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Publication Date

1973-07-01

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Presented at the Third Symposium on
the Physics and Chemistry of Fission,
Rochester, New York, August 13-17,
1973

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July 1973

Prepared for the U. S. Atomic Energy Commission
under Contract W-7405-ENG-48

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IAEA-SM-174/62

MEASUREMENT OF PROMPT GAMMA RAY LIFETIMES OF FISSION FRAGMENTS OF ^{252}Cf*

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ABSTRACT

The time of emission of the prompt gamma rays from the fission fragments of ^{252}Cf have been measured over a time range from approximately 1.0×10^{-10} to 2.0×10^{-9} seconds using the velocity and flight path of the fission fragment to determine the time. The ^{252}Cf source was deposited on a thin foil attached to a micrometer screw and located between two fission fragment detectors. The distance from the source to one of the fragment detectors was varied over a range from approximately 0.01 to 2.0 cm. A gamma ray detector was located close to the reference fragment detector and operated in coincidence with the fission events. The gamma rays associated with the stopped fragments were distinguished from those of the moving fragments on the basis of the known Doppler shift. Measurements were taken at various distances between the source and the detector. The measured fission fragment kinetic energies were used to calculate the masses of the stopped fragments. Thus the gamma ray spectra associated with the different fragment masses were obtained. The measured spectra were then used to obtain the intensities of the gamma lines at each distance. From these data it has been possible to obtain the energies and lifetimes of the electromagnetic radiation emitted by the fragments promptly after formation. Such data provide valuable information indicating values of the deformation parameters of the even-even isotopes; in particular the quadrupole moments calculated on this basis were found to agree with the theoretical values.

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*Work performed under the auspices of the U. S. Atomic Energy Commission.
Third Symposium on the Physics and Chemistry of Fission, Rochester, New York, August 13-17, 1973.

INTRODUCTION

In the recent past, interest in the neutron rich isotopes near A = 100 has been generated by the observation of rotational-like energy levels which suggested a new region of deformation. The fission of ^{252}Cf produces isotopes in this region and thus is a convenient source for use in their study.

In this paper we report the results of a new series of experiments where the lifetimes of the high yield gamma lines in the spontaneous fission of ^{252}Cf are measured by using their known velocities and defined flight paths. The length of the flight path is adjusted to six different positions. Each position corresponds to a well defined average flight-path from fission until the fragments are stopped and thus to a known flight time of the fission fragments. Due to the high velocity of the fission fragments, the gamma rays emitted during flight are Doppler shifted and easily separated from those of the stopped fragments. At each position approximately 10^7 events were collected and mass sorted to obtain gamma ray spectra as a function of the fragment mass. The intensities of the unshifted gamma lines are used along with the flight path length to obtain the lifetimes of the transitions. From the lifetimes and energies of the transitions, information on the deformation parameters of the even-even isotopes is obtained.

EXPERIMENTAL ARRANGEMENT

The experimental arrangement shown in Fig. 1 consists of five detectors. The fragment detector 1 is fixed in position and is parallel to the ^{252}Cf source and to the fission fragment detector 2(F2). The position of the ^{252}Cf source in respect to fragment (F1) detector can be varied by means of a micrometer screw in order to obtain different flight distances for the fission fragments. Since the velocity of the fragments is known, each distance corresponds to a particular time between fission and the instant when the fragment is stopped in the detector. The pulses produced by the gamma detector located behind the F2 detector are analyzed when they occur between 0 and 50 ns after a fission event is detected. The gamma rays emitted while the fragments are moving are Doppler shifted upwards by approximately 4%. This shift allows for an easy isolation of the gamma rays emitted after the fragment has stopped. Only the unshifted gamma rays from the stopped fragments are used to obtain the lifetimes. The gamma detector (3 cm^3 intrinsic germanium) is used to measure the intensities of the gamma lines from the stopped fragments. Fragment detector 2 is adjusted so that the variation in flight path over the finite acceptance angle is less than 10%. The alpha and NaI detectors operated in coincidence with the gamma detectors are used to provide gamma lines for digital gain stabilization and zero intercept corrections.

ELECTRONICS

A simplified diagram of the electronics is shown in Fig. 2. The signals from the fission and gamma detectors are transmitted to both the linear and logic sections. The linear section is composed of variable gain amplifiers, linear amplifiers, linear gates and units controlling the zero intercept. The variable gain amplifier and zero intercept units are controlled by the computer. The output from the linear circuitry feeds dimensions 1 to 4 of the analogue multiplexer and are defined as: dimension 1 fragment detector 1, dimension 2 fragment detector 2, dimension 3 low energy gamma rays (< 400 keV) and dimension 4 high energy gamma rays (< 1.2 MeV). The remaining two inputs to the analogue multiplexer are derived from the timing and logic sections. Dimension 5 is a marker which tells the computer what kind of event is being processed. Three different types of events can be processed: double coincidences between fragment detectors 1 and 2, triple coincidences between the two fragments and the gamma ray detectors, and gamma stabilization events. One out of every twenty double coincidence events is used for digital gain stabilization and zero intercept correction of the fission fragment pulse height distribution.

