# Radioactive Scandium. II

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*$Sc^{47}$:* This radioactive isotope has been reported to have a half-life of 2.62 days and to emit 1.1 Mev electrons. These observations are not confirmed. A new radioactive isotope has, however, been produced by bombarding calcium with alpha-particles and to some extent by bombarding calcium with deuteron and proton. It emits beta-rays of 0.46 Mev and has a half-life of 3.4 days. The assignment is made to $Sc^{47}$.

*$Sc^{48}$:* This isotope has been produced by the reactions $Ca^{48}(p, n)$, $Ca^{48}(d, 2n)$, $Ti^{48}(n, p)$, and $V^{51}(n, \alpha)$. From the $V^{51}(n, \alpha)$ reaction gamma-rays of 1.33 Mev and beta-rays of 0.57 Mev were observed and from the $Ca^{48}(p, n)$ reaction gamma-rays of 1.35 Mev and beta-rays of 0.57 Mev were observed. Relative saturation intensities have been calculated for $Sc^{43}$, $Sc^{44}$, $Sc^{47}$, and $Sc^{48}$ when produced by proton, deuteron, alpha-particle, and fast neutron bombardments. $Sc^{48}$ was produced free of $Sc^{44}$ by the $V^{51}(n, \alpha)$ and the $Ca^{48}(p, n)$ reactions. Electrons of 0.57 Mev and gamma-rays of 1.33 Mev were observed. $Sc^{48}$ emits approximately 14 gamma-rays per electron. All reactions associated with the scandium region are schematically summarized in a nuclear transmutation chart.

## $Sc^{47}$

A RADIOACTIVE isotope of scandium has been reported which decays with a half-life of $63\pm2$ hours.[1] Beta-rays of 1.1 Mev were observed. Gamma-rays were detected, but it was not certain that the 63-hour period emitted them. This period was tentatively assigned to $Sc^{47}$.

In the present investigation, although several attempts were made to produce this isotope, it was not observed.

A new radioactive isotope, however, has been produced by bombardments of calcium with alpha-particles. Various target holders made of copper, platinum, or gold were used in order to eliminate possible target-holder impurities in the scandium fraction.

Figure 1 shows the results obtained for a short bombardment (4 hours) and a long bombardment (2 days); the half-life period is 3.40 days.

Electrons of maximum energy 0.46 Mev were measured by absorption in aluminum. One of the absorption curves is shown in Fig. 2. Gamma-rays, if present, were too weak to measure.

The assignment of this period to $Sc^{47}$ has been made for the following reasons: This radioactive isotope is most easily produced by bombarding calcium with alpha-particles. Since $Ca^{44}$ is the second most abundant stable isotope of calcium, it is probably the one from which the new isotope is produced. Neither alpha-particle bombardments of potassium nor fast neutron bombardments of scandium produced the 3.4-day period. Therefore, an assignment to $Sc^{42}$ or $Sc^{44}$ is improbable. The 3.4-day period could not be expected at $Sc^{45}$ or any scandium isotope of lighter mass, since no positrons nor gamma-rays were observed. $Sc^{46}$ is eliminated by the fact that $Sc^{45}(d, p)$ and $Sc^{45}(n, \gamma)$ reactions failed to produce the isotope. A $V^{51}(n, \alpha)$ reaction produced only one period, the 1.83-day period which is obviously assigned at $Sc^{48}$.

The 3.4-day period has been also produced, although weakly, by bombarding calcium with protons and with deuterons.

The following reactions have, therefore, been established:

$$Ca^{44}+\alpha\rightarrow Sc^{47}+p$$
$$Ca^{46}+d\rightarrow Sc^{47}+n$$
$$Ca^{46}+p\rightarrow Sc^{47}+\gamma.$$

## $Sc^{48}$

A half-life period of 1.83 days was first assigned to $Sc^{48}$ by Walke.[2] Later by bombarding titanium and vanadium metals with fast neutrons he was able to make absorption measurements to deter-

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[1] H. Walke, Phys. Rev. **57**, 163 (1940).
[2] H. Walke, Phys. Rev. **52**, 777 (1937).

