AD-762 746

FISSION YIELD DETERMINATIONS

C. Fred Moore, et al

Texas University

Prepared for:

Office of Naval Research
Advanced Research Projects Agency

1 January 1973

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SEMI-ANNUAL REPORT

FISSION YIELD DETERMINATIONS

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Form Approved Budget Bureau No. 22-R0293

Program Code Number	OF10
ARPA Order Number	1571
Name of Contractor	The University of Texas at Austin
Date of Contract	1 January 1973
Contract Number	N00014-67-A-0126-0012
Amount of Contract	$120,000
Contract Expiration Date	31 December 1973
Short Title of Work	Fission Yield Determinations
Principal Investigators	C. Fred Moore, Professor of Physics
	G.W. Hoffmann, Assistant Professor of Physics

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I. INTRODUCTION

This is a report on the activities pursued during the first six months of the fourth year contract "Fission Yield Determinations". During this period, test and calibration experiments have been conducted with our electrostatic particle guide. Most of the present effort is being devoted to the extraction of fission mass yields from energy-time-of-flight coincidence experiments. Simple analyses of the raw data obtained thus far indicate that planned modifications and more sophisticated analysis techniques will allow the extraction of fission mass yields with good mass resolution. Modifications to the apparatus needed to study neutron-induced fission and to extract isotopic fission yields are now in the planning stage.

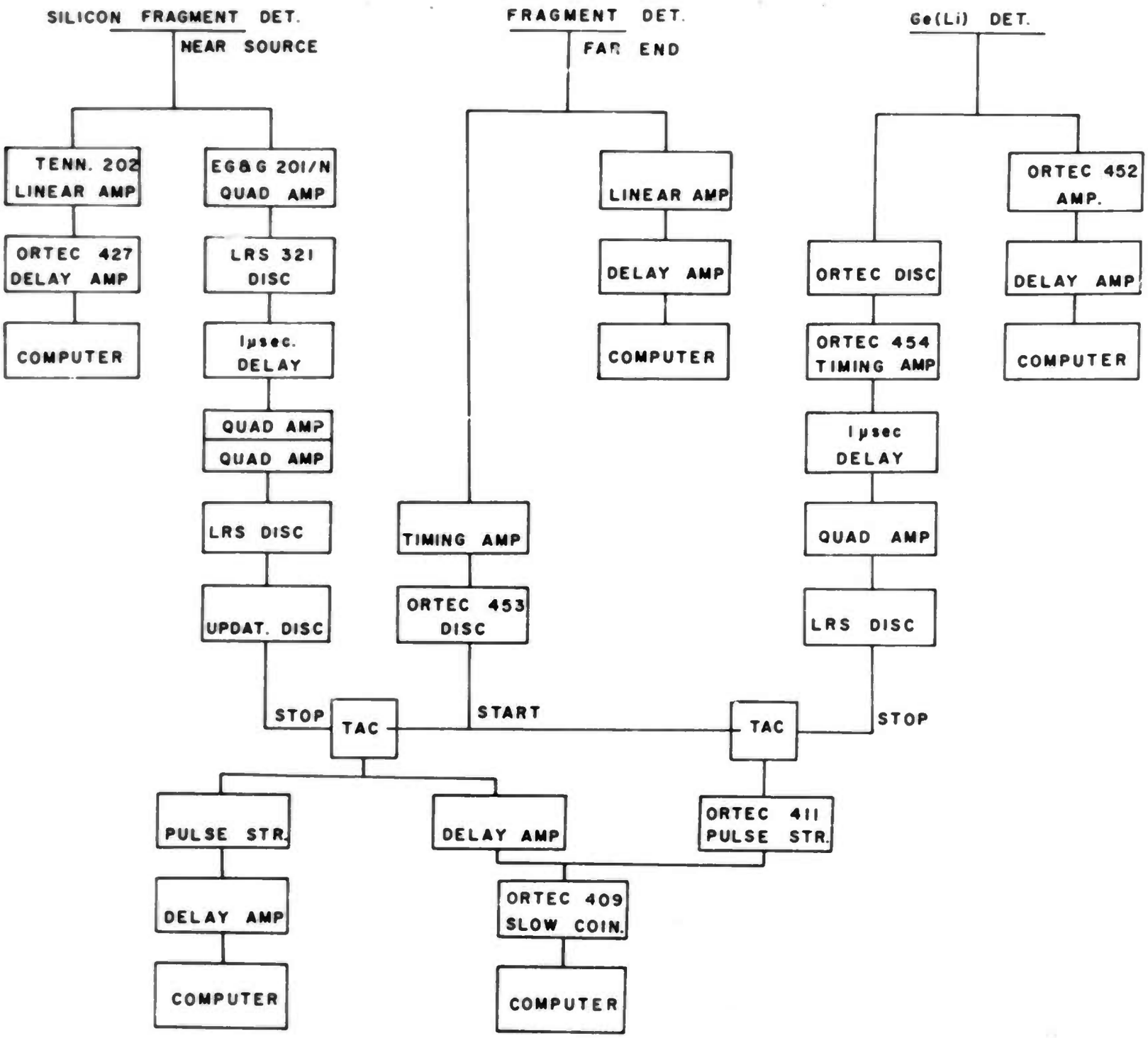
II. DETERMINATION OF FISSION MASS YIELDS

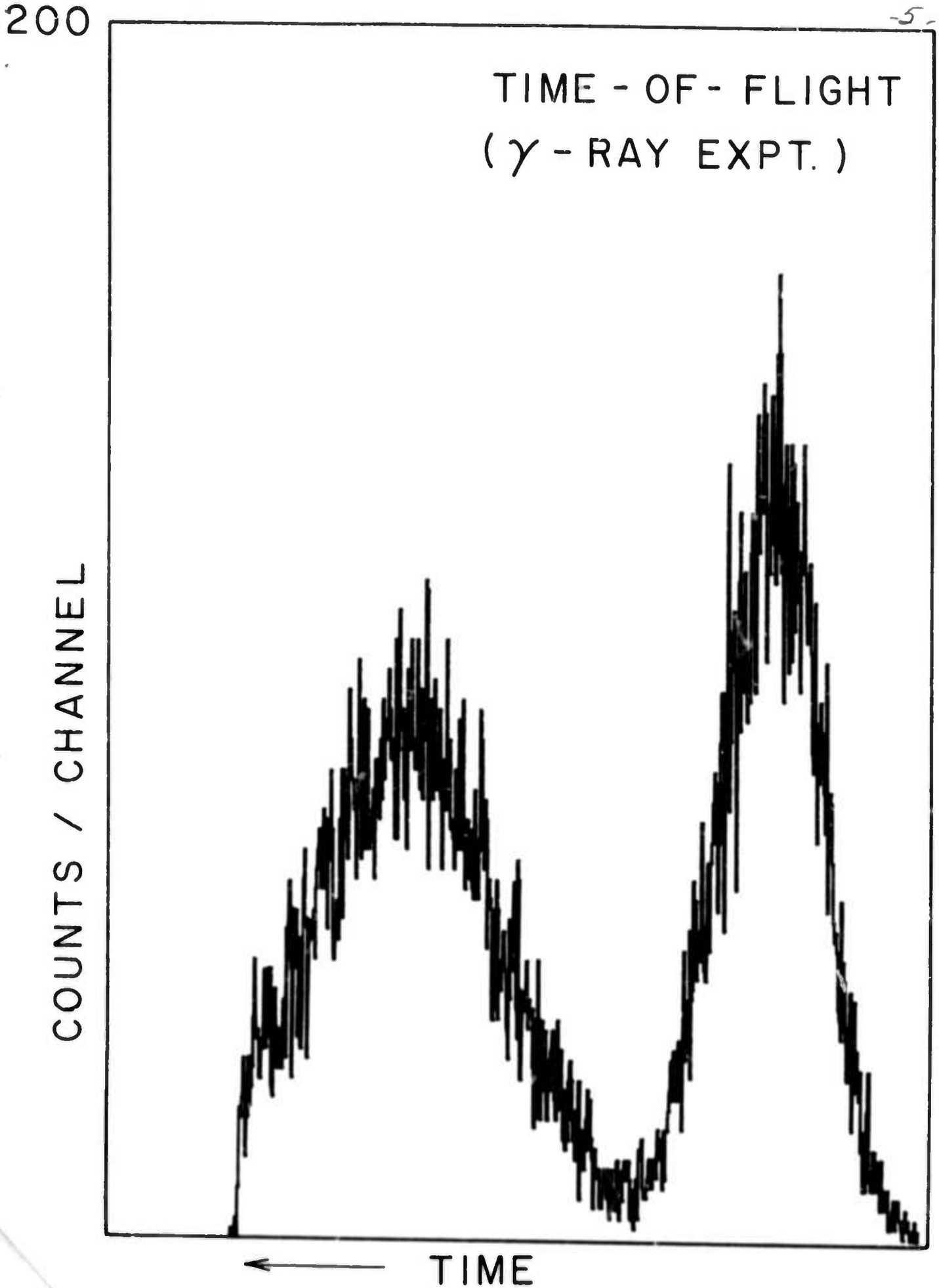
Post-neutron mass distributions (for binary or tertiary fission) can be determined by measuring the time-of-flight of one of the fragments over some distance and its kinetic energy. In order to obtain a mass resolution (FWHM) of 1 amu so that quantized A yields may be unfolded from the experimental mass spectrum with a great degree of certainty, a long flight path and a large solid angle are needed. These seemingly contradictory requirements can be obtained by use of an electrostatic particle guide [Oakey and MacFarlane, Nucl. Instr. Methods 49, 220 (1967)]. A particle guide, of modified construction relative to that of Oakey and MacFarlane, has been constructed and is in use at the Center for Nuclear Studies of the University of Texas at Austin. The design, performance, and characteristics of this particle guide have been reported in previous Annual Reports of this contract.

