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Simultaneous Velocity and Energy Measurements of Fission Fragments*

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ABSTRACT

Semiconductor detectors have been used in a double-velocity apparatus for a simultaneous measurement of fragment velocities and detector pulse heights. The purposes of this measurement were (1) to obtain the pulse-height to energy calibration of these detectors for fission fragments and (2) to evaluate a technique for the simultaneous determination of pre- and post-neutron emission parameters of the fission process from a coincident measurement of fragment velocities and energies. Fast and slow output signals were obtained from the detectors for use in the time-of-flight and pulse height measurements, respectively. The recorded data were the flight times of both fragments and the pulse height from one of the detectors for a total of 46 000 ²⁵²Cf fission events. Fragment velocities, initial masses, and initial energies were obtained in the usual manner from the time-of-flight data.

The detector calibration function was determined from the correlation between the recorded pulse heights and the final parameters of the corresponding fragments. The latter values were obtained from the initial mass, initial energy and the published values of $\bar{v}(M, E_f)$ for californium fragments. Finally the calibration function was corrected for instrumental dispersions and the dependence of the average energy on fragment mass.

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The post-neutron-emission parameters were obtained from the recorded data and available detector calibration procedures including the one given above. The average number of neutrons emitted as a function of fragment mass was obtained from the event-by-event differences of the initial and final masses. This result provided a sensitive test of the validity of this proposed technique and the various calibration procedures. Agreement with published data was found for the calibration procedure based on these data and one derived from the response of semiconductor detectors to accelerated bromine and iodine ions. In each case the root-mean-square deviation from the published values of $\bar{\nu}$ was less than 0.7 of a neutron.

1. Introduction

The development of semiconductor detectors has made possible the simultaneous determination of the salient pre- and post-neutron emission parameters of the fission process. These detectors provide good pulse-height resolution together with a fast response time and, therefore, exhibit the two characteristics required for a coincident measurement of fission fragment velocities and energies. Such measurements, however, are sensitive to the absolute pulse-height-to-energy calibration of these detectors. Previous measurements with accelerated bromine and iodine ions [1] have shown that the response of these detectors is dependent on the mass of the incident ion. Fortunately detailed information in regard to this detector calibration can be obtained from a coincident measurement of the velocities of the fragment pairs and the pulse-height response of the semiconductor detector to ^{252}Cf fragments. In this case the dependence of $\bar{\nu}(M, E_K)$, the average number of neutrons emitted from each fragment as a function of fragment mass, M , and total kinetic energy, E_K , of the fission event is known [2]. For each fragment incident on the detector, the initial (before neutron emission) mass and energy of the fragment as well as the total kinetic energy of the event may be found from the velocities of the fragment pairs. The corresponding final (after neutron emission) mass and energy of the incident fragment then may be obtained from these initial values and the function $\bar{\nu}(M, E_K)$. Thus it appears possible with the same apparatus to obtain not only the proper pulse-height-to-energy calibration for a particular semiconductor detector for incident ^{252}Cf fission fragments but also the initial and final parameters of other fissioning systems.

The purposes of this paper are to describe the apparatus developed for the simultaneous measurement of fragment velocities and detector pulse heights and to present results obtained with a spontaneous fission source of ^{252}Cf . These

data have been analyzed to obtain an approximate pulse-height-to-energy calibration for the particular detector used. In addition the same data have been analyzed using the above calibration and the one derived from the response of semiconductor detectors to accelerated bromine and iodine ions [3]. Some of the interesting initial and final distributions are presented and, in particular, the dependence of $\bar{v}$ on fragment mass obtained from both calibration procedures is given. The degree of similarity between these results and published values [2,4] is considered to be a sensitive test of the accuracy of this method.

