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# Excited States in $^{97}$Tc from the Reaction $^{97}$Mo($p$, $n\gamma$)$^{97}$Tc†

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In-beam $\gamma$-ray measurements of the excited states in $^{97}$Tc have been made using the reaction $^{97}$Mo($p,n\gamma$)$^{97}$Tc at incident proton energies between 3.0 and 6.0 MeV. Singles and $\gamma$-$\gamma$ coincidence measurements were made using Ge(Li) detectors and an on-line two-parameter data-acquisition system. By these methods about 50 $\gamma$ rays associated with the deexcitation of levels in $^{97}$Tc have been observed. Coincidence spectra produced by gates on 11 of the stronger transitions were used along with the singles measurements to identify 28 levels with energies up to 1580 keV excitation. The states at 807, 896, 1127, 1141, 1173, 1220, and 1311 keV have not been previously reported. Evidence is given for states at 833, 850, 1240, and 1410 keV, of which the 850-keV level is isomeric. Branching ratios are given along with a decay scheme for $^{97}$Tc.

## 1. INTRODUCTION

Several studies have recently been made on the decay of $^{97}$Ru to $^{97}$Tc in an effort to understand the detailed level structure of $^{97}$Tc. Unik and Rasmussen[1] reported the decay of $^{97m}$Tc by a single $M4$ transition of $96.5 \pm 0.1$ keV, while other experiments[2-8] established a few of the low-lying levels. The most definitive study of $^{97}$Ru was done by Phelps and Sarantites,[9] who established levels at 96.5, 215.71, 324.49, 656.82, 785.05, 855.45, 969.79, and 994.69 keV while giving evidence for the existence of levels at 574.2 and 946.5 keV. The neutron time-of-flight measurements made by Kim *et al.*[10] on the reaction $^{97}$Mo($p$, $n$)$^{97}$Tc have been of considerable importance in studying the decay of $^{97}$Ru, since that reaction is not as selective as $\beta$ decay and hence populates most of the levels. A recent study of $^{97}$Tc via the reaction $^{96}$Mo($d$, $n$)$^{97}$Tc using neutron time-of-flight measurements has been done by Riley *et al.*[11] The resolution of the time-of-flight spectra, however, was not good compared with that obtained in $\gamma$-ray studies, and the present experiment, therefore, was undertaken to determine more exactly the detailed level structure of $^{97}$Tc, in which there has been considerable interest, since it has 54 neutrons and thus lies in the region just beyond the 50-neutron closed shell. This nucleus has also received attention from those attempting to understand the properties of the low-lying states in nuclei with $N$ or $Z = 43$, 45, or 47.[9] Both $\gamma$-ray singles and $\gamma$-$\gamma$ coincidence data were obtained using high-resolution Ge(Li) detectors, making it possible to resolve levels which are spaced too closely to have been resolved by time-of-flight experiments[10,11] or which were missed due to the low count rate of previous measurements.[10]

## 2. EXPERIMENTAL PROCEDURES

### A. Singles Measurements

The experimental arrangement for measuring the prompt $\gamma$ rays from $^{97}$Mo($p$, $n\gamma$) is shown in Fig. 1. A 302-$\mu$g/cm$^2$ (92.8% enriched) $^{97}$Mo target was bombarded by a proton beam from a tandem electrostatic accelerator at energies between 3.0 and 6.0 MeV. Singles $\gamma$-ray spectra were taken at 90° to the incident beam axis using a coaxially-drifted Ge(Li) detector with an active volume of 20 cm$^3$. The typical in-beam energy resolution was 4.0 keV full width at half maximum (FWHM) for 1.0-MeV $\gamma$ rays. The beam intensity was varied from 20–100 nA, decreasing with increasing proton energy, to prevent pulse pileup and neutron damage to detectors. After passing through the target, the proton beam was dumped into a 2-m-thick concrete wall. This experimental arrangement was advantageous in reducing the contaminant radiations from $(n, \gamma)$ reactions and in reducing the neutron flux at the detector. Background spectra were taken, with and without the beam and target, in the configuration shown in Fig. 1. Contaminant $\gamma$ radiations from $^{56,57}$Co $\beta$ decay were traced to a nearby steel scattering chamber. Transitions having the energies of these contaminants were ignored in the spectra obtained from the $^{97}$Mo$(p, n\gamma)$ reaction.

The $Q$ value for the $^{97}$Mo$(p, n)$ reaction is given

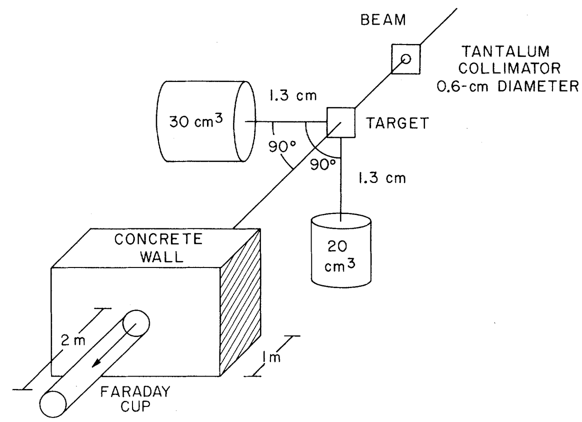


FIG. 1. Experimental configuration with Ge(Li) $\gamma$-ray detectors, which was used for both singles and coincidence measurements.

