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**Fission Product Beta and Gamma Energy
Release Quarterly Progress Report for
October-December 1975**

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Neutron Physics Division

FISSION PRODUCT BETA AND GAMMA ENERGY RELEASE
QUARTERLY PROGRESS REPORT FOR OCTOBER-DECEMBER 1975

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Abstract

Preliminary experimental information for beta-ray energy release from fission product decay following thermal-neutron fission of ^{235}U has been obtained for cooling times between 3 and 14,400 secs. The data were obtained as pulse-height spectra for beta energies between 0.25 and 8 MeV using a two-crystal scintillation spectrometer, and were unfolded to give beta-ray energy spectra of moderate resolution. Two irradiation times, $t_i = 2.4$ and 100 sec, were studied. The energy release data were obtained by integrating the observed spectra and then estimating the contribution for $E_\beta < 0.25$ MeV. Difficulties encountered in this first experiment using the beta-ray detection equipment are discussed.

Previously reported preliminary gamma-ray spectra have been compared with spectra calculated using spectral information in the ENDF/B-IV data file for ~ 180 fission products. Several comparisons are presented for $t_i = 100$ secs. As expected the comparison is not very good for short cooling times, but is encouraging for $t_{\text{cool}} \sim 2000$ secs.

INTRODUCTION

The purpose of this experiment is to measure the total beta and gamma energy release rate from fission product decay following thermal neutron fission of fuel materials ^{235}U and then ^{239}Pu and perhaps other nuclides. The accuracy goal is $\pm 3\%$ on the overall energy release rate for ^{235}U and $\pm 4\%$ for ^{239}Pu for times following fission of 2 to at least 2000 sec. The experimental methods were outlined in the first quarterly report,¹ and details of the detector systems, fission-monitoring, samples and sample transport, and data accumulation computer have been reported in subsequent quarterly reports.² Preliminary measurements and results for gamma-ray energy release data were reported in the last quarterly report.³

EXPERIMENTAL PROGRESS

During the quarter emphasis was placed on obtaining, reducing and reporting preliminary beta-ray energy release data for a "quick look" comparison with other data^{4,5} as well as calculations. In addition, it was anticipated that this first pass through the whole experiment for the beta-ray data would provide answers to questions about methods and procedures which had not previously been attempted, and would serve to emphasize those methods and procedures requiring improvement prior to the final data accumulation runs.

To date a satisfactory sample holder has not been fabricated for the beta-ray measurements. The sample configuration ought to approach one made by sealing the ^{235}U between two sheets of plastic material, each sheet being just thick enough to contain the most energetic fission fragments. This sample holder ought to be mounted near to the end of

the "rabbit" (used to transport the sample to and from the reactor) so as to minimize the air path between sample and detector. This problem of source holder has proved to be very stubborn. For the first data run, the sample holders were a rather thick 55 mg/cm^2 , about ten times thicker than needed. As a consequence data could not be obtained for $E_\beta < 0.25 \text{ MeV}$.

The beta-ray detector as used in the preliminary measurements is shown in Fig 1. The two-scintillator system is designed to identify and reject part of the gamma radiation detected, and also to provide an active shield against general room background. Magnetic separation of betas from gammas is accomplished by using a strong magnetic field applied between the first collimator and the source position. The measurements consisted of two types: (a) without the magnetic field, the detector system records essentially all incident betas and some fraction, f , of the incident gammas, since $(1-f)$ of the incident gamma radiation is identified and rejected by the electronic pulse-shape discrimination; (b) with the magnetic field, the detector system records only the fraction, f , of the incident gamma radiation. Data reduction includes subtracting data runs of type (b) from those of type (a). The resulting spectrum is, therefore, expected to be due to betas only. It is binned into suitable pulse-height bins and then unfolded. Prior to this step, however, a response matrix had to be determined for the detector configuration used.

A beta-ray response matrix was calculated based upon the assumptions that every beta ray striking the detector is registered, that the attenuation of betas through scattering by the source holder - air - entrance

Fig 1. Beta-ray scintillation spectrometer as used for preliminary beta-ray energy release measurements. The beta-ray source position is about 8 mm from the entrance foil. For some measurements a strong magnetic field (~ 2700 gauss) is placed between the entrance foil and the first collimator perpendicular to the path between source and detector. The "Light Pulser, ^{241}Am " is used to monitor possible gain shifts during data taking.

window can be calculated, and that energy loss can also be calculated. For $E_{\beta} < 1$ MeV conversion electron sources provided information on the intrinsic resolution of the detector as well as information on the departure of the response from pure Gaussian. For $E_{\beta} > 1$ MeV these effects were extrapolated to calculate responses.

Beta-ray energy-release data for thermal-neutron fission of ^{235}U were obtained during the quarter and were processed using this response matrix. In addition, data were obtained for a ^{207}Bi conversion electron source. After unfolding, the results were within 3% for the 484-keV and 975-keV conversion-electron yields calculated from the known ^{207}Bi source strength and conversion electron branching ratios. Data were also obtained for an aluminum sample; the betas measured were the 2.86-MeV beta rays from ^{28}Al . These data are shown in Fig 2. The dashed curve represents the expected spectrum. The comparison for $E_{\beta} > 1$ MeV is quite good, but for $E_{\beta} < 0.8$ MeV, the differences are large enough to be of concern. Further study is required prior to final data taking.