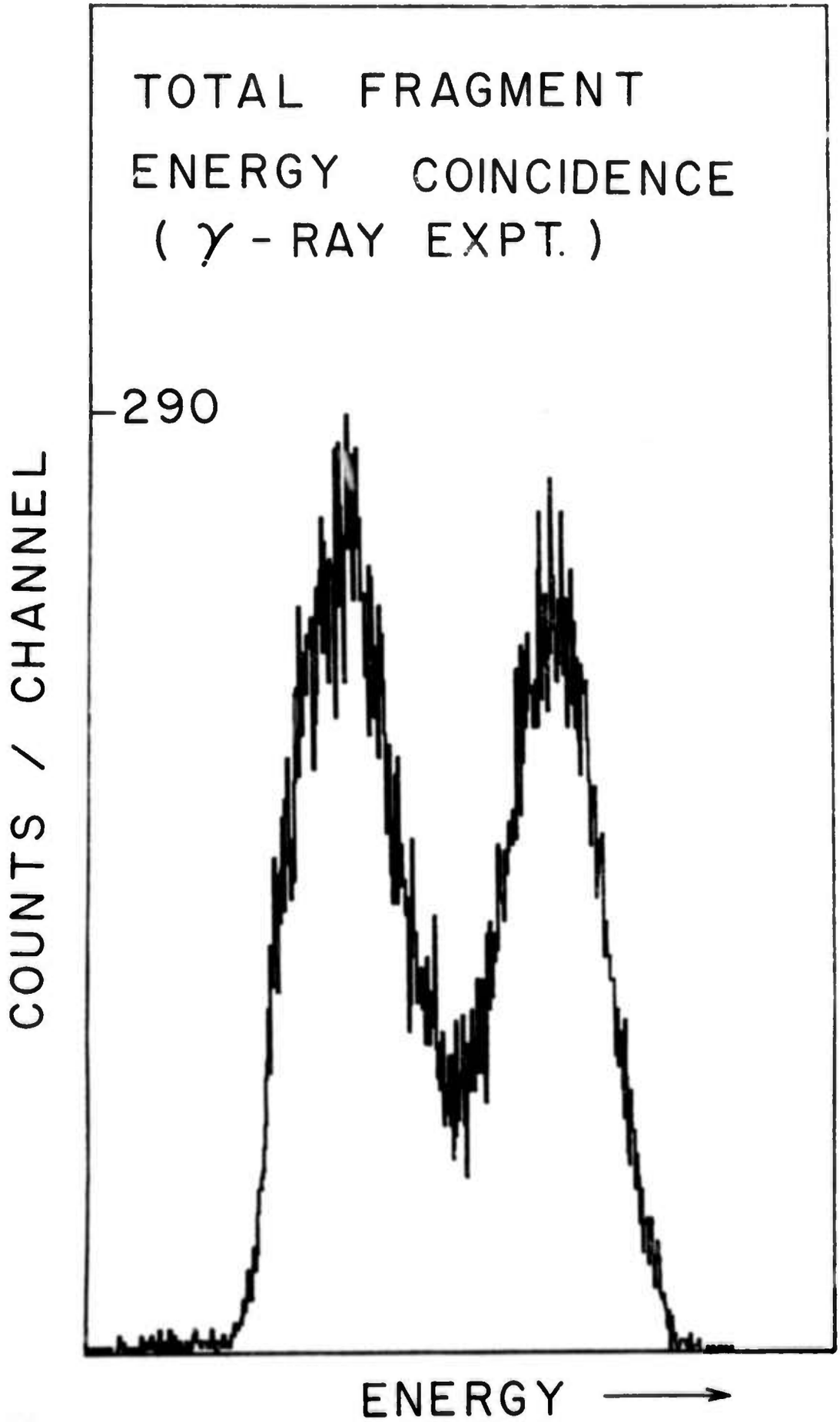
During the last seven months two triple-coincidence experiments have been performed to test and calibrate the particle guide. A 0.09 μg ^{252}Cf source was positioned on the horizontal axis of the guide. A Si surface-barrier detector, mounted inside the target chamber, was located directly behind the source; while a low-energy photon detector, located outside the vacuum-tight target chamber, was positioned to look at the target. An ORTEC 130 fission-fragment detector was positioned,

