LOST WORLDS: Nuclear Science and Archaeology

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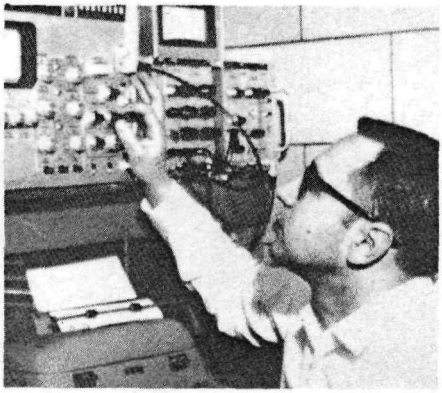


The Author

Dr. Bernard Keisch received his B.S. degree from Rensselaer Polytechnic Institute and his Ph. D. from Washington University. He is a Senior Fellow with the Division of Sponsored Research of Carnegie-Mellon University in Pittsburgh. He is presently engaged in a project that deals with the applications of nuclear technology to art identification. This is jointly sponsored by the U. S. Atomic Energy Commission and the National Gallery of Art. Previously he was a nuclear research chemist with the Phillips Petroleum Company and senior scientist at the Nuclear Science and Engineering Corporation. He has contributed articles on art authentication to a number of journals. For the AEC, in addition to this booklet, he has written "The Atomic Fingerprint: Neutron Activation Analysis", "The Mysterious Box: Nuclear Science and Art", and "Secrets of the Past: Nuclear Energy Applications in Art and Archaeology".

Nuclear energy is playing a vital role in the life of every man, woman, and child in the United States today. In the years ahead it will affect increasingly all the peoples of the earth. It is essential that all Americans gain an understanding of this vital force if they are to discharge thoughtfully their responsibilities as citizens and if they are to realize fully the myriad benefits that nuclear energy offers them.

The United States Atomic Energy Commission provides this booklet to help you achieve such understanding.

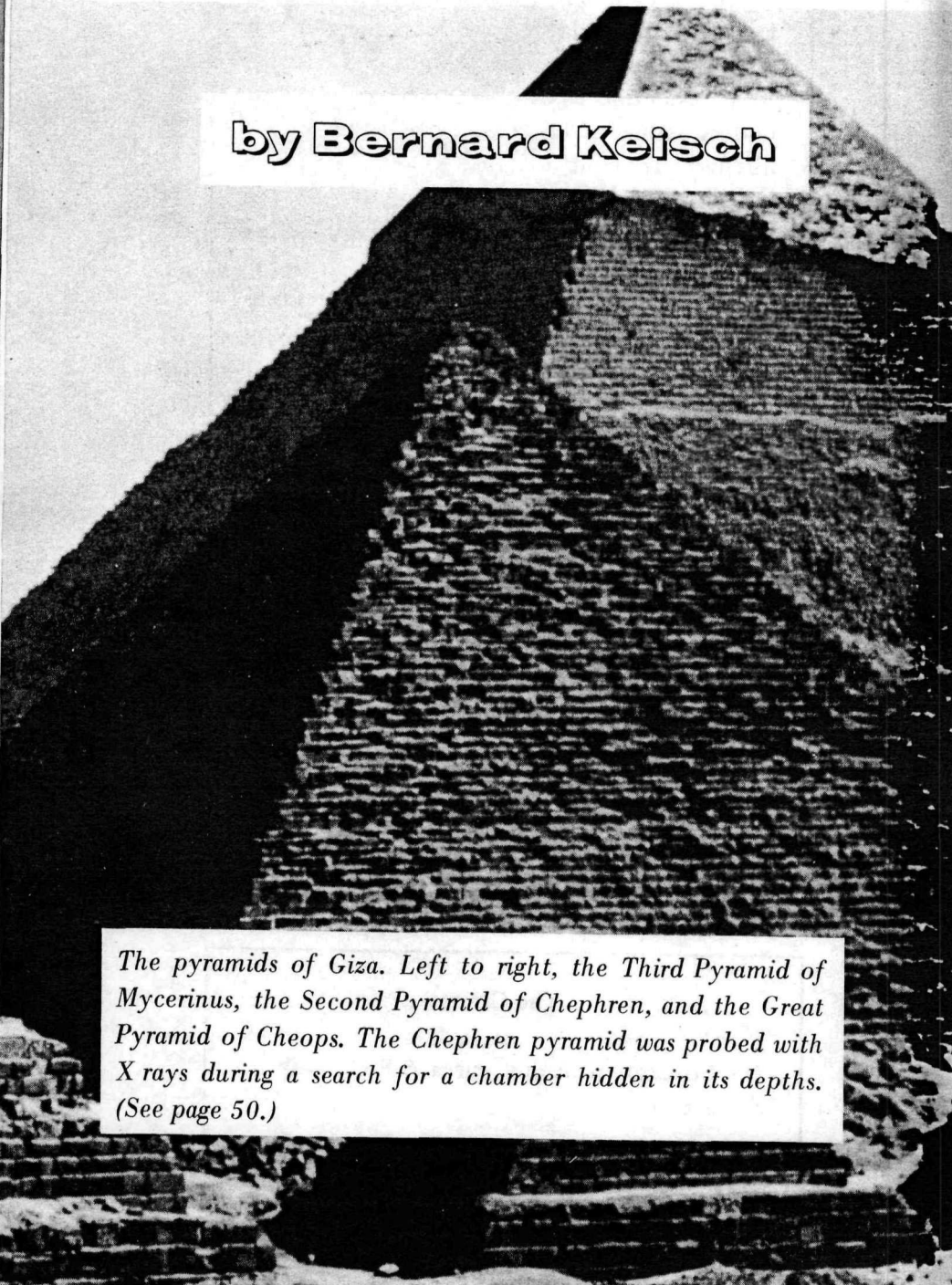
The author of this booklet thought it would be more interesting to present his subject as a short story. The techniques and instruments described are factual, but the characters and plot are imaginary.

The Cover

An Etruscan wine jug, circa 6 B.C., with an engraved design.

LOST WORLDS: Nuclear

by Bernard Keisch



The pyramids of Giza. Left to right, the Third Pyramid of Mycerinus, the Second Pyramid of Chephren, and the Great Pyramid of Cheops. The Chephren pyramid was probed with X rays during a search for a chamber hidden in its depths. *(See page 50.)*

Science and Archeology

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This carved wooden figure, found near the source of the Seine River in France, was made approximately 2000 years ago. It is believed that it and other similar carvings were used as offerings in the worship of Sequanna, a Celtic goddess of healing.

The rain stopped. The three boys reluctantly left the dusty shop where they had spent the past half hour. Each carried a small package that he had purchased after entering to seek shelter from the sudden downpour.

They were in Amsterdam and had gone for a little walk on a side street near the hotel where they were staying as guests of the Dutch Government.* Now Mom and Dad were packing for the trip home, so the boys hurried back to show them the unusual things they had just bought in the little shop.

As they entered the hotel room, Martin, the youngest, cried out, "Mom! Dad! Look what we got!" In less than a minute, the packages were opened and their treasures were displayed.

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*To find out why, see *The Mysterious Box: Nuclear Science and Art,* a companion booklet in this series.

Bill, the oldest, had a carved wooden figure of a man. The figure, wrapped in plastic, was damp and looked ancient.

Harley held up a cracked piece of pottery that looked like a water pitcher. Decorated with hunters and animals, it was quite nice looking in spite of its cracked condition.

Martin showed them a coin about the size of a quarter. It was worn but still shone with a golden luster.

"Do you suppose these things are worth anything?" asked Bill.

"They really look old," said Harley, "and we thought maybe Dad's scientist friends could figure out what they are."

