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NEUTRON INELASTIC SCATTERING CROSS SECTIONS FOR Ni AND Cr DETERMINED FROM THE (n,n'γ) REACTION

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Abstract: Absolute 125-deg differential gamma-ray production cross sections have been measured for about 400 gamma rays produced in natural nickel and chromium by the (n,n'γ) reaction in the incident neutron energy range from 4.1 to 5.6 MeV. Gamma-ray yields were measured by a 80 cm^3 high purity Ge detector housed in a lead shield surrounded by lithium carbonate and boric acid. The pulsed beam time-of-flight (TOF)techniques was used for background reduction. Angle-integrated gamma-ray production cross sections were inferred from the differential measurements using gamma-ray angular distributions obtained from compound nucleus statistical model calculations. On the basis of the angle-integrated cross sections and measured branching ratios, neutron inelastic scattering cross sections were deduced for 28 and 40 energy levels in natural nickel and chromium, respectively. These results are compared with the evaluated nuclear data files, JENDL-3 for Cr and ENDF/B-IV for Ni. The present measurements indicate that for inelastic scattering to the second excited state (4+)in Cr-52 and Ni-58, the cross sections are significantly overestimated in the evaluated nuclear data files.

(Nuclear reaction Ni(n,n'γ) and Cr(n,n'γ), σ(n,n'γ), deduced levels, high purity Ge detector, natural targets.)

Introduction

Neutron inelastic scattering from individual levels in the region En ≤ 4 MeV has been studied by a number of investigators using either fast-neutron spectrometers or the (n,n'γ)technique/1/. At higher neutron energies than 4 MeV, the cross sections of (n,n'γ) reaction are not well known. Taking the advantage of high-resolution germanium detector, neutron inelastic scattering cross sections for individual states can be determined from the measurement of absolute gamma-ray cross sections for neutron scattering.
Having used natural nickel and chromium samples, we therefore report here inelastic neutron excitation functions inferred from our (n,n'γ) gamma-ray production measurements at incident energy from 4.1 to 5.6 MeV.

Experimental procedure and analysis

The experiments were carried out at Tohoku University Fast Neutron Laboratory using a 4.5 MV Dynamitron accelerator. In the present experiment, excitation functions were measured at 125 degree in energy increments approximately equal to less than the energy spread of the incident neutron beam. The 2 MHz pulsed beam impinged on a deuterium gas target cell to produce neutrons via the D(d,n)He-3 reaction.
A 2"x2" NE-213 liquid scintillator measured the neutron fluence during the acquisition of a gamma-ray spectrum. This detector was placed at an angle of 30 degree relative to the incident neutron beam. Gamma-ray yields were measured by a 80 cm^3 high purity Ge detector(HP-Ge) housed in a lead shield surrounded by lithium carbonate and water-boric acid to reduce background. The distance from the center of the scattering sample to the HP-Ge detector was 155 cm. Both detectors were used with standard TOF electronics to reduce the neutron and gamma-ray back-ground.

The cylindrical samples were a 4.0 cm high x 3.0 cm diameter and a 3.5 cm high x 2.0 cm diam. of high purity of 99.9 % for natural nickel and chromium, respectively and positioned 10 cm from the deutrium gas cell. All measured scatterng cross sections were corrected for the attenuation and mutiple scattering of the incident neutrons, the gamma-ray attenuation, the nonparallel nature of neutron flux, and the angle variation of D(d,n)He yield over the solid angle subtended by the sample using the CASSE code /2/. The particular apparatuses and details of the methods are described elsewhere/3,4/.