The timing and logic circuitry that provides dimension 5 and the coincidence signal to the analogue multiplexer is fed by all 5 detectors and performs the normal coincidence ($2\tau = 100$ nsec) and logic functions. The sum of the fission stabilization events is used to give the number of fissions recorded during the data acquisition process and is used to determine the yields of the gamma lines per fission. The event by event data obtained from the analogue-to-digital converter are accepted by the computer and recorded on magnetic tape to be used for additional off-line sorting of the data, if necessary. In addition, the computer makes an on-line mass sort to obtain gamma-ray distributions as a function of mass. There are 32 such distributions, 4096 channels long, corresponding to adjacent mass windows of 2 amu. The gamma distributions are analyzed in a larger computer at the end of the experiment to obtain the gamma-ray intensities.

The mass calculation is performed by means of a table look-up procedure. An array containing masses indexed by the two fragments pulse height F1, F2 is precalculated and used as the table. The mass calculation is similar to that described by Watson _et al_. [1]. We differ in that we are using the neutron data from Nifenecker _et al_. [2]. Possible grid effects were removed by recording fission fragments pulse heights with 4096 channels.

DATA REDUCTION

The gamma-ray spectrum associated with each mass window is analyzed with the photopeak analysis code developed by Routti and Prussin [3] to obtain the gamma line intensities. Since the mass resolution (σ = 2-4 amu) is much broader than our mass windows (2 amu) it is necessary to fit the intensities of a particular gamma line as a function of mass assuming the shape of a gaussian in order (Fig. 3) to obtain the total yield at each position.

As mentioned above six positions with respect to distance were used in the experiment: 0.008, 0.1250, 0.2500, 0.5000, 1.000, and 2.000 cm. Figure 3 shows an example of the intensities obtained for the 2 → 0 transition in ^{102}Zr. From these distances, the acceptance angle of the fission detectors and the velocities of the fission fragments the average velocity of the fragments that produced a specific isotope after neutron emission was determined by first taking the Z of that isotope and using the experimental data of Reisdorf et al. [4] that gives the average preneutron mass (A^*) for the production of each charge. The mass of the isotope produced (A_F) is then subtracted from this mass to obtain the average number of neutrons emitted ($\bar{\nu} = A^* - A_F$). The number of neutrons emitted is then used along with the preneutron mass as indexes in the experimental data that gives the relationship of the total kinetic energy (E_K) of the fission fragments to $\bar{\nu}$ and A^* of Nifenecker et al. [2] to determine E_K. This value of E_K and A^* are then used in Eq. (1) to define the average value of the velocity.

$$V_1 = \sqrt{\left(\frac{2}{A^*} - \frac{1}{126}\right)E_K} \qquad (1)$$

The lengths (ℓ) listed earlier for the distances from the source to the F1 detector are converted by Eq. (2) before calculating the lifetimes

$$\bar{\ell} = -\ell\left(\frac{\ln|\cos\theta|}{1 - \cos\theta}\right) \qquad (2)$$

The angle θ is the acceptance angle of the fission fragment detectors. This correction was needed to define the length of the average flight path of the fragments. Using these distances and velocities of individual isotopes each position of the source is converted to a time between fission and the instant when a particular fragment of measured mass is stopped. This time is then used along with the gamma line yield at each position to determine the lifetime of each gamma transition.

The lifetimes of the gamma lines were then used to determine the reduced electric-quadrupole transition widths ($B(E2)_{ex}$), intrinsic electric quadrupole moments (Q_0) and β_2. These parameters which appear in Table 1 were obtained following the procedure of Stelson and Grodzins [5]. The isotopic assignments in Table 1 are taken from previous work of this group [6]. These isotopic assignments have since been confirmed by Khan et al. [7] partially. Figure 4 shows an example of the gamma ray spectra for different distances, in this case centered around mass 148. The ^{148}Ce line position is marked in the upper left in Fig. 4. This line shows no significant Doppler shifted component at short times but at longer times the Doppler shifted component becomes equivalent to the unshifted one. A small amount of ^{146}Ba can also be seen in this figure. Figure 5 shows the results determining the total yield of these lines over the appropriate masses at each position. The figure shows one of the two examples of a 2 component decay curve observed in this experiment. The two cases of multiple decay curves are ^{146}Ba and ^{110}Ru.

No attempt has been made to correct the data for the hyperfine interaction (HFI) which couples the nuclear and the electronic spins of the fission fragments. This effect is expected to be strong for highly ionized fission fragments. This correction is such as to decrease the lifetimes as reported in this experiment. The magnitude of the correction could be as large as 20% if the destruction of the fission fragment alignment by the HFI occurred in a time comparable to the half life of the gamma transition. It is expected, however, that the characteristic time for the spin deorientation, should be much shorter than the half lives reported here and, therefore, that such effects are probably negligible.

The results of this experiment do not agree well with the previous results of our group [6] using a two point decay curve. Figure 6 shows the values of β_2 and $B(E2)/B(E2)_{sp}$ obtained from both experiments. It is seen that the half-lives measured in this experiment are approximately 50% longer than those reported earlier. The results of this experiment are also compared with the calculations of Ragnarsson et al. [8]. In Fig. 7 it can be seen that the agreement between calculated values for prolate shapes and the experimental ones is remarkably good. This of course does not prove that the system is prolate because we can not determine the sign of Q_0.

It should be noted that the previously reported large deformation of zirconium ($\beta_2 \sim 0.6$) 102 is disproved in this experiment.