"I hope they're worth what we paid for them," said Martin.

"Well," said Dad, "after we get home, we can take them to a museum, and then we'll know whether they're worth bothering about."

"Can we use some of the same tests that were tried on the paintings we found?"* asked Bill, "Or are there others?"

"We can use a few of the same ones," explained Dad. "But since we're dealing with different materials that are much older, most of the methods will also be different.

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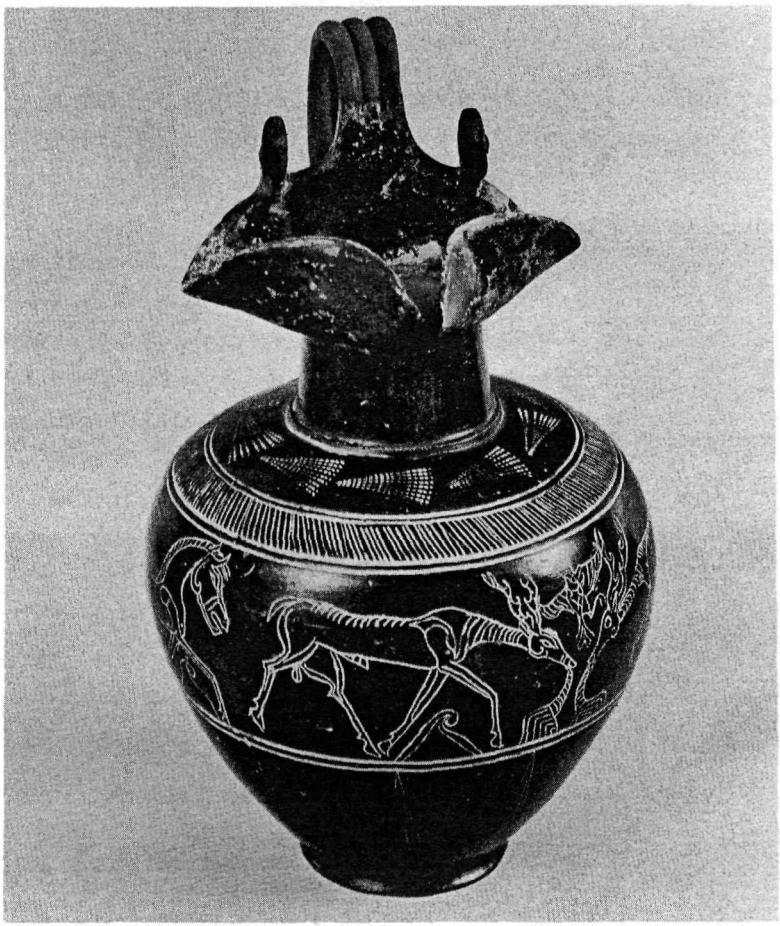
*See *The Mysterious Box: Nuclear Science and Art*, a companion booklet in this series.



An Etruscan wine jug, circa 6 B. C., with an engraved design.

This gold Roman coin was minted about 196 B. C. The head of Flamininus, a Roman general, is on one side.

"For Bill's wooden figure, we'll want to know how old it is. Carbon-14 dating can be used since wood is mostly carbon.

"For Harley's pottery, we'll also want to know its age. But there is little or no carbon in pottery so other methods, such as thermoluminescence or fission recoil track dating, might be used.

"There isn't any good way to date Martin's coin, but an analysis using X-ray fluorescence or neutron activation should allow us to compare it with similar coins so that we can positively identify it. Harley's pottery could also be analyzed for comparison with similar pottery."

"When can we start?" asked Martin.

"As soon as we get home," answered Mom. "Now let's finish packing or we'll never get there."

During the weeks following their return home, the boys took their artifacts* to a museum where several archaeologists examined them carefully. Their opinions were somewhat divided as to whether the things were really valuable. But the wooden figure appeared to be very similar to those found at the source of the Seine River in France. If genuine, it would be about 2000 years old.

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*Artifacts are objects that have been manufactured. This term is usually applied to those objects that are of archaeological interest. Archaeology is the study of history from ancient artifacts.

And the pitcher might just be Etruscan, which would mean it was produced by a civilization that thrived in a part of what is now Italy before the founding of Rome. That would make it about 2400 years old if it was authentic.

Finally, the coin looked like those used in Rome approximately 1700 years ago. One thing was certain: Various tests and analyses would have to be carried out before anyone could really be certain about the age of the artifacts.

The important tests were those that Dad had mentioned the day that the boys bought their things. The people at the museum explained that the special equipment used for the measurements was only available in a few places.

Naturally, the boys wanted to see how each measurement was made. Dad wrote letters to scientists and experts who he hoped could be persuaded to help with the work of analysis and identification. Each day they anxiously waited for the mailman.

Harley's turn came first.

Dating Pottery—Thermoluminescence and Fission Recoil Tracks

Following directions in a letter, Dad and Harley arrived at the laboratory entrance of a museum that belonged to a university. There they were met by Dr. Bell, a scientist who led

them to a room in the basement. They were shown the apparatus for thermoluminescence measurements and Harley asked the scientist how it worked.

Dr. Bell explained, "It's really a very simple process.* This equipment is designed to gradually heat up a small sample of material while it measures the amount of light coming from the heated substance."

"I know things begin to glow when they get hot, but what's that got to do with how old they are?" asked Harley.

"All matter is being constantly bombarded by radiation from cosmic rays and from small amounts of naturally radioactive substances such as uranium, thorium, and an isotope of potassium. When crystalline material, such as a rock or a piece of pottery, absorbs this radiation, it stores a substantial part of the energy in its structure. When this happens the electrons of the atoms are 'knocked out' of their normal positions in the crystal structure.

"As time passes, these dislocations occur again and again and more energy is stored up just as if a spring was compressed tighter and tighter.

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*The method of thermoluminescence dating was first applied by George Kennedy and fully developed by workers at Oxford University in England and at the University of Pennsylvania.

"When the material is heated, the crystal structure relaxes, the electrons return to their normal position, and the stored energy is emitted, or given up—some of it in the form of light."

"I get it," interrupted Harley. "The longer a piece of pottery has been storing energy, the more light it gives up when it's heated."

"That's right," said Dr. Bell, "but there are some problems in using this method to actually tell how old a sample is. We also have to determine how much radiation the sample has been exposed to, as well as how readily the radiation 'damage' is stored in the particular material, and how readily it emits light when it's heated. The last two are necessary because different substances behave in different ways. Would you like to see how it's done?"

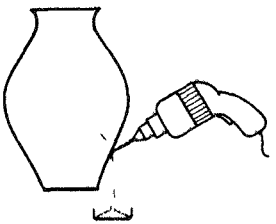
"Would I!" exclaimed Harley.

Harley and Dad followed Dr. Bell to another room where the lights were dim.

The scientist explained, "This is where we'll take a sample from your pottery. The lights must be dim because bright lights shining on the sample when it's powdered can sometimes make the material yield less light when it's tested in the thermoluminescence equipment."

