reactions leading to other products. Spallation products might be expected in general to show similar excitation functions, though the maximum can be obscured where there are available several reaction paths leading to the same product.

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Number of Prompt Neutrons Emitted per Thorium-232 Fission

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The number of prompt neutrons emitted per Th^{232} fission [$\nu_{Th^{232}}$] is compared to the number emitted per U^{238} fission [$\nu_{U^{238}}$]. At a bombarding neutron energy of 1.4 Mev the ratio $\nu_{Th^{232}}/\nu_{U^{238}}=0.98\pm0.08$.

INTRODUCTION

THE number of prompt neutrons emitted per Th^{232} fission has been measured at 14.2 Mev[1] ($\nu_{Th^{232}}=4.64\pm0.2$) and at an effective neutron energy of 3.5 Mev[2] ($\nu_{Th^{232}}=2.35\pm0.07$). These two measurements lead to a value of $d\nu/dE$ considerably larger than that found for any other fission process.[3] Furthermore they suggest that $\nu_{Th^{232}}<\nu_{U^{238}}$ at neutron energies near the fission threshold. These conclusions are not encouraging to fast thorium reactor concepts.

In order to extend the existing measurements and to obtain information at neutron energies of interest in reactor design, this experiment was undertaken.

EXPERIMENTAL METHOD

Th^{232} and U^{238} samples were contained within a large fission chamber. Neutrons which originated in fission events within the chamber were detected by an adjacent Hornyak[4] button. Throughout the experiment it was assumed that the detection efficiency of the button was identical for both Th^{232} and U^{238} fission neutrons. This assumption is valid if the fission neutron spectra of Th^{232} and U^{238} are similar as is suggested by present knowledge of fission spectra.[5-8] The fission chamber and Hornyak button were irradiated with (1.4±0.08)-Mev neutrons. These neutrons were obtained from the $Li^7(p,n)$ reaction utilizing a Van de Graaff accelerator.

Electronic circuitry simultaneously recorded the following quantities:

(a) the total number of events in the neutron detector coincident with thorium fissions ($N_{Th}{}^t$),
(b) the total number of neutron events coincident with uranium fissions ($N_U{}^t$),
(c) the contribution of chance coincident events to the above two quantities ($N_{Th}{}^{ch}$,$N_U{}^{ch}$), and
(d) the number of fissions occurring in the uranium and in the thorium ($N_{Th}{}^f$,$N_U{}^f$).

The ratio $\nu_{Th^{232}}/\nu_{U^{238}}$ is related to the above experimental quantities through

$$\frac{\nu_{(Th^{232})}}{\nu_{(U^{238})}}=\frac{(N_{Th}{}^t-N_{Th}{}^{ch})/N_{Th}{}^f}{(N_U{}^t-N_U{}^{ch})/N_U{}^f}.$$

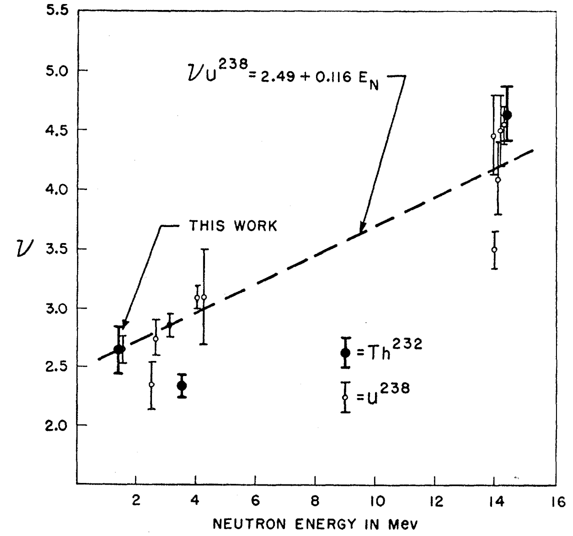

FIG. 1. The value of $\nu_{Th^{232}}$ obtained from this experiment is compared with the results of other workers. Measured values of $\nu_{U^{238}}$ are also shown.

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[5] James Terrell (to be published).

[6] A. B. Smith *et al.* (to be published).

[7] L. Cranberg *et al.*, Phys. Rev. **103**, 662 (1956).

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A small correction was made for the effect of the U^{235} content of the uranium sample.

