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MEASUREMENT OF $^{238}U(n,n'\gamma)^{238}U^*$ CROSS SECTIONS

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Production cross sections for gamma-ray transitions produced by 0.5 to 5.0-MeV neutrons on ^{238}U have been measured employing a 95-cm^3 Ge(Li) detector (at 125°), the ORELA neutron source, and a recoil proton telescope. From these data and other decay scheme information, inelastic scattering cross sections for levels from 680 to 1224 keV of excitation have been constructed and compared with statistical model calculations and the ENDF/B-V evaluation.

[Measured $^{238}U(n,n'\gamma)$, E_n = 0.5 to 5.0 MeV, deduced $^{238}U(n,n')^{238}U^*(E_x)$ for E_x = 0.680 to 1.224 MeV.]

Introduction

Accurate knowledge of neutron inelastic scattering cross sections, CS, on ^{238}U are important for fast reactor design. Although these CS do not determine neutron balance directly, they influence fast-critical and reactor parameters through the energy transfer mechanism they provide for the neutron flux. Previous measurements of these CS have been reviewed for the ENDF/B-V evaluation.[1] Accurate data is scarce for the threshold shapes of these CS which are sensitive to the model calculations employed and for the CS to the excited rotational bands which provide most of the energy transfer for MeV neutrons. To overcome the resolution and background problems associated with Van de Graaff measurements for the excited bands, we have measured the deexcitation gamma-rays production CS for inelastic levels from 0.680 to 1.224 MeV of excitation employing 0.5 to 5.0-MeV neutrons from the ORELA "white" source. From these CS and other decay scheme information inelastic scattering CS are deduced. In addition to providing needed information for ^{238}U inelastic scattering, these CS provide a stringent test for statistical model-calculated[2] inelastic scattering from highly deformed actinide nuclei.

Experimental Procedure

Eight hundred 35-nsec FWHM neutron pps were produced from the ORELA Ta target with 35 kW of time-averaged electron power. After being filtered through 0.93 g/cm^2 of ^{10}B to inhibit time overlap and 14.0 cm of Th to attenuate gamma flash, the flux was collimated into a ∿ 7-cm diam beam which traversed a proton-recoil radiator foil and ^{238}U scattering sample. The experimental arrangement is outlined in Fig. 1. The 0.00376-atom/barn ^{238}U sample consisted of a 11.11-cm diam, 0.76-mm thick, 99.92% isotopically enriched disk which was mounted in a vertical plane at a 50° grazing angle to the beam direction with its center 22.181 m from the ORELA target.

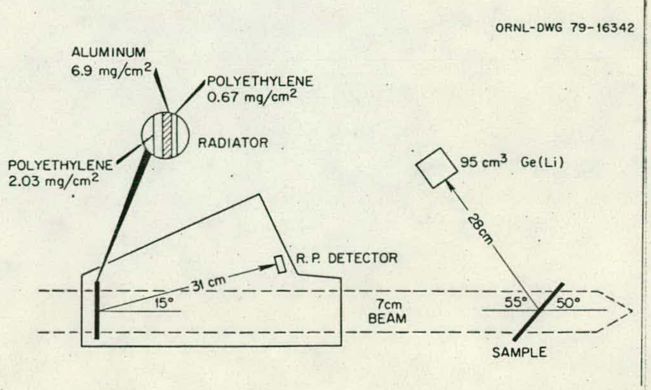

Fig. 1. Experimental arrangement. The radiator and sample centers were positioned 21.430 and 22.181 m from the ORELA target, respectively.

Photons were counted with a 95-cm^3 Ge(Li) detector with its front face 28 cm from the sample center and face-shielded with 1.8 mm of lead. This detector was mounted so that its axis was at 125° and 15° to the beam direction and sample-disk normal, respectively. The flux detector and its operation is described in detail in Ref. 3. It consisted of a radiator at 21.430 m which was composed of 2.0 and 0.67 mg/cm^2 polyethylene foils with a 6.9 mg/cm^2 Al absorber sandwiched between. Recoil protons were counted with 0.30-mm solid-state detector mounted behind an 1.27 cm^2 aperture located 30.6 cm from the radiator center.

