ORO-3820-14

On-LINE ALPHA AND PROTON DECAY SPECTROMETRY

Ronald D. Macfarlane, Principal Investigator

Annual Progress Report, 1971

Sponsor:

United States Atomic Energy Commission

Division of Research

Contract No. AT-(40-1)-3820

Texas A&M University

Department of Chemistry and Cyclotron Institute

Janaury 15, 1972 College Station, Texas 77843

On-Line Alpha and Proton Decay Spectrometry

Texas A&M University

1971-72

I. GENERAL REPORT

A. Introduction

This is the fourth annual progress report of this project covering a period from January 1, 1971 to December 31, 1971. Funds received from the AEC for this project were used to support a continuing program at the Texas A&M Cyclotron.

The scope of the research program has been considerably reduced compared to the proposed plans submitted a year ago. The cut-back of funds allocated for this project has resulted in a concentration of effort on specific problems involving the Texas A&M Cyclotron (TAMVEC). Our programs at the Yale Heavy-ion Accelerator and Texas A&M Reactor Center have been terminated. Several experiments planned (such as the time reversal invariance and parity non-conservation studies) at TAMVEC have been postponed indefinitely. Plans for our participation in the Super Hilac program are also being delayed due to insufficient funds. It is our hope that the funding situation for this project and nuclear chemistry in general will improve in the near future. It is becoming increasingly more difficult to maintain a viable and meaningful research program as the support base continues to diminish.

B. Summary of Activities

The helium jet recoil transport method has continued to gain acceptance

as a standard technique for studying the decay properties of short-lived nuclei. During the past year visitors from Germany, France, Belgium, and various laboratories in the U.S. have visited Texas A&M to participate in research and discuss various aspects and applications of the method. As a part of the development of our "on-line" mass analysis system, the mechanism of the method has been extensively studied. Highly-efficient helium-recoil separations have been achieved using the "nozzle-skimmer" technique. Employing this technique, results have been obtained for ^{8}Li, ^{20}Na, and rare earth α-emitters using our recently dcvelped time-of-flight mass analyzer. High quality ^{16}O recoil time-of-flight spectra from ^{20}Na decay have been obtained which clearly show effects related to the β-recoil, and β-ν correlations. High resolution spectra of α-recoils from the α-decay of rare earth nuclides have been obtained. The simultaneous measurement of α- and recoil-energy has verified the masses of the Er, Ho, and Dy isotopes previously reported.

The α/β branch in ^{20}Na decay has been measured using three independent methods. These results, together with data for ^{20}F, have shown that β-decay mirror symmetry is a characteristic of the decay of the mass-20 triplet, a clear departure from the expected asymmetry due to second class currents and meson exchange in the nuclear weak interaction. Advances in the line-shape analysis of α-particles associated with β-delayed decay include incorporation of the natural line-width as a free parameter, derivation of a momentum-dependent expression for the nuclear alignment of a β-recoil, finite Z-correction and coherence effects in lepton helicities. The most recent fit to the dominant G-T transition gives

α = -0.342 with χ^2/F = 1.6 .

C. Personnel

1. Supervisor

R. D. Macfarlane, Professor of Chemistry, Texas A&M.

2. Research Scientist

D. F. Torgerson, Ph.D., McMaster

3. Visiting Professor

K. Wien, Professor from Technischen Hochschule and Heavy-ion laboratory, Darmstadt, Germany

4. Research Associates

a. John Fares, Ph.D., Florida 1970

b. Hartmut Jungclas, M.S. Marburg University, Germany

5. Graduate Students

a. Alton Hassell, B.S. Baylor University, 1969

b. Raymond Skowronski, B.S. University of Michigan, 1969

c. Patricia Papa, B.S. Marquette University, 1970

6. Undergraduate Research Assistants

a. James Stevenson, Physics, 1972

b. John Rousch, Chemistry, 1973

c. Salahuddin Yosufzai, Chemistry, 1973

D. Facilities Used

The cyclotron has been used for this project at an average rate of 56 hours per month. The Cyclotron IBM 7094 has been used at a rate of 2 hours per week. With the exception of the target chambers, all of the equipment has been moved from the target area to the roof of two of the

cave areas. This has provided the space required to locate the time-of-flight tube for the mass analyzer. As many as 3 target chambers have been run in tandem to increase the effective use of the limited beam time available to this project.

