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High Energy Resolution Measurement of the ^{238}U Neutron Capture Yield in the Energy Region Between 1 and 100 keV*

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Abstract: A measurement of the ^{238}U neutron capture yield was performed at the 150 meter flight-path of the ORELA facility on two ^{238}U samples (0.0124 and 0.0031 atoms/barn). The capture yield data were normalized by Moxon's small resonance method.

The energy resolution achieved in this measurement frequently resulted in doublet and triplet splittings of what appeared to be single resonances in previous measurements. This resolution should allow extension of the resolved resonance energy region in ^{238}U from the present 4-keV limit up to 15 or 20 keV incident neutron energy.

Some 200 small resonances of the (^{238}U + n) compound nucleus have been observed which had not been detected in transmission measurements, in the energy range from 250 eV to 10 keV.

(^{238}U, Neutron Capture Yield 1 keV $< E <$ 100 keV)

Introduction

Persistent inconsistencies in the ^{238}U capture cross section, which were discussed at the Antwerp Conference on Nuclear Data for Science and Technology in September 1982, led to the formation of the ^{238}U Task Force for the Nuclear Energy Agency Nuclear Data Committee (NEANDC).

The ^{238}U Task Force[1] was set up to deal with two problems: (1) disagreement among the neutron widths of the resolved resonances above 1.4 keV (derived from transmission measurements at several laboratories) and (2) the ^{238}U capture cross section in the resolved and unresolved resonance regions. Among the most relevant conclusions arrived at by the NEANDC Task Force were that most of the capture cross-section measurements in the lower energy range (~1 to 30 keV) were old and that they disagreed among themselves by more than expected from their respective error assignments.[2] To cope with these long-standing discrepancies, the ^{238}U Task Force[1] issued the following recommendations:

1. Reanalysis of the old ^{238}U capture data would be impossible, hence new measurements are required.
2. A high-resolution capture cross-section measurement (~150 m flight-path length) is urgently needed.
3. Extension of the evaluated resolved resonance energy range to higher energies. This would allow a consistent analysis of high-resolution transmission and capture data in the energy region between 1 and ~10 keV.

In response to these requests, a measurement of the ^{238}U capture yield was performed at the 150-meter flight-path station of the Oak Ridge Electron Linear Accelerator (ORELA) facility.[3] The present experiment has utilized ORELA as a pulsed neutron source which, combined with the long (150-m) flight path, allows achievement of adequate energy resolution up to at least 20 keV. To obtain good statistical accuracy with low backgrounds, the large liquid scintillator tank (ORELAST) with an internal septum was used as a detector for capture gamma rays from the $^{238}\mathrm{U}(n,\gamma)^{239}\mathrm{U}$ reaction.

Description of the Experiment

The Oak Ridge Electron Linear Accelerator (ORELA)[3] was used to generate a pulsed beam of neutrons which was collimated on a metallic sample of ^{238}U. Neutron pulse widths ranged between 6 and 20 nanoseconds. The shape of the incident neutron energy spectrum was measured with a ^{6}Li glass scintillator[4] which was positioned upstream of the ORELAST[5] liquid scintillator gamma-ray detector surrounding the ^{238}U sample. The neutron capture rate in the sample was measured, as a function of neutron time-of-flight, by detecting the gamma rays from the $^{238}\mathrm{U}(n,\gamma)^{239}\mathrm{U}$ reaction. At each energy, the capture yield is proportional to the observed capture rate divided by the measured intensity of the neutron beam. The cross section for the reaction $^{238}\mathrm{U}(n,\gamma)^{239}\mathrm{U}$ can be derived from the capture yield if one applies appropriate corrections for neutron multiple scattering and resonance self-shielding in the sample. The electronics and data acquisition systems are described in detail elsewhere.[6] Measurements were performed on two ^{238}U high purity disk samples (0.0124 and 0.0031 atoms/barn).

Analysis of the Data

The capture yield is defined as a function of the neutron energy, E, by the relation

$$E^{1/2}Y_c(E) = a_n \left[\frac{C(E)}{S(E)}\right] R(E)(b \cdot eV^{1/2}) \qquad (1)$$

where

a_n = normalization constant,
$C(E)$ = background corrected count rate from the ORELAST detector,
$S(E)$ = background corrected count rate from the lithium glass neutron flux monitor,

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$R(E)$ = a factor which accounts for the deviation of the ^{6}Li$(n,\alpha)T$ cross section from $1/\nu$ behavior and corrects for neutron absorption in the glass.

