MASTER

Neutron Activation Analysis of Coins and Coin-Streaks

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Introduction

The science of numismatics has contributed immeasurably to the understanding of history as attested to by the thousands of articles and books on the subject. Although much use has been made of the information contained on many of the 30,000,000 or so ancient and medieval coins that are extant today, very few studies have been directed toward the determination of what is in a coin. In the last 150 years perhaps only about 2000 ancient and medieval coins have been analysed chemically. The reasons for this limited study are clear: the analysis process is time consuming and, most important in many cases, the coin is destroyed. Even reactor neutron activation, which is non-destructive, has been used for the analysis of only about 1000 coins. Although a coin irradiated in this manner is unharmed, measurable amounts of a form (isotope) of radioactive silver having a half-life¹ of 255 days are produced. The level of silver radioactivity in each irradiated coin is generally quite low and of no concern; but, it would probably not be good policy to have in a single collection a large number (e.g. a few thousand) of silver coins each mildly radioactive.

Because of the interest expressed a few years ago by various University of Michigan historians in having available non-destructive analysis data on the silver fineness of coins, we devised and perfected two non-destructive methods based on neutron activation analysis (NNA). Both methods avoid the problem of residual silver radioactivity.

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The first method, which requires that we borrow the coins for a few days, involves the irradiation of a coin, not in a nuclear reactor, but instead in a low-intensity beam of neutrons emitted by a radioactive plutonium-beryllium mixture². This neutron source is generally contained in a movable barrel filled with water or tallow and the whole arrangement is called a neutron Howitzer.

When coins are irradiated in the Howitzer, because of the very low neutron intensity, only isotopes of silver having half-lives of 24 sec. and 2.4 min. are detected. None of the 255 day half-life silver radioactivity is observed³. As described in a later section, this method of analysis requires only $2\frac{1}{2}$ minutes per coin. We have determined the silver contents of over 3000 coins using this Howitzer method of analysis.

The second method of analysis does not even require that we borrow the coins. What is done is to take small samples in the form of metal streaks on etched quartz tubing. These rubbings from the edge of a coin look much like pencil markings, weigh less than 0.0001gm., and can be taken in a coin room; generally 100-200 coins can be streaked per day. About 40 streaks are then irradiated per day in a nuclear reactor and it is possible to detect not only the long-lived radioactive silver which is produced but also radioactive gold, copper, and occasionally arsenic, antimony, and zinc. Lead is not detected and other elements such as tin and nickel would be detected only if we modified our methods of radioactivity measurement. We have analysed over 4000 coins and silver art objects using this method.

Although this second method of analysis provides us with data on the silver fineness of a coin, because of the data obtained for the other elements, and in particular gold, we have been able to

derive from these analyses information of relevance to the following fields: geology, ancient technology, archaeology, political history, economic history, and art history. In addition, the data have permitted us, in some cases, to be able to identify modern forgeries of ancient and medieval coins and silver art objects.

The two methods outlined above were devised with an emphasis on the speed of analysis since we wanted to be able to obtain data for a large-enough number of coins to permit obtaining statistically relevant results. Since we have been able to obtain a significant amount of new information from the streak method of analysis, even though our original intent was only to obtain data on the silver fineness of the coins, the major portion of this article will be devoted to these new data. The bulk of the coins we have analysed by both methods are from Persia and for purposes of illustration data are presented for coins from the Sasanian (224-651 A.D.) and the Umayyad (661-750 A.D.) periods.

Howitzer Method

Shown in Fig. 1 is a student inserting into the neutron Howitzer a cartridge containing the coin. The coin, together with a silver disk, is irradiated (Fig. 2) for one-minute. Following the irradiation the coin and disk are removed from the Howitzer and each is placed next to a separate radiation detector where the silver radioactivity counts are determined for one minute. A 25 second period elapses between the end of the irradiation and the beginning of the counting period.