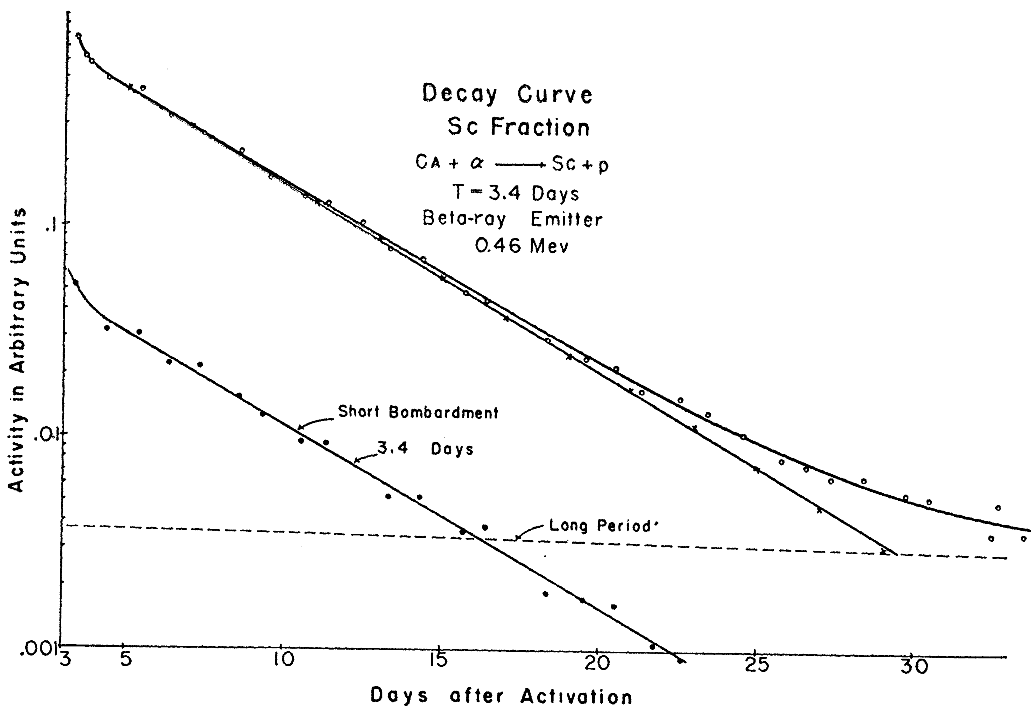


FIG. 1. $Sc^{47}$: Decay curve showing a half-life of 3.4 days for beta-rays.

mine the energies of the beta-rays (electrons) and of the gamma-rays. Two groups of beta-rays, one of 0.5 Mev (90 percent) and another of 1.4 Mev

