Radioactive Isotopes of Mo and Tc

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Evidence is presented which permits the assignment of a 4.3-day Tc activity to Tc^{96}. It decays by K-capture. X-ray photographs of long-period Tc activities show Mo x-rays resulting from K-capture decay of a 52-day Tc activity. Tc x-rays resulting from an isomeric transition involving a 95-day Tc^{97*} activity were also photographed.

I. 67-HOUR Mo^{99} AND 4.3-DAY Tc^{96}

A 4.6–DAY Tc activity which decays by K-capture has been produced[1] by proton bombardment of Mo. Gamma-rays of energy 0.05 Mev and 0.5 Mev and beta-rays of energy 0.6 Mev were found to be associated with the activity. A Tc activity with a period of approximately 2 days was also reported.[2] It was produced by deuteron bombardment of Mo and strong x-rays characteristic of Mo were found.

A 67-hour activity assigned to Mo^{99} has been produced by the reactions $Mo(d, p)$[2], $Mo(n, \gamma)$[2,3], $Mo(n, 2n)$[2,3], $Zr(\alpha, n)$[4,5] and is found in fission products from U and Th.[5–8] The isotope, with

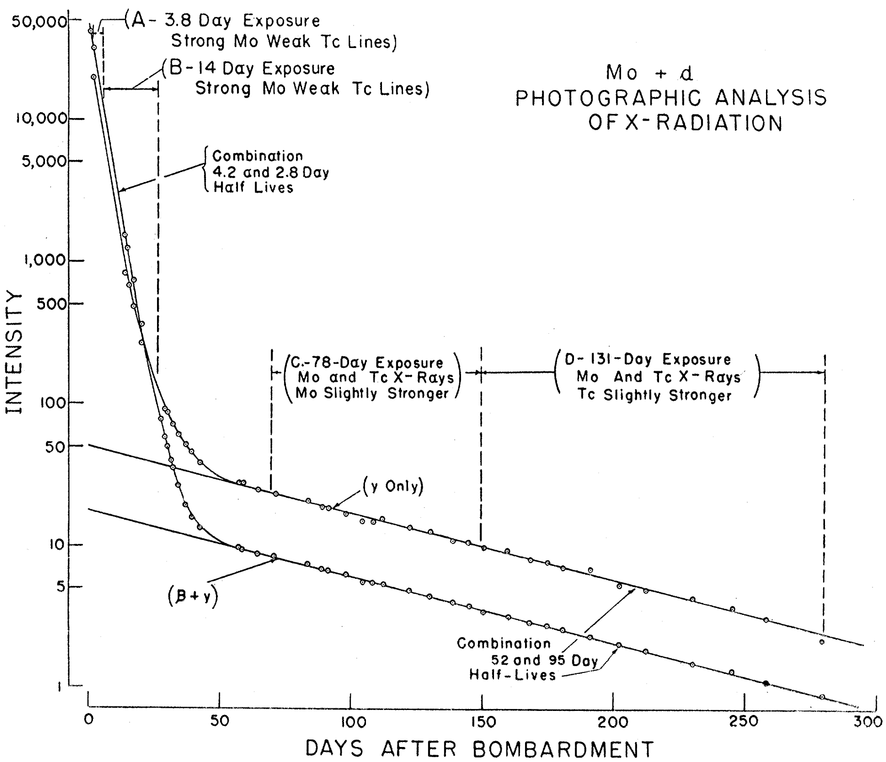

FIG. 1. Decay curves from Mo+d showing procedure of x-ray photography.

