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On-Line Alpha and Proton Decay Spectrometry

Annual Progress Report, 1973

Ronald D. Macfarlane, Principal Investigator

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I. General Report

A. Introduction

This is the sixth annual progress report of this project covering a period from January 1, 1973 to December 31, 1973. Funds received from the AEC for this project were used to support a continuing program at the Texas A&M Cyclotron Institute.

B. Summary of Activities

The MAGGIE "on-line" time-of-flight mass spectrometer was used extensively in studies of short-lived nuclei. Most of the experiments were to determine the properties of β-recoils and recoil-surface interactions. Considerable developmental work concentrated on improving mass resolution for the purpose of atomic mass measurements of β-recoils. Experiments were started on the measurement of β-ν correlations in ^{8}Li. Some difficulty was encountered in the preparation of ^{8}Li sources on ultra-thin backings. This problem was recently solved and some preliminary spectra have been obtained.

The application of MAGGIE to "off-line" studies has proceeded extremely well. A ^{252}Cf source mounted on a thin backing has been used as an ion source and time marker for time-of-flight mass spectroscopy of biologically-important compounds. It appears that we may have developed a new approach to mass spectroscopy with this technique which has several unique features.

The β-ν correlation studies in ^{20}Na decay were completed. The results show that the α-particle broadening technique for determining the correlation is reliable over a wide range of β- end-point energies and natural line widths. All transitions except one (to the T = 1 analog state in ^{20}Ne) are consistent with pure G-T decay showing no evidence for isospin mixing.

C. Personnel

1. Principal Investigator

R. D. Macfarlane, Professor of Chemistry

2. Research Scientist

D. F. Torgerson, Lecturer of Chemistry

3. Visiting Professor (September 1973-January 1974)

A. Pape (from Strasbourg, France)

4. Research Associates

a. Örjan Skeppstedt (from Chalmers University, Göteborg, Sweden)

b. John Fares, Ph.D. Florida

5. Graduate Students

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

b. Raymund Skowronski, B.S. Michigan, 1970

c. Patricia Papa, B.S. Marquette University, 1970 (graduated with M.S. December 1973)

d. Laurence Spiegel, B.S. Reed College, 1973

e. Duane Piper, B.S. LeTourneau College, 1973

f. Paul Jagodzinski, B.S. Brooklyn Polytechnic Institute, 1973

6. Undergraduate Assistants

a. Salahuddin Yosufzai

b. Rosemary Christmas

c. Harry Tang

D. Facilities Used

The cyclotron has been used for this project at an average rate of 40 hours per month. The Cyclotron IBM 7094 was used for all of our data analysis and the PDP-15 computer was used for the β-ν correlation experiments on ^{8}Li.

The Cyclotron Institute has purchased a high quality low-energy photon spectrometer which is available to this project for the x-ray-β-recoil measurements. The continued support of the Cyclotron Institute in acquiring important new pieces of equipment has been vital to the progress of our research program.

E. Publications and Presentations, 1973

1. Work published or accepted for publication in refereed journals during calendar year 1973:

a. β^{+} Decay of ^{20}Na, D. F. Torgerson, K. Wien, Y. Fares, N. S. Oakey, and R. D. Macfarlane, Phys. Rev. C 8, 161 (1973).

b. "On-Line" Beta-Recoil Mass Spectrometry (MAGGIE), R. D. Macfarlane, D. F. Torgerson, Y. Fares, and A. Hassell, Nucl. Instr. Meth. (accepted).

c. "Techniques for the Study of Short-Lived Nuclei," with W. McHarris, Section IIC, Academia Press, N. Y. (1974).

2. Invited papers:

a. Techniques for the Study of Short-Lived Nuclei, Gordon Research Conference on Nuclear Structure, June 1973.

b. A New Approach to "On-Line Mass Spectrometry of Short-Lived Nuclei, Gordon Research Conference on Nuclear Chemistry, June 1973.

c. Beta-Recoil Mass Spectrometry, American Physical Society, National Meeting, Bloomington, Indiana, October 1973.

3. Contributed papers:

a. High Resolution Mass Spectrometry in the (od-1s) Shell, American Chemical Society Meeting (Nuclear Chemistry Division), January 1973 (Newport Beach, California).

II. Abstracts of Work Published or Accepted for Publication,

A. β^+ Decay of ^{20}Na, D. F. Torgerson, K. Wien, Y. Fares, N. S. Oakey, and R. D. Macfarlane, Phys. Rev. C 8, 161 (1973).

The decay scheme of ^{20}Na has been studied in detail to obtain information on the β-decay mirror symmetry properties of the mass-20 multiplet and to determine the Fermi decay strength to the T = 1 isobaric analog state in ^{20}Ne. The ratio ft^+/ft^- was determined to be 1.026±0.024 for the β^+ transitions to the first excited state of ^{20}Ne. The ft value for the transition to the T = 1, 10.278-MeV level was measured to be 2992±233 sec indicating that most of the Fermi strength is concentrated in this transition. A weak γ transition from the 2^+ isobaric analog state to the 2^+ first excited state of ^{20}Ne was observed and new β^+-delayed α groups are reported at 3.27, 5.272, and 5.701 MeV. Theoretical ft values derived from the shell-model wave functions ar compared with experiment.

B. "On-Line" Beta-Recoil Mass Spectrometry (MAGGIE), R. D. Macfarlane, D. F. Torgerson, Y. Fares, and A. Hassell, Nucl. Instr. Meth. (1974).

A new approach to "on-line" mass identification of short-lived nuclides is described. The method is based on a time-of-flight measurement of β-recoil ions accelerated from near rest to a fixed kinetic energy. Results have been obtained for flight paths ranging from 25 to 800 cm. The shorter flight lengths give a resolution sufficient for adjacent mass identification and the longest flight path may be used to measure atomic masses of the β-recoils.

C. Techniques for the Study of Short-Lived Nuclei, R. D. Macfarlane and W. McHarris, Chapter in Nuclear Spectroscopy, Academic Press (1974). Scope of Chapter:

The literature is full of brilliant and/or clever techniques that have worked or ought to work in studying short-lived nuclei, and it is not feasible to cover them all in a chapter such as this. Instead, we shall concentrate on techniques that have or promise to have widespread applications. These include old standbys such as rabbit systems, rotating wheels, accelerator pulsing, gas transport of both volatile and nonvolatile species, and electrostatic particle guides. Some novel and exemplary chemical techniques are also covered, although an excellent review article on this subject was written recently (Herrmann and Denschlag, 1969), and the reader is referred to that for more extensive coverage. Newer and more novel techniques that are covered include MAGGIE and RAMA (discussed later). These have not been debugged completely, but they show such promise that they are included to illustrate the directions in which to look for new techniques. In short, this chapter has been written for the experimentalist who is interested in studying short-lived nuclei but who wishes to be spared some of the developmental difficulties. By comparing some of the examples given here he can perhaps choose an appropriate technique for his own experiments.

