IDENTIFICATION AND CHARACTERIZATION OF 3.8 min $^{134\,m}$I

C. D. CORYELL[†], H. N. ERTEN[††], P. K. HOPKE[†††] and W. B. WALTERS[§]

Arthur A. Noyes Nuclear Chemistry Center[§§], Massachusetts Institute of Technology, Cambridge, Massachusetts, USA

and

R. DAMS[§§§] and H. C. GRIFFIN

University of Michigan, Ann Arbor, Michigan, USA

Abstract: The γ-ray spectra of iodine fractions rapidly separated from the products of slow neutron fission of ^{235}U were studied. A 3.8 ± 0.2 min species was found and was identified as $^{134\,m}$I from observations of corresponding growth in the intensities of the prominent 847 and 884 keV γ-rays of 53 min ^{134}I. This isomer is analogous to the 2.9 h isomer $^{134\,m}$Cs and decays by the sequence $^{134\,m}$I $(J^\pi = 8^-) \xrightarrow{\text{E3}} (J^\pi = 5^+) \xrightarrow{\text{M1}} {}^{134}$I $(J^\pi = 4^+)$ by transitions of 271.9 ± 0.2 keV $(t_{\frac{1}{2}} = 3.8$ min; $\alpha_{\rm K} < 0.3)$ and 44.4 ± 0.1 keV $(t_{\frac{1}{2}} < 10$ ns; $\alpha_{\rm K} < 7)$, respectively. For a 316 keV cross-over γ-ray an upper limit of 1 % was obtained, and is near the intensity predicted by M4 systematics. A low-intensity γ-ray of 234.3 ± 0.5 keV was found. This γ-ray is interpreted as evidence for β-decay (2 %) of the isomer, possibly to the 0.29 sec 7^- isomeric level in ^{134}Xe.

1. Introduction

The short-lived halogen fission products have been studied by many workers, including Sugarman[1], Perlow and Stehney[2], Johnson and O'Kelley[3], Denschlag and Gordus[4], and Lundán and Siivola[5]. The decay of 53 min ^{134}I in particular has been widely studied[6–10]. The ^{134}I sources used in those studies were obtained by milking iodine from fission-product 42 min ^{134}Te. This method of preparation would not yield an appreciable amount of any high-spin isomer as the β-decay of 0^+ ^{134}Te is not known to populate even the 5^+ level at 44 keV discovered in this study.

In the course of studies of the γ-ray spectra of short-lived fission product iodine activities, evidence was obtained[11] for a 3.8 min isomer of ^{134}I. These studies revealed that the predominant mode of decay leads to 53 min ^{134}I and involves γ-rays of 272

[†] Deceased, January 7, 1971.
[††] On leave from Middle East Technical University, Ankara, Turkey.
[†††] Present address: Department of Chemistry, State University College, Fredonia, New York 14063.
[§] Present address: Department of Chemistry, University of Maryland, College Park, Maryland 20742.
[§§] Supported in part by Atomic Energy Commission under Contract AT(30-1)-905.
[§§§] Present address: University of Gent, Gent, Belgium.

and 44 keV as well as iodine K X-rays. It appears that failure to identify this isomer in the previous studies of γ-ray spectra of short-lived isotopes of iodine resulted from the assumption that the 273 keV γ-ray is associated with the decay of 3.9 min ^{137}Xe. However, Holm [12]) has made a detailed study of the decay of ^{137}Xe and did not find a γ-ray near 272 keV, even in low intensity.

Delucci et al. [13]) have suggested that the non-Gaussian charge dispersion of the $A = 134$ isobars produced in the fission of ^{235}U could be explained by the existence of isomers in ^{134}Sb or ^{134}I if the postulated isomer decayed largely by β^- decay. Our initial studies of $^{134\,m}$I and the results of independent work by Carraz, Blachot, Monnand, and Moussa [14]) failed to reveal a β^- branch in the decay of the isomer. Therefore we attempted to obtain more detailed information on this decay scheme, with particular attention to the possibility of β-decay and the relative independent yields in fission of the ground and metastable states.

Iodine samples rapidly separated from the thermal-neutron fission products of ^{235}U contain a mixture of iodine nucleides and their daughter nucleides. The pertinent species are indicated in fig. 1. Iodine isotopes with mass numbers below 134 have long half-lives and are not observed because they are not formed directly in fission in high yield. Those with mass numbers above 137 have very short half-lives. The main species observed are short-lived activities with half-lives of 45 sec, 83 sec, 3.8 min ($^{134\,m}$I), and 53 min ($^{134\,g}$I). The 83 sec species is ^{136}I, studied by Johnson and O'Kelley [3]), and by Lundan and Siivola [5]). The 45 sec species has generally been characterized as an isomer of ^{136}I [ref. [5])]. Initially [11]) we had inferred that this species was a high-spin isomer with mass number greater than 135, possibly an odd-mass I isomer. We subsequently confirmed [15]) the Lundan and Siivola assignment as an isomer of ^{136}I.