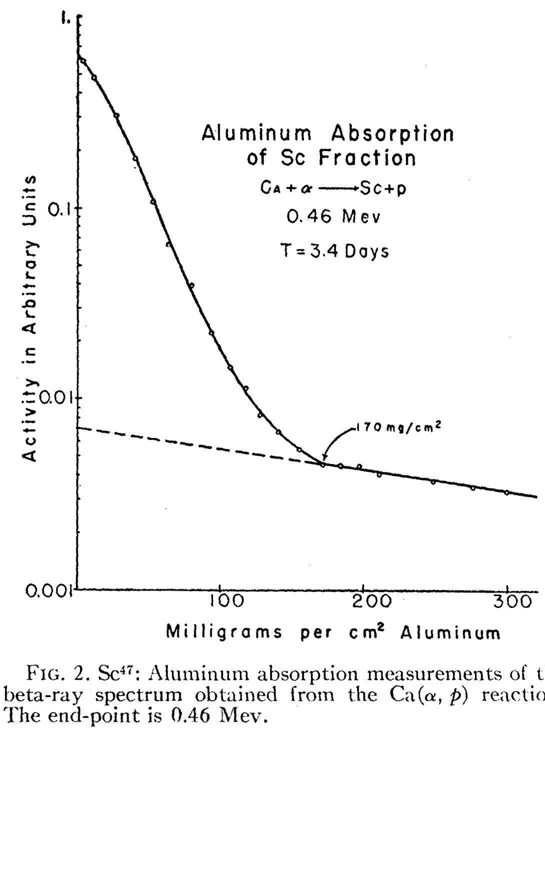


FIG. 2. $Sc^{47}$: Aluminum absorption measurements of the beta-ray spectrum obtained from the Ca(α, *p*) reaction. The end-point is 0.46 Mev.

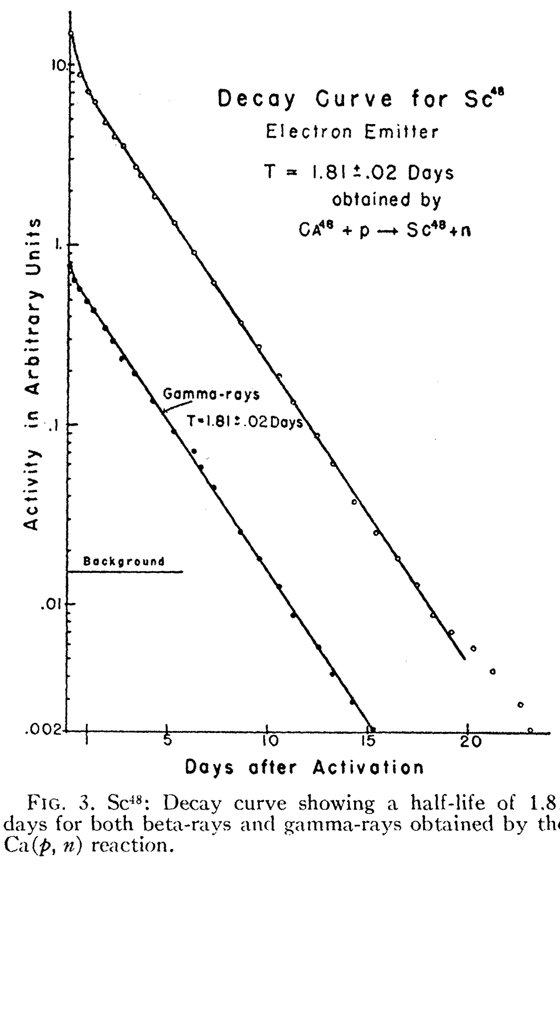


FIG. 3. $Sc^{48}$: Decay curve showing a half-life of 1.81 days for both beta-rays and gamma-rays obtained by the Ca(*p*, *n*) reaction.

