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Publication Date

1959-08-01

UCRL 8864

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Contract No. W-7405-eng-48

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August 1959

Printed for the U. S. Atomic Energy Commission

VIBRATIONAL STATES IN U^{234} EXCITED BY Np^{234} DECAY AND EVIDENCE FOR AN EO - TRANSITION BETWEEN STATES WITH $I \neq 0$.*

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August 1959

ABSTRACT

Transitions following the EC-capture of 4.4-day Np^{234} have been investigated with 99-, 160-, and 350-gauss permanent magnets, a solenoidal "long lens" spectrometer, and NaI (Tl) scintillation detectors with a 100-channel analyzer. Many internal conversion electron lines were observed, and assigned to transitions at 43.49, 99.70, 233.6, 234.6, 238.6, 247.9, 297.6, 450.5, 482.8, 485.1, 515.7, 525.9, 556.8, 744.1, 751.7, 767.9, 787.8, 793.8, 810.0, 812, 854, 1003, 1105, 1196, 1240, 1395, 1439, 1531, 1562, 1575, and 1606 kev. A few other weak electron lines were observed, but not assigned to transitions. Transitions following Np^{236}, Np^{238}, and Np^{239} decay were also observed on the same plates and identified, helping to insure correctness of the isotopic assignment of the U^{234} transitions. The above transitions have been interpreted to establish levels in U^{234} at 43.9, 143.2, 788, 812, 854, 1049, 1090, 1092, 1240, 1340, 1439, 1575, and 1606 kev. The 812-kev E0 transition has been resolved into two components, one of which is interpreted to be an E0-transition between two 2+ states. Transition multipolarities and possible level spin and parity assignments are discussed. A comparison of the known data on relative energies of vibrational states indicates that the β-vibrational states have lower energies than the γ-vibrational states in the few nuclei where the energies of both are known.

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*This work was supported by the United States Atomic Energy Commission.

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INTRODUCTION

The spectra of deformed even-even nuclei in the rare earth and heavy element regions of the periodic table have been shown to be remarkably similar. Qualitative understanding of these spectra has been achieved largely on the basis of the Bohr-Mottelson model,[1] which describes these states as due to collective rotational and vibrational motions of many nucleons. The rotational states have been extensively studied,[2] whereas considerably less is known about the vibrational states.[3,4,5,6] When this work was begun no spectra had been reported in which both the theoretically predicted "β-" and "γ-" "vibrational" states had been observed. The present study was undertaken in an attempt to obtain information on the relative energies of the β- and γ-vibrational levels in a single nucleus, and also perhaps the rotational states based upon them. Neptunium-234 was chosen because earlier work[7-9] on the decay of this nuclide had shown strong cascade transitions, suggesting possible excitation of vibrational states decaying through lower lying vibrational states, and also that a 0+ level in U^{234} at approximately 800 kev is populated.

PREVIOUS RESULTS ON THE LEVELS OF U^{234}

Before beginning the discussion of the present experiment, let us review the previous work on the levels of U^{234}, as populated by the EC decay of Np^{234}, the β^--decay of the Pa^{234} isomer, and the alpha decay of Pu^{238}.

The 4.40-day electron capturing isotope Np^{234} was first reported by Hyde, Studier, and Ghiorso.[10] Early spectroscopic studies were made by Orth[7] and who reported 0.177-, 0.442-, 0.803-, and 1.42-Mev transitions. Hoff[8] remeasured the spectrum and reported 0.76-, 0.81-, and 1.57-Mev transitions and a K/L x-ray ratio of 10/7, from which he concluded a K/L electron-capture ratio of ~1. Prestwood, Smith, Brown and Hoffman[11] reported the presence of a β^+ group of 0.8-Mev endpoint, and a β^+/EC ratio of $4.6 \pm 1 \times 10^{-4}$. The decay energy of 1.8 Mev determined by this method agrees with the closed-cycle calculations of Foreman.[12]

The most recent work on this isotope was done by Huizenga, Engelkemeir, Freedman, Porter, and Gindler,[9] who reported evidence for 18 gamma transitions on the basis of scintillation spectroscopy and internal conversion data. The transitions they reported are shown in Table I. They also reported the coincidence data shown in Table II. They did not, however, postulate a definite decay scheme for Np^{234}. Thus no definite U^{234} level scheme has been proposed on the basis of Np^{234} decay.

Studies of the beta decay of UX complex by many workers[2] have indicated that these nuclides populate many levels in U^{234}. The latest work on the isomers has been reported by Ong, Verschoor, and Born,[13] who reported evidence for 24 transitions based on conversion electron and gamma scintillation studies. The transitions were interpreted to establish the U^{234} level scheme shown in Figure 4.

Almost all of the authors mentioned above reported that the 812 kev transition (our energy value) was probably an E0, as its K-internal conversion coefficient was too large to assign it other than E0 multipolarity. This assignment was checked in Pa^{234} (UX) decay by Cross,[14] and later rechecked by Ong et al.[13] The latter measured both internal and external conversion lines, and reported no evidence for gamma rays of ~0.80 Mev. It is interesting to note here that Ong et al., apparently resolved the 812-kev transition into two components, of which they concluded at least one had to be appreciably E0.

In addition to these studies of the decays of the Pa^{234} isomers and Np^{234}, studies of the alpha decay of Pu^{238} have established[2] the 43.5-, 143.2-, and 812-kev levels in U^{234}. The level energies we quote are those determined in the present study.

The population of an 812-kev 0+ state following Pu^{238} alpha decay has been reported by Perlman, Asaro, Harvey, and Stephens.[5] They were able to set limits on the conversion coefficient of an ~800-kev transition, essentially ruling out everything except E0 multipolarity, and thus confirming the results of the earlier workers.

EXPERIMENTAL

A. Instruments and Experimental Techniques.

Three permanent magnet spectrographs[15] of 0.1% and a "long lens" annular focusing spectrometer at 2.2% momentum resolution were used to study the electron spectrum. The detector in the spectrometer was a 3/4-inch-diameter, 1/8-inch-thick anthracene crystal attached by a 1-inch diameter Lucite light pipe 6 inches long to a DuMont 6292 phototube. Eastman Kodak No-Screen x-ray film was used in the spectrographs. No attempt was made to obtain numerical intensities from the photographic plates; we report only visual estimates on these intensities. A 1-1/2 inch NaI (Tl) scintillation spectrometer of ~8% resolution (at 1 Mev) with a Penco 100-channel analyzer was used to obtain gamma intensities.

B. Source Preparation.

Approximately 1 millicurie of Np^{234} was prepared by the $U^{235}(d,3n)Np^{234}$ reaction in the Berkeley 60-inch cyclotron. The isotopic composition of the U^{235} was ~93% U^{235} and ~7% U^{238}. The rigorous chemical method used to isolate the neptunium fraction is described in the appendix. The carrier-free activity obtained was deposited on 0.010-inch platinum wires by cathodic electrodeposition from 1 $\underline{M}$ $(NH_4)_2\ C_2O_4$ plating solution at 150 ma and 5 volts for 15 minutes. The source for the long-lens spectrometer was made by evaporating approximately 50 μl containing 0.2 cm of Np activity on a Tygon film of approximately 100 $\mu g/cm^2$ thickness.

C. Experimental Results.

1. Permanent Magnets. Spectra taken with the permanent magnets indicated the presence of Np^{236}, Np^{238}, and Np^{239} activities in addition to the Np^{234}. Fortunately these isotopes have been studied at high resolution and their spectra are well known. The lines of Np^{236}, Np^{238}, and Np^{239} which we observed are indicated in Table VII, VIII and IX in the appendix. A tabulation of the electron spectrum in order of increasing electron line energy, and also the electron line energies supporting the transition assignments, is given in Tables X through XIV in Appendix II. The Np^{236} spectrum contained two new lines, corresponding to a new level in U^{236} at 688 kev. A separate bombardment was

made to show that the activities producing these lines decayed with a 22-hour half-life. The Np^{236} assignments were based on the work of Gray,[16] the Np^{238} on the summary of data by Albridge and Hollander,[17] and the Np^{239} on the results of Hollander, Smith and Mihelich.[18] A rough check of the half-lives of the individual lines was made by taking a series of exposures at four-day intervals for a period of approximately 3 weeks following the irradiation.

The Np^{234} electron spectrum proved to be extremely complex, especially in the high energy region. The portion of the electron spectrum which yielded to analysis, and which could be assigned to transitions, is reported in Table III. Only visual intensity estimates are reported. The energy calibration on the lines below 500-kev was made relative to the reported energies of the Np^{239} transitions. Because of the less accurate calibration of the high energy spectrograph the values reported for high energy transitions are estimated to have an absolute error of ±2%. The transitions of Np^{238} were not used to calibrate the spectrum because they had been measured on the same instrument and in addition did not extend to as high energies as the transitions of Np^{234} decay. However, if the Np^{238} lines are used to calibrate the spectrograph field, the energies reported in Table III for the transitions above about 800 kev should be decreased by approximately 1 kev. Regardless of the absolute error, the overall relative energies have excellent internal agreement, and the sums which serve as the basis for the decay scheme are shown in Table IV. The electron binding energies reported by Hill[19] were used in analyzing the data.

Electron lines which could not be readily assigned to transitions are tabulated in Table V. In most cases these are probably due to KLM and KLN Auger electrons.

2. Ring Focusing Spectrometer and Gamma Scintillation Detector Measurements. The electron spectrum measured in the ring-focusing spectrometer above about 650 kev is shown in Fig. 1. The spectrum shown is a composite spectrum of data gathered over a period of approximately 3 weeks. The data were corrected only for background and the decay of 4.40-day Np^{234}. As a consequence, the presence of Np^{238} causes the beta spectrum shown.

