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October 1964

COMPARISON OF THE PROMPT FISSION GAMMA
SPECTRUM OF U-233 INDUCED BY THERMAL NEUTRONS
AND BY 1.8 eV RESONANCE NEUTRONS

M. S. Moore and R. R. Spencer

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**NATIONAL REACTOR TESTING STATION
US ATOMIC ENERGY COMMISSION**

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IDO-17025
AEC Research and Development Report
Physics
TID-4500 (3rd Ed.)
Issued: October 1964

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Contract AT(10-1)-205

Idaho Operations Office

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ABSTRACT

With the use of a single-crystal NaI(Tl) gamma-ray spectrometer, the spectrum of prompt fission gamma rays of U-233 was investigated. A comparison was made of the gamma-ray spectrum in coincidence with fragments of fission induced by near thermal neutrons (0.06 eV) and by neutrons of 1.8 eV, corresponding to the energy of the first large resonance in U-233. Within the limits of accuracy of the measurement, the gamma ray spectra obtained at the two neutron energies are identical.

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I. Introduction

It has become customary in recent years to consider the phenomenon of fission of a heavy nucleus, induced by slow neutron absorption, as a multistage process. The existence of resonances in the cross section is due to the properties of the compound nucleus. The interference effects observed among resonances in the fission cross section are thought to be related to the conditions which exist (the channel structure) at the saddle point in the potential barrier⁽¹⁾ which the fissioning nucleus must cross in order to split into two fragments. The characteristics of the fragment mass distribution and the fragment kinetic-energy distribution are considered to be related to a still later stage in the process - the scission point⁽²⁾, or the point at which the nuclear forces between the fragments cease to operate. Finally, as they move apart, the fragments reorient themselves from the configuration which existed at the scission point. Probably at this stage they emit most or all of the observed prompt neutrons^(3,4) and prompt fission gamma radiation.

The dependence on neutron energy of the fission interference in the fissile nuclides is easily observed, and has been studied in some detail⁽⁵⁻¹³⁾. The fission-fragment mass distribution has also been found to depend on neutron energy⁽¹⁴⁻¹⁹⁾, although not as strongly. Recently, the total kinetic energy of the fragments has also been

shown to have a slight neutron-energy dependence⁽²⁰⁾. The possibility of a variation of $\bar{\nu}$, the average number of prompt neutrons emitted per fission, has also been studied. The number of prompt neutrons emitted is not observed to depend on the neutron energy⁽²¹⁻²³⁾, however, unless the neutron has sufficient energy to contribute appreciably to the excitation of the compound nucleus⁽²⁴⁾ or to permit the formation of p-wave or higher angular momenta resonances⁽²⁵⁾.

The prompt fission gamma spectrum has not previously been studied as a function of neutron energy. There have been some detailed investigations of the gamma spectrum following fission of U-235^(26,27), with fixed-energy (thermal) neutrons. The prompt fission gamma spectrum is found to be broad and for the most part featureless, peaking at about 150 keV, with a long tail which extends to perhaps 8 MeV or higher. There is a slight hint of structure in the prompt spectrum, and in the delayed spectrum this structure becomes more prominent. The prompt fission gamma spectrum is thought to consist primarily of E2 radiation, which is emitted from fragments with a large angular momentum, and which can thus compete favorably with neutron emission^(28,29).

The present study on U-233 was a preliminary survey intended to detect the possibility of gamma emission before fission. Such gamma emission would be expected to consist of discrete lines, and perhaps to depend strongly on the resonance characteristics of the compound nucleus. The first large resonance in U-233 occurs at 1.8 eV. This resonance (and the others below 10 eV in U-233) appear to be superimposed on a smooth "background" fission component, which varies, at least approximately, as $1/\nu$. It has been conjectured that this component is due to broad, unresolved resonances which are not observed⁽⁷⁾, or perhaps to

the wings of broad resonances, some of which are observed^(8,9). An alternate suggestion is that this "background" fission is due to a direct process⁽³⁰⁾, possibly of the same type as the direct radiative capture process described by Lane and Lynn^(31,32). Such a direct fission event could be expected to be accompanied by discrete, relatively low energy gamma rays, whose relative intensity should vary markedly with neutron energy, depending on the ratio of "direct fission" to resonance fission. The present study was carried out as an attempt to observe such gamma radiation.

II. Experimental Results

The study of the prompt fission gamma spectrum of U-233 was carried out on the MTR crystal spectrometer at two neutron energies, 0.06 eV and 1.8 eV. At 0.06 eV, the maximum neutron intensity is obtained in the Bragg beam of the spectrometer, and the fission cross section of U-233 is thought to be primarily ($\geq 90\%$) due to the fission "background" component discussed above. At the 1.8 eV resonance, only approximately 15% of the fission cross section is due to the "background" component.

Fission fragments were detected in a multiplate ionization chamber, containing twelve independent sections, with a total of 150 mg of U-233. This material was deposited in the form of U_3O_8 , 500 $\mu g/cm^2$ thick, on thin aluminum backings.

Prompt gamma radiation was detected in coincidence with fission fragment pulses by a 2 in. D x 2 in. long NaI(Tl) scintillation spectrometer, which was shielded from reactor background radiation by 4 in. of lead. The largest source of background, against which the detector

could not be shielded, consisted of activity from the fission foils, due to U-232 and its decay products. A pulse height spectrum of the background (singles) radiation is shown in Figure 1. The structure is that of a radiothorium (Th-228) source, in equilibrium with decay products. The chance coincidence rate amounted to 10-20% of the true rate.

The pulse-height distribution of prompt radiation in coincidence with fission fragments is shown in Figure 2. The solid circles represent data taken at 0.06 eV neutron energy, and the open circles are data taken at 1.8 eV. Within the limits of accuracy of the experiment, the spectra are the same, showing no evidence for any pre-fission gamma emission which depends on neutron energy.

It should be pointed out that no attempt was made to unfold the observed pulse-height distribution to obtain a spectrum of relative gamma-ray yield. Also, the resolving time of the coincidence system was large ($2\tau = 200$ nsec.) so that the discrimination between prompt gamma radiation and prompt neutrons was not done. In addition, complete gamma spectra were not obtained (i.e., reliable data were not obtained in the region below 100 keV gamma energy at both neutron energies).

Figure 1 - Pulse height spectrum of background (singles) gamma radiation observed. The structure can be attributed to decay products of U-232 contained in the U-233 fission foils.

Figure 2 - Pulse height spectrum of prompt radiation in coincidence with fission fragments, showing a comparison of the spectrum observed at 0.06 eV neutron energy (solid circles) and at 1.8 eV (open circles). The slight disagreement of the two sets of data near 100 keV is attributed to experimental error: the inadequacy of a correction for somewhat different absorbers between target and detector.

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