PHYSICAL REVIEW C VOLUME 8, NUMBER 2 AUGUST 1973

Decay Energies of Gaseous Fission Products and their Daughters for $A = 138$ to 142

J. P. Adams,* G. H. Carlson, M. A. Lee,† W. L. Talbert, Jr., F. K. Wohn, J. R. Clifford,‡ and J. R. McConnell

Ames Laboratory-USAEC, and Department of Physics, Iowa State University, Ames, Iowa 50010

(Received 23 March 1973)

The β-decay energies for several mass-separated Xe fission products and their daughters have been measured at the TRISTAN on-line separator facility at the Ames Laboratory research reactor. A well-type plastic scintillator was used in coincidence with a Ge(Li) γ detector to determine β-group end-point energies and deduce Q values. The following β-decay energies have been determined: ^{138}Xe, 2.83 ± 0.08 MeV; ^{138}Cs, 5.29 ± 0.07 MeV; ^{139}Xe, 4.88 ± 0.06 MeV; ^{139}Cs, 4.29 ± 0.07 MeV; ^{140}Xe, 4.06 ± 0.06 MeV; ^{140}Cs, 5.8 ± 0.1 MeV; ^{141}Xe, 6.0 ± 0.1 MeV; ^{141}Cs, 4.98 ± 0.08 MeV; ^{141}Ba, 3.01 ± 0.06 MeV; ^{142}Xe, 4.9 ± 0.1 MeV; and ^{142}Cs, 6.89 ± 0.06 MeV. The decay energies are compared with previous measurements, systematics predictions, and two currently accepted mass relations. The energies are also used to predict the β-decay energies for seven additional nuclei by means of systematics.

I. INTRODUCTION

Knowledge of the decay energy and ground-state branching is necessary for an accurate determination of the comparative half-life or logft value of a particular β group, which then can be used to define a range for the spin-parity difference between the energy levels connected by the β transition. In this work, the decay energies of 11 short-lived nuclei were measured, using β-γ coincidence and β singles techniques: the nuclei studied were ^{138}Xe ^{138}Cs, ^{139}Xe, ^{139}Cs, ^{140}Xe, ^{140}Cs, ^{141}Xe, ^{141}Cs, ^{141}Ba, ^{142}Xe, and ^{142}Cs. The results reported here were obtained from data taken in conjunction with another study of the Kr fission product and daughter activities.[1] The β-γ coincidence technique is based on the fact that the end-point energy of the β group feeding an energy level in a daughter nucleus is equal to the decay energy of the parent nucleus minus the excitation energy of the daughter nucleus level. Thus, the decay energy of the parent nucleus can be determined by measuring the end-point energy of the β group in coincidence with a γ ray deexciting a known energy level.

The decay energies measured in this work are compared with the previously measured decay energies compiled by Wapstra and Gove.[2] In addition to the compiled values, the decay energies of ^{140}Xe, ^{141}Cs, and ^{142}Cs were predicted by Wapstra and Gove. In this prediction, they required simultaneous smoothness of two-neutron separation energies, two-proton separation energies, and α- and β-decay energies as a function of A, using the method developed by Way and Wood.[3] The newly measured β-decay energies in this work were used as a basis for systematics predictions of the β-decay energies, as yet unmeasured, for ^{143}Ba, ^{144}Ba, ^{137}I, ^{138}I, ^{139}I, ^{140}I, and ^{144}La using the method of Way and Wood.

The β-decay energies measured in this work are also compared with two mass relations, the first being the semiempirical mass law developed from the liquid-drop model by von Weisäcker and expanded to include shell effects and BCS theory pairing energies by Seeger,[4] and the second being the isospin-based mass relation developed by Garvey *et al.*[5] and modified by Sorensen.[6] All mass formulas are semiempirical in nature; that is, the values for the parameters that make up the formulas are determined using experimental results. Although the mass formulas are most accurate near the line of β stability, where most of the data exist, they are used to predict properties of nuclei in regions not accessible by experiment and sometimes far removed from stability. An example of this was reported by Seeger in his discussion of the "r process" of nucleogenesis[4] where he used several mass formulas to predict the relative isotopic abundances. Of all the formulas he tested, his own came closest to predicting the naturally occurring isotopic abundances.

Another example of the extrapolation of the mass formulas is in the area of "superheavy" elements, a subject of great contemporary interest. Nix[7] has proposed a means of predicting fission barriers for the (as yet) undiscovered superheavy nuclei by synthesizing a microscopic theory, the shell model, with the macroscopic liquid-drop model.

In these varied predictions, the mass formulas used known data near stability to predict information not yet accessible by experiment. Measurement of masses far from stability offers a critical test of these extrapolations and may indicate ways to improve the mass formulas. A mass formula can also be tested by its ability to predict the occurrence of delayed neutron precursors. The formulas developed by Seeger[4] and Garvey *et al.*[5] were chosen for comparison with the results of this work from the other available mass formulas because of their success in predicting the occurrence of delayed neutron precursors[8,9] as well as their relative accuracy in fitting known masses.