E. Publications (1971)

1. Work Published in Refereed Journals during Calendar Year 1971

   a. Beta-Neutrino Correlations and Longitudinal Nuclear Alignment in the Decay of ^{20}Na, R. D. Macfarlane, N. S. Oakey and R. J. Nickles, Phys. Lett. 34B, 133 (1971)

   b. Evidence for Large Cluster Formation of Nuclear Reaction Recoils Thermalized in Helium, H. Jungclas, R. D. Macfarlane and Y. Fares, Phys. Rev. Lett. 27, 556 (1971)

   c. Crystal Lattice Effects in the ^{149}Sm(n,α)^{146}Nd Reaction Induced by Thermal Neutrons, D. W. Mueller, R. D. Macfarlane, K. Bet and A. D. Suttle, Jr., Phys. Lett. 36B, 74 (1971)

   d. Beta Recoil Effects in the Delayed Alpha Decay of ^{20}Na, R. D. Macfarlane and N. S. Oakey, Izvestia Akad. Nauk (USSR) 34, 2109 (1970) [English Translation: Bulletin of the Academy of Sciences of the USSR Physical Series 34, 1880 (1971)

2. Work Published in Conference Proceedings in 1971

   a. A New Approach to the Study of Beta-Delayed Particle Emitters, D. F. Torgerson and R. D. Macfarlane, Proceedings of the International Conference on Heavy Ion Physics (Dubna, U.S.S.R. Feb. 1971) p 288

b. Recent Results on Light β-delayed Particle Emitters, R. D. Macfarlane, R. J. Nickles, and N. S. Oakey, The Nuclear Structure Symposium of the Thousand Lakes (Jontsa, Finland, Aug. 1970) p. 136

c. Beta-Neutrino Correlations and Recoil Nuclear Alignment Effects in Light Delayed Particle Emitters, R. D. Macfarlane, R. J. Nickles, and N. S. Oakey, Proceedings of the International Conference on the Properties of Nuclei Far From the Region of Beta-Stability (Leysin, Switzerland, August 1970) p. 447

3. Contributed Papers to Meetings, 1971

Beta Decay Mirror Symmetry in the Mass-20 Multiplet, D. F. Torgerson, K. Wien, and R. D. Macfarlane, Bull. Amer. Phys. Soc. 16, 1178 (1971)

4. Papers Accepted for Publication in 1971

a. Beta-Delayed Alpha Emission from the Isomers of ^{24}Al, D. F. Torgerson, N. S. Oakey, and R. D. Macfarlane, (Nuclear Physics, December 1971)

b. A New Approach to "On-Line" Mass Analysis, H. Jungclas, R. D. Macfarlane, and Y. Fares, (Radiochemica Acta, November, 1971)

5. Papers Submitted (but not yet accepted) for Publication in 1971

Mirror Symmetry in the Mass-20 Multiplet, R. D. Macfarlane, D. F. Torgerson, and K. Wien (submitted to Phys. Rev. Lett.)

6. Invited Colloquia and Seminars

   a. McMaster University, January 1971 - "Recent results on the Nuclear Weak Interaction"

   b. Oak Ridge National Laboratory, May 1971 - "A New Approach to "On-Line" Mass Analysis"

   c. Michigan State University - July 1971 - Two Lectures: "Heavy-ion Reactions Near the N=126 Closed Shell" and "MAGGIE - A New Tool for Studying the Atomic Nucleus"

7. Honors

   a. Appointed NSF Distinguished Lecturer, Michigan State University, 1971

II. Work Completed - 1971

The following studies have been completed. Abstracts of papers related to these studies appear below.

a. Beta-Neutrino Correlations and Longitudinal Nuclear Alignment in the Decay of ^{20}Na, R. D. Macfarlane, N. S. Oakey, and R. J. Nickles, Phys. Lett. 34B, 133 (1971).

