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Publication Date

1954-10-20

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Radiation Laboratory

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Contract No. W-7405-eng-48

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ABSTRACT

A radiochemical study of some neutron deficient nuclides in the noble metal region has been undertaken, and several new chains identified. The method used to establish genetic relationships was that of timed chemical separations, where the parent activities are initially produced by cyclotron or linear accelerator bombardments.

The following chains have been identified:

This work was performed under the auspices of the Atomic Energy Commission.

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INTRODUCTION

Recent nuclear level studies^{1, 2, 3} of odd-mass nuclei in the region $A = 191$ through $A = 197$ have shown that interesting regularities exist in the movement of proton and neutron energy levels as pairs of nucleons of the other kind are added. In this laboratory several isotopes of platinum and gold with mass number less than 191 had been observed in the course of other work, but a systematic radiochemical study of this region had not been pursued. Because of recent interest, however, it seemed worthwhile to search for and identify new neutron deficient chains in gold and platinum with $A \leq 191$ which might be susceptible to spectroscopic investigation. In this paper we report on the synthesis and identification of the following chains:

EXPERIMENTAL METHOD

In the work reported here, targets of element Z were bombarded in general with protons from the 184-inch cyclotron to produce isotopes of element $(Z + 1)$ by the (p, xn) reactions. The proton energy was varied between 50 and 130 Mev, to bring in various values of x . Some excitation function experiments were also performed with the 32-Mev proton beam of the Berkeley linear accelerator, and a few proton and heavy ion bombardments were made in the 60-inch cyclotron.

The Geiger counter decay curves of the primary $(Z + 1)$ chemical fractions were in general so complex that their resolution was difficult at best and often unsuccessful. Consequently, half lives and genetic chain relationships were often determined by means of the chemical "milking" technique introduced by Neumann and Perlman⁴ and Karraker and Templeton⁵. In this method, chemical separations of daughter activities from the purified $(Z + 1)$ fractions are made at a sequence of equal time intervals, the interval corresponding approximately to the expected half life of the parent.

The number of atoms of a daughter substance present at a time t after purification of its parent is given by the formula

$$N_2 = \frac{\lambda_1}{\lambda_2 - \lambda_1} N_1^0 (e^{-\lambda_1 t} - e^{-\lambda_2 t}).$$

The activity of the daughter is then

$$A_2 = \frac{dN_2}{dt} = C_2 \lambda_2 N_2 = \frac{C_2 \lambda_2 \lambda_1}{\lambda_2 - \lambda_1} N_1^0 (e^{-\lambda_1 t} - e^{-\lambda_2 t}),$$

where C_2 is the counting efficiency of the daughter. Since the time interval between successive chemical separations is held constant,

the exponential terms become a constant factor, and A_2 is proportional to the disintegration rate ($\lambda_1 N_1^0$) of the parent at the beginning of each growth period. Thus, if one plots the logarithm of the initial activity of each daughter fraction against the time of separation, the slope of the line will correspond to the half life of the parent.

Although the primary emphasis in this work has been on the radiochemical analysis, examination of the gamma ray spectra of some of these neutron-deficient nuclides has also been made with a NaI (Tl) scintillation spectrometer coupled to a 50-channel differential analyzer. These gamma ray data are far from definitive, but they have been helpful in the identification of the various nuclides encountered, both new and old. Some of these data will be quoted here when they appear to provide relevant information.

RADIOCHEMICAL RESULTS

Figure 1 is a segment of an isotopic chart in the noble metal region showing the activities identified in the present study. The half lives of previously reported activities are also given in parentheses.

The following is a summary of the experimental results given by mass number.

A = 191. Genetics

Following a 120-Mev proton irradiation of gold metal, a pure mercury fraction was prepared by a procedure involving removal of the Au into amyl acetate and precipitation of Hg metal with SnCl_2 . The decay curve of the Hg fraction itself was complex, with at least five components. Therefore, a series of seven timed gold separations was made from this fraction at intervals of eight minutes, by amyl acetate

extraction. These gold "milkings" showed the activities and genetic relationships illustrated in Table I and Fig. 2.