ACKNOWLEDGMENTS

We wish to thank J. B. Hunter for help at various stages of the experiment and to J. Blachot for checking of numerical calculations.

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FIGURE CAPTIONS

Fig. 1. The arrangement of the detectors.
Fig. 2. Simplified diagram of the electronics.

Fig. 3. A composite plot of the intensity of ^{102}Zr $2^+ \rightarrow 0^+$ transition as a function of mass for each position. The counts are in arbitrary units and are not normalized to the number of fissions.

Fig. 4. Gamma spectra at different distances. The counts are in arbitrary units and are not normalized to the number of fissions.

Fig. 5. Decay curves for ^{148}Ce and ^{146}Ba.

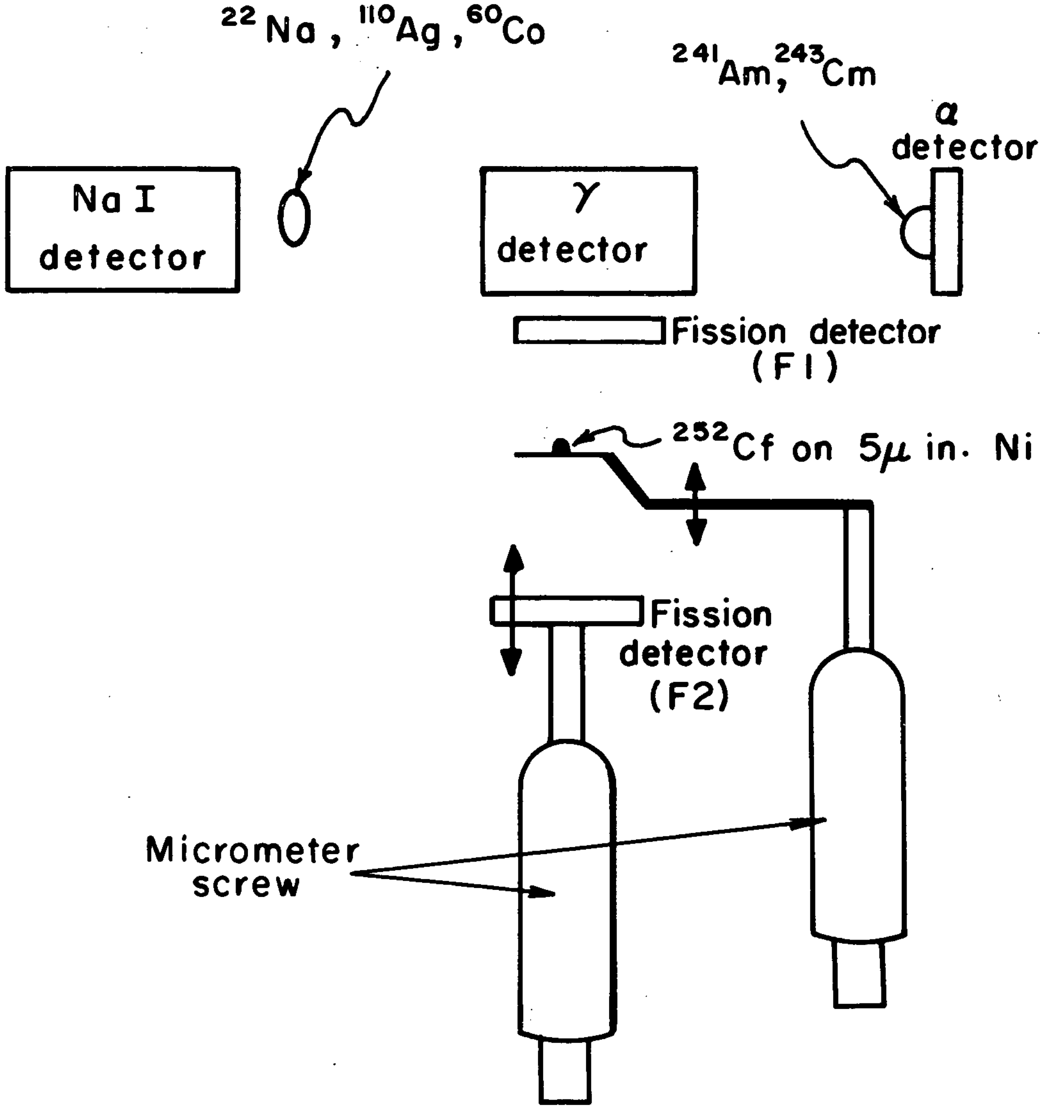
Fig. 6. Comparison of the β_2 $B(E2)/B(E2)_{sp}$ values of the experiment of Cheifetz *et al.* and this work. The Δ are Cheifetz *et al.* and the Θ are this work.

Fig. 7. A comparison of experimental and the calculated results of Ragnarsson, Ref. 7.

Table 1.