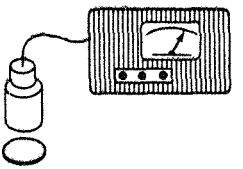
Dr. Bell used a high-speed drill with a $\frac{1}{16}$ inch diameter tungsten carbide drill bit. (Tungsten carbide is a very hard man-made substance often used, as in the present case, for cutting hard materials.) He used it to clean

The Process of Thermoluminescence Dating

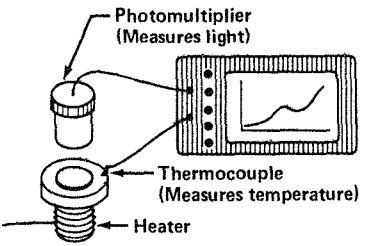


① Sample the pottery with a drill

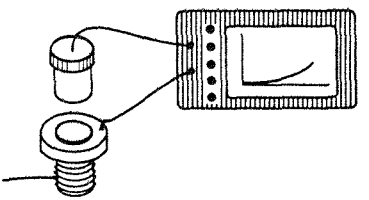
② Prepare discs coated with fine powder



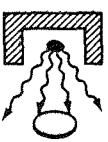
③ Measure radioactivity



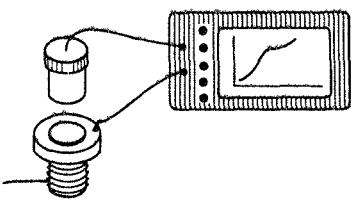
④ Heat sample and measure light output and temperature at the same time.



⑤ Repeat heating to get "background"

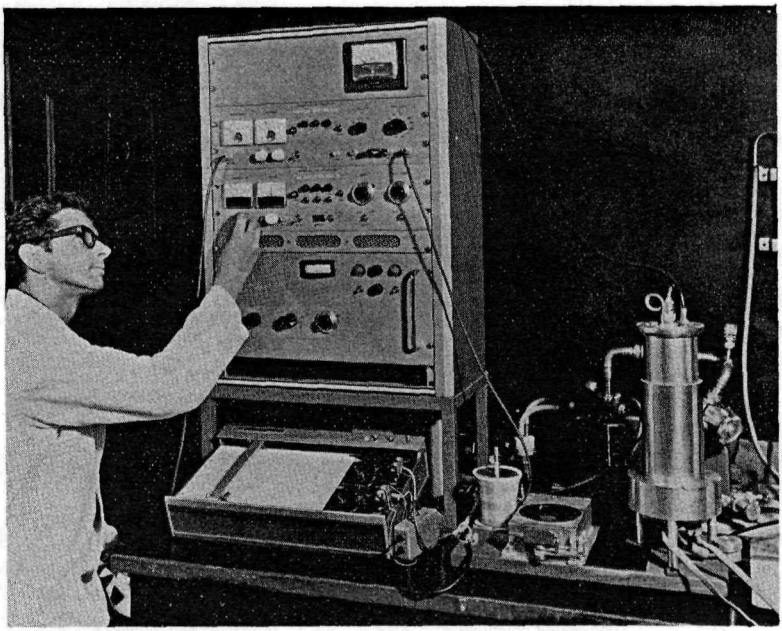


⑥ Expose sample to known dose of radiation



⑦ Repeat heating to get "susceptibility"

⑧ Calculate time since last heating.



Thermoluminescence dating equipment. The large cylinder on the right contains a temperature-controlled oven and a photomultiplier tube. As the sample is slowly heated through a controlled temperature range, the light output is measured and automatically plotted on the chart (lower left).

away a small area on the bottom of the pitcher. Then he drilled into the pottery and carefully collected the powder removed by the drill. The hole left in the pitcher was barely noticeable.

The powder was stirred in a test tube that was partly full of acetone.* After a few minutes, the larger, heavier particles settled

*Acetone is a colorless liquid often used as a solvent, for example, it is used in nail polish removers and plastic cements.

out and the scientist removed some of the acetone that had fine particles suspended in it. He then placed a few drops on each of several small discs of aluminum foil and allowed the acetone to evaporate. This left a thin, even layer of very fine material on each disc.*

"Now we measure its radioactivity," said Dr. Bell.

In another room, he placed a tiny, weighed quantity of the remaining powder from the pottery on a small dish inside a chamber in which there was a detector for measuring radioactivity. Then they all went to lunch.

After lunch they returned to the radiation counter and noted that it had registered a few hundred counts in the hour that had passed.

The next step was the thermoluminescence measurement. One of the discs was placed in contact with a metal heating block under a photomultiplier tube. This tube would convert light emitted by the sample into electrical signals. With a few adjustments of the controls, the scientist started the measurement.

They all watched as a curve was automatically produced on a graph by the electronic equipment. It looked something like the sketch on the next page.

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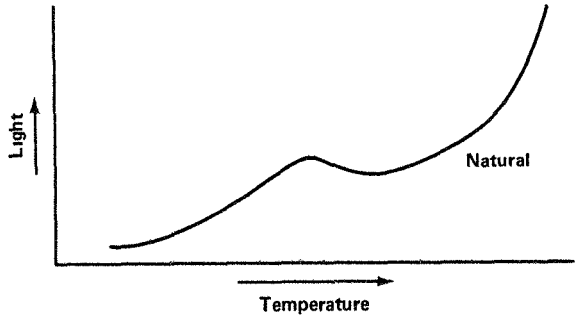
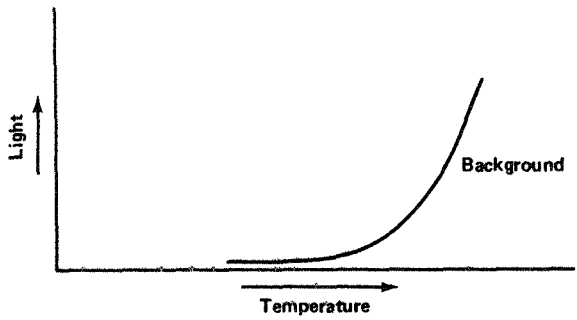
*There are several techniques for thermoluminescence dating. The description given here is a simplification of one of them.



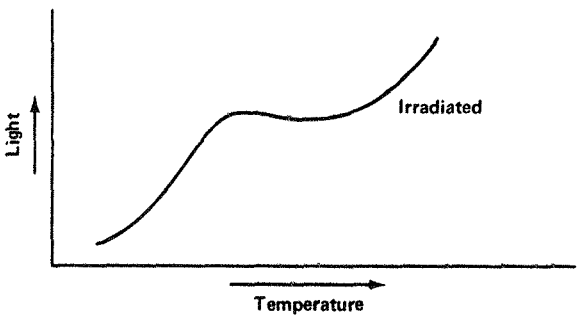
The scientist allowed the sample to cool and started the heating cycle again. This time the curve looked like this:



"As you can see," said Dr. Bell, "there was some extra light emitted the first time. The amount is a measure of how long ago the pottery was last heated—probably when it was made.

"And now we must see how susceptible the sample is to the radiation damage that makes it give off light."