If we take the absence of $^{134\,m}$I among the products of the decay of ^{134}Te as evidence for relatively high spin for this isomer, and if we assume the long half-life of the isomer implies a spin at least 3 units higher or lower than the 4^+ ground state of ^{134}I, we conclude that the isomer has spin ≥ 7. Therefore β-transitions of observable intensity to ^{134}Xe would be limited to transitions to states with spins ≥ 5. Because of the large β-decay energy of $^{134\,m}$I (4.15 MeV), many levels of high spin may be accessible to β-decay of the isomer, but few high-spin states are known. However, a likely candidate for such a state is the 7^- two-neutron isomer identified by Winn and Clark [16]). This isomer is reported to decay by a cascade of γ-rays, the first of which has an energy of 233 ± 1.5 keV, and is not populated in the decay of $^{134\,g}$I [ref. [10])]. Therefore we have sought a γ-ray of about this energy in the decay of $^{134\,m}$I.

2. Experimental methods and results

2.1. SOURCE PREPARATION

The I samples were isolated rapidly from the products of slow-neutron fission of ^{235}U. Separations employing distillation and solvent extraction were used. The

distillation method was based on the procedure of Op de Beeck and Walters [17]). The solvent extraction method used the nitrite oxidation and sulfite reduction steps of Campbell and Brady [18]). Although some contamination was found in samples prepared by the distillation method, no contaminants were found in samples prepared by solvent extraction followed by precipitation and filtration of AgI. Final samples consisted of aqueous solutions (for study of γ-rays of 200–400 keV), extracts of I_2 in toluene based scintillator (β-γ anticoincidence studies), or filtered precipitates of AgI or AgBr(I). The AgBr(I) samples contained only small amounts ($< 500 \,\mu g$) of I to permit the study of iodine K X-rays without interference from fluorescence of the bulk material.

For measurements of low-intensity transitions in the decay of the isomer, the timings of the various steps in the separations were chosen to enhance the purity of the 3.8 min ^{134m}I relative to the other iodine activities and xenon daughters. The pertinent genetic relations are given in fig. 1. In order to minimize the activity of 53 min ^{134}I,

SOME IODINE FISSION PRODUCTS

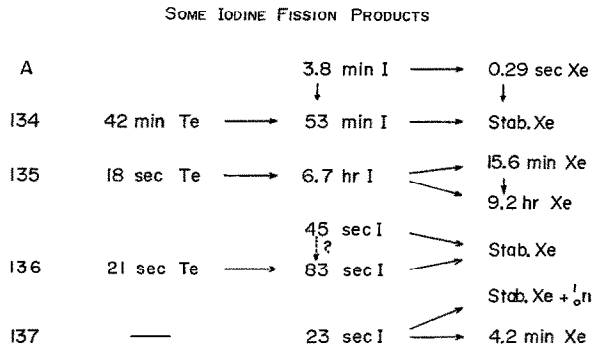| A | | 3.8 min I ⟶ 0.29 sec Xe |
134	42 min Te ⟶	53 min I ⟶ Stab. Xe
135	18 sec Te ⟶	6.7 hr I ⟶ 15.6 min Xe ↓ 9.2 hr Xe
136	21 sec Te ⟶	45 sec I ⟶ 83 sec I ⟶ Stab. Xe
137	—	23 sec I ⟶ Stab. Xe + $^1_0$n 4.2 min Xe

Fig. 1. Some iodine fission products observed in rapidly separated iodine samples.

the initial isolation of I from fission products was made soon after a short irradiation, typically within 1 min after a 20 sec irradiation. The precipitation and filtration steps were delayed (≈ 4 min after irradiation) to minimize the amount of 4.2 min ^{137}Xe in the final sample. In order to determine contributions from species other than ^{134m}I, the timings were varied in a variety of additional measurements.

