**Title**
GAMMA MY STUDIES ON THE DECAY CHAIN Zr86-->Y86u> Sr86



**Authors**
Hyde, E.K.
Florence, M.G.
Stephens, P.S.

**Publication Date**
1954-12-10

UNIVERSITY OF
CALIFORNIA

# Radiation Laboratory

BERKELEY, CALIFORNIA

## DISCLAIMER

UCRL-2813
Unclassified Chemistry

UNIVERSITY OF CALIFORNIA

Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

# GAMMA RAY STUDIES ON THE DECAY CHAIN

# $Zr^{86} \longrightarrow Y^{86} \longrightarrow Sr^{86}$

E. K. Hyde, M. G. Florence and F. S. Stephens

December 10, 1954

Printed for the U.S. Atomic Energy Commission

# GAMMA RAY STUDIES ON THE DECAY CHAIN $Zr^{86} \longrightarrow Y^{86} \longrightarrow Sr^{86}$

E. K. Hyde, M. G. Florence and F. S. Stephens
Radiation Laboratory and Department of Chemistry
University of California, Berkeley, California

December 10, 1954

## ABSTRACT

The 14.6-hour $Y^{86}$ decays by positron emission with positron group maximum energies of 1.8 and ~1.19 Mev. The $Sr^{86}$ level reached by the 1.8-Mev group deactivates to ground with a 180-kev, 1.93-Mev and 1.08-Mev gamma cascade yielding an overall decay energy of 6.01 Mev. No crossover gamma rays were observed. $Zr^{86}$ decays by electron capture with a 17-hour half life to a 241-kev level in $Y^{86}$ which deactivates to the ground state within $5 \times 10^{-6}$ second. There are no other gamma rays in the decay of $Zr^{86}$.

# GAMMA RAY STUDIES ON THE DECAY CHAIN $Zr^{86} \rightarrow Y^{86} \rightarrow Sr^{86}$

E. K. Hyde, M. G. Florence and F. S. Stephens
Radiation Laboratory and Department of Chemistry
University of California, Berkeley, California

December 10, 1954

## I. INTRODUCTION

The isotope, $Y^{86}$, was originally isolated by Hyde and O'Kelley[1] as the daughter of $Zr^{86}$ produced in proton bombardments of niobium. Castner[2] prepared $Y^{86}$ by the (p,3n) reaction on $Sr^{88}$. The isotope decays by positron emission with a half life of 14.6 hours. Hyde and O'Kelley[1] showed that the positron spectrum consisted of two main groups of 1.80- and ~1.19-Mev energy and that the spectrum of the latter component had a shape characteristic of a $\Delta I = 2$,yes transition. From absorption measurements on the gamma radiation it was reported that a 1.4-Mev gamma ray was present.[1,2]

We have reinvestigated the gamma radiation of $Y^{86}$ by scintillation techniques and have found that gamma rays of 180 kev, 635 kev, 1.08 Mev and 1.93 Mev are present. Gamma-gamma coincidence experiments to be described below are interpretable only in terms of the decay scheme shown in Fig. 1. This decay scheme is interesting because of the unusually large decay energy, and the absence of crossover transitions. The $Zr^{86}$ was also restudied as will be described below.

## II. STUDY OF GAMMA RAYS OF $Y^{86}$

Niobium metal foils were bombarded in the 184-inch cyclotron with 100-Mev protons. After 24 hours' bombardment a carrier-free zirconium fraction was removed by coprecipitation on $LaF_3$, extracted as the thenoyltrifluoacetone complex into benzene, and adsorbed on Dowex-1 anion-exchange resin as the chloride complex.[1] Yttrium daughter activity was separated by washing the Dowex-1 resin column with 12 M HCl. In this way carrier-free $Y^{86}$ of high radiochemical purity was prepared.

