the need to make more specific calculation of P_t. We take

$$P_t = 0.00 \pm 0.05. \qquad (15)$$

(e) Calculation of σ_c (theor)

Upon assembling the values from the preceding subsections, the result is found to be

$$\sigma_c(\text{theor}) = (0.303 \pm 0.006)(1 - 0.326 dP_D - 0.112 d\rho_s + 0.140 dP_t)\ \text{b}, \qquad (16)$$

the more interesting errors being displayed explicitly in (16). The error in the leading coefficient comes from the factors not explicitly displayed and is due to the uncertainties in a_s, $\rho_t(0, -\epsilon)$, and γ, each contributing roughly the same amount.

If the various numerical estimates of error are inserted in (16) and combined on a random basis, the final result is

$$\sigma_c(\text{theor}) = (0.303 \pm 0.012)\ \text{b}, \qquad (17)$$

this to be compared with the measured value

$$\sigma_c(\text{exp}) = (0.3315 \pm 0.0017)\ \text{b}.$$

III. CONCLUSIONS

The interaction effect increase of the capture cross section appears well established. It has the value

$$(0.028 \pm 0.012)\ \text{b},$$

and is about ten percent of the uncorrected cross section. Such a large effect is entirely unexpected. Nevertheless it does not appear possible to manipulate ρ_s, the least known of the quantities in σ_c(theor), to such an extent as to make the effect disappear. Thus ρ_s would have to decrease to 1.86 to make the effect vanish, or to 2.20 to make the magnitude of the effect equal that of the estimated uncertainty. Evidently a direct measurement of ρ_s would be very helpful.

A large interaction effect change in a magnetic multipole is not impossible and does not violate "Siegert's theorem." Nevertheless the effect found is surprising. It is worthwhile to note that this effect cannot be attributed to the $(\mathbf{L}\cdot\mathbf{S})$ interaction between nucleons, as the magnetic dipole operator which that force implies has no matrix elements between the states in question.

Note added in proof.—It has been suggested that the *n-p* capture must have a contribution from the electric quadrupole transition from the continuum ^3S state to the ^3D part of the ground state. This quadrupole process does not interfere with the magnetic dipole process, hence it is expected to give a small change in the cross section. Explicit calculation shows the ratio of $E2$ and $M1$ cross sections to be about 10^{-9}, so the $E2$ cross section is negligible. We are grateful to Dr. C. J. Goebel for reminding us of the $E2$ process, and for discussions of its magnitude.

IV. ACKNOWLEDGMENT

It is a pleasure to acknowledge an extensive correspondence in 1954 and 1955 between M. Sugawara and N. Austern.

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Decay of Os^{182} and Os^{183}. I. Gamma and Beta Spectroscopy*

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Four activities, produced by the bombardment of tungsten with alpha particles having energies up to 48 Mev, were identified. They have half-lives of 9.9±0.3, 13.67±0.1, 21.1±0.3, and >500 hours. From the excitation functions and other measurements these are attributed to the decay of Os^{183m}, Os^{183}, and Os^{185}, respectively. Measurements on the gamma-ray spectra and conversion line spectra are reported. The spectra are complex, and a total of 251 conversion lines was observed. In many cases the decay of individual gamma rays and conversion lines was studied.

1. INTRODUCTION

UNTIL a short time ago the only information reported on the decay properties of the K-capturing nuclei Os^{182} and Os^{183} was that the half-lives were 24±1 hour and 12±0.5 hours (Stover[1]). More recently Foster, Hilborn, and Yaffe[2] reported a half-life of 21.9+0.1 hours for Os^{182} and two distinct half-lives of 15.4±0.3 hours and 10±1 hour for Os^{183}. They also report a number of transitions which they assign to these various decays.

The present work was undertaken because it was thought to be of interest to study nuclei in the transition

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* Work done under the auspices of the U. S. Atomic Energy Commission.

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[1] B. J. Stover, Phys. Rev. **80**, 99 (1950).

[2] J. S. Foster, J. W. Hilborn, and L. Yaffe, Can. J. Phys. **36**, 555 (1958).

region between those having large deformations and hence rotational states and those whose collective behavior appears to be described by oscillations about a spherical equilibrium shape. In fact it turns out that the lower lying levels of the nucleus Os^{183} can be described fairly well by the deformed nucleus model.

Certain discrepancies appear between the results of this work and that of Foster *et al.* No evidence was found for the existence of an isomeric state in Os^{187} with a half-life of 39 hours as reported by Greenlees and Kuo.[3] If this state exists it would be surprising that it was not seen in this work.

2. EXPERIMENTAL PROCEDURE

2.1 Preparation of the Sources

The sources were prepared by bombarding both natural metallic tungsten and separated isotopes of tungsten with alpha particles from the 60-inch Crocker laboratory cyclotron. Most of the work was done with the targets obtained from natural tungsten, the separated targets being used only for assignment confirmation.

The tungsten foils were dissolved in a fused mixture of 86% KOH and 14% KNO_3. This was then dissolved in water and transferred to a distilling flask. Nitric acid was added drop by drop to the solution until a yellow precipitate of tungstic acid was observed. The mixture was gently heated and osmium, which had been oxidized to the volatile tetroxide by the nitrate ions, was distilled off. It was collected in a small amount of 0.1-M ammonium bisulphate solution buffered to a pH of 3.6 and cooled in ice. A gamma-ray survey meter placed close to the receiver was used to follow the progress of the distillation. The osmium first began to distil over as drops of water began to be consdensed at the top of the still. The distillation was stopped after about 80% of the osmium had been collected; the solution in the receiver was at that time about 0.03 M in NH_4 HSO_4 and had a *p*H of about 1.

Since very few water soluble inorganic substances will distil over at the boiling point of water this is a very effective method of purification and moreover it produces a carrier free source. Trouble may arise however when an oxide target has been bombarded. In this case 112-min F^{18} is formed, presumably from the $O^{16}(\alpha,d)F^{18}$ or $O^{16}(\alpha,pn)F^{18}$ reactions, and this can distill over. It does not cause trouble for measurement of conversion electrons but does for measurements of gamma spectra since it decays by positron emission and therefore produces 510-kev annihilation radiation.