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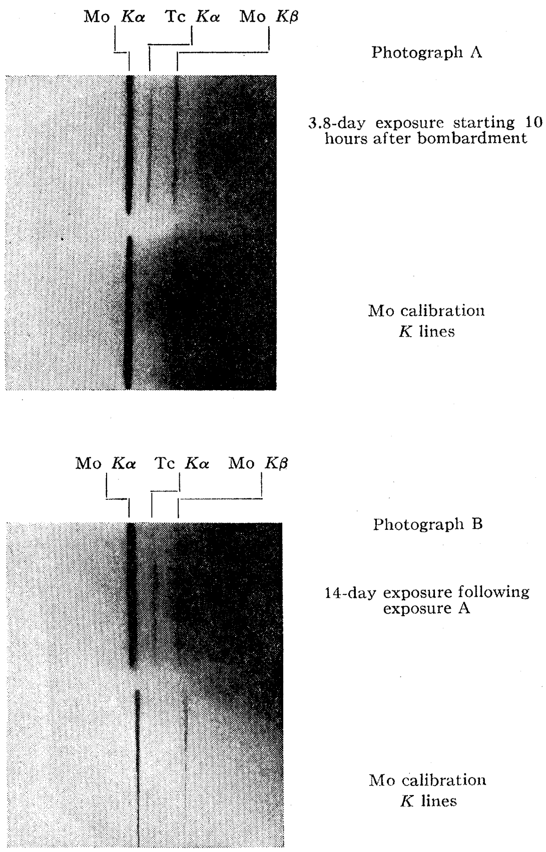

FIG. 2. Photographs of the combination of 4.3-day Tc^{96} and 67-hour Mo^{99}.

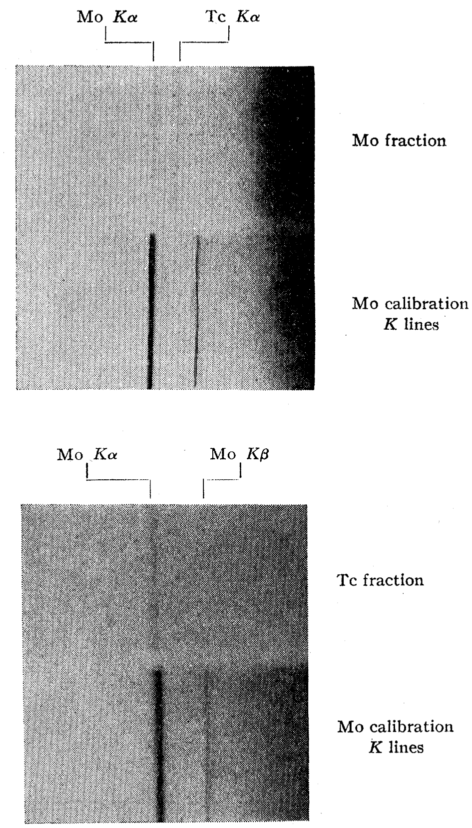

FIG. 3. Exposures of 11 days; chemical fractions from Mo+d were used. Exposures started 10 hours after bombardment.

characteristic radiations of 1.5 and 1.2-Mev β-particles and gamma-rays of 0.4, 0.24, and 0.75 Mev, decays to a 6-hour daughter product Tc^{99*}. The 6-hour activity with the emission of 0.136 and 0.18-Mev gamma-rays and conversion electrons drops to the ground state,[5] 4×10^6 year Tc^{99}. The K and L conversion electrons[9] and x-rays[10] characteristic of Tc have been identified photographically.

4.3-day Tc and 67-hour Mo^{99} activities are both produced by deuteron bombardment of Mo. A study of the x-rays associated with the decay of these isotopes and long-lived Tc isotopes was undertaken using curved mica crystal spectrographs.[11] A deuteron activated Mo sample was photographed for a total of 422 days. Five successive photographs were made. The photographic procedure for the first 4 photographs is shown in Fig. 1. Photographs A and B (Fig. 2) were obtained while the 67-hour Mo^{99} and the 4.3-day Tc were predominant in the activity. Very strong Mo K lines and a weak Tc K line are found in both photographs. The absence of any marked difference in the relative intensities of the Mo $K\alpha$ and Tc $K\alpha$ lines indicates that the sources of the Mo and Tc x-rays have half-lives of the same order of magnitude.