Table I

Activity	Half life of Hg parent (or ancestor)	Assignment
40 ± 10 min	20 ± 10 min	Au^{189}
3.0 ± 0.5 hr	55 ± 10 min	Au^{191}
15 hr (weak)	>50 min	Au^{193}
3 d (weak)	~50 min	Pt^{191}

The 40-minute gold activity is Au^{189} , and will be discussed under that mass number. The 3-hour and 3-day activities descend from the same mercury ancestor, whose half life is ~50 minutes. Further chemical experiments with this gold "milking" fraction have identified the 3-hour activity as an isotope of gold and the 3-day activity as platinum, hence probably the daughter of the 3-hour gold. Since Pt^{191} is a fairly well known 3.0-day activity^{6,7}, this chain can be assigned to mass 191.

These results are in agreement with the recent work of Gillon et al.², who found in their study of conversion lines from 60-Mev proton bombardments of Au:

The genetic relationship between the 3-hour Au^{191} and 3.0-day Pt^{191} was also established independently in two other ways.

(a) Platinum was irradiated with 130-Mev protons, and a pure gold fraction prepared. Seven timed platinum separations were made at 30-minute intervals, with the results shown in Table II and Fig. 3.

Table II

Pt activity	$t_{1/2}$ of gold parent	Assignment
3 day	2.5 ± 0.5 hr	Pt ¹⁹¹
11 ± 1 hr	40 ± 10 min	Pt ¹⁸⁹
3 ± 0.5 hr	15 - 20 min	Pt ¹⁸⁷

This experiment indicates a half life of 2.5 ± 0.5 hours for Au¹⁹¹. The other activities will be discussed under the appropriate mass numbers.

(b) Gold was irradiated with 120-Mev protons, and a pure Hg fraction separated. This was allowed to stand for about two hours, after which a gold separation was made from it. Five "milkings" of platinum were then made from this gold fraction at 3-hour intervals. The platinum milkings contained largely 3.0-day Pt¹⁹¹, and the yields indicated a half life of 3.0 ± 0.5 hours for its gold parent.

Moon and Thompson⁸ have reported an 18-hour Au¹⁹¹ descending from a 12-hour Hg¹⁹¹. We have no evidence concerning the Hg isotope reported by these workers, but we can say about an 18-hour Au¹⁹¹ that if such an isomer exists, it is not the parent of 3-day Pt¹⁹¹, within the limits of detection of the chemical genetic experiments reported here. A small amount of a 17-hour gold activity was observed in one of the gold fractions milked from mercury, but its gamma spectrum was shown to be identical (at 8 percent resolution in a

scintillation spectrometer) to that of 17-hour Au^{193} and hence it is presumed to be Au^{193} .

A = 191. Gamma ray spectra

The gamma spectrum of 3-hour Au^{191} was examined in the scintillation spectrometer with a sample which contained mostly that isotope; one of the spectra is shown in Fig. 4. Gamma rays were seen at 140 ± 20 kev, 300 ± 10 kev, 390 ± 20 kev, 475 ± 20 kev, and 600 ± 20 kev, with intensities relative to the K x-rays of 0.14, 0.55, 0.05, 0.04, and 0.14, respectively. Because of the high intensity of the x-rays at ~ 60 kev, we cannot say anything about the possible existence of gamma radiation softer than ~ 100 kev.

In the course of several "milking" experiments, samples containing essentially pure 3-day Pt^{191} were obtained. Scintillation spectra taken with these samples showed, in addition to the K x-rays, gamma rays at 125 ± 10 kev, 175 ± 10 kev, 265 ± 10 kev, 345 ± 10 kev, 405 ± 10 kev, 445 ± 20 kev, and 530 ± 10 kev. One of these scintillation spectra is reproduced in Fig. 5. The relative intensities of the 265, 345, 405, 445, and 530 kev gamma rays as determined from the areas under their photopeaks are 0.2, 1.00, 0.8, 0.2, and 1.7, respectively. The areas of the 125 and 175 kev gamma ray photopeaks were measured as 0.5 and 0.7 relative to that of the 345-kev gamma ray; however, the Compton electron background under these peaks is rising sharply and there must also be some contribution from backscattered radiation. Because of the difficulty of estimating these effects, the relative abundances of these two gamma rays are uncertain.

