present method is limited by the fact that the spectra of singly and multiply charged recoil ions cannot be studied separately. In addition, a small correction for the energy dependence of the probability of ionization of the recoil atoms should be applied. We conclude that the limited accuracy of our present experiments rules out an admixture of more than 10% of either the tensor or scalar interactions with the *VA* combination.

ACKNOWLEDGMENTS

We wish to thank Dr. W. H. McCorkle, Dr. J. H. McMillen, and the staff of the CP-5 reactor for the provision of facilities for some of the experiments. We are indebted to J. T. Heinrich who helped to construct part of the apparatus. The assistance of the staff of the University of Illinois cyclotron during the cyclotron bombardments is gratefully acknowledged.

PHYSICAL REVIEW VOLUME 116, NUMBER 1 OCTOBER 1, 1959

Decay of U^{240} and 7.3-min Np^{240}†

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(Received May 1, 1959)

The radiations of U^{240} and 7.3-min Np^{240} have been studied with a solenoidal beta spectrometer, beta- and gamma-scintillation spectrometers, and 180° permanent-magnet spectrographs. The principal decay branch of U^{240} is a 0.36-Mev beta transition to the 7.3-min state of Np^{240}. The only other radiations observed which are attributed to U^{240} are the conversion lines associated with a 0.044-Mev transition.

The decay scheme of 7.3-min Np^{240} is considerably more complicated than that indicated by previous investigations. On the basis of coincidence studies, intensity data, internal conversion coefficients, and the measured transition energies, a consistent level scheme for Pu^{240} is proposed which has excited states at 0.043, 0.142, 0.597, 0.858, 0.900, 0.942, 1.42, 1.53, and 1.62 Mev. The ground-state transition from the 0.858-Mev level is of $E0$ multipolarity, identifying this level as a 0+ state. There are beta transitions to the ground state of Pu^{240} ($Q_\beta = 2.18$ Mev) and to each of the above excited states except the one at 0.142 Mev. Consideration of the beta-decay information leads to a spin and parity assignment of 1+ for 7.3-min Np^{240}. Various features of the decay scheme are compared with the predictions of current models of nuclear structure.

I. INTRODUCTION

SPECTROMETRIC examination of the β and γ radiations of 14.1-hr U^{240} and its daughter nuclide, 7.3-min Np^{240}, was first reported in 1953.[1] The continuous β-ray spectrum associated with these two activities (in equilibrium) was resolved into β groups with end-point energies of 2.156, 1.59, 1.26, 0.76, and 0.36 Mev. It was proposed that the 0.36-Mev group represents the $U^{240} \rightarrow Np^{240}$ (7.3 min) transition, and that the 2.156-Mev group represents the Np^{240} (7.3 min) $\rightarrow Pu^{240}$ ground-state transition. Assignment of the remaining β groups as representing transitions to excited states of Pu^{240} was supported by scintillation measurements which indicated that γ rays of energies ~0.56, ~0.90, and ~1.40 Mev accompany the decay of Np^{240}.

More recent investigations have shown that the 7.3-min Np^{240} decay scheme is considerably more complex than the one outlined above. Measurements of internal-conversion electron spectra and γ-ray scintillation spectra[2,3] have established the existence of γ-ray transitions of energies 0.0429, 0.557, and 0.600 Mev (presumably associated with the de-excitation of levels at 0.0429 and 0.600 Mev in Pu^{240}), and have provided evidence for "complexes" of γ rays at ~0.85 and ~1.5 Mev.

Additional information on the energy levels of Pu^{240} has been obtained from studies of the radiations which accompany β decay of the 63-min isomer of Np^{240} [4–6] (which is not formed in the decay of U^{240}), electron-capture decay of Am^{240},[7,8] and α decay of Cm^{244},[9–11] but thus far it has not been possible to synthesize all of the known data into a consistent level scheme.

As additional source material has become available at this Laboratory at various times subsequent to the initial report,[1] we have been able to make further studies of the radiations of U^{240} and 7.3-min Np^{240}.

† Work done under the auspices of the U. S. Atomic Energy Commission.
[1] Knight, Bunker, Warren, and Starner, Phys. Rev. **91**, 889 (1953).
[2] Stephens, Asaro, and Perlman (private communication, March, 1957), and J. M. Hollander (private communication, March, 1957), cited in reference 3.
[3] Strominger, Hollander, and Seaborg, Revs. Modern Phys. **30**, 585 (1958).
[4] D. A. Orth and K. Street, Jr. (unpublished data, 1951), cited in reference 3.
[5] R. M. Lessler, University of California Radiation Laboratory Report UCRL-2647, July, 1954 (unpublished), and UCRL-8439, October, 1958 (unpublished).
[6] Lefevre, Kinderman, and Van Tuyl, Bull. Am. Phys. Soc. **1**, 62 (1956).
[7] R. A. Glass, University of California Radiation Laboratory Report UCRL-2560, April, 1954 (unpublished).
[8] Smith, Gibson, and Hollander, Phys. Rev. **105**, 1514 (1957).
[9] W. G. Smith and J. M. Hollander, Phys. Rev. **101**, 746 (1956).
[10] Asaro, Stephens, and Perlman (unpublished data, March, 1957), cited in reference 3.
[11] White, Rourke, Sheffield, Schuman, and Huizenga, Phys. Rev. **109**, 437 (1958).

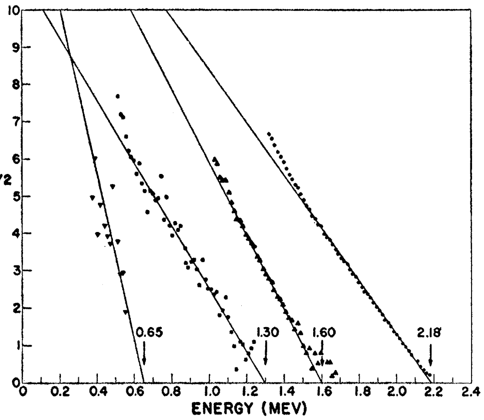

FIG. 1. Fermi-Kurie plot of the high-energy portion (>0.4 Mev) of the U^{240}-Np^{240} beta spectrum.

Improvements both in instrumentation and in understanding of the behavior of heavy nuclei have made possible a more accurate and detailed analysis of the decay of these two nuclides. The present report is a summary of the results accumulated to date.

II. SOURCE PREPARATION

The U^{240} activity was produced by the reaction sequence $U^{238}(n,\gamma)U^{239}(n,\gamma)U^{240}$ in uranium which was exposed to very high instantaneous neutron fluxes. The U^{240}-Np^{240} source material, which contained 6.75-day U^{237} as an unavoidable β-active contaminant, was isolated from fission products and other radioactive substances by a carrier-free procedure[12] employing cupferron by-product extraction and tributyl phosphate product extraction steps, followed by adsorption-elution cycles with anion and cation resin columns.

Beta spectrometer sources were prepared by evaporation of a drop of source solution on 1.0 mg/cm² aluminized Mylar backing. In the experiments devoted primarily to measurement of the high-energy (>0.4 Mev) portion of the Np^{240} β-ray spectrum, the source deposits were about 3 mm in diameter. In the experiment concerned with measurement of conversion electron spectra and the U^{240} β-ray spectrum, the source solution was put through an ether extraction step to remove the last traces of foreign solids, and the extract obtained was concentrated and evaporated on the aluminized Mylar as a spot approximately 1.5 mm in diameter. The thickness of this source deposit was estimated to be less than 3 μg/cm².

The 180°-spectrograph source consisted of a strip 15 mm×0.5 mm cut out of a source deposit which had been evaporated on 0.00025-in. aluminum foil backed with Scotch tape.

Sources for the scintillation experiments were prepared by evaporating portions of source solution to dryness on 0.003-in. copper foil.