III. Work Completed - 1973

A. Beta-Neutrino Correlations in the Decay of ^{20}Na, R. D. Macfarlane, D. F. Torgerson, and R. J. Nickles.

This work was begun two years ago and preliminary results were given in the last progress report. Because of the increased significance of this type of experiment to fundamental questions in the nuclear weak interaction, it was determined that the experiment should be repeated under better experimental conditions to achieve improved energy resolution and precision. The complicated analysis program that extracts the β-ν correlation coefficient, "α", and the natural line width, Γ, achieved final form. Included in the program are the momentum dependence of the longitudinal nuclear alignment of the β-recoils, coherence of the helicity states of the β, and Coulomb effects. The final results are given in Table I.

Table I. Summary of results on β-ν correlations in ^{20}Na decay.

State in ^{20}Ne (E^*, (MeV)J^π, T)	α	$\Gamma_{C.M.}$ (Measured)	$\Gamma_{C.M.}$ (Literature)
7.415,2^+,0	-0.32±0.02	11 keV	8 keV
7.286,2^+,0	-0.28±0.04	3.5 keV	2 keV
9.481,2^+,0	-0.31±0.03	22 keV	29±15 keV
10.278,2^+,1	+0.86±0.07	0.36 (fixed) keV	0.36 keV
10.584,2^+,0	-0.32±0.04	2 keV	24 keV
10.848,2^+,0	-0.4±0.1	15 keV	13 keV

For a pure G-T transition and assuming no second order contributions, $\alpha = -1/3$. For a pure Fermi transition, $\alpha = +1$. The result for the transition to the T = 1, 10.278 MeV state shows that it is mixed Fermi-Gamow-Teller, a result that was expected because both decay modes are allowed. The transition to the 7.286 MeV state may be significantly different from the others. We have observed a relatively large β-ν anisotropy indicating that there might be important contributions from second order effects.

B. Development of MAGGIE System for "Off-Line" Applications, R. D. Macfarlane, R. Skowronski, and A. Pape.

In MAGGIE experiments where β-delayed α-emitters were produced, we observed that the α-particles were ionizing surface molecules giving, in the time-of-flight spectra, molecular ions that were in coincidence with β-particles. We have utilized this observation to develop a new application of the MAGGIE system that can be used to obtain mass spectra of samples without using a conventional ion source.

A 1 μg source of ^{252}Cf is mounted on a thin Ni foil and placed in back of a thin target which is maintained in vacuum at a high voltage. When a fission event takes place, one of the fission fragments enters a Si(Au) surface barrier detector and generates a fast-timing start signal. The other fission fragment, emitted 180° to the other, penetrates the sample and produces a dense ionization track. Ions that are formed or diffuse to the surface are then accelerated through an electric field gradient and the velocity is measured through time-of-flight. Figure 1 shows a TOF spectrum for an Al foil. In addition to the ^{27}Al peak, there are intense lines corresponding to H^+, H_2^+, H_3^+, Na^+, K^+ and several lines from hydrocarbons adsorbed on the surface from the gases in the system vacuum. Samples of known composition have been studied and the mass spectra have been compared with conventional electron-impact mass spectroscopy. An interesting feature of the ^{252}Cf-induced ionization is that the negative ion spectrum is readily obtained. Thus, both positive and negative-ion mass spectroscopy can be compared for each sample studied. A paper describing the system, its properties in relation to the variables of the system, and including representative TOF spectra will be submitted to the International Journal of Mass Spectroscopy and Ion Physics.

IV. Work in Progress - 1973-74

A. Beta-Neutrino Correlations in ^8Li and ^8B, Ö. Skeppstedt, D. F. Torgerson, and R. D. Macfarlane.

We have devised an experiment which measures the β-ν correlation in ^8Li(^8B) as a function of ^8Be excitation energy. The critical measurement is the α-particle spectra of both α-particles emitted in the breakup of ^8Be following β-decay. This means producing a thin source of ^8Li(^8B) (in steady state) on an ultra-thin backing. ^8Li was produced by the reaction $^7Li(d,p)^8Li$ and ^8Li was transported by the helium-jet recoil transport technique to the vacuum chamber of the detection system. The activity was deposited on various thin films (<50 μg/cm^2) and the ^8Be breakup was detected by two α-particle detectors located on both sides of the foil. With this arrangement, the thin foils were rapidly decomposed by chemically-active components of the He-jet (presumably free radicals and ions). After considerable effort it was finally decided to use a "ruggedized" Si(Au) surface barrier detector (ORTEC) as both collector and detector. This solved the problem and one experiment has been performed on ^{8}Li. Reasonable looking sum and difference plots of the coincident α-particle spectra have been obtained but the β-ν analysis of the data has not yet been attempted. Considerably more effort will have to be made to assure the acquisition of reliable data.

B. Beta-Gamma Angular Correlations in the M = 20 Multiplet, R. D. Macfarlane and A. Hassell.

This problem has just begun. The β-detection system will be the one used in previous experiments and the γ-detector will be NaI(Tl) to increase photopeak efficiency. The major experimental problem has been in the collection of ^{20}F by the He-jet method. Thus far, efforts to collect the activity have failed to produce a measurable yield. Efforts are being directed toward doing some hot atom chemistry in the target chamber to get the ^{20}F in a more condensable form.

The experiment involves a measurement of the β-γ angular correlation of ^{20}F(^{20}Na) to the 1.633 MeV state in ^{20}Ne as a function of β-energy. This gives the amplitude of weak magnetism and second class current contributions to the β-decay. A measurement of the M1 radiative width from the analog state at 10.278 MeV in ^{20}Ne to the 1.633 MeV state gives the weak magnetism contribution alone.

C. On-Line Mass Spectrometer Development (MAGGIE), R. D. Macfarlane and D. F. Torgerson.

Considerable advances were made in the development of the MAGGIE β-recoil time-of-flight mass spectrometer. These included installation of a magnetic shield around the drift tube to minimize effects of the earth's magnetic field and stray fields on ion trajectories, design and fabrication of an adjustable collector to optimize the directional properties of the ion trajectories and installation of a CHEVRON electron multiplier to replace the CEMA-photomultiplier array. Several preliminary studies were made using the β^+-β^+-recoil TOF modes determining β^+-recoil yield for many elements. A decision was made to concentrate efforts on the high resolution capability of the device for atomic mass measurements rather than for decay scheme identification. Atomic mass measurements of radioactive species would represent a unique capability with possibilities of contributing fundamental information on nuclear binding energy effects.

Development of the high mass resolution capability requires further studies in line-broadening effects and the construction of a moving tape system to enhance yields and minimize background and residual pressure near the collector.

A high mass resolution spectrum of ^{23}Na recoils from ^{23}Mg decay is shown in Fig. 2. Figure 3 shows a low-resolution spectrum of decay products from the reaction ^{112}Sn + ^{14}N which shows some higher mass products and demonstrates that high mass recoils with small recoil energies can be studied by this technique.