II. EXPERIMENTAL FACILITY

A. TRISTAN On-Line Isotope Separator System

The facility used in this experiment, located at the Ames Laboratory research reactor, consisted of the TRISTAN isotope separator on line to the reactor, a moving tape collector (MTC), and various detectors and electronics.

The on-line isotope separator system has been described previously in several publications[10-13]; therefore, only a brief description will be given here. The gaseous fission products Kr and Xe are emanated from a totally enriched ^{235}U sample placed in a neutron flux, introduced into the separator by molecular flow transfer, and ionized in an ion cource. The ionized beam is then accelerated through 50 kV, focused, and introduced into a 1.6-m, 90° analyzing magent. In the collector box, situated at the focal plane of the magnet where the ion beams are well separated, a slit selects the mass of interest from the other mass components of the beam. The mass-selected beam passes through the defining slit and into a switching magnet. The switching magnet further focuses and mass separates the beam while directing it into the MTC.

There are six detector ports on the MTC, of which four are for detectors outside of the MTC vacuum, and two are used for detectors (β or electron) connected to the MTC vacuum. One of the connected ports and two of the external ports surround the tape on three sides at the position of beam deposition. The other three ports, arranged in a similar array, are located approximately 0.45 m "downstream" in the tape motion. The first three ports are used for examining parent or short-lived daughter activities. The MTC is thus used for isobaric separation of the activities in the decay chain of the collected sample. To accomplish this most effectively, the MTC can be operated in any of three modes. The parent activity can be emphasized by moving the tape continuously at a speed fast enough to emphasize the parent activity and yet retain a good count rate. To study daughter activities at the "downstream" ports, the MTC can be operated in the sequential mode with collect, delay, accumulate, and transport times counted sequentially, or in a special "high-duty-factor" mode in which a new sample is collected and delayed while the previous one is being counted. Times used for operation of the MTC to optimize both the separation and the count rate of a desired daughter activity were determined by use of the program ISOBAR.[14]

B. Detector Systems

The plastic scintillator β detector used in this work was a well-type cylindrical scintillator made of Pilot-B plastic. Figure 1 shows the plastic scintillator mounted at the first vacuum-connected port of the MTC. The well is in the shape of a truncated cone with an entrance diameter of 1.9 cm and a depth of 2.3 cm. The detector is situated so that the source is at the vertex of the cone, a distance of 5.7 cm from the front of the well. The solid angle subtended by the well through the defining aperture is 0.7% of 4π sr. The effect of the well is to greatly reduce the backscattering out of the detector, at the expense of producing a quadratic energy calibration curve. The response of the scintillator to monoenergetic electrons has been measured as a function of energy for analysis of the measured spectrum. The finite resolution and backscattering for the detector cause the major distortions in the spectrum. Calibration of the plastic scintillator and further details in the description of this scintillator are available in the literature.[15,16]

An ORTEC 60-cm^3 coaxial-type Ge(Li) γ-ray detector was used in this work. The full width at half-maximum (FWHM) resolution was approximately 2.5 keV for the 1.33-MeV transition in the decay of ^{60}Co and the peak-to-Compton ratio was 28:1. The efficiency of the detector was 11% compared to a 7.6-cm by 7.6-cm NaI(Tl) detector. The detector was situated approximately 5 cm from the source and subtended a solid angle of approximately 2% of 4π sr.

The experimental data were processed by a two-parameter format selector into a buffer tape unit. The buffer tape unit was used to store the data in a 4096 by 4096 array by sequentially recording

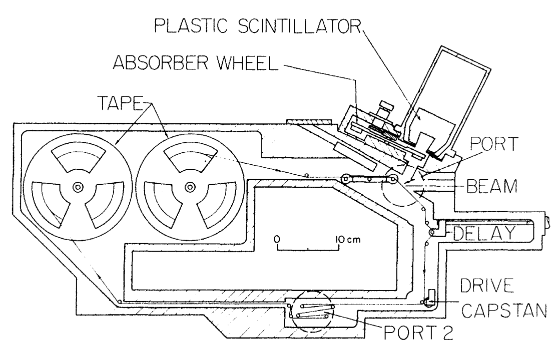

FIG. 1. The MTC and plastic scintillator with the tape in position.

pairs of coincidence events onto a magnetic tape for later examination.