[12] The details of the procedure are described in the Los Alamos Scientific Laboratory Report LA-1721, December, 1956 (unpublished).

III. BETA SPECTROMETER MEASUREMENTS

The β-ray and internal-conversion electron spectra were measured with a uniform-field, ring-focusing solenoidal spectrometer patterned after the design of Schmidt.[13] The baffle system was set to give a nominal transmission of 1%; at this setting, a momentum resolution of ~1.2% was obtained with the 3-mm sources, and a momentum resolution of ~0.6% was obtained with the 1.5-mm source. Decay corrections and Fermi-Kurie analyses were performed with an IBM 704 digital computer. The manner in which the spectrometric measurements were performed was influenced to a considerable degree by the limited number of sources available and by the varying but large amounts of U^{237} present in the sources.

The results contained in the previous report[1] plus the γ-ray spectra observed in the present work indicated that all of the 7.3-min Np^{240} β-ray groups have end-point energies >0.4 Mev, the upper energy limit of U^{240} and U^{237} interference. In Fig. 1 are shown the results of a Fermi-Kurie analysis of that portion of the U^{240}-Np^{240} β-ray spectrum above 0.4 Mev, obtained with a 3-mm source. Four principal components were resolved, with end-point energies of 2.18, 1.60, 1.30, and ~0.65 Mev and intensities of 52, 31, 10, and ~7%, respectively. These results are not significantly different from those obtained in the earlier investigation.[1] However, on the basis of the γ-ray data, we know that several of the observed β-ray groups are composites of two or more groups of similar energy.

Measurements of the portion of the U^{240}-Np^{240} spectrum below 0.4 Mev were arbitrarily limited to the narrow regions between the intense internal-conversion

TABLE I. Internal-conversion electron data obtained with the β-ray spectrometer.

Electron energy (kev)	Assigned shell	Transition energy (kev)	Intensity[a] $\times 10^4$
432.4	K	554.1	19.6±1.5
530.7	L_I	553.8	3.8±0.7
474.8	K	596.5	9.8±1.0
573.3	L_I	596.4	2.0±0.6
636.5	K	758.2	1.8±0.6
694.3	K	816.0	2.2±0.6
736.2	K	857.9	14.0±1.2
835.4	L_I	858.5	2.7±0.6
776.0	K	897.7	1.5±0.7
819.9	K	941.6	3.5±0.7

[a] Area of the conversion line relative to the area of the total Np^{240} β-ray spectrum.

[13] F. H. Schmidt, Rev. Sci. Instr. **23**, 361 (1952).

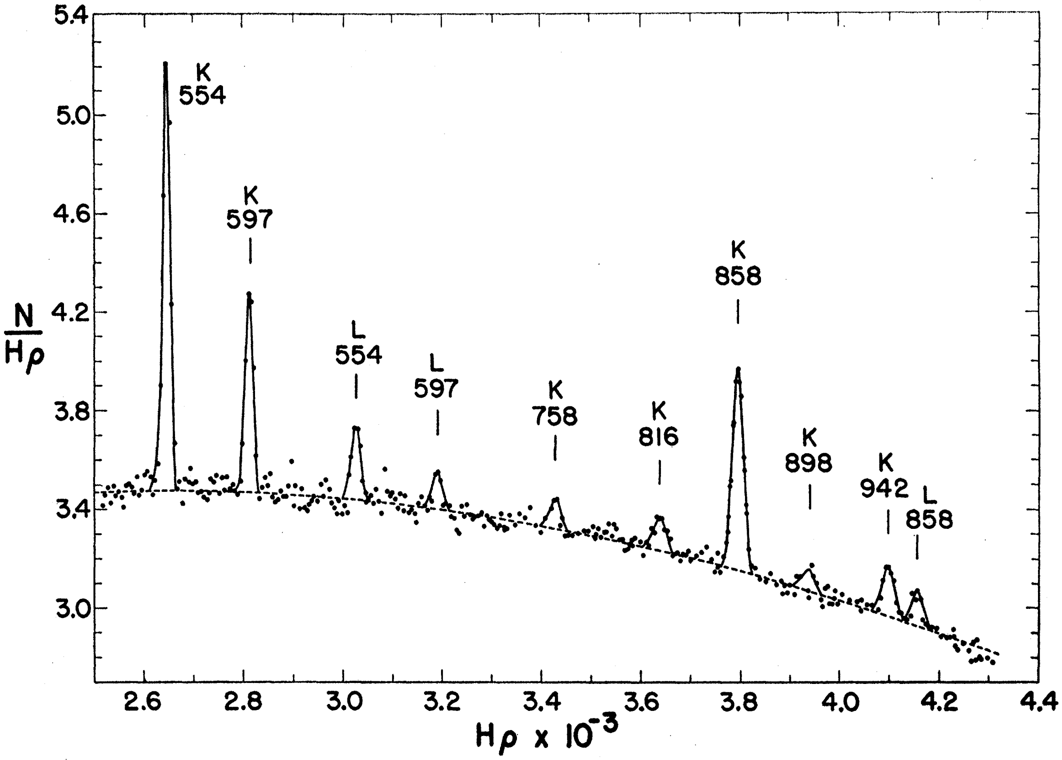

FIG. 2. The portion of the U^{240}-Np^{240} beta spectrum between 0.40 and 0.88 Mev. All of the indicated conversion lines are associated with 7.3-min Np^{240}.

peaks of the U^{237} spectrum. The U^{237} contribution at each point was computed from a second set of measurements performed 10 days after the first set. The U^{240}-Np^{240} spectrum was observed to rise sharply below 0.4 Mev. This intense low-energy distribution, which is attributed to U^{240}, was found to have an end-point energy of 0.36±0.02 Mev. This value is relatively insensitive to the exact shape assumed for that part of the 7.3-min Np^{240} spectrum below 0.4 Mev. Since only a few scattered data points were obtained, it was not feasible to attempt the resolution of other possible lower-energy groups. Compared to these data, the previously-obtained[1] U^{240} β-spectrum data are probably more reliable because of a more favorable U^{240}/U^{237} ratio.

The data obtained with the 3-mm sources revealed the existence of several internal conversion lines in the region above 0.4 Mev. Consequently, a series of higher resolution measurements was undertaken with the 1.5-mm source previously described in an effort to obtain more complete information on the conversion-electron spectrum. A representative set of data is plotted in Fig. 2. The peaks that are labeled in Fig. 2 were observed in every run; the remaining low-intensity peak-like structures are attributed to statistical fluctuations. A summary of the information obtained from these data is given in Table I. The γ-ray scintillation data (Sec. V) were used as a guide to the identity of some of the weaker peaks. All of the peaks are assigned to transitions in Pu^{240}.

IV. 180°-SPECTROGRAPH MEASUREMENTS

The low-energy (<0.4-Mev) region of the internal-conversion electron spectrum of the U^{240}-Np^{240} mixture was examined with 77-gauss and 141-gauss, 180° permanent-magnet spectrographs. These spectrographs, which have a momentum resolution of ~0.25%, have been described previously.[14]

Most of the conversion lines observed were shown to be associated with the decay of U^{237}. However, there were five low-intensity lines, observable in the first few spectrograms, which decayed with a half-life of ~14 hours. The data on these lines are summarized in Table II.

The energies and relative intensities of the lines observed at 20.6 and 24.8 kev leave little doubt that they are the L_{II} and L_{III} lines of the previously reported[2,8–10] 42.9-kev $E2$ transition in Pu^{240}. The energy separation of the 21.6- and 22.4-kev lines suggests that they are the L_I and L_{II} conversion lines of another low-energy transition in either Np^{240} or Pu^{240}. Another argument in favor of L-shell assignment of the 21.6-kev line is that if this relatively strong line were a K line, we believe that at least one of the associated L lines (which would

[14] Mize, Bunker, and Starner, Phys. Rev. **100**, 1390 (1955).

