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EVALUATION OF NEUTRON-INDUCED CROSS SECTIONS OF CHROMIUM, IRON AND NICKEL FOR JENDL-3

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Abstract Neutron cross sections of elemental Cr, Fe and Ni and their isotopes were evaluated for neutron energy between 0.01 meV and 20 MeV. New experimental data for resonance parameters and total and threshold reaction cross sections up to 1986 were utilized as much as possible. Theoretical calculations were performed with the combination of the preequilibrium theory, the statistical theory and the DWBA method. Level density parameters and preequilibrium strength were adjusted to fit the particle spectrum data and the excitation cross sections of threshold reactions. The results were compared favorably with recent experimental data of the double differential neutron emission spectra, the gamma-ray spectra and the gas production cross sections. The evaluation is being finalized reflecting the integral test results and a close comparison with differential data.

(neutron cross sections,Cr,Fe,Ni,element,isotopes,evaluation,JENDL-3)

Introduction

Since the completion of JENDL-2/1/ there have been much progress in the theoretical tools of cross section calculation and the experimental data on neutron nuclear data for structural materials. In the present evaluation for JENDL-3 an emphasis was put on to the applications to dosimetry, induced activity evaluation and radiation damage study as well as to the reactor and shielding calculations. Compared to the previous JENDLs /2,3/, the threshold cross sections were evaluated more extensively and the gamma-ray production cross sectioins were newly entried. The evaluated data were assembled as JENDL-3 preliminary file in ENDF/B-5 format in spring, 1987 followed by the test with integral data. Evaluation is being finalized by a close comparison with differential data and reflecting the observations from the integral tests, paricularly on the shielding and dosimetry. Present report describes the main features of the evaluated cross sections of the preliminary file.

Method of calculation and evaluation

Evaluation was made for each isotope. Cross sections for natural elements were constructed mostly from the isotopic data files except that the total cross sections above a few hundred keV were evaluated separately based on the fine resolution experimental data. The elastic scattering cross sections were determined as the total cross section minus the sum of the reaction cross sections.

Resolved resonance cross sections were calculated with the multi-level Breit-Wigner formula using the recent data of resonance parameters. Negative resonance parameters were adjusted to fit the low energy total and capture cross sections.

Theoretical calculation was performed with the combination of DWUCK/4/, GNASH/5/, PEGASUS/6/ and CASTHY/7/ codes. In all of the calculation, the spherical optical model was used. The level density parameters of Gilbert-Cameron type were determined from neutron resonance data and the low-lying level schemes. Systematics was used when necessary. Level density parameters and the preequilibrium strengths were adjusted to fit the excitation cross sections and the 14 MeV neutron-induced particle **spectrum data**.

Evaluated cross sections

Total and capure cross sections

Since the measured resonance parameters often lack the informations on p- and d-wave resonances, the background capture cross section had to be added in resolved resonance region above a few tens of keV to fit the the energy-averaged capture cross section data.

The elemental total cross section above resolved resonances was evaluated based on the data of fine-resolution measurements simulating the structures. The fine-resolution data of Cierjacks et al./8/ for Cr and Fe are consistently lower by 2-3 % than that of the lower resolution data, e.g., of Perey et al. /9/ for neutron energy above a few MeV. The absolute values of Cr and Fe cross sections are to be corrected by comparing the energy-averaged cross sections of the fine-resolution and lower resolution data. This is in the direction as suggested from the integral test on the deep penetration of neutrons in iron.

For natural Ni, recent data of Larson et al./10/ were adopted which are also larger than that of Cierjacks et al./8 / by 2 - 3 % above 5 MeV. The energy-averaged cross sections for Cr, Fe and Ni are shown in Fig. 1.

Threshold reaction cross sections

Threshold reaction cross sections were re-evaluated almost completely based on recent data of excitation cross sections and particle spectrum data. The gas production cross sections from natural elements are shown in Fig. 2 in comparison with experimental data. In Fig. 3 are shown Ni-58 (n,p) and (n,n'p) cross sections comparing with recent experimental data and ENDF/B-V.