Samples of this $Y^{86}$ were placed in a scintillation counter consisting of a 1 inch x 1.5 inch sodium iodide crystal and Dumont-6292 photomultiplier tube coupled to a 50-channel pulse-height analyzer. Some typical gamma-ray spectra are shown in Fig. 2. Gamma-gamma coincidence experiments were carried out using two sodium iodide crystals mounted back to back. The output of the gate side was fed to a variable single-channel analyzer and pulses corresponding to a particular energy gamma ray were selected to gate the 50-channel analyzer. The pulses resulting from gamma rays intercepted in the other sodium iodide crystal were fed to the 50-channel analyzer. Those arriving in coincidence with a gate pulse within the resolving time of about $5 \times 10^{-6}$ second were registered. Each gamma ray in turn was applied to the gate circuit and the gamma spectrum in coincidence with it was determined. It was found that all gamma rays were in coincidence with each other and with annihilation radiation. This was contrary to our original expectation because of the fact that the 1.93-Mev gamma ray is close in energy to the sum of the 180-, 635-kev and 1.08-Mev gamma rays, suggesting a crossover transition. Repeat

experiments with various thicknesses of lead absorber in front of the gate crystal to eliminate any possible contribution to spurious 1.93-Mev gate pulses still showed the coincidence of the 1.93-Mev radiation with the others. Various other experiments confirmed this beyond doubt.

For example, a coincidence experiment was performed in which the 50-channel analyzer was gated with 1.93-Mev gamma rays detected in the gate sodium iodide crystal and an anthracene crystal 1/4-inch thick was used on the signal side to detect positrons in coincidence. The positron spectrum so obtained showed an endpoint of 1.9 Mev (see Fig. 3) and was no different in shape from one determined with the anthracene crystal before its incorporation into the coincidence circuit. Hence, it is certain that the principal positron decay goes to a level at least 1.93 Mev above ground.

These facts lead to the decay scheme of Fig. 1. The placement of the 1.08-Mev gamma ray derives from the work of Zaffarano,[2] Kern and Mitchell[3] and of Macklin, Lidofsky and Wu[4] on $Rb^{86}$ from which it is clear that the first excited state of $Sr^{86}$ lies at 1.08 Mev. The 635-kev gamma ray must represent the difference between the states reached by the two positron groups. The placement of the 180-kev gamma ray is not certain.

The large decay energy represented by Fig. 1 was checked in another manner. Two sodium iodide crystals of 2 inch x 3 inch dimensions were arranged in the coincidence circuit diagrammed schematically in Fig. 4. Signal pulses from gamma rays registering simultaneously in the two crystals within about 1 microsecond were added and then displayed on a 50-channel pulse-height analyzer. Care was taken to adjust amplification of

the pulses in either branch of the circuit to an equivalent amount. To cut background pulses to a negligible quantity the 50-channel analyzer was turned on only when simultaneous signal pulses were registered in the two photomultiplier tubes. Figure 4 indicates the curves obtained with an $Y^{86}$ sample and with a $Na^{22}$ standard. In the latter case the peaks correspond to the registration of one annihilation quantum, two annihilation quanta, one annihilation quantum plus the 1.28-Mev gamma ray and finally both annihilation quanta plus the gamma ray. The counting efficiency for any combination of gamma rays is the product of the counting efficiency of the individual gamma rays. The single annihilation quantum is registered only when a Compton electron is absorbed in one crystal and the Compton scattered gamma ray is registered in the other.

In the case of the $Y^{86}$ spectrum the counting efficiency of the 1.08- and 1.93-Mev gamma rays is quite low. Hence, the counting efficiency for the entire gamma ray cascade is too low to register as a distinct peak. The 4.2-Mev endpoint corresponds to a stackup of two annihilation quanta plus one 180-kev, one 1.08- and one 1.93-Mev gamma ray. The only gamma ray missing is the 635-kev ray which was not seen because the counting efficiency for the 4.84-Mev peak was a factor of 5 lower. The $Y^{86}$ is an extreme case to which to apply this method. Nevertheless Fig. 4 does have the value that it demonstrates unambiguously that the 1.93-Mev, and the 1.08-Mev rays are in cascade following positron decay. We are greatly indebted to Dr. Lloyd G. Mann for carrying out these measurements for us on his scintillation counter equipment.

The absence of crossover transitions and of positron decay to the ground state and first excited level of $Sr^{86}$, known to be 0+ and 2+, respectively, suggested that the levels reached by positron decay must have spins of $\geq 4$. It would be reasonable to assign 4- to the ground state of $Y^{86}$ in analogy to $Y^{88}$. This would correspond to a $p_{1/2}$ proton and $g_{9/2}$ neutron for the odd particles. In combination with this, the Fermi plot shape characteristic of a $\Delta I = 2$, yes decay observed for the 1.19-Mev positron group of $Y^{86}$ by Hyde and O'Kelley would lead to a 6+ assignment of the uppermost level in $Sr^{86}$.