Silver absorbs neutrons (undergoes a nuclear reaction) very readily; as a result, fewer neutrons reach the part of the coin farther from the neutron source. In addition, some of the neutrons are initially of high energy. In passing through the coin the

neutrons may collide with silver and lose energy. What complicates the process is that the extent to which silver absorbs neutrons depends on the neutron energy. As a result, the amount of detected silver radioactivity per gram of silver in the coin is dependent in a somewhat complicated way on both the silver fineness of the coin and on the coin thickness (Fig. 3). These factors could be taken into account, as was done by Wyttenbach and Hermann⁴ by correcting the data in terms of the coin thickness. However, since many coins are somewhat variable in thickness, we have found that errors of up to 10 to 20% in silver fineness could result.

To eliminate the thickness factor from the measurements we rely on the data from the silver disk. The radioactivity produced in the disk is related to the number of neutrons that pass through the coin and reach the disk. The thicker the coin or the higher the silver-fineness of the coin, the lower the silver radioactivity produced in the disk. We have found, by experimentation, that a combination of the radioactivity levels in the coin, C, and in the disk, D, will result mathematically in an equation that is thickness independent and valid for all but a few very thin coins. The equation is:

$$\frac{C}{D \times \% \text{ silver in coin} \times \text{weight of coin}} = \text{a constant} = R$$

Eq. (1)

Now, if various 20th century coins of different measured thicknesses and known silver contents are irradiated together with disks, the value of R can be calculated for each coin. As is seen in Fig. 4, R, which is plotted versus the coin thickness is quite constant, except for very, very, thin coins. The average R value found from these standards (the modern coins of known silver contents) can now be used with the data obtained for coins being analysed. The equation is now:

$$\frac{C}{D \times \text{weight of coin} \times \text{average } R} = \% \text{ silver in coin} \quad \text{Eq. (2)}$$

In practice, we usually spend a minimum of three hours at a time on these analyses during which we obtain about 12-15 R values and C and D data for about 100 coin irradiations. Since the silver radioactivity being detected is due to isotopes having half-lives of only 24 sec. and 2.4 min. almost no radioactivity would be detectable after about 10-15 minutes following the irradiation. As a result, we can re-irradiate each coin as many times as we wish and we generally perform about 10 such analyses per coin. The average silver fineness from the 10 repeat analyses is almost always within ± 1.0 to $\pm 1.5\%$ of the true silver content with two exceptions: (1) coins having very high relief, such as some ancient Greek coins, generally result in much poorer data, (2) very thin coins, for which the R value is out of the linear range in Fig. 4 would result in erroneously low calculated silver contents. In the few cases where we have analysed very thin coins we have used specially prepared standards of the same thickness to determine R values.

A more complete discussion of this method has already been published elsewhere⁵.

Shown in Fig. 5 are silver fineness data for over 400 Sasanian coins. Alternating open and closed circles are used to assist in the visual correlation of the data with the ruling monarch issuing the coins. Those coins beginning with the reign of Kavad I have inscribed on them the year of issue and the data in Fig. 5 are arranged in accord with these dates. Prior to these analyses, many historians had assumed that, except for some obvious debased-looking issues of Shapur I, all other Sasanian drachms were of better than 90% silver.

It is interesting to note that a number of periods that involved

large military campaigns also involved the debasement of the currency. This should not, however, be regarded as a universal cause-and-effect relationship since counter examples can be given. For instance, Peroz waged war against the Ephthalites, was defeated, and was required to pay heavy tribute. Yet, even though additional financial strain occurred during his reign because of a widespread famine, the coinage of Peroz did not undergo debasement⁶.

As noted in the next section, the various mints issuing coins during the reign of Khosrau II and during the Umayyad period frequently show differing patterns of debasement.

Streak Analysis Method

The oxidized surface of a coin and the non-tarnished portion in immediate contact with the corrosion layer generally have a composition quite different from that in the interior of the coin⁷. This results from the fact that the more reactive elements such as copper are oxidized and lost from the surface more readily than the less reactive elements silver and gold. Because of this surface depletion effect it is necessary to be certain that samples are taken at a depth where the composition is that of the original coin.