TABLE II. Internal-conversion electron data obtained with permanent-magnet spectrographs.

Electron energy (kev)	Shell assignment	Transition energy (kev)	Relative intensity (visual estimate)
20.6	L_{II} (Pu)	42.9	~2
21.6	L_I (Np)	44.0	~2
22.4	L_{II} (Np)	44.0	~0.5
24.8	L_{III} (Pu)	42.9	~2
38.3	{M_{III} (Pu), M_I (Np)}	{42.9, 44.0}	~1

occur at ~120 kev, in a "line-free" region of the conversion spectrum from U^{237}) would have been observed. If it is assumed, then, that the 21.6-kev line is an L_I line, the M_I line should have been observed since the L_I/M_I ratio is expected to be $\lesssim 4$.[15] The M_I line would occur at either 38.8 or 38.3 kev, depending on whether it is associated with a 44.7-kev transition in Pu^{240} or 44.0-kev transition in Np^{240}. Although a line was indeed observed at 38.3 kev, this energy is identical with that of the M_{III} line of the 42.9-kev transition in Pu^{240}. However, the intensity of the observed 38.3-kev line is estimated to be almost a factor of two higher than the expected intensity of the above M_{III} line, and we believe, therefore, that the observed line is an unresolved doublet. Our low-energy conversion-electron data are therefore consistent with the assumption that a 44.0-kev transition is involved in the $U^{240} \rightarrow Np^{240}$ decay scheme.

It was not possible to observe the M_{II} line of the 42.9-kev transition because of its close proximity (~0.14 kev lower) to the intense L_I line of the 59.57-kev transition of U^{237}.

V. SCINTILLATION MEASUREMENTS

A. Gamma-Ray Spectra

The scintillation detector used to study γ-ray spectra consisted of a 2×2-in. NaI(Tl) crystal mounted on an RCA-6342 photomultiplier tube by the method described by Lazar and Klema.[16] Pulse-height analysis was accomplished with a fast 100-channel pulse-height analyzer (average dead-time ≈72 μsec). Between the source and detector were a β-absorber, consisting of $\frac{1}{2}$ in. of Lucite, and a composite absorber for low-energy photons, consisting of 0.020 in. of lead, 0.035 in. of cadmium, and 0.005 in. of copper. The Pb-Cd-Cu absorber was necessary to reduce the detection sensitivity of the spectrometer for the intense low-energy radiations associated with U^{237}.

TABLE III. Analysis of ungated γ-ray scintillation spectrum of 7.3-min Np^{240}.

Photopeak energy (Mev)	Intensity[a]
0.56	63 ±4
0.60	37 ±4
0.76	3.8±0.5
0.82	5.6±0.7
0.93[b]	10.2±1.1
1.51[b]	9.9±1.0
1.62	2.1±0.3

[a] Normalized to an assumed value of 100 for the sum of the intensities of the 0.56- and 0.60-Mev γ rays.
[b] Too broad to be a "single-component" peak.

The observed γ-ray spectrum of a U^{240}-Np^{240} sample is shown in Fig. 3. A source-to-crystal distance of 35 cm was used. The portion of the spectrum below 0.4 Mev was obscured by the U^{237} spectrum. Analysis of the data of Fig. 3 yielded the results summarized in Table III. Our γ-γ coincidence data indicate that there are several additional γ-ray transitions above 0.4 Mev which were not resolved in the unfolding of the single-crystal spectrum and that some of the peaks listed in Table III result from two or more γ rays of about the same energy.

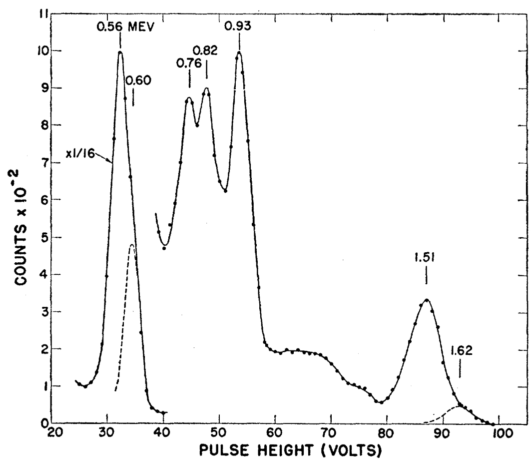

FIG. 3. Gamma-ray scintillation spectrum of a U^{240}-Np^{240} equilibrium source, measured with a 2×2-in. NaI(Tl) crystal.

In order to verify that the entire spectrum of Fig. 3 is associated with the 7.3-min activity, we examined the γ-ray spectrum of a Np^{240} source which had been isolated from U^{240}-Np^{240}-U^{237} sample material by a rapid chemical separation. The γ-ray spectrum (above 0.4 Mev) of this source (which had a uranium/neptunium ratio about 10-fold smaller than that of the parent material) was found to be identical with that shown in Fig. 3 and was observed to decay with a half-life of ~7 min. We therefore conclude that all of the γ rays observed above 0.4 Mev are associated with the decay of 7.3-min Np^{240}. With the above source, an attempt was made to obtain that part of the Np^{240} spectrum below 0.4 Mev by subtraction of the U^{237} contribution. The "difference" spectrum exhibited low-intensity pho-

[15] M. E. Rose, *Internal Conversion Coefficients* (North-Holland Publishing Company, Amsterdam, 1958). The M-shell coefficients given in these tables may be high by as much as a factor of two because of the neglect of screening (M. E. Rose, private communication).

[16] N. H. Lazar and E. D. Klema, Phys. Rev. **98**, 710 (1955).

topeaks at about 0.10, 0.26, and 0.31 Mev, but the relatively poor statistics precluded detailed analysis of these data.

B. Gamma-Gamma Coincidence Experiments

All of the γ-γ coincidence measurements were performed with a "slow" coincidence circuit which has a resolving time of $2\tau = 4\times 10^{-7}$ sec. The two detectors, which were 2×2-inch NaI(Tl) crystals mounted on RCA-6342 photomultiplier tubes, were oriented in a 180° geometry. All of the coincidence spectra were recorded with the 100-channel analyzer.

The γ-ray spectrum in coincidence with L x-rays was measured to show which of the observed γ rays populate the known excited states of Pu^{240} at 0.043 and 0.142 Mev.[8] Both of these levels de-excite predominantly by L electron emission and are believed to be responsible for most of the L x-rays associated with the decay of 7.3-min Np^{240}. In this experiment, the only

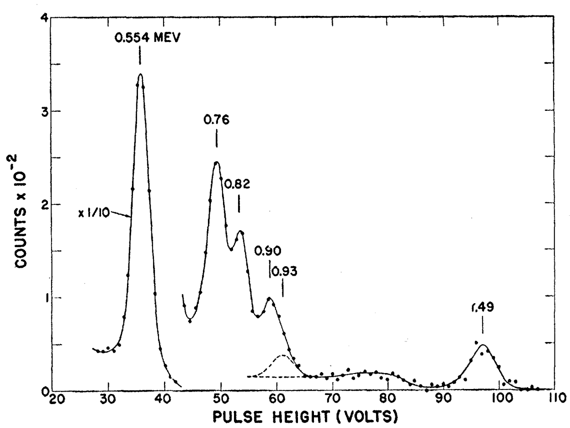

FIG. 4. High-energy portion of the gamma-ray spectrum in coincidence with L x-rays.

absorber interposed between the source and the gate detector was 0.8 gm/cm² of beryllium. An absorber arrangement identical to that described in the previous section was used in front of the analyzer detector. The gate interval corresponded to an energy range of 10–25 kev. The coincidence spectrum obtained is plotted in Fig. 4. Analysis of these data yielded the results given in Table IV.