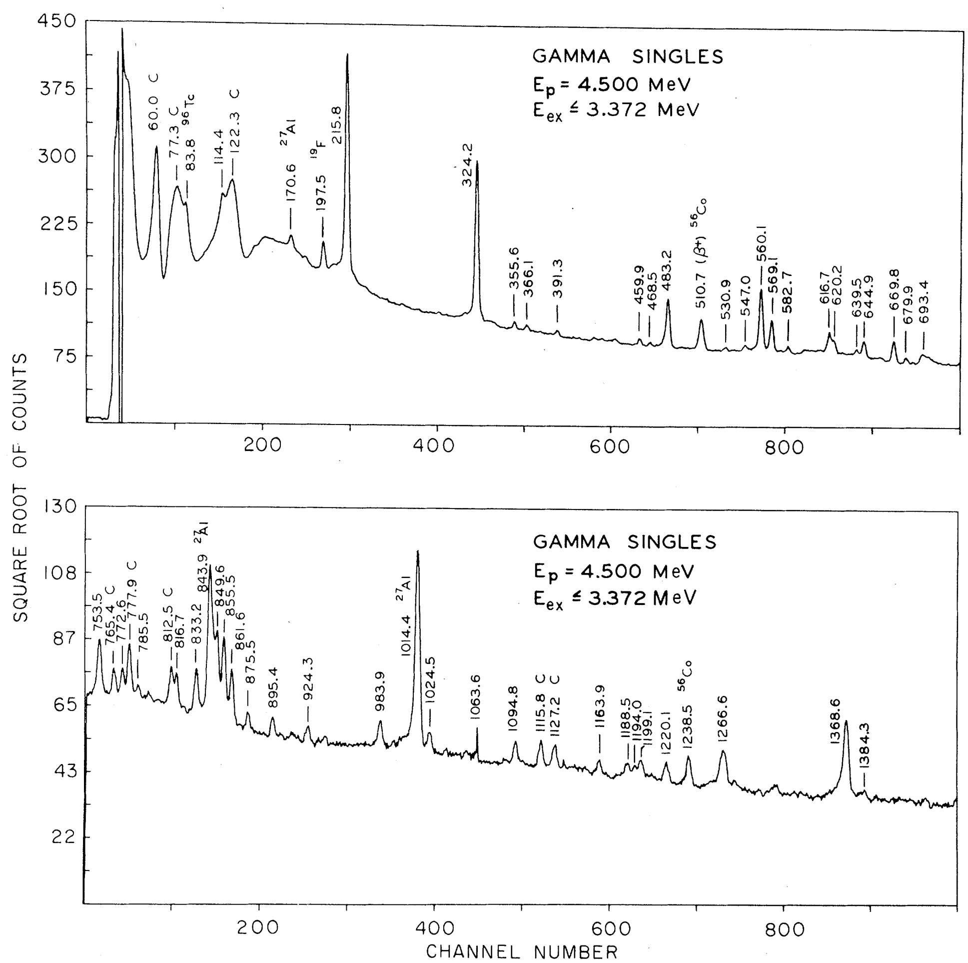


FIG. 2. Singles spectra taken with 20-cm$^3$ Ge(Li) detector at $E_p$ = 4.5 MeV. Peaks denoted C are contaminants from background.

by Kim *et al.*[10] to be −1.128± 0.008 MeV. The target used, however, contained the following Mo isotopes, with the percentage of the total weight and the $Q$ value for the Mo($p,n$) reaction given in parentheses: $^{92}$Mo (0.271%, $Q$ = −8.836 MeV), $^{94}$Mo (0.24%, $Q$ = −5.0429 MeV), $^{95}$Mo (0.68%, $Q$ = −2.4413 MeV, $^{96}$Mo (1.69%, $Q$ = −3.7167 MeV), $^{98}$Mo (3.97%, $Q$ = −2.3721 MeV), and $^{100}$Mo (0.37%, $Q$ = −1.1177 MeV).[12] All but the $^{92}$Mo($p,n$) reaction have $Q$ values less than 6.0 MeV in magnitude and could be the sources of $\gamma$ rays in the spectra taken. Separate singles spectra, therefore, were taken with a target enriched with the isotope $^{95}$Mo to determine whether any $\gamma$ rays corresponding to transitions in $^{95}$Tc appeared in the spectra obtained from the $^{97}$Mo($p,n\gamma$) reaction and, therefore, to test the importance of the other Mo isotopes in the target used for this experiment. Numerous low-energy (50–200 keV) $\gamma$ rays and x rays plagued the singles spectra. To see if they were obscuring low-energy $^{97}$Tc transitions, $\gamma$-ray spectra were also measured with a high-resolution (500 eV FWHM at 100 keV) low-energy photon detector made by ORTEC. Energies shown in Figs. 2 and 4–7 were obtained by a least-squares fit to calibration points from $\gamma$-ray standards, such as $^{56}$Co and $^{133}$Ba. The relative efficiencies of all detectors were determined using calibrated sources in the configuration of Fig. 1. A relative efficiency curve for the 20-cm$^3$ detector is given in the paper on the reaction

TABLE I. Energies and relative intensities of $\gamma$ transitions observed in $^{97}$Mo($p,n\gamma$)$^{97}$Tc ($E_p$=4.500 MeV).