Strontium x-rays were identified in $Y^{86}$ by pulse-height analysis of pulses produced in a xenon-filled proportional counter, but no quantitative intensity measurements were made. The x-rays are in coincidence with the other gamma rays.

## III. STUDY OF GAMMA RAYS OF $Zr^{86}$

It was decided to study $Zr^{86}$ to see whether something could be learned to confirm or disprove our ground state assignment in $Y^{86}$. The even-even $Zr^{86}$ undoubtedly has ground state 0+ so that electron capture decay to a 4- ground state of $Y^{86}$ would be highly hindered. Decay would be expected to proceed predominantly to an upper level in $Y^{86}$. If $Y^{86}$ were quite similar to $Y^{88}$ one might expect the first excited state to be 1+ with a delayed E3 gamma transition to the 4- ground state.[6]

Hyde and O'Kelley had produced $Zr^{86}$ by proton bombardment of niobium and shown indirectly that it decayed by electron capture with a 17-hour half life. We prepared $Zr^{86}$ in pure form by bombarding arsenic targets with nitrogen ions in the 60-inch cyclotron. The reaction was,

$$_{33}As^{75} + _{7}N^{14} \longrightarrow _{40}Zr^{86} + 3_{0}n^{1} .$$

After bombardment the $Zr^{86}$ was isolated in a carrier-free condition by a chemical method very similar to that outlined above. No detectable amounts of other zirconium isotopes were found 2 hours after bombardment. Figure 5 shows the gamma spectrum of $Zr^{86}$. There is a single gamma ray at 241 kev. The small amount of gamma radiation above 241 kev is assignable to daughter $Y^{86}$ activity. The low level of 510-kev annihilation radiation sets an upper limit of a few percent to the positron branching of $Zr^{86}$. The decay of the 241-kev gamma ray was followed to confirm in a direct fashion the 17-hour half life obtained previously. The gamma radiations of $Y^{86}$ were observed to grow into the sample reconfirming the genetic relationship between the two isotopes. Gamma-gamma coincidence experiments were performed to see whether the x-rays resulting from the electron capture process were in coincidence with the 241-kev gamma ray. In this experiment a sodium iodide crystal with a beryllium window was used to increase the transmission of the 15-kev x-rays. It was found that the x-rays and gamma rays were in coincidence within the resolving time of $5 \times 10^{-6}$ second. This eliminates the possibility that the first excited state in $Y^{86}$ is 1+ in analogy to $Y^{88}$.[6]

The conversion electrons from the 241-kev gamma ray were measured in a double-focusing beta ray spectrometer of high resolution. For this measurement a more intense sample was required than could be prepared by bombardment of arsenic with nitrogen ions. This was prepared by bombarding niobium foil with 150-Mev protons for 2 hours. A day later a carrier-free

zirconium fraction was isolated and highly purified. This zirconium fraction contained 80-hour $Zr^{89}$ and 85-day $Zr^{88}$ but these activities created no interference in the measurement of the conversion electrons of $Zr^{86}$. The K and L lines of the $Zr^{86}$ gamma ray are shown in Fig. 6. The gamma ray energy is 241 ± 2 kev. The K/L ratio was calculated to be 9.3.

Further work is required to establish the spin and parity assignments of the $Y^{86}$ and $Sr^{86}$ levels discussed in this report.

## IV. ACKNOWLEDGMENTS

The bombardments on the 184-inch cyclotron were carried out with the cooperation of James T. Vale, Lloyd Houser and members of the operating crew. For the nitrogen ion bombardments we are indebted to G. B. Rossi, A. Ghiorso and members of the 60-inch cyclotron crew. James R. Schooley and Jose Juliano took data on the conversion electron spectrum.

One of us (MGF) acknowledges the support of the U.S.A.F. Institute of Technology, Wright Patterson Air Force Base, Dayton, Ohio.

This work was performed under the auspices of the United States Atomic Energy Commission.