Fast timing pulses were obtained from the Ge(Li) detector with an ORTEC 473A constant fraction discriminator operated with slow rise-time reject and from the proton-recoil detector with an ORNL Q3066B crossover timing discriminator. From these fast pulses neutron flight times for both detectors were measured with an EG&G TDC100 time digitizer operated in the single stop mode. Simultaneous slow pulses produced 2048- and 256-channel pulse-height spectra, respectively, for each of 160 timing bins. The efficiency with respect to 4π steradians of the Pb-shielded Ge(Li) detector was measured *in situ* with standard sources to ± 3%. The TOF scale, and hence energy scale since the path length is known to within a few mm, is believed accurate to ± 5 nsec and has been verified by observing the ^{12}C 2.078-MeV transmission dip.[4]

Data Reduction

The counting rate and line shape from the Ge(Li) detector were monitored with 662-keV gamma radiation from a ^{137}Cs source near the sample. After the clock deadtime correction, events from this source showed no counting losses at long flight times; however, at the short flight times of interest peak tailing and a consistent 10% counting loss from pileup and electronic deadtimes were measured.

For spectra from 36-nsec wide incident neutron bins, the number of photon events at 125° for various ^{238}U lines were determined, clock deadtime corrected, normalized to 4π steradians through the efficiency calibration, and corrected for the measured 10% electronic deadtime and pileup loss. Using known[5] n-p CS, analysis of the two-dimensional proton recoil data provided a flux measurement with an estimated systematic uncertainty of less than 5%. Events from an ^{241}Am alpha source mounted in the proton-recoil detector provided a pulse-height energy calibration for the Si diode and assured that after the clock deadtime correction there were no counting losses.

The resultant gamma-ray production CS were corrected for neutron multiple scattering, neutron flux and gamma-ray attenuation, and the small solid

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angle variations from the finite sample size using Monte Carlo procedures. More experimental details, listings and plots of the CS, and a discussion of errors can be found in Ref. 6. In particular, the overall normalization error is believed to be less than 6% which has been somewhat verified by an accompanying measurement[7] of 478-keV gamma-ray production from neutrons on ^{7}Li. Altogether 28 gamma-ray production CS and 7 branching ratios from weak transitions were measured. In the discussion below it is assumed that the Legendre expansion of the gamma-ray angular distributions contain only zero and second order terms.

Discussion and Conclusions

From these data and other decay scheme information[7] inelastic scattering CS were calculated using the decay scheme shown in Fig. 2 which is mainly from the work of Ref. 8. With this decay scheme population CS were first calculated for each level from 680 to 1224 keV of excitation accounting for all known decays out of each level; low-energy gamma rays, E0 transitions and internal conversion. From these population CS, inelastic scattering CS were calculated by subtracting all known decays into each level from higher-energy excited states. The branching ratios employed are listed in Ref. 6.

Figure 3 compares resulting CS to the $K^{\pi} = 0^{-}$ octupole band with the ENDF/B-V evaluation and the statistical model calculations of Jary et al.[2] The data points with and without error bars are population and inelastic scattering CS, respectively. These levels have appreciable feeding from higher-energy excited states. The smooth curves from threshold to 2.0 MeV which reproduce both the shape and magnitude of the inelastic CS are the statistical-model calculated results of Jary et al.[2] The smooth curves from threshold to 5.0 MeV which overpredict the inelastic CS maxima are from the ENDF/B-V evaluation.

Other examples of the data are given in Fig. 4 which shows inelastic scattering CS to the (1^{-}), (2^{-}), and 3^{-} members of the proposed $K^{\pi} = 1^{-}$ band and to the (0^{+}), 2^{+}, and (4^{+}) members of the proposed first excited $K^{\pi} = 0^{+}$ band. The error bars are statistical only and do not include decay-scheme uncertainties. Reference 1 does not provide an evaluated CS for each level above 827.1 keV of excitation, but clusters them into level groups for which there is an evaluated CS. Figure 5 compares the ENDF/B-V CS for the 965 and 1048-keV level groups with the measured CS summed over the corresponding levels. The CS maxima agree within 10%, but the threshold shapes are discrepant.