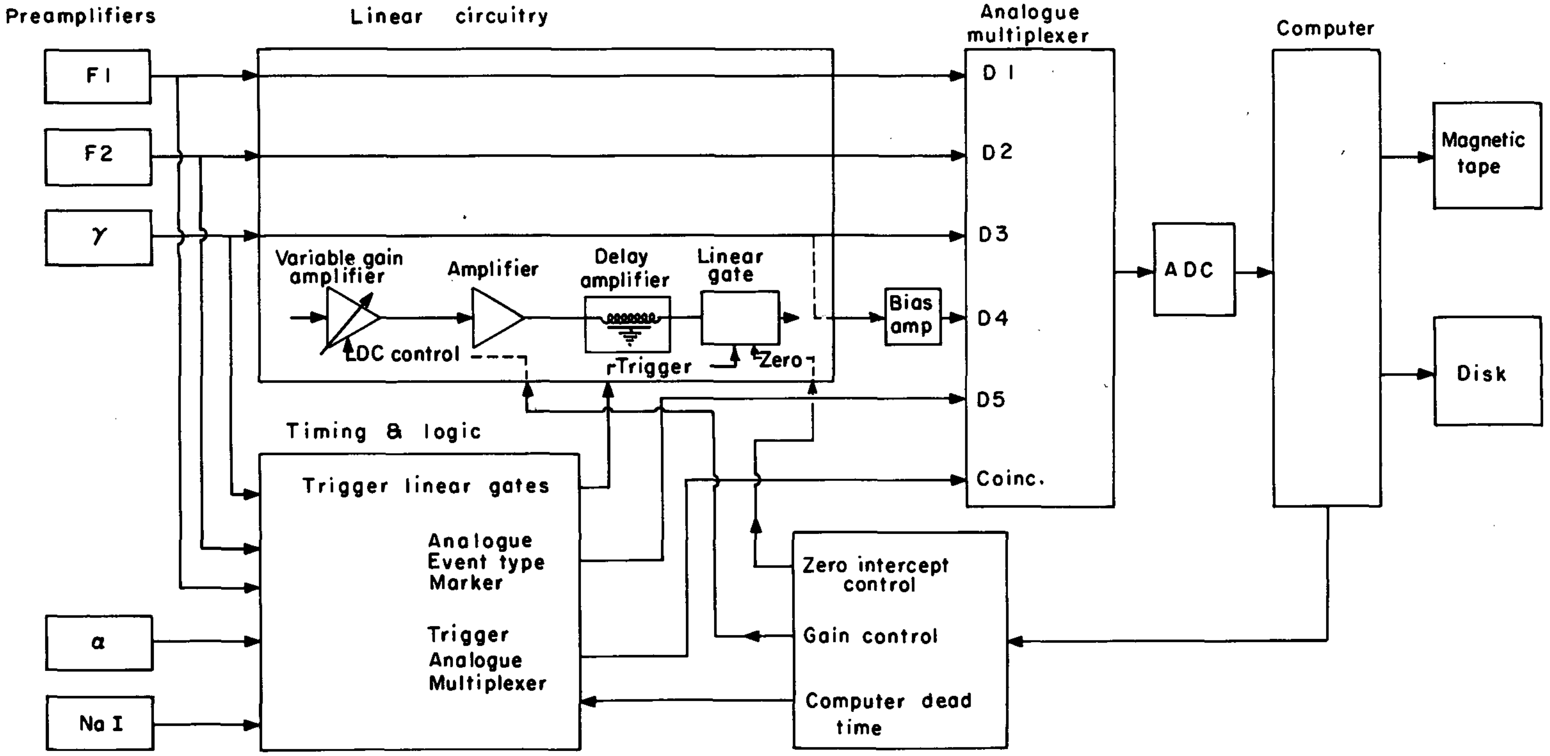
		Fragment Velocity cm/nsec	$t_{1/2}$ nsec	Energy keV	$B(E2)_{ex}$ $cm^4 \times 10^{-51}$	$\frac{B(E2)}{B(E2)_{sp}}$	β_2	$\lvert Q_0 \rvert$ $cm^2 \times 10^{-24}$	Q_0 Calculated[a]	
									Oblate	Prolate
^{100}Zr	$2^+ \rightarrow 0^+$	1.39	0.714±0.03	212.7	845±40	62±3	0.32±0.02	2.9±0.2	-2.3	3.26
^{102}Zr	$2^+ \rightarrow 0^+$	1.52	3.17±0.25	151.9	1275±100	91±8	0.38±0.02	3.6±0.2	-2.33	3.53
^{104}Mo	$2^+ \rightarrow 0^+$	1.36	0.911±0.03	192.3	1060±40	74±3	0.32±0.02	3.26±0.2	-2.36	3.22
^{106}Mo	$2^+ \rightarrow 0^+$	1.44	1.25±0.03	171.7	1300±40	88±3	0.35±0.02	3.61±0.2	-2.37	3.40
^{108}Ru	$2^+ \rightarrow 0^+$	1.28	0.345±0.03	242.3	930±80	61±6	0.28±0.02	3.05±0.2	-2.42	2.88
^{110}Ru	$2^+ \rightarrow 0^+$	1.38	0.34±0.04	240.8	970±120	62±7	0.28±0.02	3.12±0.2	-2.50	3.05
^{112}Ru	$2^+ \rightarrow 0^+$	1.44	0.32±0.03	236.8	1120±110	70±7	0.32±0.02	3.35±0.2	-2.58	3.01
^{114}Pd	$2^+ \rightarrow 0^+$	1.34	0.198±0.06	332.9	340±100	21±6	0.16±0.03	1.85±0.3	-2.42	2.73
^{116}Pd	$2^+ \rightarrow 0^+$	1.40	0.106±0.03	340.6	570±170	34±10	0.20±0.03	2.39±0.3	-2.43	2.62
^{142}Ba	$2^+ \rightarrow 0^+$	0.95	0.070±0.04	359.7	660±400	30±16	0.16±0.04	2.57±0.4		
^{144}Ba	$2^+ \rightarrow 0^+$	1.08	0.070±0.03	199.4	1100±60	49±3	0.20±0.02	3.33±0.2	-2.17	2.20
^{146}Ba	$2^+ \rightarrow 0^+$	1.09	0.86±0.06	181.0	1390±100	61±4	0.22±0.02	3.73±0.2		
^{146}Ce	$2^+ \rightarrow 0^+$	0.93	0.26±0.05	258.6	880±180	39±8	0.17±0.02	2.97±0.2	-2.56	3.03
^{148}Ce	$2^+ \rightarrow 0^+$	1.00	1.06±0.08	158.7	200±160	87±7	0.25±0.02	4.48±0.2	-3.30	4.56
^{150}Ce	$2^+ \rightarrow 0^+$	1.03	3.60±1.0	97.1	3300±950	141±40	0.32±0.04	5.76±0.4		
^{154}Nd	$2^+ \rightarrow 0^+$	0.97	7.7±2	72.8	2180±650	102±26	0.25±0.03	4.67±0.4		