The intensities of the lines measured in this spectrometer are reported in Table VI. Many of these "lines" are unresolved groups. In addition we have reported two gamma intensities in this table. These low resolution data have been normalized absolutely to give the limits on the gross line conversion coefficient shown. The absolute normalization was made possible by the $\geq$ 1% limit on the absolute conversion coefficient reported by Stephens[20] for the gross 1560-kev transition. A gamma-ray spectrum, similar to that on which these intensities are based, is shown in Fig. 2. The spectrum shows a cutoff at about 1600 kev. Such a result supports the 1800-kev decay energy obtained by closed-cycle calculations[12] and the reported positron endpoint of 0.8 Mev.[11] We have not attempted to calculate log ft values for primary branching to the various levels because we do not believe our intensity data are sufficiently good to warrant such calculations.

INTERPRETATION OF RESULTS

A. The Proposed Level Scheme of U^{234}.

The level scheme proposed on the basis of present results is shown in Fig. 3. The 43.49-, 143.2-, and 812-kev levels have been observed in Pu^{238} alpha decay. On the basis of the sums in Table IV the levels at 788, 854, 1240, 1439, 1575 and 1606 kev are reasonably well established. The levels at 1049, 1090, and 1340 kev are based on the energy difference between the transitions populating these levels from levels M and N, which are in excellent agreement with the energy NM. The 1092 level is then fixed. It is noteworthy that the proposed level scheme accounts for all of the definite transitions except the 233.6, 297.6, 1003, and 1105. The 1003 and 1105 transitions probably depopulate a level at 1146 kev; we havenot indicated it in the figure, as its assignment is considerably less certain than that of the other levels.

1. Transitions supporting the level scheme. In the introduction we stated that the purpose of this study was to obtain more information on the -vibrational levels of nuclei. Experimentally this usually means observing an E0 transition. Thus our resolution of the conversion lines of the 812-kev E0 transition into two components, both of which are quite strong, presented us with an interesting problem to interpret. First it was necessary to determine whether both components were E0; if they were, they would then have to be interpreted on the basis of a level scheme.

In order to answer the first question, we obtained a limit on the conversion coefficinets of the 812-kev transition. We measured that the ratio of the relative gross conversion coefficients $e^-_{\overline{640}}/\ \overline{760}$, $e^-_{\overline{690}}/\ \overline{760}$, and $e^-_{\overline{1440}}/\ \overline{1560}$ (where the bar indicates that the energy is the average energy of the composite peak, and the electron energies are the K-conversion line energies) was 1:26:1. Stephens[20] has measured a limit on the absolute value of the gross $e^-_{\overline{1440}}/\ \overline{1560}$ conversion coefficient and determined that it is $\geq .01$. This value corresponds to an M1 or a higher-magnetic-multipole transition. Normalizing the value above to this number yields conversion coefficients of $\geq .01$ and $\geq .26$, for the two other transitions.

To determine whether the two components are E0 we had to estimate the relative K-conversion-line intensities of the 810- and 812-kev transitions and what fraction of the 760-kev peak could be attributed to a gamma ray of 812 kev. We visually estimated that the relative intensities of the K-conversion lines of the 810- and 812-kev transitions (which were resolved on the spectrographic plate) are in the ratio 1:4±1. The estimate was based on the relative intensities of these lines in a series of 4.0 day exposures. Knowing the inherent resolution of the NaI crystal from a study of calibration sources, we were able to estimate that the maximum fraction of the 760 peak intensity that could be attributed to a gamma of 810 kev was $\leq 1/3$. Such a reduction of the 760 gamma intensity raises the limit on the second gross conversion coefficient to ≥ 0.78. On the basis of the high resolution electron data, we divide this 0.78 between the two transitions yielding limits on the conversion coefficients of ≥ 0.15 and ≥ 0.62. The second is consistent only with a very large E0 admixture. The first must be M2 or higher magnetic multipolarity ($\alpha_k(M2) \approx .15$ for this Z and energy). Because there are 3 transitions, at 788, 793, and 854 kev, which must also be included in considering a gamma peak at 810 kev (thus reducing the fraction of 1/3 appreciably, and hence raising the limit on the conversion coefficient) and because the $K/L_I/M_I$ ratio of the 810 and 812 transitions are identical to within the accuracy of the visual estimate, we believe the 810-kev transition has a large E0 admixture also. The K/L+M ratio of 3.9 for the gross peaks measured in the long-lens spectrometer is consistent with the K/L+M ratio of an E0 transitions of this Z and energy as calculated by Church and Weneser[21] and by Listengarten and Band.[22]

The second question, as to the position of the transition in the decay scheme, was to a large extent settled by sums and differences based on the many transitions observed, which established the 854-kev state with little ambiguity. The interpretation will be discussed below.

The gross conversion coefficient e^{-}_{640}/γ_{760} lies between the values for E1 and E2 radiations, and the interpretation of these transitions in the decay scheme is consistent with such a value. If the 810 and 812 are E0 transitions all the 760 gamma intensity must of course be assigned to the other transitions. Sliv and Band's[23] K- and L-shell internal conversion coefficients were used for comparison of the experimental data to theory. The 43.49 and 99.7 are E2 on the basis of their $L_I/L_{II}/L_{III}$ conversion ratios. The 233.6, 234.6 and 238.6 have very weak L-conversion-hence they are probably E1. The 247.9 has strong L_I and M_I conversion and is therefore probably magnetic. The 450.5 appears to convert in the L_I, L_{II}, and L_{III} shells and hence is probably E2, although since the L_{II} and L_{III} lines are extremely weak the assignment must be tentative. We have not ruled out the possibility that these are K-lines of unidentified transitions. Little can be said about the other transitions.

2. Basis of the level spin and parity assignments. From the present data and the data on the alpha decay of Pu^{238} the levels at 43.49, 143.2, and 812 are assigned 2+, 4+, and 0+ spins and parities. On the basis of the reported β^{+} group we assume Np^{234} has a spin 0, 1, or 2, assuming beta decay to the 0+ and/or 2+ state. We will discuss the possible spin assignments of Np^{234} in more detail below. The very strong decay of the 1575 and 1606 levels to ground, plus the gross conversion coefficient of $\geq .01$ reported by Stephens[20] for the 1560-kev peak suggests spins 1 or 2, positive parity, for both the 1575- and 1606-kev levels.

The level at 812 is 0+. The level at 854 agrees in energy with a 2+ rotational state based upon such a state. The branching from the 1606 level to the 854 and 812 levels is also similar to that from the 1606 to the 43.49 and ground state levels, which seems consistent. If we now combine this information with the at-least-partial E0 nature of the 810-kev transition, we can state that the 810-kev transition is an E0 transition between two states with $I \neq 0$. The interpretation of the 854 state as a K = 0, 2+ state implies, however, that there should be an E2 transition to the 4+ state of the ground state rotational band, of intensity 2.57 to 1 relative to the E2 transition to the first 2+ rotational state.[1,24] The conversion electrons of this transition were looked for on the photographic plates but were not observed, although the conversion electrons of the theoretically-weaker transition to the ground state were. Therefore, there remains some uncertainty as to the correct interpretation of this state because, if selection rules are not obeyed, either the assignment is wrong or K is not a good quantum number for these states.

The 1- assignment to the 788-kev level is tentative. However, the relative K-conversion electron intensities for the 744 and 788 transitions are in the ratio 2:1, in agreement with the theoretical ratio of 2 for the decay of K = 0, I = 1 states to K = 0, I = 2 and K = 0, I = 0 states.[24] We assumed in making this calculation that the 788- and 744-kev transitions are pure E1.

The levels at 1049 and 1090 (G and H) are uncertain because no transitions have been observed which depopulate them. If the levels are the expected 2+ and 3+ (K = 2) states, and the populating transitions are M1 and E2, the expected pure E2 radiations depopulating them would not be observed. We favor such an interpretation for these states.

Levels I, J, and K probably have negative parity and low spin. The parity assignments are based on the comments made regarding the probable multipolarities of the low energy transitions populating and depopulating them. Level L probably has low spin as it decays directly to the 0+ and 2+ states. Its parity is uncertain.

DISCUSSION OF RESULTS

A. Comparison of Previous Results.

The decay scheme we reported is consistent with the results reported from Pu^{238} alpha decay. The gamma transitions reported by Huizenga, et al.,[9] agree to within the limits of error with the present results, (although we have observed many more transitions) except for the 109-, 905-, and 1010-kev transitions. On the basis of our high resolution studies of the ~87-kev region of the electron spectrum we believe we can rule out the 109-kev transition. The conversion lines of the 905 and 1010 were not observed in our electron spectrum, but a definite peak appears in our gamma spectrum at this energy (see Figure 2). Furthermore, our level scheme predicts several transitions of approximately these energies. It therefore seems likely that they are present and were not observed in the electron spectrum owing to either small internal conversion coefficients or weak intensities, or both. We report the presence of a very weak line at 1440 which would not have been seen by Huizenga, et al.,[9,25] who reported that there was no line at this energy. However, in agreement with both Hoff[8] and Huizenga, et al., our data rule out the strong ~1450-kev transition reported by Orth.[7] The coincidence data of Huizenga, et al., are consistent with our proposed level scheme, with the possible exception of the 445-500 kev coincidence.