TABLE IV. Analysis of γ-ray spectrum in coincidence with L x-rays.

Photopeak energy (Mev)	Intensity[a]
0.554	63
0.76	6.7±1.2
0.82	5.0±0.9
0.90	3.1±0.6
0.93	0.8±0.3
1.49	4.5±1.0

[a] Normalized to an assumed value of 63 for the intensity of the 0.554-Mev γ ray (see Table III).

The β-spectrometer and γ-scintillation spectrometer data supported the assumption that the observed 0.554- and 0.597-Mev transitions de-excite a level at 0.597 Mev. To establish which γ transitions populate this level, we examined the γ-ray spectrum in coincidence with pulses which contribute to the (0.554+0.597)-Mev composite photopeak. In this experiment, each NaI(Tl) crystal was shielded with ½ in. of Lucite and a Pb-Cd-Cu composite absorber (Pb thicknesses: 0.020 in. for the "analyzer" detector and 0.065 in. for the "gate" detector). The observed coincidence spectrum, shown in Fig. 5, exhibits photopeaks at 0.21, 0.258, 0.304, 0.51, 0.56, 0.60, 0.82, and 0.94 Mev. Not all of the resolved peaks indicate transitions to the 0.597-Mev level. The peak at 0.21 Mev is the dominant chance-coincidence peak associated with the intense U^{237} spectrum. The peak at 0.51 Mev is attributed to annihilation quanta resulting from pair formation by the ~1.5-Mev γ rays. The peaks at 0.56 and 0.60 Mev result primarily from the presence in the gate spectrum of Compton pulses associated with the 0.82- and 0.94-Mev γ rays. In order to investigate whether the coincidence peaks at 0.258, 0.304, 0.82, and 0.94 Mev actually represent coincidences with the 0.554- and 0.597-Mev transitions or with some other weak transition(s) masked by the (0.554+0.597)-Mev composite photopeak, we performed coincidence experiments in which a narrow gate interval was centered, in turn, on 0.26, 0.30, 0.82, and 0.94 Mev. Each of the resulting coincidence spectra exhibited a peak at ~0.56 Mev which appeared to have the same shape as the (0.554+0.597)-Mev peak observed in the ungated spectrum. These results are interpreted as evidence that each of the above four γ-ray transitions populates the 0.597-Mev level (either directly or indirectly). The fraction of the (0.554+0.597)-Mev γ rays which are coincident with any one of the four indicated γ rays was calculated from (1) the "gate" and "coincidence" counting rates observed in the experi-

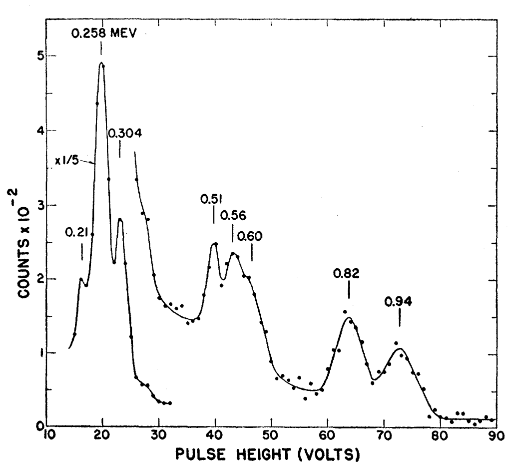

FIG. 5. Gamma-gamma coincidence spectrum. Gate interval 0.47 to 0.64 Mev.

TABLE V. Analysis of γ-ray spectrum in coincidence with the 0.554- and 0.597-Mev γ transitions, from data of Fig. 5.

Photopeak energy (Mev)	Intensity[a]
0.258	5.5±0.8
0.304	2.7±0.4
0.82	1.0±0.2
0.94	1.0±0.2

[a] Normalized to an assumed value of 100 for the sum of the intensities of the 0.554- and 0.597-Mev γ rays.

ment of Fig. 5, and (2) an empirical photopeak efficiency curve for the analyzer crystal in the geometry described. The results are summarized in Table V.

C. Beta-Gamma Coincidence Experiments

Supplementary information regarding the position in the level scheme of certain γ-ray transitions was obtained through β-γ coincidence studies. The β-ray detector was a Pilot Plastic Scintillator-B phosphor, $1\frac{3}{4}$-in. diam$\times\frac{3}{4}$ in. thick, covered with aluminum foil 0.0005 in. thick. Unless otherwise specified, the γ-ray detector was a 2×2-in. NaI(Tl) crystal, shielded with $\frac{1}{2}$ in. of Lucite and a Pb (0.020-in.)-Cd-Cu composite absorber.

No coincidences were observed between β rays of energy >1.8 Mev and photons of energy >0.050 Mev, indicating that the transitions which contribute to the observed 2.18-Mev β-ray group go either to the ground state of Pu^{240} or to a level (or levels) very near the ground state.

It was suspected that the 2.18-Mev group might be a composite of two groups, the ground-state transition and a transition to the known 43-kev state. The intensity ratio of these two postulated β transitions was examined by means of a (β, L x-ray) coincidence experiment. A $1\frac{1}{2}\times1\frac{1}{2}$-in. NaI(Tl) crystal, shielded with $\frac{1}{4}$ in. of Lucite, was used as the low-energy photon detector. The β-ray gate interval was set to extend from 1.78 to 2.30 Mev, so that all gate pulses were associated with the 2.18-Mev group. The observed coincidence spectrum, after correction for chance events, exhibited a prominent photopeak at ~18 kev, which was attributed, on the basis of its energy and shape, to plutonium L x-rays. Numerical analysis of the coincidence data revealed that the total probability of a Np^{240} β ray of energy >1.78 Mev being in coincidence with an L x-ray is ~0.07. Assuming that all of the observed (β, L x-ray) coincidences are associated with the 43-kev transition and using a value of 0.35 for the number of L x-rays emitted per transition, we calculate that the β transition to the 43-kev state is responsible for 22±7% of the intensity of the observed 2.18-Mev group.

A possible interpretation of the data of Table V is that the 0.258- and 0.304-Mev γ rays represent direct transitions to the 0.597-Mev level from levels at 0.855 and 0.901 Mev, respectively, and that the latter two levels are populated predominantly by direct β transitions. This interpretation is supported by the observation of a 1.30-Mev β-ray group and conversion lines corresponding to transition energies of 0.858 and 0.898 Mev. A more direct indication of the position in the level scheme of the 0.258- and 0.304-Mev transitions was obtained from a study of the γ-ray spectrum in coincidence with that portion of the β-ray spectrum between 0.5 and 1.6 Mev. The 0.5-Mev lower-bound setting eliminated interference from U^{237} radiations; the upper-bound setting suppressed interference from the 2.18-Mev β group. The low-energy portion of the coincidence spectrum is shown in Fig. 6. The main features of this spectrum are a strong (0.554+0.597)-Mev composite photopeak, its associated Compton "backscatter" peak at ~0.190 Mev (labeled B), and other peaks at 0.260 and 0.305 Mev. The latter two peaks are assumed to result from the same transitions as those responsible for the 0.258- and 0.304-Mev peaks of Fig. 5. The approximate energies of the principal β groups which precede the 0.260- and 0.305-Mev transitions can be determined from the data of Fig. 6 since we know (1) the "ungated" relative intensities of the 0.260-, 0.305-, and (0.554+0.597)-Mev γ rays (listed in Table V), (2) the variation of β-group "efficiency" of the β channel as a function of β-group end-point energy, and (3) the end-point energy of the principal β group which precedes the 0.554- and 0.597-Mev γ rays (presumably 1.6 Mev). This calculation indicates that the two γ rays in question are each preceded by a β transition of energy ~1.3 Mev, a result consistent with the above proposal that the 0.260- and 0.305-Mev transitions originate, respectively, at levels ~0.86 and ~0.90 Mev above the ground state.