In order to identify the atomic number of the x-ray sources in photographs A and B, photographs of the Mo and Tc chemical fractions from a deuteron-activated Mo sample were obtained (Fig. 3). The exposures were made in similar spectrographs for 11 days, starting 10 hours after bombardment. The Tc fraction showed strong

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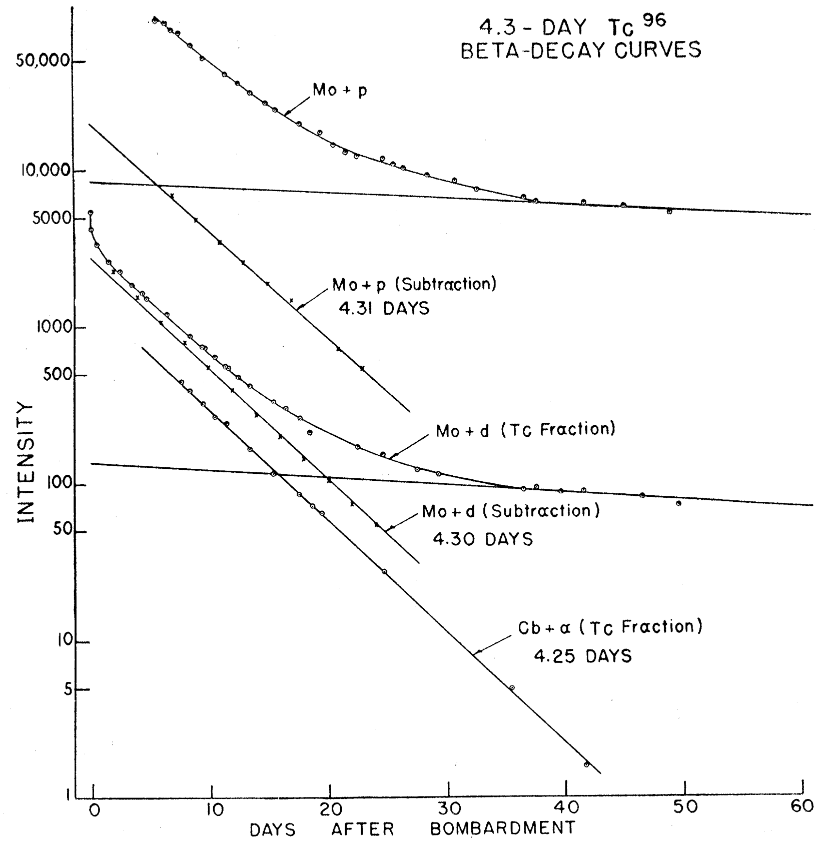

FIG. 4. Decay characteristics of the total radiation from 4.3-day Tc^{96}.

Mo lines while weak Mo and Tc x-rays were found in the Mo fraction. A small amount of Tc in the Mo fraction was responsible for the weak Mo $K\alpha$ line. Additional exposures of the two fractions for 14 days gave no lines from the Mo fraction and a very weak Mo $K\alpha$ line from the Tc fraction. These experiments demonstrate that Mo x-rays are associated with a Tc activity of a

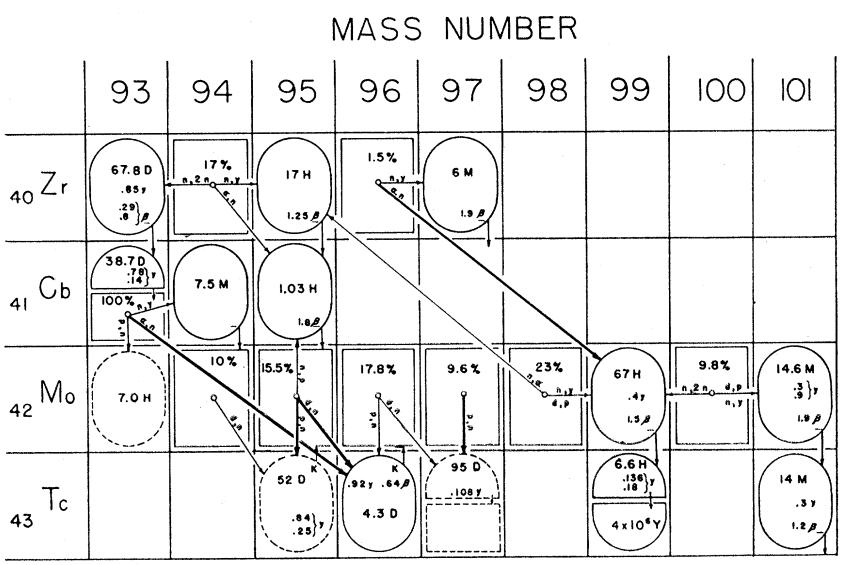

FIG. 5. Section of the atomic chart.