2.2. SINGLE DETECTOR MEASUREMENTS

Evidence for an isomeric state in ^{134}I was obtained from the time dependence of the intensity of the major γ-rays of 53 min ^{134}I in samples of I isolated from a fresh mixture of fission products. An example of the growth and decay curve observed for the 847 keV γ-ray is shown in fig. 2. The data were obtained from a series of γ-ray spectra observed with a 26 cm^3 Ge(Li) detector. The growth portion corresponds to
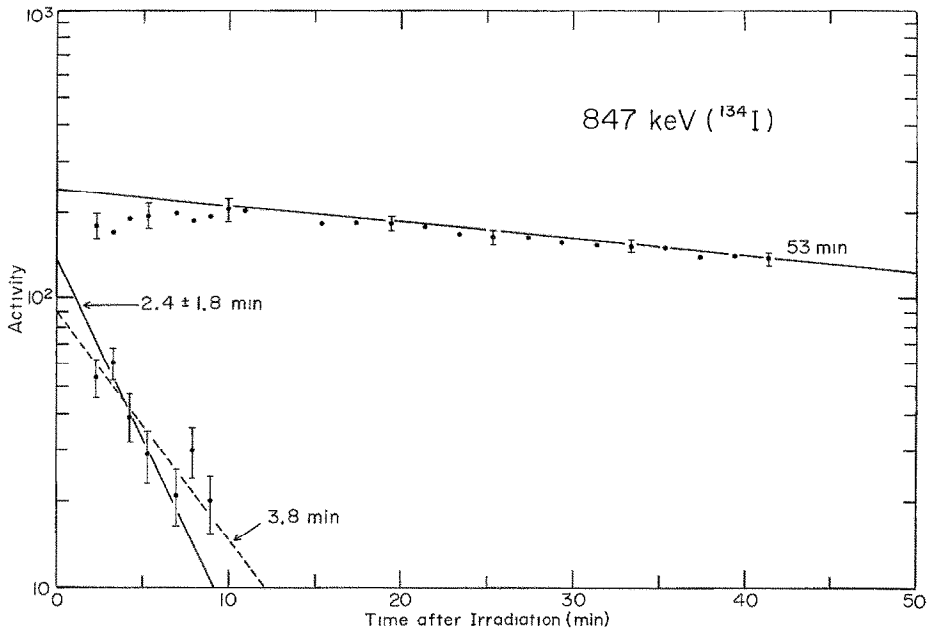
Fig. 2. The growth and decay curve of the 847 keV γ-ray belonging to the decay of ^{134}I isomers, observed with a 26 cm^3 Ge(Li) detector.

a 2.4 ± 1.8 min precursor. The large uncertainty in the half-life results from time-dependent pile-up losses from the spectral peaks and the relatively small intensity of the growth component. However this half-life is, within experimental uncertainties, in agreement with the 3.8 ± 0.2 min half-lives (see fig. 3) observed for iodine K X-rays and γ-rays of 44 and 272 keV observed in similar spectra. These data suggest the isomer decays by an isomeric transition of 44 or 272 keV, or possibly by a highly converted transition which was not detected.

Confirmation of the identification of the 3.8 min activity as an isotope of I was obtained by chemical means. When xenon was extracted into cold CCl$_4$ from an aqueous sulfite solution of fission product I, only ^{137}Xe and small amounts of ^{135m}Xe were observed. Performing a second purification cycle on the isolated I fraction failed to change the ratios of the activities of the 3.8 min component and ^{134g}I. The 3.8 min component could not be detected in the I fraction isolated from fission products 30 min after fission. This last result indicates that this component is not produced to an appreciable extent in the decay of a Te isotope with mass number less than 135.

During the study of ^{134m}I several different detectors were used. These detectors included Ge(Li) detectors with sizes of from 0.4 to 45 cm^3 and a Si(Li) detector. The most useful spectra were obtained with a 1 cm^3 high-resolution Ge(Li) detector. A typical spectrum obtained with this detector is given in fig. 4. All of the features of
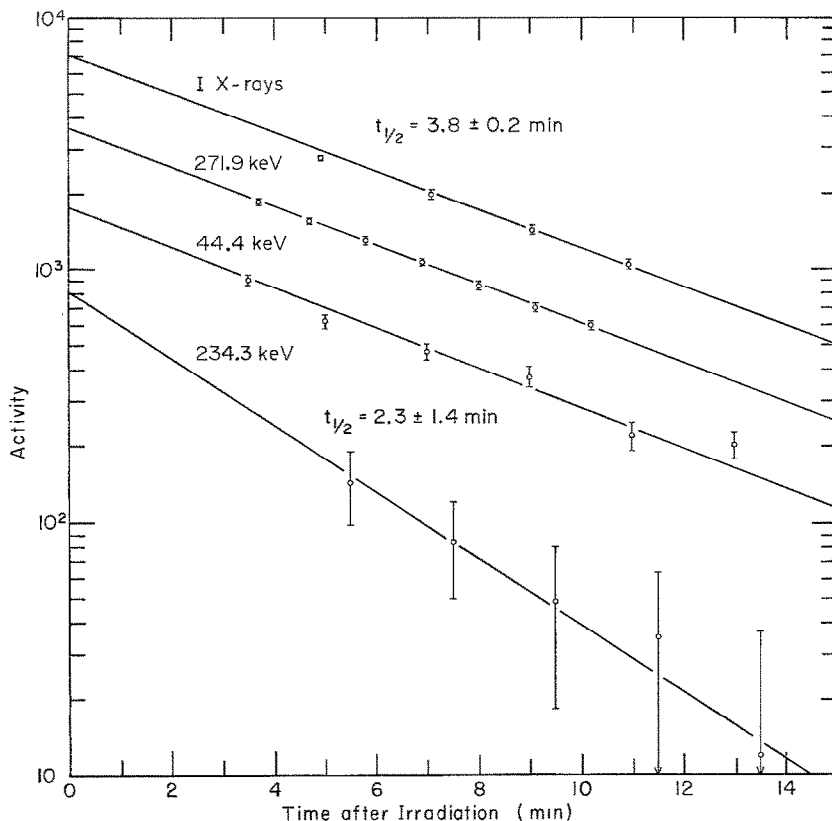
Fig. 3. Decay curves for iodine X-rays, 44.4, 271.9 and 234.3 keV γ-rays observed with 0.4 and 26 cm³ Ge(Li) detectors.