Our procedure involves first removing the corrosion layer on a tiny area on the edge of the coin by stroking the edge with fine-grained emery paper. A few extra strokes with the emery paper removes about 0.01 inches of metal. A small, cleaned piece of roughened quartz tubing is then rubbed on the brightened area of the coin edge (Fig. 6) producing a streak on the quartz tubing weighing less than about 0.0001 gm. Usually one or two additional pieces of quartz are also streaked in the same spot and used for confirmatory analyses.

Usually 40 to 50 streaks from coins plus 5 streaks from alloys of known composition are individually sealed in polyethylene and irradiated together in a nuclear reactor for two hours at a neutron intensity of 3×10^{13} neutrons $\times$ cm^{-2} $\times$ sec^{-1} . The irradiated streaks are then mounted separately on cards and analysed for their silver, gold, copper, zinc, arsenic, and antimony radioactivity. A multichannel pulse-height analyser coupled to a high-resolution Ge(Li) detector is used for the analysis. By comparing the radioactivity levels in the coin streaks with those in the standard-alloy streaks we can then calculate the ratios: $\% \text{Cu}/\% \text{Ag}$, $\% \text{Au}/\% \text{Ag}$, $\% \text{Zn}/\% \text{Ag}$, $\% \text{Sb}/\% \text{Ag}$, and $\% \text{As}/\% \text{Ag}$.

None of the coins described in this paper except a few very debased issues of Shapur I, had any significant amount of zinc, arsenic, or antimony and, therefore, we need be concerned only with the silver, copper, and gold data. This information is available to us as the two numerical values: $\% \text{Cu}/\% \text{Ag}$ and $\% \text{Au}/\% \text{Ag}$. In order to be able to calculate the three quantities: $\% \text{Ag}$, $\% \text{Cu}$, and $\% \text{Au}$, we need another numerical quantity and we have assumed that $\% \text{Ag} + \% \text{Cu} + \% \text{Au} = 100 \%$. Having now three numerical values, we can solve for the three percentages. For reasons given below, we report our data in two forms: $100 \times (\% \text{Au}/\% \text{Ag})$ and $\% \text{Ag} + \text{Au}$.

It was apparent early in our studies that the gold being detected was associated almost entirely with the silver in a coin. For instance, data for 49 coins of Shapur I are arranged in decreasing order of the $\% \text{Ag} + \text{Au}$ contents on the upper graph of Fig. 7. The lower graph of this figure illustrates that the gold-to-silver ratio for these coins is quite constant irrespective of the amount of silver in the coin. What the data on the lower graph also suggest

is that certain gold:silver ratios are occurring. There are data clusters of about 0.3, 0.4 to 0.5, 0.55, and 0.65 as well as a single point at 0.9. This must mean that as many as four or five separate sources of silver were being used by Shapur I.

Apparently the ancient minters did not know that the silver they were using contained up to one percent gold impurity and, therefore, did not attempt to remove it. Since gold and silver are chemically similar, the gold impurity level would not be changed appreciably in the silver refining process. As a result, the percent gold impurity level in silver = $100 \times (\% \text{ Au} / \% \text{ Ag})$ in a coin is an indication of the level existing in the original silver ore. Of course, there was some reuse of old coins and if coins made from different silver sources are remelted together an averaging of gold levels would result. The composite data for a series of coins from a given period or even from a single mint during a given period will not necessarily show distinct levels but instead general clusterings. More randomness would be expected for those mint-cities that rely on a number of silver sources. Similarly, cities that are principal trade centers and might receive coins from other mints which might be remelted for their own coins would also tend to show greater randomness in the gold levels of their coins. The most uniform levels of gold impurity would be expected for coins issued by small mint-cities adjacent to silver sources.