A comparison of Figures 3 and 4 shows that the U^{234} level schemes postulated by Ong, et al.,[13] decay from Pa^{234} decay and our own proposals are not in good agreement. Whether this discrepancy is the result of an actual difference in the primary branching of the different nuclei or of differences in interpretation is not certain as the lower resolution used in the Pa^{234} study make the data difficult to compare. However, the levels at ~43, ~142, and ~800 kev are common to both decay schemes, and several of the transitions following Pa^{234} decay have nearly the energies of transitions reported here. In UX these are the 230-, 255-, 770-, 803-, 807-, (1010-), 1240-, and 1440-kev transitions; in UZ decay they are the 293-, 566-, 732-, 803-, and 1240-kev transitions. It would thus appear that a high-resolution electron spectroscopic study of these isomers is in order. It is expected that such a study would yield much new information on the levels of U^{234}, besides removing some of the differences which now appear to exist.

B. The Np^{234} Ground State.

An aspect of the decay scheme which deserves further study is the determination of the primary electron-capture branching to the levels of U^{234}, which we have not attempted. The log ft $\approx$ 8.4 calculated for the β^+ transition to the ground state band suggests an appreciable hindrance for the beta decay, and would probably indicate a unique first forbidden transition if only single particle rates were considered. However, the log ft's for decay of odd-odd nuclei have not been clearly classified, and it is doubtful that strong arguments for spin assignments can be based on them at present. A direct comparison with the log ft 7.2 reported for the EC decay of Np^{236} (1+) to the U^{236} decay, and hence suggests negative parity for Np^{234}. This, coupled with the fact that the states Np^{234} populates in U^{234} appear to have low spin, can be interpreted consistently if Np^{234} has a spin in the range 0 - 2, negative parity.

Because Np^{234} is strongly deformed, the coupling rules proposed by Gallagher and Moszkowski[26] should apply. From Mottelson and Nilsson[27] the most probable proton levels are $642\uparrow$ and $523\downarrow$, and the most probable neutron levels are $633\downarrow$ and $734\uparrow$. On the basis of these most probable states and the coupling rules, the states available for the Np^{234} ground state should be 5-, 6 , 0+ or 1+. The experimental data therefore indicate a violation of the coupling rules. Assuming the coupling rules are violated, it is likely that the Np^{234} ground state is 0-. This would correspond to coupling states $523\downarrow$ and $633\downarrow$ with intrinsic spins antiparallel. Such a suggestion is made because states $523\uparrow$ and $633\uparrow$, coupled antiparallel have been postulated[26] to be the Ho^{166} ground state. In this respect the log ft = 8.0 for the ground state to ground state transition in Ho^{166} β^- decay is analogous to the log ft = 8.4 observed in Np^{234}. A direct measurement of the Np^{234} spin will apparently be necessary to settle this problem.

C. Vibrational Levels.

What can we say about the energies of the various vibrational states in U^{234} as a consequence of the present work? Primarily, we have checked the energy of the β-vibrational state and established the energy of its first rotational state. A comparison of the energies of the first rotational states of the $K = 0$ levels shows that the excited state apparently has a greater moment of inertia than the ground state. We have some evidence for the energies of the γ-vibrational state and its first rotational state, although we have not observed the transitions depopulating them. Again in this case, the apparent moment of inertia is larger than that of the ground state.

In addition we believe we have established the energy of the $K = 0$, 1- state. The energy of this 787-kev state is approximately three times the energies of the corresponding levels in the thorium and radium isotopes.[28] The energies of the 1- states in plutonium are only 200 kev less, however.[2] If our assignment is correct, this maximum in the energies of the 1- states in uranium can be interpreted to mean that the stability against octupole modes of deformation passes through a maximum in the uranium isotopes.

On the basis of the present data, U^{234} is now the second nucleus in the heavy element region in which the relative energies of the β- and γ-vibrational states are known. In Pu^{238}, the other, the β-vibrational state is also at lower energy than the γ-vibrational state. It thus appears experimentally that the β-vibrational bands lie lower in energy than the γ-vibrational bands in the heavy element region. The work of Nathan and Hultberg[29] suggests that the β-vibrational bands also lie lower in the rare earth region. The data on the relative energies of β-, γ-, and 1- vibrational states in these nuclei are illustrated in Figure 5.

D. EO Transitions.

In our opinion the most interesting experimental result in the present study is the probable identification of an EO-admixed transition between two states with $I \neq 0$. Church and Weneser[21] have predicted such transitions, but until recently no experimental evidence for such transitions had been observed. In addition to the present study, however, Nathan and Hultberg,[29] have recently reported the possible presence of an EO-admixed transition between two 2+ (K = 0) states in Sm^{152}, and have postulated, on the basis of some coincidence data and a highly-converted transition in Eu^{154} reported by Juliano and Stephens,[30] that there is also one in Gd^{154}. At the present time no half-lives for the states from which these transitions arise have been measured, and thus a direct comparison of the EO-rates to the Church-Weneser "strength factor" is not possible.

Let us speculate briefly on an interesting aspect of the appearance of EO transitions between states which have some of the expected properties of rotational states based upon K = 0 vibrational states. On the basis of simple considerations, if EO transitins appear between the 2+ states, there is no apparent reason why they should not also occur between the 4+, 6+ and higher-spin rotational states. If this is indeed the case, the presence of EO transitions may serve the very useful purpose of yielding more information on the excited β-vibrational bands which appear to be populated only weakly in the decay of most odd-odd nuclei and have been difficult to observe experimentally. Such a possibility would support the conclusions of Albridge and Hollander[17] on some apparently highly converted transitions observed in Np^{238} decay including the evidence for the K = 0, 2+ state of Pu^{238} shown in Figure 5.

ACKNOWLEDGEMENTS

We thank Professor J. O. Rasmussen and Dr. G. Manning for critically reading the manuscript. One of us (C.J.G.) acknowledges an interesting discussion with Professor S. A. Moszkowski, and also the continued interest of Professor J. W M. DuMond in this work.

APPENDIX

Chemical Procedure

The U_3O_8 target was dissolved in aqua regia. Lanthanum and zirconium carriers were added, the solution evaporated to dryness and taken up in 1 M HNO_3. Saturation of the solution with SO_2 caused the reduction of neptunium and plutonium to the IV and III states respectively. Lanthanum fluoride was precipitated, carrying neptunium and plutonium. The precipitate was dissolved in 6 M HNO_3 saturated with H_3BO_3. La $(OH)_3$ was precipitated and then redissolved in conc. HCl. Neptunium and plutonium were adsorbed on an ion-exchange column of Dowex A-1 anion exchange resin, and were stripped from the column in 3 M HCl.

The neptunium and plutonium were oxidized with bromate and the solution scavenged with LaF_3. Another reduction with SO_2 was made and the neptunium and plutonium were again carried on LaF_3. The precipitate was converted to the hydroxide by treatment with KOH, and the hydroxide was dissolved in 1 M HNO_3. After the neptunium and plutonium had again been oxidized with bromate, $Mg(NO_3)_2$ was added to the solution, and the neptunium and plutonium were extracted into ethyl ether. The activity was back-extracted into water, reduced with SO_2, and again carried on LaF_3. The fluoride precipitate was metathesized to La $(OH)_3$ with KOH. The La $(OH)_3$ was dissolved in conc. HCl. The solution was passed through a column packed with Dowex A-1 ion exchange resin. The neptunium was eluted in a minimum volume of 0.1 M HCl. The activity was then ready for source preparation.

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Table I

Transitions reported by Huizenga, et al.[9] following the decay of Np^{234}

Energies of transitions deduced from internal conversion data (kev)	Energies of additional transitions observed with scintillation detectors (kev)
43	500
109	720
234	905
247	1010
449	1190
517(?)	1540
752	
813	
1567	

Table II

Coincidence measurements reported by Huizenga et al.[9] in Np^{234} decay to U^{234}

Energy of gate (kev)	Energy of coincident transitions (kev)
500	445, 720, 905, 1010
720	445, 750
1190	235
1540	excess L x-rays

Table III

Transitions in U^{234} following Np^{234} decay. Transition assignments are based on the internal conversion data tabulated below. The isotope assignment is based on the decay of the lines observed in a series of five exposures at 4.4-day intervals over an approximately three week period. Visual intensities listed are vvs = very very strong, vs = very strong, s = strong, ms = moderately strong, m = moderate, mw = moderately weak, w = weak, vw = very weak, vvw = very very weak, ew = extremely weak, ew? = extremely weak and questionable, -d = diffuse