D. ^{252}Cf-Induced Surface Ionization Mass Spectrometry, R. D. Macfarlane, R. Skowronski, and A. Pape.

A new application of MAGGIE was developed which has the virtue that it does not use our limited cyclotron beam time. With a very simple modification, MAGGIE can be operated as a time-of-flight mass spectrometer for non-radioactive, non-volatile samples. A ^{252}Cf source is plated on a thin Ni backing and mounted in back of the sample. The ^{252}Cf source is covered with a thin VYNS film to prevent self-transfer. A Si(Au) surface barrier is mounted on an axis defined by the ^{252}Cf source and sample at approximately 0.5% of 4π relative to the source. If a fission fragment is detected, the complementary fragment enters the sample and produces an ionization track. If the sample is thin enough to pass the fission fragment, surface ionization occurs with the escape of ions of the surface material. If the sample is maintained at a high voltage, the ions can be accelerated through an electric field to ground potential. Since all the ions have the same qV, a TOF spectrum resolves the masses of the ions.

Figure 1 is a TOF spectrum from an Al foil. In addition to the ^{27}Al peak, there are also other strong lines corresponding to impurities in the Al or adsorbed on the surface. The alkali metals are easily detected because of their high mobility in the bulk Al. Many hydrocarbon impurities are from the surface and can be reduced in intensity by heating of the Al. Within ~6 hrs the impurities are readsorbed on the surface. If a layer of a sample to be studied is deposited on the Al, very interesting mass spectra are obtained, even for non-volatile species that are difficult to study by conventional mass spectrometry. Figure 4 shows a mass spectrum of KI. The K^+-ion is a strong peak in the positive ion spectrum and I^- is in evidence in the negative ion spectrum.

More interesting results are obtained with molecules of biological importance. Figure 5 shows an arginine mass spectrum. This amino acid has never been studied mass spectrometrically because of its instability during volatilization, but by this method the parent ion is very much in evidence. Figure 6 is a spectrum of cholesterol which also reveals the parent ion as well as some fragmentation products.

Some systematic studies will be made to compare this method of obtaining mass spectra with the more conventional electron impact methods and to determine the mechanism of ionization and fragmentation under these conditions.

Figure 1

7U0107 1.2MG/SC AL FOIL Ø/CHAN AT CVC 600SEC 5KV -100V 1001

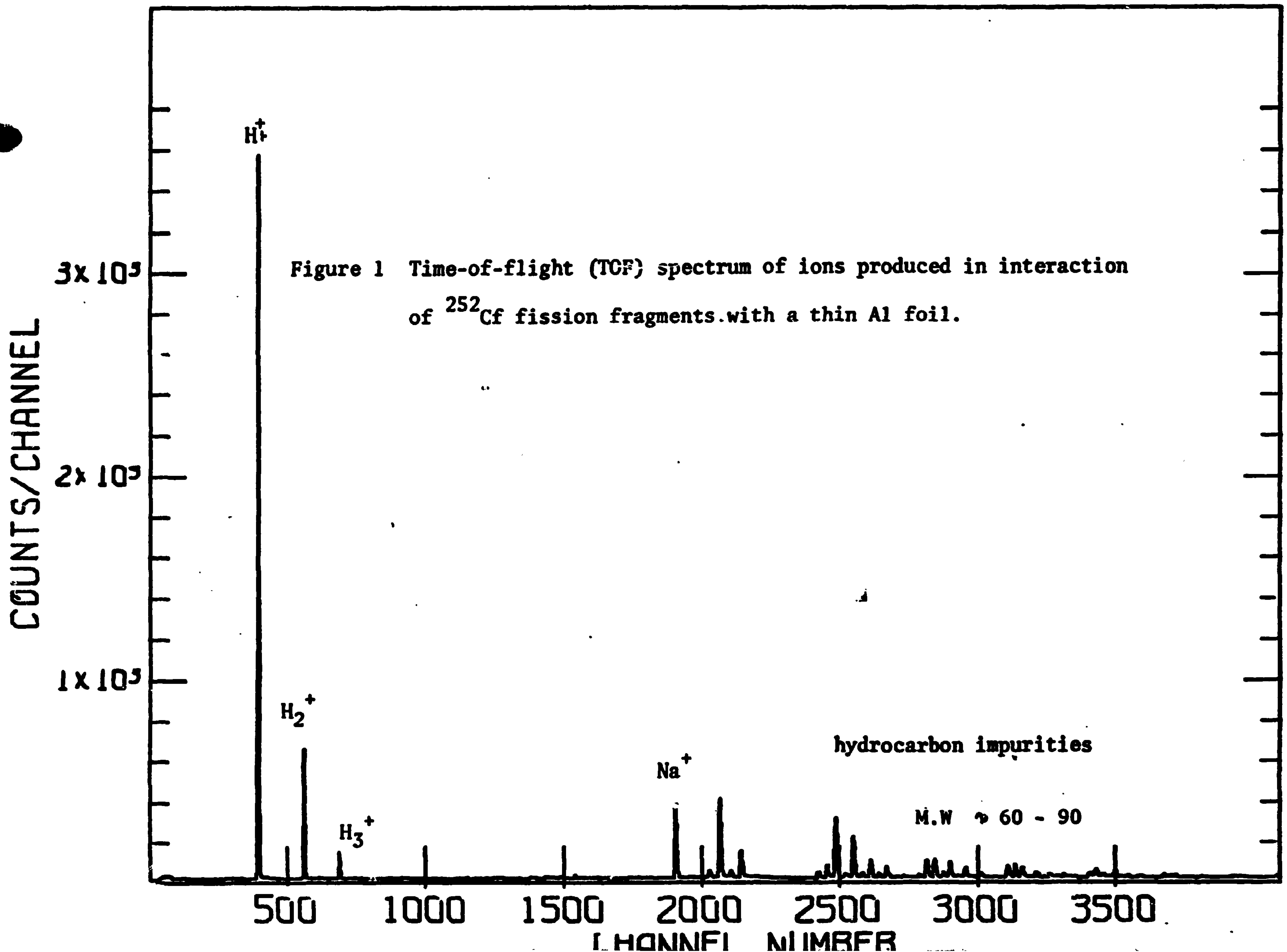

Figure 1 Time-of-flight (TOF) spectrum of ions produced in interaction of ^{252}Cf fission fragments with a thin Al foil.