| $E_\gamma$ (keV) This work | Relative $I_\gamma$ ($I_{215.8}$=100) | $E_\gamma$ (keV) Phelps and Sarantites (Ref. 9) $^{97}$Ru($\beta,\gamma$)$^{97}$Tc | $E_\gamma$ (keV) This work | Relative $I_\gamma$ ($I_{215.8}$=100) | $E_\gamma$ (keV) Phelps and Sarantites (Ref. 9) $^{97}$Ru($\beta,\gamma$)$^{97}$Tc |
|---|---|---|---|---|---|
| 108.5 [a] | Weak | 108.80 | 753.5 | 10.7 | 754.03 |
| 114.4 [a] | Weak | 114.5 | 772.6 | 3.1 | |
| 215.8 | 100 | 215.71 | 785.5 | 0.7 | 785.04 |
| 293.1 | Weak | | 816.7 | 6.7 | |
| 324.2 | 85.8 | 324.48 | 833.2 | 8.1 | |
| 355.6 | 2.0 | | 849.6 | 8.7 | 850.1 |
| 366.1 | 2.2 | | 855.5 | 15.0 | 855.45 |
| 391.3 | 1.8 | | 861.6 [b] | 12.0 | |
| 422.3 | 0.7 | | 875.5 | 2.8 | |
| 428.9 [b] | Weak | | 895.4 | 3.7 | 898.0 |
| 439.3 | Weak | | 910.9 | Weak | |
| 459.9 | 2.4 | 460.59 | 924.3 | 3.3 | |
| 468.5 | 0.8 | | 938.2 | Weak | |
| (477.7) [c] | Weak | 477.7 | 983.9 | 5.0 | |
| 483.2 | 25.3 | | 1004.5 | Weak | |
| 530.9 | 1.4 | 531.1 | 1024.5 | 4.8 | |
| 547.0 | 2.4 | | 1094.8 | 4.2 | |
| 560.1 | 40.0 | 560.32 | 1163.9 | 2.5 | |
| 569.1 | 17.0 | 569.33 | 1188.5 | 1.2 | |
| 582.7 | 2.6 | | 1194.3 | 1.0 | |
| 616.7(615.3) | 13.0 | | 1199.1 | 4.0 | |
| 620.2 | 5.2 | | 1220.1 | 4.3 | |
| 639.5 | 2.4 | 639.73 | 1256.2 [b] | Weak | |
| 644.9 | 10.6 | 645.35 | 1266.6 [b] | 8.7 | |
| 658.2 | 0.4 | | 1368.6 [b] | 20.7 | |
| 659.6 [b] | Weak | | 1384.3 [b] | Weak | |
| 669.8 | 13.6 | 670.30 | 1472.3 [b] | Weak | |
| 679.9 | 2.9 | | 1491.3 [b] | Weak | |
| 693.4 [b] | 4.3 | | 1538.4 [b] | Weak | |
| 694.8 [b] | Weak | | 1539.9 [b] | Weak | |
| 724.6 | Weak | | | | |

[a] Intensity could not be measured because of high background level at this energy.
[b] Not placed on level scheme.
[c] Obscured by 483-keV peak.

$^{91}Zr(p, n\gamma)^{91}Nb$, by Matthews *et al.*[13] The intensities of all measured transitions were corrected with that efficiency curve.

### B. Coincidence Measurements

To construct the level scheme from $\gamma$ rays observed in the deexcitation of states in $^{97}$Tc, a measurement of in-beam $\gamma$-$\gamma$ coincidence spectra was made using two Ge(Li) detectors with active volumes of 20 and 30 $cm^3$ and a multiparameter sorting program. For these measurements the detectors were placed at 90° with respect to each other and with respect to the incident beam axis, as shown in Fig. 1. Thin-walled aluminum detector wells protruding into a $10^2 \times 15$-cm rectangular aluminum scattering cell enabled both detectors to be situated 1.3 cm from the target center. For the 30-$cm^3$ detector this gave an effective solid angle of approximately 0.12 sr.

A block diagram of the electronics used in this experiment is shown in Fig. 3. Timing is accomplished via fast amplifiers which in turn trigger a constant-fraction discriminator. The resolving time $2\tau$ of the system was set at full width at 0.1 maximum (typically 25–30 nsec), although the FWHM of the timing spectrum was 15 nsec. Events coincident between the detectors within a time $2\tau$ trigger a single-channel analyzer (SCA). A pulse from the SCA opens two linear gates and accompanies the two coincident energy signals from the linear amplifiers into three 1024-channel analog-to-digital (ADC) converters. These signals are then fed into the buffer area of a PDP-7 computer with external memory, where the energy pulses from the gate detector (30 $cm^3$) are incremented and stored in a 1024-channel block of memory. Up to 42 windows can then be set on peaks in the gate detector spectrum. The computer then accumulates energy events from the 20-$cm^3$ detector which are coincident with windows in the first. By this method 42 coincidence spectra can be simultaneously accumulated. In this experiment, however, many contributions from the Compton tails of higher-energy transitions were present under windows or gated transitions. Consequently, for every window set on a transition, a window of equal width was set just to the side of the first window. Spectra from the first window then represented true-plus-Compton coincidences, while spectra from the second window represented Compton-only coincidences. The difference or true-coincidence spectra are shown in Figs. 4–7. Chance-coincidence spectra were monitored and the rate of chance coincidence kept at less than 2%.