Five measurements of the neutron TOF spectrum were performed for each of the two ^{238}U samples. Measurements were done with and without aluminum filters in the neutron beam, at LINAC repetition rates of 800 and 400 pulses per second, to determine the energy-dependent background which arises from room return and neutron-pulse overlap. The fifth measurement was performed using a polyethylene filter in the beam to determine the energy independent ("constant") component of the background. A ^{10}B filter (9.3 kg/m^2) was used in all runs to reduce low-energy (<250 eV) neutrons from the "tail" of the previous pulse (pulse "overlap").

The shape of the neutron beam energy spectrum, $C(E)$, was obtained from the TOF spectrum of the neutrons detected by the ^{6}Li glass flux monitor (7.7 wt% content of 95% enriched ^{6}Li as the active ingredient).

The correction factor, $R(E)$, for the departure from the 1/v behavior can be written as

$$R(E) = \frac{1}{N\sigma_T}\left[\frac{1-T}{T}\right]F(E) \qquad (2)$$

where, N, is the glass thickness (atoms/barn), σ_T the effective total neutron cross section of the glass and

$$T = \exp\{-N\sigma_T\} \qquad (3)$$

The factor, $F(E)$, is the ratio of the ENDF/B-VI ^{6}Li$(n,\alpha)T$ proposed standard cross section[7] to the 1/v cross section.

The normalization constant, a_n, in Eq. (1) is defined at the zero sample thickness limit, where the neutron capture yield is equal to the neutron capture cross section.

To determine this constant, a technique proposed by Moxon[8] was utilized. This technique is based on the idea that for small resonances (*i.e.*, with $g\Gamma_n$ small), the energy dependence of self-shielding and multiple scattering effects may be neglected.[6] Then the normalization constant is obtained as the ratio of calculated A_{TH} to measured A_{EXP} areas under the resonance. The resonance parameters of Olsen *et al.*[9] were used for the calculation of the theoretical area A_{TH}.

A 6% uncertainty was assigned to the normalization constant, a_n, arising mostly from the statistical uncertainties associated with the neutron widths of the small resonances.[9] Hence, the normalization of the present data must be taken as preliminary, pending a simultaneous resonance analysis of transmission data and the present capture yield data.

The systematic uncertainties arising from the background subtraction procedure were estimated to be 5% of the average capture yield up to 10 keV and 4% from 10 keV up to 100 keV.

Results

Capture data for the two ^{238}U samples used in the present measurements are shown in Fig. 1 for neutron energies in the well resolved resonance region. These results clearly show substantial sample thickness effects in the large resonances. The good energy resolution achieved is illustrated in Fig. 2, which shows the capture yield data for the 0.0124 atoms/barn sample around 23.5 keV. The energy resolution of these data will allow the possibility of extending the evaluated resolved resonance energy region for ^{238}U, beyond the present 4 keV limit. Above 20 keV the present data exhibit a substantial amount of intermediate structure[10] in the capture yield. Figure 3 shows the ^{238}U neutron capture cross section between 10 keV and 100 keV as prescribed by the ENDF/B-V evaluation,[11] with the capture yield data for the 0.00309 atoms/barn sample superimposed. It appears that the ENDF/B-V evaluation does not provide the needed amount of intermediate structure which was observed in the measurement.

Summary

The present work will allow the extension of the resolved resonance region in ^{238}U from its current limit of 4 keV up to 20 keV, since the large resonances which contribute most to the self-shielding effect are well represented in the data. In addition, some 200 ^{238}U neutron resonances in the energy range from 250 eV to 10 keV have been observed which had not been detected in previous measurements. These results are relevant for both reactor design and for the understanding of the structure of the $(^{238}U + n)$ compound nucleus.