RESULTS

Six determinations of the ratio $\nu_{\mathrm{Th}^{232}}/\nu_{\mathrm{U}^{238}}$ were made. These were averaged using the method of least squares to obtain the most probable value $\nu_{\mathrm{Th}^{232}}/\nu_{\mathrm{U}^{238}}=0.98\pm0.08$ ($E_n=1.4$ Mev). A "best value" of $\nu_{\mathrm{U}^{238}}$ at $E_n=1.4$ Mev was obtained by least-squares fitting the linear expression $\nu_{\mathrm{U}^{238}}=a+bE_n$ to the existing experimental values of $\nu_{\mathrm{U}^{238}}$. This linear fit to the experimental data is shown in Fig. 1. Using the "best value" of $\nu_{\mathrm{U}^{238}}=2.63$, this experiment yielded $\nu_{\mathrm{Th}^{232}}=2.58\pm0.20$ where the error pertains only to uncertainties in this measurement and does not reflect inaccuracies in the requisite value of $\nu_{\mathrm{U}^{238}}$.

The result of this experiment is compared in the figure with the measurements at 3.5 and 14.2 Mev. It is evident that either $\nu_{\mathrm{Th}^{232}}$ is not linearly dependent on incident neutron energy, or at least one of the experimental measurements is in error. It is perhaps interesting to point out that this experiment and the work at 14.2 Mev were carried out using essentially monoenergetic neutron sources. The results of both of these experiments indicate that $\nu_{\mathrm{Th}^{232}}\simeq\nu_{\mathrm{U}^{238}}$. The measurement of $\nu_{\mathrm{Th}^{232}}$ at an "effective" neutron energy of 3.5 Mev utilized a continuous spectrum from a fast reactor.

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Mirror Nuclei Radii Utilizing Self-Energy Term and Nonuniform Charge Distributions

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The nature of the self-energy term in the mirror nucleus energy-difference formula is investigated. Two approaches are used. In the first this self-energy term is assumed to be a constant equal to the Coulomb self-energy of a single proton, and in the second a more refined quantum mechanical approach based on the Swamy and Green Coulomb exchange energy calculations is used. Both approaches yield r_0 values which possess the correct general trend with increasing A, but which disagree with theoretical values for very low A. The effect of nonuniform charge distributions on the values of nuclear radii obtained from mirror nuclei is investigated, and expressions for the Coulomb energy for various charge distributions are given. A direct comparison between the mirror nucleus radii and those obtained from electron scattering is made in the few cases where this is possible. Finally, the possible validity of a suggested value of 0.58 Mev for the Coulomb self-energy of the proton is discussed briefly.

THE use of the Coulomb energy differences between mirror nuclei for determining nuclear radii is well known. The method requires the assumption of charge symmetry, and in addition the adoption of some particular model of nucleon or charge distribution. Earlier workers assumed a uniform distribution of charge; later work assumed a uniform distribution of nucleons, but introduced the "exchange energy" term. Still more recently, calculations have been based on the assumption of more realistic nuclear models which reproduce shell features. The situation has been reviewed by Kofoed-Hansen,[1] where a complete list of references is given.

The present investigation originated as an attempt to provide a direct comparison between the mirror nuclei method and another method of nuclear radius determination, *viz.*, that of electron scattering. This method has been surveyed by Hofstadter,[2,3] and further articles of interest appear in Part 1 of *Reviews of Modern Physics* for April, 1958. The quantity which the electron scattering workers measure is the effective nuclear charge distribution. If, then, one calculates the classical Coulomb energy $W_C(A,Z)$ from the usual expression

$$W_C(A,Z)=16\pi^2\int_0^\infty\left[\int_0^r x^2\rho(x)dx\right]r\rho(r)dr, \qquad (1)$$

one might expect that the relation

$$E_C(Z+1,Z)=W_C(A,Z+1)-W_C(A,Z) \qquad (2)$$

would hold. E_C is the mirror nuclei energy difference [Kofoed-Hansen, Eq. (5), gives exact definitions of E_C], and $\rho(r)$ is the effective (non-normalized) nuclear charge distribution. Spherical symmetry is assumed. Since we are dealing with an effective charge distribution, and not with individual proton wave functions, the "exchange energy" term would not appear to be necessary. Closer examination, however, shows that (2) is incorrect, since $E_C(Z+1,Z)$ represents not the *total* Coulomb energy difference, but merely that part of the Coulomb energy which contributes to the *binding* energy. We therefore require an extra term to take care of the difference

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