Swan, Portnoy, and Hill⁷ have examined the conversion line spectrum of Pt^{191} and have reported gamma rays at 62, 82, 94, 125, 129, 171, 178, 267, 350, 359, 408, 455, and 537 kev. The present scintillation measurements would of course not resolve the 125-129, 171-178, 350-359 pairs, but otherwise are in agreement with the results of Swan et al. above 100 kev. (We could not examine the gamma ray spectrum below 100 kev because of the overwhelming area of the K x-ray peak.)

A = 189. Genetics

An ~12-hour activity in platinum was first observed in 1950 by Thompson and Rasmussen⁹ from 50-Mev proton bombardments of iridium, but a mass assignment was not made at that time. With the aid of J. O. Rasmussen, this activity has now been assigned to Pt^{189} by means of proton excitation function experiments in which its yield from iridium is compared with that of 3.0-day Pt^{191} produced from the (p, 3n) reaction on Ir^{193} . The excitation experiments were done in the Berkeley 32-Mev proton linear accelerator with a set of stacked iridium and aluminum foils as targets and absorbers. Figure 6 shows the resulting yield curves, which exhibit similar maxima at ~28 Mev. On the basis of its production from a (p, 3n) reaction in iridium, the new activity can be only $\text{Pt}^{191\text{m}}$ or Pt^{189} . The following is evidence against its assignment to $\text{Pt}^{191\text{m}}$: (a) we have bombarded Ir with 12-Mev protons in the 60-inch cyclotron, and observe in the platinum fraction the known 3-day Pt^{191} and 4-day $\text{Pt}^{193\text{m}}$ which are produced from the (p, n) reaction. No 10-hour activity is found. This is consistent with its assignment to Pt^{189} , because a (p, 3n) reaction is energetically not

possible at this proton energy. (Anticipating the discussion of gamma ray studies of the mass 189 chain, we also observed that the gamma spectrum of the platinum fraction was identical to the spectra obtained in other experiments with Pt^{191} , and had none of the gamma rays associated with the 10-hour platinum.) (b) Wilkinson, in his study of platinum isotopes produced by 18-Mev deuteron bombardments of iridium⁶, observed no platinum activity with half life shorter than that of 3-day Pt^{191} . He should not have been able to produce Pt^{189} in appreciable yield because 18 Mev is an insufficient deuteron energy for the (d, 4n) reaction.

It is also noted from Fig. 6 that the yield curve for the 3-day component shows two maxima. The small peak at approximately 10 Mev indicates the production of 3-day Pt^{191} from the Ir^{191} (p, n) reaction and of 4-day $\text{Pt}^{193\text{m}}$ from the Ir^{193} (p, n) reaction, while the tenfold larger peak at approximately 28 Mev corresponds to the Ir^{193} (p, 3n) Pt^{191} reaction. The 11-hour component shows no peak at approximately 10 Mev as might be expected if it were $\text{Pt}^{191\text{m}}$, but it seems to be produced only from the (p, 3n) reaction.

Because of these and other considerations to be discussed below, we assign this activity to Pt^{189} . Our best value for its half life is 10.5 ± 1 hours.

In the decay curves of the platinum fractions from these low energy proton bombardments of iridium, an 11 ± 1 -day activity also appears in addition to and in comparable yield to 10.5-hour Pt^{189} and 3.0-day Pt^{191} . A similar activity was seen in the decay curves of the iridium fractions (in addition to 75-day Ir^{192}). Attempts were made to establish the parentage of this 10-day activity by the timed

separation procedure described above, but these were not successful because of lack of quantitative reproducibility of the iridium-platinum "milkings". Accordingly, platinum-iridium separations were performed on the initially pure platinum fractions after the "complete" decay of activities shorter than ~10 days, and it was found that an ~11-day activity appeared in both the platinum and the iridium fractions. The gamma ray spectra of these activities were studied with the scintillation spectrometer, and were found to be different from each other (dispelling the fear of incomplete chemical separation). The 11-day platinum activity is undoubtedly Pt^{188} ; evidence for this will be discussed under A = 188.