2. Apparatus

A block diagram of the apparatus used in this measurement is shown in Fig. 1 where the two surface barrier detectors [5], with sensitive areas of 300 mm^2 masked to 200 mm^2 and 950 mm^2 , are shown in the "remote" configuration. The ^{252}Cf source which was mounted on a thin (0.1 mg/cm^2) nickel backing was placed between the two detectors with the fissile deposit facing the smaller detector. The time-zero signal was obtained from an electron detector [6] consisting of an electron lens, a 0.003-inch thick plastic scintillator, and a 36 AVP photomultiplier. One of the fragments from each of the detected pairs traversed the source backing, another thin nickel foil (0.1 mg/cm^2) mounted on the first element of the lens, and continued to the larger remote detector. Electrons ejected from the second nickel foil by the charging fragments were accelerated and focused to the scintillator which was glued to the photomultiplier face. The distance between the source and the center of this tilted foil was 3.5 cm. In addition to the fast, time-zero signal obtained from the anode, a slow signal was obtained from the ninth dynode of the photomultiplier for use in establishing a triple coincidence between the three fragment detectors.

Both a linear signal, related to the fragment energy, and a fast pulse were obtained from each of the surface barrier detectors by means of parallel capacitive coupling. To provide the fastest possible rise time, the detectors were mounted directly on the input of a fast, low impedance preamplifier which was placed inside the evacuated flight tube. This preamplifier consisted of the first stage of a nanosecond pulse amplifier designed by Lamford [7]. After amplification by the remainder of this amplifier, which was located outside of but adjacent to the evacuated system, the fast pulses were fed to a special tunnel diode discriminator which had an avalanche transistor output. This output pulse provided the stop signal for the time-to-pulse-height converter [8]. Start signals for both converters were obtained from the electron detector and a similar tunnel diode discriminator. Linear signals from the surface barrier

detectors were fed first to conventional charge sensitive preamplifiers and then to Comco amplifiers, discriminators, and a coincidence circuit [9]. Time-of-flight and pulse height data were recorded on paper tape by means of a 400-channel, three-parameter pulse height analyzer.

A precision pulser and timer-controlled coaxial relay were also included in this system for stability tests and calibration purposes. Signals from this pulser were periodically introduced into the system, by means of decoupling circuits, at the output of each fragment detector. Both the amplitudes and time separation of these pulses were adjusted to provide a pulser peak in the upper portion of each of the recorded distributions. These fictitious events were easily identified and removed from the fission data in subsequent analysis.

A set of Styroflex [10] delay cables was used to determine the absolute time-calibration of this system. Pulse delay times of these coaxial cables were measured to an accuracy of ± 0.1 ns by a technique similar to one previously described [11].

3. System Performance

Prior to the accumulation of the correlated data, the energy and time resolution of this system were investigated. For the first of these measurements the 350 cm², 950 ohm-cm surface barrier detector was operated on the plateau of the pulse-height versus bias curve with ~ 200 pF capacitance. With the fast timing system connected and operating, the measured energy resolution for ²³⁵U and ²³⁹Pu alpha particles was less than 200 KeV, full-width at half-maximum. Previous measurements [1] with accelerated bromine and iodine ions (artificial fission fragments) have shown that the resolution of these detectors is approximately one to two MeV (FWHM). Since the present width is negligible compared to the fragment energy resolution of these detectors for fission fragments, the energy data of this experiment are insignificantly affected by the addition of the fast timing circuit.

The time resolution of this system was obtained from a comparison of the measured and intrinsic time spectra for a flight path of ~ 8 cm. To obtain the intrinsic spectrum, the time scale of published data [12], taken with a 182.5 cm flight path and 3.1 ns time resolution, was corrected so as to correspond to this shorter distance. An example of this comparison for the 350 cm² detector mounted on the electron-detector side of the source is shown in Fig. 2. In this case the time resolution was estimated to have been 0.6 ± 0.1 ns (FWHM) and the "time walk" of the heavy fragment group was less than 0.2 ns.

4. Data acquisition and analysis

4.1 Zero-time measurements

The response of each timing system for a nearly zero fragment flight time was determined by positioning the surface barrier detectors a distance of 0 cm from the electron detector or source. The time spectrum for fragments incident on the smaller surface barrier detector located on the electron detector side of the source is shown in Fig. 3a. Figure 3b is the time distribution of the complementary fragments incident on the other detector. Similar measurements were made with the positions of the detectors interchanged. These results provided an estimate of the time resolution of the two timing systems as well as the required zero-time values. The latter were obtained from the average values of the peaks and an extrapolation to zero flight paths. Measured time resolutions were 0.6 ns and 1.3 ns for the timing system associated with the smaller and larger detectors, respectively.