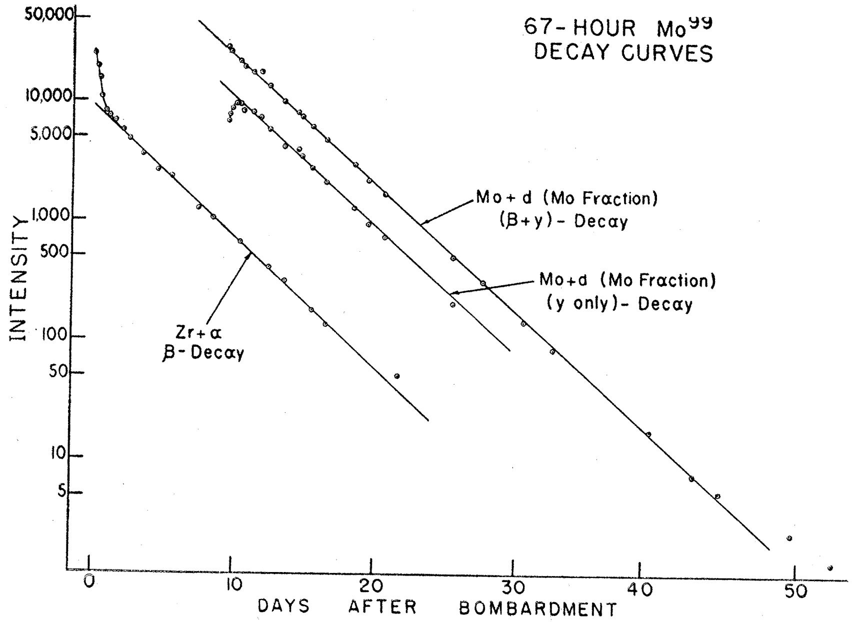

FIG. 6. Decay characteristics of 67-hour Mo^{99}.

few days half-life and Tc x-rays are associated with an Mo activity also of a few days half-life.

Decay characteristics (Fig. 4) and radiation energies of a 4.3-day Tc activity were obtained. The decay characteristics from $Mo+p$, $Mo+d$ (Tc fraction), and $Cb+\alpha$ (Tc fraction) all show half-lives of nearly 4.3 days. This 4.3-day activity can thus be definitely assigned to Tc^{96}. Long-period activities were also present in the $Mo+p$ and the $Mo+d$ (Tc fraction) samples but no activity longer than 4.3-days half-life was observed in the $Cb+\alpha$ (Tc fraction) sample. By Al and Pb absorption measurements 4.3-day Tc^{96} was found to emit x-rays characteristic of the Mo region, 0.64-Mev charged particles in agreement[1] with other work, and gamma-rays of energy 0.92 Mev. The photographic evidence of Mo x-rays associated with this activity leaves no doubt that it decays mainly by *K*-electron capture (Fig. 5).

The Tc x-rays (Fig. 3) associated with 67-hour Mo^{99} are due to internal conversion of a gamma-ray as the 6-hour daughter product, Tc^{99*}, drops to the ground state, 4×10^6 year Tc^{99}. Sixty-seven-hour Mo^{99} was produced by deuteron bombardment of Mo and by alpha-bombardment of Zr (Fig. 6). A rise of 6-hour period was observed in the gamma-radiation of the Mo fraction immediately after chemical separation from Tc. Half-life values and radiation energy measurements on Mo^{99} and Tc^{99*} are in agreement with other work.[2,10] No activities of half-life longer than 67 hours were observed in Mo.