Results and discussion

The uncertainties assigned to the measurements were estimated by taking accout of them in the extraction of photo-peak areas from the HP-Ge energy spectrum,the detector system efficiencies, the indcident neutron flux measurement, the multiple scattering and attenuation corrections, the conversion of 125-deg differential cross sections into angle integrated cross sections, and in deducing neutron inelastic cross sections. For strong transitions, this statistical contribution was small relative to other uncertainties(0.3 %). The other hand, for weaker transitions, the overall uncertainty was dominated by the statistical component(10 -30 %). The neutron attenuation and multiple scattering corrections were estimated from the measurements made for holow and solid iron scatteres, using the CASSE code/2/. Uncer-

tainties in the neutron flux were estimated to be < 6 % for most neutron energies.
In the case of some (n,n'γ)cross sections for excitation of individual levels, additional errors were involved when subtraction was necessary for cascading from higher levels. The uncertainty was estimated by taking all the above effects into account adding effects due to feeding transitions, assumed gamma-ray decays, and branching ratio uncertainties. The principal sources of experimental error in the measurements are listed in table 1. The overall systematic error was ~ 8 %.

Table 1. Principal sources of experimental error

Source of error	Error (%)
Absolute neutron flux (for most neutron energies)	≤ 6
Neutron source characteristics	≤ 3
Neutron multiple scattering and attenuation in the sample	≤ 3
Gamma-ray detector efficiency	3
Geometric effects	1
Integration procedure	≤ 2
Total root-mean-square erro	8

The 125-deg differential gamma-ray production cross sections were measured for natural nickel and chromium by the (n,n'γ) reaction.

Some typical results are shown in figures. 1 through 5 . A time-gated gamma-ray spectrum from (n,n'γ) reactions on the elemental nickel at En = 6.4 MeV is shown in figure 1. Lines are labeled by their energy in KeV for each peak. Level energies are taken from the Nuclear Data Sheets/6,7/. The present neutron inelastic scattering cross sections for individual level in Ni-58 are shown in figure 2 with the results (open circles) obtained in the region from threshold to 4 MeV by S. Traiforos et al./7/ and ENDF/B-IV (solid curves). Those for Cr-52 are shown in figs. 3 and 4 with the results (open circles) for En < 4 MeV by Karazas et al./1 / and the JENDL-3PR evaluation (solid curves).

Nickel-58

In figure 2 results obtained for the first excited state(1454-KeV 2+) in Ni-58 are good agreement with ENDF/B-IV, but other results for the higher excited states (2459-KeV 4+ and 2775-KeV 2+) are considerably smaller than the evaluation value. In the region En = 2.2 to 5.4 MeV, ENDF/B-IV total inelastic cross sections are larger than any of experimental measurements.

Chromium-52

Results for the 1434-KeV [2+] in shown in fig. 3 are excellent in agreement with JENDL-3PR but somewhat lower at En = 5.1 MeV. Our results for the 2370-KeV [4+] state are ,however, considerably smaller than JENDL-3PR, which is consistent with the previous measurements/1/ for En < 4 MeV. Cross sections for the 2647-KeV [0+] state are inconsistent with JENDL-3PR. Our cross sections determined for the 2768-KeV [4+] and 2965-KeV [2+] levels shown in figure 4 have a same tedency. The shape of excitation function in the present results connects smoothly to the values measured in the incident neutron energy range from 0.84 to 3.97 MeV by Karatzas et al. using the (n,n'γ) technique. These level cross sections are higher than JENDL-3PR in the region above En = 3.4 MeV. The present measurements for the 3162-KeV [2+] level were found to be considerably higher and ,near En = 4.4 MeV, about two times larger than JENDL-3PR values.
In JENDL-3PR, the total inelastic neutron scattering cross sections are evaluated by summing the "discrete component" of the inelastic scattering to the discrete levels below 3.2 MeV and the "continuum component" which is lumped contributions from levels above 3.26-MeV excitation energy together. Figure 5 shows the "discrete component"of the total inelastic scattering cross sections of Cr-52, which was obtained by summing the cross sections for individual levels below 3.16 MeV. The present results and those of P.T. Karatzas et al. are slight high relative to JENDL-3PR values (solid line) in the region from 3.8 to 4.8 MeV. The most pronounced discrepancy occured at En = 4.4 MeV, which are 13 % larger than the evaluated value. Thus ,as can be seen in figures 3 and 4, there are significant discrepancies between the measurements and JENDL-3PR for individual levels of chromium-52,but it was found that the cross sections summed up to 3.16 MeV were consistent with those of JENDL-3PR.