Assignment	Energy of gamma (kev)	Subshell Conversion										Multipolarity
		K	L_I	L_{II}	L_{III}	M_I	M_{II}	M_{III}	N_I	N_{II}	N_{III}	
BA	43.49±.05[a]			mw	m[b]		m[c]	ms[d]		w	vw	E2
CB	99.7 ±.1[a]			vw	ew?			ew?				E2
--	233.6 ±.2[e]	ew?	ew									
MK	234.6 ±.2[e]	vvw	w[f]			ew?			ew?			
IF	238.6 ±.4[g]	ew?										
KI	247.9 ±.2[e]	vvw-d	ew			ew						
NK	265.8 ±.5[g]	ew?										
--	297.6 ±.5[g]	ew?										
JD	450.5 ±.5	ms	vw	ew	ew?	ew?						
MI	482.8 ±1[g]	ew?										
MH	485.1 ±1[g]	ew?										
NH	515.7 ±.5	mw	ew									
MG	525.9 ±.5	ew-d										
NG	556.8 ±.6	m	ew-d[h]									
DB	744.1 ±.7	*w*										
NF	751.7 ±.8	*w*	*ew?*									
EB	768.0 ±.8	*ew-d*	*ew?*									
DA	787.8 ±.8	*vvw*										
NE	793.8 ±.8	*vw*										
FB	810.0 ±.8	*s*	*mw*			*ew*						(E0)
EA	811.6 ±.8	*vvs*	*ms*			*w*			*ew-d*			E0
FA	853.6 ±1	*ew?*										
--	1003 ±2	*vvw*	*ew?*									
--	1105 ±2	*ew?*										
JB	1196 ±2	*ew*										
JA	1240 ±2[i]	*ew??*										
LB	1395 ±3[i]	*ew??*										
LA	1439 ±3	*ew*										
MB	1531 ±3	*vw*										
NB	1562 ±3	*m*	*vvw*			*ew*						
MA	1575 ±3	*vw*	*ew*									
NA	1606 ±3	*w*	*ew*									

a. Electron lines observed on 99-gauss magnet.
b. L_{III} 43.49 (U^{234}), L_I 49.38 (Pu^{239}) superimposed.
c. M_{II} 43.49 (U^{234}), L_I 61.42 (Pu^{239}) superimposed.
d. M_{III} 43.49 (U^{234}), L_{III} 57.26 (Pu^{239}) superimposed.
e. K lines observed 99-gauss magnet. L and M lines observed on the 160- and 350-gauss magnets.
f. L_I 234.6 (U^{234}), K 333.4 (Pu^{239}) superimposed.
g. Lines observed on the 160-gauss magnet and read by only TDT.
h. All succeeding intensities (in italics) observed on the 350-gauss magnet.
i. Lines observed on the 350-gauss magnet and read by only TDT. Lines were also observed on the ring-focusing spectrometer.

Table IV

Sums and differences supporting the U^{234} level assignments

Transition 1	Transition 2	Sum or difference	Transition 3	Level energy	Level designation
1562.2	43.49	1605.69	1605.8	1606	N
1531	43.49	1574.49	1574.5	1575	M
1394.8	43.49	1438.29	1438.6	1439	L
1605.8	265.8	1340.0	--	1340	K
1574.5	234.6	1339.9	--	1340	K
1196.1	43.49	1239.59	1239.6	1240	J
787.8	450.5	1238.3	1239.6[a]	1240	J
853.6	238.6	1092.2	--	1092	I
1574.5	482.8	1091.7	--	1092	I
1605.8	515.7	1090.1	--	1090	H
1574.5	485.2	1089.3	--	1090	H
1605.8	556.8	1049.0	--	1049	G
1574.5	525.9	1048.6	--	1049	G
1605.8	751.7	854.1	853.6	854	F
809.9	43.49	853.4	853.6	854	F
1605.8	793.8	812.0	811.6	812	E
768.0	43.49	811.49	811.6	812	E
744.1	43.49	787.59	787.8	788	D

[a] The difference in energy between the sum and this crossover transition is the worst in the table, 1.3 kev. This is probably a result of the calibration used because the low energy transitions are calibrated relative to the Np^{239} transitions, whereas the high-field spectrograph has not been calibrated absolutely in this experiment.

Table V

Electron lines observed which are probably due to Np^{234} decay but which are not sufficiently well established to be assigned to transitions.
Intensity code as in Table III

Electron energy (kev)	Electron intensity	Comments or possible assignments
79.87	vvw	Pu Auger $(ML_{I}L_{II})$
88.38[a]	vw	
89.18[a]	vw-d	
90.09[a]	m	
90.42[a]	vw	
92.95[a]	s-d	Probably Uranium KLX Augers
93.54[a]	s	
96.10[a]	vvw	
97.53[a]	m	
108.73[a]	vvw	
109.96[a]	vvw	
161.64[a]	ew?	
178.96[a]	ew?	
192.51[a]	ew?	
195.93[a]	ew	
330.11[a]	ew-d	
345.55[a]	ew?	
356.37[a]	ew?	
690.6	ew	Probably due to extremely intense line at 696.5
131.9[a]	vvw	

[a] Lines read only by TDT on spectrograph plates exposed later in the series than those from which most of the data were taken.

Table VI

Intensity measurements from the instruments with low resolution. The electron intensities were measured with the long lens spectrometer at 2.2% resolution. (See Figure 1). The gamma data were measured with a NaI (Tl) scintillation spectrometer. (See Figure 2). Only the most intense gamma peaks are reported, as the complexity of the spectrum makes an accurate analysis of the gamma spectrum difficult

Electron energy (kev)	Assignment	Corresponding transitions from 350 Gauss-Magnet	Gross electron intensity $\bar{I}_K$	Gross electron intensity $\bar{I}_L$	Gross gamma intensity $\bar{I}_\gamma$	Gross conversion coefficient $\bar{\alpha}_{abs}$
408	K 523	K 482.8 K 485.1 K 515.7 K 525.9	36			
440	K 556	L 450.5 K 556.8	33			
496	L 523	L 482.8 L 485.1 L 515.7 L 525.9		5.6		
537	L 559	L 556.8		3.6		
638	K 754	K 744.1 K 751.7 K 768.0	20		1	$\geq .01$
695	K 811	K 787.8 K 793.8 K 810.0 K 811.6	529			$\geq .26$
731	L 752	L 744.1 L 751.7 L 768.0 K 853.6		2.3		
796	L 817	L 787.8 L 793.8 L+M 810.0 L+M 811.6	136			
881	K 997	K 986[a] K 1002	5.8			
899	K 1015	K 1027[a] K 1029[a]				

Table VI (cont'd.)

Electron energy (kev)	Assignment	Corresponding transitions from 350 Gauss-Magnet	Gross electron intensity		Gross gamma intensity	Gross conversion coefficient
			$\bar{I}_K$	$\bar{I}_L$	$\bar{I}_\gamma$	$\bar{\alpha}_{abs}$
988	L 1010	L 1002 K 1104	1.8			
1018	L 1041	L 1027[a] L 1029[a]		.25		
1090	K 1206	K 1196	3.7			
1124	K 1240	K 1240	.6			
1178	L 1200	L 1196		.5		
1287	K 1402	K 1395	.7			
1331	K 1447	K 1437	3.2			
1408	K 1523	K 1531	116		5.7	($\geq$ .01)[b]
1435	K 1550	K 1562				
1462	K 1577	K 1575				
1495	K 1610	K 1606				
		L 1531				
1536	L 1558	L 1562				
1561	L 1583	L 1575	25.8			
1585	L 1607	L 1606				
		M 1562				

a. Transitions in Pu^{238} from Np^{238} decay.

b. Absolute value measured by Stephens[20] and used for normalization.

Table VII

Electron lines observed in the sample which decayed with the Np^{236} half-life and which were assigned to Np^{236} on this basis. Intensity code as in Table III

Energy of gamma (kev)	Subshell conversion K	L_I	L_{II}	L_{III}	M_I	M_{II}	M_{III}	N_I	N_{II}	N_{III}
A. From electron capture to U^{236}.										
45.32			vvw	vvw-d		vw	vvw-d		vvw	ew?
641.7[a]	m	vw								
687.0[a]	mw	ew?								
B. From β^- decay to Pu^{236}.										
44.6			vvw?[b]	ew[b]						

[a] This is the first time these transitions have been reported.

[b] L_{II}, L_{III} 44.6 (Pu^{236}) superimposed on L_{II}, L_{III} 44.64 (Pu^{239}). The intensity of these transitions is not consistent with the β^--branching of Np^{236} reported by Gray.[16] They appear to be considerably weaker than previously reported.

Table VIII

Electron lines observed in the sample which agreed in energy with reported Pu^{238} transitions following the Np^{238} decay. The transition energies used in the table are taken from the compilation of Np^{238} data by Albridge and Hollander.[17] Intensity code as in Table III

Energy of gamma (kev)[a]	K	L_I	L_{II}	L_{III}	M_I	M_{II}	M_{III}
			Subshell conversion				
44.11[b]			vvw-d	vw		ew?	
101.7		not observed					
870.6		not observed					
884.6		not observed					
925.4		not observed					
940.4[c]	ew						
943.3		not observed					
985.7[c]	vw	ew?					
988.3		not observed					
1027.2[c]	ew						
1029.9[c]	vvw	ew?					

a. Energies as reported in summary of Np^{238} data by Albridge and Hollander.[17]

b. Electron lines observed with 99-gauss magnet.

c. Electron lines observed with 160-gauss magnet.

Table IX

Electron lines observed in the sample which agreed in energy with the reported Pu^{239} transitions following Np^{239} decay. The transition energies used in the table are taken from Hollander, Smith, and Mihelich.[18] The observed relative intensities are in excellent agreement with those reported by these authors. Intensity code as in Table III

Energy of gamma (kev)[a]	K	L_I	L_{II}	L_{III}	M_I	M_{II}	M_{III}	N_I	N_{II}	N_{III}	O
	Subshell conversion										
44.64		vvw	vvw?[b]	ew[b]	ew??						
49.38		m[c]	vvw-d	vvw	ew[d]	vvw[e]	vvw	ew-d			
57.25		ew?	m	ms[f]		mw	w		vvw	ew	ew-d
61.42		m[g]									
67.82			mw	mw		w	w		ew	ew	ew-d
106.12		mw	mw	--[h]	vvw	vvw	ew?				
106.43			ew?	ew?							
125.3		not observed									
181.8	ew-d										
209.9	s	w	ew		ew			w[i]			
226.4	vw				ew?						
228.4	vvs	m	ew	ew				ew			
254.6	ew?	ew									
273.1		not observed									
277.7	vs	mw	ew		vvw			mw			vw
285.6	ew??		vvw	ew-d		ew-d					
316.1		not observed									
334.5	w										

Table IX (cont'd.)