II. LONG-PERIOD ACTIVITIES IN Tc

Long-period Tc activities (90 days and 62 days) have been produced by deuteron bombardment[2,12–14] of Mo. The 62-day activity emits x-rays characteristic[2,14] of Mo while radiations from the 90-day activity are thought to be Tc x-rays[14] and conversion electrons.[15] Two converted gamma-rays in the long half-life activities have energies[15] of 0.087 Mev and 0.184 Mev. Evidence of the growth of the 90-day Tc activity from 2.8-day Ru^{97} has been reported,[16,17] permitting its assignment to Tc^{97}.

X-rays associated with long half-life activities after deuteron activation of Mo were photographed according to the procedure shown in Fig. 1. Exposures C and D (Fig. 7) were obtained with a mica crystal curved to a radius of 8 inches. Mo $K\alpha$ and Tc $K\alpha$ lines appear in both the 78-

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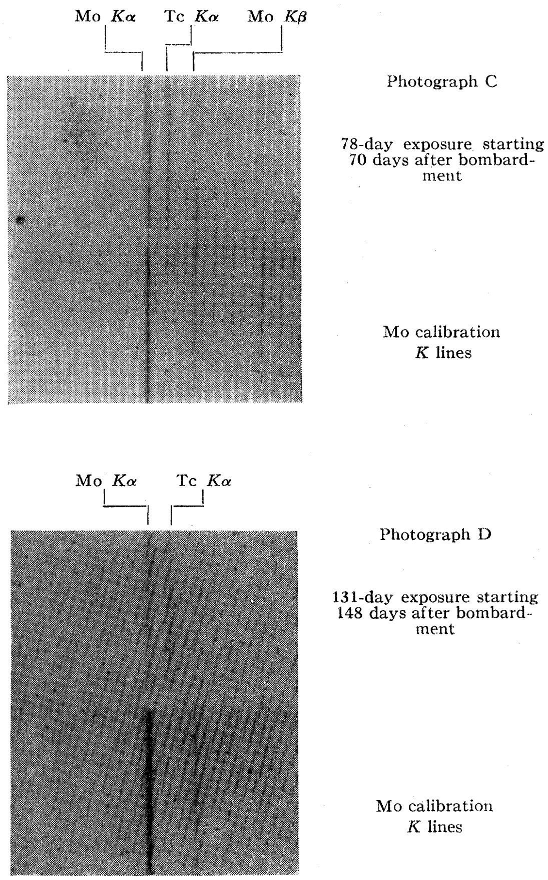

FIG. 7. Photographs of long-period Tc activities.

day exposure and the 131-day exposure with approximately the same intensity. However, it is quite evident from the original films that the Mo $K\alpha$ line in exposure C is slightly stronger than the Tc $K\alpha$ line, while in the later photograph, D, the Tc $K\alpha$ line is slightly stronger. A third exposure of 195 days following exposure D showed a very faint Tc $K\alpha$ line, but no Mo lines. From these three photographs it is obvious that the source of the Mo x-rays was decaying faster than the source of the Tc x-rays. To explain these two x-rays arising from Tc activities one must assume two activities in Tc of slightly different period. The shorter period decays by K-capture giving Mo x-rays, while the longer period Tc x-rays must result from converted gamma-radiation in an isomeric transition in Tc. The two activities cannot be genetically related since the Mo x-ray intensity dropped below the Tc x-ray intensity in the later photographs and no positrons were observed.

Decay characteristics followed for 900 days show two Tc activities fairly well resolved having half-lives of 95±5 days and 52±3 days (Fig. 8). The activities were produced by deuteron bombardment of Mo and by proton bombardment of Mo. Radiation energies from these two activities obtained by Pb and Al absorption measurements show two groups of soft electrons (Fig. 9), x-rays