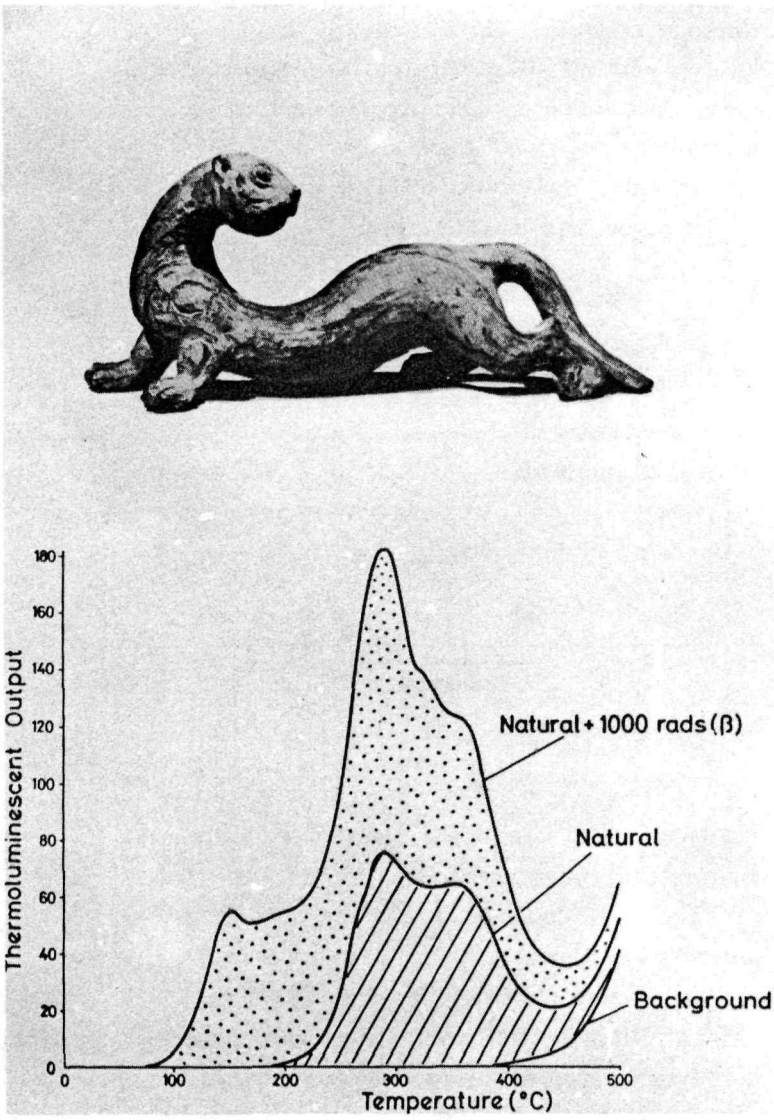
A second disc was then placed inside a shielded enclosure where it was exposed to a known amount of radiation from a disc of radioactive material. Then it went back to the thermoluminescence equipment, and once more a curve was produced. This time, it was a little higher than the first one:



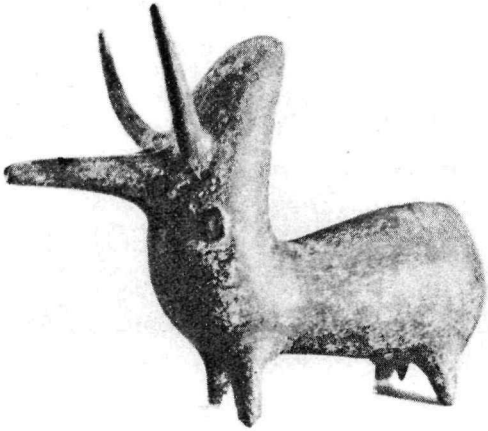
"Well, that completes a set of measurements," said the scientist.

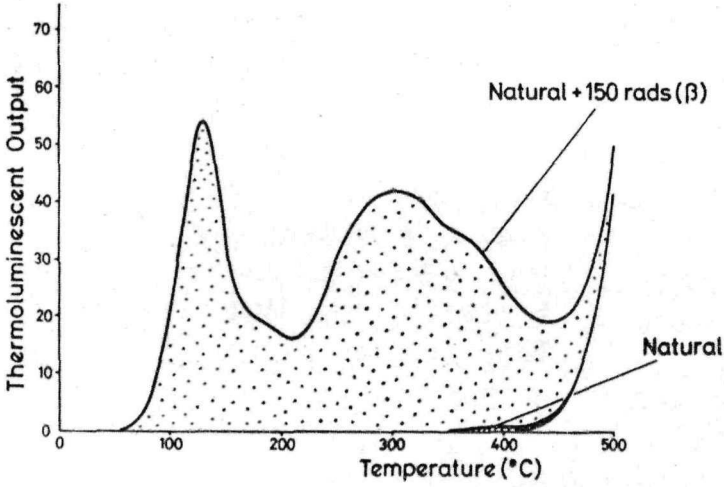
"Can you tell us how old the pottery is now?" asked Harley.

"Yes," said Dr. Bell, "but I won't tell you until I complete the calculations and make the same measurements on some of the other discs to double check my work. I should have news for you in a week or so, and I will let you know then. But for now, I will only say that it looks very much like the pottery is fairly old and I expect the news will be good."



Thermoluminescence curves of two real objects. The graphs show the output obtained when samples from the objects were heated. (The curves are marked "natural".) The old object on the left gave a relatively large amount of light while





the modern piece on the right did not. The upper curves in each case show the amount of light obtained after exposing the samples to radiation of a known amount.

Harley and Dad thanked the scientist and headed for home. On the way, they discussed another dating method that could work on pottery. This one is called fission recoil track dating.

Dad said, "This method is also based upon the radiation damage that accumulates in material as it ages. In this case, it's the nuclei of uranium atoms that occasionally fission, or split apart, which is the key."

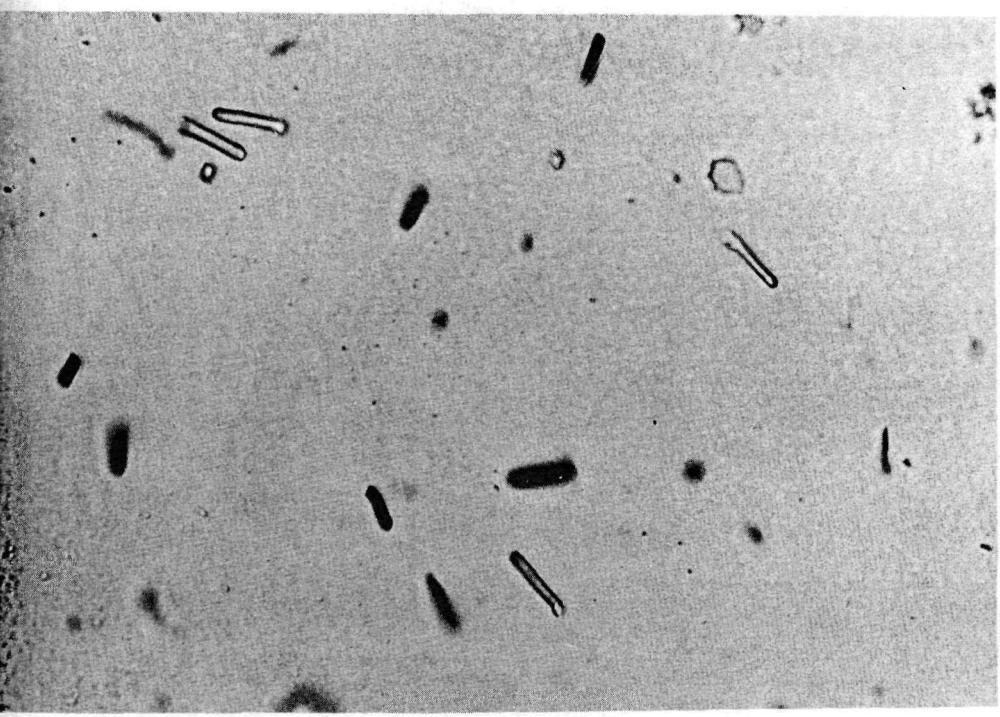
"Is there uranium in *my* pottery?" asked Harley.

"There is a small amount of uranium in all rock or clay, perhaps about 1 to 10 atoms in a million. But occasionally there is a decorative yellow glaze on pottery that contains a much larger concentration of uranium. In any case, every once in a while, a few of these uranium nuclei fission spontaneously, that is, all by themselves. When they do, a good bit of energy is released and the two halves of the original nucleus fly apart, or recoil, a short distance. In so doing, they leave a path, or track, in the crystal structure of the material by disrupting the electron in the crystal. These tracks remain in place indefinitely at ordinary room temperature."

"Can we see the tracks?" asked Harley.