An analysis of the line shapes of α-particle groups from the β-delayed α-particle decay of ^{20}Na has revealed a simple method of obtaining β^{+}-ν anisotropy coefficients and F/GT ratios. Evidence has been obtained for existence of a longitudinal nuclear alignment of β-recoils from G-T transitions.

b. Evidence for Large Cluster Formation of Nuclear Reaction Recoils Thermalized in Helium, H. Jungclas, R. D. Macfarlane, and Y. Fares, Phys. Rev. Lett. 27, 556 (1971)

It has been found that nuclear reaction recoils ejected from a target and thermalized in helium attach to large molecular clusters produced from impurities by the intense ionization generated by the beam passing through helium. When the clusters containing the recoils are entrained in a room-temperature sonic helium flow, they attain kinetic energies of up to 700 keV on account of their high molecular weights which were found to be as high as 10^8 μ. Highly efficient separations of nuclear reaction recoils from helium carrier gas have been achieved as a result of the formation of these large clusters.

c. Crystal Lattice Effects in the $^{149}Sm(n,\alpha)^{146}Nd$ Reaction Induced by Thermal Neutrons, D. W. Mueller, R. D. Macfarlane, K. Beg, and A. D. Suttle, Jr., Phys. Lett. 36B, 74 (1971)

It has been found that the relative intensities of the final states of the reaction $^{149}Sm(n,\alpha)^{146}Nd$ using thermal neutrons are sensitive to the chemical environment and temperature of the target nucleus. This is due to the special features of the thermal neutron capture of ^{149}Sm and provides a test of Lamb's theory of neutron absorption in crystals.

d. A New Approach to ON-Line Mass Analysis, H. Jungclas, R. D. Macfarlane, and Y. Fares, Radiochimica Acta, Nov. 1971 - preprints available.

A system has been developed which can be used to simultaneously

identify the mass and measure the nuclear radiation of a short-lived radioactive isotope. The system combines the helium jet recoil transport method with the electrostatic particle guide technique to measure coincident decay recoil spectra by the time-of-flight technique. Results have been obtained for the β-delayed α-emitters, ^{8}Li and ^{20}Na.

e. Beta-Delayed Alpha Emission from the Isomers of ^{24}Al, D. F. Torgerson, N. S. Oakey, and R. D. Macfarlane, Nuclear Physics, Dec. 1971 (preprints available)

Alpha particles emitted from levels in ^{24}Mg following the β-decay of the isomers of ^{24}Al have been measured. In addition to the α-groups previously reported in the β-decay of the 4^{+} ground state of ^{24}Al, new groups were observed as a result of using special techniques to reduce the β-background and to increase particle energy resolution. Alpha groups associated with the β-decay of the 1^{+} isomeric state of ^{24}Al were observed for the first time. The α particle transitions observed in this work have been correlated with known energy levels. Log ft values have been calculated or estimated from the relative intensities of the delayed α-groups.

f. Beta Decay Mirror Symmetry in the Mass-20 Multiplet, R. D. Macfarlane, D. F. Torgerson, and K. Wien (submitted to Phys. Rev. Lett.) preprints available.

The ft-value for the β^{+}-decay of ^{20}Na has been determined to be 93610 ± 1846 sec using the average of 3 independent methods. This result compared with the corresponding data for ^{20}F gives for the ratio ft^{+}/ft^{-} a value of 0.99 ± 0.02. This is inconsistent with the prediction

of mirror asymmetry in the mass-20 triplet arising from second class currents in the nuclear weak interaction.

III. Work in Progress

A. Precision Measurements of β-ν correlation coefficients in ^{20}Na β-decay

A considerable effort is being directed toward obtaining very precise values of "a", the β-ν directional correlation coefficient for ^{20}Na decay for the purpose of obtaining information on possible meson exchange effects and the presence of second class currents in the nuclean weak interaction. The β-decay of ^{20}Na is a unique case for studying the energy dependence of the correlation and for obtaining good statistics on a "pure" G-T transition to determine whether "α" is indeed precisely -1/3. The problem is developing using 2 experimental methods and a rigorous theoretical analysis of heavy-particle energy line shapes broadened by the β-recoil spectrum.

1. Experimental

a. Alpha line shape study

From our previous work, we have shown that the β-ν correlation coefficient "α" can be obtained from an α-particle line shape if the α-decay follows β-emission to α-particle unstable states as in the decay of ^{20}Na. The β-recoil energy spectrum and the resulting nuclear alignment (for G-T transitions) can be extracted from the line shape. We are attempting to obtain high quality α-spectra for ^{20}Na and a meaningful α-particle response function using short-lived α-emitters, employing the He-jet recoil

transport system. Some problems have been encountered. These include the effect of a small amount of deposition of the ^{20}Na activity on the face of the detector, straggling in the residual gas, β-α coincidences, finite source thickness. Experimental conditions are being modified to solve these problems.