SUMMARY

Gamma-ray transitions were measured from (n, n'γ) reactions on the five nickel and four chromium isotopes. Absolute gamma-ray production excitation functions at 125 degree were extracted for these transitions in the incident neutron energy region En = 4.1 to 5.6 MeV. Neutron inelastic cross sections for 28 and 40 levels in the nickel and chromium isotopes, respectively were inferred from these results and compared to the evaluated nuclear data files.

Some typical results are shown in figures 2 through 4. Cross section agreement for the first excited[2+] states in these samples is very good, but excitation functions associated with many of the higher excited states are in striking disagreement with the files. The present results for the 3162-KeV [2+] state of chromium-52 offer salient examples of this discrepancy. However, it is of great interest that the discrete component of the total inelastic scattering cross sections summed up to 3.16 MeV are consistent with those of JENDL-3PR.

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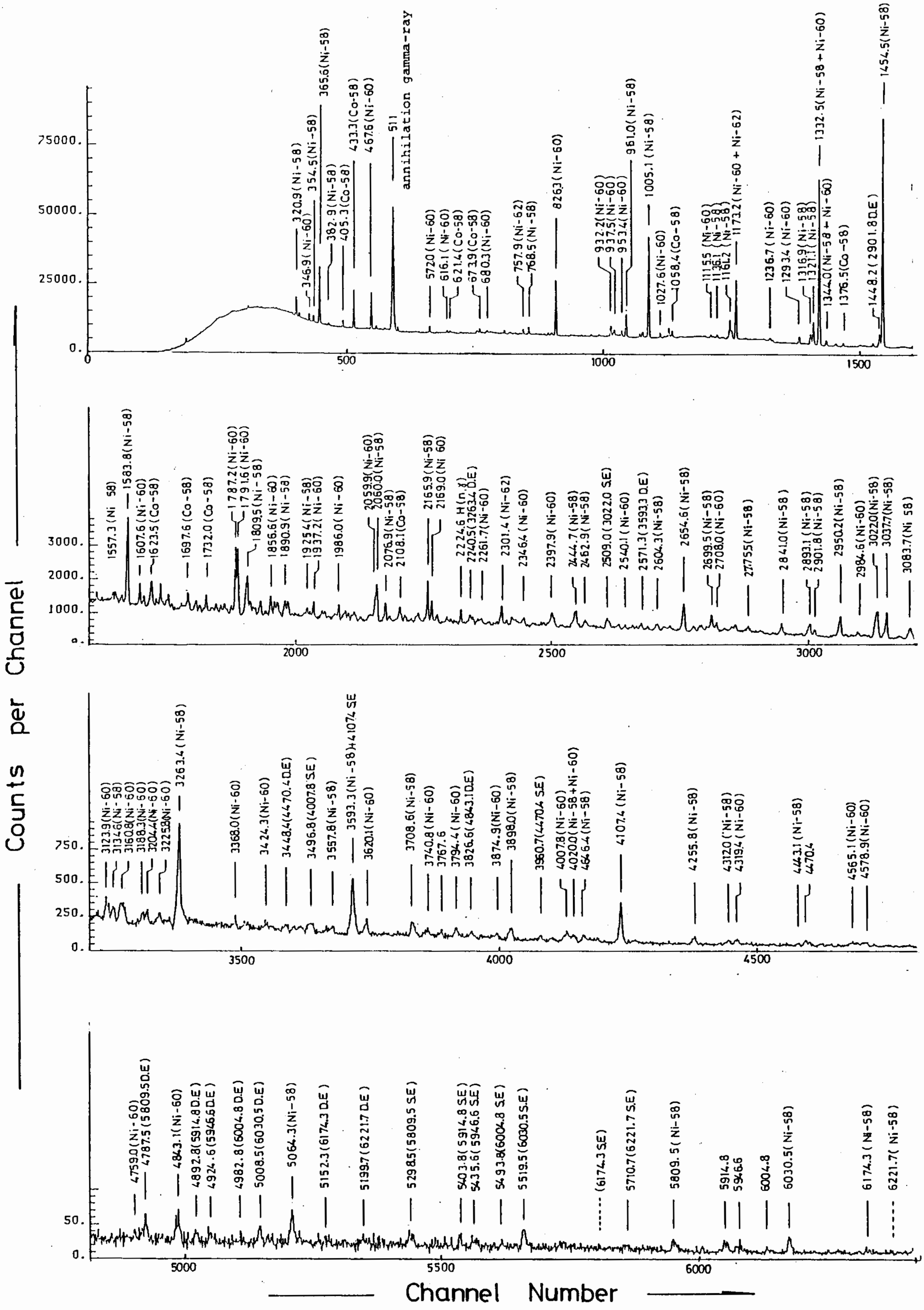