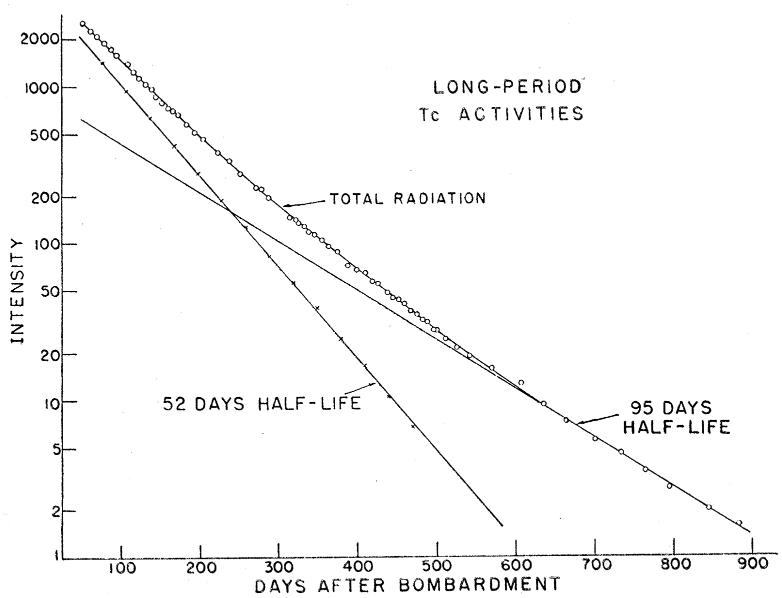

FIG. 8. Decay characteristics of long-period Tc activities.

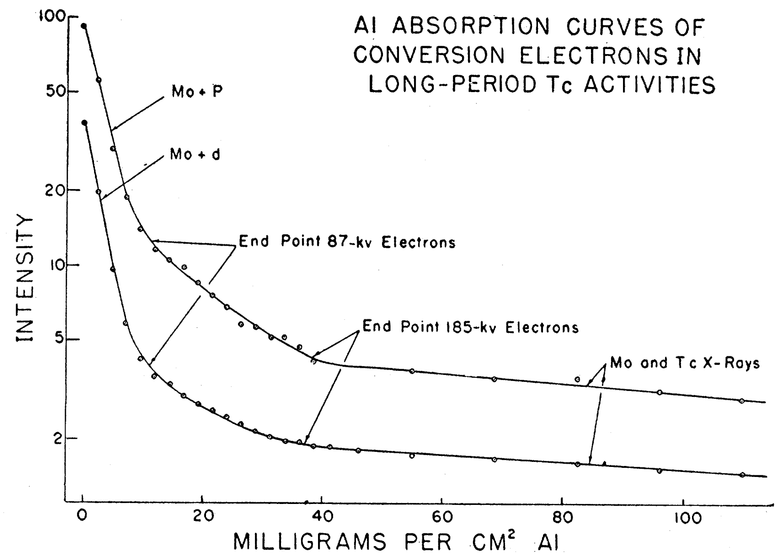

FIG. 9. Thin aluminum absorption of radiations from long-period Tc activities.

characteristic of the Mo–Tc region, and two gamma-rays of energy 0.84 Mev and 0.25 Mev. The soft electron groups are no doubt the conversion electrons previously reported.[15] Since the strong Tc x-rays following the longer 95-day half-life arise from an internally converted gamma-ray, the more intense 87-kv electrons should be associated with this activity. The evidence presented here requires the assignment of the 95-day Tc activity to a metastable state in Tc (Fig. 5). In the isomeric transition which occurs a 0.108-Mev gamma-ray is strongly internally converted giving rise to the Tc x-rays. This interpretation requires the existence of another stable or very long-lived isotope in Tc. Such a long-lived isotope could logically be placed at Tc^{97} permitting the assignment of the 95-day isotope to Tc^{97*} in agreement with previous work.[17]

Observations on the gamma-ray decay characteristics indicate that the hard gamma-rays follow the 52-day half-life. This activity decays by K-capture with associated gamma-rays of 0.84 Mev and 0.25 Mev and is tentatively assigned to Tc^{95} (Fig. 5).