III. EXPERIMENTAL RESULTS

Two different methods were used to measure β-decay energies. The most frequently used method was a β-γ method with the plastic β scintillator and the Ge(Li) γ detector used in time coincidence. The β spectra taken with the plastic scintillator are distorted (as compared with the actual spectra) by two processes: the response of the scintillator to monoenergetic β rays, and the response of the scintillator to γ rays. The effects due to the response of the detector to monoenergetic β rays were included during data analysis by "folding in" the previously measured response of the detector in a manner described by Rogers and Gordon[17] and also by Wohn *et al.*[15] The effects due to the response of the plastic to γ rays were measured during data collection by placing absorbers in front of the scintillator to eliminate the electrons as described by Clifford *et al.*[1]

The γ spectrum was examined for each decay, and the strongest γ-ray transitions in the coincidence spectrum were used as "gates" with the β spectra in coincidence with the gates being sorted out by the buffer tape unit. These "gated" spectra were plotted and the end-point energy for each was determined using a computer program, FERMI. The program FERMI is a two-parameter fitting routine which can fit a spectrum consisting of up to five individual β groups provided the relative intensity and end-point energy of each group is held fixed relative to the most energetic group. This information can be determined from the γ-ray energy level scheme. The γ-ray intensity balance for each level in the daughter nucleus was calculated to determine the relative β feeding to each level. The composition of each spectrum was determined as follows: the relative intensity of β group "i" in the spectrum in coincidence with a γ-ray depopulating level "j" is equal to the relative β feeding to level "i" times the fraction of the γ-ray intensity leaving level "i" that populates level "j."

Table I summarizes the experimental conditions of the β-decay energy measurements. Included are: the decaying nucleus, type of experiment (coincidence or single), MTC mode (either tape speed in cm/sec or collect, delay, and accumulate times in sec), and the integrated activity ratios for Xe, Cs, Ba, and La as calculated for the MTC mode.

A. ^{138}Xe

Eight gates set on γ rays depopulating four levels in ^{138}Cs were analyzed to determine the Q value for the decay of ^{138}Xe. The value of 2.83 ± 0.08 MeV obtained in this work differs by 0.1 MeV from the value of 2.72 ± 0.05 MeV reported recently by Monnand *et al.*[18] Although there is fair agreement between these two Q values our error is a weighted rms error for the eight individual values found and may be more realistic than their quoted error. The end point of the β spectrum in coincidence with the intense 258-keV γ-ray transition was used by Monnand in their Q-value determination. Recent γ-ray studies[19] of the decay of ^{138}Xe indicate that the 258-keV level in ^{138}Cs is fed mainly by γ rays depopulating higher energy levels and fed only very weakly by direct β decay. The end-point energy of the β spectrum in coincidence with the 258-keV γ ray should then be added to something greater than 258 keV to determine the Q value using this particular gate, which may account for the

TABLE I. Summary of experimental conditions.

Decaying nucleus	Coincidence or singles experiment	MTC mode	Integrated activity ratios (%) Xe	Cs	Ba	La
^{138}Xe	Coin	0.4 [a]	95	5	···	···
^{138}Cs	Coin	120, 4900, 5020 [b]	4	96	···	···
^{139}Xe	Coin	0.08 [a]	99	1	···	···
^{139}Cs	Coin	400, 400, 800 [c]	···	88	12	···
^{140}Xe	Coin	0.2 [a]	96.6	3.4	···	···
^{140}Cs	Coin	40, 50, 80 [b]	9	91	···	···
^{141}Xe	Coin	0.2 [a]	92	8	···	···
^{141}Cs	Singles	40, 15, 40 [b]	···	94	6	···
^{141}Ba	Coin	2360, 310, 2670 [c]	···	···	81	19
^{142}Xe	Coin	0.2 [a]	59	40	1	···
^{142}Cs	Coin	0.2 [a]	59	40	1	···

[a] Continuous mode—tape speed in cm/sec.
[b] Sequential mode—collect, delay, and accumulate times in sec.
[c] High-duty-factor mode—collect, delay, and accumulate times in sec.

low value of 2.73 MeV quoted by Monnand *et al.* In this work, the β feeding to higher energy levels seen in coincidence through other γ transitions has been accounted for as mentioned. For the decays of ^{138}Xe and ^{138}Cs, the relative β end-point energies and intensities necessary for this multiple β-group analysis were taken from the work of Carlson, Talbert, and McConnell.[19]

B. ^{138}Cs

The Q value for the decay of ^{138}Cs was determined to be 5.29 ± 0.07 MeV by using the information from gates set on 10 γ rays which depopulate 6 different levels in ^{138}Ba. This value is 0.45 MeV higher than that of 4.84 MeV determined by Langer, Duffield, and Stanley[20] in 1953. This difference may be due to the fact that the earlier value was determined by simply summing the β singles end-point energy and the energy of the first excited state in ^{138}Ba. In a study of the γ rays observed in the decay of ^{138}Cs from which the relative β feedings and end points were determined,[19] it was found that only 9% of the β singles spectrum directly feed the first excited state. More recently, Carraz, Monnand, and Moussa[21] reported a Q value for the decay of ^{138}Cs of 5.04 ± 0.12 MeV from a β-γ coincidence measurement.

C. ^{139}Xe

The Q value for the decay of ^{139}Xe was measured to be 4.88 ± 0.06 MeV using the β spectra in coincidence with five different γ-ray transitions. This Q value for the decay of ^{139}Xe is between the value of 4.6 ± 0.2 MeV reported by Wahlgren and Meinke[22] in 1962 and that of 5.0 reported by Holm *et al.*[23] in 1967. The decay schemes for ^{139}Xe and ^{139}Cs, from which excited-state relative β branchings were deduced, have been determined by Lee.[24]

D. ^{139}Cs

Again the Q value of 4.29 ± 0.07 MeV measured for the decay of ^{139}Cs, determined from eight gated β-ray spectra, is intermediate between two values reported previously. Zherebin, Krylov, and Polikarpov[25] reported the Q value to be 4.11 ± 0.10 MeV in 1966, and Rudstam *et al.*[26] reported the Q value to be 4.44 ± 0.06 MeV in 1970.