The sources for the spectrographs were prepared by electrodeposition from the buffer solution; a current of 150 ma for about 10 minutes was used. Those for the permanent magnet spectrographs were deposited on 0.01-inch diameter platinum wire in the manner described by Smith and Hollander.[4] The sources for the double focusing spectrometer were deposited onto nickel or stainless steel strips approximately 0.5 inch by 0.08 inch wide by 0.001 inch thick. It is preferable to use materials having lower Z than platinum as backings because they cause less backscattering of the electrons. The effect of back-scattering becomes more serious as the resolution of the spectrometer becomes less. There was however a difficulty associated with the use of these backing materials which did not apply to platinum. This was that a black deposit sometimes appeared on the backing material during the electrodeposition; it had the effect of thickening the source and also of limiting the amount of activity which could be deposited. The reason for the appearance of this black deposit in some cases and not in others was not clear. Stainless steel was somewhat better than nickel from this point of view. Sources for the lens spectrometer were deposited onto stainless steel or nickel backings approximately $\frac{1}{8}$ inch in diameter by 0.001 inch thick; these were held in position by scotch tape.

2.2 Electron Spectroscopy

Three different types of instruments were used to detect the conversion electrons. These were permanent magnet spectrographs, a double focusing spectrometer and a lens spectrometer.

The permanent magnet spectrographs have 180° focusing and photographic recording and were used for the accurate energy measurements. This type of spectrograph has been described previously by Smith and Hollander.[4] Six spectrographs of this type with different magnetic fields varying between 50 gauss and 400 gauss were used in this work so that all parts of the conversion line spectrum could be covered with optimum resolution, which was about 0.1%. The sources were carrier free and deposited on 0.01-inch diameter platinum wires by a method previously described. The errors on the energy measurements are expected to be ±0.1% when a spectrograph has been calibrated with an external standard and ±0.05% when it has been calibrated with an accurately measured internal standard.

Estimates of relative intensities can also be made if the photographic plates are scanned by a recording densitometer. In order to obtain the intensities from the densitometer traces it is necessary to assume a relation between (a) the density and exposure time (b) the efficiency of the film and electron energy, and (c) the electron intensity at the film and the orbit radius. For (a) a semiempirical curve of Hollander has been taken and for (b) and (c) the data and procedure by Smith and Hollander[4] and by Mladjenovic and Slätis[5] have been used. Considerable errors may appear in these intensity determinations. Examples of some

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[3] G. W. Greenlees L. G. Kuo, Phil. Mag. **1**, 973 (1956).

[4] W. G. Smith and J. M. Hollander, Phys. Rev. **101**, 746 (1956).

[5] M. Mladjenovic and H. Slätis, Arkiv Fhsik. **8**, 65 (1954).

of the sources of such errors are: local variations of film thickness, variations between the properties of one batch of film and another, errors in the setting up of the densitometer, source thickness etc. Also, because of the rapid variation of photographic efficiency with electron energy below about 50-kev, intensity measurements below this energy are most unreliable; the effect of source thickness is also greatest in this region. A rough estimate of the accuracy of measurements of this type above 50-kev electron energy is ±20% (standard deviation).

An alternative method of obtaining the relative intensities from the films without the use of a densitometer was also used. A series of exposures for different times of the conversion line spectrum from a Pa^{233} source were made. The ratios of integrated electron intensities for all these plates were calculated from the exposure times and from the measured half-life of Pa^{233}. Protactinum-233 is a suitable source since it has a convenient half-life of 27 days[6] and a large number of lines suitably graded in intensity. In order to compare the intensity of a given line with other lines on the osmium plates a suitable Pa^{233} line, which visually matched the osmium line in appearance, was chosen; this can be done quite accurately. The relative intensities of the other osmium lines were then obtained by matching to the same Pa^{233} line in plates having other exposure times. In order to match the lines reproducably it is necessary to view through both plates, the emulsions being placed in contact and the two lines as close together as possible. In this way errors arising from the background darkening are largely overcome. The method does of course suffer from some of the errors of the densitometer method, in fact some of them, e.g., the local variations in film thickness, are brought in twice; moreover it does not take into account line width, a very serious matter at low energies. It does, however, have one considerable advantage in that it is possible to measure the relative intensities of very weak lines which are not observable at all in the densitometer trace. The Pa^{233} source was provided by R. Albridge and the exposures were made by Mrs. V. S. Shirley.

The Berkeley double focusing spectrometer was used to obtain more reliable relative intensity estimates for the conversion electrons. This instrument has been described by O'Kelley.[7] It was used at a resolution in momentum of about 0.5%. A Geiger counter having a plastic entrance window of 100 $\mu g/cm^2$ thickness was used as a detector. The magnet current was automatically swept over a preset range; the output was fed to a ratemeter and recorder system. Owing to the much poorer resolution of this spectrometer as compared with the permanent magnet spectrometer it was only possible to measure the intensity of the more prominent transitions in the region of high conversion line density below about 150 kev. Relative intensities were estimated by measuring the areas of the peaks with a planimeter and dividing by the $H\rho$ value of the lines. The accuracy of this instrument for relative intensity measures was limited mainly by short term fluctuations in the magnet current. This instrument was also used for getting decay curves of conversion lines. However, the small transmission and consequent long scanning time (15 hours for a complete scan) made its use for this purpose rather inconvenient.

A lens spectrometer[8] was used, mainly in the energy region greater than 250 kev, to give relative intensity measurements, decay curves and conversion coefficients by a comparison method. The transmission of this instrument was about 1% and the momentum resolution about 2%. The detector was an anthracene crystal observed by a photomultiplier. For electron energies above about 100 kev it was possible to make the counting rate due to a conversion line source independent of photomultiplier voltage provided that this voltage exceeded a certain value which depended on the energy of the line.

2.3 Gamma Spectroscopy

Direct measurements of the gamma-ray spectrum were taken with NaI crystals having dimensions of 1½-inch diameter by 1 inch thick and also of 3-inch diameter by 3 inch thick together with photomultipliers, linear amplifiers and 100-channel pulse-height analyzers. The width at half height of the peak from the 662-kev gamma ray from Cs^{137} decay was about 8%. The relative intensities of the gamma rays were deduced from the areas of the photopeaks by use of the curves of Kalkstein and Hollander.[9]

An attempt was also made to obtain better resolution of the gamma rays by using a 0.0005-inch uranium photoelectric converter together with the lens spectrometer. The uranium, of diameter approximately ⅛ inch, was mounted on an aluminum shield of sufficient thickness to absorb the conversion electrons from the osmium source which was placed immediately behind it. The diameter of the source was also approximately ⅛ inch.

3. EXPERIMENTAL RESULTS

3.1 Isotope Identification

Natural tungsten consists almost entirely of the four isotopes W^{182} (26.2%), W^{183} (14.3%), W^{184} (30.7%), and W^{186} (28.7%). Bombardment of natural tungsten with alpha particles having energies up to 48 Mev, the maximum energy of the Crocker cyclotron, is most

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[6] L. D. McIsaac and E. C. Freiling, Nucleonics 14, No. 10, 65 (1956).

[7] G. D. O'Kelley, Ph.D. thesis, University of California Radiation Laboratory Report UCRL-1243, 1951 (unpublished).