these spectra can be identified with isotopes of I or their Xe daughters. In addition to the prominent radiations of ^{134m}I, namely the iodine K X-rays and γ-rays of 44.4 and 271.9 keV, a low-intensity γ-ray of 234.3$\pm$0.5 keV can be seen. The intensities of this γ-ray in several spectra of this type indicate that the parent nucleide has a half-life of between 2.5 and 5 min. However the uncertainty in the half-life indicated the need for additional data in order to assign this transition to the decay of ^{134m}I. The intensity of the 234 keV γ-ray was obtained by analyzing the broad peak at about 235 keV as a doublet consisting of a 3.8 min 234.3 keV component and a 53 min 235.3 keV component. This intensity was found to be 2.0$\pm$0.8 relative to 100 for the 271.9 keV γ-ray; this result is not sensitive to the assumed energies.

The time dependence of the intensities of the iodine K X-rays appeared to follow a pure 3.8 min half-life. No evidence for 45 sec or 85 sec components was obtained. The intensities of the Xe X-rays were much more complex, although a detailed analysis was not made. In spectra obtained within two min of the end of the irradiation, the
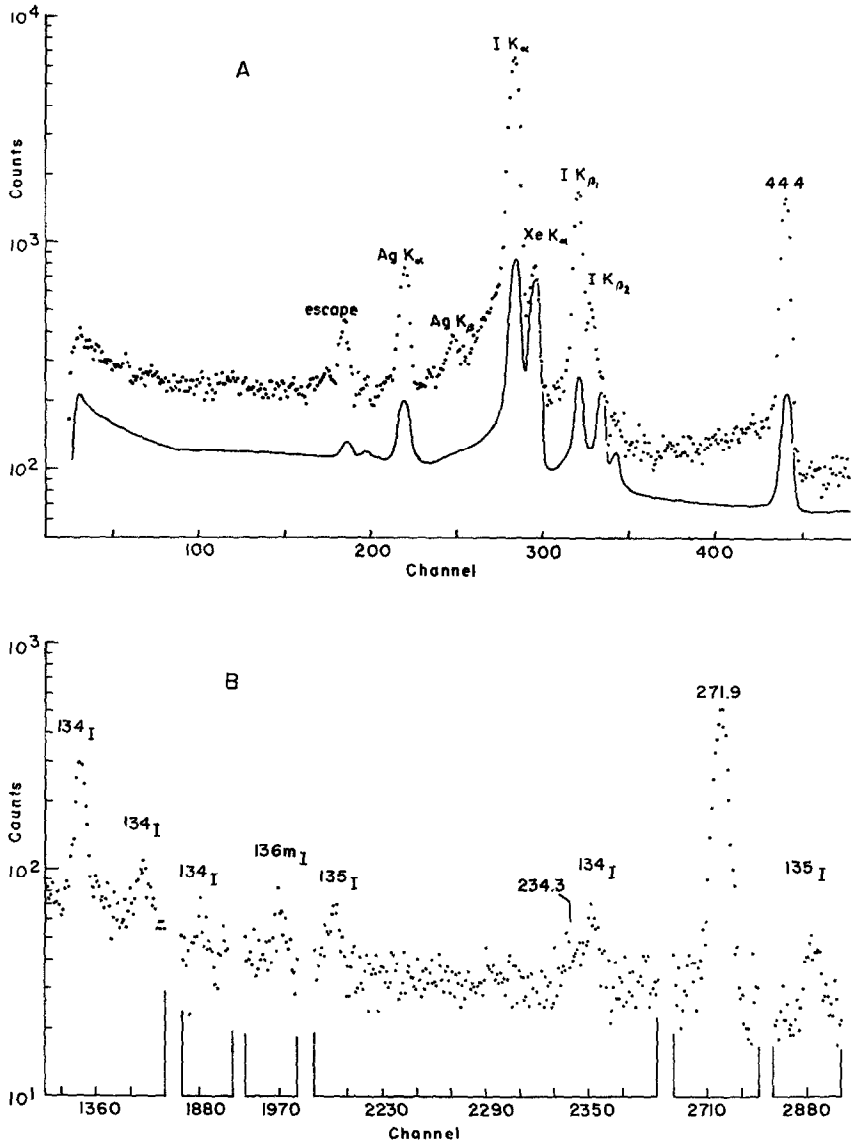
Fig. 4. High-resolution γ-ray spectrum. The points correspond to the spectrum obtained between 6.8 and 13.8 min after the end of irradiation. For the low-energy region (A) the solid curve is the spectrum obtained 12 min later. Portions of the spectrum corresponding to all of the peaks discernible in the high-energy region are given in B.

Xe X-ray peak was nearly as high as the I peak, implying that there is considerable conversion in ^{136}Xe following the decay of ^{136m}I or ^{136g}I.