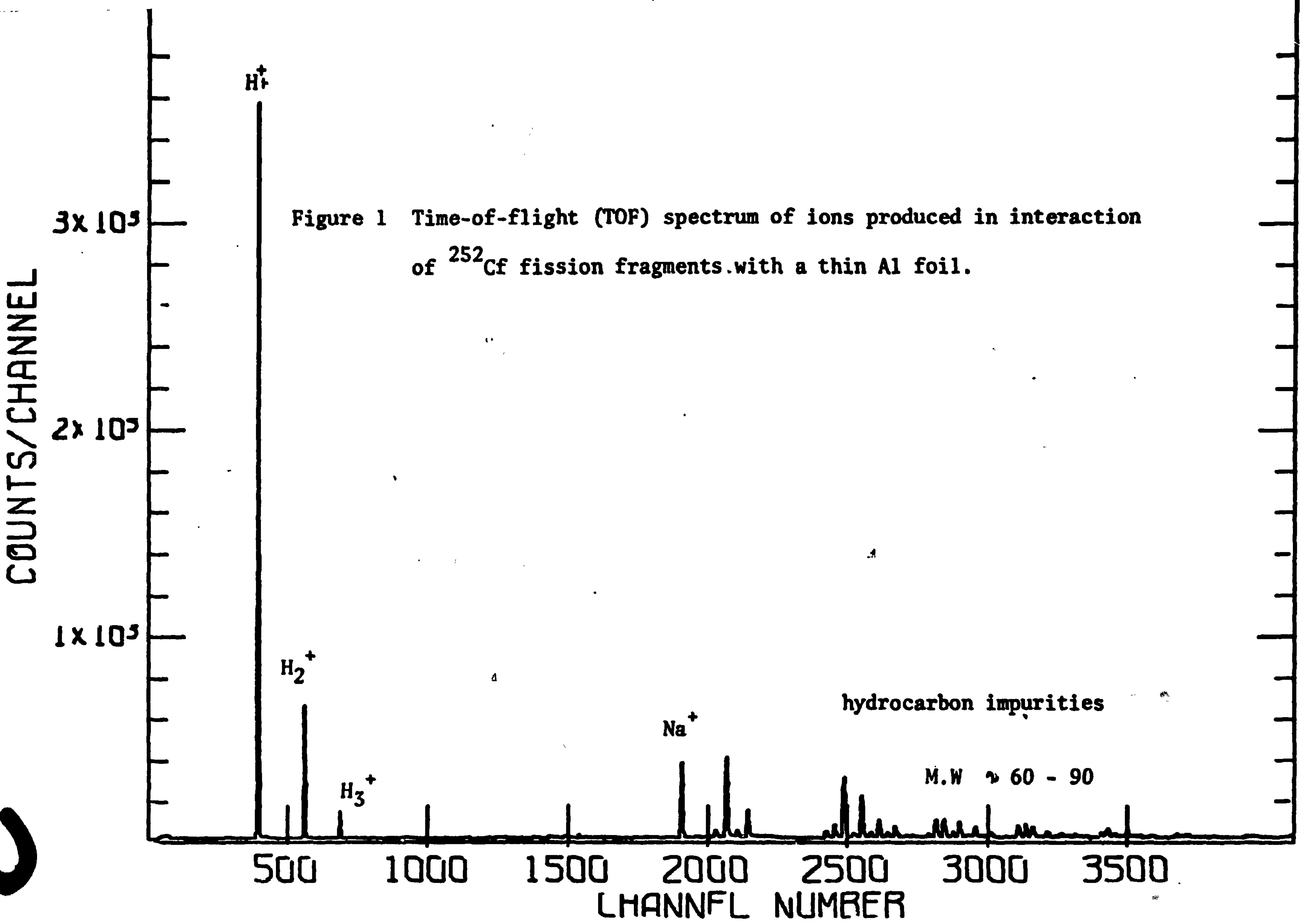

Figure 1 Time-of-flight (TOF) spectrum of ions produced in interaction of ^{252}Cf fission fragments with a thin Al foil.

Figure 2

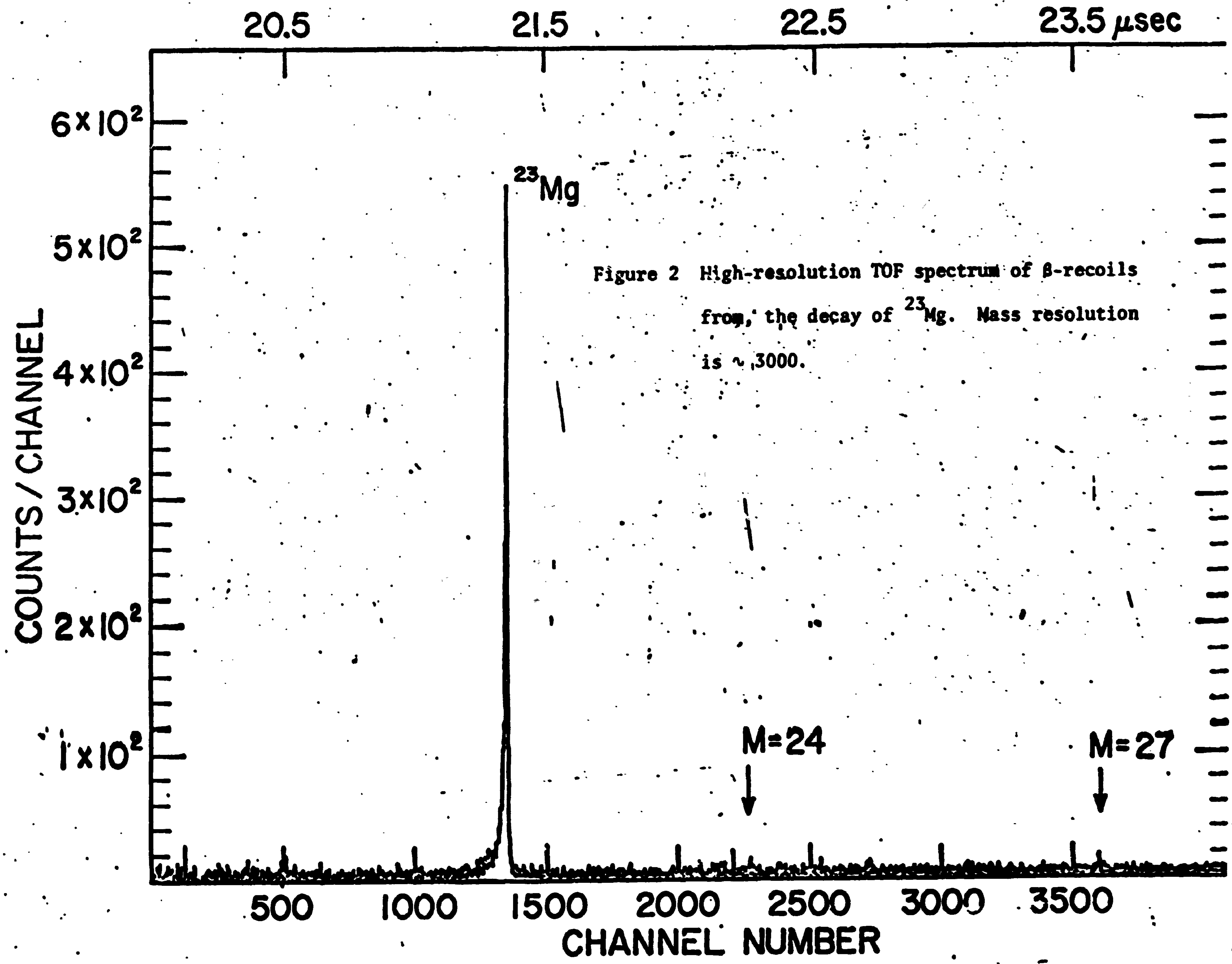

Figure 2 High-resolution TOF spectrum of β-recoils from the decay of ^{23}Mg. Mass resolution is ~ 3000.