[a] Q_0 calculated is from Ref. 7.



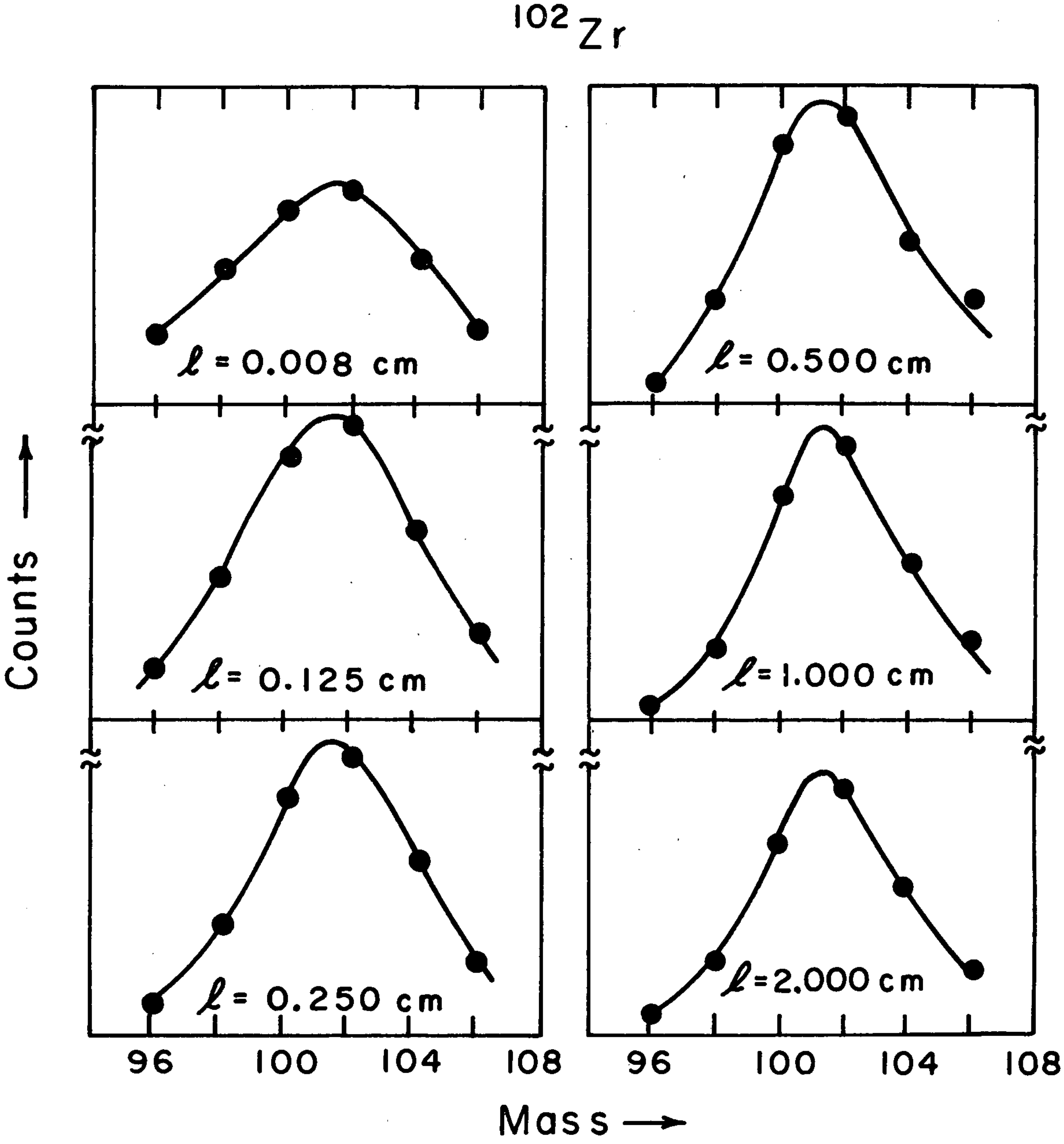
XBL736-3163

Fig. 1



XBL736-3164