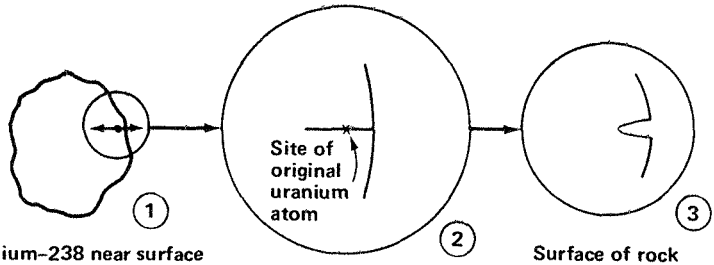
"They are visible with an electron microscope, but a group of scientists* discovered

*Robert L. Fleischer, P. Buford Price, and Robert Walker at the General Electric Research Laboratories.



A photograph taken through a microscope. This is a piece of a mineral called "mica". It has been treated for approximately 2 hours with an acid solution. Notice the slanting tracks that are visible. These are the paths of recoiling fragments of uranium atoms that have split apart over the many years since the mineral was formed in the earth. In mica the holes that are developed along these paths by the action of the acid are square in cross section and easily recognized. The picture is magnified approximately 500 times. The area shown is really only 0.05 square millimeter.

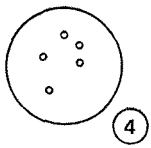
Fission-Track Dating



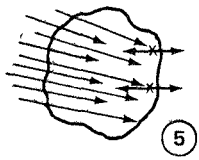
Uranium-238 near surface of rock undergoes spontaneous fission. Two pieces of split atom recoil in opposite directions damaging crystal structure.

Tracks of fission products are too small to see

Surface of rock is treated with acid to enlarge tracks

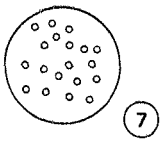


Many such tracks are observed and counted under microscope.



Rock is subjected to neutron bombardment in a reactor causing uranium-235 atoms to fission.

Re-etching of surface produces more pits.



Counting new pits under microscope tells how many uranium atoms present.

8

Calculate age of rock by using results obtained in steps 4 and 7.

that by treating the material with certain chemicals, the tracks that intersect the surface can be enlarged. They are then easily visible with an ordinary microscope."

"So how do you date pottery?" interrupted Harley.

"Well, the rate at which the spontaneous fission of uranium occurs is known, so all we have to do is:

(a) count the tracks in a fixed area;

(b) measure the uranium content in the volume represented by the thin surface layer in that area; and

(c) calculate the time that has elapsed since the last time some kind of heating annealed the tracks."

"Oh, I see. The damage is repaired by heating just like in thermoluminescence dating," exclaimed Harley. "But suppose I had uranium-glazed pottery. How would the method be carried out in that case?"

"Well, first, a small section of a piece of the glazed surface is sliced thin and polished. Then, depending on the minerals present, an etching solution is applied for a certain period of time.

"Next, the section is mounted on a microscope slide and the tracks in a fixed area are counted.

"To determine the uranium content of the piece, it is bombarded with neutrons in a nuclear reactor. This causes a large number of new fissions. This number is determined by re-etching and re-counting the tracks. By

comparing the number of new tracks (in the same area observed before) with the number produced in a mineral of known uranium content, the uranium content in the pottery can be estimated.

"For example, let's say the pottery had 1000 new tracks in a square millimeter. And suppose a mineral containing 10% uranium, which was bombarded with the same number of neutrons as the pottery, showed 10,000 tracks per square millimeter. Then the concentration of uranium in the pottery would be 1%. That would mean that there would be approximately 750,000 billion uranium atoms in each square millimeter close enough to the surface to produce a visible track.

"Now if that pottery had shown 300 tracks per square millimeter before going into the reactor, then it was fired 4800 years ago during its fabrication.

Dad showed Harley how this can be calculated from the equation: Age = (number of tracks x average time for uranium nucleus to fission*)/(number of uranium atoms)

*The *average* time for a uranium nucleus (actually the common isotope uranium-238) to fission is 12 million billion years—a long time indeed. But still, with many billions of atoms present, there is at least one that fissions every 14 years or so in this case.

The Composition of Old Coins— X-Ray Fluorescence and Diffraction and Activation Analysis

When Harley and Dad arrived home, they were greeted by Martin excitedly waving a letter.

"I've got an answer from the coin expert," Martin said.

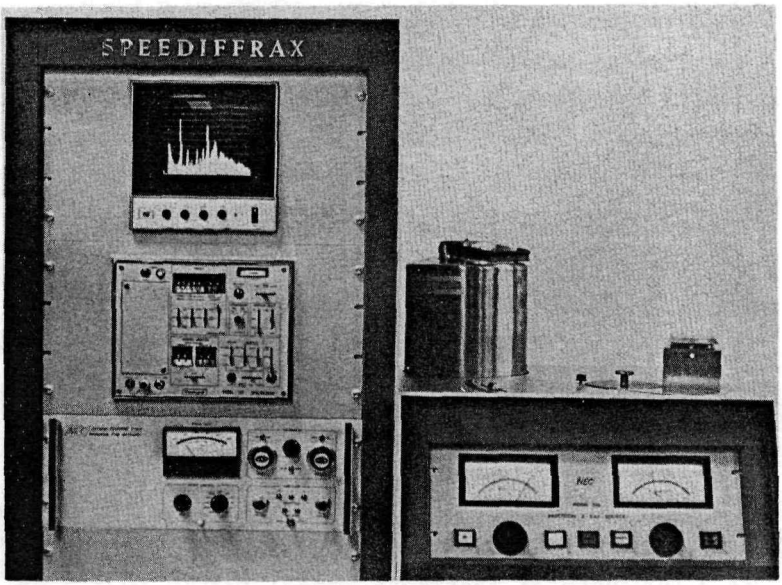
The letter contained information about the kinds and amounts of metals in gold coins that had been made in Rome about 1700 years ago, since Martin's coin appeared to have been made at that time. The expert suggested taking the coin to Dr. Dithridge right there in the city, who had the equipment necessary for chemical analysis by X-ray fluorescence.

With the letter as an introduction, Dad and Martin were able to meet with Dr. Dithridge the following week. Martin asked for an explanation of how the method worked.

"Doesn't a chemical analysis mean that part of the coin has to be removed and dissolved?" asked a worried Martin.

"Not at all," replied Dr. Dithridge. "With X-ray fluorescence, we use the whole coin but nothing happens to it. It's a nondestructive type of analysis.

"You see, X rays from a radioactive isotope, called americium-241, strike the atoms in the coin. These X rays knock the electrons out of the positions that they



Modern X-ray fluorescence equipment. In this instrument the detector is of a type developed originally for nuclear applications and the source of X rays is a conventional tube. Isotopic X-ray sources could be used as well. The pattern displayed on the screen corresponds to the impurities in a piece of natural quartz.

ordinarily occupy in many of the atoms in the coin. Some of those close to the nucleus are displaced,* and very soon afterwards (in a very small fraction of a second), electrons that are farther out "jump" in to take their places. During this jump, X rays of a lower energy than those that strike the coin are

*The electrons that circle the nucleus of an atom are arranged in levels called "shells". Those that are in the innermost, or K, shell are called K-electrons. The next levels out are called L, M, etc.

emitted by atoms in the coin. Each element in the coin emits X rays of a definite energy."