The data of Fig. 8 indicate either that the same silver sources were not being exploited for prolonged periods of time or, if they were, that the gold levels changed as the mines were being worked. In any case, the coins from each time period tend to have separate overall gold-impurity patterns. In plotting this and other bar-graphs in this paper we have chosen to use a logarithmic scale. The listing

in Table I indicates the gold impurity ranges used for constructing these graphs.

The gold levels from over 1000 Sasanian coins are shown in Fig. 9. The latter years were characterized by the partial utilization of silver having relatively low gold levels.

Of interest in Fig. 9 are the data given by open squares. These all correspond to modern fakes, some of which are pictured in Fig. 10. Some modern fake silver coins can be even more readily identified since they contain less than 0.001% gold impurity which is characteristic of modern highly-refined silver.

The fact that the gold is associated with the silver as an impurity means that the analysed gold content should be added to that of the silver content in determining the intended silver fineness of a coin. This is not the total intended silver fineness, however, since another impurity, lead, which probably remains from the silver-ore refining process, should also be included in calculating the intended fineness.

Caley, in 1957, published a series of chemical analyses on eight Umayyad dirhems⁸. His data are given in Table II as the top row of values for each coin. Also given are his % Ag + Au + Pb, which we have taken as the intended silver fineness. The second row contains his data adjusted for % Ag + Cu + Au = 100%, which is the equation we use here for reporting our data. The adjustments were made in the following manner for the first coin: experimental % Ag + Cu + Au = 98.27%. Adjusted silver = $91.49/0.9827 = 93.10\%$; adjusted copper = $6.16/0.9827 = 6.27\%$; adjusted gold = $0.62/0.9827 = 0.63\%$. It is important to note that the adjusted % Ag + Au is generally within 0.1 to 0.2% of the experimentally observed intended silver fineness. Thus, our method of reporting the data, even though we do

not detect lead or tin or iron, results in data which very closely approximate the answer to the question being asked: "What did the ancient minter intend as the fineness of the coin?" Our data for the silver content using the streak method will generally be a few percent higher than the actual silver content as is seen by the comparison of the two sets of % Ag values for each coin in Table II. We also observe this small difference when comparing the streak % Ag with the actual % Ag as found by the Howitzer method.

Umayyad Dirhems

Shown in Fig. 11 are the gold impurity data for Umayyad dirhems issued at 17 mints during the nine year period: AH 90-98/708-717 AD. The mint locations are shown in Fig. 12. It is clear from Fig. 11 that a number of silver sources were being used during this period. One silver source, being used mainly for coins minted at Hamadhan, Mahi, and al Taimara, had about 0.05 to 0.20% gold. Another source, used mainly by Wasit, but also partially by Sabur, Ardashir-Khurra, and Darabjird, had about 0.6 to 0.8% gold impurity. Sijistan used silver with about 0.8 to 1.0% gold whereas Harat, Abrashar, Sarakhs, and to some extent Merv relied heavily on silver with about 1.0 to 1.3% gold. The occasional points in the range of 0.3 to 0.4% gold in Fig. 11 could be the result of silver mixtures or could represent the occasional use of silver from yet another source. This latter hypothesis is a distinct possibility since a large number of later-dated Islamic coins have this level of gold impurity. Because of the distance from Abrashar, and the small use of silver having about 1% gold at Rayy, it would appear that the silver used at Arminiya, having about 0.9 to 1.2% gold is from a separate source. Perhaps part of the silver used at Dimishk derives from the same source being utilized by Arminiya.

Data such as those given in Fig. 11 can be used in a variety of ways.

1. In some cases, the location of particular mint-cities may be unknown. For instance, Walker⁹ states that the mint-city of Mahi may be either a city near Merv or a city near Hamadhan. The data of Fig. 11 clearly indicate that the latter is the correct choice.

2. Knowledge of the number and types of silver being used in manufacturing coins in a given city might indicate the degree of importance of that city as a trade center.