REFERENCES

1. M. Sowerby, "Summary of the Work of the NEANDC Task Force on U-238," *Int. Conf. on Nuclear Data for Basic and Applied Science*, May 13-17, 1985, Santa Fe, NM.
2. G. de Saussure and A. B. Smith, *Nuclear Data for Science and Technology*, EUR 8355 (1983), p. 9.
3. J. W. Dabbs, "Neutron Cross Section Measurements at ORELA," *Proceedings of the International Conference on Nuclear Cross Sections for Technology*, NBS Special Publication, **594** (1980).
4. R. L. Macklin, *Nucl. Instr. and Methods*, **91**, 79 (1971).
5. E. G. Silver, J. H. Todd, and J. Lewin, *Neutron Physics Division Annual Progress Report for Period Ending May 31, 1969*, ORNL-4433, p. 11 (1969); E. G. Silver, J. Lewin, and J. Todd, *Neutron Physics Division Annual Progress Report for Period Ending May 31, 1968*, ORNL-4280, p. 135 (1968).
6. Roger L. Macklin, R. B. Perez, G. de Saussure, and R. W. Ingle, *High Energy Resolution Measurement of the ^{238}U Neutron Capture Yield from 1 keV to 100 keV*, ORNL/TM-10666, January 1988.
7. R. W. Peelle, ORNL, private communication.
8. M. Moxon, Harwell (U.K.), private communication (1985).
9. D. K. Olsen and P. S. Meszaros, *Nucl. Sci. Eng.*, **83**, 174 (1983).
10. R. B. Perez, G. de Saussure, R. L. Macklin, and J. Halperin, *Phys. Rev.* **20(2)**, 528 (1979).
11. W. P. Poenitz, P. T. Guenther, A. B. Smith, *Proceedings of the NEANDC/NEACRP Specialist's Meeting on Fast-Neutron Capture Cross Sections*, ANL-83-4 and NEANDC (US)=214/L, April 1982.

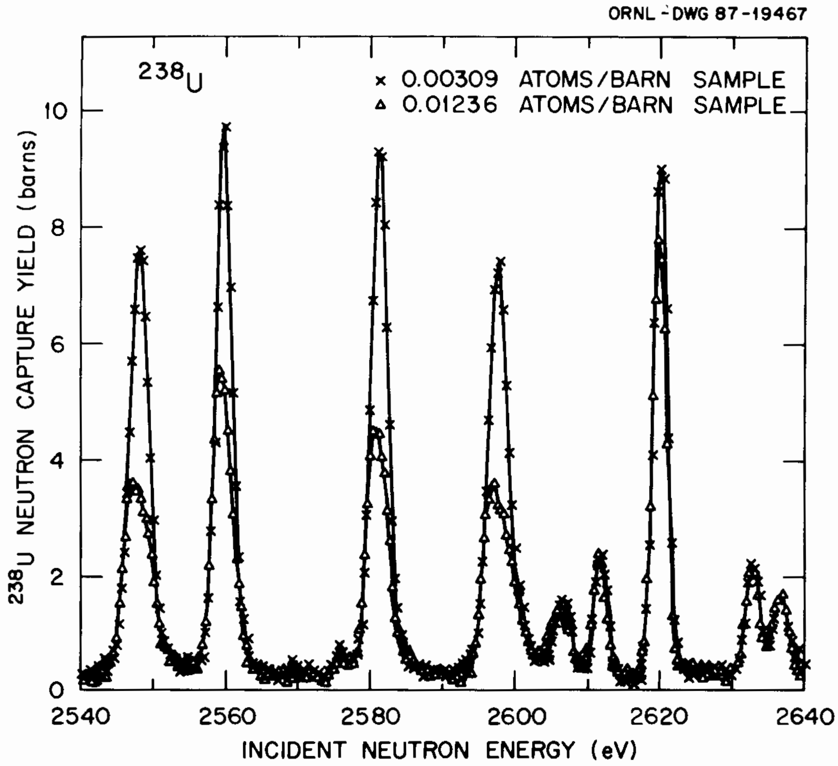

Figure 1. Capture yield data for the 0.00309 atoms/barn and 0.01236 atoms/barn samples in the neutron energy range from 2540 eV to 2640 eV. The lines shown merely connect the data symbols for each sample for clarity. Note the appearance of substantial sample thickness effects on the larger resonances.