4.2 Correlated velocity and pulse-height measurement

The data recorded were the outputs of the two time-to-pulse height converters and the pulse heights from the smaller surface barrier detector for ^{85}Kr fission events. For these measurements the detector orientation shown in Fig. 1 was used. The smaller detector faced the ^{85}Kr deposit with a flight path of 39.7 cm and the larger detector was positioned at a distance of 37.3 cm from the center of the nickel foil mounted in the electron lens. Thus the flight times and pulse heights obtained from the smaller detector were those associated with unreflected fragments. Velocity loss corrections were however required for the complementary fragments which were incident on the other detector and slowed by the two nickel foils. These corrections were obtained from the data of Waghstone [12] and the assumption of a linear dependence of velocity loss on foil thickness; they were 5.9 and 6.8 percent for the light and heavy fragments, respectively.

Velocities of the fragment pairs were obtained from the recorded data, zero-time values, and the flight paths. Since the neutron emission time of about 10^{-14} s [14] is small compared with the fragment flight times of 50 to 50 ns in this experiment, the measured quantities were the velocities after neutron emission. It has been shown [2], however, that the neutron angular distribution is approximately isotropic in the center-of-mass system of the fragment. Therefore on the average fission fragment velocities are essentially unchanged by neutron emission. Thus the measured final velocities were considered to be the fragment

velocities before neutron emission, with an increased velocity dispersion for each prompt neutron emitted in addition to the instrumental dispersion. Since the dispersions associated with these quantities are unequal, it will be useful to distinguish between all pre- and post-neutron emission parameters with capital and lower case symbols, respectively. Conservation of momentum and mass number yield the relations between the initial masses and velocities of the two fragments: $M_1 V_1 = M_2 V_2$ and $M_1 + M_2 = M$, where M is the mass number of the fissioning nucleus. The initial mass and energy of each fragment incident on the smaller surface barrier detector are given by $M_1 = M / (1 + V_1/V_2)$ and $E_1 = M_1 V_1^2 / 2$. Similar equations yield the energy of the complementary fragment, E_2 , and the total kinetic energy of the event, E_K , is given by $E_K = E_1 + E_2$.

4.3 Detector calibration

To obtain the pulse-height-to-energy calibration of this detector for fission fragments the published [8] dependence of $\bar{V}(M_1, E_K)$ on initial mass and total kinetic energy for ^{252}Cf was used. For each fragment incident on the detector the final mass and energy were obtained from the relations $M_1 = M_2 - \bar{V}(M_1, E_K) M_n$, where M_n (neutron mass) is taken to be unity, and $E_1 = M_1 V_1^2 / 2$. These values together with the recorded pulse height, P_1 , were used to obtain the average pulse height for various final masses and energies. These results uncorrected for dispersions and the finite width of the mass and energy intervals (2.7 units) are shown in Fig. 4. The data indicate a linear dependence of pulse height on energy for fragments of constant mass and are well represented by a family of nearly parallel straight lines in the pulse-height, energy plane. Slopes and intercepts of the lines shown were obtained by a least-squares fit of the observed data. In a manner previously described [19], these values were corrected for dispersions and the dependence of the average energy on fragment mass. The corrected slopes and energy intercepts when plotted versus fragment mass are consistent with a calibration function represented by a nearly constant slope and an intercept increasing linearly with mass of the form $E = (a_1 + a_2 m) P + (b_1 + b_2 m)$ proposed by Schmitt et al [3].

Corrected slopes and intercepts for the masses 99.1 and 147.7 were used to obtain the four constants in this expression. Energies corresponding to the average pulse heights of the light and heavy groups were then found for these two fragment masses. In this determination the average pulse heights were obtained from a least squares fit of two Gaussian distributions to the observed pulse-height spectrum. The energies so determined were as follows:
 $E_L(147.7) = 118.47 \text{ MeV}$; $E_H(147.7) = 51.20 \text{ MeV}$; $E_L(99.1) = 103.40 \text{ MeV}$; $E_H(99.1) = 72.74 \text{ MeV}$.