The approximate positions of the levels at which the dominant γ transitions in the 0.7- to 1.0-Mev region originate were studied in a similar β-γ coincidence experiment. The upper bound of the β-ray gate interval was set at 1.4 Mev, and the lower bound was set at

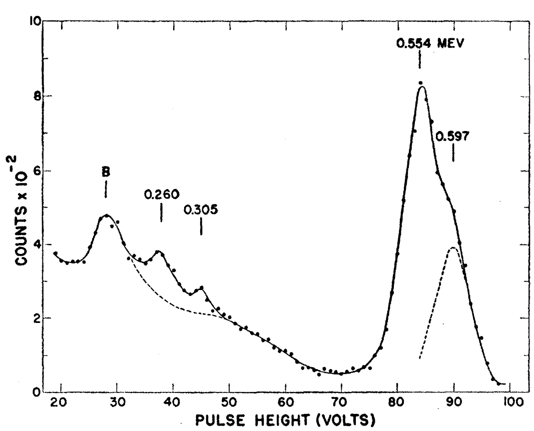

FIG. 6. Low-energy region of the gamma-ray spectrum in coincidence with that portion of the beta-ray spectrum between 0.5 and 1.6 Mev.

0.62 Mev, the approximate maximum energy of direct β transitions to levels at $\gtrsim$1.5 Mev. The coincidence spectrum obtained, shown in Fig. 7, is similar to the corresponding portion of the ungated spectrum except for the expected attenuation of the pulse-height distribution associated with the γ rays above 1.0 Mev. Comparison of the intensities of the peaks in the gated and ungated spectra indicates that all of the principal γ rays with energies between 0.7 and 1.0 Mev are preceded by β transitions with energies between 1.1 and 1.4 Mev. Essentially the same deduction was made from the γ-γ coincidence experiments, which indicate that none of the dominant γ transitions in the (0.7–1.0)-Mev region originates at levels as high as 1.5 Mev.

VI. DISCUSSION OF 7.3-MIN Np^{240} RESULTS

A. Decay Scheme

A decay scheme for 7.3-min Np^{240} consistent with the measurements described above is shown in Fig. 8. The main arguments which support this scheme are presented below.

The existence of levels in Pu^{240} at 42.9 and 141.8 kev is known from studies of the decay of Am^{240} [8] and Cm^{244}.[9,10] Although our coincidence data indicate that both of these levels are populated in Np^{240} decay, we were able to directly observe only the 42.9-kev transition (see Table II); the much weaker 98.9-kev transition, which depopulates the 141.8-kev level,[8] was not detected.

On the sole basis of intensity and energy balance, one is led to the conclusion that the strong 0.56- and 0.60-Mev γ rays observed in the scintillation studies follow the 1.60-Mev β-ray transition. The β-γ and γ-γ coincidence results confirm this hypothesis. The conversion-electron data (Table I) yield the more accurate energies of 0.554 and 0.597 Mev for the above γ-ray transitions. Since these two energies differ by 43 kev, and since the

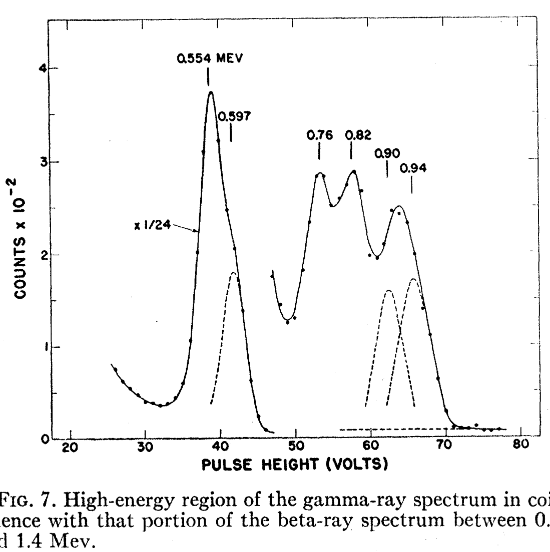

FIG. 7. High-energy region of the gamma-ray spectrum in coincidence with that portion of the beta-ray spectrum between 0.62 and 1.4 Mev.

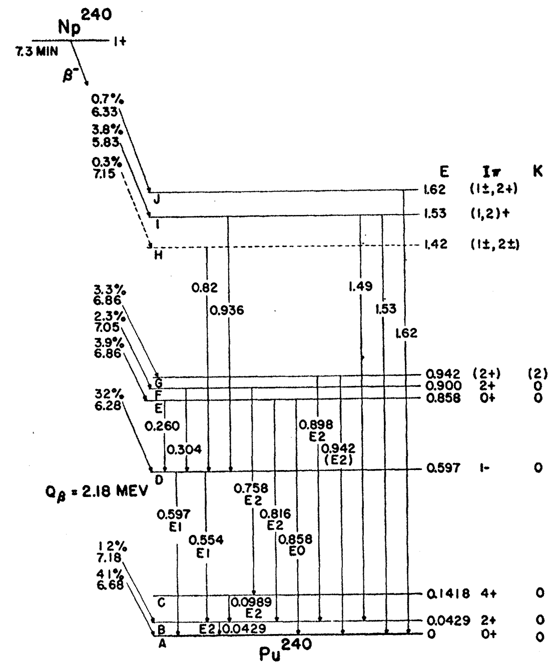

FIG. 8. Decay scheme proposed for 7.3-min Np^{240}.

0.554-Mev γ ray is in strong coincidence with L x-rays but the 0.597-Mev γ ray is not, it is concluded that the 0.597-Mev transition goes to the ground state and that the 0.554-Mev transition proceeds from the indicated 0.597-Mev level to the level at 0.0429 Mev. This portion of the level scheme agrees with that proposed by Stephens *et al.*[2]

We have already shown that the γ-γ coincidence results indicate the existence of a level at $\sim$0.86 Mev. Independent evidence for such a level is provided by the conversion electron data. From intensity considerations, the conversion lines observed at 0.736 and 0.835 Mev must be assigned, respectively, as the K and L lines of a 0.858-Mev transition. However, no evidence was found for this transition in the scintillation measurements. An estimated upper limit for the intensity of 0.858-Mev γ rays is $\sim 1.7\times 10^{-3}$ per disintegration, whereas the corresponding K electron intensity is $\sim 1.4 \times 10^{-3}$. Thus, the K conversion coefficient of the 0.858-Mev transition is $\geq$0.8. The only plausible explanation of this large conversion coefficient is that the multipolarity of the 0.858-Mev transition is electric monopole (E0). We therefore conclude that there is a level at 0.858 Mev with spin and parity 0+.

It appears very probable that the observed 0.76-, 0.82-, and 0.93-Mev photopeaks of Fig. 3 are caused principally by the 0.758-, 0.816-, 0.898-, and 0.942-Mev transitions indicated by the conversion electron data (Table I). Analysis of the 0.93-Mev photopeak into components with energies of 0.898 and 0.942 Mev yields an intensity ratio for the two corresponding γ-ray groups of $I(0.942)/I(0.898)\approx 1.5$. It is then evident, from comparison of the intensity data of Tables III and V, that none of the above four principal transitions populates the 0.597-Mev level; the peaks at 0.82 and 0.94 Mev in the coincidence spectrum of Fig. 5 are instead interpreted as evidence for other relatively weak transitions (*not* identifiable with the 0.816- and 0.942-Mev transitions) which lead to the 0.597-Mev level. These conclusions are confirmed by the β-γ coincidence results. The exact placement of the 0.758-, 0.816-, 0.898-, and 0.942-Mev transitions in the decay scheme is based to a large extent on the results of the (γ, L x-ray) coincidence experiment (see Fig. 4 and Table IV). Any transition which directly populates the 42.9-kev state will have the same intensity (relative to the 0.554-Mev transition) in the L x-ray gated spectrum as in the ungated spectrum; in comparison, a transition which populates the 141.8-kev level should appear to be enhanced by a factor of $\sim$2 in the gated spectrum since the 98.9-kev transition is expected to give rise to almost as many L x-rays (per transition) as does the 42.9-kev transition. Thus, comparison of the intensity data of Tables III and V leads to the following conclusions:

(1) The 0.942-Mev transition is not in sufficiently strong coincidence with L x-rays to be a transition to either the 42.9-kev or 141.8-kev levels; it is therefore postulated to be a ground-state transition from a level at 0.942 Mev.