G. Heavy Recoil Line Shape Study

The MAGGIE system has been used to obtain time-of-flight spectra of the ^{16}O recoils associated with the β-delayed α-decay of ^{20}Na. Fig. 1 shows one of the spectra which have been recently obtained. The perturbation of the line shapes due to the β-recoil is considerably greater than the instrumental resolution (factor of 100 in the most favorable case). Some source thickness problem has been encountered but this has been resolved by continuous heating of the collector. This technique may prove to be the most powerful for our β-ν correlation work.

2. Theoretical Analysis (with R. J. Nickles, University of Wisconsin)

Although β-recoil energies are generally very small (< 1 keV), a precise measurement of the energy spectrum can be obtained indirectly if the β-decay is rapidly followed ($< 10^{-17}$ sec) by α-particle emission. The vector addition of the β-recoil and α-velocities can give rise to a significant Doppler shift of the α-particle energy (as much as 40 keV for a 3 keV β-recoil of M = 20). The extraction of the β-recoil spectrum (and hence the β-ν directional correlation) is the function of the program JETSAM. In its presently developed form the α-particle momentum vector is first kinematically connected to the

β-recoil momentum vector. To obtain the transition probability for the β-decay from a mixture of initial magnetic substates to a set of final state magnetic substates and a given β-recoil energy, the density matrix is evaluated summing over all lepton energies and helicities. Effectively the probability of emission of a recoil with a specific energy and distribution of magnetic substates as a function of β-recoil energy is evaluated. The magnetic substate population determines the α-particle directional anisotropy relative to the recoil momentum direction when the α-particle transition involves angular momentum changes. The calculations include corrections for finite-Z and treat the natural line width of the α-emitting state as a free parameter, treatment of the effect of two different helicity states for the β^+. The questions of whether the positive and negative helicities add coherently or incoherently is a fundamental question that may be resolved in these experiments. The program has been written to take account of either coherent or incoherent summing of the β^+-helicities. Very preliminary results seem to indicate that a slightly better fit to the data for ^{20}Na is obtained for coherent summing of the helicities. The weakest point in the analysis is the lack of a proper response function. A simple Gaussian function has been assumed in the analysis and the departures from theoretical are at the extremes of the α-line where departures from pure Gaussian are known to exist. For the most intense α-line in the decay of ^{20}Na, known to be a pure G-T transition ($\Delta T = 1$), a value $\alpha = -0.34$ with a χ^2/F of 1.6 has been obtained taking 93% of the peak area.

The program is now being modified for use in analyzing heavy-recoil time-of-flight spectra.

B. Alpha Recoil Spectroscopy

The first known measurement of the energy (or velocity) spectrum of a ground state α-emitter has been achieved using our MAGGIE recoil-time-of-flight mass analyzer. A spectrum is shown in Fig. 2. A Bendix Channeltron electron multiplier was used to detect the 100 keV rare earth recoils from the α-decay of isotopes of Dy, Ho, and Er in the mass 150-153 range. The mass assignments of these isotopes have been confirmed. The data of Fig. 2 can be considerably improved by operating the MAGGIE system with a better vacuum. Modifications are now in progress.