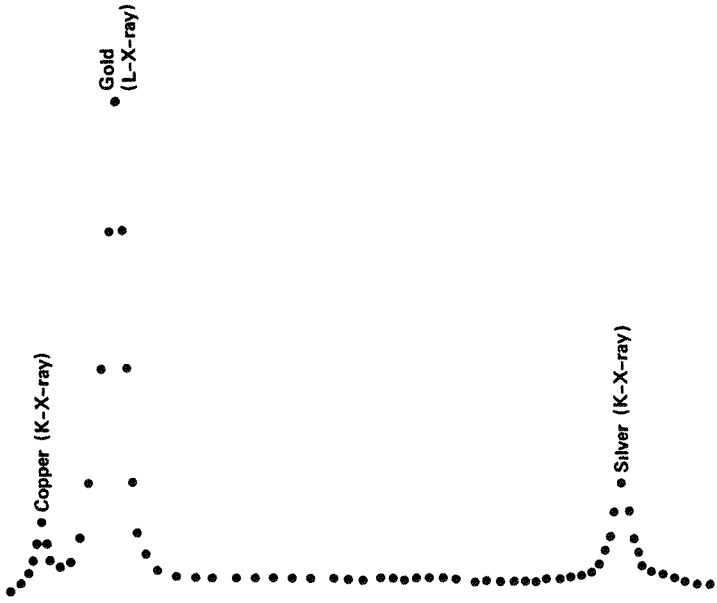
Dr. Dithridge led the way to his instrument. He placed the coin in a support directly above something that looked like a tin can on top of a large steel bottle.

"Inside the top of that can is an X-ray detector," he explained. "The large metal container is a kind of thermos bottle full of liquid nitrogen to keep the detector cold. This detector, which is made mostly of silicon,* is a relatively recent invention. It delivers an electrical pulse every time an X ray is absorbed and the size of the pulse is proportional to the energy of the X ray. Not long ago, we used a different detector system that was bulky and could only measure X rays of one energy at a time."

Dr. Dithridge then placed a round metal object over the coin and the end of the detector. This contained his radioactive americium-241, which would bombard the coin with X rays. He explained that he could have used an X-ray machine just as well, but that the radioactive source was closer at hand.

He then moved over to a machine, called a pulse-height analyzer, with dials, switches, and something that looked like a small television screen. After adjusting a few knobs, he

*Silicon is a very common element that occurs in nature mostly as the oxide in ordinary sand. The element itself is of a class called "semiconductors". It is commonly used in transistors.



The dots that appeared on the screen when Martin's coin was analyzed by X-ray fluorescence. This showed the amounts of gold, silver, and copper that were present. Accurate information on the heights of the peaks tells how much of each element is present. (Actually, the curve obtained for a real sample would be more complicated.)

pushed a button and there appeared on the screen a line of flickering dots that gradually grew into a curve with a few peaks and valleys. In a few minutes, a light flashed on and the flickering stopped.

"It's finished," said Dr. Dithridge as he retrieved the coin and handed it back to Martin.

"Can you tell anything about the coin now?" asked Martin.

"Yes, but it looks like bad news," answered Dr. Dithridge. "You see, each of those peaks in the curve on the screen represents a number of X rays of a particular energy. The location of any one peak in the horizontal direction identifies the element that emitted the corresponding X ray. The height of a peak tells how much of that element is present.

"If your coin were genuine," he continued pointing to the screen, "there would be a big peak right there, corresponding to gold and only a small one, here, corresponding to copper. In this case, the copper peak seems to me to be quite a bit bigger than it should be."

Dr. Dithridge then turned on an electric typewriter that printed out rows and columns of numbers which he said were the actual numbers of X rays recorded by the analyzer.

"Now I'll be able to calculate exactly the percentage of each element. I'll call you in a few hours to let you know the results that I obtain."

Martin and Dad thanked the scientist and left.

"Too bad," said Dad, "It doesn't look like you've got the real thing there."

"He wasn't sure," said Martin. "What if the calculations show that the amount of gold and copper is OK in my coin? Would that make it genuine?"

"Not necessarily. But the chances would be better. Additional tests and analyses would be needed."

"Like what?" asked Martin.

"Like X-ray diffraction to tell whether the coin was struck or cast," answered Dad. "You see, the image on a real coin is formed by stamping it with a hard metal die that has a mirror image cut into its surface. Fake coins are often cast by pouring molten metal into a mold.

"X-ray diffraction can often tell this difference because the rays are bounced off the surface and bent by the rows of atoms in the crystal. This gives a pattern that would be distorted if the atoms on the surface had been disarranged by the force of striking the coin."

"So couldn't anybody make a fake coin by using the right metals and striking the image?" asked Martin.

"Now you're catching on," said Dad. "So far, these tests can only prove that a coin is a fake; they can't prove that it is genuine. But a more complete chemical analysis might prove that it is genuine.

"You see," continued Dad, "while a coin like yours contains mostly gold, silver, and copper, there are always very small amounts, say a few atoms out of every million, of other metals, that are there only by accident. These are called 'trace elements', and in a way, they can 'fingerprint' a coin for us."

"How does that work?" asked Martin.

TRACE ELEMENT "FINGERPRINTS"

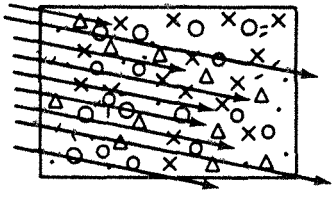
Chemical Element	Concentration (parts per million)		
	Unknown Coin	Known Genuine Coin	Known Forgery
Arsenic	3	4	10
Antimony	14	15	2
Lead	120	110	120
Tin	25	22	75
Magnesium	50	49	20

This is a list of results that might be obtained for three samples taken from coins. Notice the great similarity between the old coin and the coin whose origin is unknown. The forgery is completely different. In actual practice, many more coins would be analyzed to find a match, and many more elements might be determined. In this simple example, one might say that the "fingerprints" match for the first two coins.

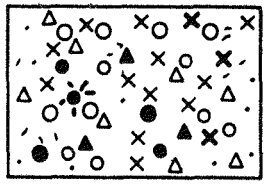
"Let's say that a big batch of metal was produced out of which a thousand coins were made. Suppose there were three major elements that were deliberately mixed into the melt. There would probably also be a dozen or more elements in very small amounts that were there only by accident and were unknown to the workers themselves. Yet, every coin produced from that batch would contain the same trace elements in very nearly the same proportions. The chances that this pattern would accidentally occur again when a forger tried to duplicate those coins would be pretty small. Just about as small as the chance of finding two people with the same fingerprints."

SIMPLE NEUTRON ACTIVATION ANALYSIS

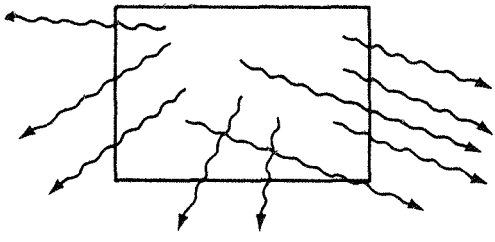
① Bombard sample with neutrons from reactor



② Some of the different atoms become radioactive



③ These give off characteristic γ-rays



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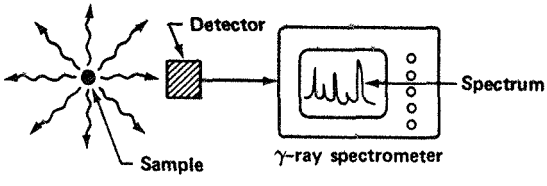
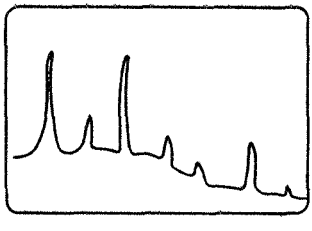


The γ-rays are measured and a "spectrum" is obtained

⑤



The position of each peak in the spectrum can indicate the presence of a particular chemical element and the height of each peak indicates how much of that element is present.

"But isn't it pretty difficult to analyze a coin for such small amounts of the trace elements?"