2.3. THE γ-γ COINCIDENCE MEASUREMENTS

The genetic relation between the 44.4 and 271.9 keV γ-rays was established by coincidence measurements and inferences based on conversion coefficients. In the coincidence measurements a 5 cm × 5 cm NaI(Tl) detector was used to detect low-energy photons (primarily I K X-rays), and a Ge(Li) detector was used for the 271.9 keV γ-ray. The spectrum of radiations coincident with the 271.9 keV γ-ray shows features which are consistent with iodine K X-rays and an incompletely resolved 44 keV γ-ray. In this spectrum the relative intensities of the X-rays and the 44 keV γ-ray appear to be about the same as in the singles spectra. The spectrum coincident with the peak identified as iodine K X-rays shows the 271.9 keV γ-ray as the major component for energies above the 100 keV cut-off in that channel. These results indicate that the predominant mode of decay involves a two-step cascade with transitions of 44.4 and 271.9 keV. However the order is not determined.

Several attempts were made to measure the half-life of the intermediate state in the cascade. Such a measurement would also determine the order of the cascade. One method employed Naton plastic detectors and fast electronics. No energy selection, other that discriminators, was used. The time spectra were dominated by prompt coincidences ($\Delta t \approx 1$ nsec) which could not be assigned to $^{134\text{m}}$I. Other measurements employed NaI(Tl) detectors and 10-stage photomultipliers with poor timing characteristics. In these measurements pulse-height selection was used, and the time spectra from a time-to-amplitude converter showed variation of intensity with time which corresponds to 3.8 min $^{134\text{m}}$I. However the time resolution (≈ 30 nsec) was so poor and statistical uncertainties so large that no clear deviation from the prompt calibration curve could be detected. These measurements indicate that the half life of the 44.4 keV level is less than 10 nsec.

2.4. THE β-γ ANTICOINCIDENCE MEASUREMENTS

The main interference with detection of 234 or 316 keV γ-rays which might be emitted in the decay of $^{134\text{m}}$I was due to contributions of $^{134\text{g}}$I and ^{135}I to the spectra. If the 234 keV γ-ray results from decay of the 0.29 sec 7$^-$ level in ^{134}Xe and the 316 keV γ-ray is the crossover transition in isomeric decay of $^{134\text{m}}$I, neither of these γ-rays will be in prompt coincidence with β-rays. The β-γ anticoincidence measurements were performed as follows. The I was isolated by extraction of I_2 into toluene, by washing, and by extraction of I^- into aqueous sulfite solution. The I was reoxidized and extracted into 15 ml of toluene-based scintillator solution. The loaded scintillator was transferred to a glass vial optically coupled to a 4 cm photomultiplier. Gamma rays were detected in a 35 cm^3 Ge(Li) detector, the pulses from which were controlled by a conventional anticoincidence circuit and linear gate. The anticoincidence efficiency was a function of count rate because of the dead-time of the anticoincidence circuit. However in favourable cases the contributions from γ-rays in prompt coincidence with β-rays could be reduced to about 5% their intensity in singles spectra.

A spectrum obtained in the anticoincidence configuration is given in fig. 5. Although the resolution of the detector was insufficient to resolve the 234 keV γ-ray of $^{134\,m}$I from the 235.3 keV γ-ray of $^{134\,g}$I, the presence of the 234 keV γ-ray is evident in the short half-life of the main component at 234 keV and the shift in energy of this
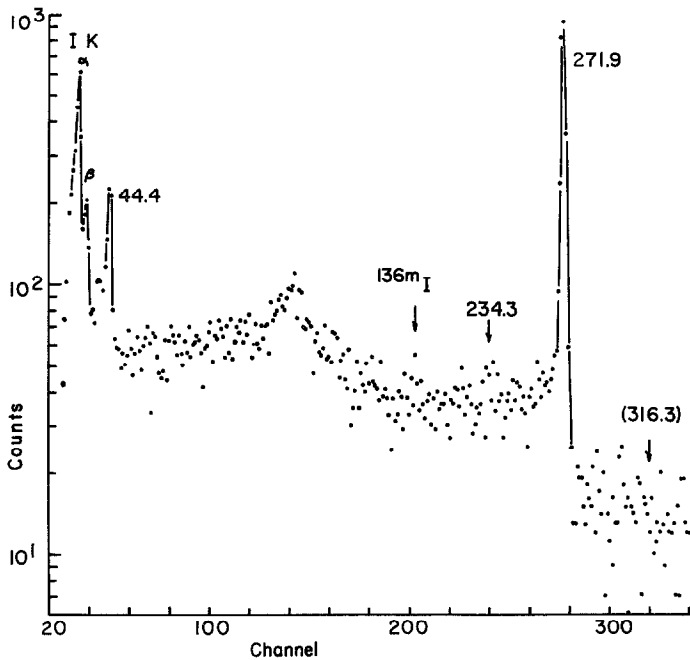