[8] G. D. O'Kelley, California Research and Development Company MTA Report-38, May, 1954 (unpublished).

[9] M. I. Kalkstein and J. M. Hollander, University of California Radiation Laboratory Report UCRL-2764, 1954 (unpublished).

likely to produce reactions of the type (α,xn), where x is the number of emitted neutrons. Reactions involving the emission of charged particles are expected to be relatively unlikely because of the high Coulomb potential barrier.

The (α,xn) reactions proceed by two main processes which are (a) direct interaction and (b) compound nucleus. This subject has been discussed in detail by Jackson.[10] A brief outline is given below. The direct interaction process is not strongly energy dependent when the alpha energy is above the threshold for the particular process. The process involving compound nucleus formation, the more important of the two at our bombarding energies, is, however, strongly energy dependent since most of the neutrons are evaporated with relatively low energies. The cross section as a function of alpha energy for the emission of a given number of neutrons is a well defined peak. The difference in energy between peaks corresponding to the emission of x and $(x+1)$ neutrons is roughly $B+2T$, where B is the neutron binding energy and T the nuclear temperature; this corresponds approximately to the average energy taken away by the $(x+1)$th neutron. Neither the neutron binding energies nor the nuclear temperatures are known accurately in the region of the light osmium isotopes. However, the average value of B is likely to be about 7 Mev and that of T to be about 2 Mev, thus $B+2T$ will be of the order of 11 Mev. Alpha particles in osmium nuclei are unbound to the extent of 2 to 3-Mev hence with 48-Mev alpha particles bombarding tungsten it is likely that the reactions of the type (α,n), $(\alpha,2n)$, $(\alpha,3n)$, and $(\alpha,4n)$ will occur mainly, the peak energies being roughly at 13 Mev, 24 Mev, 40 Mev, and 51 Mev, repeatively. It should be noted however that the thresholds for the $(\alpha,5n)$ and $(\alpha,6n)$ reactions are roughly at 37 Mev and 44 Mev so that these reactions can also occur theoretically with 48-Mev incident energy; their cross sections will, however, be expected to be extremely low.

In Table I are shown the mass numbers of the osmium isotopes which can be formed from reactions of the type (α,xn) with tungsten isotopes; the rare isotope W^{180} (0.14%) has not been included. Stable isotopes are indicated by the brackets; these however may have isomeric states. It can be seen that the only unstable isotopes formed are Os^{182}, Os^{183}, and Os^{185}; these are all expected to decay mainly by K capture.

TABLE I. Mass numbers of osmium isotopes formed from (α,xn) reactions with tungsten isotopes. The brackets indicate stable isotopes.

	W^{182}	W^{183}	W^{184}	W^{186}
α,n	185	(186)	(187)	(189)
$\alpha,2n$	(184)	185	(186)	(188)
$\alpha,3n$	183	(184)	185	(187)
$\alpha,4n$	182	183	(184)	(186)

The isotope Os^{185} has already had extensive study by Johns, Nablo, and King[11] and by Marty and Vergnes.[12] Isomeric states in any of the nuclei of Table I could also be detected in principle; such states in Os^{187} and Os^{189} have been reported by Greenlees and Kuo[3] and in Os^{189} by Scharff-Goldhaber, Alburger, Harbottle, and McKeown.[13]

In the section on gamma spectroscopy (3.2) it will be shown that the observed gamma rays could be assigned to the decay of activities with half-lives of 9.9, 13.67, and 21.1 hours and to the decay of Os^{185} which has a long half-life (93.6 days). In addition other radiation which showed an initial rise in intensity followed by decay was seen; this belongs to the decay of daughter nuclei. The production of these isotopes as a function of energy was studied by bombarding a stack of 0.001-inch thick tungsten foils in a Faraday cup with 48-Mev alpha particles. The gamma radiation from each of these foils, from which the osmium was not chemically separated, was studied with a sodium iodide spectrometer and the intensities of prominent peaks associated with each of the above decays were measured. The prominent peaks measured had energies of 1100 kev, 382 kev, 510 kev, and 646 kev corresponding to the 9.9 hour, 13.67 hour, 21.1 hour, and long decays, respectively. The efficiency of the spectrometer was determined with a standard Am^{241} source and from the curves of Kalkstein and Hollander.[9] The Am^{241} source was assumed to have 0.36 of the 60-kev gammas per alpha particle.[14]

In order to estimate the energy of the alpha particles in each foil the range-energy curves of Aron, Hoffman, and Williams[15] were used. The foils were "moderately thin" relative to the peak widths expected in these reactions; the points for each foil are plotted at the mean alpha energy in the foil. Assuming decay schemes to be given later for the 9.9-hour, 13.67-hour, and 21.1-hour activities and the decay scheme of Johns *et al.*,[11] for Os^{185}, absolute cross sections were derived for the various processes. To do this an assumption had to be made as to which isotope contributed to the process. The results are shown in Fig. 1.

From the previous discussion it seems very likely that the 9.9-hour and 13.67-hour activities are formed in $(\alpha,3n)$ and perhaps $(\alpha,4n)$ processes and that the 21.1-hour activity is formed in an $(\alpha,4n)$ process. Thus from Table I it seems that the 9.9-hour and 13.67-hour activities can be ascribed to Os^{183} and the 21.1-hour activity to Os^{182}. The excitation function for the long lived activity is consistent with it arising from (α,n), $(\alpha,2n)$, and $(\alpha,3n)$ processes as expected for Os^{185}.

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[10] J. D. Jackson, Can. J. Phys. **34**, 767 (1956).

[11] M. W. Johns, S. V. Nablo, and W. J. King, Can. J. Phys. **35**, 1159 (1957).

[12] N. Marty and M. Vergnes, J. phys. radium **18**, 223 (1957).

[13] G. Scharff-Goldhaber, D. E. Alburger, G. Harbottle, and M. McKeown, Phys. Rev. **111**, 913 (1958).

[14] L. B. Magnusson, Phys. Rev. **107**, 161 (1957).

[15] W. A. Aron, B. G. Hoffman, and F. C. Williams, Atomic Energy Commission Report AECU-663, 1949 (unpublished).