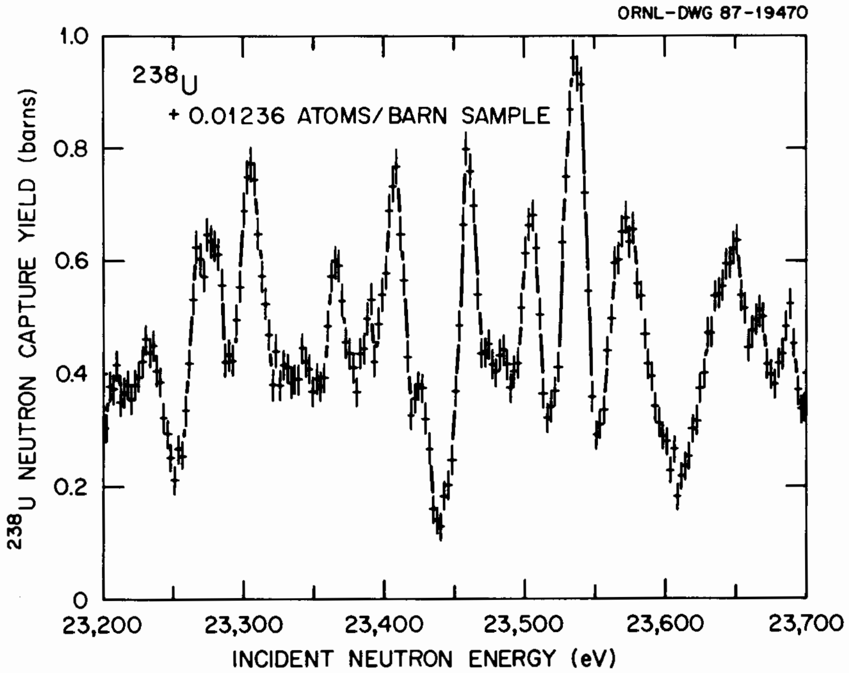

Figure 2. Capture yield data in the neutron energy range from 23.2 keV to 23.7 keV for the 0.01236 atoms/barn sample. Note the high resolution achieved by the present measurement which is a factor of three better than any previous measurement in this energy region. The vertical bars indicate statistical uncertainties only.

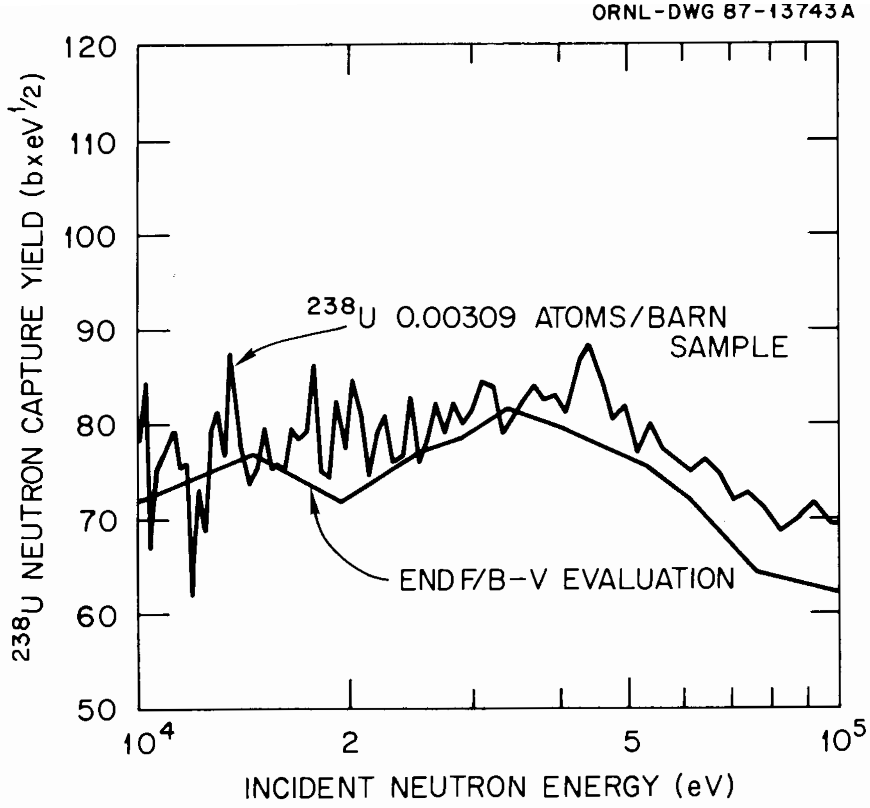

Figure 3. Comparison of the intermediate structure observed in the capture yield data for the 0.00309 atoms/barn sample with the structure introduced in the ^{238}U capture cross section by the ENDF/B-V evaluation (reference 11) in the neutron energy range from 10 keV to 100 keV. The data have been averaged over 250-channel intervals. Because of the lack of sample thickness corrections in the capture yield data, the present comparison is only intended to be of a qualitative nature.