The 11-day iridium can be only Ir^{189} or an isomer of stable Ir^{191} , since it arises from the decay of Pt^{189} or Pt^{191} (Pt^{190} is stable and could not give rise to the previously reported^{10, 11} 10-12-day Ir^{190}). Evidence against the existence of such an Ir^{191} isomer was initially provided by Wilkinson⁶, who searched radiochemically for an active daughter of Pt^{191} with negative results. Subsequently, Swan et al.⁷ have carefully examined the radiations of Pt^{191} and have not reported the growth of an ~11-day daughter activity. Our own data on this point are not conclusive as yet, but they indicate that 3-day Pt^{191} does not decay into a 10-day activity, whereas decay curves of samples containing 11-hour Pt^{189} always show the 10-day "tail". We therefore assign the 11-day iridium activity to Ir^{189} .

Once the chain Pt^{189} - Ir^{189} has been established, it becomes easier to identify its Au^{189} parent. This isotope has been produced in several different ways:

(a) Bombardments of tantalum ($Z = 73$) with high energy carbon ions in the 60-inch cyclotron produced activities in the gold fraction of half lives 10 ± 5 min, 42 ± 5 min (predominant), ~ 11 hour, and ~ 10 day (weak). The yields were very low in these experiments because of inadequate beam currents, but timed platinum separations from the gold fraction indicated that the 11-hour platinum (^{189}Pt) is the daughter of an approximately 35-minute gold parent activity.

(b) Platinum metal was irradiated with 130-Mev protons, and a gold chemical fraction isolated. Timed milkings of platinum from this fraction (done in separate experiments at intervals of 10 minutes and 30 minutes, respectively) verified that 11-hour Pt^{189} has a gold parent of 40 ± 10 minutes half life. The yield curves from these milking experiments are shown in Figs. 3 and 13.

These experiments demonstrate that Au^{189} is an isotope of half life 42 ± 5 minutes.

In the experiment discussed under $A = 191$ (the results of which are given in Table I and Fig. 2), it was seen that the 40-minute gold activity grew from an approximately 20-minute Hg parent. The experiments cited here which establish the 42-minute gold as Au^{189} therefore also set the half life of Hg^{189} as approximately 20 minutes. This Hg^{189} half life, however, is the result of only one experiment, so a considerable uncertainty is attached to this value.

The mass 189 chain, insofar as we have studied it, can be written as:

A = 189. Gamma ray spectra

When the decay data from some of the "milking" experiments had been evaluated, it appeared that samples quite rich in one or more of the mass 189 isobars had been obtained. Because of the many unknowns present at the time of the experiments, however, some of the gamma ray data obtained were incomplete, especially for Pt^{189} .

A fairly pure Au^{189} sample was obtained from the carbon ion bombardment of tantalum. Gamma ray spectra taken during the first few hours of its decay show, in addition to x-rays, a very prominent gamma ray at 290 ± 10 kev, decaying with the ~ 40 -minute half life of Au^{189} (see Fig. 7). A gamma ray is also seen at 135 ± 10 kev in about 10 percent of the intensity of the 290-kev gamma ray. High energy radiations (>800 kev) may also be present.

Bombardments of iridium with 32-Mev protons produce in the platinum fraction active isotopes of masses 193, 191, 189, and 188. If one allows this fraction to decay for several weeks and then removes iridium from it, quite good samples of Ir^{189} and Ir^{188} are obtained, because Pt^{191} and $\text{Pt}^{193\text{m}}$ have no active iridium daughters. The 11-day Ir^{189} can be distinguished from 41-hour Ir^{188} by virtue of their very different half lives. We have obtained in this way the spectrum of Ir^{189} (see Fig. 8), which shows a strong gamma ray at 245 ± 10 kev, and perhaps a weak gamma at ~ 135 kev (although this may be back-scattered 245-kev radiation). No other radiations than x-rays were seen which could be attributed to Ir^{189} .