Particle and gamma-ray emission spectra

Fig. 4 is reproduced from Takahashi et al./11/ showing the angle-integrated neutron emission spectra from natural chromium for 14.1 MeV neutrons in comparison with experimental data /11/ and ENDF/B-IV. Figure 5 shows the proton emission spectra from main isotopes of Cr, Fe and Ni induced by 14.8 MeV neutrons. Calculation with PEGASUS is compared with the data of Grimes et al./12/ Nice agreement is obtained except at low proton energy. These spectral data have been used to adjust the model parameters.

The gamma-ray production cross section from natural iron for neutron energy of about 14 MeV is shown in Fig. 6 together with the experimental data at ORNL/13/. For neutron energies above about 5 MeV, the calculated spectra for energy bins of 0.75 - 1.75 MeV were in underestimation by about a factor of 2 compared with the experimental data, resulting also in underestimation of the total photon production cross sections. In the present evaluation the calculated spectra of these bins were replaced by the experimental values. This may have violated the energy balance by about 5 % for neutron energy above 5 MeV. The gamma-ray spectra for keV neutrons were adopted from the recent experimental data by Igashira et al./14/

Concluding remarks

Although many new experimental data have become available in past ten years, further data of importance are required. These are :

(a) The capture cross sections of main isotopes above a few tens of keV are still ambiguous due to insufficient knowldge of p-wave and d-wave resonances. Recent data of Perey et al./15/ on Fe-56 and Ni-58,-60 have provided an excellent data base on this point. More data are required for other main isotopes of structural materials.

(b) MeV total cross sections of natural Cr and Fe are still discrepant.

(c) The (n,2n) data for natural Ni and its isotopes other than Ni-58 are very scanty. The data of Auchampaugh et al. on Ni were reported as withdrawn, while the data of Frehaut et al./16/ may not be adoptable because the data are too large than that theoretically expected.

(d) Themal neutron capture gamma-ray spectrum data are lacking.

As to the theoretical side, a considerable underestimation of the low energy gamma-ray emission spectra for neutron energy above several MeV has to be solved. The charged particle spectra as well as the double differential neutron spectra, except the direct inelastic scattering, are discarded in JENDL-3. Preparation of a separate file is under consideration to include these data in ENDF/B-6 format.

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REFERENCES

1. Summary of JENDL-2 General Purpose File, (T.Nakagawa,ed.), JAERI-M 84-103, June 1984
2. T.Asami: Status of JENDL-2 Evaluated Data for Structural Materials,IAEA Consultants' Meeting on Nuclear Data for Structural Materials, Nov.1983, Vienna, INDC(NDS)-152/L (1984)p.114
3. Y. Kikuchi et al.:J.Nucl.Sci.Technol 26 499 (1986). Also, Y. Kikuchi, N. Sekine : JAERI-M 85- 101 (1985)
4. P.D.Kunz, DWUCK, A Distorted Wave Born Approximation Code (unpublished)
5. P.G.Young, A.D.Arthur : GNASH, LA-6947 (1977)
6. S.Iijima et al : JAERI-M 87-025, p.337 (1987)
7. S.Igarasi : J.Nucl.Sci.Technol. 12 67 (1975)
8. P.Cierjacks et al.:KFK-1000 (1968)
9. F.G.Perey et al. : ORNL-4823 (1972)
10. D.C.Larson et al.: ORNL-TM-8203 (1983)
11. A.Takahashi et al.:Proc.1987 Seminar on Nulear Datar, Nov. 1987, JAERI-M 88-065 p.279
12. S.M. Grimes et al.: Phys. Rev. C19 2127(1979)
13. J.K.Dickens et al.: Nucl.Sci.Eng. 62 515 (1979)
14. M.Igashira : Priv. Comm. (1988)
15. F.G. Perey et al.: Proc. Specialists' Meeting on Neutron Data of Structural Materials for Fast Reactors, Geel,1977, p.476.
    C.M. Perey et al.: ORNL-5893(1982)
16. J.Frehaut et al.: EXFOR(20416001).