For thermal-neutron fission of ^{235}U beta-ray data were obtained for irradiation times of 2.4 and 100 secs, and for counting time intervals the same as were used for the gamma-ray data reported last quarter.³ The unfolded beta-ray energy spectra were compared with data of Tsoulfanidis, et al.;⁴ a typical comparison is shown in Fig 3. The causes for observed differences have not yet been investigated.

The thick absorbing layer, 55 mg/cm² of plastic between the sample and the detector, required that the lowest energy portion of the spectrum be extrapolated in order to obtain the integral heat-release data. These estimates ranged between 1% for shortest cooling times to 12% for longest

Fig 2. Spectrum of betas obtained by bombarding a 1.7 mg sample of Al for 10 sec in a thermal flux of 3.6×10^{13} n/cm²/sec, and unfolding the raw data using the response matrix discussed in the text. The dashed line is calculated assuming an allowed transition, that is, a straight line would result when the data are manipulated to give a Fermi plot.

Fig 3. Comparison of present preliminary beta-ray data with those of Tsoulfanidis, et al. (Ref 4) for cooling times of 60 to 70 secs.

cooling times. An example of the latter is shown in Fig 4; the estimate is shown as the dashed line and is probably an overestimate since $E_{\beta} \times Y_{\beta}$ should be identically zero for zero energy.

Of concern was the apparent lack of precision for data obtained under presumed identical conditions. Integral values of some of the experimental data (e.g. number of pulses presented to the Analog-to-Digital Converter, etc.) were obtained during each run using scalers. During the data reduction, a study was made to obtain the degree of reproducibility of these integral values, since this is one measure of the internal consistency of the data. The results of this study are given in Table 1, along with equivalent results for the preliminary gamma-ray energy-release data. Because of the inconsistencies for the beta-ray data, the final experimental values are shown with uncertainties of 11% or greater. For this reason, as well as the expectation of substantial improvement in methods and techniques (e.g. in sample cover thickness) which may be anticipated for data accumulation runs being planned, use of these beta-ray data should be restricted to unpublished studies.

The resulting preliminary beta-ray energy release data are included in Table 2, along with preliminary gamma-ray energy release data³ and calculated energy release data using the ENDF/B-IV data file.⁶ For these calculations the function $f(t)$ = energy release/fission/sec after a cooling time t , for an instantaneous burst of fission was obtained separately for beta-ray and gamma-ray energy release by R. Schenter⁷ (Hanford) using the RIBD code. Each $f(t)$ was numerically integrated over the irradiation time to create $F(t, t_{\text{irrad}})$, where the notation is

Fig 4. Present preliminary beta-ray data plotted as Yield x Energy vs. Energy to show the extrapolation at low E_{β} in order to obtain the integral heat. For shorter cooling times the estimated heat for $E_{\beta} < 0.25 \text{ MeV}$ is a smaller percentage of the total integral than shown here. In addition, Yield x Energy $\rightarrow 0$ for Zero Energy which is not indicated here; hence the estimate may be conservative.

TABLE 1. INTERNAL CONSISTENCY OF PRELIMINARY DATA
(Representative Values for 1 σ Variations)

A. Gamma-Ray Data

1) $T_i = 2.4$ sec	Low gain	3.8%
2) $T_i = 100$ sec	Low gain	1.0%
3) $T_i = 2.4$ sec	High gain	4.2%
4) $T_i = 100$ sec	High gain	One Sample
5) $T_i = 2.4$ sec	No. of fissions	4.5%
6) $T_i = 100$ sec	No. of fissions	1.7%

B. Beta-Ray Data

1) $T_i = 2.4$ sec	Low gain	8.3%
2) $T_i = 100$ sec	Low gain	One Sample
3) $T_i = 2.4$ sec	High gain	11.3%
4) $T_i = 100$ sec	High gain	9.0%
5) $T_i = 2.4$ sec	No. of fissions	3.7%
6) $T_i = 100$ sec	No. of fissions	1.9%

Table 2. PRELIMINARY ENERGY RELEASE DATA AND COMPARISONS

(December 1975)