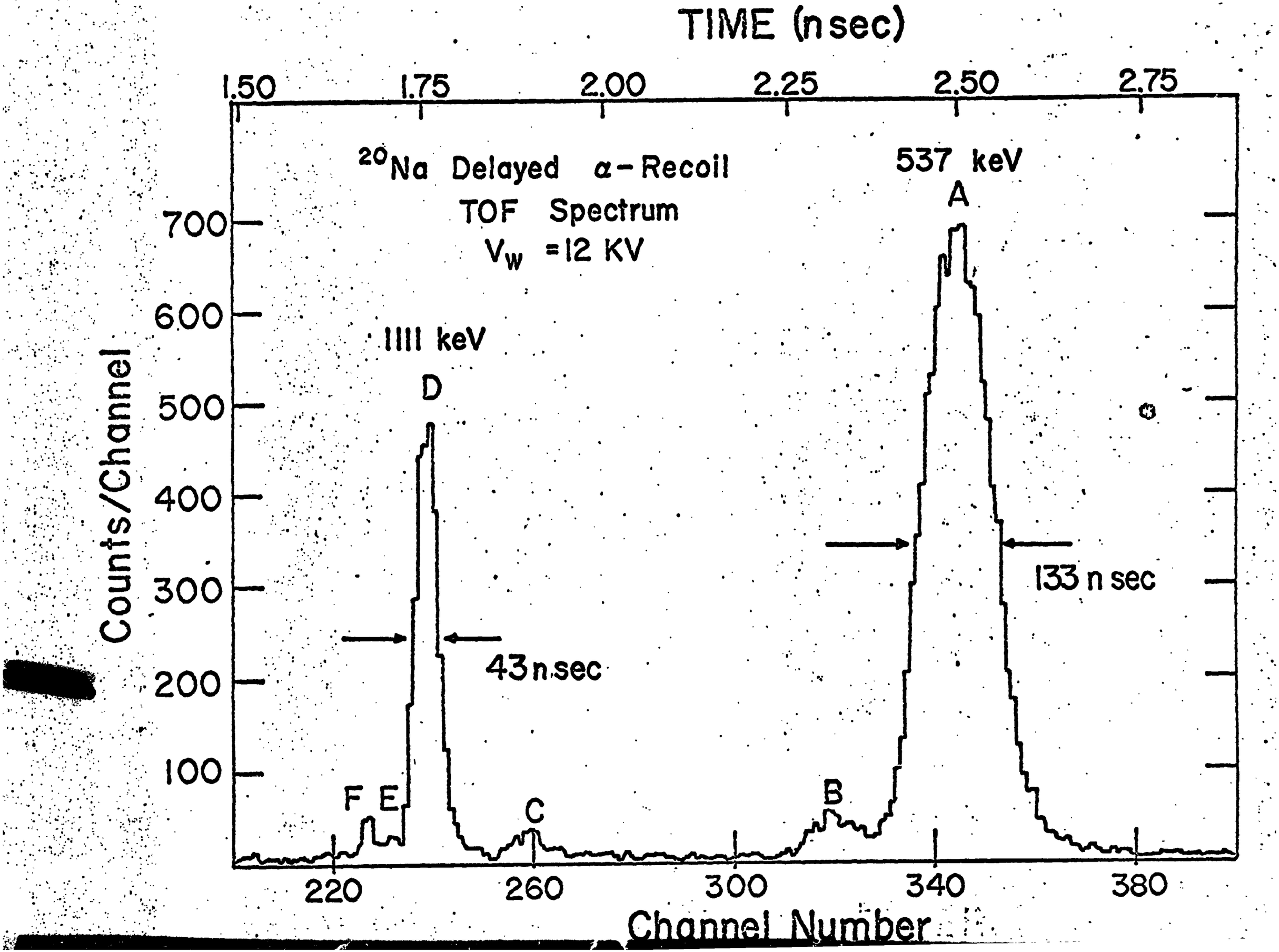
C. Orbit Calculations for the Electrostatic Particle Guide (EPG)

An essential capability for the successful performance of the EPG section of the MAGGIE system is a theoretical analysis of the performance under a variety of conditions. The source location and size, wire and tube dimensions and field strength are inter-related. Particle orbit calculations are being carried out to optimize the critical parameters to achieve optimum performance.

D. Use of the Helium-Jet Recoil Transport Method for ^{252}Cf Fission Studies

With the recent availability of intense ^{252}Cf sources, the possibility of studying new short-lived fission products without using a reactor or accelerator becomes feasible. The application of the He-jet recoil transport method seemed a logical method for the transport of

activity from the source. However, it was found that the yield was extremely small. From the results obtained in the cyclotron experiments, it appeared that the presence of ionizing radiation was an essential part of the method. To verify this, the helium-filled chamber containing the ^{252}Cf source was irradiated with intense light from a carbon arc at the same time that the helium was being transfered through a capillary tube to a second chamber by differential pumping. A factor of 15 enhancement was observed in the transfer. Assuming that the far UV and x-ray part of the arc emission spectrum was responsible for the production of ion pairs, the carbon arc was replaced by a Xe UV lamp. The intensity of the transmitted activity was enhanced a factor of 170 using the Xe lamp. Experiments are underway to determine the effect of gas composition and impurities on the transport efficiency. A mixture of He and air + H_2O vapor appears to give the best performance. It is clear that the helium jet recoil transport method can be used for "off-line" experiments provided an intense ionizing source is used to produce the charged cluster molecules necessary to transport the recoils.