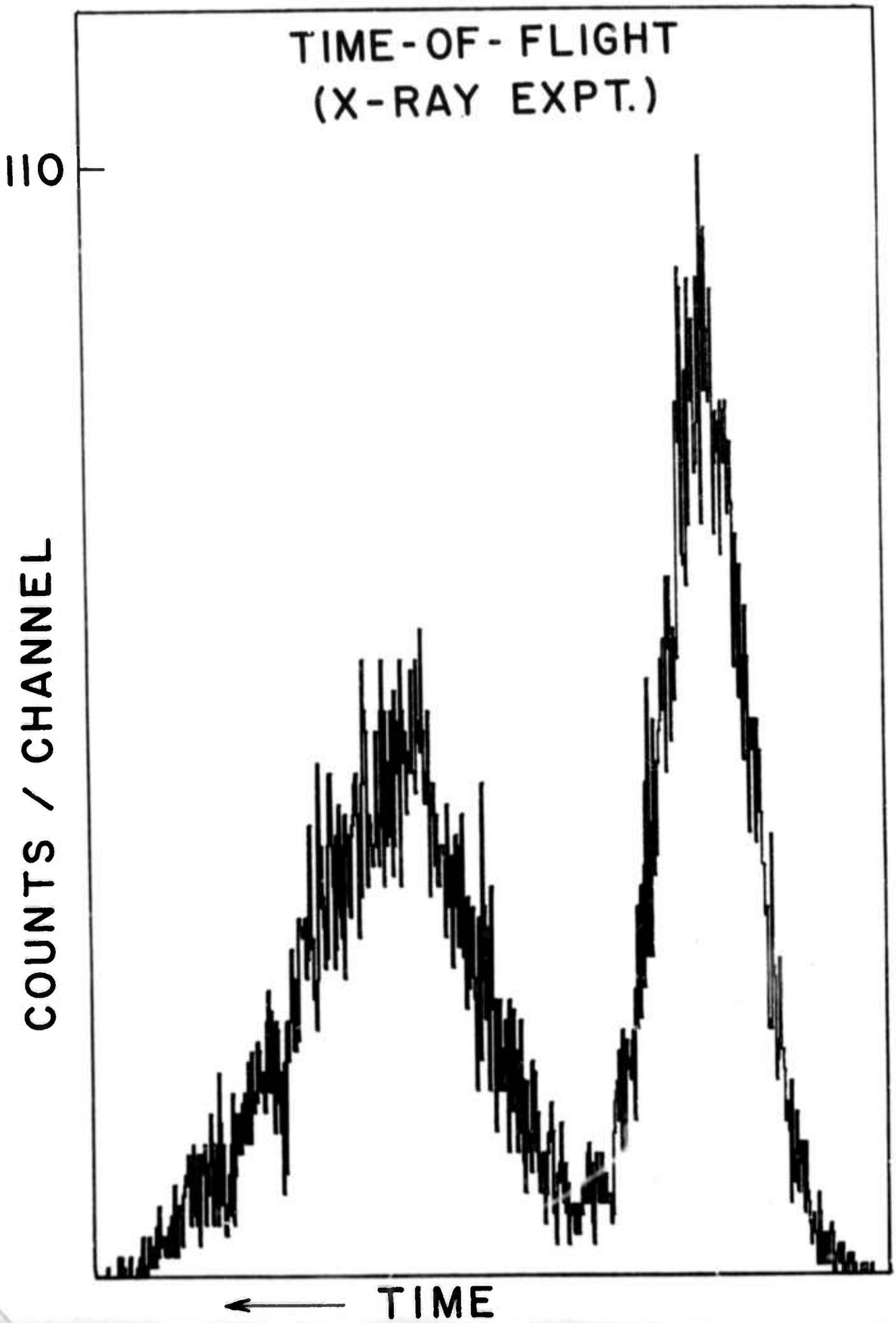
on axis, at the far end of the particle guide. All three detectors were cooled: the fission-fragment detector by ice water, the surface-barrier detector by dry ice, and the photon detector by liquid nitrogen. The time signal from the fission-fragment detector was delayed and used as a start signal. The stop signal was obtained from the surface-barrier detector. A triple coincidence was required between the two particle detectors and the photon detector. The resultant count rate for these triple-coincidence experiments was approximately one count per minute. The time-of-flight and energy (derived from the fission-fragment detector) of the fragment traversing the guide, as well as the photon energy (gamma ray of X-ray), were recorded on magnetic tape for off-line analysis. A schematic of the electronics circuitry used is given in Figure 1. The data were collected and analyzed (calculated total mass spectra and obtained gated spectra for gates set on peaks in photon spectra) by a PDP-15 computer.

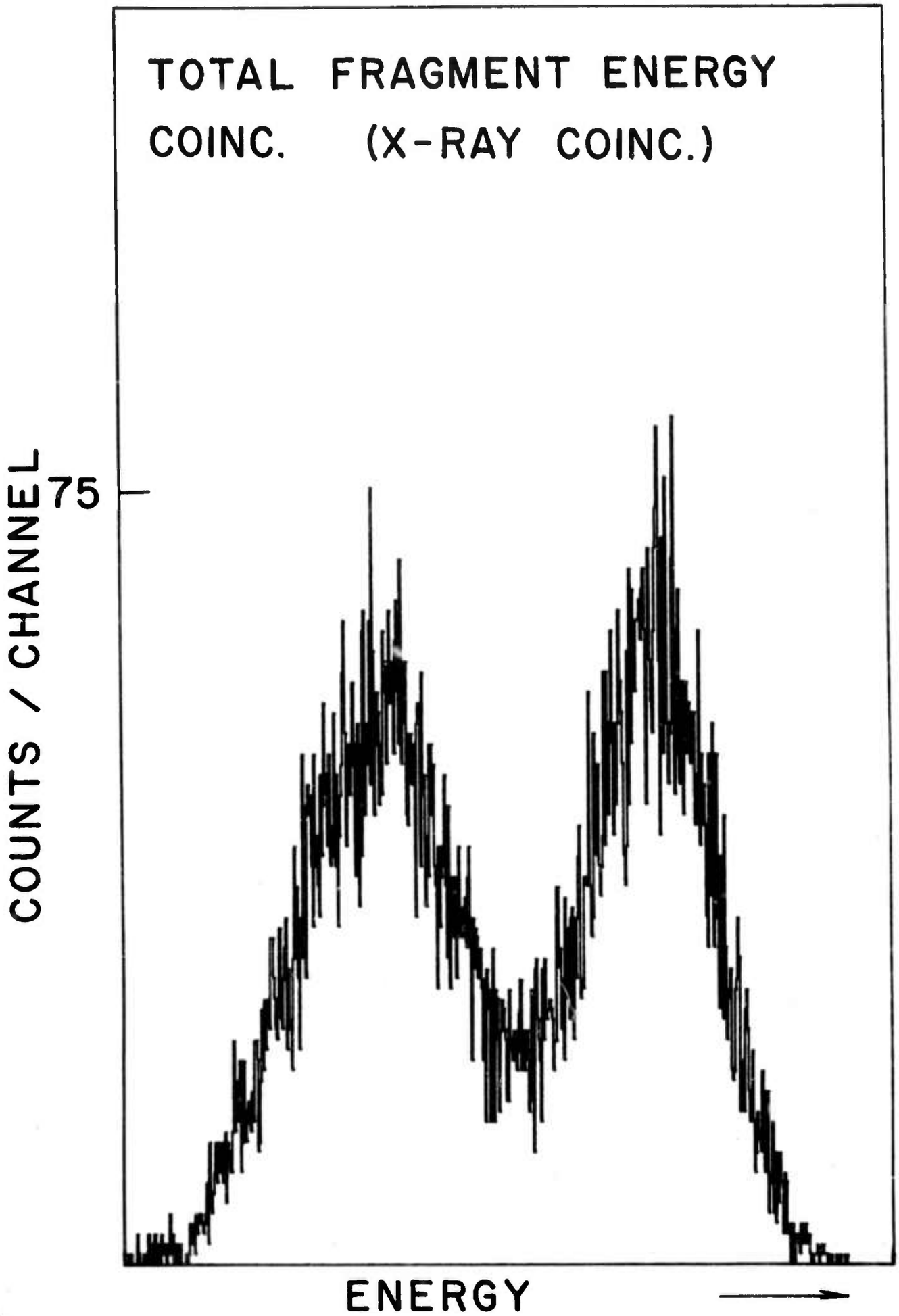
The raw data obtained in the two triple-coincidence experiments are shown in Figures 2-5. The time-of-flight and fragment-energy spectra for the γ-ray coincidence experiment are shown in Figures 2 and 3, while those for the X-ray coincidence experiment are shown in Figures 4 and 5. The raw data shown are uncorrected for the efficiency of the electrostatic particle guide. The transmission efficiency of the guide varies as q/E where q is the ionic charge and E is the