TABLE II. Results of $\gamma$-$\gamma$ coincidence on $^{97}$Tc ($E_p$ = 6.000 MeV).

| Gated $\gamma$-ray energy (keV) | Coincident $\gamma$-ray energy (keV) |
|---|---|
| 215.8 | 108.5, 569.1, 616.7, 639.5, 679.9, 753.5, 910.9, 983.9, 1094.8, 1163.9, (1194.3) |
| 324.2 | 459.9, (530.9), 616.7(615.3), 644.9, 669.8, 724.6, 816.7, 875.5, 895.4, 1199.1 |
| 483.2 | 215.8, 324.2, 366.1, 468.5 |
| 560.1 | 215.8, 391.3, (582.7), 620.2, 924.3 |
| 569.1 | 215.8, (355.6) |
| 616.7–620.2 | 215.8, 560.1 |
| 644.9 | 324.2 |
| 669.8 | 324.2 |
| 753.5 | 215.8 |
| 816.7 | 324.2 |
| 833.2 | (547.0) |

## 3. RESULTS

### A. Singles Spectra

Singles spectra were taken between the energies of 3.0 and 6.0 MeV, but since the $Q$ value was low for the $^{97}Mo(p, n\gamma)$ reaction and the $\gamma$ rays observed were below 1500 keV, very little new information was gained from the spectra observed for the higher excitation energies. Threshold spectra were not taken at energies below 3.0 MeV, as the Cou-

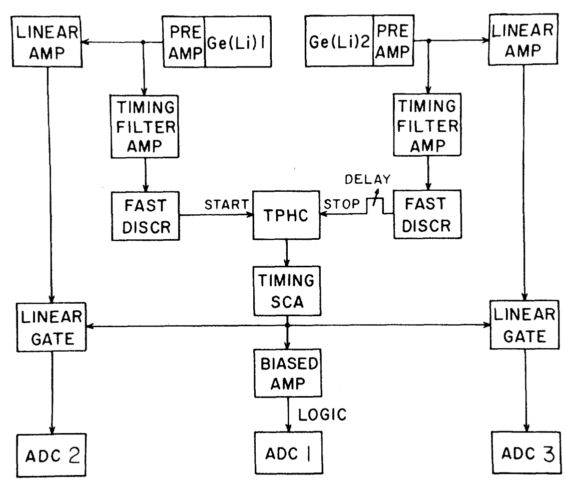


FIG. 3. Block diagram of electronics used in the on-line computer analysis of coincidence data. Several delay units have been omitted. TPHC: time-to-pulse-height converter; other abbreviations are given in text.

lomb barrier would have kept the count rate very low. Singles spectra taken at the proton energy of 4.5 MeV are shown in Fig. 2. The indicated transition energies are averages over the measurements made at the different proton energies between 3.0 and 6.0 MeV. The spectrum is plotted on a square-root scale for easy identification of the peaks above the background.

Large Compton background from the abundance of high-energy transitions made identification of the low-lying transitions difficult. A low-energy measurement using a special high-resolution detector (see Sec. 2A), however, confirmed the weak transitions at 108.5 and 114.4 keV.

There were several sources of contaminant $\gamma$ rays in the spectra taken with the 20-$cm^3$ Ge(Li) detector. Weak transitions in $^{95}$Tc and $^{96}$Tc at 336.2 and 83.8 keV, respectively, were observed along with transitions at 170.6, 790.4, 843.9, and 1014.4 keV from the $^{27}$Al$(p, p'\gamma)$ reaction. The 109.8- and 197.5-keV transitions from $^{19}$F$(p, p'\gamma)$ were also observed as in the experiment by Mathews *et al.*[13] The $\gamma$ rays coming from other Tc isotopes were not seen in the spectra, as far as could be determined from experiments done previously.[14] Little information could be found on $^{98}$Tc, but the fact that $^{98}$Mo has an even number of neutrons indicates that the cross section would be small for the $^{98}$Mo$(p, n)$ reaction. The associated $\gamma$ rays would, therefore, be weak.

All transitions reported by Phelps and Sarantites[9] were observed in this experiment, except for the weak 898.0-keV transition, as shown in Table I. It is possible that the background obscured the 898.0-keV transition in our spectra, although the possibility of its coming from some other Ru isotope must be recognized, since the other weak transitions seen in previous experiments were observed in this experiment as well. The weak 477.7-keV transition was somewhat obscured by the nearby strong 483.2-keV transition. The weak 428.9-, 659.6-, 693.4-, and 694.8-keV transitions could not be placed on the level scheme, nor could the strong 861.6-keV transition and the transitions above 1220.1 keV listed in Table I. At least some of these are thought to be from sources