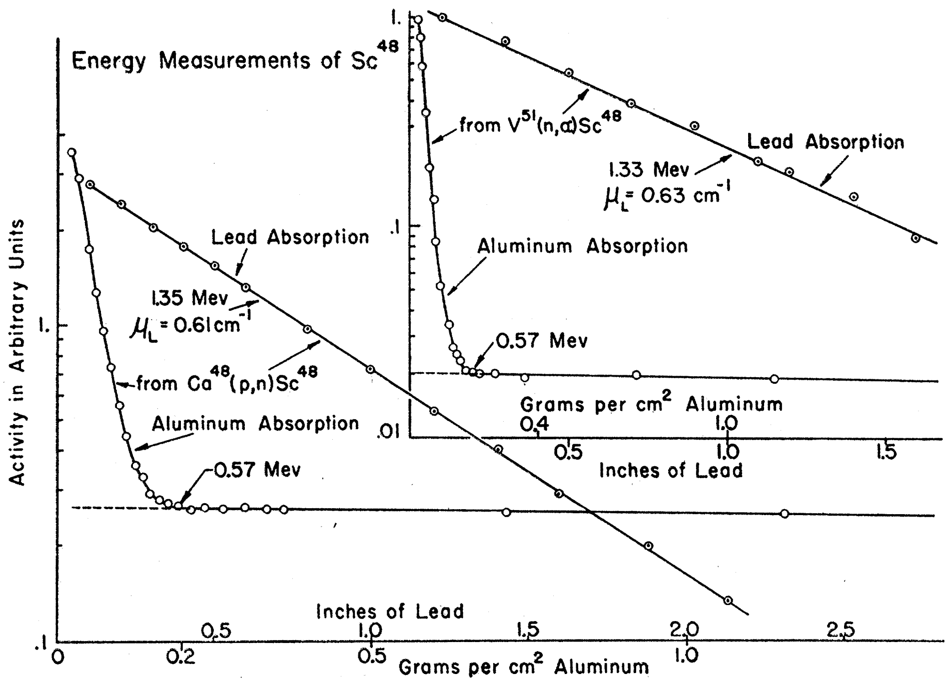


FIG. 4. $Sc^{48}$: Aluminum and lead absorption measurements showing a beta-ray end-point of 0.57 Mev, and a gamma-ray energy of 1.35 Mev.

(10 percent), were reported. A gamma-ray of 0.9 Mev energy was also reported.

In the present work, long bombardments with fast neutrons were made. In order to increase the amount of vanadium in the target material, vanadium pentoxide was pressed into small pellets under great pressure. In this way sufficient activity was obtained to follow the decay for ten half-lives from which the half-life was found to be 1.83 days for both gamma-rays and electrons.

By lead absorption measurements, a gamma-ray of 1.33 Mev was observed, which is the same energy as was found for the 3.92-hour period of $Sc^{44}$. An aluminum absorption measurement shows that only one group of electrons of maximum energy of 0.57 Mev is present.

Having determined the characteristics of $Sc^{48}$ by the $V^{51}(n, \alpha)$ reaction, which produced $Sc^{48}$ free of $Sc^{44}$, it was then found that $Sc^{48}$ is also produced free of $Sc^{44}$ by bombarding calcium with 5 Mev protons as shown in Fig. 3. For both the gamma-rays and electrons a half-life of $1.81 \pm 0.02$ days was calculated. Absorption measurements with aluminum indicate electrons of the same energy as for $V^{51}(n, \alpha)$ reactions. By absorption in lead the energy of the gamma-rays was found to be 1.35 Mev. Absorption measurements for both bombardments are shown in Fig. 4.

By the method of semicircular focusing of Compton recoils in a magnetic spectrograph Mandeville has likewise found gamma-rays which he attributed to decay of $Sc^{48}$. His measurements indicate a quantum energy of 1.35 Mev.[3]

Electrons of 0.64-Mev energy attributed to $Sc^{48}$ have been reported by Smith.[4] These measurements were made with a magnetic beta-ray spectrometer on scandium fractions from calcium bombarded with deuterons.

Fast neutron bombardments of titanium produce weak $Sc^{48}$ activities.

In all bombardments, the ratio of the intensity of the ionization produced by the beta-rays to that by the gamma-rays is approximately 15, which corresponds to an emission of about 14 gamma-rays per electron.

*K*-electron capture is therefore strongly suggested in lieu of many excited titanium nuclear

[3] C. E. Mandeville, Phys. Rev. **62**, 555 (1942); **64**, 147 (1943).

[4] Gail P. Smith, Phys. Rev. **61**, 578 (1942).