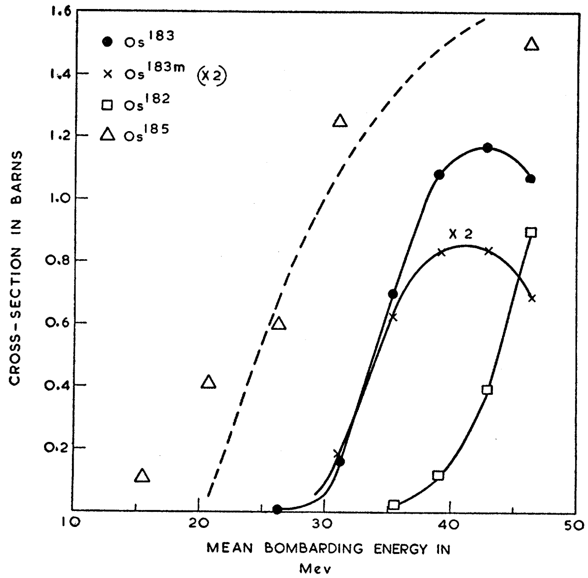

FIG. 1. Excitation functions for the production of the 9.9-hour (Os^{183m}), 13.67-hour (Os^{183}), 21.1-hour (Os^{182}) and >500-hour (Os^{185}) activities from the reactions $W+\alpha$. The dotted curve corresponds to a calculated compound nucleus cross section with an interaction radius of 10.1 fermis.

The cross sections are however likely to be overestimated for Os^{185} since in general more than one isotope contributed.

In Fig. 1 is also given a curve showing the expected compound nucleus cross section for the interaction radius $r=10.1$ fermis, deduced by extrapolation from the curves of Blatt and Weisskopf.[16] The experimental results seem roughly consistent with this curve.

Targets of separated W^{182} and W^{186} in the form of the oxide were also bombarded. The activities described above were seen from the W^{182} target and not from the W^{186} target, in agreement with the interpretation above. Chemical separations were performed on these targets. Annihilation radiation attributable to the decay of F^{18} was also observed. The F^{18} is presumably formed from the reaction $O^{16}(\alpha,pn)F^{18}$ or $O^{16}(\alpha,d)F^{18}$; apparently it is possible for the fluorine to distil over together with the OsO$_4$. Fluorine-18 was identified from its half-life of 112 min,[17] our value being 111 min.

3.2 Gamma Spectroscopy

In most of the bombardments two tungsten foils of thickness 0.003-inch were bombarded. The alpha energy in the first foil varied between about 46 Mev and 35 Mev and that in the second foil between about 35 Mev and 21 Mev. Thus the first foil contained a mixture of the isotopes Os^{182}, Os^{183}, and Os^{185} while the second contained a mixture of Os^{183} and Os^{185}. Chemical separation of the osmium was made in most of the experiments though there seemed little if any difference in the gamma spectrum when unseparated tungsten was observed.

A typical complete spectrum arising from all three isotopes and taken in a $1\frac{1}{2}$-inch diameter by 1-inch thick NaI crystal is shown in Fig. 2. Prominent peaks corresponding to radiations having energies in kev of 62, 114, 167, 382, 510, 650, 850, 1100, and 1440 can be seen. The 62-kev peak is due to the K x-rays of rhenium. Consideration of the shape of the Compton spectrum of the 382-kev gamma ray, deduced from that of the 411-kev gamma ray of Au^{198}, shows the presence of another peak due to a gamma ray of energy 236 kev. Similarly it can be shown by subtracting the Compton spectrum of the 1100-kev radiation that another peak of energy 1050 kev is present. The 850-kev and 1440-kev peaks are clearly broad. The spectrum of Fig. 2 was not used to obtain the energies and intensities of these peaks; spectra with more expanded scales were used for this purpose. The dotted region above about 1300 kev is taken from another spectrum which has been normalized to that of Fig. 2. In Fig. 3 is shown the gamma-ray spectrum arising from the decay of Os^{182}. It was obtained by subtracting a spectram arising from Os^{183} only from one arising from the two isotopes. The points scatter badly at the edges of large peaks in the original spectra owing to a slight gain shift.

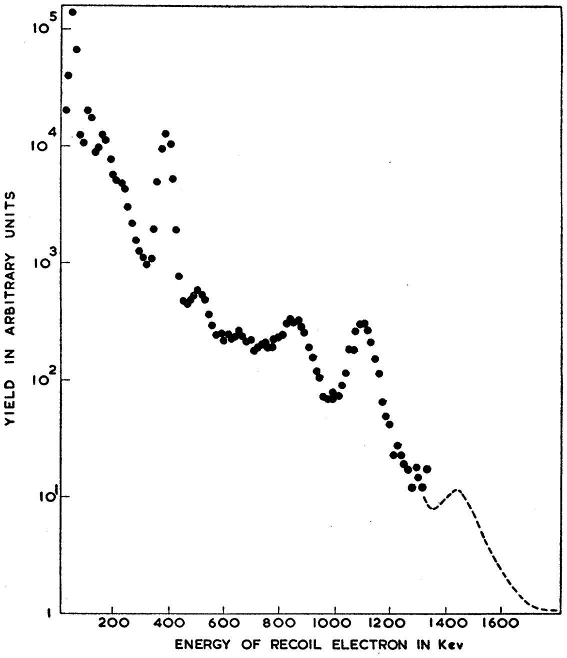

FIG. 2. Gamma-ray spectrum from a source containing Os^{183}, Os^{183m}, Os^{182}, and Os^{185} taken in a $1\frac{1}{2}$-in. diam × 1-in. NaI crystal. The dotted high-energy part of the curve is taken from another spectrum and normalized to this one.

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[16] J. M. Blatt and V. F. Weisskopf, *Theoretical Nuclear Physics* (John Wiley and Sons, Inc., New York, 1952).

[17] J. P. Blaser, F. Boehm, and P. Marmier, Phys. Rev. **75**, 1953 (1949).

The intensities and shapes of the spectra were studied for periods of several days with a number of sources. In addition to the peaks mentioned above, other peaks grew in to the spectra; they correspond to radiations from the daughter nuclei. These are Re^{183} with a half-life of about 71 days[18,2] and the 13-hour isomer of Re^{182},[19]; Re^{185} is stable. Since the Re^{182} isomer has such a short half-life the gamma rays from it grew in very quickly after separation and were of high intensity; those from Re^{183} were not very troublesome.

In Fig. 4 are shown decay curves for the principal gamma rays of the three short-lived activities formed. The points for the 1100-kev gamma ray are less accurate than those for the other two because it was necessary to subtract out a contribution to the peak of radiation from the 13-hour Re^{182} isomer; this gives a series of gamma rays in the range 1100 to 1200 kev.[19] The shape of the contribution was deduced from the spectrum of a well-decayed source which was rich in Os^{182}. The half-lives deduced for the various radiations together with their relative intensities and assignments are shown in Table II. As will be seen later some of the peaks are not due to single transitions. The energies given for the gamma rays, with the exception of that for the 1440-kev transition, are deduced from the more accurate conversion-line data. It can be seen that there is a serious discrepancy between our value of 13.67±0.1 hours for the half-life of the 382-kev gamma ray and that of 15.4±0.3 hours given by Foster *et al.*[2] This discrepancy can probably be explained as will be shown in the second paper.