Irrad. Time (Sec)	Cool Time (Sec)	Count Time (Sec)	D A T A			Calculation (ENDF/B-IV)			Ratio Calc./Data		
			Gamma (a) Ray	Beta (b) Ray	Total	Gamma Ray	Beta Ray	Total	Gamma Ray	Beta Ray	Total
2.4	3	1	} 0.219 ±0.026	0.144 ±0.021	} 0.483	0.188	0.142	} 0.451	0.858	0.986	} 0.934
	4	1		0.120 ±0.018			0.121			1.008	
	5	2	0.164 ±0.013	0.197 ±0.025	0.361	0.144	0.198	0.342	0.878	1.005	0.947
	7	2	0.133 ±0.011	0.150 ±0.018	0.283	0.118	0.161	0.279	0.887	1.073	0.986
	9	5	0.242 ±0.023	0.267 ±0.029	0.509	0.229	0.290	0.519	0.946	1.086	1.020
	14	5	0.178 ±0.011	0.183 ±0.021	0.361	0.173	0.203	0.376	0.972	1.109	1.042
	19	10	0.260 ±0.015	0.237 ±0.025	0.497	0.257	0.262	0.519	0.988	1.106	1.044
	29	10	0.190 ±0.011	0.159 ±0.017	0.349	0.189	0.182	0.371	0.995	1.144	1.063
	39	20	0.278 ±0.016	0.216 ±0.022	0.494	0.273	0.277	0.550	0.982	1.282	1.113
	59	20	0.195 ±0.011	0.145 ±0.015	0.340	0.194	0.200	0.394	0.995	1.379	1.159
	79	20	0.149 ±0.008	0.108 ±0.011	0.257	0.141	0.128	0.269	0.946	1.185	1.047
	99	50	0.254 ±0.009	0.185 ±0.019	0.439	0.233	0.241	0.474	0.917	1.303	1.080
	149	50	0.163 ±0.012	0.119 ±0.013	0.282	0.168	0.147	0.315	1.031	1.235	1.117
	199	100	0.206 ±0.020	0.153 ±0.017	0.359	0.221	0.164	0.385	1.073	1.072	1.072
100.4	10	10	} 0.227 ±0.022	0.118 ±0.017	} 0.434	0.241	0.141	} 0.492	1.061	1.195	} 1.134
	20	10		0.089 ±0.013			0.110			1.236	
	30	20	0.161 ±0.013	0.130 ±0.018	0.291	0.168	0.166	0.334	1.043	1.277	1.148
	50	50	0.266 ±0.018	0.203 ±0.023	0.469	0.277	0.268	0.545	1.041	1.320	1.162
	100	50	0.169 ±0.010	0.125 ±0.014	0.294	0.179	0.171	0.350	1.059	1.368	1.190
	150	100	0.212 ±0.012	0.155 ±0.017	0.367	0.230	0.219	0.449	1.084	1.413	1.223
	250	100	0.138 ±0.008	0.100 ±0.011	0.238	0.147	0.143	0.290	1.065	1.430	1.219
	350	200	0.186 ±0.010	0.137 ±0.015	0.323	0.197	0.192	0.389	1.059	1.402	1.204
	550	200	0.129 ±0.007	0.099 ±0.011	0.228	0.140	0.131	0.271	1.085	1.323	1.189
	750	200	0.101 ±0.006	0.077 ±0.009	0.188	0.109	0.099	0.208	1.079	1.286	1.106
	950	500	0.185 ±0.010	0.142 ±0.017	0.327	0.207	0.177	0.384	1.119	1.247	1.174
	1450	500	0.132 ±0.007	0.097 ±0.012	0.229	0.149	0.119	0.268	1.129	1.227	1.170
	1950	500	0.100 ±0.006	0.069 ±0.009	0.169	0.117	0.088	0.205	1.170	1.275	1.213
	2450	500	} 0.636 ±0.041	0.052 ±0.007	} 1.017	0.833	0.071	} 1.375	1.310	1.365	} 1.352
	2950	500		0.041 ±0.006			0.055			1.342	
	3450	10950		0.288 ±0.043			0.416			1.444	

(a) For $E_Y > 0.05$ MeV(b) Includes estimates for $E_B < 0.25$ MeV

taken from the recent Perry, et al.,⁸ report: $F(t, T)$ = energy release/fission after a cooling time t for an irradiation at constant power for a period T . Then $F(t, T)$ was numerically integrated over each counting time interval to get the expected yields, and these are shown in Table 2 as "Calculation." The last three columns of Table 2 give the ratios of calculated values to data. The ratios are larger than anticipated. The beta-ray data-taking system is being subjected to a thorough analysis; in particular, efforts continue to fabricate sample holders with thin plastic foils which can withstand the mechanical shocks incurred during movement to and from the reactor.

COMPARISONS OF GAMMA-RAY SPECTRA WITH CALCULATED SPECTRA

During the quarter calculations using the ORIGEN code and those isotopes in the ENDF/B-IV data file having discrete spectral information were carried out to compute the gamma-ray spectrum expected for a given irradiation and counting time. The calculated results were compared with the data³ obtained for $t_{\text{irrad}} = 100$ secs. Two of these comparisons are shown in Figs 5 and 6. Only ~ 180 of the > 500 fission products have spectral information given in ENDF/B-IV. Even with the "poor" resolution associated with the NaI system, these comparisons should be of material benefit as a guide to improving the ENDF/B data file.

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Fig 5. Comparison of present preliminary gamma-ray data with calculations using ORIGEN and spectral information for fission products in the ENDF/B-IV data file. Parameters of the measurement are given on the figure.

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Fig 6. Comparison of present preliminary gamma-ray data with calculations using ORIGEN and spectral information for fission products in the ENDF/B-IV data file. Parameters of the measurement are given on the figure.

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