4.2 Post-neutron emission parameters

With a given detector calibration, the present data may be analyzed to obtain the final masses and energies of the fragments incident on the smaller detector. These values were found for each fission event by a solution of the following equations: $\epsilon_1 = m_1 v_1^2/2$ and $\epsilon_1 = (a_1 + a_2 m_1)P_1 + b_1 + b_2 m_1$. In addition the mass differences were obtained for each event, $v_1 = (M_1 - m_1)/M_1$ and the average value of v was found as a function of initial mass, $\bar{v}(M)$. For this analysis the detector calibration described by Schmitt et al [3] and the one given in section 4.3 were used.

5. Results and discussion

A pulse-height-to-energy calibration based on the response of semiconductor detectors to accelerated krypton and iodine ions [3] was used to obtain the post-neutron emission parameters. Initial and final energy distributions of the fragments incident on the smaller detector are shown in Fig. 5. The distortion of the energy spectrum by neutron emission is evident. Also shown is the increased energy shift of the light fragments which is consistent with the larger energy per nucleon of these fragments. This feature has been discussed previously by Terrell [4].

Shown in the lower part of Fig. 5 are the initial and final mass distributions of fragments incident on the smaller detector. As is evident from the relative areas of the two peaks in the initial distribution, the light and heavy fragments were recorded with slightly different efficiencies. This small difference, which is presumably caused by preferential scattering of the heavier fragments in the nickel foils, is of little consequence. Here these distributions represent the same fission data analyzed by different procedures. The initial mass distribution exhibits most of the known deviations [13] from a smooth curve and a hint of another heavy mass pair 95-157. This discontinuity corresponds to the weak structure at mass 156 reported by Froese et al [16] for $^{235}\text{U} + n$ and ^{235}Uf and also by Thomas and Vandeweyer [17] for $^{235}\text{U} + n$, $^{233}\text{U} + n$, $^{239}\text{Pu} + n$. These investigators have shown that the perturbations of the mass yield curve are related to the even-odd structure of the mass surface which results in a larger energy release for even-even products than for odd-odd fragments. Consequently the even-even fragments may share a larger excitation energy than the odd-odd products. Corresponding discontinuities are reflected in the displaced, final mass distribution in most instances.

The average number of neutrons emitted as a function of fragment mass, $\bar{v}(M)$, is shown in the upper part of Fig. 6. Included for comparison are the

results of Bowman et al [3] (dashed line) and Terrell [4] (solid line) for $\bar{v}$. The general mass-tooth dependence of $\bar{v}$ on mass is well reproduced in these results. Although the present values are high in the region of the light fragments, they indicate a possible peak of the neutron yield near mass 99, a leveling off in the mass region 135 to 145, and a dip at mass 152 in general agreement with previous determinations. The root-mean-square deviation of these results from published values [4] is less than 0.7 of a neutron.

5.2 Calibration based on fission data

The detector calibration given in section 4.3 was also used with these data. A final energy distribution with characteristics similar to the one shown in Fig. 3 was obtained.

Shown in the lower part of Fig. 7 is the final mass distribution obtained with this calibration. For comparison the same initial mass distribution derived from the velocity measurements is repeated. Although they are less pronounced, discontinuities are observed in the final distribution which reflect the preferred yields in the initial mass distribution.

Values of $\bar{v}(M)$ in the upper part of Fig. 7 exhibit the same general trends as the previous results, but are in better agreement with the published data. This better agreement is undoubtedly caused by the additional constraints placed on the $\bar{v}$ values at the masses (99.1 and 147.7) selected for this calibration procedure. An enhanced neutron yield in the vicinity of mass 99, a leveling off in the region of masses 135 to 145, and a dip at mass 153 are again evident in these results obtained with this different detector calibration.

6. Conclusions

The crucial item in the extension of the double-velocity technique to determine the post neutron emission parameters as well as the initial quantities appears to be the pulse-height-to-energy calibration of the surface barrier detectors. Further studies with a variety of fissioning nuclei will be required to obtain a sufficiently accurate universal calibration procedure which would allow the precise determination of the absolute values of $\bar{v}(M)$. The credibility of the calibration given in section 4.3 must still be established for fragments of widely different masses and energies from those encountered in this measurement.