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a. Energies as reported by Hollander, Smith, and Mihelich. All intensities except those otherwise indicated were obtained on the 99-gauss magnets.

b. L_{II}, L_{III} 44.64 (Pu^{239}) and L_{II}, L_{III} 44.6 (Pu^{236}) superimposed.

c. L_{I} 49.38 (Pu^{239}), L_{III} 43.49 (U^{234}) superimposed.

d. M_{I} 49.38 (Pu^{239}), O_{III} 43.49 (U^{234}) superimposed.

e. M_{II} 49.38 (Pu^{239}), N_{II} 45.32 (U^{236}) superimposed.

f. L_{III} 47.26 (Pu^{239}), M_{III} 43.49 (U^{234}) superimposed.

g. L_{I} 61.42 (Pu^{239}), M_{II} 43.49 (U^{234}) superimposed.

h. May be masked.

i. All intensities underlined were observed on the 160-gauss permanent magnet.

Table X

Observed electron energies

Electron energy (kev)	Bρ (Gauss-cm)	Intensity	Permanent magnet	Plate No.	Assignment		
					Isotope[a]	Subshell	E_γ(kev)
21.68[b]	501.71	vvw	2	882	239	L_{I}	44.64
21.88	504.14	vvw(d)	"	"	238	L_{II}	44.11
22.36	510.86	vvw(?)	"	"	236(Pu) 239	L_{II} L_{II}	44.6 44.64
22.65	513.13	mw	"	"	234	L_{II}	43.49
24.44	533.39	vvw	"	"	236(U)	L_{II}	45.32
26.11	551.74	vw	"	"	238	L_{III}	44.11
26.42	555.15	m	"	"	234 239	L_{III} L_{I}	43.49 49.38
26.62	551.27	ew	"	"	236(Pu) 239	L_{III} L_{III}	44.6 44.64
27.28	564.34	vvw(d)	"	"	239	L_{II}	49.40
28.18	573.84	vvw(d)	"	"	236(U)	L_{III}	45.32
31.45	607.12	vvw	"	"	239	L_{III}	49.40
34.36	635.47	ew?	"	"	239	L_{I}	57.25
35.25	643.92	m	"	"	239	L_{II}	57.25
38.48	673.81	m	"	"	239 239	L_{I} M_{II}	61.42 43.49
38.69	675.73	ew?	"	"	238	M_{II}	44.11
38.91	677.71	ew??	"	"	239	M_{I}	44.64
39.43	682.36	ms	"	"	234 239	M_{III} L_{III}	43.49 57.25
39.67	684.54	vvw	"	"	238	M_{III}	44.11
40.22	689.45	vw	"	"	236(U)	M_{II}	45.32
41.10	697.27	vvw(d)	"	"	236(U)	M_{III}	45.32
42.41	708.69	w	"	"	234	N_{II}	43.49
42.62	710.47	vw	"	"	234	N_{III}	43.49
43.44	717.64	vvw	"	"	234	O_{II}	43.49
43.62	719.13	ew	"	"	234	O_{III}	43.49
44.08	723.08	vvw	"	"	236(U) 239	N_{II} M_{II}	45.32 49.40

Table X (cont'd.)

Electron energy (kev)	B ρ (Gauss-cm)	Intensity	Permanent magnet	Plate No.	Assignment		
					Isotope[a]	Subshell	E_γ (kev)
44.55	727.09	ew?	2	882	236(U)	N_{III}	45.32
45.11	731.84	vvw	"	"	239	M_{III}	49.40
45.81	737.77	mw	"	"	239	L_{II}	67.83
48.45	759.66	Broad ew(d)	"	"	239	N_I, N_{II}	49.40
50.07	772.81	mw	"	"	239	L_{III}	67.87
52.03	788.05	mw	"	"	239	M_{II}	57.25
52.99	796.11	w	"	"	239	M_{III}	57.25
56.14	820.62	vvw	"	"	239	N_{II}	57.25
56.39	822.55	ew	"	"	239	N_{III}	57.25
57.33	829.73	ew(d)	"	"	239	O	57.25
60.18	851.23	ew(d)	"	"	239	K	181.8
62.59	869.09	w	"	"	239	M_{II}	67.82
63.57	876.26	w	"	"	239	M_{III}	67.81
66.69	898.81	ew	"	"	239	N_{II}	67.79
66.98	900.84	ew	"	"	239	N_{III}	67.83
67.97	907.87	ew(d)	"	"	239	O_I	67.83
72.06	936.56	vw(d)	"	"	U	$KL_I L_I$	
72.83	941.90	w(d)	"	"	U	$KL_I L_{II}$	
76.25	965.26	ew?	"	"	Pu	$KL_I L_{II}$	
76.63	967.83	ew?	"	"	U	$KL_I L_{III}$	
77.39	972.97	vw	"	"	U	$KL_{II} L_{III}$	
79.19	985.00	vw	"	"	234	L_{II}	99.7
79.87	989.50	vvw	"	"	Pu(?)	$KL_I L_{II}$	(?)
81.29	998.95	ew(d)	"	"	U Pu	$KL_{III} L_{III}$ $KL_{II} L_{III}$	
82.86	1009.4	ew?	"	"	234	L_{III}	99.7
83.26	1011.9	mw	"	"	239	L_I	106.12
84.11	1017.4	mw	"	"	239	L_{II}	106.12
84.51	1020.0	ew?	"	"	239	L_{II}	106.43
87.94	1042.1	s vvs[‡]	7	887[*]	239	K	209.9

Table X (cont'd.)

Electron energy (kev)	$B\rho$ (Gauss-cm)	Intensity	Permanent magnet	Plate No.	Assignment		
					Isotope[a]	Subshell	E_γ (kev)
88.38†	1044.9	vw	7	887*			
88.86	1048.0	ew(?) vw	2	882	239	L_{III}	106.43
89.18†	1050.0	vw(d)	7	887*			
90.09†	1055.8	m	"	"			
90.42	1057.9	ew? vw	2	882			
92.95†	1073.8	sd	7	887*			
93.54	1077.5	ew? s	2	882			
95.00	1086.6	ew? vs	"	"	234	M_{II}	99.7
95.41†	1089.2	s	7	887*	234	M_{III}	99.7
96.10†	1093.4	vvw	"	"			
97.53	1102.2	ew(d) m	2	882			
98.57†	1108.6	mw	7	887*	234	N_{II} N_{III}	99.7
100.47	1120.2	vvw vs	2	882	239	M_I	106.12
100.90	1122.1	vvw	"	"	239	M_{II}	106.12
101.82	1128.3	ew? w	7	887	239	M_{III}	106.12
102.54	1132.7	vvw	7	887*	239	L_I	125.3
104.89	1146.8	vw	2	882	239	K	226.4
106.71	1157.8	vvs	"	"	239	K	228.47
108.73	1169.6	vvw	7	887*			
109.96	1176.8	vvw	"	"*			
118.35	1225.4	ew?	2	882	234	K	233.6
119.32	1231.0	vvw	"	"	234	K	234.6
122.77	1250.5	vvw	7	887*	234	K	238.6
132.56	1305.0	vvw(d)	2	882	234	K	247.9
132.92	1306.9	ew?	"	"	239	K	254.6
149.70	1397.0	vvw	7	887	234	K	265.8
150.99	1403.8	vvw	"	"	239	K	273.1
156.32	1431.6	vs	2	882	239	K	277.9
158.45	1442.6	vvw(d)	7	887*	239	L_I	181.8
159.98*	1450.5	ew?	7	884*	239	L_{II}	181.8
161.64	1459.0	ew?	7	887*			

Table X (cont'd.)

Electron energy (kev)	Bρ (Gauss-cm)	Intensity	Permanent magnet	Plate No.	Assignment		
					Isotope[a]	Subshell	E_γ (kev)
164.03	1411.2	ew??	2	882	239	K	285.6
176.13	1532.3	vw	7	887*	239	M_I	181.8
177.13	1537.3	ew?	"	" *	239	M_{III}	181.8
178.96	1546.4	ew?	"	" *			
180.84	1557.7	ew?	"	" *	239	N_I	181.8
182.04	1561.6	vvw	"	" *	234	K	297.6
187.06	1586.3	w	2	882	239	L_I	209.9
187.86	1590.2	ew	"	"	239	L_{II}	209.9
192.51	1612.9	ew	7	884*			
193.98	1620.0	vvw	"	" *	239	K	316.1
195.93	1629.4	ew	"	" *			
204.19	1669.1	ew	2	882	239	M_I	209.9
205.5	1675.3	m	"	"	239	L_I	228.4
206.26	1678.9	ew	"	"	239	L_{II}	228.4
208.04	1687.3	w	7	881	239	N_I	209.9
211.20	1702.3	ew?	"	"	234	L_I	233.6
212.22	1709.1	w	"	"	234 239	L_I K	237.6 333.4
219.91	1743.2	ew?	"	"	239?	M's	226.4
222.11	1753.4	vw	"	"	239	M_I	228.4
225.9	(Interpolated) (CJG)	ew	7	881	234	L_I	247.9
226.37	1773.2	m	"	"	239	N_I	228.4
227.43	1778.1	w	"	"	239	O_I	228.4
228.74	1784.2	ew?	"	"	234	M_I	234.6
230.95	1794.3	ew	"	"	239	L_I	254.6
241.99	1844.8	ew	"	"	234	M_I	247.9
254.36	1900.6	vs	"	"	239	L_I	277.7
255.08	1903.8	m	"	"	239	L_{II}	277.7
259.15	1922.0	ew-d	"	"	239	L_{III}	277.7
262.88	1938.6	vvw	"	"	239	L_{II}	285.6

Table X (cont'd.)