The Pt^{189} results were inconclusive, but a gamma ray at 140 ± 10 kev is fairly certain, with probable gamma rays also at ~ 550 kev, slightly greater than 550 kev, and at ~ 700 kev.

A = 188. Genetics and gamma spectra

Naumann¹² has reported the synthesis of a new neutron deficient isotope of platinum, Pt^{188} , with a half life of 10.3 days. Although the present work was aimed primarily toward the study of new odd-particle chains, it was of interest to examine the 188 chain because of the possibility of confusion of this 10-day Pt^{188} with the 10-day Ir^{189} reported here. (It has already been mentioned under A = 189 that we had observed a 10-day activity in both the platinum and the iridium fractions from 30-50 Mev proton bombardments of iridium.)

We have studied the Pt^{188} - Ir^{188} pair in the following way: a proton bombardment of iridium metal was made at 32 Mev, and a platinum fraction chemically separated. This fraction was allowed to stand for about a month, at which time an iridium-platinum separation was performed. This second platinum fraction exhibited an initial growth, and then decayed with a 10.0 ± 0.3 day half life. Analysis of the growth curve¹³ plus direct decay data yields a daughter half life of 41 ± 4 hours. This curve is shown in Fig. 9.

Our evidence for the assignment of the 10-day activity to Pt^{188} , in agreement with Naumann, is the following:

(a) We have observed this 10-day platinum in bombardments of iridium with 32-Mev protons, which is consistent with its production from the reaction $\text{Ir}^{191}(p, 4n)\text{Pt}^{188}$.

(b) The daughter iridium activity has been assigned by Chu¹¹ to Ir^{188} on the basis of its production by an $(\alpha, 3n)$ reaction on enriched Re^{187} .

(c) Our studies of the gamma spectrum of the 41-hour iridium (described below) show that the energies of the first two excited states in osmium which are populated by its decay are the same as those produced from the beta decay of Re^{188} . This is fairly convincing evidence for its assignment to Ir^{188} .

The gamma spectrum of Pt^{188} is shown in Fig. 10. Gamma rays are seen at 195 ± 10 kev, 305 ± 30 kev, and there is a broad peak between 375 and 425 kev which may represent two unresolved gamma rays. The measured relative abundances are 0.3, 0.04, and 0.08, respectively, relative to K x-rays. As the Ir^{188} grows into the sample, gamma rays appear at 150 ± 10 kev, 475 ± 10 kev, and 625 ± 15 kev. The relative intensities were measured directly in the second iridium fraction which contains Ir^{188} plus a small fraction of Ir^{189} activity. From the Ir^{188} spectrum (shown in Fig. 11) we obtain relative intensities 0.9, 0.6, and 1.0 for the three gamma rays, respectively. There also seems to be some harder gamma radiation in low intensity.

Richmond, Grant, and Rose¹⁴ have studied the beta decay of Re^{188} (which leads to the same daughter nucleus as does the E.C. decay of Ir^{188}) and have observed gamma rays of 152, 476, 638, 933, and ~1300 kev. The first three are in good agreement with the gamma rays observed by us from the decay of Ir^{188} ; we have no comparison with the two high energy gamma rays of Re^{188} other than to say that if the 933-kev gamma ray is present in the decay of Ir^{188} its intensity is less than one-third that of the 625-kev gamma ray.

In two 130-Mev proton bombardments where platinum was milked from a gold parent fraction, we have obtained preliminary evidence

that the half life of Au^{188} is of the order of 10 minutes. We have no further data concerning Au^{188} .