3. By determining which mints use which types of silver it is possible to approximate the locations of silver sources and to suggest the silver trade-route patterns. For example, a silver source must have existed in the vicinity of Hamadhan-Mahi-al Taimara. Such geological considerations are of particular importance in view of the fact that the Iranian geological survey report¹⁰ does not list a single silver source in the whole of Iran!¹¹

4. As we will discuss in the next section, the gold impurity data can assist in deciphering some of the Sasanian mint-names which are inscribed in the ancient script Pehlevi.

5. The gold impurity levels found in silver art objects can be compared with the levels found in coins to suggest periods or regions of manufacture of the art objects.

6. When an art object is clearly of a design indicative of a given period and region of manufacture, yet has a grossly different gold level (generally lower) as compared with authentic coins of the same period and region, this observation can frequently be taken as evidence that the art object is a modern forgery.

7. Similarly, modern fakes of ancient coins can frequently be detected by their having gold levels different from those of authentic

coins.

Figures 13 to 15 contain intended silver fineness data as well as the gold impurity levels for coins from six Umayyad mints. From his analysis of eight Umayyad dirhems Caley⁸ noted, as is very evident in Figs. 13 and 14, that the silver fineness was increased in the latter part of the Umayyad period. He suggested that "one cause might be a change in the sources of the silver so that a purer metal became available at a later time." But he also said that "a more likely cause is that some improved method for producing silver of high quality was discovered and put into practice at some time in the period covered by this series of coins."

Our analysis data from 461 Umayyad dirhems indicates that neither of the explanations is correct and that the increase in silver fineness was a deliberate economic decision on the part of those who controlled the mints. If the improvement in fineness was due to a new technological method of refining silver then other ~~mints~~ mints besides Wasit would also have produced very high quality coins. Yet, the mint at Damascus, Fig. 14, although increasing the quality of its coins, does so only gradually. It is true that at about the same time that Wasit begins producing coins of high silver content the mint also begins using silver from a new source as is seen in the lower graph of Fig. 13. Yet, Wasit still relies occasionally on its older source of silver for the production of some of the high-quality coins and, further, its new source of silver probably is the one in the Hamadhan-Mahi region, Fig. 11, which is used by these mints tens years earlier for the production of dirhems having only about 97 to 98% Ag + Au.

The marked increase in the fineness of the coins from Wasit occurs at the same time when most coin production was consolidated at that

mint. Political and economic considerations must be the reasons for this change¹³.

Sasanian Coins

Given in Fig. 16 are gold impurity-level data for 501 coins of the Sasanian monarch: Khousraw II (591-628 AD). The data are grouped according to the mint signatures appearing on the coins and are arranged according to the scale given in Table I.

It has been suggested by both Walker¹⁴ and G6bl¹⁵ that certain mint signatures refer to the same cities. ZD is defined as a variant of RD and both are identified as Rayy. Similarly, MB is considered as a variation of the script for MR, identified as Merv. The data of Fig. 16 show that RD and ZD have clearly differing patterns of gold levels indicating their reliance on different combinations of silver sources. The same is true of the data for MR and MB. Thus, four separate mints are indicated by these four mint signatures.

The identification of MR as Merv is consistent with the fact that a good fraction of the coins have high gold contents (range 21, Table I) as do the Umayyad coins from this mint (Fig. 11). Also, RD as al Rayy is consistent with the observation that some of its coins are also made of silver having a high gold level (range 21) since both Rayy and Merv were major stops on a northern trade route (Fig. 17).

The mint signatures BIS and ART have been unambiguously identified as Bishapur and Ardashir-Khurra¹⁶, cities that were less than 100 miles apart. Their gold distribution patterns in Fig. 16 are similar in that each has a majority of its coins in range 18 and also produced a few coins using silver of much lower gold content. On this basis, DA would appear correct as the identification of

Darabjird. The suggestion that DR also refers to Darabjird^{14,15} may not be correct according to Fig. 16.