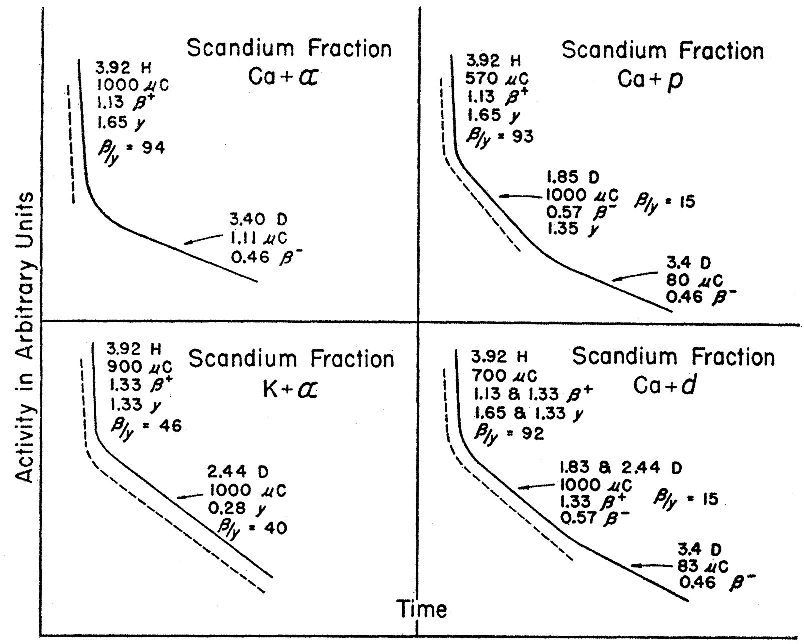


FIG. 5. Schematic summary of relative saturation intensities of various scandium periods obtained by various reactions.

levels.[5] This suggestion was given support by several absorption measurements which were made with the inverted electrometer and the thinnest pieces of aluminum and beryllium obtainable. Characteristic x-rays associated with $K$-electron capture for this region are of the order of 3A. The experimental values obtained ranged between 2.4A and approximately 3A.

## RELATIVE INTENSITIES

All of the radioactive periods and their relative intensities are schematically shown in Fig. 5. Solid lines represent typical decay curves for beta-rays and broken lines, gamma-rays.

Relative intensities, as calculated for infinite bombardment, are indicated on the arbitrary basis of 1000 for the most intense half-life period produced. The ratio of the intensity of the beta-rays to the intensity of the gamma-rays is indicated for each half-life period.

Two main periods were produced by alpha-particle bombardments of calcium. The 3.4-day period of $Sc^{47}$ and the 3.92-hour period of $Sc^{43}$ have saturation intensities of 1.11 and 1000, respectively. The latter is the most intense period of scandium and may have an initial intensity 30,000 times background.

The isomers of $Sc^{44}$, when produced by the $K^{41}(\alpha, n)$ reaction, are found to have approximately equal saturation intensities; namely 900 for the 3.92-hour period and 1000 for the 2.44-day period.

$Sc^{48}$ was the main isotope produced by 5 Mev proton bombardments of calcium. $Sc^{43}$ was also

TABLE I. Summary of results.

| Active isotope | Observed periods | Produced by | Energy of beta-rays in Mev | Energy of gamma-rays in Mev |
|---|---|---|---|---|
| $Sc^{42}$ | Not observed | | | |
| $Sc^{43}$ | 3.92 hours | Ca-$\alpha$-$p$<br>Ca-$p$-$n$<br>Ca-$d$-$n$<br>Ca-$d$-$2n$ | 1.13(+) | 1.65 |
| $Sc^{44}$ | 3.92 hours | K-$\alpha$-$n$<br>Sc-$n$-$2n$<br>Ca-$d$-$n$<br>Ca-$d$-$2n$ | 1.33(+) | 1.33 |
| | 2.44 days | | | 0.28 |
| $Sc^{47}$ | 3.40 days | Ca-$\alpha$-$p$<br>Ca-$d$-$n$<br>Ca-$p$-$\gamma$ | 0.46(−) | |
| $Sc^{48}$ | 1.83 days | V-$n$-$\alpha$<br>Ti-$n$-$p$<br>Ca-$d$-$2n$<br>Ca-$p$-$n$ | 0.57(−) | 1.33 |

[5] Ernest Pollard, Phys. Rev. **54**, 411 (1938).