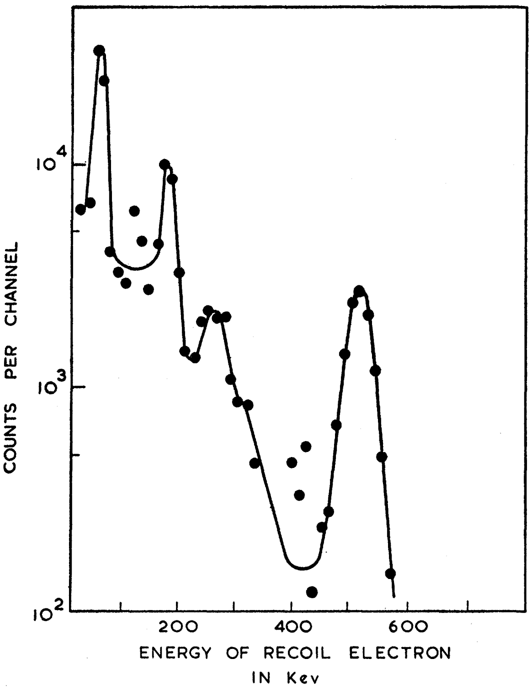

FIG. 3. Gamma-ray spectrum of Os^{182} taken in a $1\frac{1}{2}$-in. diam × 1 NaI crystal.

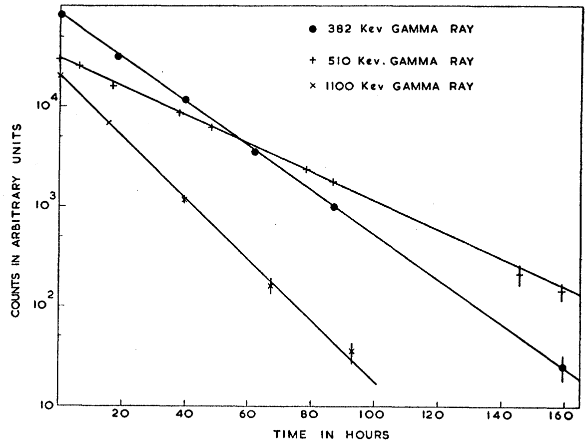

FIG. 4. Decay curves for the 382-kev, 510-kev, and 1100-kev gamma rays.

From the conversion line spectra it is known that the "850-kev peak" is made up of contributions from four gamma rays having energies of 807.8, 851.1, 887.5, and 889.4 kev; all of these are attributed to the decay of Os^{183}. An attempt was made to resolve them by using a uranium converter and the lens spectrometer. The resolution of this instrument is not sufficiently good to resolve the 887.5- and 889.4-kev lines from one another but is good enough to resolve the sum of these two and the other two lines.

The curve obtained is shown in Fig. 5. Unfortunately the peaks lie on top of a high undetermined background

TABLE II. Energies, assignments, half-lives, and relative intensities of the gamma rays. Upper limits are given to the intensities of some transitions known to be present from other data.

Energy kev	Assignment	Measured half-life (hours)	Os^{183} relative intensities
62	Re*KX*		1.96
114	Os^{183}	13.6±0.8	2.7×10^{-1}
167	Os^{183}	13.6±0.8	1.1×10^{-1}
180	Os^{182}		$(7\pm1.5)\times10^{-1}$ [a]
236	Os^{183}	14.5±1.8	6.8×10^{-2}
262	Os^{182}		$(1.4\pm0.3)\times10^{-1}$ [a]
382	Os^{183}	13.67±0.1	1.00
477	Os^{183}		$\leq7\times10^{-2}$
490	Os^{183}		$\leq5\times10^{-2}$
510	Os^{182}	21.1±0.3	1.00[a]
646	Os^{185}	long	
737	Os^{183}		$\leq5\times10^{-3}$
850	Os^{183}	14.0±0.7	7.6×10^{-2}
1050	Os^{183m}		2.5×10^{-2} [b]
1105	Os^{183m}	9.9±0.3	2.0×10^{-1} [b]
1440±20	Os^{183}	14.5±1.2	1.1×10^{-2}

[a] Relative to 510-kev gamma.
[b] At end of bombardment.

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[18] C. J. Gallagher, D. Strominger, and J. P. Unik, Phys. Rev. **110**, 725 (1958).

[19] C. J. Gallagher, J. O. Newton, and V. S. Shirley, Phys. Rev. **113**, 1298 (1959).

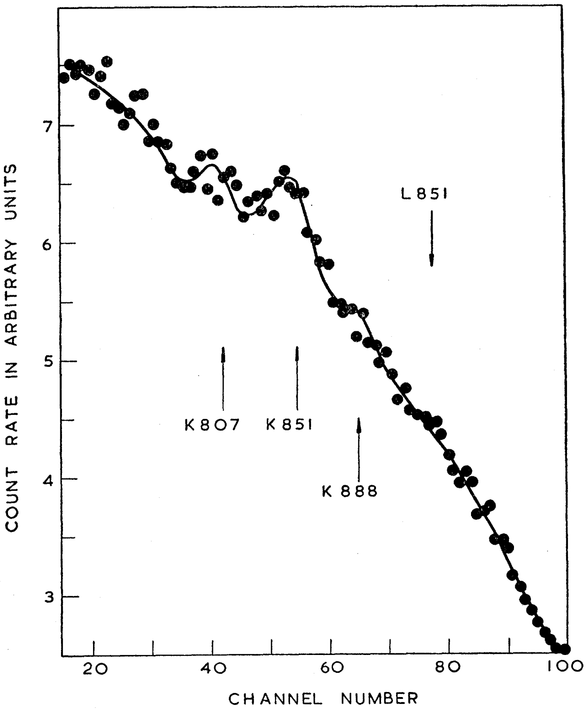

FIG. 5. Spectrum of the complex "850-kev gamma ray" taken with a uranium photoelectric converter and a lens spectrometer.

and moreover the errors on the points seem to be somewhat greater than the very small (+0.6%) statistical errors. The peak due to the *K* line of the 851-kev transition is clearly seen, but the peaks due to the *K* lines of the 807- and 888-kev transitions are less definite. Allowing for the change of photoelectric efficiency with energy it seems that the intensities for the 807- and 888-kev transitions relative to that of the 851-kev transitions are 0.3 ± 0.1 and $0.3^{+0.1}_{-0.2}$, respectively; the assessment of the errors is arbitrary. The value of about $\frac{1}{3}$ for the relative intensity of the two weaker transitions seems consistent with the shape of the broad 850-kev peak in the sodium iodide spectra.