In the absence of this universal function however it is possible by means of this technique to obtain useful and interesting information regarding the qualitative features of the post neutron emission parameters of the fission process.

process. With the aid of constraints on $\bar{\nu}(M)$, obtained from measured or calculated values of the total number of neutrons emitted either as a function of mass ratio or averaged over-all fission modes, it should be possible to obtain final parameters and $\bar{\nu}(M)$ values as accurate as those given in this work for fission at low, moderate, or high excitation energies of the compound nucleus.

A possible correlation exists in these results between the enhanced neutron yield and the irregularities of the initial mass distribution. This may be an indication of the energetically favored even-even fragments sharing a larger than normal excitation energy.

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References

1. SCHMITT, H. W., WALTER, F. J., NEILER, J. H., MOAK, C. D., GIBSON, W. M., and THOMAS, T. D., ORNL Physics Division Annual Report, ORNL-3425 (1963).
2. BOWMAN, H. R., MILTON, J. C. D., THOMPSON, S. G., and SWIATECKI, W. J., Physical Review 129 (1963) 2133/2147.
3. SCHMITT, H. W., KYKER, W. E., and WILLIAMS, C. W., Physical Review, in press.
4. FERRILL, J., Physical Review 127 (1962) 880/904.
5. Oak Ridge Technical Enterprises Corporation, Oak Ridge, Tennessee.
6. STEIN, W. E. and LEACHMAN, R. B., The Review of Scientific Instruments 27 (1956) 1049/1050.
7. LANSFORD, J. B., The Review of Scientific Instruments 35 (1964) 1483/1485.
8. WEBER, W., JOHNSONE, G. W., and CRANBERG, L., The Review of Scientific Instruments 27 (1956) 166/170.
9. Cosmic Radiation Labs., Inc., Ballport, N. Y.
10. Phelps Dodge Electronic Products Corporation, North Haven, Connecticut.
11. McALEER, H. F., Electronics (January 13, 1961) 102.
12. MILTON, J. C. D. and FRASER, J. S., Physical Review 111 (1958) 877/885.
13. WHETSTONE, S. L., Physical Review 131 (1963) 1232/1243.
14. FRASER, J. S., Physical Review 88 (1952) 536/541.
15. STEIN, W. E. and WHETSTONE, S. L. JR., Physical Review 110 (1958) 476/484.
16. FRASER, J. S., Milton, J. C. D., BOWMAN, H. R., and THOMPSON, S. G., Canadian Journal of Physics 41 (1963) 2080/2097.
17. THOMAS, T. D. and VANDERBOSCH, R., Physical Review 133 (1964) B976/B982.

Figure Captions

- Fig. 1 -- Block diagram of the apparatus used in the simultaneous measurement of fission fragment velocities and detector pulse height. Position and orientation of the surface barrier detectors were changed for the zero-time measurements. Abbreviations are: T.D. Disc = Tunnel diode discriminator; ADC = Analog-to-digital converter.
- Fig. 2 -- Time spectrum obtained with a 300 cm^2 , 950 ohm-cm surface barrier detector located on electron-detector side of the apparatus. Flight path was 8 cm. The intrinsic time spectrum (dashed curve) was from Ref. 12.
- Fig. 3 -- Time spectra from one of the zero-time measurements. The smaller detector was on the electron-detector side with 8.4 cm flight path and the larger detector was 7.4 cm from the source. Parts (a) and (b) refer to time spectra obtained from timing circuits associated with the smaller and larger detectors, respectively.
- Fig. 4 -- Energy versus pulse height relation of the smaller surface barrier detector for fission fragments. Lines represent least squares fits to a linear function for selected fragment masses.
- Fig. 5 -- The observed energy distributions. Solid circles represent the initial energy spectrum obtained from the time-of-flight data. Open circles are the final energy spectrum obtained from these data and the detector calibration of Ref. 3.
- Fig. 6 -- Mass distributions and average number of neutrons $\bar{\nu}(M)$. Detector calibration was from Ref. 3.
- Fig. 7 -- Mass distributions and average number of neutrons $\bar{\nu}(M)$. Detector calibration was from section 4.3.

Figure 1

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