Our genetic data on the mass 188 chain are summarized as:

A = 187. Genetics and gamma spectra

An 11.8-hour iridium isotope was discovered by Chu¹¹ and assigned by him to Ir^{187} on the basis of its production from an $(\alpha, 2n)$ reaction upon Re^{185} . The shape of the excitation curve which he presents (as $\alpha, 2n$ plus small contribution from $\alpha, 4n$) is not convincing, however, especially in view of the fact that others have been unable to detect an $(\alpha, 4n)$ reaction with 38-Mev alpha particles in the 60-inch cyclotron. Although our genetic data neither prove nor disprove this mass assignment, but only establish the gold and platinum activities which are isobaric with the 12-hour iridium, we shall here specify this reference activity as Ir^{187} . It will be seen, however, that our gamma ray data tend to support this assignment.

We have identified Pt^{187} in the following way: iridium metal was bombarded with 120-Mev protons and a pure platinum fraction chemically separated. (Its decay curve was complex, with components of 2 1/2 hours, ~10 hours, ~2.2 days, and ~10 days.) After allowing this platinum fraction to stand for one day, iridium was separated from it. This first iridium milking contained largely 14 ± 1 hour (Ir^{187}) and 43 ± 4 hour (Ir^{188}) activities, with a ratio (in c/m) of $\text{Ir}^{187}/\text{Ir}^{188}$ of 6.5. The same platinum fraction was then allowed to stand for an additional day, and iridium was again removed. The ratio (in c/m) of $\text{Ir}^{187}/\text{Ir}^{188}$ present in this second milking was much lower, ~0.2. Because Ir^{188} grows

from a "long"-lived parent (10-day Pt^{188}), its actual yield during the two intervals of growth is roughly constant and hence the ratio of $\text{Ir}^{187}/\text{Ir}^{188}$ in the two milkings gives some idea of the half life of the parent of Ir^{187} . By the factor of ~ 32 decrease in Ir^{187} in 24 hours, one would say that the half life of its parent is ~ 5 hours. A possible error would arise from a small amount of 10-hour Pt^{189} impurity in the iridium milkings, which would cause the half life of Pt^{187} to appear too long. The experiment, then, indicates that the half life of Pt^{187} is ≤ 5 hours, and probably is the 2.5-hour platinum seen in the original platinum fraction.

Several other genetic experiments were done to identify the mass 187 chain. On two occasions, platinum metal was irradiated with 130-Mev protons, and pure gold fractions prepared. As was expected, the gold fraction decay curves were complex, with at least five components. Therefore, timed platinum milkings were made in each experiment by aqueous extraction of the platinum from the gold, which was in an amyl acetate solution. The results of these milkings are given in Table III, and some of the yield curves are shown in Figs. 12 and 13.

Our genetic data on the mass 187 chain are summarized as:

The only reasonably good gamma ray data at mass 187 were obtained with 14-hour Ir^{187} . Three gamma rays are seen, at 135 ± 10 kev, 300 ± 10 kev, and 435 ± 15 kev, with relative intensities respectively 1.0/1.1/0.8. Weak gamma rays are also seen at ~ 500 kev and at ~ 625 kev, but these may belong in part to Ir^{188} . This spectrum is shown in Fig. 14.

Table III

Activity	Half life of gold parent or ancestor	Assignment
Experiment A--five milkings at 7-minute intervals		
2.5 ± 0.5 hr	~ 13 minutes	Pt^{187}
12 ± 2 hr	~ 14 minutes	Ir^{187}
Experiment B--eight milkings at 10-minute intervals		
3 ± 0.5 hr	~ 17 minutes	Pt^{187}
12 ± 2 hr	~ 12 minutes (plus ~ 40 minutes)	Ir^{187} (plus Pt^{189})

One further remark may be made about the assignment of this chain to mass 187. In two bombardments of iridium with 32-Mev protons where fast chemistry was done, the 2.5-hour platinum activity has not been observed, whereas Pt^{188} , Pt^{189} and heavier platinum isotopes are all found. We interpret this as evidence that this isotope has a mass lighter than 188, since it is produced from high energy proton bombardments of iridium. Yet it could not be lighter than 186, or Chu^{11} could not have produced it from an $(\alpha, 3n)$ reaction on Re^{185} . Of the two remaining choices, mass 186 or 187, our gamma ray data on the 14-hour iridium daughter lead us to prefer mass 187. The first two excited states of the even-even nucleus Os^{186} , defined by the beta decay of Re^{186} , are at 137 and 764 kev^{15,16}, with gamma rays observed at 137, 627, and 764 kev. The principal gamma rays which we observe from the decay of the 14-hour iridium, however, are at 135, 300, and 435 kev. These do not fit into the Os^{186} level pattern, whereas in the case of mass 188, the gamma ray energies

which we observe from the decay of Ir^{188} agree quite well with those found¹⁴ from the beta decay of Re^{188} .