(2) The (L x-ray, 0.82-Mev) and (L x-ray, 0.90-Mev) coincidence rates are consistent with the assumption that both of these transitions populate the 42.9-kev state. On the basis of the energy sums $0.816+0.043=0.859$ and $0.898+0.043=0.941$, it is assumed that the 0.816- and 0.898-Mev transitions depopulate, respectively, the proposed levels at 0.858 and 0.942 Mev.

(3) The (L x-ray, 0.76-Mev) coincidence rate is consistent with the assumption that the 0.758-Mev transition populates the 141.8-kev level, thus indicating the existence of a level at 0.900 Mev. Additional evidence for a level at this energy is the observation of 0.597-, 0.304-Mev coincidences.

The fact that there is a 1.49-Mev γ ray in coincidence with L x-rays, coupled with the fact that the 1.51-Mev photopeak in the ungated scintillation spectrum is analyzable into two components (of roughly equal intensity) having energies of 1.49 and 1.53 Mev, is consistent with the assumption that there is a level at 1.53 Mev which decays both to the ground state and to the 42.9-kev state. Similarly, since the 1.62-Mev transition is not in coincidence with L x-rays, it is assumed to be the ground-state transition from a 1.62-Mev level.

The γ-γ coincidence results suggest that there is a 0.94-Mev transition which populates the 0.597-Mev level (see Table V). Since this 0.94-Mev transition would necessarily be in coincidence with the 42.9-kev transition, one would expect there to be a 0.94-Mev peak in the L x-ray gated coincidence spectrum. A simple calculation shows that the intensity of this coincidence peak should be $\sim$0.7 (on the intensity scale of Table IV). Since there is a peak at $\sim$0.93 Mev in the (γ, L x-ray) coincidence spectrum which has an intensity of 0.8 ± 0.2, it seems probable that this peak and the 0.94-Mev peak of Fig. 5 are associated with the same transition and that this transition does indeed terminate at the 0.597-Mev level. Also, since the energy difference between 1.53 and 0.597 Mev is 0.933 Mev, it is assumed that the above 0.94-Mev transition depopulates the 1.53-Mev level. Consideration of the available data on the energy of this transition leads to a "best" value of 0.936 ± 0.006 Mev.

For reasons given in Sec. V-B, it is believed that the 0.82-Mev transition of Table V also populates the 0.597-Mev level, suggesting the existence of a level at 1.42 Mev. Since there is no other evidence for this level, it is shown as a dotted line in Fig. 8.

It is evident from the γ-γ coincidence results (see Table V) that the 0.597-Mev level is populated predominantly ($\sim$90%) by the 1.60-Mev β-ray group. Since the intensity of this β group is well defined ($\pm$6%) by the Fermi-Kurie analysis, the sum of the intensities of the 0.554- and 0.597-Mev transitions (per β disintegration) can be determined within narrow limits, thus permitting expression of all γ-ray intensities in terms of γ rays per disintegration.

A summary of the γ-ray transition data is presented in Table VI. The tabulated photon intensities are our estimated "best" values and do not necessarily represent the results obtained in a specific experiment. From the data of Table VI and the proposed level scheme, it is evident that the observed 1.30- and 0.65-Mev β-ray groups are each composites of several groups of similar energy. A list of all the observed and indicated β-ray groups is given in Table VII. The intensities of those groups with energies <1.6 Mev are based on the γ-ray intensity data. It is noteworthy that the sum of

TABLE VI. Transitions in Pu^{240} which follow the decay of 7.3-min Np^{240}.

Energy (Mev)	Transition	Photon intensity[a]	K conversion coefficient $\times 10^2$ Exptl.	K conversion coefficient $\times 10^2$ Theor.[b]	Assigned multipolarity	Total estimated transition intensity[a]
0.0429	*BA*	···	···	···	*E*2	39 ±5
0.0989[c]	*CB*	···	···	···	*E*2	1.3 ±0.2
0.260	*ED*	1.9 ±0.3	···	4.3	*E*1	2.0 ±0.3
0.304	*FD*	0.9 ±0.2	···	3.1	*E*1	0.9 ±0.2
0.554	*DB*	21.4 ±1.5	0.92 ±0.09	0.94	*E*1	21.6 ±1.5
0.597	*DA*	12.6 ±1.4	0.78 ±0.12	0.81	*E*1	12.7 ±1.4
0.758	*FC*	1.3 ±0.2	1.4 ±0.5	1.50	*E*2	1.3 ±0.2
0.816	*EB*	1.6 ±0.3	1.4 ±0.5	1.32	*E*2	1.6 ±0.3
0.82	*HD*	0.3 ±0.1	···	(0.45)	(*E*1)	0.3 ±0.1
0.858	*EA*	<0.17	>80		*E*0	0.14 ±0.01
0.898	*GB*	1.2 ±0.3	1.2 ±0.7	1.16	*E*2	1.2 ±0.3
0.936	*ID*	0.3 ±0.1	···	(0.36)	(*E*1)	0.3 ±0.1
0.942	*GA*	1.9 ±0.5	1.8 ±0.7	0.94	*E*2	1.9 ±0.5
1.49	*IB*	1.5 ±0.3	···	(0.46)	(*E*2)	1.5 ±0.3
1.53	*IA*	1.9 ±0.5	···	(0.44)	(*E*2)	1.9 ±0.5
1.62	*JA*	0.7 ±0.1	···	(0.40)	(*E*2)	0.7 ±0.1

[a] Per 100 disintegrations.
[b] Values obtained from the tables of L. A. Sliv and I. M. Band, Leningrad Physico-Technical Institute Report, 1956 [translation: Report 57 ICC K1, issued by Physics Department, University of Illinois, Urbana, Illinois (unpublished)] for the multipolarities shown in the next column.
[c] Not observed in the present experiments.

TABLE VII. Beta-ray transitions of Np^{240}.

Observed groups[a]		Postulated transitions[b]			
End-point energy (Mev)	Intensity (%)	End-point energy (Mev)	Intensity (%)	Logft	I, π final state
2.18±0.02	52±3	2.18 2.14	41 ±5 12 ±4	6.68 7.18	0+ 2+
1.60±0.03	31±2	1.60	32 ±2	6.28	1−
1.30±0.05	10±1	1.32 1.28 1.24	3.9±0.5 2.3±0.3 3.3±0.5	6.86 7.05 6.86	0+ 2+ (2+)
0.65±0.10	7±3	0.76 0.65 0.57	0.3±0.1 3.8±0.5 0.7±0.1	7.15 5.83 6.33	(1±, 2±) (1, 2)+ (1±, 2+)

[a] Deduced from Fermi-Kurie analysis of the β spectrum.
[b] Deduced from analysis of γ-ray spectra.

the intensities of the component groups which contribute to the 1.30-Mev "group" is in good agreement with the corresponding intensity deduced from the Fermi-Kurie plot. The fact that the Fermi-Kurie analysis yields a greater intensity for the 0.65-Mev "group" than that indicated by the γ-ray data is attributed to the detection of degraded β particles from the higher-energy groups.