## V. REFERENCES

1. E. K. Hyde and G. D. O'Kelley, Phys. Rev. 82, 944 (1951).

2. S. V. Castner, University of California Unclassified Report UCRL-1099 (January 1951) (unpublished).

3. D. J. Zaffarano, B. D. Kern, and A. C. G. Mitchell, Phys. Rev. 74, 682 (1948).

4. P. A. Macklin, L. I. Lidofsky, and C. S. Wu, Phys. Rev. 82, 334A (1951).

5. R. B. Schwartz, M. L. Perlman, and W. Bernstein, Phys. Rev. 91, 883 (1953).

6. E. K. Hyde, M. G. Florence, and A. E. Larsh, University of California Unclassified Report UCRL-2768 (October 1954); Phys. Rev., submitted for publication.

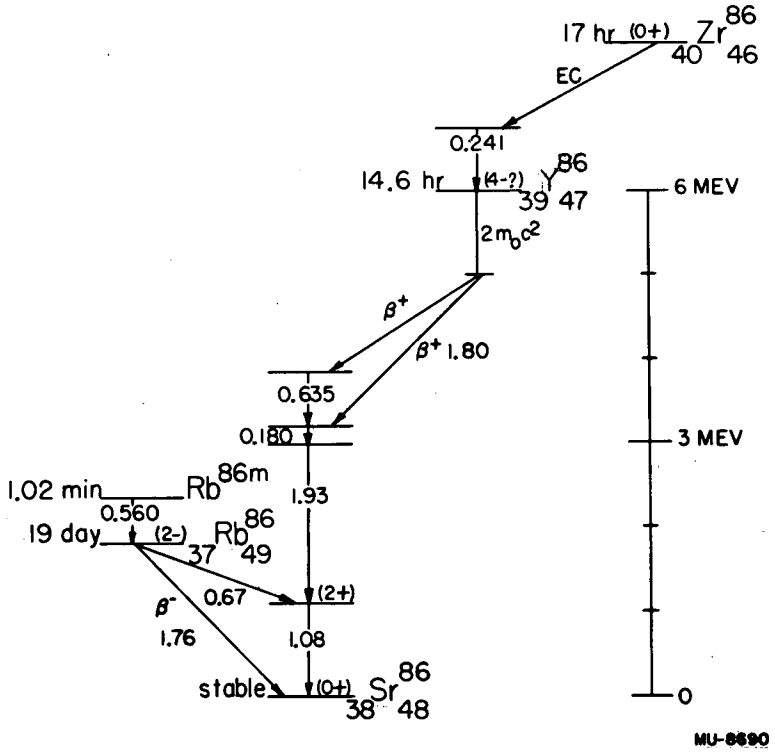


Fig. 1. Decay scheme of $Zr^{86} \rightarrow Y^{86} \rightarrow Sr^{86}$ chain. Spin and parity values of some levels are shown in parentheses. Data on $Rb^{86}$ taken from work of Macklin et al.[4] and of Schwartz et al.[5]