Figure 3

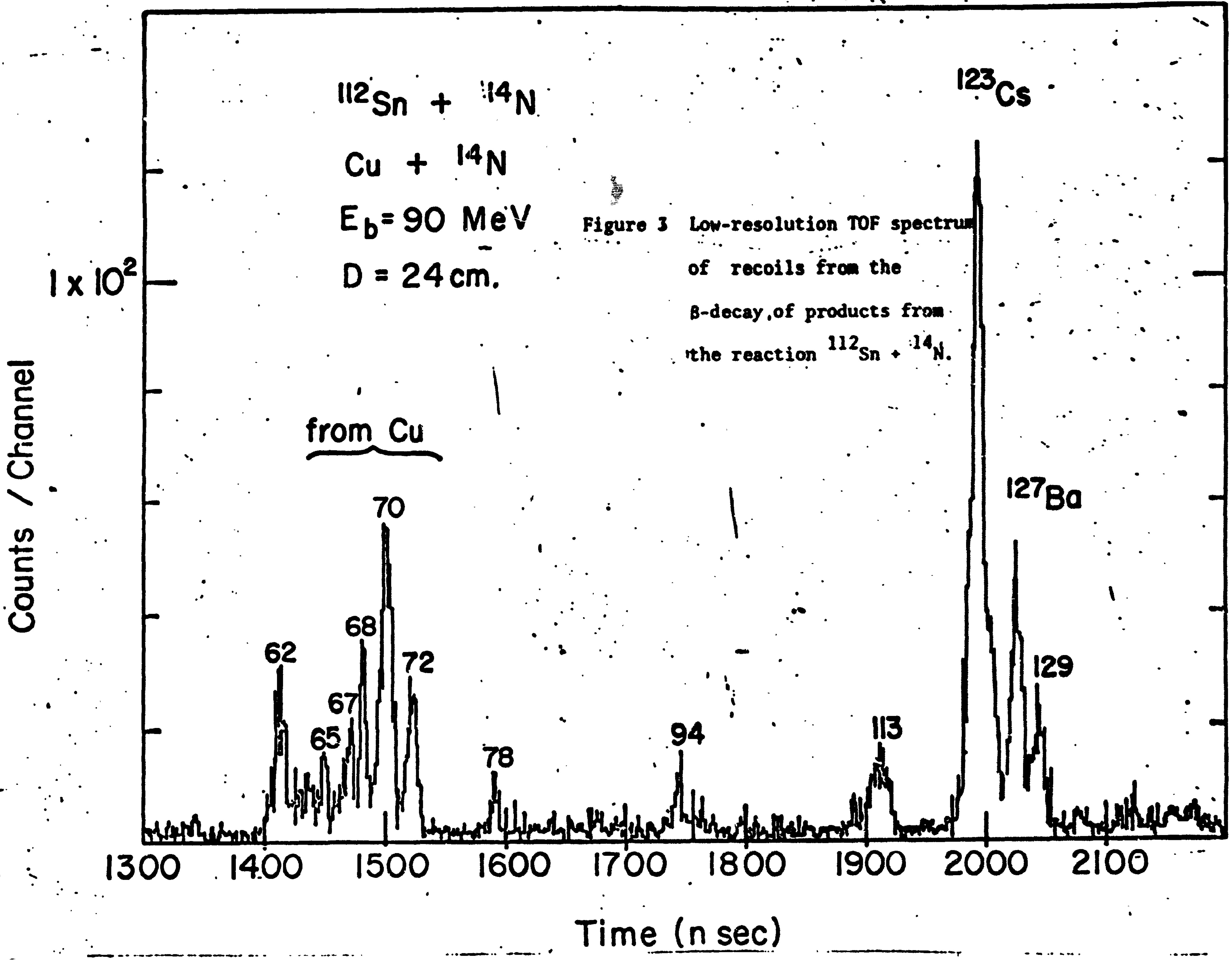

Figure 3 Low-resolution TOF spectrum of recoils from the β-decay of products from the reaction $^{112}Sn + ^{14}N$.