3.3 Electron Spectroscopy

The observed electron spectra are exceedingly complex; in all, 251 lines were observed. In Table II the energies, intensities, and assignments of the lines which are attributed to the decay of the osmium isotopes 182, 183, 183*m*, and 185 are given. The energies are in all cases those obtained with the permanent magnet spectrographs. This table does not contain all of the observed lines since there are so many of them; the other lines are listed below with only group assignments, if any. The lines attributed to the isomeric state of Os^{189} [13] and to the Auger lines of rhenium will be the subject of another publication. It is thought desirable to give all of the observed lines since the spectrum is so complex and some lines, particularly the weaker ones, may be incorrectly assigned or not assigned at all. In order to give an idea of the degree of confidence which may be placed in the present assignments the status of each line in Table III is indicated.

The following lines were also observed. They are assigned to the decays of various nuclei or unassigned as indicated. An indication of their relative intensities is given in brackets after each line. These intensities are given as numbers which are related to the conventional beta spectroscopic code as follows: 9, *VVS*; 8, *VS*; 7, *S*; 6 *ms*; 5, *m*; 4, *wm*; 3, *w*; 2, *vw*; 1 *vvw*. A prefix of 7 means doubtful and a prefix of 8 means broad. As far as possible the intensities for a given series are for one photographic plate; a dash in a series indicates that there is a change of plate and instrument at this point. Some lines may appear in more than one series; this may be because of line overlap or because they were observed under different conditions.

13-hr Re^{182}: 15.20 (5); 30.59 (6); 44.22 (4); 47.01 (5); 53.65 (4); 54.17 (1); 55.62 (6); 56.18 (5); 57.54 (5); 62.86 (82); 64.94 (4); 65.14 (71); 65.47 (3); 67.20 (3); 72.59 (6); 73.07 (4); 74.43 (4); 81.87 (4); 82.15 (1); 82.38 (71); 82.91 (4); 84.07 (3); 88.02 (6); 88.52 (8); 89.92 (8); 97.56 (7); 97.81 (7); 99.59 (5); 100.00 (2); 140.43 (1); −400.6 (4); 825.2 (1); 1051.9 (3); 1119.7 (2); 1152.5 (2).

Re^{183}: 15.20 (5); 29.56 (5); 34.40 (8); 34.93 (6); 36.30 (5); 38.43 (6); 40.19 (7); 40.49 (7); 41.06 (4); 43.61 (7); 43.92 (4); 44.22 (4); 45.86 (5); 49.77 (5); 50.08 (71); 52.01 (3); 70.76 (3); 71.39 (3); 72.59 (6); 87.49 (3); 88.78 (6); 92.80 (9); 96.82 (4); 98.62 (4); 106.13 (3); 106.90 (3); 123.14 (2); 139.32 (5); 150.32 (6); 150.89 (4); 152.20 (3); 161.86 (83); 176.67 (3); 196.92 (3).

Os^{189}: 17.89 (5); 18.47 (2); 19.95; 27.74 (5); 28.37 (7); 30.14 (3); 30.31 (5); 30.76 (3).

Re Auger: 46.40 (6); 47.01 (7); 47.51 (1); 48.37 (6); 48.91 (7); 50.37 (6); 56.19 (4); 56.39 (4); 56.68 (4); 56.91 (1); 57.30 (3); 57.71 (1); 58.11 (1); 58.35 (4); 58.65 (4); 59.15 (3); 60.66 (83); 61.08 (1).

W Auger: 45.11 (4); 45.68 (84); 56.91 (3).

Unassigned—probably Os^{183} or Os^{182}: 6.65 (1); 8.10 (2); 8.38 (2); 8.51 (2); 9.77 (2); 10.01 (1); 10.33 (1); 19.70 (2); 20.24 (2); 21.60 (2); 21.95 (1); 28.92 (1); 29.24 (1); 35.89 (2); 38.78 (4); 39.72 (2); 65.93 (2); 67.14 (3); 67.31 (3); 68.74 (2); 71.84 (2); 92.15 (3); 112.14 (2); 115.87 (1); 118.30 (1); 120.3 (1); 129.22 (1)—129.22 (5); 131.0 (5); 132.1 (5); 151.3 (2); 153.7 (7); 168.8 (2); 170.7 (3); 172.2 (2); 177.4 (4); 202.6 (3); 217.8 (2); 222.5 (1); 457.8 (1); 465.4 (1); 776.1 (1); 832.2 (1); 877.2 (1); 882.7 (1); 986.4 (1); 1110.2 (1).

The line assignments were made in various ways as follows. With many sources a series of exposures, usually each of twelve hours duration, was taken in a permanent magnet spectrograph. By comparing the intensities of a given line in a series of such plates it is

TABLE III. Observed electron lines attributed to the decay of the osmium isotopes of mass numbers 182, 183, and 185. The meanings of the letters at the heads of the intensity columns are as follows: PMD, permanent magnet densitometer method; PMC, permanent magnet comparison method; D.F., double focusing spectrometer; *L*, lens spectrometer. The column labelled $T_{\frac{1}{2}}$ gives the measured half-life of a line in hours. In the Status column, *A* means a very well supported assignment, *B* means a moderately well supported assignment, *C* means a rather poorly supported assignment. 183 I.T. means an isomeric transition in the nucleus Os^{183}.