"It used to be several years ago, but now we have neutron activation analysis."*

"What's that?" asked Martin.

"It works like this. Most elements become radioactive when they are bombarded by neutrons. The radioactivity produced has certain characteristics that make it identifiable as coming from one particular element. And the more of that element there is present, the more radioactivity is produced.

"Because of the sensitivity of modern nuclear instruments, very small quantities of many different elements can be detected and measured. Sometimes, as little as 1 atom in every million.

"Other bombarding particles such as protons and alpha particles, can be used also. And this means that there are different kinds of activation analysis. Neutrons are the most commonly used, however, because large numbers of them are available inside a nuclear reactor."

"Do you need to take a large sample of the coin?" asked Martin.

"Actually, if you don't mind having a slightly radioactive coin for a while, we can bombard (or irradiate) the whole thing. Some

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*Neutron activation analysis is described more completely in *The Mysterious Box: Nuclear Science and Art*, a companion booklet in this series.

workers have done this since the coin is not harmed or changed in appearance. Other analysts have taken tiny samples by drilling or by simply making a tiny mark on a small ground quartz* plate by scraping the edge of the coin against it."

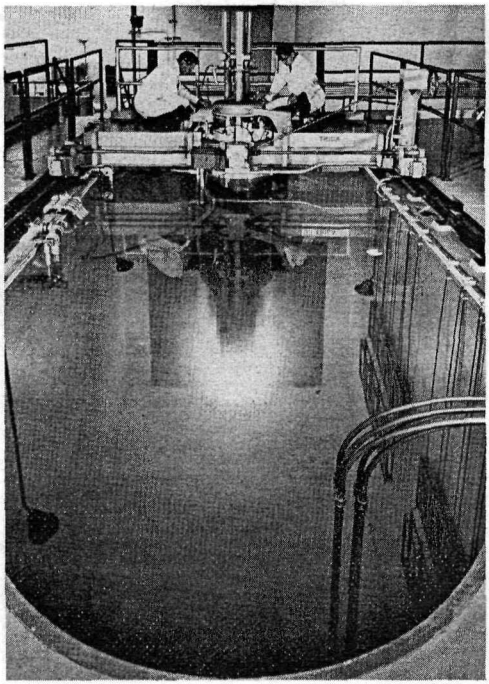
"Has activation analysis been used often?"

"It certainly has and in many fields. In archaeology, it has not only been used to identify the source of coins like yours, but also of pottery† like Harley's. For example, it is being used to establish the trade routes and locations of old manufacturing centers by comparing the composition of clay deposits in well-known locations with that of finished pottery."

A few hours after they arrived home, Dr. Dithridge called. It was just as he expected. The results of the X-ray fluorescence analysis were conclusive. The high copper concentration (5%), the low gold concentration (only 70%), and the presence of other elements like lead and silver made it certain that the coin was only a copy. Roman coins

*Quartz is a glass-like material that is similar to glass in appearance but much purer.

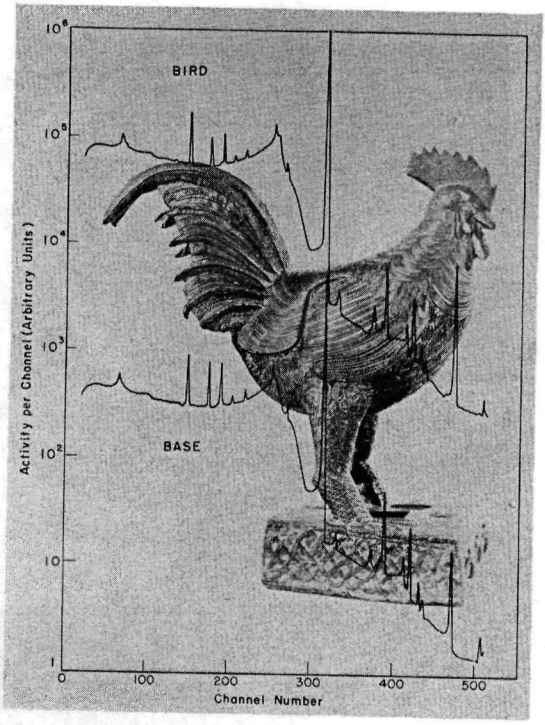
†Edward Sayre and Richard Dodson at Brookhaven National Laboratory were the first to apply neutron activation analysis to archaeological problems. There have been many others since.



This type of nuclear reactor is used for neutron activation analysis.

of that period were always nearly pure gold that usually contained no more than about ½% of copper and about the same amount of silver.

"Oh well," said Martin, "it will still make a good charm for Mom's bracelet."



Neutron activation analysis of a brass rooster. This 18th century brass rooster was made by the Benin people in the part of Africa that is now Nigeria. It was constructed of two parts, the bird itself and the base, and a question was raised as to whether the two parts were made by the same people. Superimposed on the photograph are the gamma-ray spectra obtained when samples taken from the two parts were activated by neutrons in a reactor. Notice how similar the shapes of the two spectra are. Each peak represents a gamma ray of a particular energy and can be identified as coming from a particular element in the brass. The height of each gamma ray is related to the quantity of that element present. In all, seven elements were identified and found in almost identical concentrations in the two parts of this sculpture. This tends to prove that the two parts, although made separately, were made at the same time and place.

The Wooden Figure—Carbon-14 Dating

Now it was Bill's turn. Mr. Allenby, one of the experts at the Archaeological Museum, had said that Bill's carved wooden figure, which he called "Sampson", looked like a fine example of primitive carving of the type made in France at the source of the Seine River about 2000 years ago. In fact, since he was so certain that the figure was genuine he suggested that the wood be "dated" as proof of its age.

With Mr. Allenby's help, Bill and Dad contacted a special laboratory where they hoped to learn Sampson's age by using the carbon-14 dating method.

They found the laboratory on the campus of a large university and since Mr. Allenby had arranged for an appointment, Dr. James Gordon, the scientist who would work on Sampson, met them at the door.

Bill could hardly wait to start asking questions. "How can you possibly tell how old Sampson is? He looks as if he's made out of wood just like any other wood I've ever seen," said Bill.

Dr. Gordon smiled and said, "The method we use is a very ingenious one and has meant more to modern archaeology than any other dating method. It was first worked out by Willard F. Libby, and if you have the time, I'll try to explain it to you."

"Great!" answered Bill, "I'm all ears!"

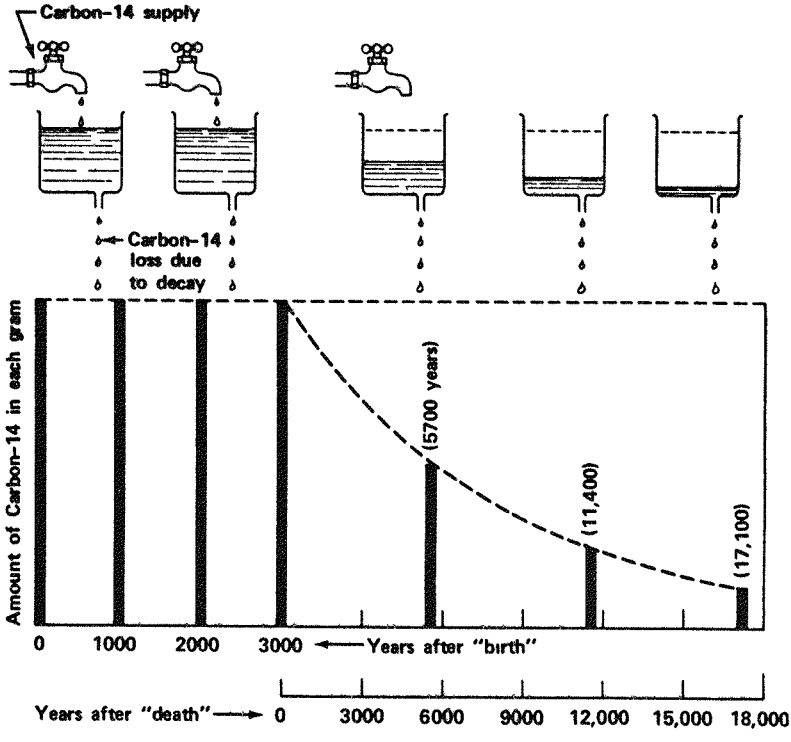
"Okay," said the scientist, "first of all you have to understand a little about radioactive atoms and what we mean by 'half-life'."