Fig. 5. Beta-anticoincidence γ-ray spectrum. The counting interval was 8 to 13 min after irradiation. Although no evidence for a 316.3 keV cross-over was found, the position at which it would be found is indicated.

peak from about 234 keV for early counts to 235 keV when the $^{134\,m}$I was gone. An analysis of the intensity of the 3.8 min component relative to the intensity of the 272 keV γ-ray yielded a ratio of 0.010 ± 0.004. This ratio is lower than the ratio of γ-ray intensities observed in singles spectra because of the appreciable detection efficiency for the 847 and 884 keV γ-rays in the liquid scintillator. The probability that one or both would be detected was estimated from Compton cross sections and found to be between 0.4 and 0.6. Therefore the true ratio of γ-ray intensities is 0.02 ± 0.01, in agreement with the intensity determined from singles spectra. In particular the enhancement of the detection efficiency, relative to γ-rays of $^{134\,g}$I, in the anti-coincidence configuration supports the assignment as a delayed transition in ^{134}Xe.

No evidence for the 316 keV γ-ray could be obtained. The upper limit of 1 % (relative to the 271.9 keV γ-ray) obtained from these spectra is about the same as the limit obtained from singles spectra.

2.5. CONSTRUCTION OF THE DECAY SCHEME

The energies and intensities of the radiations of ^{134m}I are summarized in columns 1 and 2 of table 1. The energies were determined by comparison with γ-ray standards in composite spectra of ^{134m}I and standards. The relative intensities of the major radiations were obtained primarily from spectra observed with the high resolution detectors suitable for clear resolution of the low-energy radiations. The intensity of the 234 keV γ-ray was obtained from singles measurements with the high-resolution detector and from the β-γ anticoincidence measurements. The upper limit for the 316 keV crossover transition was obtained from anticoincidence measurements and from singles measurements with large Ge(Li) detectors.

TABLE 1

The electromagnetic radiations from ^{134m}I

Energy (keV)	Relative γ-ray intensity	Assumed conversion coefficient	Relative transition intensity
iodine K X-rays	114 ± 10	0.86 (K fluorescence yield)	133 ± 12
44.4 ± 0.2	13 ± 1	7.90	116 ± 8
234.3 ± 0.5	2 ± 1	0.46	2.9 ± 1
271.9 ± 0.3	100	0.23	123
316.3 ± 1	<0.6	1.95	<1.8

The γ-γ coincidence measurements indicate that the predominant mode of decay of the isomer involves a cascade of transitions of 44.4 and 271.9 keV. The experiments do not specify which transition is the slow (3.8 min) step. The ratio of intensities of iodine K X-rays and the 44.4 keV γ-ray indicate that the K conversion coefficient of the 44.4 keV transition is no more than about 8, which limits the transition to E1, M1 or E2. For any of these choices, a half-life of 3.8 min would be exceedingly long. The limits on the conversion of the 271.9 keV γ-ray, if the strong coincidence between this γ-ray and K X-rays is taken to imply that only a small portion of the X-rays arise from conversion of this γ-ray, restrict this transition to E3 or lower multi-polarities. Although the required hindrance of the 271.9 keV γ-ray must be about 10^5 if this is the isomeric transition, this hindrance is about the same as that for the E3 transition in ^{134m}Cs, which appears to be analogous to ^{134m}I. If the 271.9 keV transition is E3, the most likely assignment of the 44.4 keV transition is M1. Therefore we infer that the major mode of decay is a 271.9 (E3)-44.4 (M1) cascade, as indicated in the decay scheme given in fig. 6.

Although the intensity of the 234 keV γ-ray is near the detection limit of the methods employed and a good half-life for this radiation could not be obtained, it appears likely that the assignment to ^{134m}I is correct. It is not clear that the presence of this γ-ray implies direct β-feeding of the 7^- level of ^{134}Xe. The assignment of such

a branch is based on the fact that no other γ-rays were detected, although any low-intensity γ-rays with energies below the Compton edge for the 272 keV γ-ray would not have been seen.

2.6. CALCULATION OF INDEPENDENT FISSION YIELDS

The intensity of the β-branch has a large effect on the apparent fission yield ratio of the ^{134}I isomers. The decay modes given in the decay scheme (fig. 6) imply that the activity of the 847 keV γ-ray at any given time contains contributions from decay