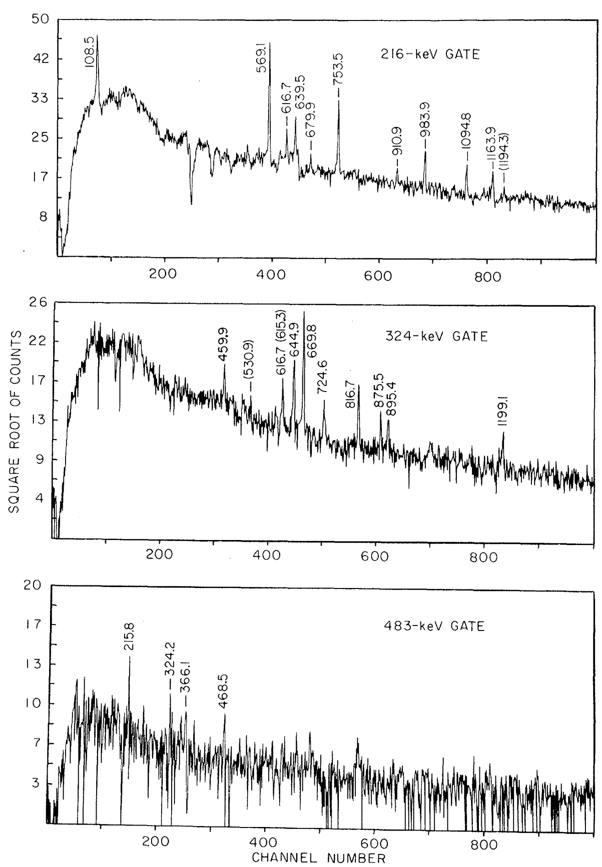


FIG. 4. Display of $\gamma$-$\gamma$ coincidence spectra from $^{97}$Mo-$(p,n\gamma$-$\gamma)^{97}$Tc at $E_p = 6.0$ MeV with two Ge(Li) detectors.

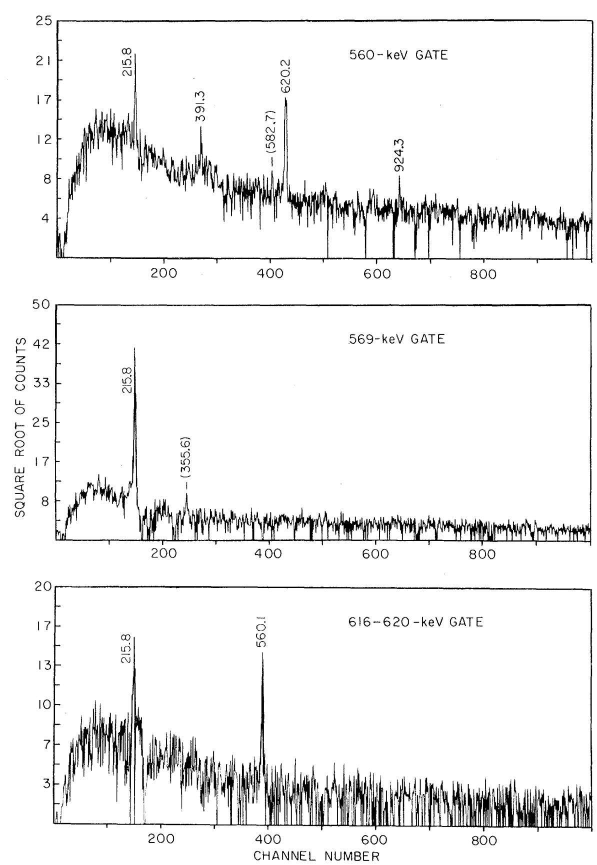


FIG. 5. Display of $\gamma$-$\gamma$ coincidence spectra from $^{97}$Mo-$(p,n\gamma$-$\gamma)^{97}$Tc at $E_p = 6.0$ MeV with two Ge(Li) detectors.

other than $^{97}$Tc, but could not be definitely attributed to any specific source. The existence of a weak transition at approximately 615.3 keV obscured by the nearby 616.7-keV transition was considered probable, although the limitations of detector resolution (about 4.0 keV) prevented the confirmation of its presence in the spectra. Finally we noted that, in the background run taken with the beam on and no target at the end of the experiment, the 849.6-keV transition was not observed, while it was observed as a strong transition when the target was in the scattering cell with the beam turned off. This is at least a reasonable indication that it is an isomeric transition to the ground state of $^{97}$Tc.

### B. Coincidence Spectra

The coincidence spectra which yielded useful information are shown in Figs. 4–7 and summarized in Table II. Even the gates set on the strong 215.8- and 324.2-keV transitions were characterized by low count levels (after Compton subtraction), especially toward the high-energy end of the spectra, where the detector efficiency decreases. The coincidence results confirmed the previous measurements by Phelps and Sarantites,[9] but much new information was obtained due to the fact that levels higher in energy than those allowed by $\beta$ decay were populated.