Figure 4

731228 KI ON AL POSITIVE IONS 3/CHAN 1000SEC AT CVC 5KV -100V 1001

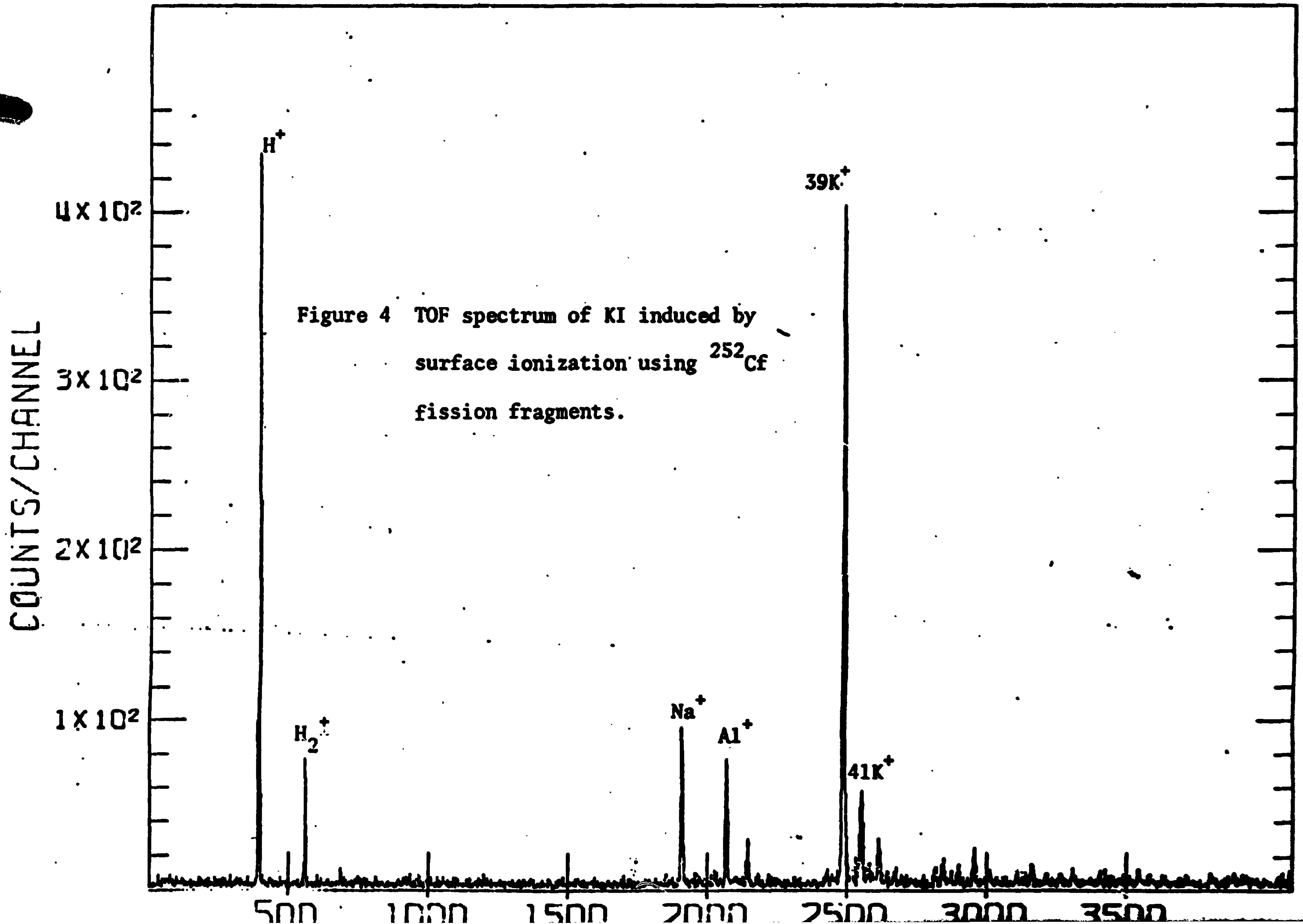

Figure 4 TOF spectrum of KI induced by surface ionization using ^{252}Cf fission fragments.

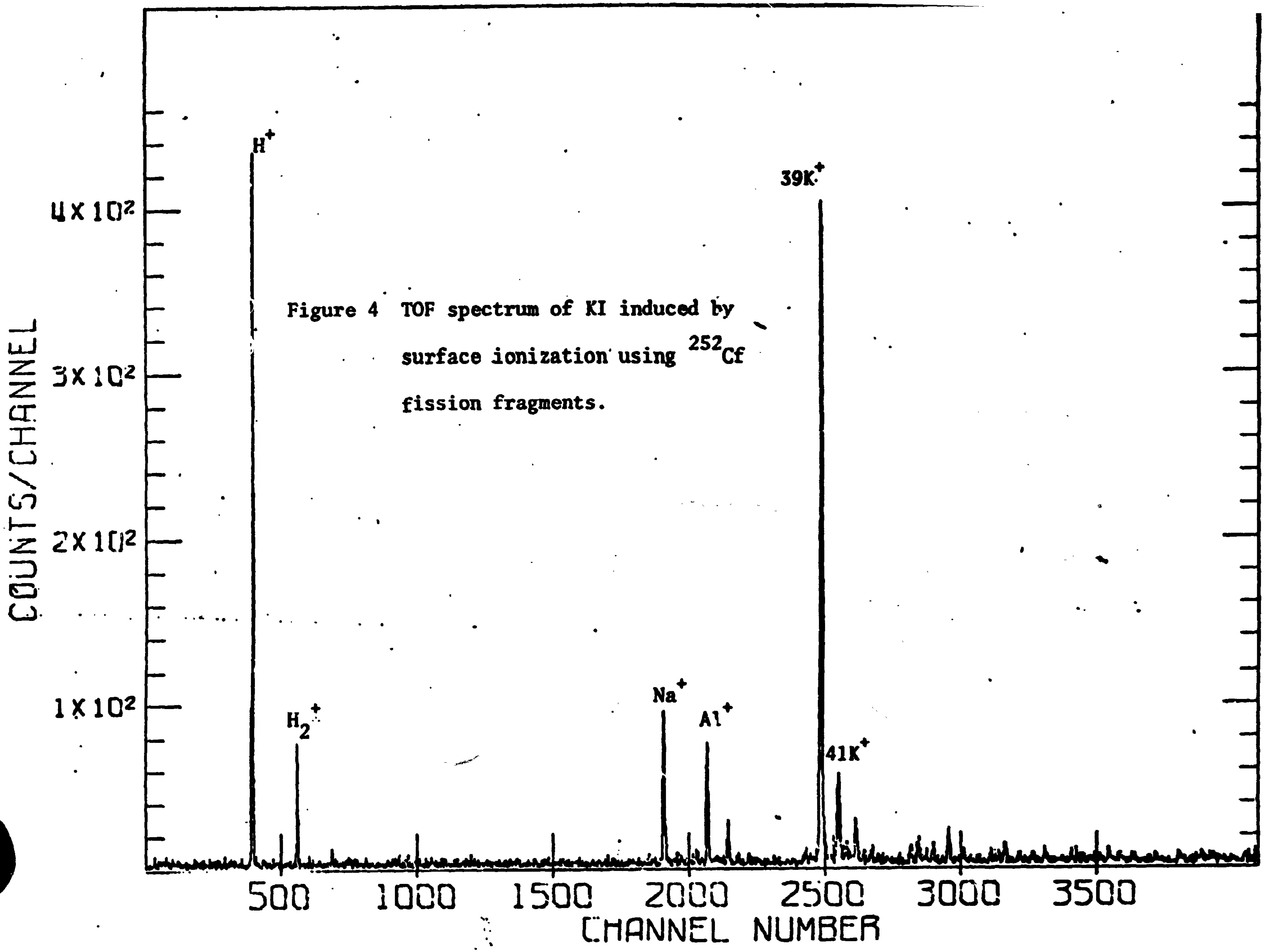

Figure 4 TOF spectrum of KI induced by surface ionization using ^{252}Cf fission fragments.