E. ^{140}Xe

The β spectra in coincidence with 13 γ-ray transitions were used to determine the decay energy for ^{140}Xe. According to the decay scheme determined by Schick, Talbert, and McConnell[27] these 13 γ-ray transitions represent deexcitations from 6 levels in ^{140}Cs, with 7 of the transitions deexciting the 1.4276-MeV level highly fed by β decay. The weighted average of the several determinations of the Q value for the decay of ^{140}Xe is 4.06 ± 0.06 MeV. Alväger *et al.*[28] estimated this energy to be 4.7 ± 0.5 MeV using plastic scintillator singles data. Figure 2 shows the FERMI fit to the β spectrum in coincidence with the 0.744-MeV transition in this decay. The figure serves as an example of a single β group fitted for this study.

F. ^{140}Cs

In this decay, only one γ-ray gate was found to produce sufficient statistics for proper analysis. This gate was the 0.602-MeV transition from the first excited state to the ground state in ^{140}Ba. The decay scheme is not yet published, but has been preliminarily determined by Schick.[29] The Q value for ^{140}Cs, based on the result of this one spectrum, is 5.8 ± 0.1 MeV. Alväger *et al.*[28] estimated this energy to be 6.2 ± 0.6 MeV, and Zherebin, Krylov, and Polikarpov[25] measured it to be 5.7 ± 0.1 MeV.

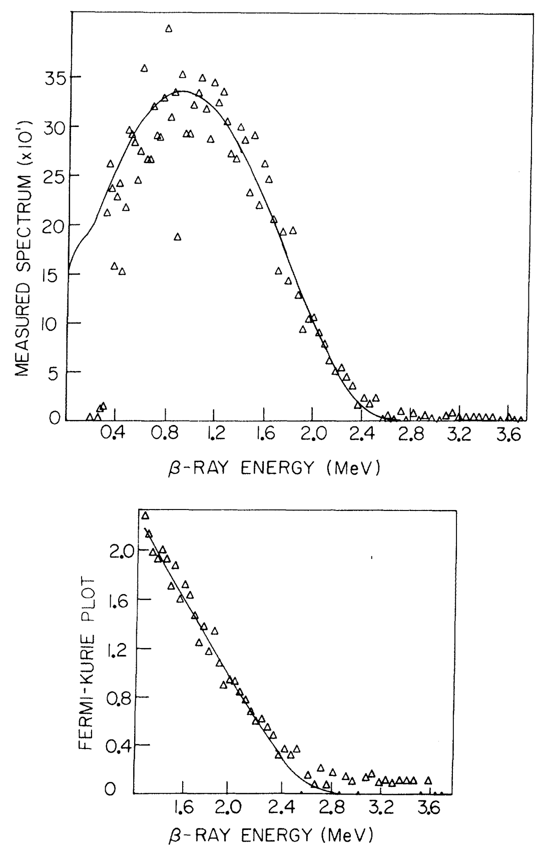

FIG. 2. Measured spectrum and Kurie plot for the β spectrum in coincidence with the 0.774-MeV γ ray in the decay of ^{140}Xe and the FERMI fit to each.

G. ^{141}Xe

Six gates, set on transitions depopulating four different levels in ^{141}Cs, were used to determine the Q value of 6.0 ± 0.1 MeV for ^{141}Xe. The preliminary ^{141}Cs level scheme used to determine the composition of various coincidence spectra was determined by Cook.[30] Figure 3 shows the two-group FERMI fit to the β spectrum in coincidence with the 0.909-MeV transition in this decay. It was assumed that two β groups make up the spectrum with 78% of the β feeding to the 1.097-MeV level in ^{141}Cs and 22% of the β feeding to the 1.556-MeV level in ^{141}Cs.

H. ^{141}Cs

According to the study in progress by Cook,[30] the decay of ^{141}Cs should proceed mainly to the ground state of ^{141}Ba. In the light of this study, a decision was made not to attempt a β-γ coincidence experiment on this decay and instead to perform a β singles experiment. The spectrum obtained was analyzed after unfolding the effects of the detector response. No assumptions about the composition of the spectrum were made in the analysis. The fit shown in the Kurie plot of Fig. 4 was obtained with four β groups, the outer (ground-state) group having an intensity of about 50% and the next group having an end-point energy 1.6 MeV below the Q value and an intensity of about $\frac{1}{4}$ that of the outer group. The two groups at lower energies contained small components due to the 6% contamination of ^{141}Ba which has a Q value of 3.03 MeV. The measured Q value for the decay of ^{141}Cs is 4.98 ± 0.08 MeV, where the uncertainty reflects primarily that of the scintillator energy calibration.