There are several points of uncertainty, however, which should be discussed. The first involves the 616.7-620.2-keV doublet. As remarked previously (Sec. 3A), the presence of a weaker transition at 615.3 is probable. Indeed, the 215.8-keV gate yielded a peak identified as the 616.7-keV transition, while the 324.2-keV gate produced a peak shifted lower in energy by a channel (about 1.4 keV) with respect to the above peak. Two explanations are possible: Either there are two different transitions [hence the notation 616.7 (615.3) keV in the tables and figures] or the same 616.7-keV transition appears in both spectra. The latter would be explained as a transition to the 324-keV level and a subsequent cascade to the 216-keV level via the well-established 108.5-keV transition between the two levels (see Table II). Evidence supporting the former possibility, that the 324.2-keV transition is coincident with a 615.3-keV transition while the 215.8- and 616.7-keV transitions are coincident, is found in the spectrum obtained from the gate set on the doublet at 616.7 and 620.2 keV. This window did not include the channels in which a transition at 615.3 keV would have been found, and, as shown in Fig. 5, the spectrum contained no evidence of the 324.2-keV transition, which would have been in coincidence with the

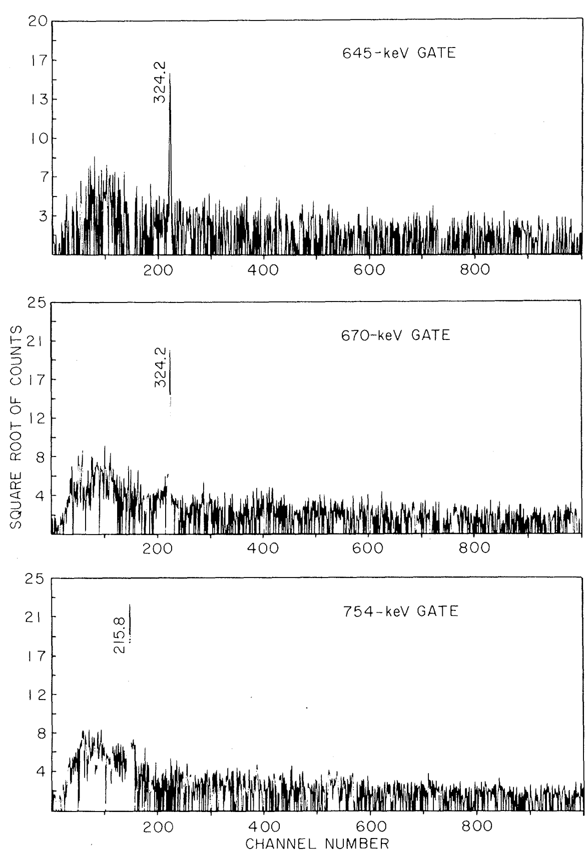


FIG. 6. Display of $\gamma$-$\gamma$ coincidence spectra from $^{97}$Mo-$(p,n\gamma$-$\gamma)^{97}$Tc at $E_p = 6.0$ MeV with two Ge(Li) detectors.

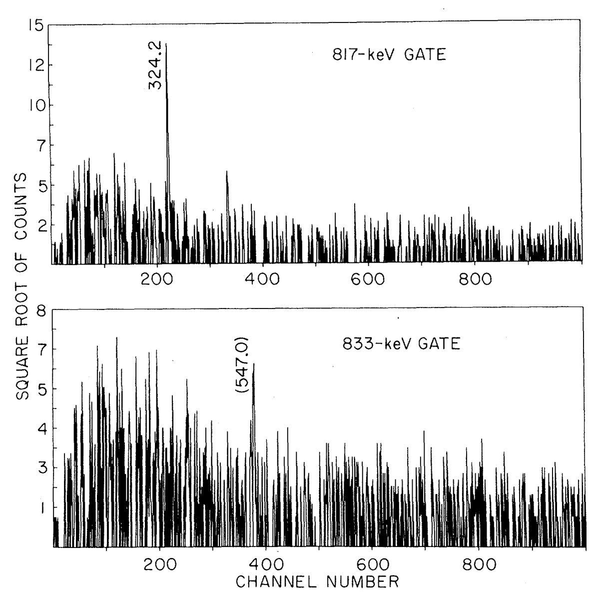


FIG. 7. Display of $\gamma$-$\gamma$ coincidence spectra from $^{97}$Mo-$(p,n\gamma$-$\gamma)^{97}$Tc at $E_p = 6.0$ MeV with two Ge(Li) detectors.

615.3-keV $\gamma$ ray, while strong transitions are present at 215.8 and 560.1 keV, shown by the gates set on them to be in coincidence with $\gamma$ rays at 616.7 and 620.2 keV, respectively. The implications of these results are discussed in the next section, covering the level scheme.

The 483.2-keV gate, set on a transition not seen in the $\gamma$-decay measurements,[9] again contains both the 215.8- and 324.2-keV transitions and is explainable only by a 483.2-keV transition to the 324.2-keV level with a subsequent cascade to the 215.8-keV level. Unlike Phelps and Sarantites,[9] we observed $\gamma$ rays coincident with the 560.1-keV transition. Assuming that the 560.1-keV transition goes from a level at 657 keV to the isomeric level at 96.5 keV,[9] the presence of the 215.8-keV transition in the spectrum of the 560.1-keV gate must be explained by the proximity of the strong 569.1-keV transition to that at 560.1 keV, as part of the 569.1-keV peak, strongly coincident with the 215.8-keV transition, must fall in the gate set on the peak at 560.1 keV. It should be noted that the 620.2-keV peak appearing in this spectrum was broader than the others and could have been a doublet.

All of the rest of the spectra except the last merely confirmed the coincidences of the 644.9-, 669.8-, and 816.7-keV transitions with that at 324.2 keV and the coincidence of the 753.5-keV transition with the 215.8-keV transition. The gate on the 833.2-keV peak yielded evidence of a weak 547.0-keV transition in coincidence with it and is important to the discussion of the level scheme with respect to the ambiguities associated with the 616.7-620.2-keV doublet.