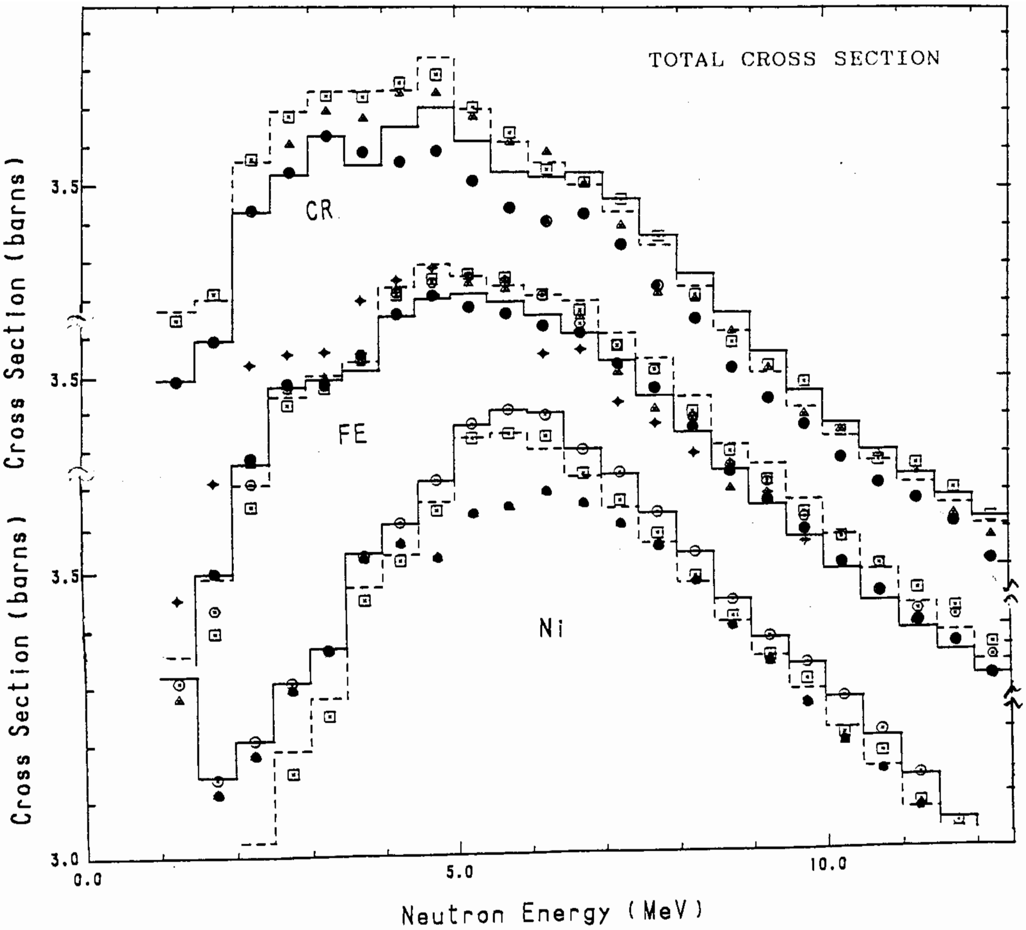

Fig.1 Energy-averaged total cross sections of chromium, iron and nickel. Comparison of evaluated and experimental data.

—— JENDL-3T, ---- ENDF/B-IV.

CR : ● 68Cierjacks+, ⊠ 73Perey+
△ 71Foster+
FE : ● 68Cierjacks+, ⊠ 72Perey+
△ 70Carlson+, ⬠ 72Schwartz+
✦ 87Baba+
NI : ● 68Cierjacks+, ⊠ 72Perey+
⊗ 86Larson+