I. ^{141}Ba

The decay energy for ^{141}Ba was determined using four gates set on transitions leaving three low-energy levels in ^{141}La. Levy and Zemal[31] reported the Q value of ^{141}Ba to be 2.9 MeV in 1948, and Maly *et al.*[32] reported a value of 1.93 ± 0.1 MeV in 1958. The most recent measurement of this energy was by Fritze and Kennett[33] in 1962, who reported a value of 3.0 ± 0.1 MeV, in excellent agreement with our measurement of 3.01 ± 0.06 MeV. The ^{141}Ba decay scheme determined by Cook[30] was used in determining the relative intensities and energy differences of the β groups fitted to the measured spectra.

J. ^{142}Xe

The γ-ray decay schemes for the decays of ^{142}Xe and ^{142}Cs have been determined by Larsen, Talbert, and McConnell.[34] A separation of the two isobars was not attempted since the respective half-lives of these two isobars are 1.24 and 1.67 sec. The conditions required to provide effective separation for such similar half-lives reduce the available source activity to an intolerably low level for a coincidence experiment. A total of five gates were used to determine a Q value for ^{142}Xe of 4.9 ± 0.1 MeV.

K. ^{142}Cs

Four gates were used to determine a Q value for ^{142}Cs of 6.8 ± 0.10 MeV. Using only three gates (excluding the 1175-keV gate, which is uncertainly placed in the decay scheme), the weighted average of the resulting decay energy values is 6.89 ± 0.06 MeV. The two values are well within the uncertainties indicated. Alväger *et al.*[28] estimated the

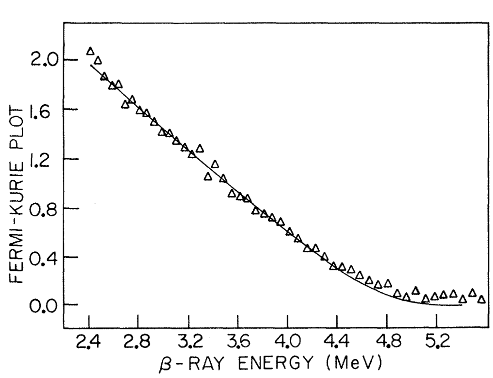

FIG. 3. Kurie plot for the β spectrum in coincidence with the 0.909-MeV γ ray in the decay of ^{141}Xe.

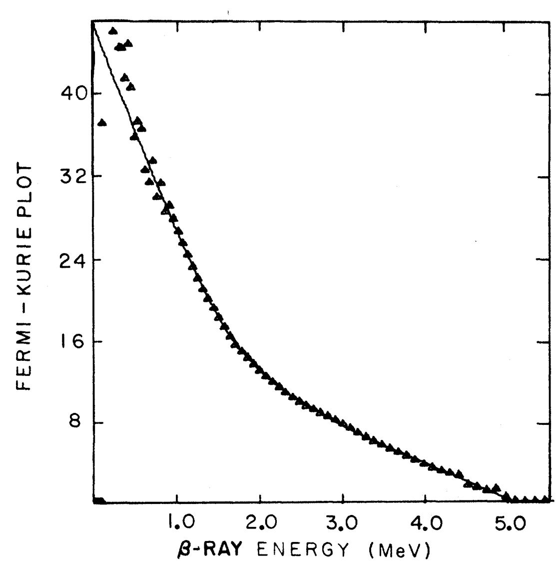

FIG. 4. Kurie plot for the ^{141}Cs singles measurement.

TABLE II. β-decay energy results.

Decaying nucleus	Predicted energy Garvey et al., (Ref. 5) (MeV)	Seeger (Ref. 4) (MeV)	Wapstra and Gove (Ref. 2) (MeV)	Results, this work Decay energy (MeV)	No. gates used
^{138}Xe	2.70	3.1	2.8 ±0.2 [a]	2.83±0.08	8
^{138}Cs	5.27	5.4	5.4	5.29±0.07	10
^{139}Xe	4.71	5.3	4.8 ±0.2 [a]	4.88±0.06	5
^{139}Cs	4.10	3.8	4.15±0.10 [a]	4.29±0.07	8
^{140}Xe	3.58	4.2	4.3	4.06±0.06	13
^{140}Cs	6.12	5.9	5.7 ±0.1 [a]	5.8 ±0.1	1
^{141}Xe	5.85	6.3		6.0 ±0.1	8
^{141}Cs	4.97	4.9	5.1	4.98±0.08	Singles
^{141}Ba	3.02	3.5	3.0 ±0.1 [a]	3.01±0.06	4
^{142}Xe	4.14	5.1		4.9 ±0.1	5
^{142}Cs	7.24	7.0	6.7	6.89±0.06	3

[a] This value is from a previous measurement.

decay energy for ^{142}Cs to be 7.65±0.8 MeV.