ZR as Zarang may also be correct but its gold pattern suggests that the mint used silver from a number of sources and, in particular, had the heaviest reliance of any of the mints on the silver source or sources having low gold contents. It is premature to speculate about the remaining mint patterns.¹⁷

The coin data represented in Fig. 16 span a period of 37 years. Examination of a more limited portion of these data for the regnal years 2-10 of Khusrau II results in the patterns shown in Fig. 18. These data, which are arranged for each mint according to the regnal years, show for many of the mints a general pattern of debasement, although certain mints such as DA issue relatively stable coinage.

The lower portion of Fig. 18 also indicates that RD is not the same mint as ZD and that Mr is not the same mint as MB. It also appears that NH and NAR are not the same and that AB is different from both APR and NB. The gold data for ST appear out of line with the data for BIS and APR which are in the same geographical location as Istakar, the proposed^{14,15} identification of ST. AU would appear not to be the same mint as ART. Analysis of coins of Khusrau I and Hormizd IV should assist in making comparisons more unambiguously.

There appears on some of the coins of Khusrau II the phrase "afid" in the obverse right margin. We have found that these coins invariably contain a very high % Ag + Au content (usually greater than 99%) and almost always are of higher intended silver fineness than coins of the same mints and dates which do not have the extra inscription. Apparently these coins served a special purpose, such as being the accepted coinage for the payment of taxes.

Sasanian Art Objects

The largest collection of silver Sasanian art objects is in the Hermitage museum, Leningrad. We have been able to obtain streaks from their entire collection as well as from those housed in other major museums of the world. In most cases the gold impurity levels agree remarkably well with the gold levels from coins of the king portrayed on the art object. For example, two plates from the Hermitage¹⁸ with Shapur II as well as the large head of Shapur II at the Metropolitan Museum of Art in New York have gold levels of 0.95, 0.69, and 0.67%, respectively. This fits very well with the data of Fig. 8 for this monarch. A Hermitage plate with Peroz¹⁹ has 0.77% gold impurity; another Peroz plate at the Metropolitan Museum of Art has 0.84% gold. Both are in agreement with the data for Peroz coins.

There are some exceptions, however. The most notable is another Hermitage plate with Shapur II²⁰ having only 0.18% gold impurity--clearly outside the range for this king. This plate, for which there is no reason to question its authenticity, must have been made in a later, perhaps post-Sasanian period. Another plate in the Hermitage²¹, which is identified as a 19th century copy of the Bahram V plate which is part of the Oxus treasure in the British Museum, has only 0.019% gold impurity.

Data on these and other silver art objects will be published separately.

Other Studies

Using the Howitzer and streak method of analysis we are also analysing various coins, both silver and gold, of the Crusader kingdoms, various Roman, Greek, Byzantine, Anglo-Saxon, Merovingian, and

Carolingian coins, Near Eastern coins of the Parthian, Ayyubid, and Buyid dynasties, Italian coinage of the 10th-14th centuries, French, Spanish, Mexican, and Peruvian coinage of the 16th century, and, as the most modern, Mexican coins issued by the Zapatista revolutionaries in 1913-1915.

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Table I. Logarithmic gold-impurity
ranges used in constructing
bar-graphs.

% Gold	Range	% Gold	Range
0.011	1	0.114	12
0.014	2	0.142	13
0.018	3	0.180	14
0.023	4	0.225	15
0.029	5	0.288	16
0.036	6	0.360	17
0.045	7	0.450	18
0.057	8	0.567	19
0.072	9	0.715	20
0.090	10	0.900	21
0.114	11	1.140	22

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Table II. Original and adjusted chemical analysis data of E. Caley.*