Fig. 2



XBL737 - 3527

Fig. 3

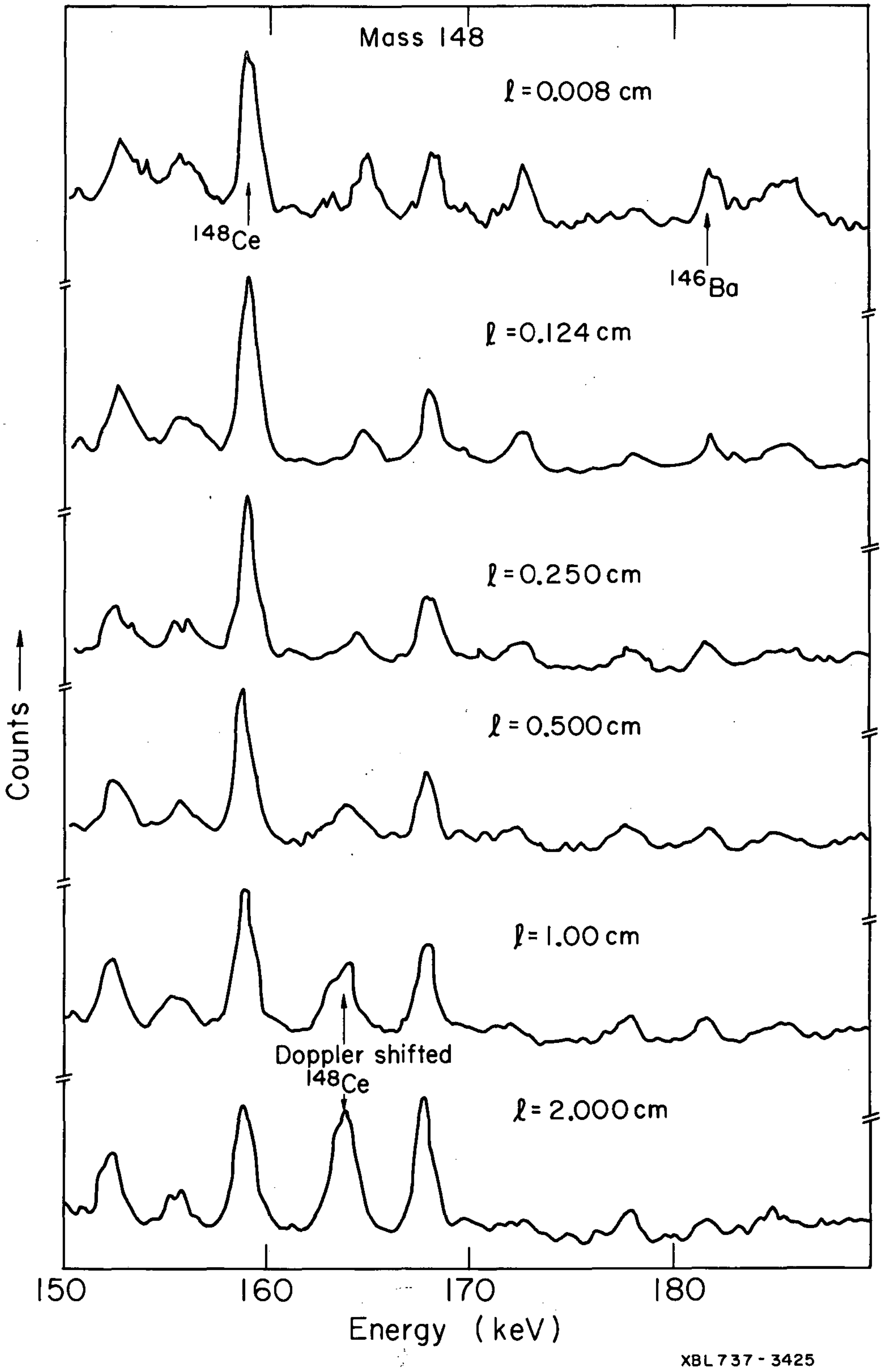
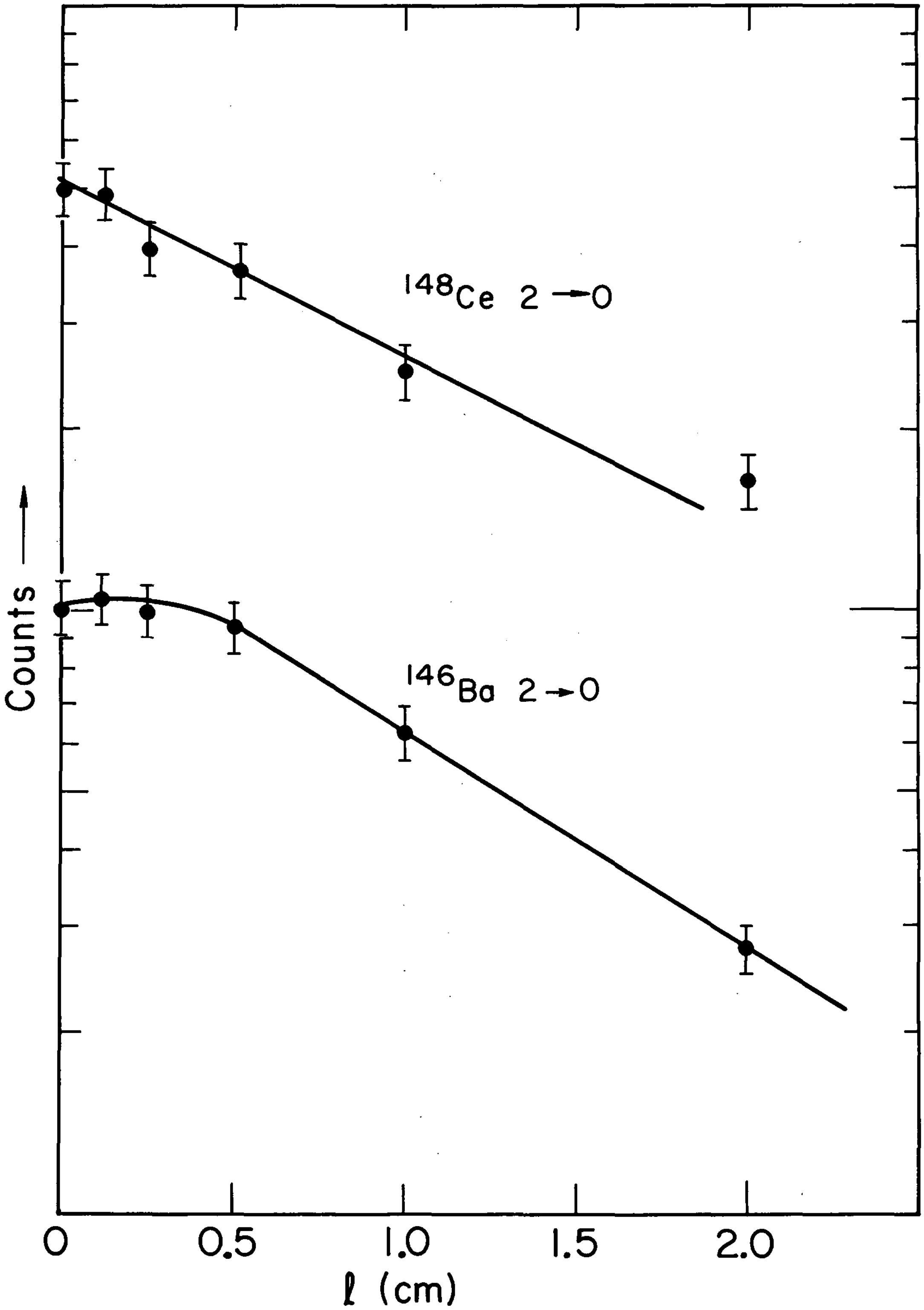