SILICON FRAGMENT DET.
NEAR SOURCE
TENN. 202 LINEAR AMP
ORTEC 427 DELAY AMP
COMPUTER
EG&G 201/N QUAD AMP
LRS 321 DISC
1μsec. DELAY
QUAD AMP
QUAD AMP
LRS DISC
UPDAT. DISC
STOP
FRAGMENT DET.
FAR END
LINEAR AMP
DELAY AMP
COMPUTER
TIMING AMP
ORTEC 453 DISC
START
Ge(Li) DET.
ORTEC 452 AMP.
DELAY AMP
COMPUTER
ORTEC DISC
ORTEC 454 TIMING AMP
1μsec DELAY
QUAD AMP
LRS DISC
STOP
TAC
TAC
PULSE STR.
DELAY AMP
COMPUTER
DELAY AMP
ORTEC 411 PULSE STR.
ORTEC 409 SLOW COIN.
COMPUTER


200
TIME - OF - FLIGHT
(γ - RAY EXPT.)
COUNTS / CHANNEL
TIME


TOTAL FRAGMENT
ENERGY COINCIDENCE
(γ - RAY EXPT.)
290
COUNTS / CHANNEL
ENERGY


TIME-OF-FLIGHT
(X-RAY EXPT.)
110
COUNTS / CHANNEL
TIME

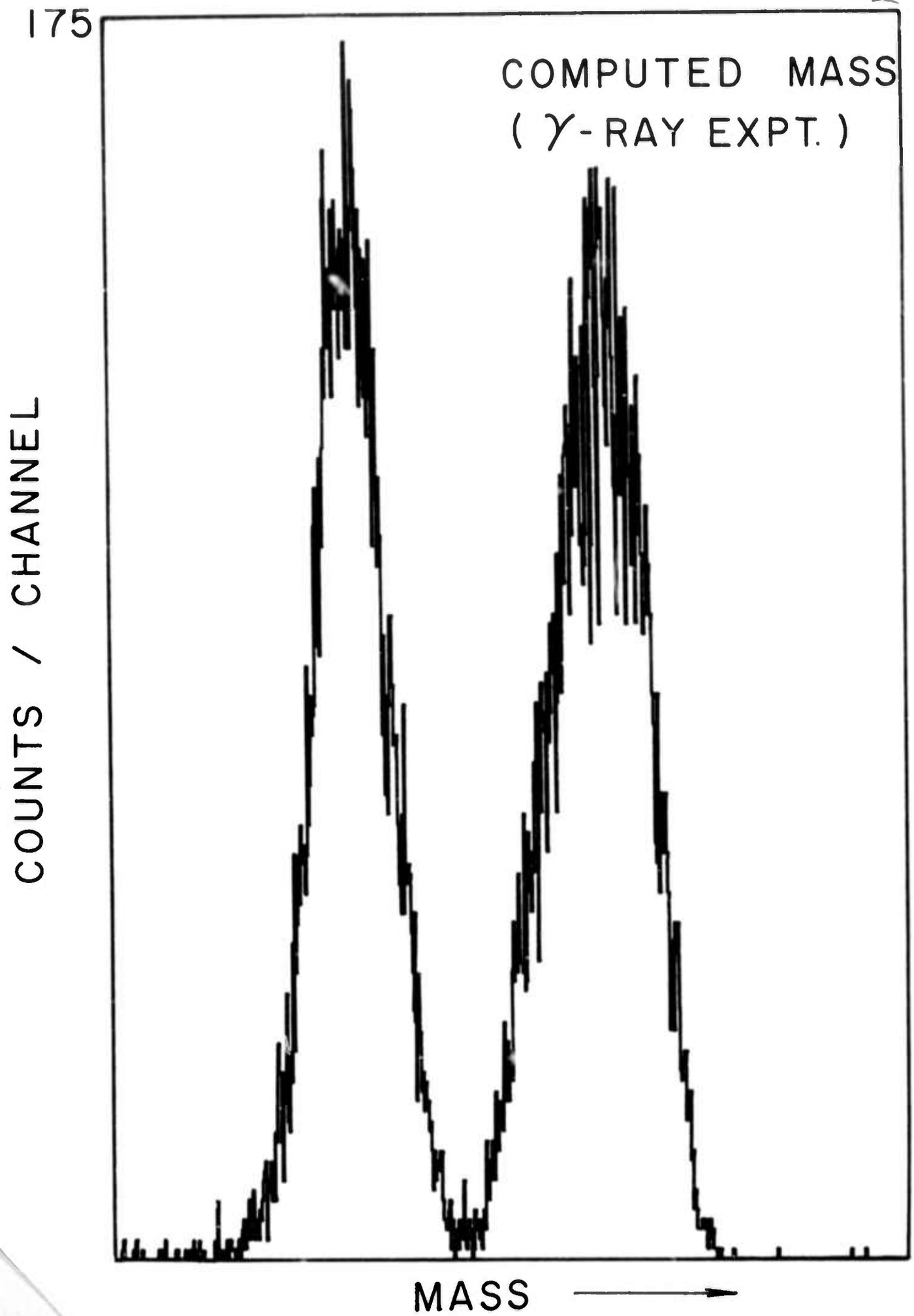

TOTAL FRAGMENT ENERGY
COINC. (X-RAY COINC.)
COUNTS / CHANNEL
75
ENERGY

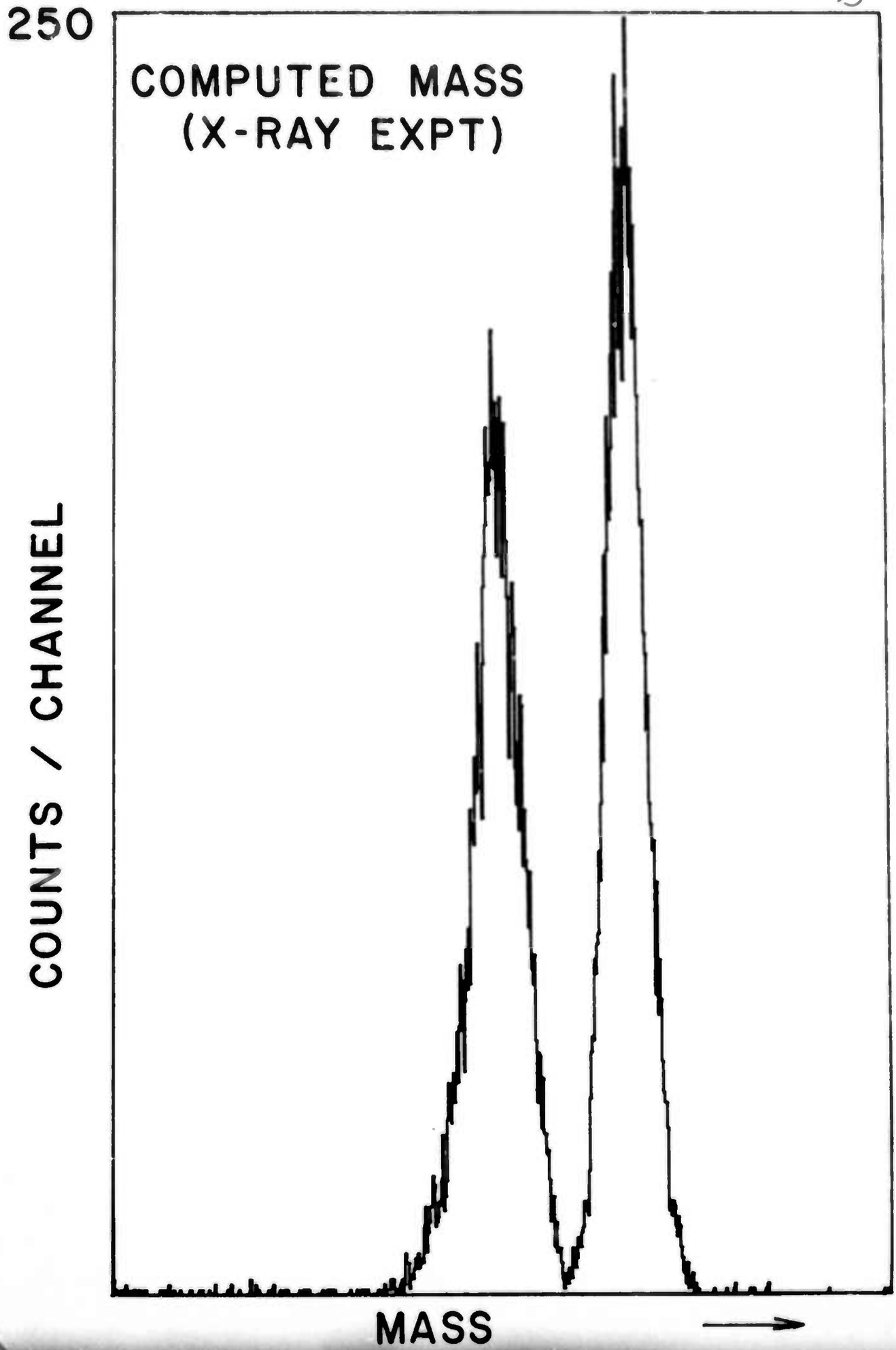
kinetic energy of the fission fragment. For the mean energies, the guide collects the heavy fission fragments roughly 1.75 times more efficiently than it collects the light fission fragments. This effect is clearly evident when Figures 2 and 3 are compared to the corresponding absolute spectra in Schmitt et al. [Phys. Rev. 137, B837 (1965)]. Such a comparison shows that the peaks for the longer times and lower energies (corresponding to the heavier masses) are enhanced in the present raw data, as expected from the variation of the guide's efficiency. For example, the total yield in the low-energy peak is roughly 1.6 times greater than that in the high-energy peak.

When intercomparing the time-of-flight and fragment-energy spectra of the two coincidence experiments, it is not necessary to take into account the efficiency of the particle guide. However, a difference between the spectra would be expected since there is a direct correlation between the X-ray energy and the Z of the fission fragment (no such correlation between a range of γ-ray energies and the M or Z of the fission fragment exists) and it has been established [Watson et al., Phys. Rev. C 1, 1866 (1970)] that, per fission, the heavy fission fragments emit twice as many K-X-rays as the light fission fragments. In the present experiment, however, this difference was cancelled by the fact that the low-energy photon detector used was twice as efficient for X-rays in the light-mass

region as for X-rays in the heavy-mass region. (This was determined by summing the number of X-rays in both ranges in a singles γ-ray spectrum accumulated with the same detector and electronics. It was found that the heavy-mass region contained approximately 5% fewer X-rays than the light-mass region.) Thus, it is to be expected that the time-of-flight and fragment-energy spectra for the two coincidence experiments should be quite similar. However, when the fragment-energy spectra are compared, it is found that the enhancement of the low-energy (heavy-mass) peak with respect to the high-energy (light-mass) peak is 60% for the γ-ray experiment but only 10% for the X-ray experiment. The same situation