Umayyad Mint	Date AH	% Ag	% Cu	% Au	% Pb	% Sn	% Fe	Total	% Ag + Au + Pb	% Ag + Au
Wasit	AH-85	91.49	6.16	0.62	1.58	0.05	0.05	99.95	93.69	
		93.10	6.27	0.63	--	--	--	100.00		93.73
Darabjird	AH-92	92.73	4.25	0.66	1.85	0.12	0.18	99.79	95.24	
		94.97	4.35	0.68	--	--	--	100.00		95.65
Kirman	AH-95	94.15	3.56	0.67	1.48	0.10	0.10	100.06	96.30	
		95.70	3.62	0.68	--	--	--	100.00		96.38
al-Basra	AH-100	91.17	6.36	0.42	1.63	0.10	0.09	99.77	93.22	
		93.08	6.49	0.43	--	--	--	100.00		93.51
Dimishk	AH-100	95.58	2.24	1.35	0.68	0.07	0.07	99.99	97.61	
		96.38	2.26	1.36	--	--	--	100.00		97.74
Ifriqiyyah	AH-112	98.06	0.84	0.70	0.42	0.10	0.05	100.17	99.18	
		98.45	0.85	0.70	--	--	--	100.00		99.15
al Andalus	AH-118	94.21	3.96	0.60	1.10	0.05	0.06	99.98	95.91	
		95.48	4.01	0.61	--	--	--	100.00		95.99
Wasit	AH-124	98.46	0.23	0.06	1.10	0.01	0.04	99.90	99.62	
		99.70	0.23	0.06	--	--	--	100.00		99.77

*Am. Num. Soc. Museum Notes, VII, 211 (1957).

Footnotes

1. The half-life is the duration of time required for the radioactivity level of an isotope to decrease to one-half of its original level. Thus, in two half-lives the level would be $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$; in three half-lives it would be $\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = 1/8$ of the original level, etc.
2. The neutron intensity from these sources is typically 10^{-9} of that in a reactor.
3. This is not to say that none of the long-lived silver is produced. Calculations indicate that in each coin there results about one disintegration every four months of this long-lived silver isotope. Such levels of radioactivity are undetectable and, of course, totally harmless. For comparison, it should be noted that the human body contains about 200,000 disintegrations per minute of radioactive carbon and potassium and, since the advent of nuclear bombs, additional levels of radioactive strontium.
4. A. Wyttenbach and H. Hermann, *Archaeometry*, 9, 139 (1966).
5. A. A. Gordus, *Archaeometry*, 10, 78 (1967); also short summaries are given in : A. A. Gordus, *The Numismatic Circular*, LXXVI, Mar., 1968 and A. A. Gordus, *The New Scientist*, October 17, 1968, p. 129.
6. A. A. Gordus and J. Bachrach, to be published.
7. J. Condamin and M. Picon, *Archaeometry*, 7, 98 (1964) and 8, 110 (1965); G. F. Carter, *Archaeometry*, 7, 106 (1964). For extremely heavily corroded coins, or coins corroded throughout it is important to emphasize that no method of analysis, including destructive chemical analysis will yield composition data indicative of the original coin.
8. E. Caley, *Am. Num. Soc. Museum Notes*, VII, 211 (1957).

9. J. Walker, "A Catalog of Arab-Byzantine and Post-Reform Umayyad Coins", Oxford Univ. Press, 1956.
10. "Preliminary Metallogenic Map of Iran", Geologic Survey of Iran, Report No. 7, Ministry of Economy, 1965.
11. The suggestion that the ancient Persians obtained their silver¹² as the impurity in the lead ores which exist in Iran cannot be correct. Iranian lead ores contain at most about 500-700 gm of silver per ton of ore¹⁰. Thus, to obtain enough silver for 100 silver dirhems there would also have been produced up to 1000 lbs. of lead. Since tens of thousands and perhaps even 100,000 or more dirhems were produced each year, there would have been a vast surplus of lead. Yet, virtually no lead artifacts, utensils, or art objects are found in archaeological sites.
12. T. A. Wertime, Science, 159, 927 (1968).
13. A. A. Gordus and A. Ehrenkreutz, to be published.
14. J. Walker, "A Catalog of the Arab-Sassanian Coins", Oxford Univ. Press, 1967.
15. R. Gobl, "Sasanidische Numismatik", Kliukhardt and Biermann, Braunschweig, 1968.
16. Ref. 14, pg. c.
17. Additional extensive data to be obtained from the analysis of coins of Khusrau I and Hormizd IV should assist markedly in resolving the difficult question of the Sasanian mint-signatures.
18. V. G. Lukonin, "Archaeologia Mundi: Persia II", Nagel Publishers, Geneva, 1967. Figs. 139 and 140.
19. Ref. 18, fig. 143.
20. Ref. 18, fig. 138.
21. J. Orbeli and C. Trever, "Orfeverie Sassanide", Moscow and Leningrad, 1935. Fig. 10.