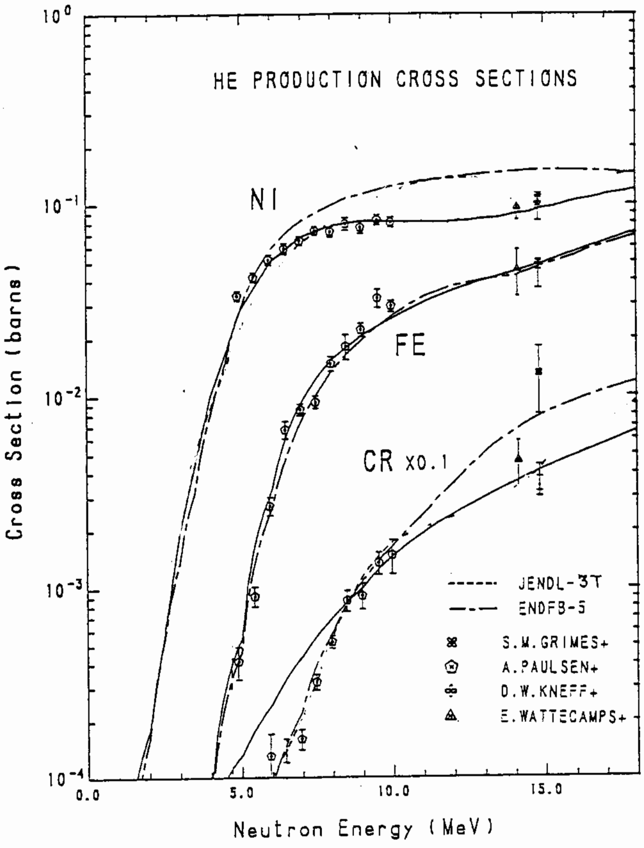

Fig. 2 Helium production cross sections

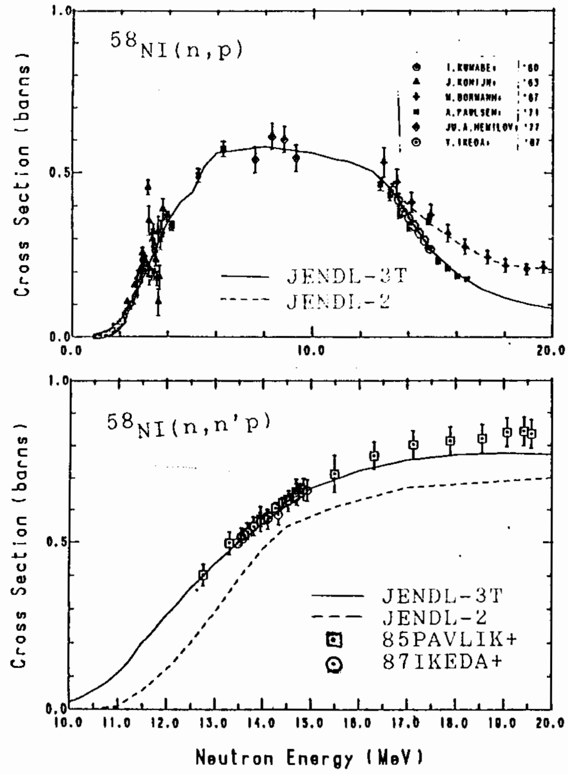

Fig. 3 ^{58}Ni(n,p) and (n,n'p) cross sections.

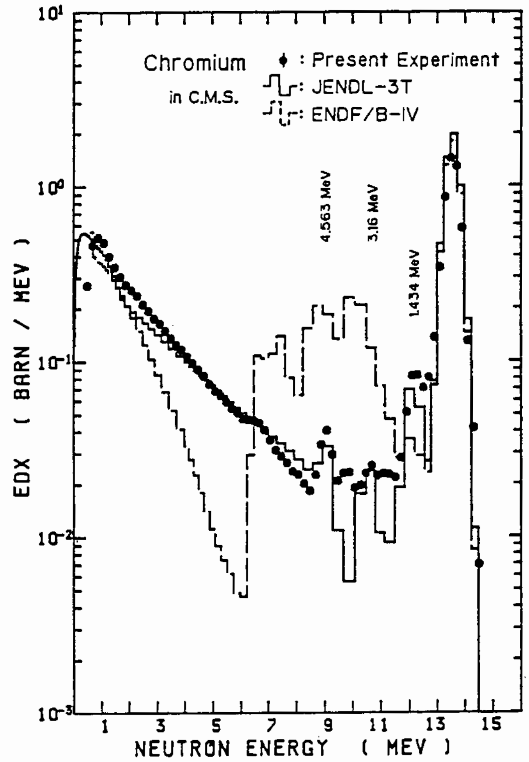

Fig. 4 Neutron emission spectrum from chromium induced by 14.1 MeV neutrons.(Reproduced from /11/)