Electron energy (kev)	Bρ (Gauss-cm)	Intensity	Permanent magnet	Plate No.	Assignment		
					Isotope[a]	Subshell	E_γ (kev)
267.18	1957.7	ew-d	"	881	239	L_{III}	285.6
271.60	1977.2	s	"	"	239	M_I	277.7
275.78	1995.6	mw	"	"	239	N_I	277.7
277.05	2001.1	vw	"	"	239	O_I	277.7
279.45	2011.6	ew?-d	"	"	239	M_{II} M_{III}	285.6
330.11	2228.5	ew-d	"	" *			
335.06	2249.2	ms	"	"	234	K	450.5
345.55	2293.0	ew?	"	" *			
356.37	2337.8	ew?	"	" *			
367.25	2382.6	ew	"	" *	234	K	482.8
369.55	2392.0	ew	"	" *	234	K	485.1
400.06	2517.9	mw	"	"	234	K	515.7
410.28	2557.0	ew-d	"	"	234	K	525.9
428.8	2630.8	vw	"	"	234	L_I	450.5
429.4	2633.1	ew	"	"	234	L_{II}	450.5
430	(Interpolated) (CJG)	ew?	"	"	234	L_{III}	450.5
441.2	2679.9	vw	"	"	234	K	556.8
444.9	2694.7	ew?	"	"	234	M_I	450.5
448.7	2709.5	ew??	"	"	234	N_I	450.5
494.1	2886.8	ew	"	"	234	L_I	515.7
526.1	3010.3	w	"	"	236	K	641.7
537.0	3051.9	ew-d	4	880	234	L_I	556.8
571.4	3183.0	mw	7	881	236	K	687.0
622.1	3373.4	vw	4	880	236	L_I	641.7
628.5	3397.2	w	"	"	234	K	744.1
636.1	3425.9	w	"	"	234	K	751.7
652.4	3486.3	ew-d	"	"	234	K	768.0
667.2	3541.2	ew?	"	"	236(U)	L_I	687.0
672.3	3559.8	vvw	"	"	234	K	787.8
678.2	3581.8	vw	"	"	234	K	793.8

Table X (cont'd.)

Electron energy (kev)	B ρ (Gauss-cm)	Intensity	Permanent magnet	Plate No.	Assignment		
					Isotope[a]	Subshell	E_γ (kev)
690.6	3627.5	ew	4	880			
694.4	3641.4	s	"	"	234	K	810.0
696.5	3649.2	vvs	"	"	234	K	811.6
730.7	3775.0	ew?	"	"	234	L_I	751.7
738.4	3803.0	ew??	"	"	234	K	853.6
746.5	3832.5	ew?	"	"	234	L_I	768.0
788.2	3984.2	mw	"	"	234	L_I	810.0
789.8	3990.3	ms	"	"	234	L_I	811.6
804.3	4043.0	ew	"	"	234	M_I	810.0
806.0	4048.8	w	"	"	234	M_I	811.6
810.2	4064.2	ew-d	"	"	234	N_I	811.6
819.2	4096.7	ew	"	"	238	K	940.4
864.5	4259.9	vw	"	"	238	K	985.7
887.2	4341.4	vvw	"	"	234	K	1003
906.2	4409.1	ew	"	"	238	K	1027.2
908.4	4417.2	vvw	"	"	238	K	1029.9
963.6	4614.1	ew?	"	"	238	L_I	985.7
981.7	4678.2	ew?	"	"	234	L_I	1003
988.9	4703.9	ew?	"	"	234	K	1105
1007.7	4770.5	ew?	"	"	238	L_I	1029.9
1080.5	5027.4	ew	"	"	234	K	1196
1124.0	5180.7	ew-d	"	" *	234	K	1240
1279.2	5722.7	ew?	"	" *	234	K	1395
1318.9	5861.2	vvw	"	" *			
1323.0	5875.5	vw	"	"	234	K	1439
1415.4	6195.6	vw	"	"	234	K	1531
1446.7	6304.0	m	"	"	234	K	1562
1458.9	6346.2	vw	"	"	234	K	1575
1490.2	6454.2	w	"	"	234	K	1606
1509.6	6520.9	ew	"	"	234	L_I	1531

Table X (cont'd.)

Electron energy (kev)	$B\rho$ (Gauss-cm)	Intensity	Permanent magnet	Plate No.	Assignment		
					Isotope[a]	Subshell	E_γ (kev)
1541.0	6629.2	vvw	4	880	234	L_I	1562
1552	6667.2	ew	"	884	234	L_I	1575
1556.7	6683.4	ew	"	"	234	M_I	1562
1584.1	6777.3	ew	"	"	234	L_I	1606

‡ Underlined intensities are the intensities for this line on plate 887.

† Electron energies read only by TDT; the electron energies have not been calibrated relative to the lines on plate 882.

* Electron lines read only by TDT on a plate taken later in the series than that from which most of the reported data were taken.

a. The electron line energies reported here are not calibrated, but are as calculated directly from the readings on the spectrographic plates. The U^{234} transition energies reported in this paper have not all been calibrated identically. The low energy transitions were calibrated relative to the energies of the Pu^{239} lines reported by Hollander, Smith, and Mihelich; the high energy electron lines have not been calibrated and the transition energies are as calculated directly from the electron lines.

Table XI

Gamma ray energies for the electron capture decay of Np^{234}

Energy of gamma (kev)	Electron energy (kev)	Intensity	Subshell	E_γ calculated from E_e	Comments
43.49[a]	22.65	mw	L_{II}	43.59	
	26.42	m	L_{III}	43.58	L_{III} 43.49(U^{234}),L_I 49.38(Pu^{239})superimposed
	38.48	m	M_{II}	43.66	M_{II}43.49(U^{234}),L_I61.42(Pu^{239})superimposed
	39.43	ms	M_{III}	43.73	M_{III}43.49(U^{234}),L_{III}57.25(Pu^{239})superimposed
	42.41	w	N_{II}	43.79	
	42.62	vw	N_{III}	43.75	
	43.44	vvw	O_{II}	43.69	
	43.62	ew	O_{III}	43.81	O_{III}43.49(U^{234}),M_I 49.38(Pu^{239})superimposed
99.7	79.19	vw	L_{II}	100.13	
	82.86	ew?	L_{III}	100.02	
	95.00	vs	M_{II}	100.18	
	95.41	s	M_{III}	99.71	M and N lines observed on 160-gauss magnets
	98.57	mw	N_{II}	99.95	
233.6	118.35	ew?	K	233.94	K line observed on 99-gauss magnet
	211.20	ew	L_I	232.96	L line on 160-gauss magnet
234.6	119.32	vvw	K	234.91	K line observed on 99-gauss magnet
	212.22	w	L_I	233.98	L line on 160-gauss magnet
238.6	122.77	vvw	K	238.36	
247.9	132.56	vvw-d	K	248.15	K line observed on 99-gauss magnet
	225.9	ew	L_I	247.7	L and M lines on 160-gauss magnet
	241.99	ew	M_I	247.54	
265.8	149.70	vvw	K	265.29	
297.6	182.04	vvw	K	297.63	
450.5	335.1	ms	K	450.69	
	428.8	vw	L_I	450.56	
	429.4	ew	L_{II}	450.34	
	430	ew?	L_{III}	447	Line observed only by CJG.Energy interpolated roughly

Table XI (cont'd.)

Energy of gamma (kev)	Electron energy (kev)	Intensity	Subshell	E_γ calculated from E_e	Comments
	444.9	ew?	M_I	450.45	
	448.7	ew??	N_I	450.14	
482.8	367.3	ew-d	K	482.89	Lines read only by TDT
485.2	369.6	ew-d	K	485.19	Lines read only by TDT
515.7	400.1	mw	K	515.69	
	494.1	ew	L_I	515.86	
525.9	410.3	ew-d	K	525.89	
556.8	441.2	m	K	556.79	
	537.0	ew-d	L_I	558.76	This line, and all others below, observed on 350-gauss magnet
720	604.5	ew??	K	720.09	Line very weak. Read only by TDT
744.1	628.5	w	K	744.09	
751.7	636.1	w	K	751.69	
	730.7	ew?	L_I	752.46	
768.0	652.4	ew-d	K	767.99	
	746.5	ew?	L_I	768.26	
787.9	672.3	vvw	K	787.89	
793.8	678.2	vw	K	793.79	
810.0	694.4	s	K	809.99	
	788.2	mw	L_I	809.96	
	804.3	ew	M_I	809.85	
811.6	696.5	vvs	K	812.09	
	789.8	ms	L_I	811.56	

Table XI (cont'd.)

Energy of gamma (kev)	Electron energy (kev)	Intensity	Subshell	E_γ calculated from E_e	Comments
	806.0	w	M_I	811.55	
	810.2	ew-d	N_I	811.64	
853.6	738.	ew?	K	853.59	
1003	887.2	vvw	K	1002.79	
	981.7	ew?	L_I	1003.46	
1105	988.9	ew?	K	1104.49	
1196	1080.5	ew	K	1196.09	
1240	1124	ew??	K	1239.6	Read only by TDT
1395	1279.2	ew??	K	1394.8	Read only by TDT
1439	1323.0	ew	K	1438.6	
1531	1415.4	vw	K	1531.0	
		ew	L_I		
1562	1446.7	m	K	1562.3	
	1541.0	vvw	L_I	1562.8	
	1556.7	ew	M_I	1562.2	
1575	1458.9	vw	K	1574.5	
	1552.	ew	L_I	1573.8	
1606	1490.2	w	K	1605.79	
	1584.1	ew	L_I	1605.86	

a. The energies listed in this table are the result of correcting the average photon energy deduced from the electron lines of each transition by a factor ΔE. ΔE was determined as an empirical correction from a ΔE versus ρ (radius of curvature) curve, where ΔE is the energy increment needed to bring the Pu^{239} transition energies measured in this study into agreement with the reported energies of Hollander, Smith and Mihelich. We have listed only uncorrected electron data in this and the following tables.