is found for the time-of-flight spectra. In addition, the longer-time (heavy-mass) peak is shifted toward shorter times in the X-ray coincidence experiment relative to the γ-ray coincidence experiment (the shapes and widths of the peaks remain constant). On the other hand, when the light- and heavy-mass regions are summed in the coincidence X-ray spectra obtained (see Figure 9), it is found that the yield in the heavy-mass region is 45% greater than that in the light-mass region (as would be expected). This would seem to indicate that in the X-ray coincidence experiment there was a problem with the timing circuitry used. This possibility is now being studied.

The calculated mass spectra obtained by a simple analysis of the raw data from the triple-coincidence experiments are shown in Figures 6 and 7 (a different scale is used in the two figures). The mass is calculated by expressing the velocity in the kinetic energy equation in terms of the time-of-flight (T) of the fragment and the length (L) of the flight path: $M = 2ET^2/L^2$. For the calculations shown in the figures, the time scale was estimated using mean energies and masses for the light- and heavy-fragment peaks and the length of the flight path was measured mechanically. In the future the time scale will be calibrated electronically and the flight path will be measured using a new zero-time detector (see below) and alpha particles of known energy. In addition, the use of the zero-time detector will eliminate the fact that in the coincidence experiments performed there was a time delay in the stop signal due to the fact that the surface-barrier detector was located a finite distance behind the ^{252}Cf source. Another error which is introduced into the mass calculation is due to the fact that the real energy of the fission fragment is not simply proportional to the energy pulse height obtained from the fission-fragment detector. Schmitt et al. [Phys. Rev. 137, B837 (1965)] have proposed a general formula for the energy calibration of fission-fragment detectors of the form:


175
COMPUTED MASS
(γ-RAY EXPT.)
COUNTS / CHANNEL
MASS


250
COMPUTED MASS
(X-RAY EXPT)
COUNTS / CHANNEL
MASS

$$E = (a+a'M)\ X + b + b'\ M$$

where X is the observed pulse height in MeV and a,a',b, and b' are coefficients characteristic of the detector.

The difference between the real mass M and the instrumentally observed mass due to the pulse-height defect and the time delay in the stop signal can be written in the form:

$$\Delta M = M\left\{\frac{1}{E}\left(1 - \frac{SV}{LV_c}\right)^2 \left(\Delta X - \frac{b+b'M}{a+a'M}\right) - \frac{1}{a+a'M}\left[1 - \left(1-\frac{SV}{LV_c}\right)^2\right]\right\}$$

where

ΔX = pulse-height defect in MeV,

S = distance from source to surface-barrier detector,

V = velocity of fission fragment detected, and

V_c = velocity of complementary fission fragment.

The pulse-height increment which must be added to the observed pulse height is obtained by setting $\Delta M = 0$:

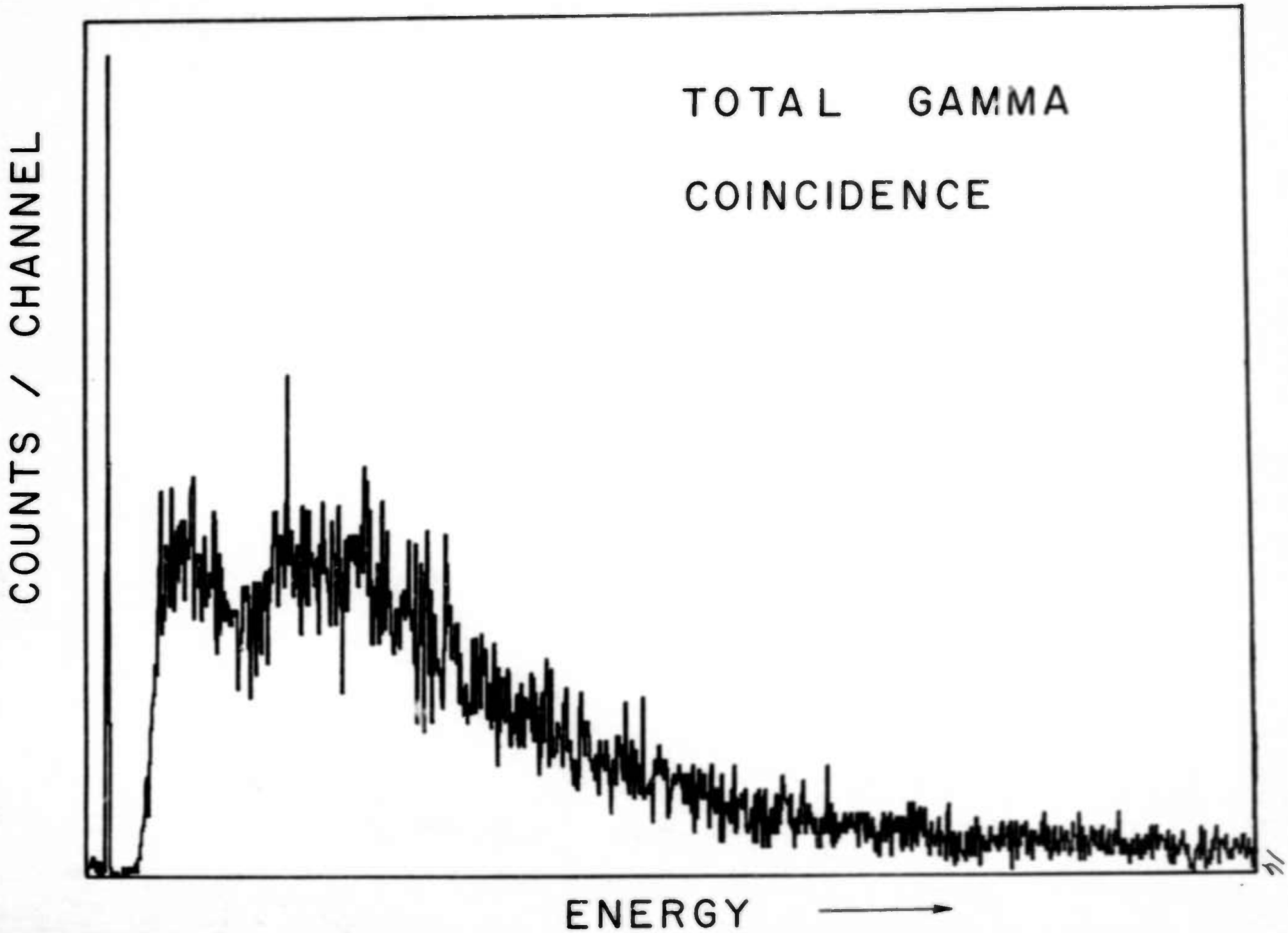
$$\Delta X_0 = \frac{1}{a+a'M}\left\{b + b'\ M + E\left[\left(1 - \frac{SV}{LV_c}\right)^{-2} - 1\right]\right\}.$$

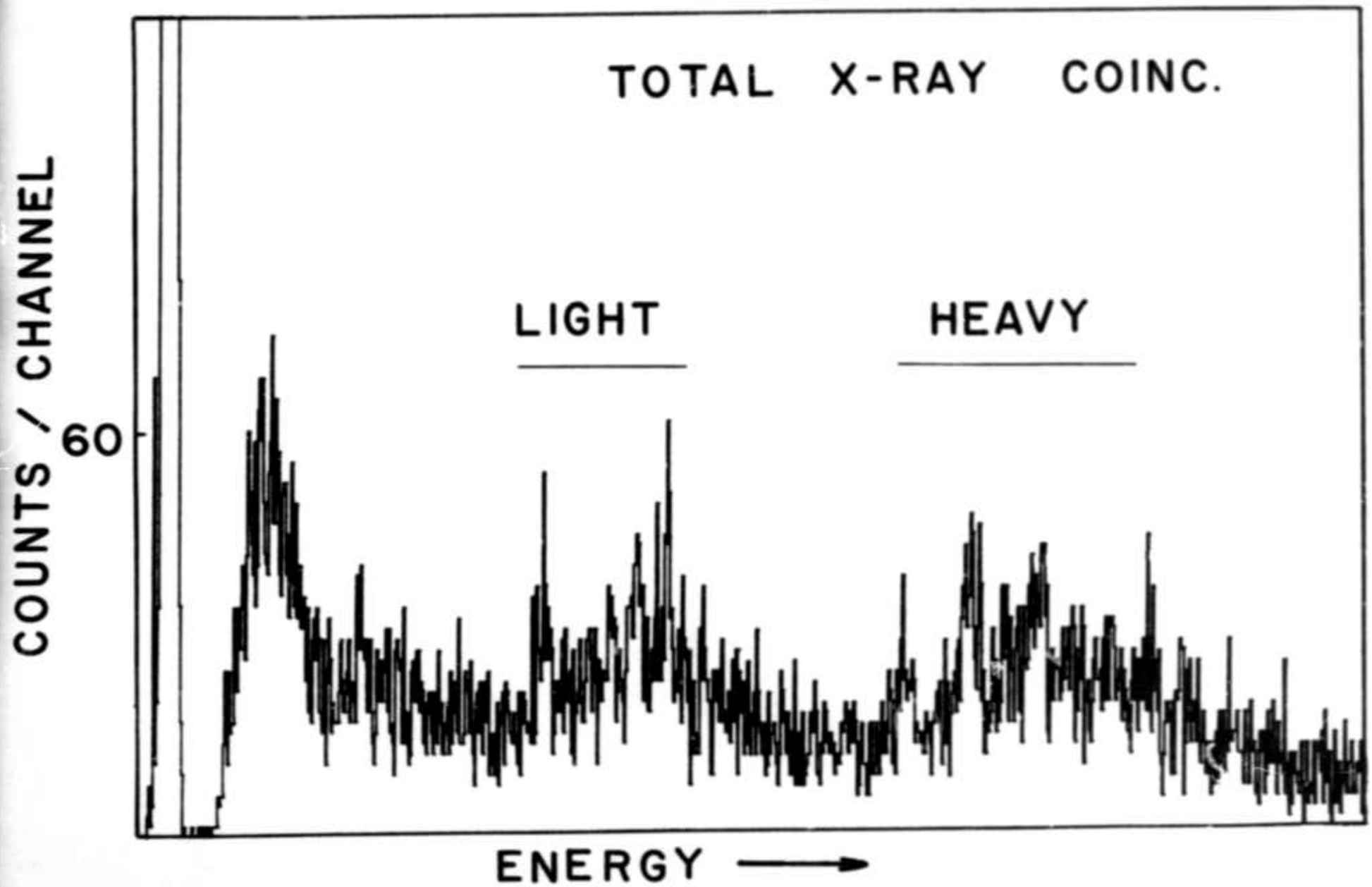
If the quantities M,E,V, and V_c are replaced by their mean values for each fission-fragment group , and if these mean values and the characteristic coefficients of the detector determined by Schmitt et al. are used, the pulse-height increment is calculated to be 5.1 MeV for the light fragments and 4.8 MeV for the heavy fragments (if the detector characteristic