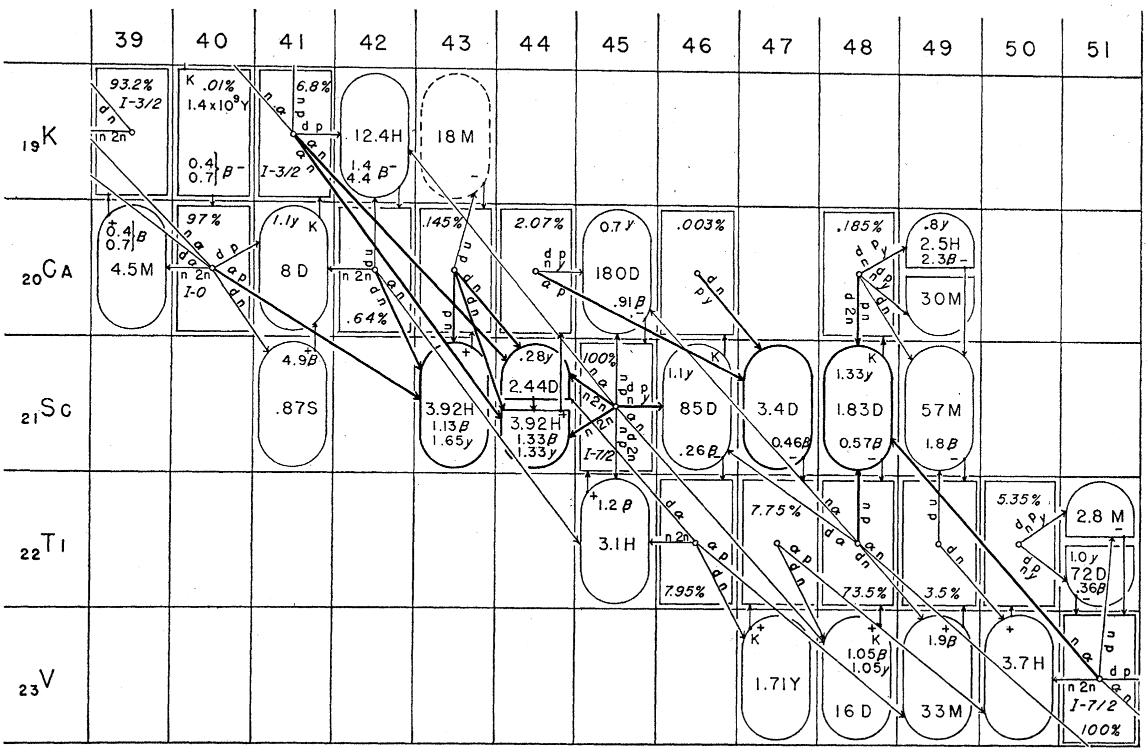


FIG. 6. Transmutation chart showing the scandium region and reactions leading to radioactive scandium isotopes.

produced, but no evidence was found to indicate $Sc^{44}$; however, a weak period of 3.4 days due to $Sc^{47}$ was present. The saturation intensities of these isotopes, $Sc^{48}$, $Sc^{43}$, $Sc^{44}$, and $Sc^{47}$, are, respectively, 1000, 570, 0, and 80.

Deuteron-bombardments of calcium produced several radioactive isotopes of scandium, namely $Sc^{43}$, $Sc^{44}$, $Sc^{47}$, and $Sc^{48}$. $Sc^{48}$ was the main isotope produced and was approximately seven times as intense as $Sc^{44}$. The composite decay curve of these activities is so complex that an attempt to discover the individual periods by subtractions could only fail. The half-life discrepancies reported in the literature based upon deuteron bombardments may in this way be reconciled.

The saturation intensity of the $Sc^{43}$ 3.92-hour period plus the $Sc^{44}$ 3.92-hour period is 700. The intensities of the 1.83-day period of $Sc^{48}$ plus the 2.44 day period of $Sc^{44}$ is 1000. The 3.4-day period of $Sc^{47}$ has an intensity of 83.

The results of this investigation and that reported earlier[6] are summarized in Table I and Fig. 6.

**ACKNOWLEDGMENT**

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[6] Hibdon, Pool, and Kurbatov, Phys. Rev. **67**, 289 (1945).