Figure 5

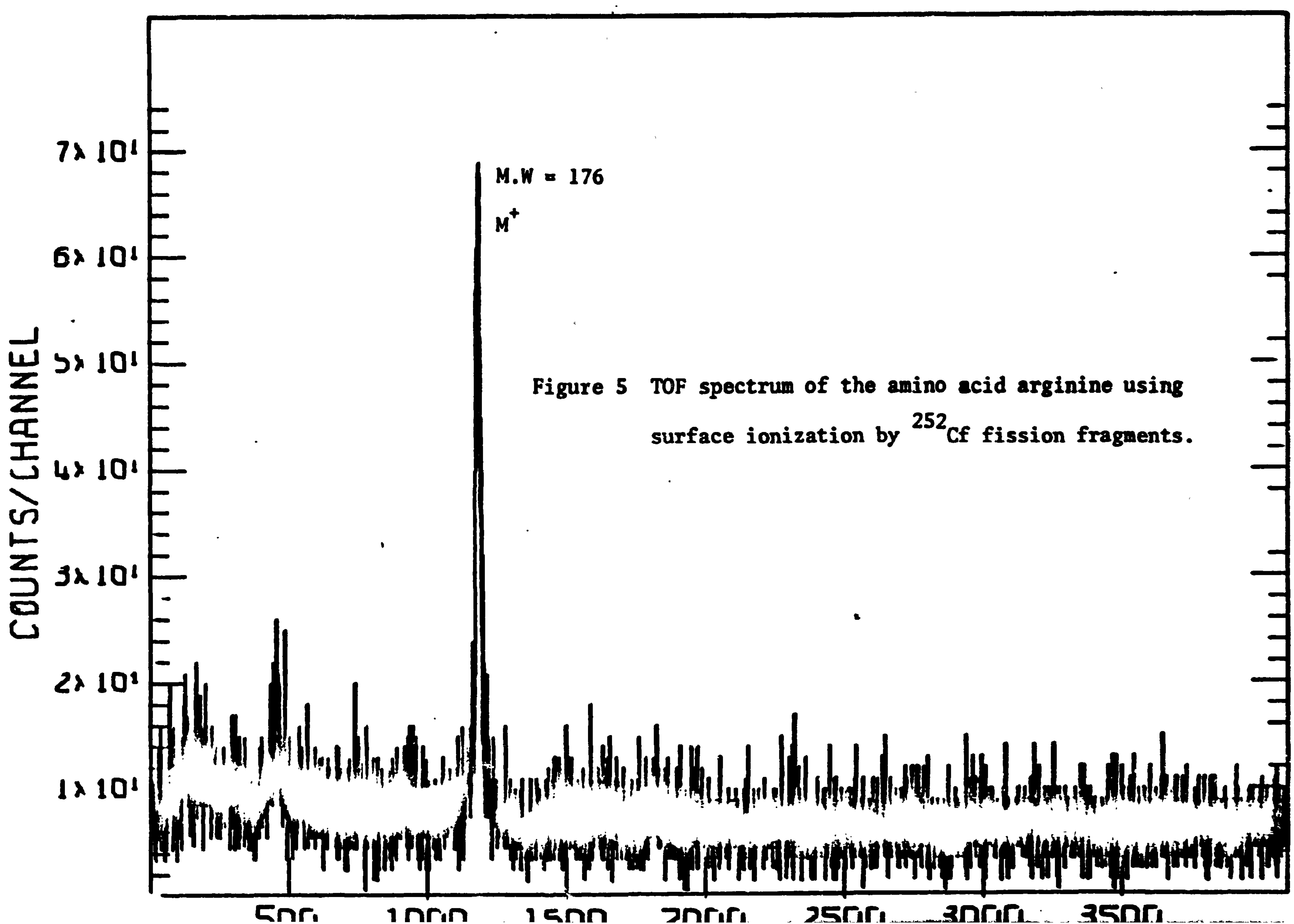

Figure 5 TOF spectrum of the amino acid arginine using surface ionization by ^{252}Cf fission fragments.

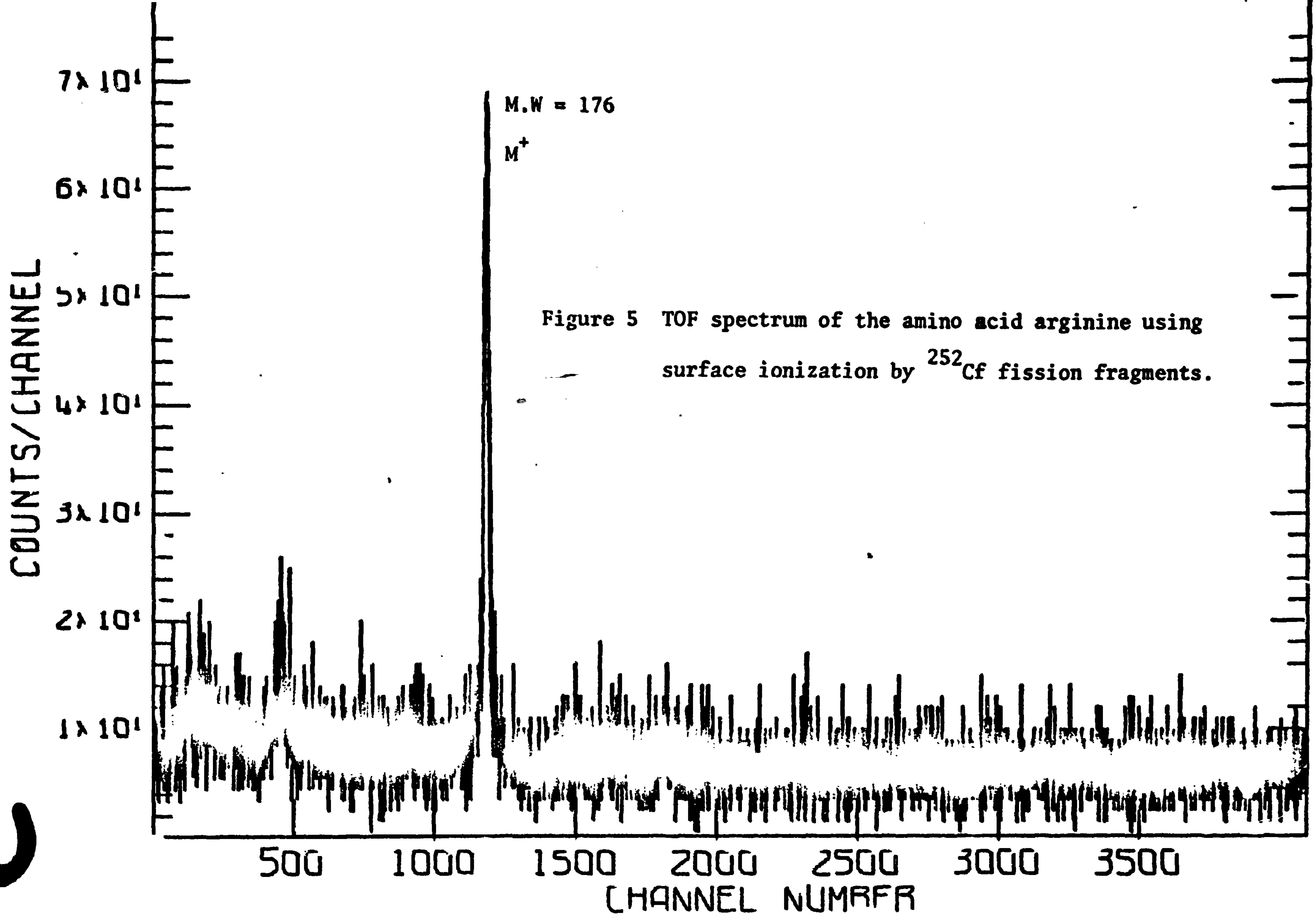

Figure 5 TOF spectrum of the amino acid arginine using surface ionization by ^{252}Cf fission fragments.