Line energy in kev	Relative intensities				$T_{\frac{1}{2}}$	Interpretation		
	PMD	PMC	D.F.	*L*	hr	Transition	Isotope	Status
15.09	5.8[a]					$L_{\mathrm{I}}27.60$	182	*B*
15.65	1.3[a]					$L_{\mathrm{II}}27.60$	182	*B*
17.10						$L_{\mathrm{III}}27.60$	182	*B*
24.62	0.95[a]					$M_{\mathrm{I}}27.60$	182	*B*
24.93	0.26[a]					$M_{\mathrm{II}}27.60$	182	*B*
26.95	0.31[a]					$N_{\mathrm{I}}27.60$	182	*B*
27.52						$O27.60$	182	*B*
42.80	32		36		15±2	$K114.44$	183	*A*
42.99						$L_{\mathrm{I}}55.50$	182	*AB*
43.54	0.5[a]					$L_{\mathrm{II}}55.50$	182	*AB*
44.94						$L_{\mathrm{III}}55.50$	182	*AB*
52.59	1.2[a]				20±2	$M_{\mathrm{I}}55.50$	182	*AB*
52.81	0.17[a]					$M_{\mathrm{II}}55.50$	182	*AB*
53.17	0.042[a]					$M_{\mathrm{III}}55.50$	182	*AB*
53.65						$K125.3$	185	*A*
54.73	0.37[b]					$L_{\mathrm{I}}67.26$	183^{m}	*B*
54.86						$N_{\mathrm{I}}55.50$	182	*AB*
64.34	0.10[b]					$M_{\mathrm{I}}67.26$	183^{m}	*B*
66.64						$N_{\mathrm{I}}67.26$	183^{m}	*B*
73.70	1.6	1.9	1.5		15±2	$K145.39$	183	*A*
75.34	0.10[b]					$K147.00$	183^{m}	*B*
79.36	0.19	0.22				$K151.02$	183	*B*
91.19						$K162.85$	185	*A*
96.17	5.9	5.2	7.5		14±1.5	$K167.90$	183	*A*
96.78	0.85[b]	0.90[b]				$K170.72$	183*IT*	*A*
101.92	6.5	4.9	8.6		13±1	$L_{\mathrm{I}}114.44$	183	*A*
102.43	1.0	0.8				$L_{\mathrm{II}}114.44$	183	*A*
103.86	0.36	0.40	0.51			$L_{\mathrm{III}}114.44$	183	*A*
108.52	0.47[a]	0.60[a]			22±2.5	$K180.18$	182	*AB*
111.51	1.5	1.2	2.1		15±2	$M_{\mathrm{I}}114.44$	183	*A*
112.87						$L_{\mathrm{I}}125.3$	185	*A*
113.85	0.44	0.54	0.64			$N_{\mathrm{I}}114.44$	183	*A*
114.39	0.13	0.16				$O_{\mathrm{I}}114.44$	183	*A*
125.50	0.09	0.09	0.08			$K197.10$	183	*AB*
132.92	0.32	0.31	0.34			$L_{\mathrm{I}}145.39$	183	*A*
133.40	0.055	0.1				$L_{\mathrm{II}}145.39$	183	*A*
134.45						$L_{\mathrm{I}}147.00$	183^{m}	*B*
134.86	0.02	0.02				$L_{\mathrm{III}}145.39$	183	*A*
138.49	0.05					$L_{\mathrm{I}}151.02$	183	*B*
142.46	0.10	0.09	0.08			$M_{\mathrm{I}}145.39$	183	*A*
145.25						$K216.9$	182 or 183	*C*
144.88						$N_{\mathrm{I}}145.39$	183	*A*
148.20						$M_{\mathrm{I}}151.02$	183	*B*
155.42	1.3	1.2	1.1		13±1	$L_{\mathrm{I}}167.90$	183	*A*
155.98	0.17	0.17				$L_{\mathrm{II}}167.90$	183	*A*
157.76	0.65[b]	0.69[b]	0.75[b]		9.5±0.6	$L_{\mathrm{I}}170.72$	183*IT*	*A*
158.37	0.23[b]	0.21[b]				$L_{\mathrm{II}}170.72$	183*IT*	*A*
159.95	1.00[b]	1.00[b]	1.00[b]		10±1	$L_{\mathrm{III}}170.72$	183*IT*	*A*
164.98	0.47	0.48	0.34			$M_{\mathrm{I}}167.90$	183	*A*
167.31			0.13			$N_{\mathrm{I}}167.90$	183	*A*
167.71	0.30[b]	0.22[b]	0.26[b]			$M_{\mathrm{I}}170.72$ $L_{\mathrm{I}}\ 180.18$	183*IT* 182	*A* *C*
168.27	0.35[b]	0.39[b]	0.38[b]			$M_{\mathrm{III}}170.72$	183*IT*	*A*
170.18	0.19[b]	0.17[b]	0.15[b]			$N_{\mathrm{III}}170.72$	183*IT*	*A*
173.9		0.015				$K245.6$	183	*C*
175.1						$K246.8$	183	*C*
180.00		0.016				$K251.61$	183	*C*
184.54		0.015				$L_{\mathrm{I}}197.10$	183	*B*
188.27		0.020				$K259.83$	183	*B*
191.65		0.013[a]				$K263.27$	182	*C*
194.16						$M_{\mathrm{I}}197.10$	183	*B*
202.6						$K274.3$	183	*C*
204.25						$L_{\mathrm{I}}216.9$	182 or 183	*C*
214.2						$M_{\mathrm{I}}216.9$	182 or 183	*C*
223.71		0.020				$L_{\mathrm{I}}236.20$	183	*AB*
224.31		0.005				$L_{\mathrm{II}}236.20$	183	*AB*
225.70		0.005				$L_{\mathrm{III}}236.20$	183	*AB*
233.22		0.008				$M_{\mathrm{I}}236.20$	183	*AB*
239.04		0.003				$L_{\mathrm{I}}251.61$	183	*C*

TABLE III.—*Continued.*

Line energy in kev	Relative intensities PMD	PMC	D.F.	L	$T_{\frac{1}{2}}$ hr	Interpretation Transition	Isotope	Status
247.79		0.006				$L_{\mathrm{I,II}}259.83$	183	*B*
249.30		0.006				$L_{\mathrm{III}}259.83$	183	*B*
250.70						$L_{\mathrm{I}}263.27$	182	*C*
283.67		0.017				$K355.45$	183	*B*
303.25						$K374.91$	182 or 183	*C*
310.09	1.00	1.00	1.00	1.00	13.5±0.4	$K381.76$	183	*A*
343.3						$L_{\mathrm{I}}355.45$	183	*C*
369.22	0.12	0.12	0.15	0.15	14.0±0.7	$L_{\mathrm{I}}381.76$	183	*A*
369.72	0.03	0.02				$L_{\mathrm{II}}381.76$	183	*A*
371.12	0.016	0.018				$L_{\mathrm{III}}381.76$	183	*A*
378.86	0.034	0.032	0.039			$M_{\mathrm{I}}381.76$	183	*A*
381.04		0.014	0.009			$N_{\mathrm{I}}381.76$	183	*A*
405.5	0.017	0.022	0.020			$K477.2$	183	*B*
424.4	0.083	0.085	0.084	0.076	12±2	$K496.1$	183	*AB*
438.3	1.00$^{\mathrm{a}}$	1.00$^{\mathrm{a}}$			21.7±0.5	$K509.9$	182	*A*
483.5	0.017	0.017	0.015	0.015		$L_{\mathrm{I}}496.1$	183	*AB*
492.8		0.005				$M_{\mathrm{I}}496.1$	183	*AB*
497.4	0.18$^{\mathrm{a}}$	0.15$^{\mathrm{a}}$	0.15$^{\mathrm{a}}$			$L_{\mathrm{I}}509.9$	182	*A*
506.7	0.04$^{\mathrm{a}}$	0.06$^{\mathrm{a}}$	0.046$^{\mathrm{a}}$			$M_{\mathrm{I}}509.9$	182	*A*
509.0	0.01$^{\mathrm{a}}$					$N_{\mathrm{I}}509.9$	182	*A*
574.5					long	$K646.2$	185	*A*
633.8					long	$L_{\mathrm{I}}646.2$	185	*A*
665.2	0.005	0.009	0.004			$K736.9$	183	*BC*
736.1	0.008	0.013	0.014	0.014	13.8±1	$K807.8$	183	*A*
779.4	0.050	0.053	0.049	0.068	13.3±0.5	$K851.1$	183	*A*
815.8	0.011	0.012	0.015	0.023	14±1	$K887.5$	183	*A*
817.7	0.010	0.012				$K889.4$	183	*A*
838.7	0.007	0.007	0.008			$L_{\mathrm{I}}851.1$	183	*A*
848.1			0.0025			$M_{\mathrm{I}}851.1$	183	*A*
963.1	0.21$^{\mathrm{c}}$	0.22$^{\mathrm{c}}$	0.29$^{\mathrm{c}}$		10.6±1.5	$K1034.8$	183$^{\mathrm{m}}$	*AB*
1030.3	1.0$^{\mathrm{c}}$	1.0$^{\mathrm{c}}$	1.2$^{\mathrm{c}}$		10.0±0.5	$K1102.0$	183$^{\mathrm{m}}$	*A*
1036.4	1.0$^{\mathrm{c}}$	1.0$^{\mathrm{c}}$	1.0$^{\mathrm{c}}$			$K1108.1$	183$^{\mathrm{m}}$	*A*
1091.2					11.1±1	$K1162.9$	183 and or 183$^{\mathrm{m}}$	*C*
1110.2						$K1181.9$	183	*C*