TIME (nsec)
1.50
1.75
2.00
2.25
2.50
2.75
^{20}Na Delayed α-Recoil
TOF Spectrum
V_W =12 KV
537 keV
A
1111 keV
D
700
600
500
400
300
200
100
Counts/Channel
43 n sec
133 n sec
F
E
C
B
220
260
300
340
380
Channel Number

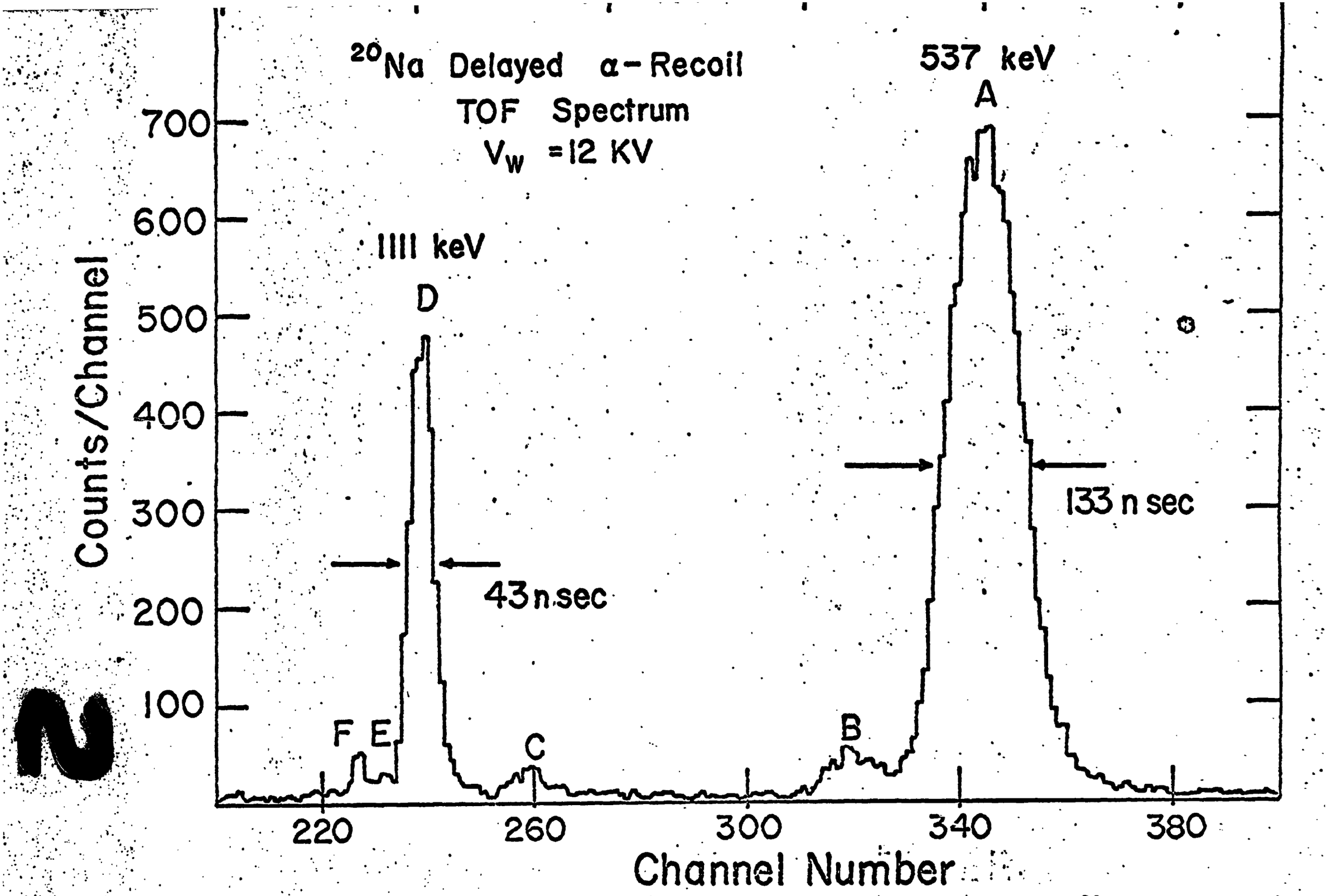


Figure 1 - Time-of-flight spectrum of ^{16}O recoils from the β-delayed α-decay of ^{20}Na

TIME (μsec)