A compilation of all the β-decay energies obtained in this work is shown in Table II, which includes the decaying nucleus, the theoretical prediction of the decay energy according to the mass relations developed by Garvey *et al.*[5] and Seeger,[4] the previously measured or predicted decay energy compiled by Wapstra and Gove,[2] and the decay energy according to this work, with the number of gates used. A more detailed description and presentation of the results of this study for $A=140$, 141, and 142 can be found in Adams.[35]

IV. DISCUSSION

The weighted root-mean-square (rms) deviation of the decay energies listed in Table II from those predicted by Garvey *et al.* is 0.34 MeV. The weighted rms deviation for the same comparison, using the Seeger mass formula, is 0.30 MeV. Garvey *et al.* quote and average deviation of less than 0.2 MeV for their over-all fit to the known masses, which is about one half the rms deviation of their mass law from the β-decay energies measured in this work. Seeger, however, quotes an average

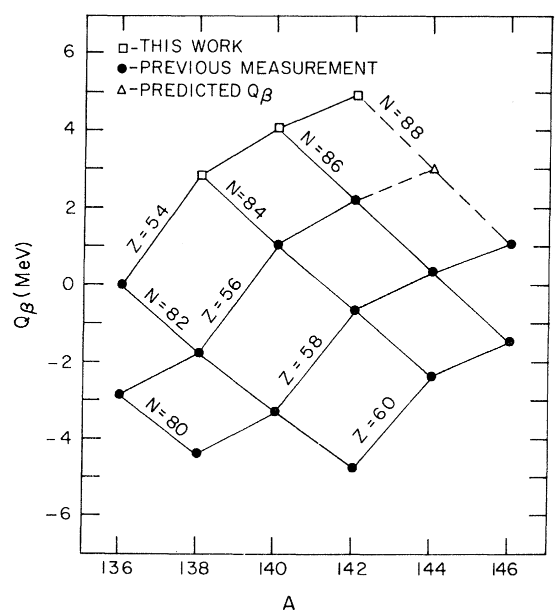

FIG. 5. Way-Wood diagram for even-A–even-Z nuclei in the mass range around $A=140$.

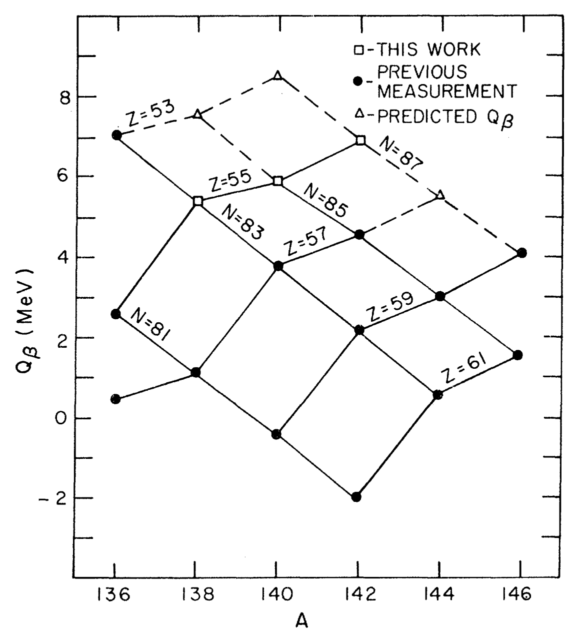

FIG. 6. Way-Wood diagram for even-A–odd-Z nuclei in the mass range around $A=140$.

deviation of 0.73 MeV to the known masses, making the 0.30-MeV rms deviation of the values in this work from those of his mass formula well within the deviation for the known masses. Although no conclusive evidence can be given, the increase of the deviation for masses of the nuclei in this study from the mass relation of Garvey *et al.* could indicate an onset of a breakdown for this relation in the regions far from β stability. On the other hand, the predictions of Seeger are still within his quoted deviation in the region of this study. Sorenson[6] recently presented a modification of the Garvey *et al.* mass relation which, when applied, results in a 0.31-MeV rms deviation from the masses measured in this experiment. Although this modification gives a small improvement over the predictions of the Garvey mass formula alone, compared to the results presented here, there was no striking improvement in favor of either the masses farthest removed or those closest to β stability. A similar study done by Clifford *et al.*[1] on the β-decay energies of gaseous Kr fission products and their daughters yielded similar results regarding the Sorenson correction. On the basis of these conparisons and errors expected in the tabulations, it appears that the mass relation of Garvey *et al.* should be used to predict decay energies for short-lived radioactive nuclei likely to be studied in the reasonable future, but the mass formula of Seeger is uncontested (although untested directly) for use in the extreme neutron-rich region traversed in nucleogenesis calculations.