[a] Relative to K of 509.9.
[b] Relative to L_3 of 170.72.
[c] Relative to K of 1108.1.

usually possible, provided that the line is sufficiently intense initially, to see whether it decays with a 10-hour, 13-hour, or 21-hour half-life or if it shows an initial rise followed by decay, which is characteristic of a daughter nucleus. It should be stressed however that it is not in general possible to get an accurate value for a half-life by this method. Thus, although it may be possible to distinguish between 10-hour and 13-hour lines, if these are known to be the only ones present, erroneous conclusions may be drawn if, say, there is a nine hour component, which is not known, also present; this nine hour line would be assigned to the 10-hour activity.

Assignments to an element could be made in some cases when two or more lines of a transition were observed, since the electron binding energies depend on the charge number. Considerable help in picking out the lines due to the daughter nuclei was given by the accurately known energies and the intensities of the electron lines in Re^{183} decay[18,20] and in 60-hour Re^{182} decay.[20,21] Osmium-182 decay has been shown by Gallagher, Newton, and Shirley[19] to lead to the 13-hour Re^{182} isomer which decays through many of the same states in W^{182} as does the 60-hour isomer.

More accurate assignments to some lines were made by observing their decay rates with the double focusing spectrometer or with the lens spectrometer. The half-lives obtained by such direct measurements on the conversion lines are given also in Table III. In some cases strong transitions could be assigned with good confidence because the gamma transitions, with measured lifetimes, were observed.

It will be noticed that there is a contradiction between these results and the results of Foster *et al.*[2] regarding the half-lives of the transitions which are reported here as 167.90 kev and 170.72 kev and which Foster *et al.* report as 168.1 kev and 168.7 kev; these are presumably the same transitions. Foster *et al.* give the higher energy transition as having a 15-hour half-life and the lower energy transition as having a 10-hour half-life. It seems clear however both from visual inspection of permanent magnet spectrograph plates and from direct half-life measurements in the double focusing spectrometer that this cannot be correct; in Fig. 6 are shown the decay curves for the L_{I} lines of the 167.90- and 170.72-

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[20] J. J. Murray, F. Boehm, P. Marmier, and J. W. M. DuMond, Phys. Rev. **97**, 1007 (1955).

[21] C. J. Gallagher and J. O. Rasmussen, Phys. Rev. **112**, 1730 (1958).

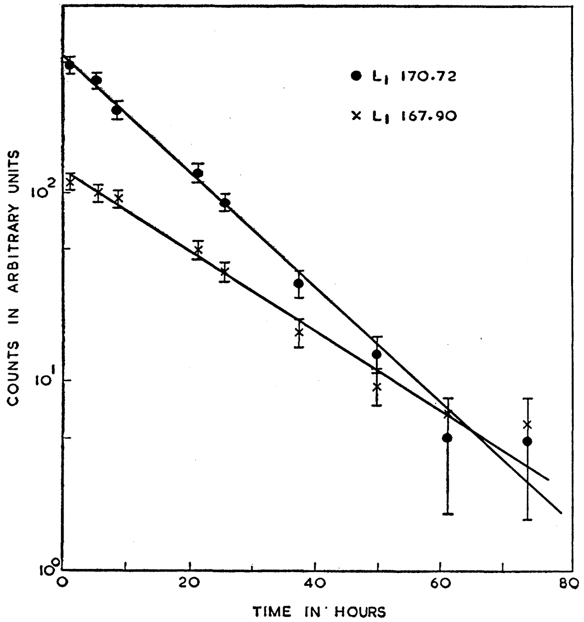

FIG. 6. Decay curves for the L_I lines of the 167.90- and 170.72-kev transitions taken with the double focusing spectrometer.

kev transitions. A further contradiction arises with the 850-kev transition which is ascribed to the 10-hour activity by Foster *et al.* From our measurements, both of the gamma spectra and of the conversion lines, it seems that the 850-kev transition belongs to the 13-hour activity. The reasons for these discrepancies are not clear.

No evidence has been found for the existence of a 39-hour isomeric state in Os^{187} as reported by Greenlees and Kuo[3] from observations on the *K* x-rays. If such a state exists it seems very surprising that it was not seen in this work; its existence must therefore be considered very doubtful.

The energy measurements could in general be made with considerable precision because of the presence of internal energy standards. These were the conversion lines arising from the decay of the daughter nuclei Re^{183} and 13-hour Re^{182}. Most of the transition energies in these decays have been measured with great accruacy (±0.02%) by Murray, Boehm, Marmier, and DuMond,[20] the accuracy arising from the use of a bent crystal gamma spectrometer. In addition the 400-gauss spectrograph was calibrated externally with a Bi^{206} source; the conversion lines of this have been measured by Alburger and Pryce[22] with an accuracy of about ±0.05%. It is thought that the accuracy of measurement of most of the stronger lines is ±0.05%. The very weak lines may be rather less accurate and ±0.1% is probably a better estimate for these. The energies given in Table III are in general the means of the values from a number of different plates, the number being as high as ten for some of the stronger lines.

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[22] D. E. Alburger and M. H. L. Pryce, Phys. Rev. **95**, 1482 (1954).