15.5 16.0 16.5 17.0

α-Recoil TOF Spectrum
of Products from $^{144}Sm + ^{12}C$

^{148}Dy (^{152}Er)
130 keV

^{149}Dy (^{153}Er)
125 keV

^{148}Tb (^{152}Ho)
120 keV

118 keV

^{146}Gd (^{150}Dy)
116 keV

Counts/Channel

50 40 30 20 10

820 860 900 940 980

Channel Number

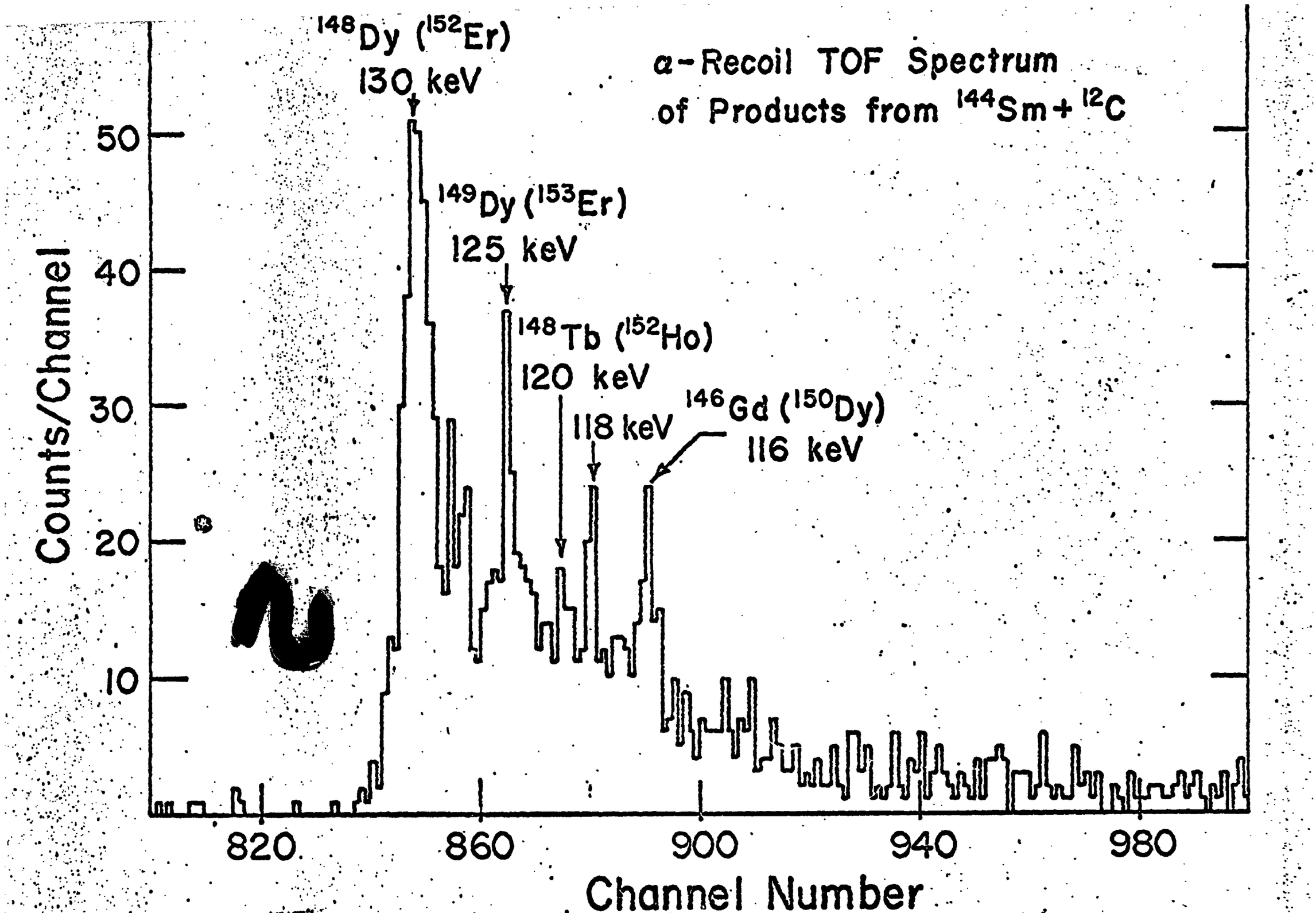


Figure 2 - Time-of-flight spectrum of recoils from the α-decay of rare earch isotopes produced in the reaction ^{144}Sm + 100 MeV ^{12}C.