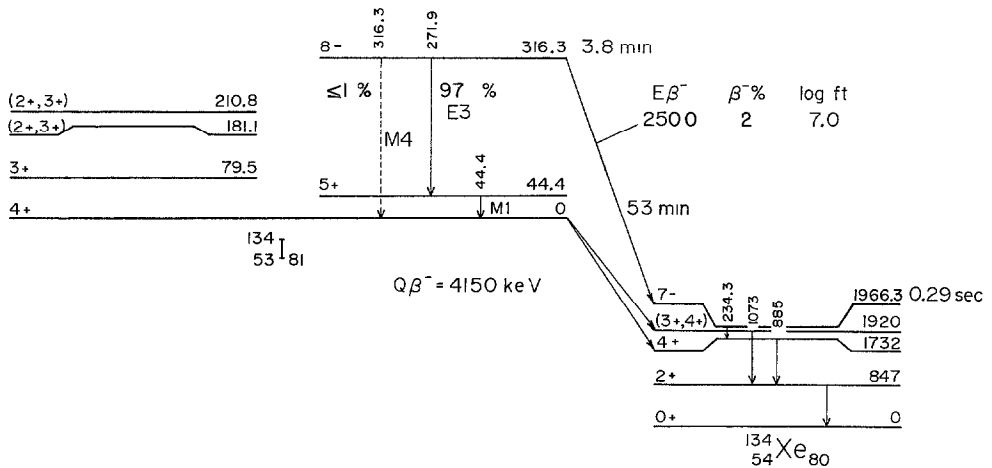

Fig. 6. Decay scheme of 3.8 min ^{134m}I and levels of ^{134}I observed in the β-decay of ^{134}Te.

of ^{134g}I and from β-decay of ^{134m}I. Even if no ^{134g}I were produced in fission ($\sigma_m/\sigma_g = \infty$), the 847 keV γ-ray would show no growth if the β-branch were about 7 %. The activity of the 847 keV γ-ray is given by

$$A_{\mathrm{T}} = \left[A_g^0 + \frac{\lambda_g}{\lambda_m - \lambda_g} A_m^0 (1-f) \right] x_g \mathrm{e}^{-\lambda_g t} + \left[f x_m - \frac{\lambda_g}{\lambda_m - \lambda_g} (1-f) x_g \right] A_m^0 \mathrm{e}^{-\lambda_m t},$$

where $A_g^0 =$ activity at $t = 0$ coming from 53 min ^{134g}I decay, $A_m^0 =$ activity at $t = 0$ coming from 3.8 min ^{134m}I decay, $\lambda_g =$ decay constant of 53 min ^{134g}I, $\lambda_m =$ decay

constant of 3.8 min ^{134m}I, x_g = fraction of decays of 53 min ^{134g}I giving rise to 847 keV γ-ray, x_m = fraction of decays of 3.8 min ^{134m}I giving rise to 847 keV γ-ray, f = fraction of the 3.8 min ^{134m}I β^- decaying, $1 - f$ = fraction of the 3.8 min ^{134m}I decaying by IT.

From experimental values for the intensities of the 847 and 272 keV γ-rays, theoretical conversion coefficients [19], the presumed decay schemes for ^{134m}I (fig. 6) and ^{134g}I [ref. [10]], the isomer ratio, σ_m/σ_g is found to be 1.4 $\pm$ 0.7.

3. Discussion

The decay of ^{134m}Cs is known [20] to occur predominantly by a two-step cascade of γ-transitions. The spins and parities of the levels and the multipolarities of the transitions are the same as those inferred for ^{134m}I in the present work. Therefore, it is of interest to compare the rates of the transitions observed in the decay of these two isomers. In addition to the data given in [ref. [20]], the half-life of the 11.2 keV 5^+ level in ^{134}Cs has been determined by Lynch and Glendenin [21], and the intensity of the 138.6 keV crossover transition has been determined by Griffin [22]. The intensity of the 138.6 keV γ-ray is in agreement with the intensities of conversion electrons observed by Sunyar, Mihelich and Goldhaber [23] and the assumption that the transition is M4. The data for ^{134m}Cs and the extrapolations to ^{134m}I are compared by Griffin [22] and are consistent. The extrapolations were obtained by using the energy dependence for single-particle radiative transitions (e. g., E_γ^7 for E3 transitions) to correct for differences in transition energies; pure multipole transitions were assumed. From the comparison it is clear that the E3 transitions are quite similar, and that the upper limit for the intensity of the M4 transition in ^{134}I is analogous to that in ^{134}Cs.

The configurations of the 4^+ and 8^- isomers of ^{134}I involve the odd 53rd proton lying either in the $g_{\frac{7}{2}}$ ground state or $d_{\frac{5}{2}}$ first excited state found at [24] 312 keV in ^{133}I and the single neutron hole [25] lying either in the $d_{\frac{3}{2}}$ ground state, $h_{\frac{11}{2}}$ first excited state at 334.5 keV or $s_{\frac{1}{2}}$ second excited state at 423.5 keV in ^{133}Te. The 5^+ state at 44 keV can be constructed from only the $(\pi g_{\frac{7}{2}} \nu d_{\frac{3}{2}})_{5^+}$ coupling whereas the 8^- isomer can either be a $(\pi g_{\frac{7}{2}} \nu h_{\frac{11}{2}})_{8^-}$ or $(\pi d_{\frac{5}{2}} \nu h_{\frac{11}{2}})_{8^-}$ state and the 4^+ state can be $(\pi g_{\frac{7}{2}} \nu d_{\frac{3}{2}})_{4^+}$, $(\pi d_{\frac{5}{2}} \nu d_{\frac{3}{2}})_{4^+}$, or $(\pi g_{\frac{7}{2}} \nu s_{\frac{1}{2}})_{4^+}$. Because of the fixed configuration of the 5^+ intermediate state it may be seen that the 3.8 min IT represents effectively the M4 transition of the neutron from the $h_{\frac{11}{2}}$ state to the $d_{\frac{3}{2}}$ state. The 3.8 min half-life for this E3 transition may be compared with the 0.29 sec half-life of the 234 keV E3 transition in ^{134}Xe. The transition in I is hindered by a factor of ≈ 2300 relative to the transition in Xe. On the other hand, the 3.8 min transition may be compared to the 334 keV M4 transition in ^{133}Te whose γ de-excitation half-life is ≈ 440 min and an enhancement of only about 10^3 found. These considerations support the above proposed configurations for the 4^+, 5^+, and 8^- levels in ^{134}I. One configuration that can mix into the 8^- state and lead to an E3 transition to the 5^+ state is $(\pi g_{\frac{7}{2}} \nu h_{\frac{9}{2}})_{8^-}$. The $\nu h_{\frac{9}{2}}$ level lies [26,27] above the $N = 82$ closed shell and is ≈ 3 MeV