Fig. 1 Time-gated gamma-ray spectrum obtained from inelastic scattering from a nickel for En = 6.4 MeV at 125 degree.

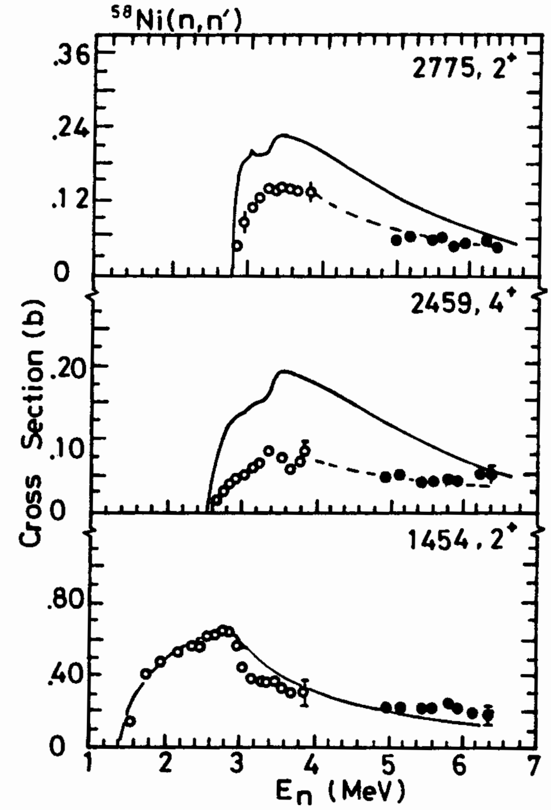

Fig. 2 Natural nickel cross sections of levels in Nickel-58. The solid lines are ENDF/B-IV cross sections, o, S.Traiforos et al. The dashed curves are eye guide .