Our "best" value for the β-decay energy of 7.3-min Np^{240} is 2.18±0.02 Mev.

B. State Assignments and Transition Probabilities

States B and C have been previously identified[8] as the 2+ and 4+ levels, respectively, of the ground-state rotational band.

The measured K conversion coefficients of the 0.554- and 0.597-Mev transitions, 9.2×10^{-3} and 7.8×10^{-3}, respectively, indicate that both transitions are of $E1$ multipolarity (theoretical conversion coefficients[17] for a 0.554-Mev transition at $Z=94$: $\alpha_1^K=9.4\times10^{-3}$, $\alpha_2^K=2.6\times10^{-2}$, $\beta_1^K=1.8\times10^{-1}$). Therefore, level D has a spin and parity of 1−. For a state of spin 1, the quantum number K of the unified model[18–20] can have possible values of 0 or 1. If $K=0$, the theoretical[20] value for the ratio of the reduced transition probabilities of the γ-ray transitions to the 0+ and 2+ states turns out to be $B(E1;\,1-\rightarrow0+)/B(E1;\,1-\rightarrow2+)=0.5$. For $K=1$, this ratio is 2.0. In the present case, the experimental value for the reduced transition probability ratio is $B(E1;\,0.597)/B(E1;\,0.554)=0.47\pm0.05$. Thus, level D is clearly a $K=0$ state. A 1−, $K=0$ state occurs in Pu^{238} at an energy of 0.605 Mev.[21] It has been suggested[22,23] that these 1− levels correspond to octupole vibrational states.

The 0+ assignment for level E has already been discussed. It seems probable that this state corresponds to the Bohr-Mottelson[19] β-vibrational excitation with quantum numbers $n_\beta=1$, $n_\gamma=0$, and $K=0$. There is evidence that such a state occurs in Pu^{238} at 0.935 Mev,[21] in U^{234} at 0.803 Mev,[10] and in Th^{232} at 0.74 Mev.[24–26]

On the basis of the logft values of the β branches to levels A, B, and D (Table VII), 7.3-min Np^{240} obviously has a spin of 1. It then follows from the logft values of the β branches to states F, G, H, I, and J that these states all have spin values ≤2. Consequently, if transition FC is of $E2$ multipolarity, as seems indicated by its K conversion coefficient, the spin and parity of state F is 2+. Since the energy difference between states E and F is ~42 kev, which is very close to the (0+)-(2+) spacing of the ground-state rotational band, level F is tentatively interpreted as the 2+ member of the rotational band based on level E. The fact that transitions FD and FC have comparable intensities is consistent with the proposed $K=0$ character of state F, but would not be consistent with a $K=2$ assignment. On the other hand, there is considerable lack of agreement between the experimental and theoretical reduced transition probability ratios for the transitions from state F to the ground-state rotational band (see Table VIII). We recognize that this apparent disagreement could be the result of misinterpretation of our experimental data; however, we have not been able to arrange an alternative decay scheme which is consistent with all of the present experiments. A possible explanation of the above anomalous transition probability ratios is that state F has admixed components with $K\neq0$.

The 0.942-Mev transition proceeds to the ground state and must therefore be a pure multipole. However, our measured value for the K conversion coefficient of this transition is $(1.8\pm0.7)\times10^{-2}$, whereas the two

TABLE VIII. Reduced transition probability ratios for $E2$ deexcitation of the 0.900- and 0.942-Mev states of Pu^{240}.

Initial state $I\pi$, K	Transitions compared	Relative reduced transition probabilities	
		Theoretical[a]	Experimental
2+, 0	$FC/FB/FA$	2.57/1.43/1	2.6/<0.2/<0.2
2+, 2	$GC/GB/GA$	0.07/1.43/1	<0.12/0.8/1

[a] A. Bohr and B. R. Mottelson, in *Beta- and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (Interscience Publishers Inc., New York, 1955), Chap. XVII, p. 482, Eqs. (13) and (14).

[17] L. A. Sliv and I. M. Band, Leningrad Physico-Technical Institute Report, 1956 [translation: Report 57ICCK1, issued by Physics Department, University of Illinois, Urbana, Illinois (unpublished)].
[18] A. Bohr, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **26**, No. 14 (1952).
[19] A. Bohr and B. R. Mottelson, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **27**, No. 16 (1953).
[20] Alaga, Alder, Bohr, and Mottelson, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **29**, No. 9 (1955).
[21] I. Perlman and J. O. Rasmussen, *Handbuch der Physik*, edited by S. Flügge (Springer-Verlag, 1957), Vol. 42, p. 195.
[22] R. F. Christy (private communication), reported in Bohr, Froman, and Mottelson, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **29**, No. 10 (1955).
[23] R. Sheline, Proceedings of the University of Pittsburgh Conference on Nuclear Structure, June, 1957 (unpublished).
[24] Alder, Bohr, Huus, Mottelson, and Winther, Revs. Modern Phys. **28**, 432 (1956).
[25] F. K. McGowan and P. H. Stelson, Bull. Am. Phys. Soc. Ser. II, **2**, 207 (1957).
[26] E. M. Bernstein, Bull. Am. Phys. Soc. Ser. II, 4, 9 (1959).

nearest theoretical[17] pure-multipole coefficients are $\beta_1^K=4.3\times10^{-2}$ and $\alpha_2^K=0.94\times10^{-2}$. This apparent disagreement has not been satisfactorily explained. Since the experimental K conversion coefficient is closest to the theoretical $E2$ value, transition GA is presumed to be pure $E2$. Consequently, level G is assigned as 2+. This state possibly represents the Bohr-Mottelson[19] γ-vibrational excitation with quantum numbers $n_\beta=0$, $n_\gamma=1$, and $K=2$; the fact that such states have been found in other heavy-element even-even nuclei at $\sim$1 Mev[21,27–30] provides support for this assignment. It is noted (see Table VIII) that the γ branching to the ground-state rotational band does not strictly conform to the theoretical ratios which apply if we assume that level G is a $K=2$ state. This apparent discrepancy may be an indication that level G is not a pure $K=2$ vibrational state.

We have no experimental evidence which points unambiguously to a definite spin and parity for any one of the upper three levels (H, I, and J). The possible choices are shown in Fig. 8.

C. Further Discussion of the 0.858-Mev $E0$ Transition

The magnitude of the electric monopole "strength parameter," ρ,[31,32] associated with transition EA can be estimated from the competition between this transition and transition EB. Transition EB is presumably a collective vibrational transition between a member of the $n_\beta=1$ rotational band and the $n_\beta=0$ (ground-state) band. Such transitions are expected to have transition probabilities larger than for a particle transition, but smaller than for a rotational transition.[33] This prediction has been confirmed experimentally through Coulomb excitation of the 0.790-Mev level of Th^{232},[25] believed to be the 2+ member of the $K=0$, $n_\beta=1$ rotational band.[25,26,34] If the Th^{232} results are accepted as a guide to vibrational transition probabilities in the heavy element region, it would seem reasonable to assume that the value of the reduced transition probability of transition EB lies somewhere between 10 and 50 times the single-particle (or "Weisskopf"[35]) estimate.[36] The corresponding range of values of ρ for transition EA, based on the monopole conversion probability calculations of Church and Weneser[32] and our observed ratio of emission probabilities, $W_K(0.858)/W_\gamma(0.816)=0.091$, is $0.13<\rho<0.30$. It has been predicted[32] that the value of ρ for zero-zero β-vibrational transitions should be $\sim$0.2. Recently, in Coulomb excitation experiments on Th^{232},[26] Bernstein has found a value for ρ of $\sim$1/13 in the case of a 0.74-Mev ($E2+E0$) transition which is believed to be of β-vibrational character.