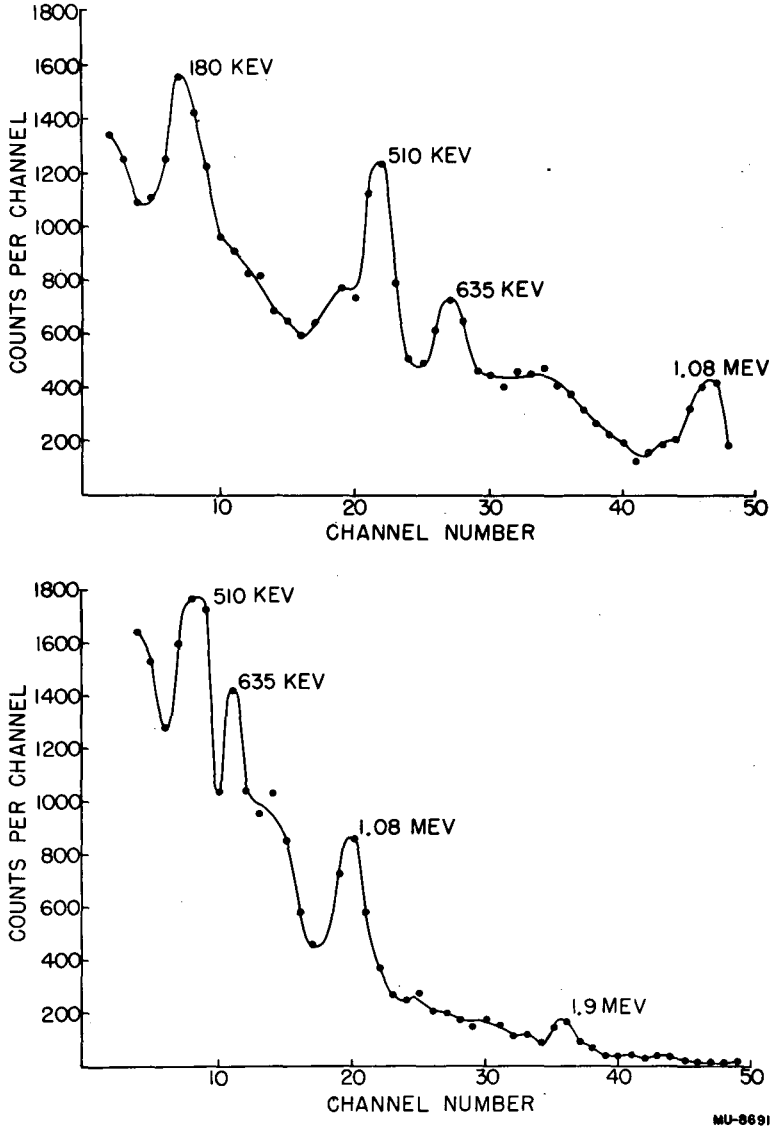


Fig. 2. Gamma spectrum of $Y^{86}$.

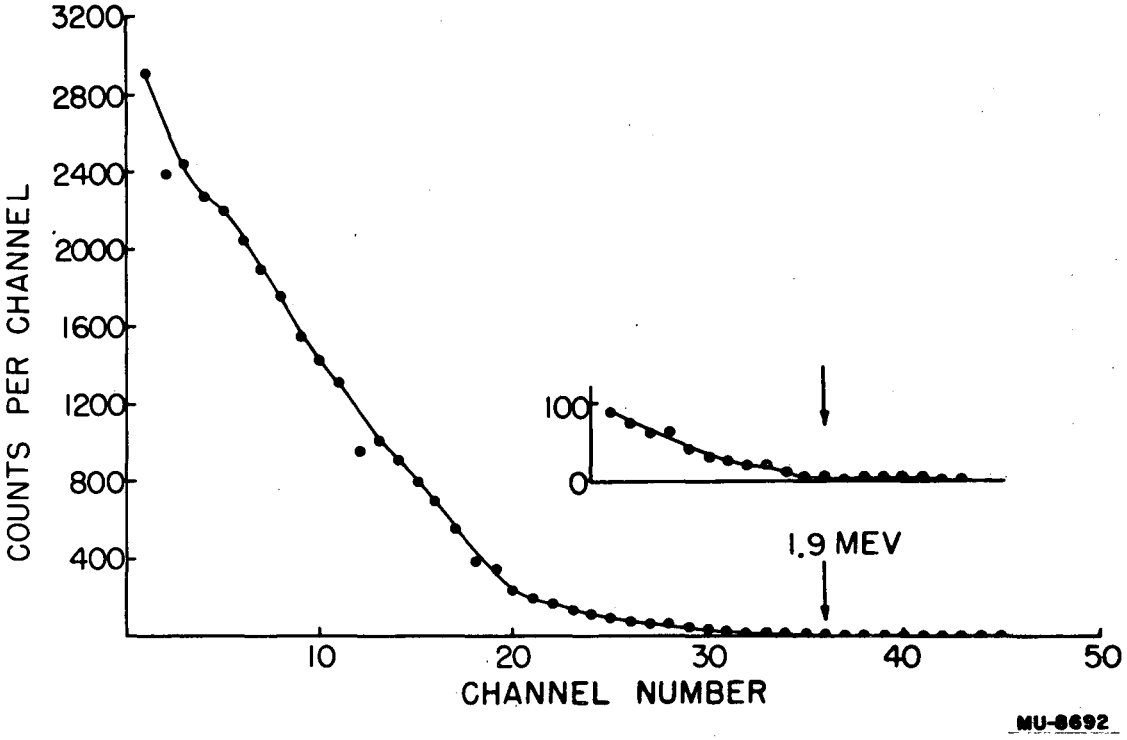


Fig. 3. Positron spectrum of $Y^{86}$ in coincidence with 1.93-Mev gamma ray. Positrons were absorbed in an anthracene crystal.