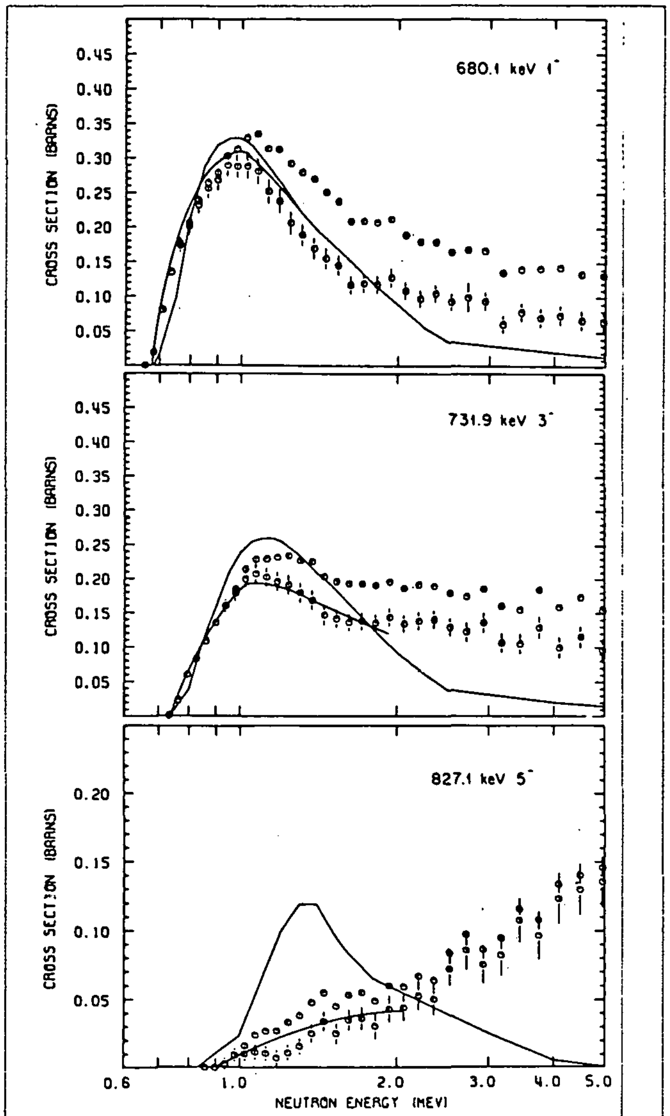

Fig. 3. Inelastic scattering CS to the K = 0 octupole band. Data points with and without error bars are population and inelastic scattering CS, respectively, which differ by the feeding from higher energy excited states. The calculated curves to 2.0 MeV which reproduce both the shape and magnitude of the inelastic scattering CS are from Ref. 2. The curves to 5.0 MeV which overpredict the CS maxima are the ENDF/B-V evaluation.

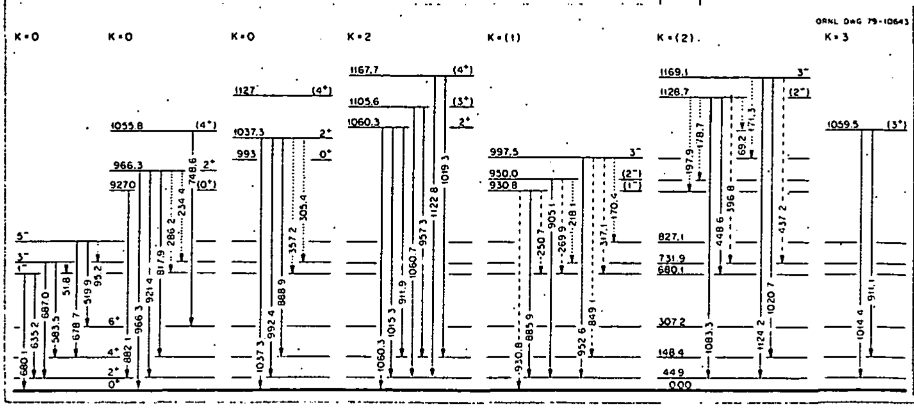

Fig. 2. Proposed ^{238}U rotational band structure of Ref. 8. The solid lines represent transitions whose gamma-ray production CS have been measured in the present work. The dashed and dotted lines represent transitions whose branching ratios have been measured in this work and by other workers, respectively. In addition, CS to levels at 1199.8, 1208.3, and 1223.9 keV of excitation were also measured.

