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MEASUREMENT OF THE ENERGY DEPENDENCE OF PROMPT FISSION NEUTRON EMISSION FROM ^{233}U, ^{235}U, AND ^{239}Pu FOR E = 0.0005 TO 10 MeV RELATIVE TO EMISSION FROM SPONTANEOUS FISSION OF ^{252}Cf*

R. GWIN, R. R. SPENCER, and R. W. INGLE
Oak Ridge National Laboratory, Oak Ridge, Tennessee, 37831 USA

Abstract A series of experiments has been performed to measure the dependence on the incident neutron energy of $\bar{\nu}_p(E)$, the average number of prompt neutrons emitted per fission, of ^{233}U, ^{235}U, and ^{239}Pu relative to $\bar{\nu}_p$ (^{252}Cf), the average number of prompt neutrons emitted in spontaneous fission of ^{252}Cf. The incident energy range was 0.0005 to 10 MeV. A white neutron source was generated by the Oak Ridge Electron Linear Accelerator and the energies of the neutrons incident on the fissile samples were determined by time-of-flight techniques. The fissile sample and the ^{252}Cf standard were contained in a fission chamber surrounded by a large volume (0.91 m^3) liquid scintillator loaded with gadolinium. Fissions were detected by the fission chamber and the neutrons were detected by the scintillator. The results for ^{239}Pu agree over most of the energy range with the results of the evaluation of Manero and Konshin. However, the present results are larger for ^{235}U than those of Manero and Konshin and for ^{233}U the present data yield a different energy dependence in the interval 100 to 600 keV. Final results are displayed.

INTRODUCTION

The values of $\bar{\nu}_p(E)$ for the fissile isotopes were measured relative to $\bar{\nu}_p$ (^{252}Cf); thus the quantity defined in this work is the ratio

$$\bar{R}_p(E) = \bar{\nu}_p(E)/\bar{\nu}_p(^{252}Cf) \quad . \tag{1}$$

Experiments using methods similar to the type used in this work have been performed by other investigators, for example, Diven *et al.*[1] and Mather *et al.*[2] Measurements of $\bar{R}_p(E)$ for the fissile isotopes in the thermal neutron energy region

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have been reported by the present authors[3] and a measurement of the absolute value of $\bar{\nu}_p$ for ^{252}Cf has been reported by Spencer *et al.*[4] Both refs. 3 and 4 discuss the experimental and analytical methods used in the present work.

The coatings of the fissile isotopes used in the fission chamber were 1 g/m^2. The volume of the large liquid scintillator was 0.91 m^3. The fission chamber was located 83.4 m from the neutron source and centered in the neutron detector via a through tube (neutron beam tube). For the ^{233}U experiments a beam tube 8.8 cm in diameter was used and for ^{235}U and ^{239}Pu a tube 13.9 cm in diameter was used.

A collimator system was used to give a neutron beam diameter of 5 cm at the sample position. A fission event defined by a coincidence between pulses from the fission chamber (fission fragments) and the neutron detector (prompt gamma rays from fission) initiated a time gate for counting pulses from the neutron detector. A counting interval extending from 1 to 32 μs after fission was used, and 75% of the prompt fission neutrons were detected in this interval.

Measurements of the background in the neutron detector were made by generating counting gates randomly. For the ^{252}Cf data the background gate was generated using a NaI(Tℓ) detector system and a ^{137}Cs source. A pulse ionization chamber filled with BF_3 and located 82.5 m from the neutron source was used to initiate the background counting gates for the data for the fissile isotopes through the ^{10}B(n,α) reaction.

In addition to the correction for the background in the neutron detector, corrections were made for pulse pileup in the counting gate, false fissions caused by random pileup of pulses from the fissile chamber and neutron detector systems, impurity fissions caused by sample contamination, delayed gamma rays from fission, different energy spectra for the fission neutrons for the various isotopes and for displacement of the samples from the center of the through tube. A systematic uncertainty of 0.17, 0.14, and 0.17% must be folded with the statistical uncertainty shown in the figures for $\bar{R}_p(E)$ for ^{233}U, ^{235}U, and ^{239}Pu, respectively.

The present data $\bar{R}_p(E)$ and $\Delta\bar{R}_p(E)$ were folded with a neutron spectrum characteristic of ZPR6/7[5,6] and the neutron fission cross section to obtain an estimate of the uncertainty in the criticality constant k due to the statistical uncertainties in $\bar{R}_p(E)$. Uncertainties of 0.23, 0.15, and 0.34% in k were obtained for ^{233}U, ^{235}U, and ^{239}Pu, respectively.

Figure 1 shows values of $\bar{R}_p(E)$ (averaged over energy ranges) for ^{235}U and ^{239}Pu over the neutron energy range 0.05 to 10 MeV. Figure 2 shows $\bar{R}_p(E)$ for ^{233}U over the range 0.05 to 2.0 MeV. Also shown in the figures are the results from ENDF/B-V[7] and from the evaluation of Manero and Konshin.[8] Figure 2 also shows the experimental results of Boldeman *et al.*,[9] and Walsh and Boldeman.[10] No distinct differences between the energy dependence of the present work and that of refs. 7 and 8 are noted except for ^{233}U. As seen in Fig. 2, the present $\bar{R}_p(E)$ for ^{233}U vary in an approximately linear fashion up to 2 MeV whereas the evaluation of Manero and Konshin[8] exhibits a relative minimum in $\bar{R}_p(E)$ between 0 and 2 MeV.