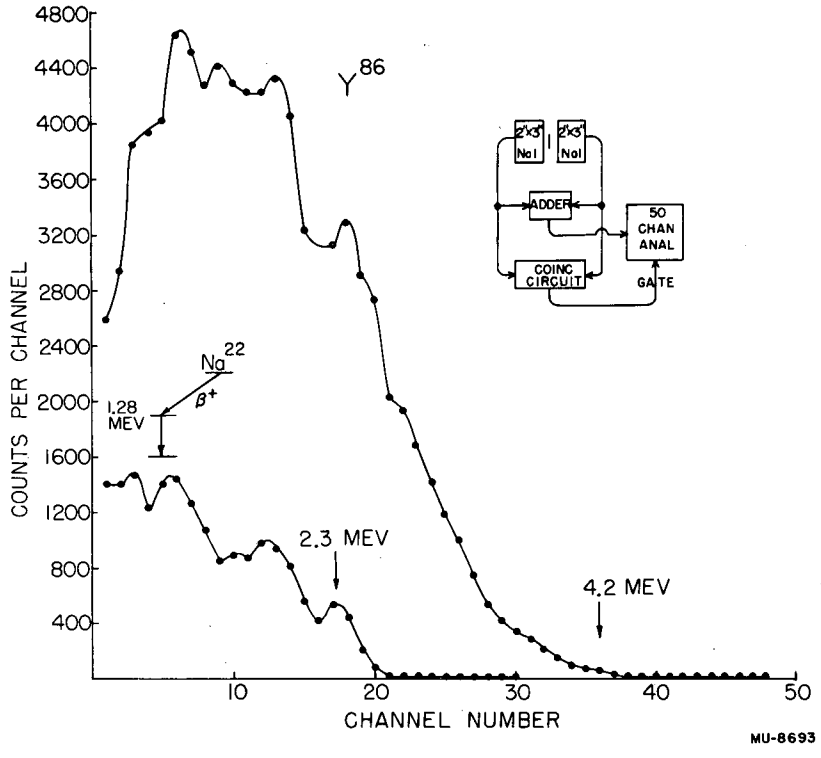


Fig. 4. Summation gamma spectra of $Y^{86}$ and of $Na^{22}$ standard confirming large decay energy of $Y^{86}$. Circuit arrangement diagrammed in figure. Equipment and data by Lloyd G. Mann.