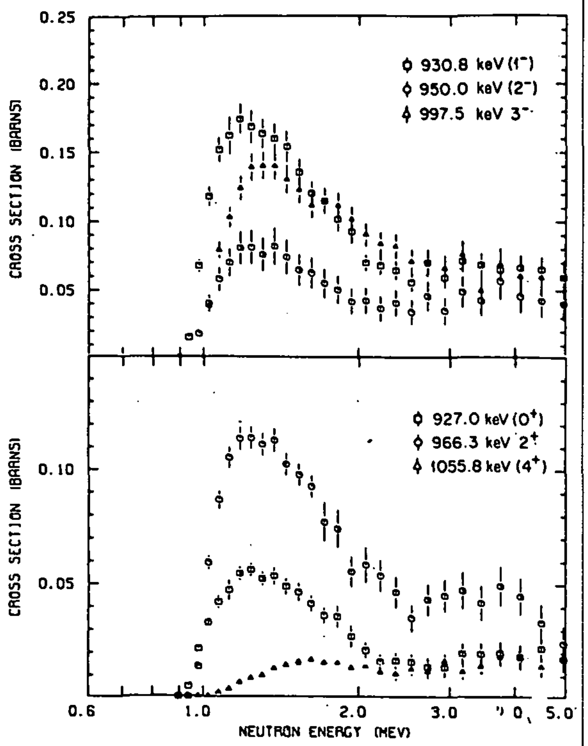

Fig. 4. Inelastic scattering cross sections to the (1^-), (2^-), and 3^- members of the proposed $K^\pi = 1^-$ band and the (0^+), 2^+, and (4^+) members of the proposed first-excited $K^\pi = 0^+$ band.

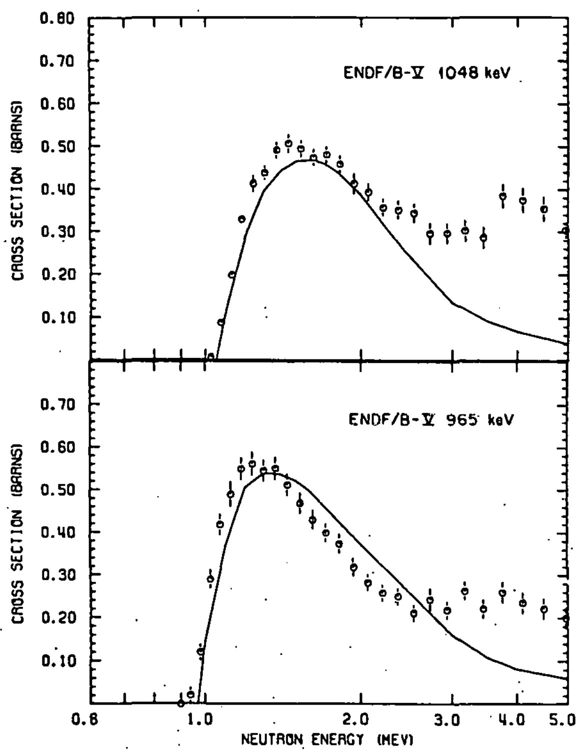

Fig. 5. Comparison between the ENDF/B-V evaluated level-group CS and the corresponding summed measured CS. The 965-keV level group consists of the 927.0, 930.8, 950.0, 966.3, 993, and 997.5 keV levels and the 1048 keV level group consists of the 1037.3, 1055.8, 1059.5, and 1060.3 keV levels.

The deduced inelastic scattering CS are sensitive to imprecisely known decay scheme information whose uncertainties are not contained in the plotted errors. In particular, possible unmeasured E0 transitions, unknown E2-M1 mixing ratios, and discrepant[7] gamma-ray branching ratios all cause confusion. Nevertheless, these results provide the most accurate CS threshold shape determination for these levels and probably the most accurate measurement of the scattering CS to the various individual levels for neutron energies below ∿ 1.5 MeV.

Acknowledgement

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