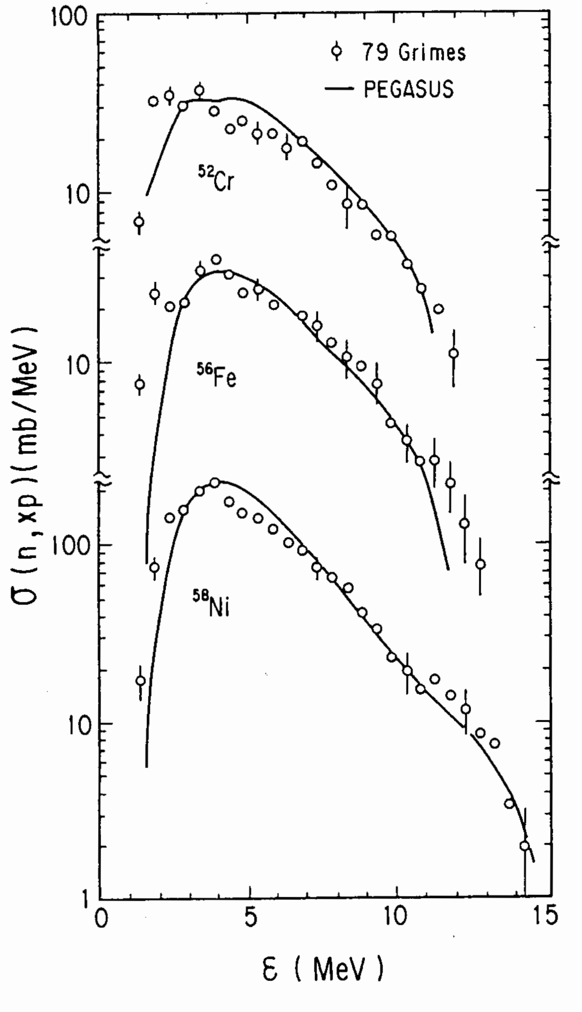

Fig. 5 Proton emission spectra induced by 14.8 MeV neutrons.

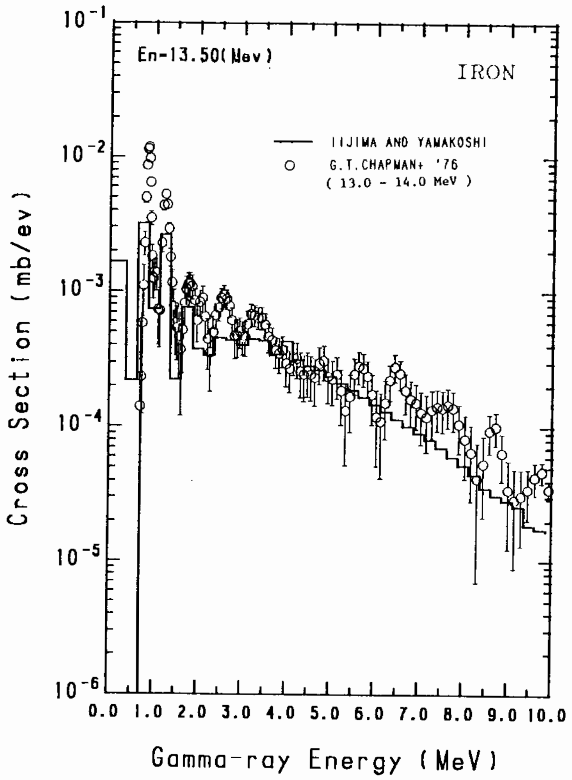

Fig. 6 Gamma-ray emission spectra from Fe induced by 13-14 MeV neutrons.