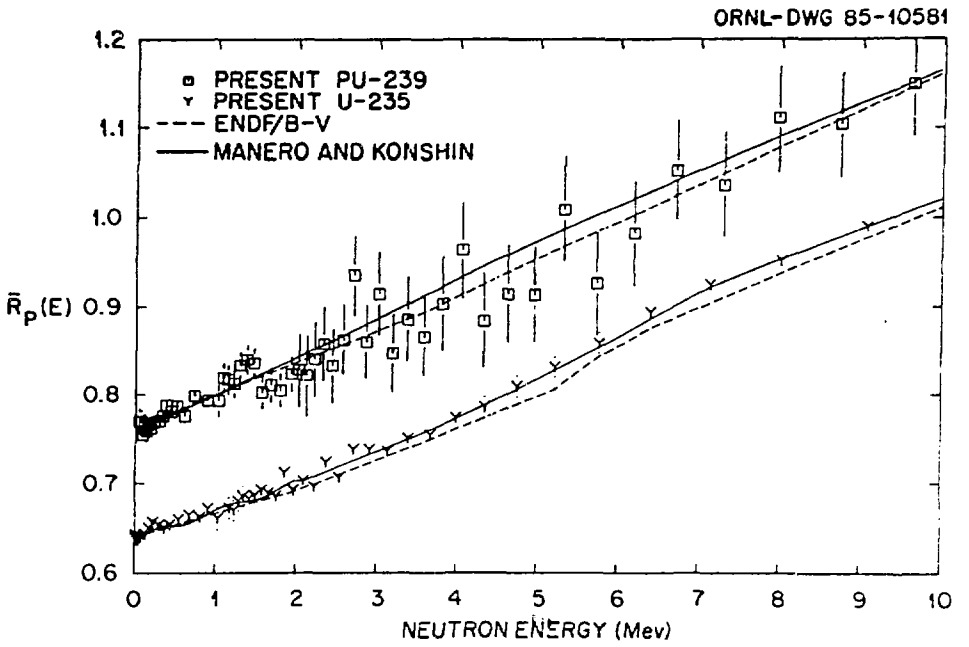

Fig. 1. Energy dependence for ^{235}U and ^{239}Pu, 0.005 to 10 MeV. The present values are averages and are plotted at the midpoint of the interval over which the average was made.

Boldeman *et al.*[9] also measured $\bar{E}(k)$, the average total kinetic energy of the fission fragments for ^{233}U. $\bar{E}(k)$ (ref. 9) increased with neutron energy, reaching a plateau at 300 keV. It was noted in ref. 7 that the energy dependence of $\bar{E}(k)$[9] and $\bar{R}_p(E)$[9,10] were physically consistent if mass and charge division were independent of incident neutron energy.

The present experiments and those of ref. 7 and 8 were similar and most of the corrections were about the same size. The differences in the value (−1%) and the energy dependence of $\bar{R}_p(E)$ for ^{233}U suggest unknown problems in measurements of $\bar{R}_p(E)$.

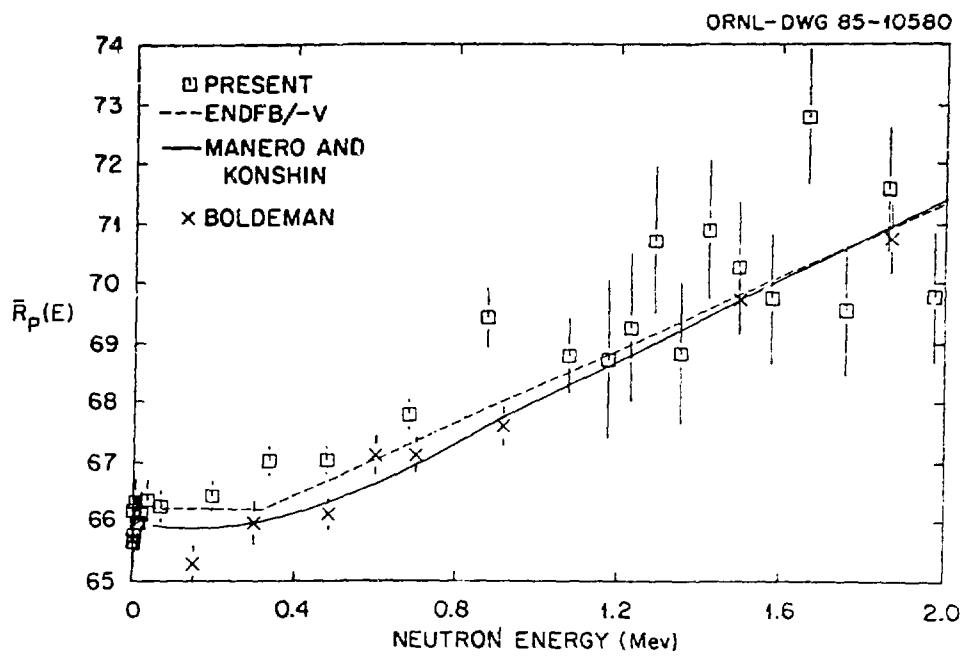

Fig. 2. Energy dependence for ^{233}U, 0.005 to 1.0 MeV. The present values are averages with the value plotted at the midpoint of the energy interval over which the interval was made.

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