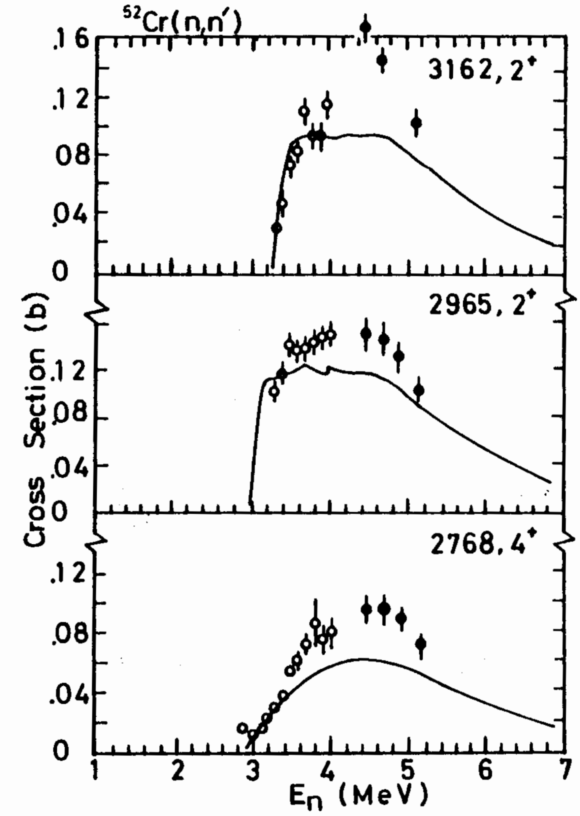

Fig. 4 Natural chromium cross sections of levels in Cr-52 (for higher excited levels).

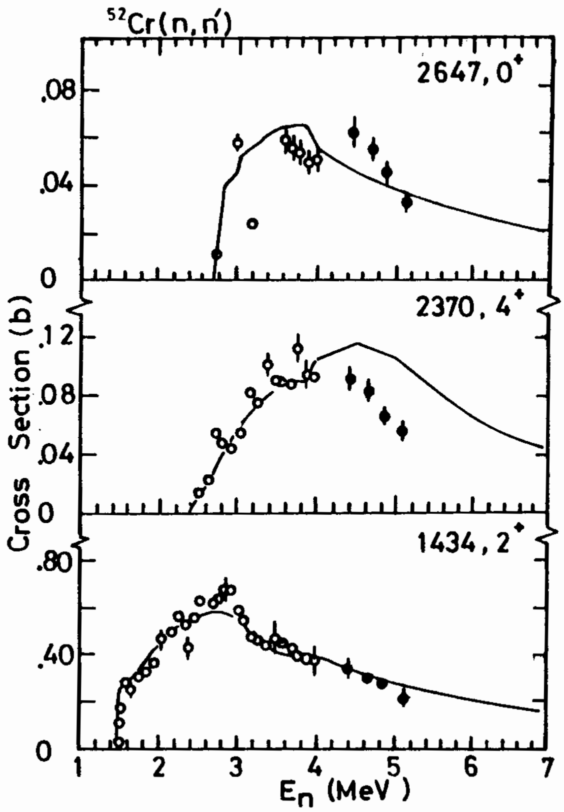

Fig. 3 Natural chromoum cross sections of levels in Cr-52. The solid curves are JENDL-3PR cross sections, o, P.T. Karatzas et al.

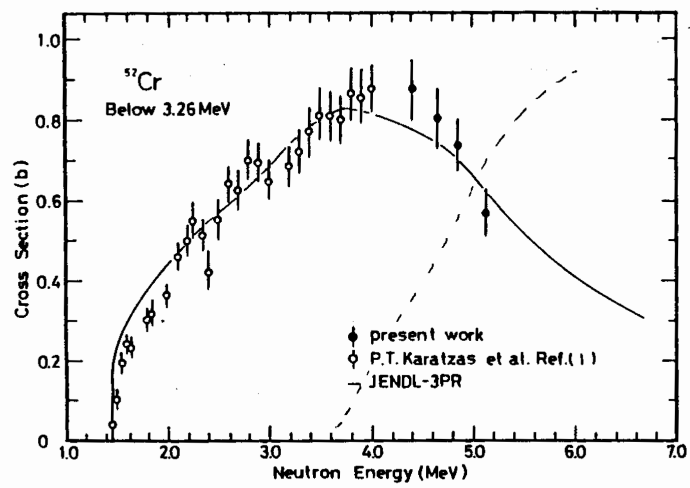

Fig. 5 The cross sections summed up to 3.16 MeV in Cr-52, together with total neutron inelastic cross sections by Karatzas et al.(open circle) and JENDL-3PR ("discrete" part: solid line, "continuum" part: dashed line).