Figure Captions

1. A student is inserting into the neutron Howitzer a cartridge containing the coin and silver disk which will be irradiated.
2. Schematic representation of the Howitzer irradiation.
3. Silver radioactivity per gram of silver in the coin as a function of the coin thickness X silver content of the coin.
4. Value of the constant R as a function of the coin thickness. The identification of the symbols are given in Fig. 3.
5. Silver contents of Sasanian coins as determined by the Howitzer method of analysis.
6. Method of streaking a coin.
7. Streak analysis data for 49 coins of Shapur I arranged in order of decreasing intended silver fineness.
8. Gold impurity-level data for coins issued by five Sasanian kings. Logarithmic ranges used in preparing graphs are given in Table I.
9. Gold impurity-level data for over 1000 Sasanian coins. Open squares are data for modern fake Sasanian coins.
10. Some of the modern fake Sasanian coins for which data are given in Fig. 9.
11. Gold impurity-level data for Umayyad coins from 17 mints for the period AH 90-98/708-717 AD.
12. Location of Umayyad mint-cities.
13. Streak analysis data for Umayyad coins minted at Wasit. Data given by closed circles are the adjusted chemical data of Caley, Ref. 8, Table II.
14. Streak analysis data for Umayyad coins minted at Dimishk. Data given by closed circles are the adjusted chemical analysis data of Caley, Table II, Ref. 8.

15. Streak analysis data for Umayyad coins from three mints. Data given by closed circles are the adjusted chemical analysis data of Caley, Table II, ref. 8.
16. Gold impurity-levels for Sasanian coins of Khusrau II arranged according to mint signatures. Logarithmic ranges used in preparing graphs are given in Table I. Markings at the bottom of each graph separate the ranges 5 and 6, 10 and 11, 15 and 16, and 20 and 21.
17. Location of Sasanian cities.
18. Streak analysis data for coins of Khusrau II for regnal years 2 to 10 arranged according to mint signature.

Neutrons
from
Howitzer
Source

A series of eight horizontal arrows of varying lengths pointing to the right, representing a beam of neutrons. The arrows are arranged in a slightly staggered vertical column.

A schematic diagram showing a vertical assembly. On the left is a thick, dark vertical bar. To its right is a thinner vertical bar with horizontal hatching. A small, dark, rectangular object is positioned between the two bars, slightly offset towards the thinner bar. Two arrows point from text labels to this object.

Coin being
tested

U.S. 10¢ or
Silver Disk

Figure 3

Figure 4

Reigns of Sasanian Kings

SASANIAN COINS OF SHAPUR I

SHAPUR I
241 - 272 A.D.

SHAPUR II
309 - 379 A.D.

PEROZ
457 - 484 A.D.

KHOSRO I
531 - 579 A.D.

HORMIZD IV
579 - 591 A.D.

ARDASHIR III
628 - 629 A.D.

% GOLD IMPURITY IN SILVER

	بشاپور BIS	BISHAPUR	
	استاکار ST	ISTAKAR	
	اردشیر ART	ARDASHIR-KHURRA	
	اردشیر AU	ARDASHIR-KHURRA	
	دارابجرد DA	DARABJIRD	
	زارنگ ZR	ZARANG	
	ابرشار APR	ABRASHAR	
	مر MR	MERV	
	مر MB	(MERV)	
	رای ZD	(RAYY)	
	جرجان GO	(JURJAN)	
	ابرشار AB	(ABRASHAR)	
	ابرشار NB	(ABRASHAR)	
	نهر تیرا NAR	(NAHR-TIRA)	