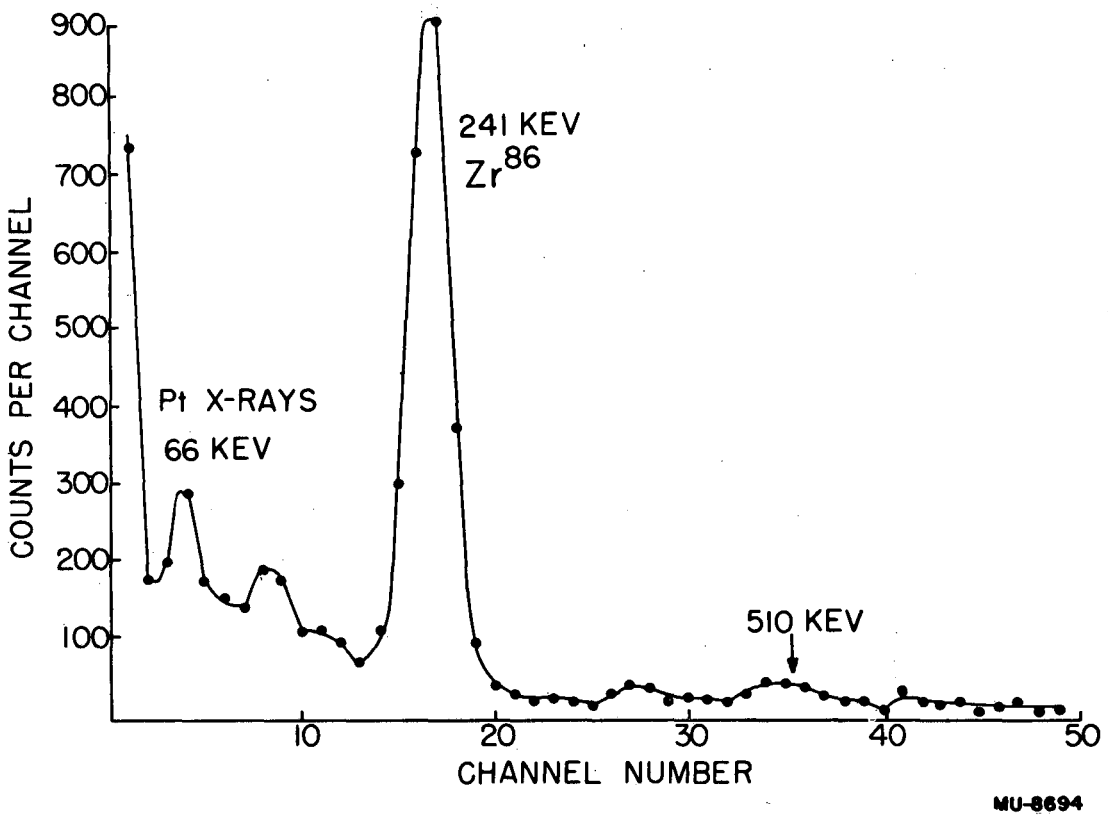


Fig. 5. Gamma spectrum of $Zr^{86}$. This curve was run about 2 hours after final purification from $Y^{86}$ daughter. Sample mounted on platinum.

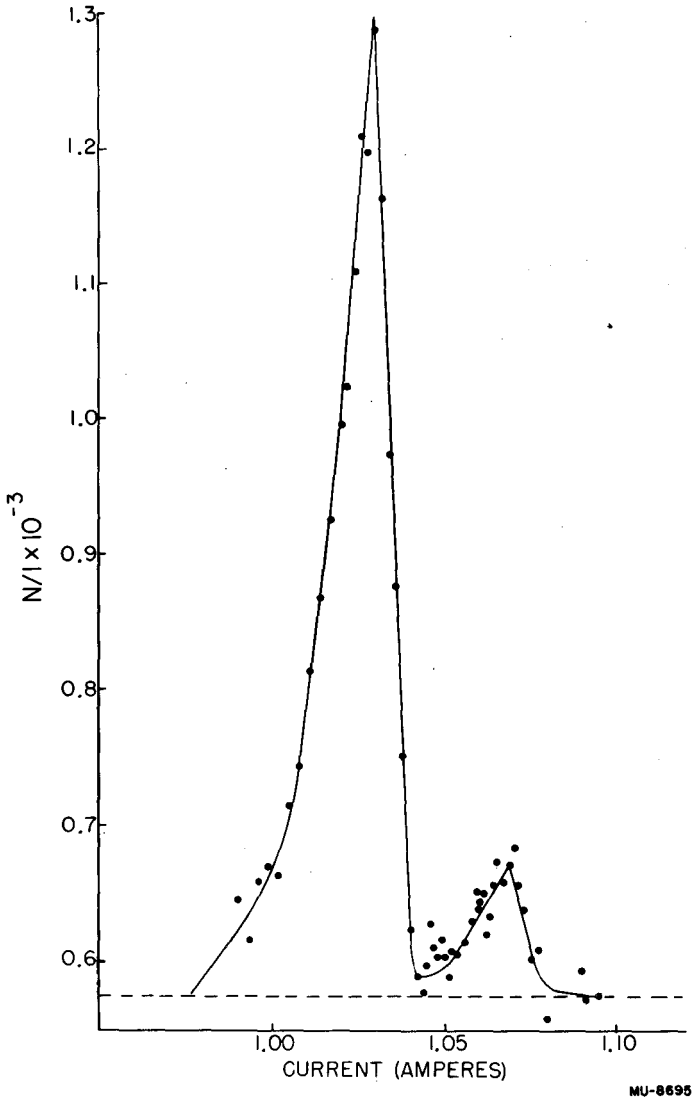


Fig. 6. Conversion electron spectrum of 241-kev gamma ray of $Zr^{86}$. N = counts per minute. I = amperes. The dotted line represents the background level subtracted in calculating a K/L ratio of 9.3.