In a systematic study of the β-decay energies, Way and Wood[3] compared the decay energies between nuclei of four groups: odd-Z-odd-N, odd-Z-even-N, even-Z-odd-N, and even-Z-even-N. For nuclei within each of these groups, the semi-empirical mass formula predicts linear or almost linear dependence of the β-decay energy on N for constant Z, constant A, or constant $(N-Z)$. This linear behavior was tested by Way and Wood who discovered that the deviation from linearity is very pronounced in those regions near major shell closure. This behavior is expected since the semi-empirical mass formula used has no shell-model dependence. Examples of this deviation are shown in Figs. 5 through 8 which show "Way-Wood" diagrams for the mass region around $A = 140$ for even-even, odd-odd, odd-A-odd-Z, and odd-A-even-Z nuclei, respectively. These diagrams conform to the recent convention[2] of plotting β-decay energy versus mass number, connecting points of constant Z and N. Previously measured β-decay energies are indicated by closed circles while the results of this work are indicated by open squares. It may be noted that the line of constant Z shows a large discontinuity in slope as the major shell at $N = 82$ is crossed. This slope change appears to be independent of Z, at least for neighboring lines. Even though the linearity itself breaks down, lines of adjacent Z remain remarkably parallel which al-

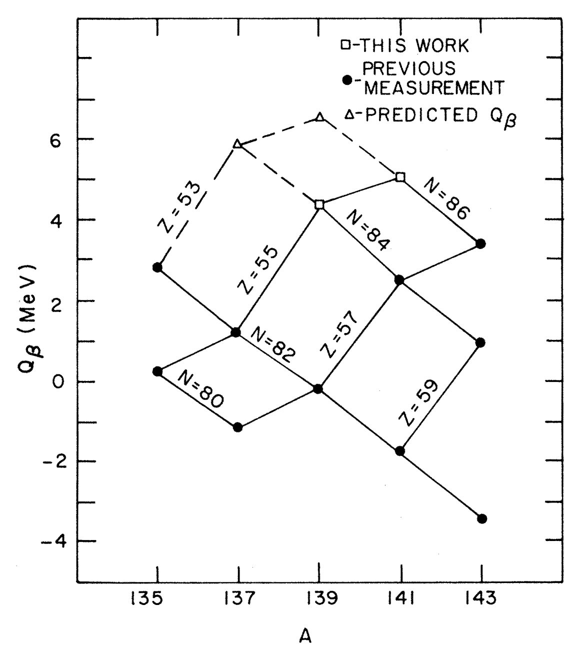

FIG. 7. Way-Wood diagram for odd-A-odd-Z nuclei in the mass range around $A = 140$.

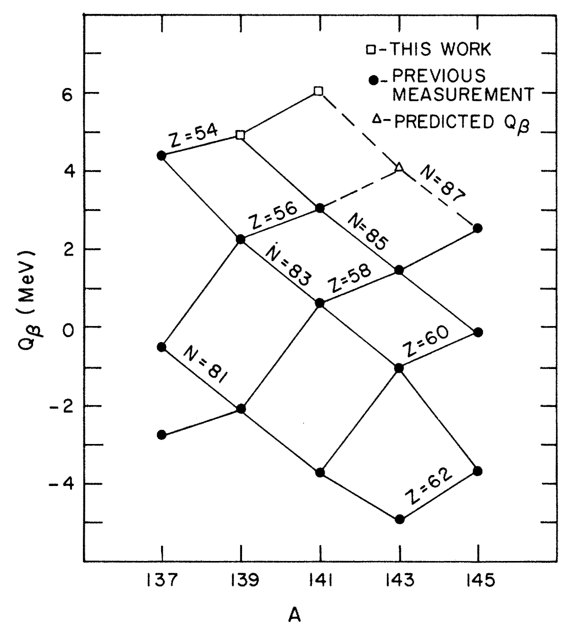

FIG. 8. Way-Wood diagram for odd-A-even-Z nuclei in the mass range around $A = 140$.

TABLE III. Predicted β-decay energies.

Decaying nucleus	Systematic prediction (MeV)	Garvey *et al.* (Ref. 5) (MeV)	Seeger (Ref. 4) (MeV)
^{137}I	5.8	5.8	5.7
^{138}I	7.5	7.8	7.8
^{139}I	6.5	6.7	6.7
^{140}I	8.5	8.9	8.9
^{143}Ba	4.0	4.1	4.5
^{144}Ba	3.2	2.6	3.0
^{144}La	5.5	5.6	5.3

lows decay energies to be predicted. For example, the β decay energies for ^{140}Xe, ^{141}Cs, and ^{142}Cs were predicted to be 4.3, 5.1, and 6.7 MeV, respectively, on the basis of the parallel structure. These values have an rms deviation of less than 0.2 MeV when compared to the results of this work.

Table III lists the results of applying the Way-Wood systematics to predict the β-decay energies of ^{137,138,139,140}I, ^{143,144}Ba, and ^{144}La, made possible by the β-decay energies measured in this work. The uncertainty in these predictions is expected to be no more than 0.4 to 0.5 MeV. This error represents a combination of the deviation from parallel slopes and the accuracy with which the method predicted β-decay energies measured in this work. Using the predicted value for the β-decay energy of ^{138}I as a standard, the value for the β decay energy of ^{140}I is predicted to be 8.5 MeV as shown in Fig. 7. However, since the decay energy of ^{138}I is itself a predicted value, it may be expected that the uncertainty involved would increase to about 0.5 to 0.6 MeV, reflecting simple error propagation. Similarly, using the prediction of 5.8 MeV for the decay energy of ^{137}I, that for ^{139}I is predicted to be 6.5 MeV. The α-decay, two-neutron separation, and the two-proton separation energies for these seven nuclei are unknown so the above predictions are based solely on the previously measured β-decay energies in this region and the characteristics of the Way-Wood systematics.