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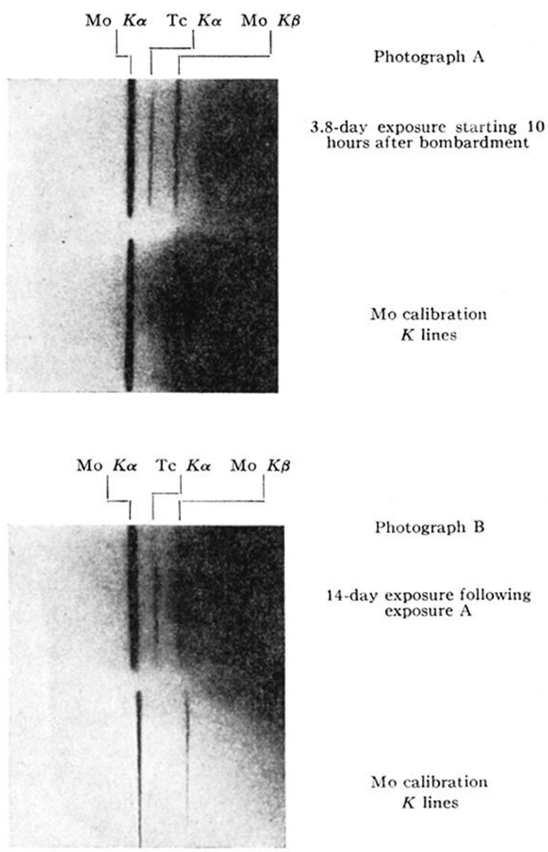

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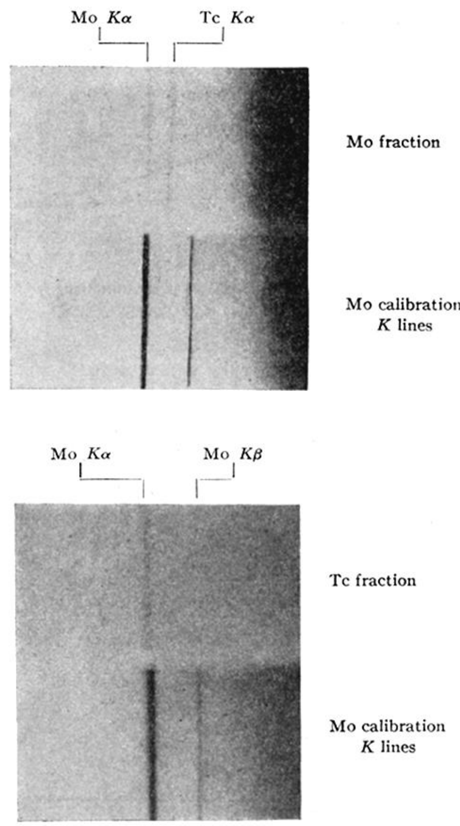

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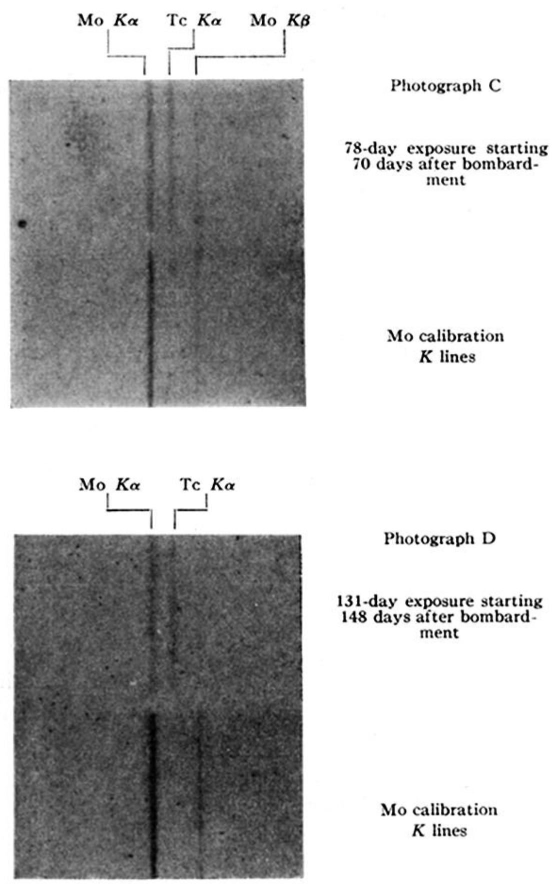

FIG. 7. Photographs of long-period Tc activities.