Table XII

Gamma ray energies for the beta decay of Np^{239}

Energy of gamma (kev)	Electron energy (kev)	Intensity	Subshell	E_γ calculated from E_e	Comments
44.64[a]	21.68	vvw	L_I	44.78	
	22.36	vvw?	L_{II}	44.61	
	26.62	ew	L_{III}	44.68	
		ew??	M_I		
49.38	26.42	m	L_I	49.52	L_I 49.38(Pu^{239}),L_{III}43.49(U^{234})superimposed
	27.28	vvw-d	L_{II}	49.53	
	31.45	vvw	L_{III}	49.51	
	43.62	ew	M_I	49.55	M_I 49.38(Pu^{239}),O_{III}43.49(U^{234})superimposed
	44.08	vvw	M_{II}	49.64	
	45.11	vvw	M_{III}	49.67	
	48.45	ew-d	$N_{II}N_{III}$	49.58	
57.25	34.36	ew?	L_I	57.46	
	35.25	m	L_{II}	57.50	
	39.43	ms	L_{III}	57.49	L_{III} 57.25(Pu^{239}),M_{III}43.49(U^{234})superimposed
	52.03	mw	M_{II}	57.58	
	52.99	w	M_{III}	57.55	
	56.14	vvw	N_{II}	57.52	
	56.39	ew	N_{III}	57.52	
	57.33	ew-d	$O_{II}O_{III}$		
61.42	38.48	vw	L_I	61.58	L_I 61.58(Pu^{239}),M_{II} 43.49(U^{234})superimposed
67.83	45.81	mw	L_{II}	68.06	
	50.07	mw	L_{III}	68.13	
	62.59	w	M_{II}	68.15	
	63.57	w	M_{III}	68.13	
	66.69	ew	N_{II}	68.07	
	66.98	ew	N_{III}	68.11	
	67.97	ew-d	O_{III}		

Table XII (cont'd.)

Energy of gamma (kev)	Electron energy (kev)	Intensity	Subshell	E_{γ} calculated from E_{e}	Comments
106.12	83.26	mw	L_{I}	106.36	
	84.11	mw	L_{II}	106.36	
	--	--	L_{III}	--	Probably masked
	100.47	vvw	M_{I}	106.40	
	100.90	vvw	M_{II}	106.46	
	101.82	ew	M_{III}	106.38	
106.43	84.51	vw	L_{II}	106.76	
	88.86	vvw	L_{III}	106.92	
125.3	--	--	K	--	Not read on high-field plates on which L-line was observed.
	102.54	vvw	L_{I}	125.64	
181.8	60.18	ew-d	K	181.93	
	158.45	vvw-d	L_{I}	181.55	L,M,N lines seen on different magnet than K
	159.98	ew?	L_{II}	182.23	
	176.13	vw	M_{I}	182.06	
	177.13	ew?	M_{III}	182.69	
	180.84	ew?	N_{I}	182.40	
209.9	88.30	s	K	210.05	
	187.06	w	L_{I}	210.16	
	187.86	ew	L_{II}	210.11	
	204.19	ew	M_{I}	210.12	
226.4	104.89	vw	K	226.64	
228.4	106.71	vvs	K	228.46	
	205.50	m	L_{I}	228.60	
	206.26	ew	L_{II}	228.51	
	222.60	vw	M_{I}	228.53	
	226.95	ew	N_{I}	228.51	
	228.16	ew?	O_{I}	--	
254.6	132.92	ew?	K	254.67	

Table XII (cont'd.)

Energy of gamma (kev)	Electron energy (kev)	Intensity	Subshell	E_γ calculated from E_e	Comments
273.1	150.99	vvw	K	272.74	
277.7	156.32	vs	K	278.07	
	254.61	mw	L_I	277.71	
	255.46	ew	L_{II}	277.71	
	271.69	vvw	M_I	277.62	
	275.93	ew?	N_I	277.49	
285.6	164.03	ew??	K	285.78	
316.1	193.98	vvw	K	315.73	
634.5	212.22	w	K	333.97	K 334.5(Pu^{239}), L_I 234.6(U^{234})superimposed

Plutonium K-Augers

Line	Energy	Intensity
$KL_I L_{II}$	76.25	ew?
$KL_{II} L_{III}$	81.29	ew-d

a. See discussion in footnote (a), Table XI.

Table XIII

Gamma ray energies for the beta decay of Np^{238}

Energy of gamma (kev)	Electron energy (kev)	Intensity	Subshell	E_γ calculated from E_e
44.11	21.88	vvw-d	L_{II}	44.13
	26.11	vw	L_{III}	44.17
	38.69	ew?	M_{II}	44.25
	39.67	vvw	M_{III}	44.23
940.4	819.2	ew	K	940.9
985.7	864.5	vw	K	986.2
	963.6	ew?	L_I	986.7
1027.2	906.2	ew	K	1027.9
1029.9	908.4	vvw	K	1030.1
	1007.7	ew?	L_I	1030.8

Table XIV

Gamma ray energies for the decay of Np^{236}

Energy of gamma (kev)	Electron energy (kev)	Intensity	Subshell	E_γ calculated from E_e	Comments
From electron capture to U^{236}					
45.32	24.44	vvw	L_{II}	45.38	
	28.18	vvw-d	L_{III}	45.34	
	40.22	vw	M_{II}	45.40	
	41.10	vvw-d	M_{III}	45.40	
	44.08	vvw	N_{II}	45.35	
	44.55	ew?	N_{III}	45.59	
641.7	526.1	m	K	641.7	These transitions are reported here for the first time.
	622.1	vw	L_I	643.9	
687.0	571.4	mw	K	687.0	
	667.2	ew?	L_I	688.96	
From β^- decay to Pu^{236}					
44.6	22.36	vvw?	L_{II}	44.61	Lines coincide with 44.64 transition in Pu^{239}.
	26.62	ew	L_{III}	44.68	

FIGURE CAPTIONS

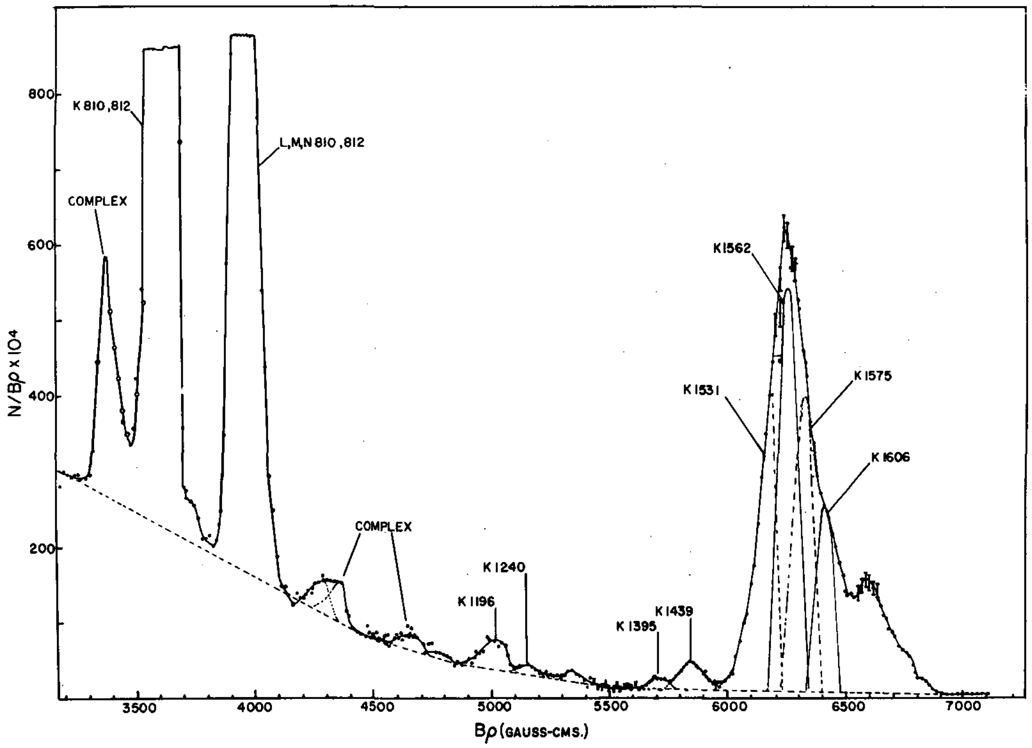
Fig. 1. The electron spectrum between approximately 650 and 1600 kev following Np^{234} decay. The resolution is 2.2%. The curve represents the average of 3 runs over the spectrum using constant counts. (Hence the variation in statistics.) The data were corrected for the decay of Np^{234} and hence the Np^{238} beta spectrum causes some distortion of the background.

Fig. 2. The gamma spectrum following Np^{234} decay between approximately 650 and 1700 kev. The data shown were taken with 1 gram of lead between source and crystal.

Fig. 3. Some of the levels of U^{234} populated by Np^{234} decay. The dashed transitions appeared on the spectrograph plates, but were too weak to be read accurately. They are not reported in Table I. The dashed levels are so represented because no transitions are observed to depopulate them.