Figure 6

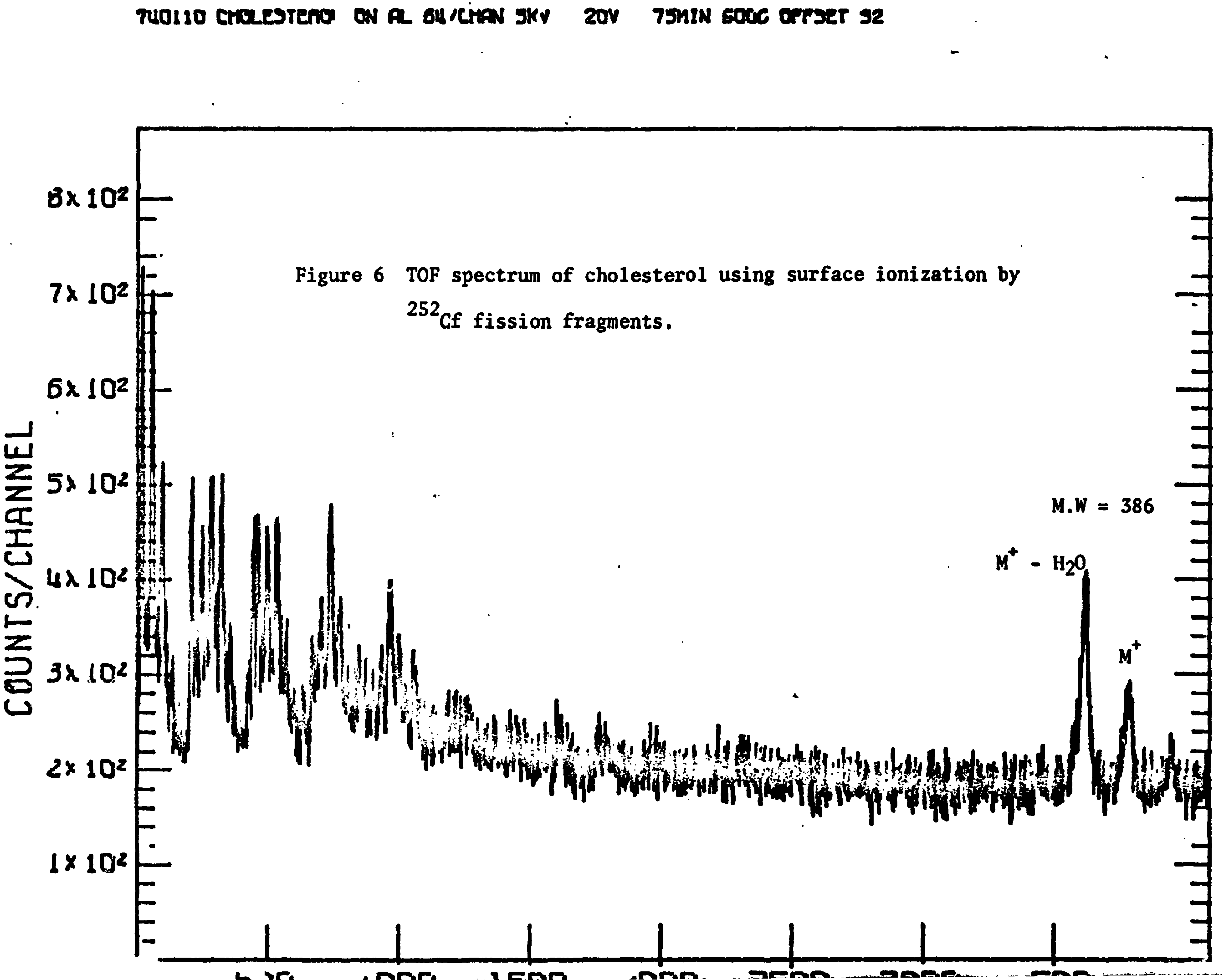

Figure 6 TOF spectrum of cholesterol using surface ionization by ^{252}Cf fission fragments.

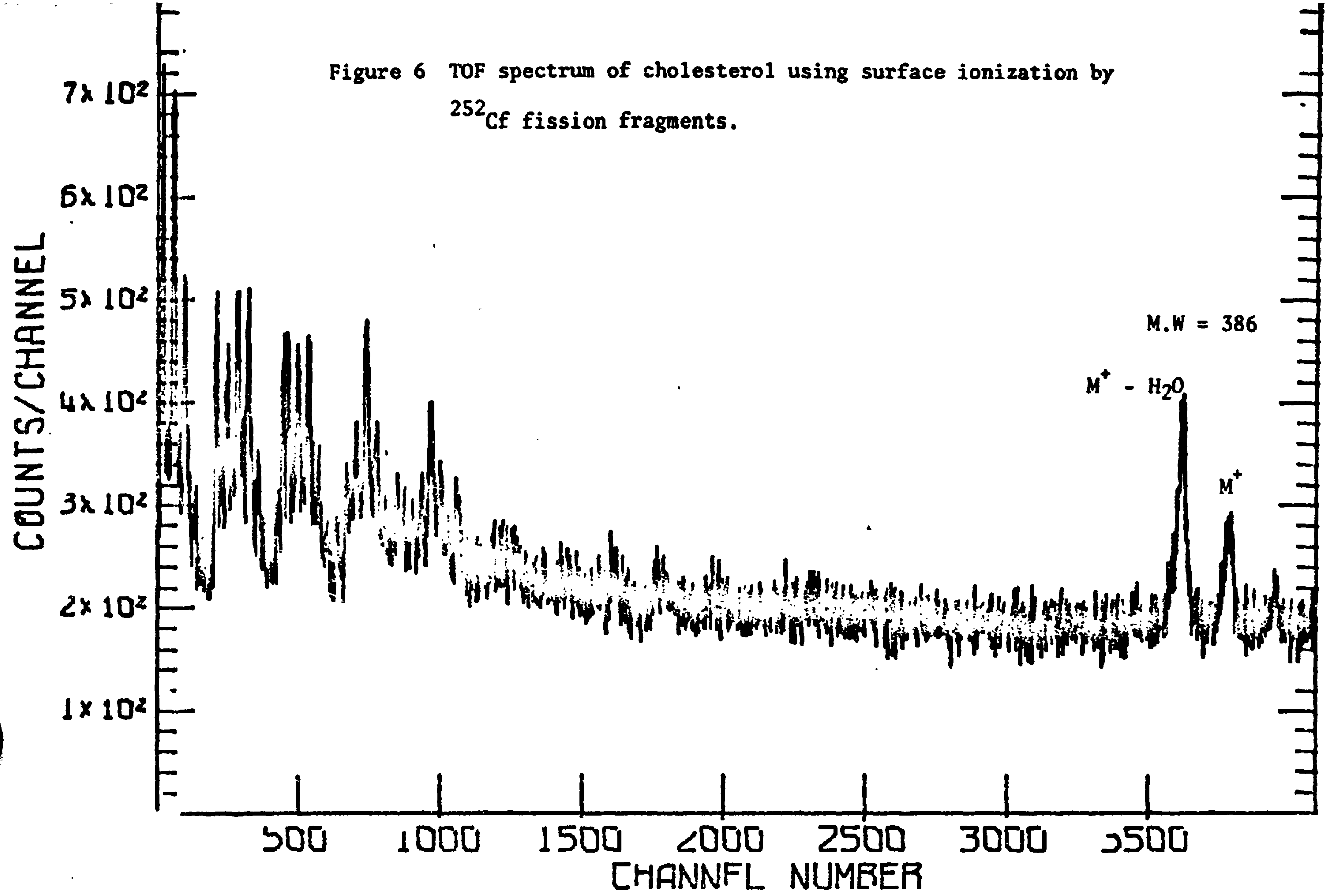

Figure 6 TOF spectrum of cholesterol using surface ionization by ^{252}Cf fission fragments.