## 4. LEVEL SCHEME AND DISCUSSION

The level scheme for $^{97}$Tc, as established from the present work, is shown in Fig. 8. The spin

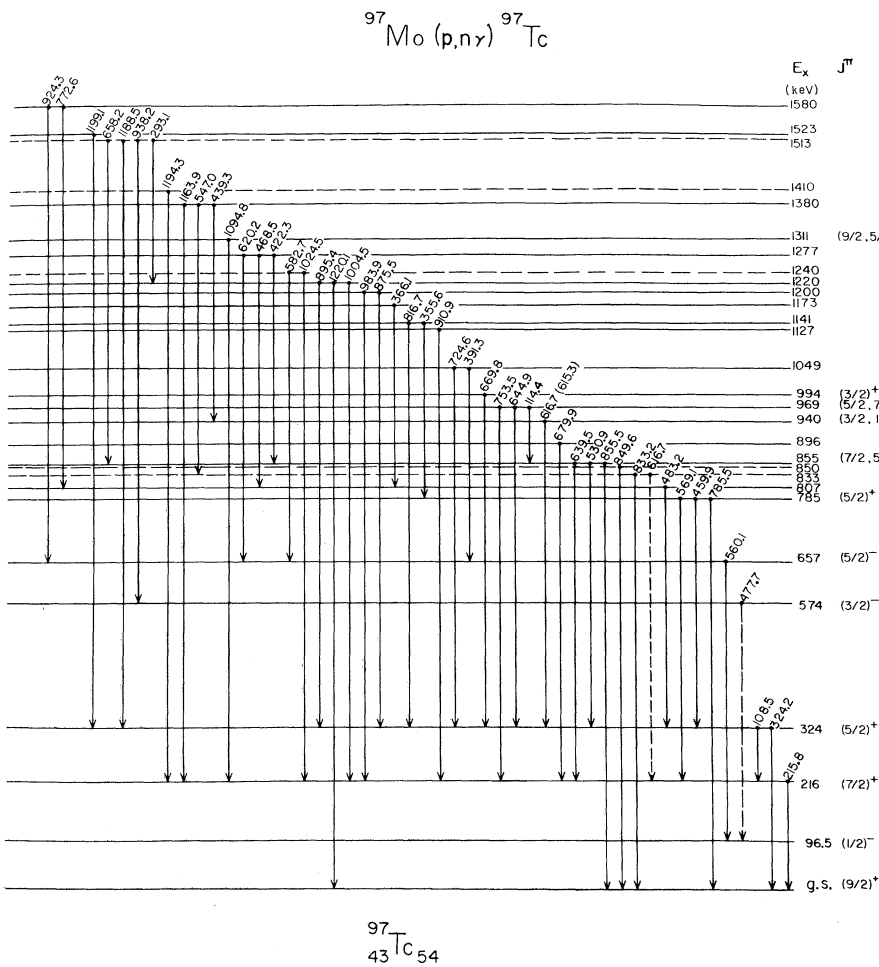


FIG. 8. Level scheme for $^{97}$Tc. Dashed levels are tentative.

and parity assignments of some of the levels are shown at the side, those of the 940- and 1311-keV states as given in Ref. 11 and the rest as shown in Ref. 9. The branching ratios for some of the levels are shown in Table III. The accuracy of these branching ratios depends on the isotropy of the $\gamma$ radiation from the $^{97}$Mo($p, n$) reaction. Preliminary measurements show isotropy to be valid within 5–10%. The levels shown were obtained by energy sums based on cascades in coincidence measurements, as well as sum and difference relationships based on levels found in previous works (see Table IV). The level energies are accurate to 1 keV.

TABLE III. Branching ratios for levels in $^{97}$Tc ($E_p$=6.000 MeV).

| $E_x$ (keV) | $\gamma$ branches (keV) | Relative $I_\gamma$ | Branching ratio (%) |
|---|---|---|---|
| 324 | 324.2 | 85.8 | 99 |
| | 108.5 | Weak | ... |
| 785 | 785.5 | 0.7 | 3 |
| | 569.1 | 17.0 | 85 |
| | 459.9 | 2.4 | 12 |
| 855 | 855.5 | 15.0 | 80 |
| | 639.5 | 2.4 | 13 |
| | 530.9 | 1.4 | 7 |
| 969 | 753.5 | 10.7 | 50 |
| | 644.9 | 10.6 | 50 |
| | 114.3 | Weak | ... |
| 1049 | 724.6 | Weak | Uncertain |
| | 391.3 | 1.8 | Uncertain |
| 1141 | 816.7 | 6.7 | 77 |
| | 355.6 | 2.0 | 23 |
| 1200 | 983.9 | 5.0 | 64 |
| | 875.5 | 2.8 | 36 |
| 1220 | 1220.1 | 4.3 | 53 |
| | 1004.5 | Weak | ... |
| | 895.4 | 3.7 | 46 |
| (1240) | 1024.5 | 4.8 | 65 |
| | 582.7 | 2.6 | 35 |
| 1277 | 620.2 | 5.2 | 78 |
| | 468.5 | 0.8 | 12 |
| | 422.3 | 0.7 | 10 |
| 1380 | 1163.9 | 2.5 | 50 |
| | 547.0 | 2.4 | 50 |
| | 439.3 | Weak | ... |
| (1513) | 1188.5 | 1.2 | 75 |
| | 938.2 | Weak | ... |
| | 658.2 | 0.4 | 24 |
| | 293.1 | Weak | ... |
| 1580 | 924.3 | 3.3 | 52 |
| | 772.6 | 3.1 | 48 |

In all, 28 levels were assigned to $^{97}$Tc, in contrast to the 10 levels reported by Phelps and Sarantites.[9] The levels at 96.5, 216, 324, 574, 657, 785, 855, 969, and 994 keV are in agreement with those of Ref. 9 except for the 477.7-keV peak, which was somewhat obscured by the 483.2-keV transition seen in this work, and the 898.0-keV transition, which was not observed in this experiment.

