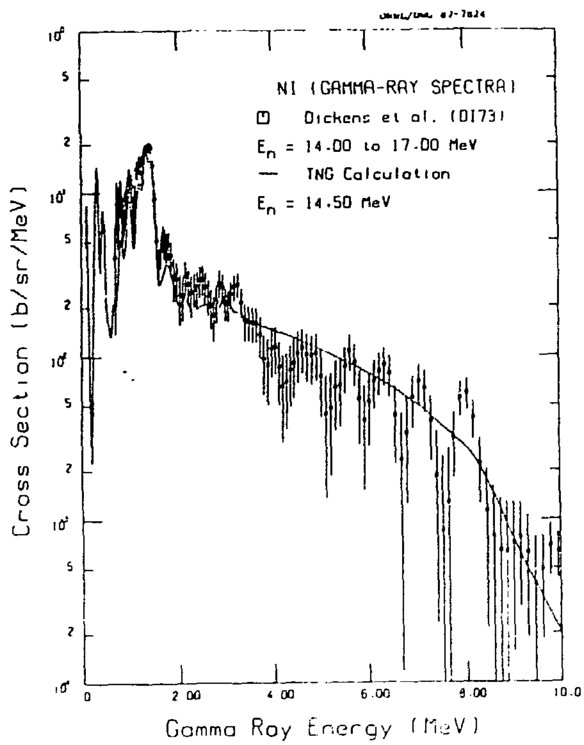

Fig. 8. Secondary gamma-ray spectra versus gamma-ray energy from the TNG calculation (incident energy E_n = 14.5 MeV) compared with the data of Dickens et al. (DI73).