We would like to express our appreciation to Professor J. O. Rasmussen and to Dr. M. I. Kalkstein for their extensive assistance during the course of this study, and also to Professors G. T. Seaborg and I. Perlman for their helpful comments. The cooperation of the staffs and crew members of the 184-inch cyclotron, linear accelerator, and 60-inch cyclotron is also gratefully acknowledged.

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13. The total amount of activity at time t can be expressed as

$$A = \sum_i a_i e^{-\lambda_i t},$$

where the a_i 's can be either positive or negative. To resolve this growth and decay curve, the "tail" was extrapolated back to the time of purification of the parent and subtracted from the observed curve. The series of negative differences, when plotted, gives the half life of the daughter.

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Z	80			Hg ¹⁸⁹ 20 ± 10 min (30 min)		Hg ¹⁹¹ 55 ± 10 min (57 min) (12 hr)
	79	Au ¹⁸⁷ ~15 min	Au ¹⁸⁸ ~10 min	Au ¹⁸⁹ 42 ± 5 min		Au ¹⁹¹ 3.0 ± 0.5 hr (~4 hr) (~18 hr) (~1 day)
	78	Pt ¹⁸⁷ 2.5 ± 0.5 hr	Pt ¹⁸⁸ 10.0 ± 0.3 day (10.3 day)	Pt ¹⁸⁹ 10.5 ± 1 hr		Pt ¹⁹¹ 3.0 ± 0.3 day (3.0 day)
	77	Ir ¹⁸⁷ 14 ± 2 hr (11.8 hr)	Ir ¹⁸⁸ 41 ± 4 hr (41.5 hr) (40 hr)	Ir ¹⁸⁹ 11 ± 2 day	Ir ¹⁹⁰ (3.2 hr) (12.6 day) (10.7 day)	
		187	188	189	190	191
		A				

MU-8434

Fig. 1. Segment of an isotopic chart in the noble element region.
(Half lives in parentheses are previously reported values.)

Fig. 2. Radiochemical yield of daughter activities as a function of time. Gold separated from parent mercury fraction at 8-minute intervals. (Bombardment: Au + 120-Mev protons)

MU-8436

Fig. 3. Radiochemical yield of daughter activities as a function of time. Platinum separated from parent gold fraction at 30-minute intervals. (Bombardment: Pt + 130-Mev protons)

MU-8437

Fig. 4. Gamma-ray spectrum of Au^{191} .

MU-8438

Fig. 5. Gamma-ray spectrum of Pt^{191} .

MU-8439

Fig. 6. Excitation curves for the production of 3-day Pt^{191} and 10-hour Pt^{189} .

MU-8440

Fig. 7. Gamma-ray spectrum of Au^{189} .

Fig. 8. Gamma-ray spectrum of Ir¹⁸⁹.

MU-8442

Fig. 9. Growth and decay curve for Pt^{188} , as daughter Ir^{188} grows into equilibrium with parent.

Fig. 10. Gamma-ray spectrum of Pt^{188} .

Fig. 11. Gamma-ray spectrum of Ir¹⁸⁸.

Fig. 12. Radiochemical yield of daughter activities as a function of time. Platinum separated from parent gold fraction at 7-minute intervals.
(Bombardment: Pt + 130-Mev protons)

Fig. 13. Radiochemical yield of daughter activities as a function of time. Platinum separated from parent gold fraction at 10-minute intervals.
(Bombardment: Pt + 130-Mev protons)

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Fig. 14. Gamma-ray spectrum of Ir^{187} .