The observed K/L ratio, 5.2 ± 1.2, for transition EA is in reasonable agreement with the theoretical[32] ratio of $\sim$4.8 (for a monopole transition of energy 0.858 Mev).

VII. DISCUSSION OF U^{240} RESULTS

The intense 0.36-Mev β-ray group is believed to represent the direct β transition from U^{240} to 7.3-min Np^{240}. Association of this group with the decay of 7.3-min Np^{240} would imply strong population of a 1.82-Mev level of Pu^{240}, in obvious disagreement with the γ-ray data. Aside from the 0.36-Mev β group, the only other radiations observed to accompany the decay of U^{240} are the conversion lines associated with a 44.0-kev transition in Np^{240} (see Sec. IV). Fortunately, it is possible to estimate the intensity of this transition from the conversion electron spectrum. The observed L-subshell ratios for the 44.0-kev transition, estimated visually to be $L_{\rm I}:L_{\rm II}:L_{\rm III}=4:1:<0.5$, are consistent only with a multipolarity assignment of $M1+E2$.[37,38] Consequently, we can compare the intensities of the 44.0-kev (Np^{240}) and 42.9-kev (Pu^{240}) transitions by comparing the relative intensities of their L-shell spectra, since in both cases L conversion should account for approximately the same fraction ($\sim$75%) of the transition intensity.[15] Thus, from the data of Table I, it appears that the 44.0-kev transition is slightly more than half as strong as the 42.9-kev transition, which means that it is involved in about 25% of the U^{240} disintegrations. We therefore tentatively propose the decay scheme for U^{240} shown in Fig. 9. Our data on the U^{240} β-ray spectrum are too meager to prove or disprove the existence of a 0.32-Mev β-ray group of 25% intensity.

Since the ground state of U^{240} is surely 0+, the logft value (5.7) of the 0.36-Mev β transition suggests a positive parity assignment for 7.3-min Np^{240}, shown above to have $I=1$. If this 1+ assignment is correct, then it is evident that 1+ is the only spin and parity

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[27] It has been proposed that the 1.030-Mev level of Pu^{238} (see references 21, 28, and 29) and the 0.965-Mev level of Th^{228} (see reference 30) are $K=2$, γ-vibrational states.

[28] Rasmussen, Slätis, and Passell, Phys. Rev. **99**, 42 (1955).

[29] Rasmussen, Stephens, Strominger, and Åström, Phys. Rev. **99**, 47 (1955).

[30] Bjørnholm, Nathan, Nielsen, and Sheline, Nuclear Phys. 4, 313 (1957).

[31] In the notation of Church and Weneser (reference 32), the absolute transition probability for $E0$ conversion, W, is written as $W=\Omega\rho^2$, where Ω is the reduced monopole conversion probability and ρ is a nuclear "strength parameter."

[32] E. L. Church and J. Weneser, Phys. Rev. **103**, 1035 (1956).

[33] See reference 19, p. 110.

[34] See reference 24, p. 540.

[35] V. F. Weisskopf, Phys. Rev. **83**, 1073 (1951).

[36] The transitions in Th^{232} analogous to transitions FA, FB, and FC were found to be faster than single-particle transitions by factors of 5, 10, and 8.5, respectively (reference 25). The enhancement factor for the Th^{232} analog of transition EB is expected theoretically (reference 20) to be related to the above factors through the ratios $EB:FA:FB:FC=5:1:1.43:2.57$.

[37] The theoretical $L_{\rm I}:L_{\rm II}:L_{\rm III}$ ratios (reference 38) for a 44.0-kev low-multipole transition, $Z=93$, are approximately 0.9:1:1.1 for $E1$, 0.04:1:0.8 for $E2$, 8:1:0.05 for $M1$, and 14:1:6 for $M2$.

[38] L. A. Sliv and I. M. Band, Leningrad Physico-Technical Institute Report, 1956 [translation: Report 58ICCL1, issued by Physics Department, University of Illinois, Urbana, Illinois (unpublished)].

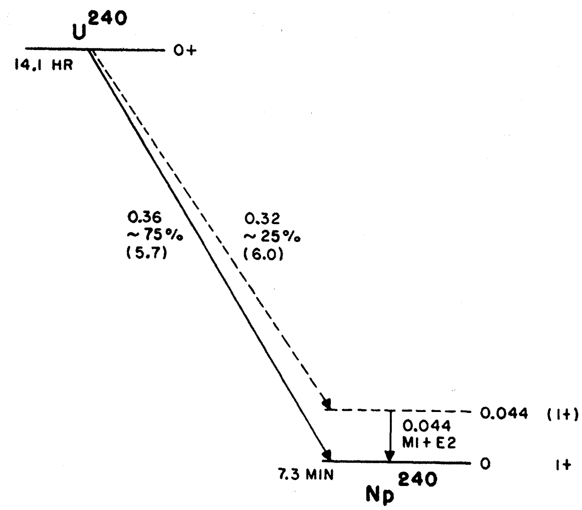

FIG. 9. Decay scheme proposed for U^{240}.

assignment for the 44.0-kev state which is consistent with both the log*ft* value (~6.0) of the hypothetical 0.32-Mev β transition and the $M1+E2$ character of the 44.0-kev transition.

The most reasonable choice of Nilsson orbitals[39,40] which when coupled according to the extension[41] of Nordheim's[42] rules to deformed nuclei, yields a spin and parity of 1+ for Np^{240} are $5/2+(642+)$[43] for the odd proton and $7/2+(624-)$ for the odd neutron. Thus, the asymptotic classification [39,44] of the 0.36-Mev (U^{240}) and 2.18-Mev (7.3-min Np^{240}) β transitions is probably "allowed, hindered," which provides at least a partial explanation of the relatively high *ft* values of these two allowed transitions.

It is noted that several of the reasonable combinations of Nilsson orbitals for 93 protons and 147 neutrons would be expected to yield high spins, e.g., the coupling of a $5/2+(642+)$ proton and a $5/2+(622+)$ neutron would presumably result in a $(\leq 5)+$ state, and the coupling of a $5/2-(523-)$ proton and a $7/2+(624-)$ neutron would yield a $(\leq 6)-$ state. The 63-min isomeric state of Np^{240} may be attributable to one of these combinations. It seems probable that this state has a spin ≥ 2 because there is no evidence that it is formed in the decay of U^{240}. Since the isomeric transition has not been observed and since the Np^{240} (63-min) decay scheme is not well established, it is not yet clear whether the 7.3-min isomer or the 63-min isomer is the ground state.

ACKNOWLEDGMENTS

We wish to express our appreciation to Dr. K. W. Ford for helpful discussions concerning some of the theoretical aspects of this problem. We also wish to thank Mr. R. F. Chavez for extensive assistance in the computation and plotting of data, and Mrs. H. L. Smith for assistance in preparation of some of the source material.

[39] S. G. Nilsson, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **29**, No. 16 (1955); B. R. Mottelson and S. G. Nilsson, Phys. Rev. **99**, 1615 (1955) and Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. (to be published). A recent Nilsson energy-level diagram (for the heavy-element region) is shown in reference 40.

[40] J. M. Hollander, Phys. Rev. **105**, 1518 (1957).

[41] C. J. Gallagher, Jr., and S. A. Moszkowski, Phys. Rev. **111**, 1282 (1958).

[42] L. A. Nordheim, Revs. Modern Phys. **23**, 322 (1951).

[43] The notation used here is $\Omega\pi(Nn_z\Lambda\pm)$, the symbols being defined in reference 40 and the $\pm$ indicating the appropriate sign in the relation $\Omega=\Lambda\pm\frac{1}{2}$.

[44] G. Alaga, Phys. Rev. **100**, 432 (1955); Nuclear Phys. **4**, 625 (1957).