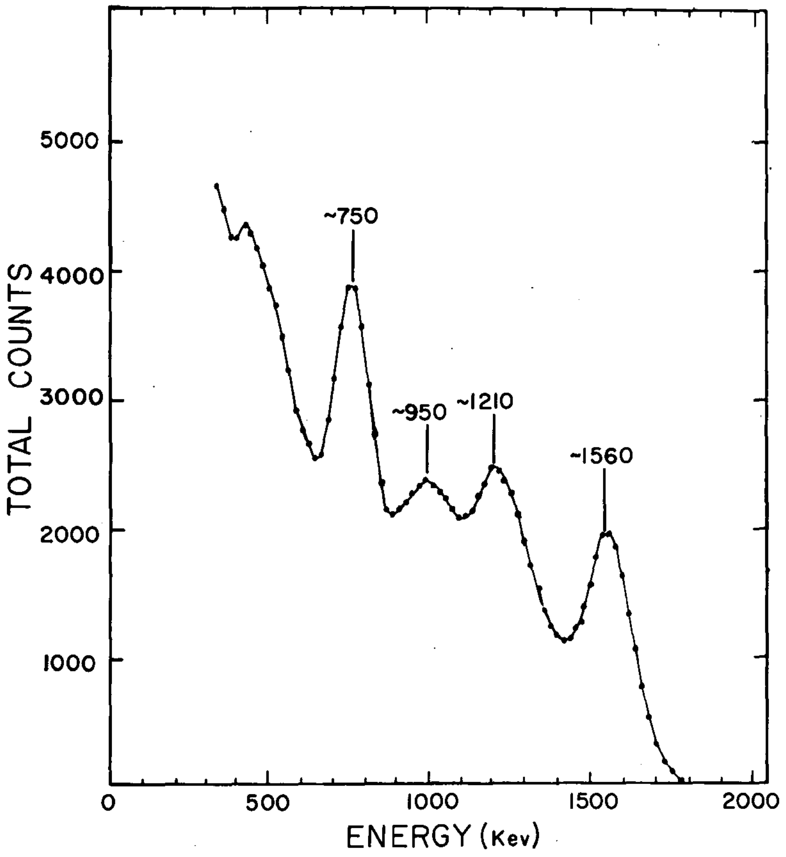
Fig. 4. Level scheme of U^{234} as previously reported by Ong, Verschoor, and Born from Pa^{234} decay.

Fig. 5. Comparison of β-, γ-, and 1- vibrational state energies in nuclides where they are known. The Np^{238} data are from Ref. 17; the Sm^{152} and Gd^{154} data from Ref. 29. The single asterisk indicates the level assignment is uncertain. The double asterisk on the Gd^{154} level indicates the assignment was postulated by Nathan and Hultberg[29] on the basis of the work of Juliano and Stephens.[30]



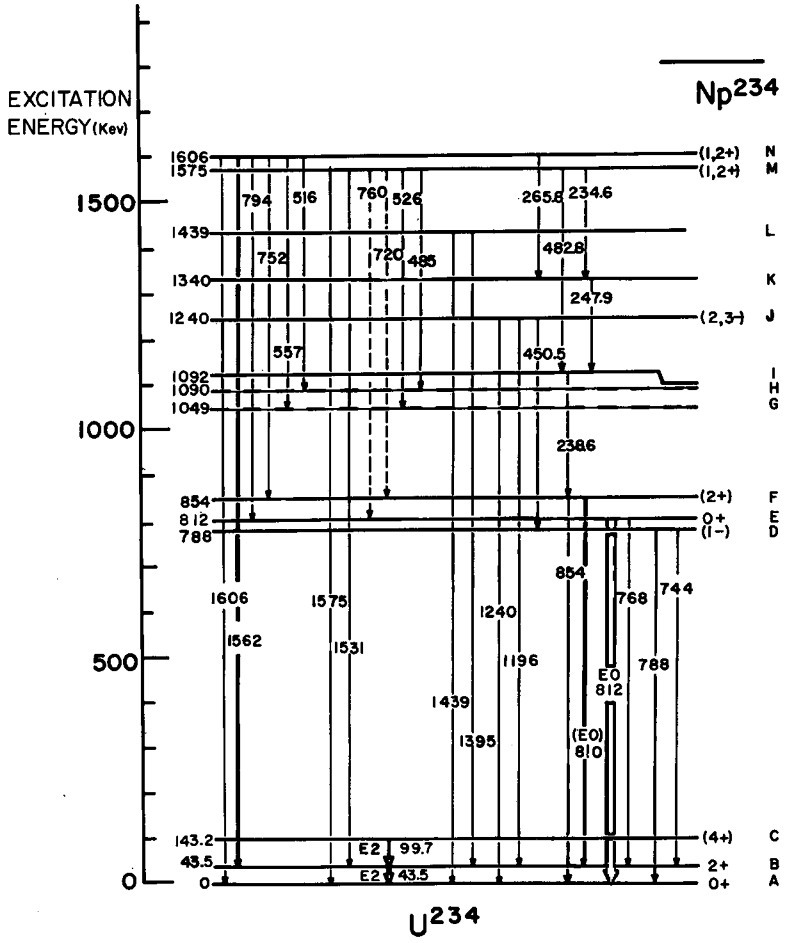
MU-18345

Fig. 1.



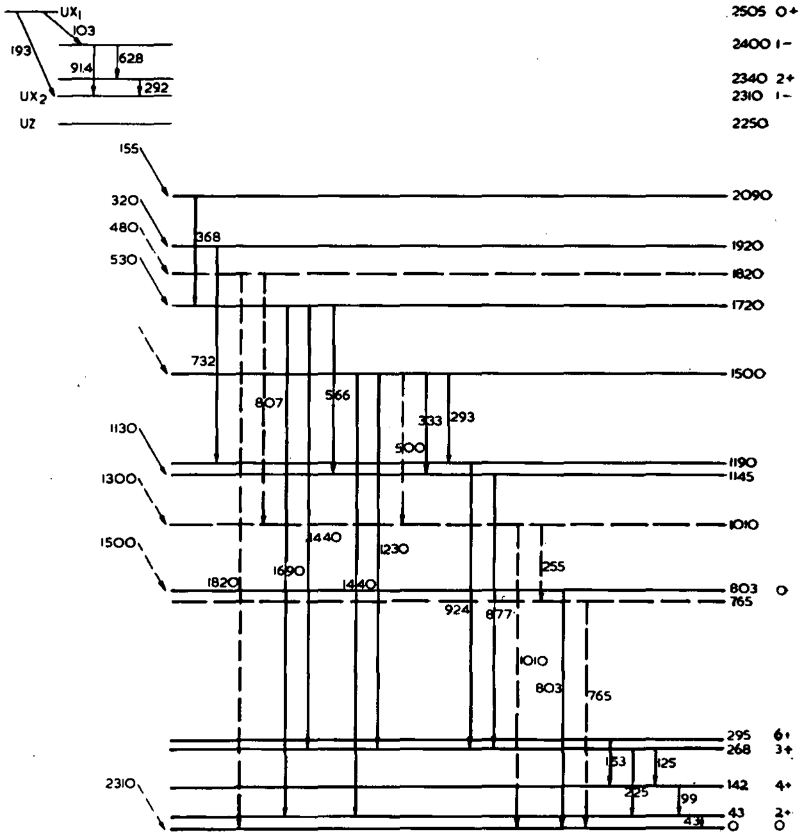
MU-18346

Fig. 2.



MU-18347

Fig. 3.



MU-18348

Fig. 4.

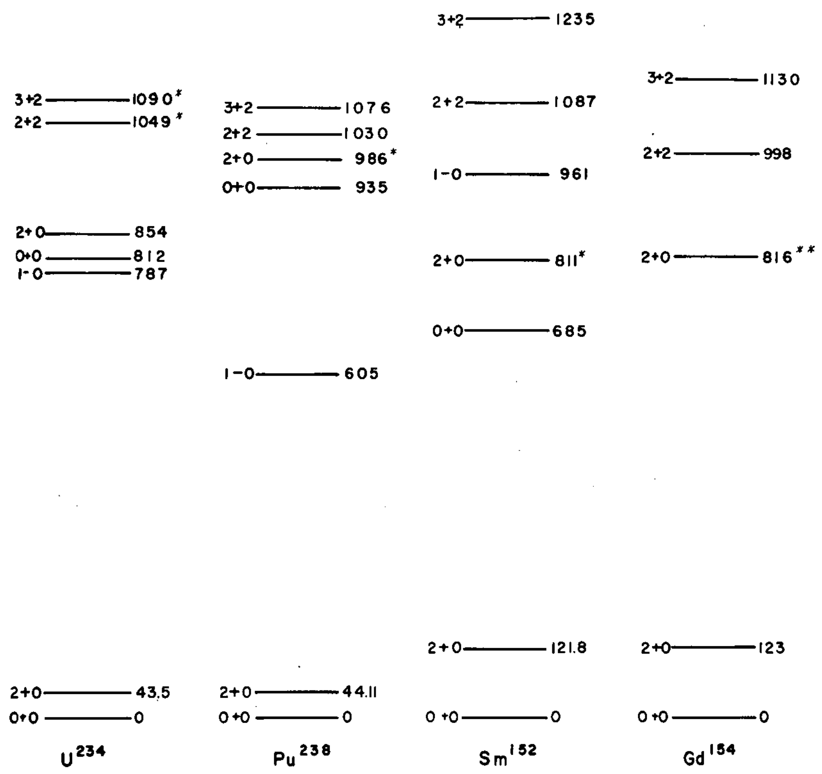


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Fig. 5.