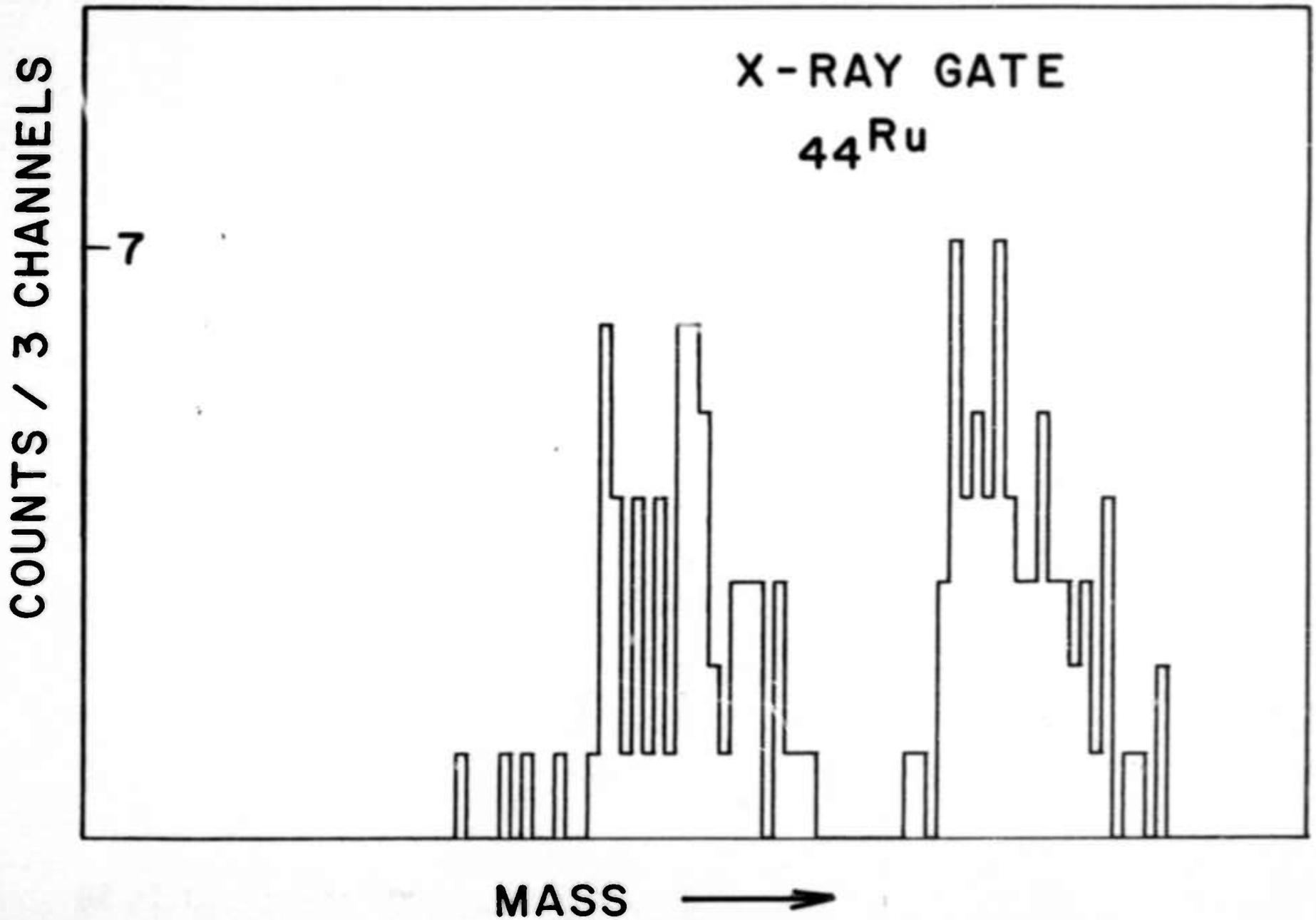
coefficients determined by Shiraishi and Hosoe [Nucl. Instr. Methods 107, 493 (1973)] are used, the corresponding pulse-height increments are 6.4 and 6.0 MeV). The fission-fragment detector being used for the present experiments will be calibrated using the method outlined by Schmitt et al. or by use of the data obtained from the gated photon spectra.

The coincidence photon spectra obtained in the two triple coincidence experiments are shown in Figures 8 and 9. The regions corresponding to light- and heavy-mass Kα-X-rays are indicated in Figure 9. An example of a gated X-ray spectrum is shown in Figure 10. The illustrated gate is set on the Ru(Z=44) Kα-X-ray. Previously, the following isotopes of Ru have been detected in ^{252}Cf(sf): 105,106,108,109,110,111, and 112. The spectrum shown was obtained by compressing the experimental spectrum by a factor of three. In this compressed spectrum, one channel corresponds to approximately 1 amu.

A new zero-time detector has been constructed and is being installed on the particle guide. This detector consists of a hemi-spherical mirror, a plastic scintillator, and a photomultiplier tube. The hemi-spherical mirror (a hemi-spherical piece of glass with tin evaporated onto it) has small holes in opposing sides for the fission fragments to pass through and is located in the target chamber between the source (target) and the particle guide. The mirror is positioned so


TOTAL GAMMA
COINCIDENCE
COUNTS / CHANNEL
ENERGY


TOTAL X-RAY COINC.
LIGHT
HEAVY
COUNTS / CHANNEL
60
ENERGY


X-RAY GATE
44Ru
7
COUNTS / 3 CHANNELS
MASS

that the beam holes are on the horizontal axis of the particle guide. The thin plastic film (scintillator) is supported from the apex of the mirror and the center of the film is colinear with the beam holes in the mirror. The photons created when a fission fragment traverses the thin plastic film are focused by the mirror onto the face of the photomultiplier (PM) tube. The PM tube views the open end of the mirror and is located outside of the target chamber. A schematic of this zero-time detector is given in Figure 11.

In the past the energy resolution of the fission-fragment detector has been degraded somewhat by oil collecting on the face of the detector when it was cooled. Before the X-ray coincidence experiment, the particle guide was completely dismantled and thoroughly cleaned. Heating strips were then wrapped around the outside of the guide. The strips were covered with insulating and reflecting material. The guide was baked out at a temperature of 180°F for several days before the X-ray coincidence experiment was performed. After six weeks of being cooled during the experiment, the detector was found to have only a small amount of oil deposited on it. A model 3102D Welch turbo-molecular pump has been purchased and is now being installed on the particle guide. Once this pump has been installed, the guide will be baked out again for several days. No further problems with oil deposition on the detectors are anticipated.