Mass 148
ℓ = 0.008 cm
^{148}Ce
^{146}Ba
ℓ = 0.124 cm
ℓ = 0.250 cm
ℓ = 0.500 cm
ℓ = 1.00 cm
Doppler shifted
^{148}Ce
ℓ = 2.000 cm
Counts →
150
160
170
180
Energy (keV)
XBL 737 - 3425

Fig. 4



XBL737-3427

Fig. 5

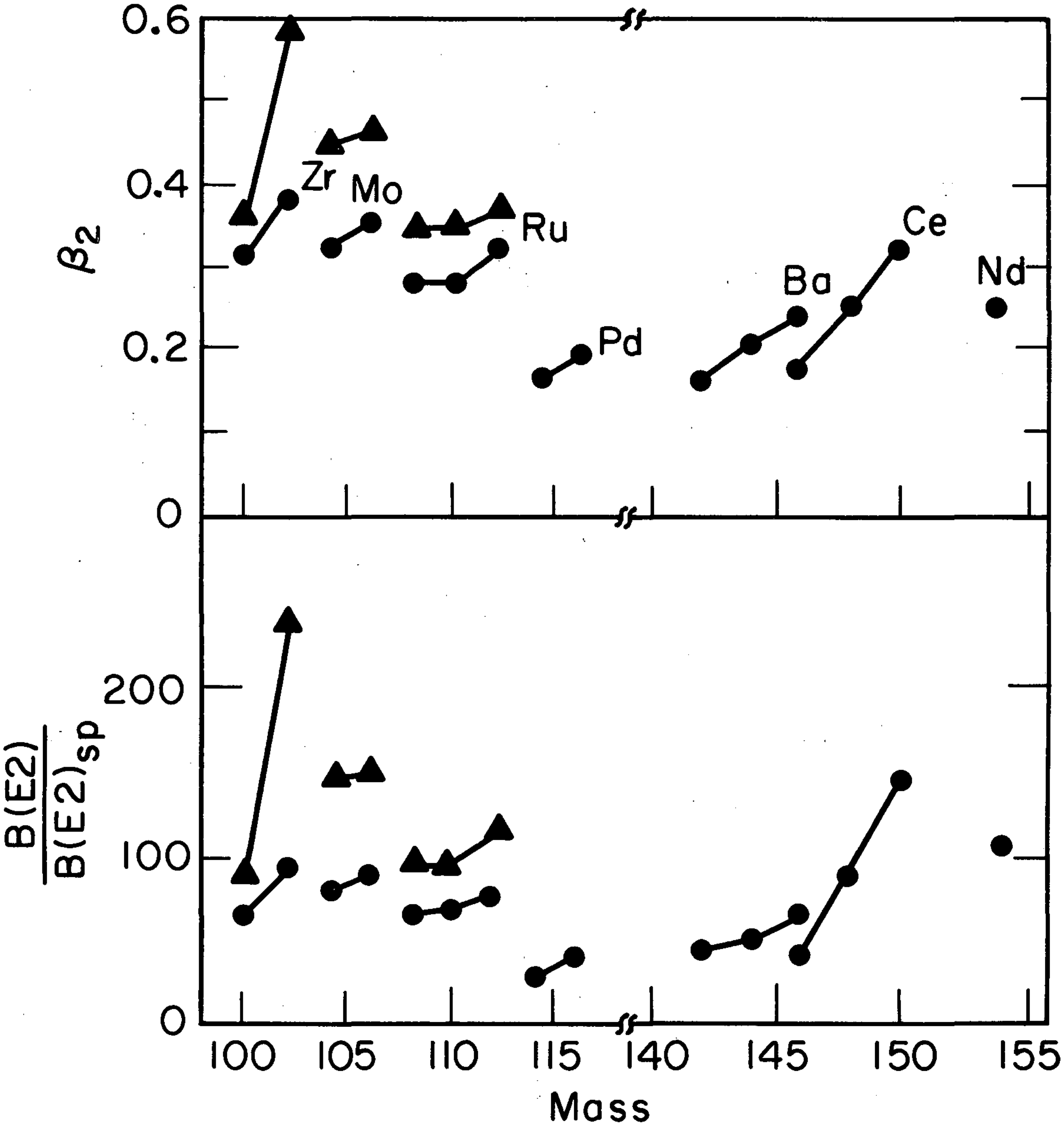


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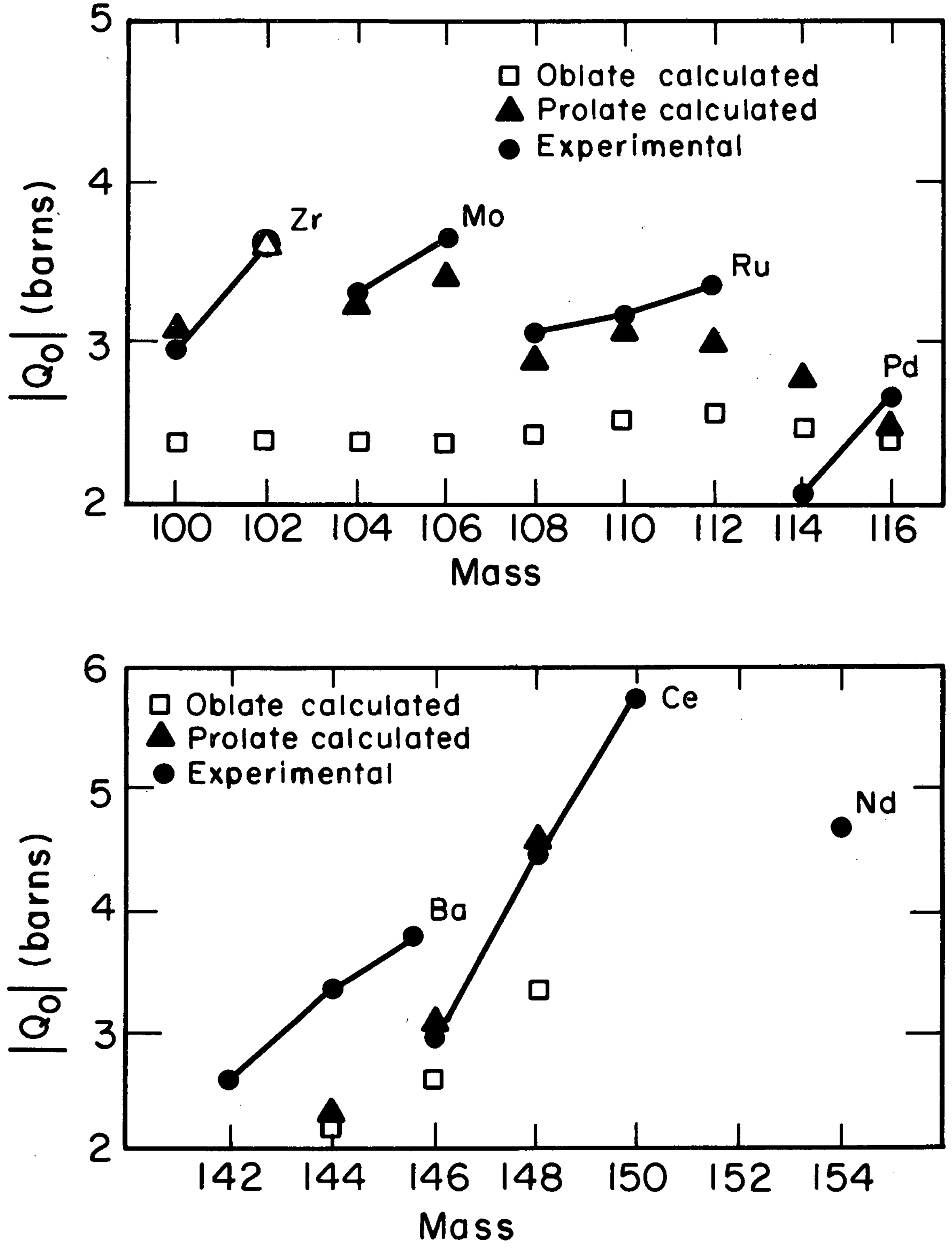
Fig. 6



XBL 737-3430

Fig. 7

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