above the $h_{\frac{11}{2}}$ state. Only a small admixture of such a state is indicated or required to account for the observed half-lives.

If all of the intensity of the 234 keV γ-ray is assumed to arise from direct β-feeding of the 7$^-$ level in ^{134}Xe, the log ft value of that transition is about 7. This value is somewhat high for, but not inconsistent with, an allowed transition. From a microscopic point of view, however, β-decay of ^{134}I involves decay of the 81st neutron to produce the 54th proton, and direct β-decay to a two-neutron state [16] is not expected.

Even though the intensity of the β-decay branch (or branches) of ^{134m}I is not well known, it is clear that most of the decay leads to ^{134g}I. Therefore the existence of this isomer cannot explain the unexpected low fission yield [13] of ^{134g}I.

References

1) N. Sugarman, J. Chem. Phys. **17** (1949) 11
2) G. J. Perlow and A. F. Stehney, Phys. Rev. **113** (1959) 1269
3) N. R. Johnson and G. D. O'Kelley, Phys. Rev. **114** (1959) 279
4) H. O. Denschlag and A. A. Gordus, Zeit. anal. Chem. **226** (1967) 62
5) A. Lundan and A. Siivola, Ann. Acad. Scient. Fennicae **A VI** (1968) 287
6) M. McKeown and S. Katcoff, Phys. Rev. **94** (1954) 965
7) G. Holm and H. Ryde, Ark. Fys. **15** (1959) 387
8) N. R. Johnson, E. Eichler, G. D. O'Kelley, J. W. Chase and J. T. Wasson, Phys. Rev. **122** (1961) 1546
9) E. Takekoshi, H. Umezawa and T. Suzuki, Nucl. Phys. **A133** (1969) 493
10) W. G. Winn and D. G. Sarantites, Phys. Rev. **184** (1969) 1188
11) H. N. Erten, C. D. Coryell and W. B. Walters, Bull. Am. Phys. Soc. **14** (1969) 1225
12) G. Holm, Ark. Fys. **37** (1968) 1
13) A. A. Delucchi, A. E. Greendale and P. O. Strom, Phys. Rev. **173** (1968) 1159
14) L. C. Carraz, J. Blachot, E. Monnand and A. Moussa, Compt. Rend. B **270** (1970) 358
15) H. N. Erten, C. D. Coryell and W. B. Walters, J. Inorg. Nucl. Chem. (1971), in press
16) W. G. Winn and D. C. Clark, Bull. Am. Phys. Soc. **11** (1966) 775; W. G. Winn, Ph. D. thesis, Cornell Univ., Ithaca, N. Y. (1968), unpublished
17) J. P. Op de Beeck and W. B. Walters, J. Inorg. Nucl. Chem. **30** (1968) 228
18) G. W. Campbell and E. L. Brady, Radiochemical studies· the fission products, eds. C. D. Coryell and N. Sugarman (McGraw-Hill, New York, 1951), paper 277, p. 1623
19) R. S. Hager and E. C. Seltzer, Nucl. Data **4** (1968) 1
20) C. M. Lederer, J. M. Hollander and I. Perlman, Table of isotopes, 6th ed., 1967
21) F. J. Lynch and L. E. Glendenin, Phys. Rev. **186** (1969) 1250
22) H. C. Griffin, to be published
23) A. W. Sunyar, J. W. Mihelich and M. Goldhaber, Phys. Rev. **95** (1954) 570
24) B. Parsa, G. E. Gordon and W. B. Walters, Nucl. Phys. **A110** (1968) 674
25) H. N. Erten, C. D. Coryell and W. B. Walters, Nucl. Phys. March 1971, submitted
26) E. S. Macias and W. B. Walters, Nucl. Phys. **A169** (1971) 309
27) D. von Ehrenstein, G. C. Morrison, J. A. Nolen, Jr., and N. Williams, Phys. Rev. **C1** (1970) 2066