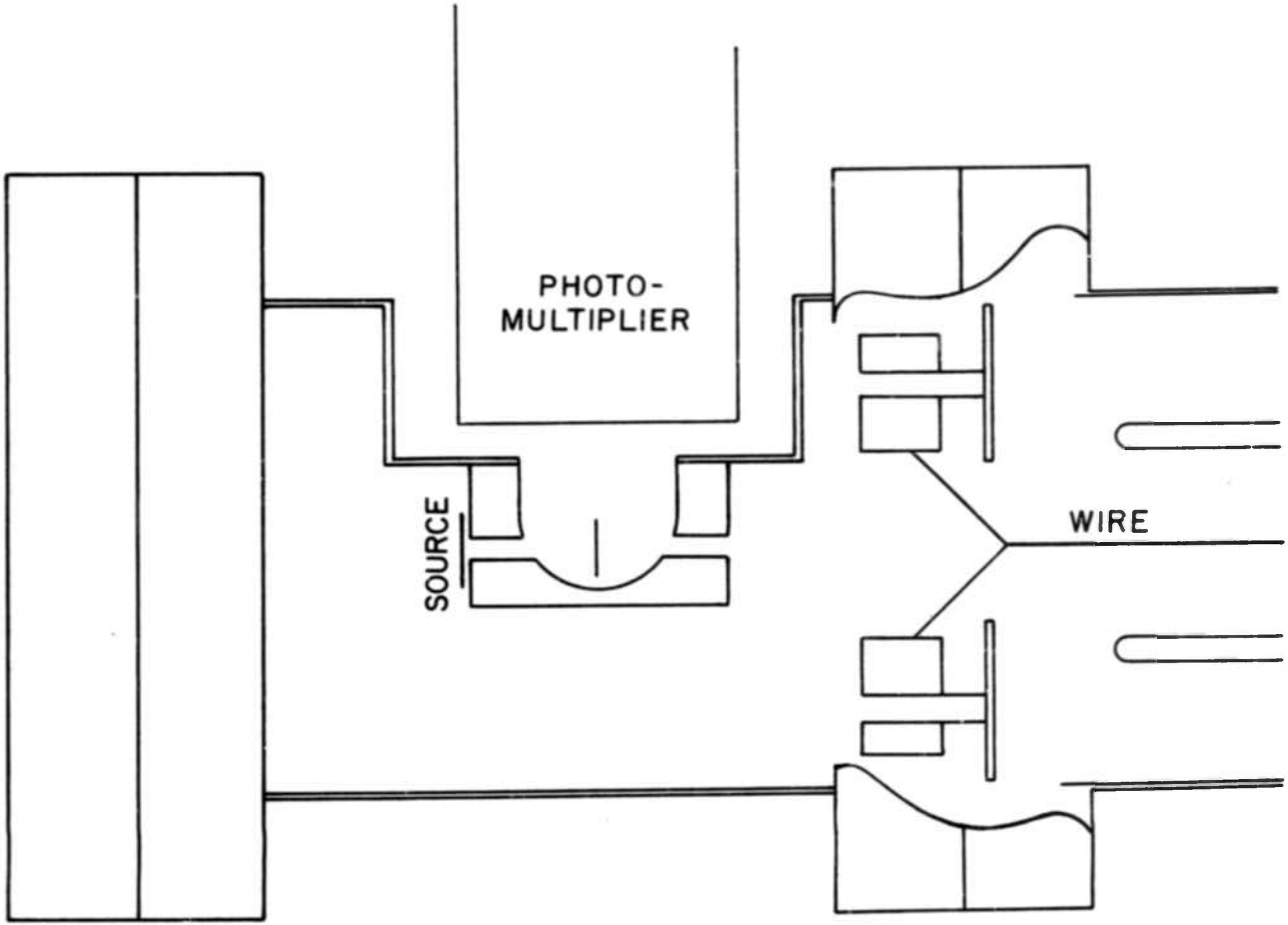


PHOTO-
MULTIPLIER
SOURCE
WIRE

III. NEUTRON-INDUCED FISSION

The goal of this project is to study the isotopic yields for neutron-induced fission of $^{235,238}U$ and ^{239}Pu. Once the experimental techniques to be used for the determination of fission mass yields have been tested completely and calibration experiments have been done using a ^{252}Cf source, experiments will be performed to extract the mass yields for neutron-induced fission of $^{235,238}U$ and ^{239}Pu. The loan of a 3.7 mg ^{252}Cf source has been obtained and the source is now in storage at the Center for Nuclear Studies. This source will be used as a neutron source for the neutron-induced-fission experiments. The modifications to the apparatus which are necessary for the performance of these experiments are now in the planning stage. Upon the successful completion of these neutron-induced-fission mass-yield determinations and of the perfection and calibration of experimental techniques to determine isotopic fission yields (see Section IV), experiments to study the isotopic yields for neutron-induced-fission of $^{235,238}U$ and ^{239}Pu will be undertaken.

IV. DETERMINATION OF ISOTOPIC FISSION YIELDS

The time-of-flight-energy measurements outlined in Section II only allow mass determination. In order to obtain isotopic fission yields, both charge and mass must be determined simultaneously by direct physical techniques involving the measurement in coincidence of fission-fragment parameters from which A and Z can be determined.

The obtainable resolution in photon spectroscopy is such that any characteristic X-rays emitted from the fission fragments may be experimentally observed to unambiguously identify the nuclear charge of these fragments. It has been established (see previous Annual Reports of this contract) that the X-rays emitted from the fission fragments shortly after the time of fission are due to nuclear de-excitation of the fragments via internal conversion. Since internal conversion probabilities are nuclear-structure dependent and the structure of the fission fragments is largely unknown, observation of the X-rays emitted immediately after the time of fission can yield information only on particular fission-fragment elements and can yield little, or no, information about elemental yields. However, it has also been established (see the last Annual Report of this contract) that when the fission fragments pass through a thin foil, electron vacancies are created in the

electron shells of the fission fragments. The X-rays (mainly L-X-rays) resulting from electron transitions to fill these vacancies can be observed by a high-resolution photon detector near the foil, and fluorescence yields (the probability that a vacancy in a given shell results in a radiative transition) can be obtained. Since the fluorescence yields have been measured experimentally and are understood theoretically, the extraction of fission charge yields should be possible.

The combination of the energy-time-of-flight technique discussed in Section II and the induced L-X-ray technique discussed above should make it possible to determine isotopic fission yields. The installation of a zero-time detector now makes it possible to install the X-ray-induction foil a short distance after the source (target) and before the zero-time detector. (This is due to the fact that the energy which must be known accurately is the energy the fission fragment has when it passes through the zero-time detector.) By requiring a triple coincidence between the induced X-ray, the zero-time detector, and the fragment detector at the end of the electrostatic particle guide, sufficient data to determine isotopic fission yields should be obtainable.

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VI. WORK STATEMENT

The contractor shall conduct research involving the measurement of prompt fission processes. This research shall include, but not necessarily be limited to the following:

A. Studies of the spontaneous fission of ^{252}Cf employing various combinations of multi-parameter coincidence experiments. Parameters may include fission fragment, X-ray, alpha particle, gamma-ray, time-of-flight, and neutron.

B. Studies of neutron-induced fission of $^{235,238}U$ and ^{239}Pu employing various combinations of multiple-parameter coincidence experiments described above, less the alpha particle measurements.

C. From an analysis of the above measurements begin a compilation of the total chain yield and the prompt isotopic yield ratios for fission of $^{235,238}U$ and ^{239}Pu as a function of neutron energy. Give priority to ^{235}U and ^{239}Pu fission mass distribution resulting from fission spectrum and 14 MeV neutrons.

VII. PERSONNEL

1 January 1973 to 31 June 1973

(a) NUCLEAR SCIENTISTS

C. Fred Moore, Professor (6 mo.*)	6 mo.
Gerald W. Hoffmann, Asst. Professor (6 mo.*)	6 mo.
Larry L. Lynn, Research Scientist Associate III	6 mo.

(b) PRE-DOCTORAL APPOINTMENTS (GRADUATE STUDENTS)

John R. White, Research Asst. I	6 mo.
Jeffry Fitch, Research Asst. I	6 mo.

(c) ENGINEERING/TECHNICAL STAFF

Mary George, Administrative Clerk (6 mo.*)	6 mo.
Bonnie Wolf, Secretary (5 mo.*)	5 mo.
Shannon Trad, Secretary (1 mo.*)	1 mo.
J. P. Coose, Technical Asst. IV	6 mo.
Kenric Speed, Laboratory Asst. II	5 mo.
Hunter Ellinger, Computer Programmer I (6 mo.*)	6 mo.
A. L. Mitchell, Research Engineer III (6 mo.*)	6 mo.

(d) LABORATORY STAFF (UNDERGRADUATE STUDENTS)

Roger Jordan, Laboratory Asst. I	5 mo.
Claude Camp, Laboratory Asst. II	6 mo.
Brian Cuthbertson, Laboratory Asst. II	1 mo.
Lester Smith, Laboratory Asst. II	1 mo.

*At no pay.