The 807- and 1173-keV levels are established only by coincidence spectra from the gate on the 483.2-keV transition and were seen in neither $\beta$ decay[9] nor time-of-flight measurements.[10,11] The coincidence data, however, establish the 468.5-keV transition from the 1277-keV level to the 807-keV level, and the existence of the 1277-keV state is substantiated by the strong coincidence of the 620.2- and 560.1-keV $\gamma$ rays and the 1268± 8-keV state observed by Kim *et al.*[10] The assignment of a level at 807 keV, therefore, appears to be justified by the above statements.

The 833-keV state is suggested by the possibility that there exists a doublet at 615.3 and 616.7 keV

TABLE IV. Excitation energies $E_x$ of states in $^{97}$Tc.

| Level No. | Present work ±1 (keV) | $^{97}$Ru($\beta, \gamma$)$^{97}$Tc Ref. 9 (keV) | $^{97}$Mo($p,n$)$^{97}$Tc Ref. 10 (keV) |
|---|---|---|---|
| 1 | 96.5 | 96.5 | 101 |
| 2 | 216 | 215.71 | 213 |
| 3 | 324 | 324.49 | 328 |
| 4 | 574 | 574.2 | 575 |
| 5 | 657 | 656.82 | 662 |
| 6 | 785 | 785.05 | 785 |
| 7 | 807 | | |
| 8 | (833) | | |
| 9 | (850) | | |
| 10 | 855 | 855.45 | 857 |
| 11 | 896 | | |
| 12 | 940 | | 941 |
| 13 | | (946.5) | |
| 14 | 969 | 969.79 | 962 |
| 15 | 994 | 994.69 | (987) |
| 16 | 1049 | | 1050 |
| 17 | 1127 | | |
| 18 | 1141 | | 1134 |
| 19 | 1173 | | |
| 20 | 1200 | | 1202 |
| 21 | 1220 | | |
| 22 | (1240) | | 1234 |
| 23 | 1277 | | 1268 |
| 24 | 1311 | | |
| 25 | 1380 | | 1376 |
| 26 | (1410) | | (1407) |
| 27 | (1513) | | 1517 [a] |
| 28 | 1523 | | |
| 29 | 1580 | | 1580 |

[a] At least a doublet.

and, hence, that the 616.7-keV transition is in coincidence with that at 215.8 keV, as discussed in the previous section. The existence of a transition at 833.2 keV lends further support to the existence of a level of that energy, especially since the coincident 547.0-keV transition comes from the 1380-keV level, which is established by the coincidence of the 1163.9- and 215.8-keV $\gamma$ rays and the 1376 ± 8-keV level seen by Kim *et al.*[10]

As discussed in the previous section, the 849.6-keV transition is believed to come from an isomeric level at 850 keV and is not a transition from a level at 946.5 keV to the 96.5-keV state, as indicated by Phelps and Sarantites.[9] It is felt that such a transition would more likely go to the ground state rather than to the isomeric level at 96.5 keV. Further evidence is the clear establishment by coincidence data of a state at 940± 1 keV and, hence, agreement with Kim *et al.*,[10] who observed a state at 941± 9 keV. The existence of another level at 946.5 keV is considered doubtful.

Other new levels established by the coincidence data and consistent with the work of Kim *et al.*[10] are as follows: 1049, 1200, 1523, and 1580 keV, in addition to the states at 1127 and 1141 keV, which correspond to the single level at 1134± 8 keV in Ref. 10. The 1311-keV state is also supported by the coincidence spectra and is in good agreement with the 1.32-MeV state observed by Riley *et al.*[11] The 1173- and 1220-keV states, which have not been reported previously, are substantiated by the coincidence data and the existence of a 1220.1-keV transition in the singles spectra. The weak coincidences of the 582.7- and 560.1-keV transitions and the 1194.3- and 215.8-keV transitions were used in conjunction with the $^{97}$Mo($p$, $n$) data of Kim *et al.*[10] to indicate the strong possibility that levels exist at 1240 and 1410 keV. Finally, a level fitting program was used to place $\gamma$ transitions which did not appear in the coincidence spectra on the level scheme. The fact that four transitions were consistent with a level at 1513 keV plus the indication by Kim *et al.*[10] that a doublet exists at approximately 1517 keV gave reasonable evidence of a level at 1513 keV.

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*Note added*: P. D. Bond[15] has recently reported levels seen in the Coulomb excitation of $^{97}$Mo at 659.0 and 1024.6 keV which could possibly account for $\gamma$ rays of those energies seen in our spectra. This, however, would alter the level diagram of $^{97}$Tc shown in Fig. 8 little.

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