*Present address: Physics Department, University of Notre Dame, Notre Dame, Indiana 46556.

†Present address: Physics Department, Wartburg College, Waverly, Iowa 50677.

‡Present address: Physics Department, United States Air Force Academy, Colorado 80840.

[1]J. R. CLifford, W. L. Talbert, Jr., F. K. Wohn, J. P. Adams, and J. R. McConnell, to be published.

[2]A. H. Wapstra and N. B. Gove, Nucl. Data A9, 265 (1971).

[3]K. Way and M. Wood, Phys. Rev. **94**, 119 (1954).

[4]P. A. Seeger, CERN Report No. 70-30, 1970 (unpublished), Vol. 1, p. 217.

[5]G. T. Garvey, I. Kelson, W. J. Gerace, R. L. Jaffe, and I. Talmi, Rev. Mod. Phys. **41**, S1 (1969).

[6]R. A. Sorensen, Phys. Lett. B **34B**, 21 (1971).

[7]J. R. Nix, CERN Report No. 70-30, 1970 (unpublished), Vol. 2, p. 605.

[8]W. L. Talbert, Jr., A. B. Tucker, and G. M. Day, Phys. Rev. **177**, 1805 (1969).

[9]W. L. Talbert, Jr., Phys. Rev. C **1**, 1135 (1970).

[10]J. T. Larsen, Ph.D. thesis, Iowa State University, 1970 (unpublished).

[11]R. J. Olson, Ph.D. thesis, Iowa State University, 1971 (unpublished).

[12]W. L. Talbert, Jr., and D. Thomas, Nucl. Instrum. Methods **38**, 306 (1965).

[13]W. L. Talbert, Jr., and J. R. McConnell, Ark. Fys. **36**, 99 (1967).

[14]J. H. Norman, W. L. Talbert, Jr., and D. M. Roberts, U. S. Atomic Energy Commission Report No. IS-1893, Iowa State University, 1968 (unpublished).

[15]F. K. Wohn, J. R. Clifford, G. H. Carlson, and W. L. Talbert, Jr., Nucl. Instrum. Methods **101**, 343 (1972).

[16]J. R. CLifford, Ph.D. thesis, Iowa State University, 1972 (unpublished).

[17]P. C. Rogers, and G. E. Gordon, Nucl. Instrum. Methods **37**, 259 (1965).

[18]E. Monnand, R. Brissot, L. C. Carraz, J. Crançon, C. Ristori, F. Schussler, and A. Moussa, Nucl. Phys. **A195**, 192 (1972).

[19]G. H. Carlson, W. L. Talbert, Jr., and J. R. McConnell, to be published.

[20]L. M. Langer, R. B. Duffield, and C. W. Stanley, Phys. Rev. **89**, 907 (1953).

[21]L. C. Carraz, E. Monnand, and A. Moussa, Nucl. Phys. **A171**, 209 (1971).

[22]M. A. Wahlgren and W. W. Meinke, J. Inorg. Nucl. Chem. **24**, 1527 (1962).

[23]G. Holm, S. Borg, U. Fägerquist, and F. Kropff, Ark. Fys. **34**, 447 (1967).

[24]M. A. Lee, Ph.D. thesis, Iowa State University, 1973 (unpublished).

[25]E. A. Zherebin, A. I. Krylov, and V. I. Polikarpov, Yad. Fiz. **3**, 981 (1966) [transl.: Sov. J. Nucl. Phys. 3, 717 (1966)].

[26]G. Rudstam, E. Lund, L. Westgaard, and B. Grappengiesser, CERN Report No. 70-30, 1970 (unpublished), Vol. 1, p. 341.

[27]W. C. Schick, Jr., W. L. Talbert, Jr., and J. R. McConnell, Phys. Rev. C **4**, 507 (1971).

[28]T. Alväger, R. A. Naumann, R. F. Petry, G. Sidenius, and T. D. Thomas, Phys. Rev. **167**, 1105 (1968).

[29]W. C. Schick, Jr., private communication.

[30]J. W. Cook, private communication.

[31]H. A. Levy and B. Zemal, U. S. Atomic Energy Commission Report No. ORNL-176, Oak Ridge National Laboratory, 1948 (unpublished).

[32]J. Maly, V. Knoblock, D. Imprisova, Z. Prasil, and Z. Urbanec, Collect. Czech. Chem. Commun. **23**, 1886 (1958).

[33]K. Fritze and T. J. Kennett, Phys. Rev. **127**, 1262 (1962).

[34]J. T. Larsen, W. L. Talbert, Jr., and J. R. McConnell, Phys. Rev. C 3, 1372 (1971).

[35]J. P. Adams, Ph.D. thesis, Iowa State University, 1972 (unpublished).