"Oh, I understand that," exclaimed Bill. "Radioactive atoms are the kind that sort of 'fall apart' all by themselves to form different atoms and when they do, they give off certain kinds of particles and rays. And the half-life is the time it takes for half the atoms in a radioactive element to disintegrate into different atoms."

"Very good!" said Dr. Gordon. "But just remember that during each half-life period, half the atoms that were present at the beginning of that period decay so that after two half-lives, one quarter of the original number will still be left. This diagram shows how this works."

"I remember that," said Bill, "but how about the dating method?"

"It works this way," continued Dr. Gordon. "The earth and its atmosphere are continually being bombarded by cosmic rays. These consist of particles and rays that are produced by radioactive decay and other processes that take place in the nuclei of atoms in distant stars (and in our sun also) all over the universe. While the earth's magnetic field turns aside most of these rays, there are still quite a few that bombard our upper atmosphere. There, some of the particles—the neutrons—strike atoms of nitrogen with



The carbon concentration in a tree that was felled when it was 3000 years old. Up to that moment the carbon-14 was replenished as fast as it decayed. The "leaky pot" represents this system with a supply of water dripping in as fast as the water leaks out. Once the tree is felled the carbon-14 decreases, according to the law of radioactive decay, with a half-life of 5700 years. The "water supply" stops and the "pot" starts to empty. After three half-lives, or 17,100 years, only one-eighth of the original amount is left.

enough energy to produce carbon-14, a radioactive isotope of carbon."

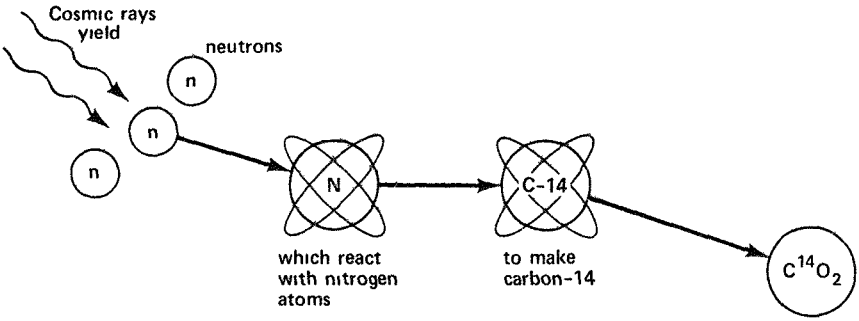
"Oh yes," said Bill, "I learned that most of ordinary carbon is carbon-12 with 6 protons and 6 neutrons in the nucleus of each atom. And also that there was a small amount of carbon-13 with 1 extra neutron."

"That's right," said the scientist. Carbon-12 and carbon-13 are stable (nonradioactive) isotopes of carbon. Carbon-14 with 8 neutrons is radioactive and has a half-life of about 5700 years.

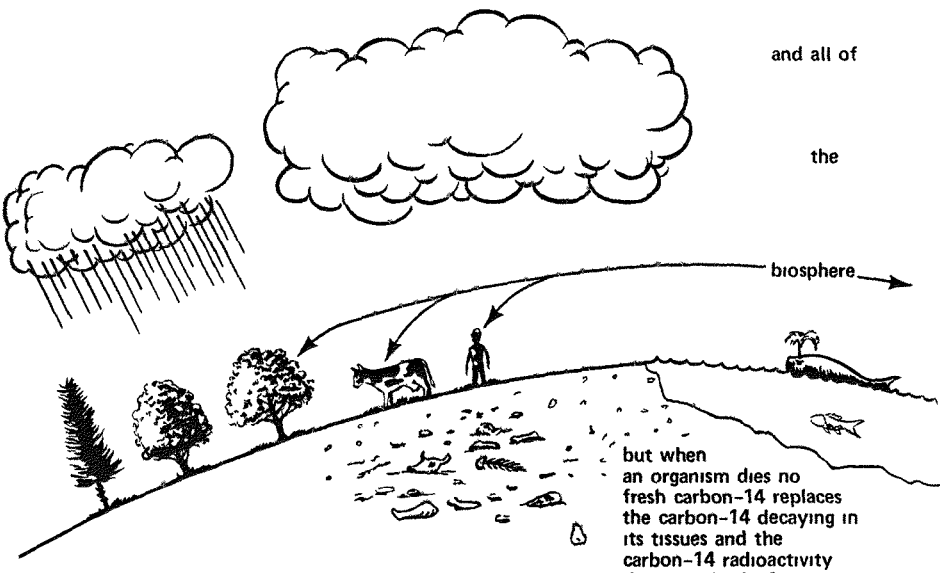
"Now then," Dr. Gordon continued, "the carbon-14 produced in the upper atmosphere quickly combines with oxygen to form CO_2, which eventually mixes into the whole atmosphere. Then plants pick it up and thus the carbon-14 becomes a part of every plant and, because plants are eaten by animals, of every animal too. In other words, there is carbon-14 in every living creature on the earth.

"The next important point in the scheme to use carbon-14 for dating is that the concentration of natural carbon-14 in the atmosphere (and in living things) has been about the same for a long time—tens of thousands of years. That is, for a given number of nonradioactive carbon atoms in living creatures there always was a certain number of carbon-14 atoms while that creature lived. The reason that this number remained about the same was that although the carbon-14 atoms slowly disappeared be-

Carbon-14 dating.



which shows up as carbon dioxide throughout the atmosphere, the hydrosphere,



and all of the

but when an organism dies no fresh carbon-14 replaces the carbon-14 decaying in its tissues and the carbon-14 radioactivity decreases by half every 5700 years

cause of radioactive decay, the creature always obtains more from the world around him.*

"It's as if each cell of a living thing were a pot with a hole in it set under a dripping faucet. The water dripping out of the hole represents the loss of carbon-14 because of radioactive decay. The dripping faucet represents the fresh carbon-14 coming in through the food chain from the upper atmosphere.

"Imagine that the hole in the pot is just the right size so that, if there were no faucet, half the water in the pot would run out in 5700 years. But the drip from the faucet exactly replenishes the leak. When the cell dies, however, the faucet is shut off and the water level in the pot begins to decrease.

"After 5700 years, the pot is only half full; after 11,400 years, it is only one-quarter full; after 17,100 years, it is only one-eighth full; and so on."

"Then, if you came along sometime after the faucet was turned off, and you saw how full the pot was, you could figure out how

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*Actually recent comparisons of carbon-14 measurement and tree-ring counts in nearly 4000-year-old Bristlecone pine trees have shown that there have been small but definite changes in the carbon-14 concentration over the past several thousand years. The corrections can be applied whenever they are known. These variations are probably due to variations in the number of cosmic rays that reach our atmosphere.

long ago the faucet had stopped?" asked Bill.

"Exactly," said Dr. Gordon, "and that's how carbon-14 dating works. I'll measure how much carbon-14 Sampson has left in him. And because I know how much carbon-14 was in the tree from which Sampson came, I'll know how long ago that tree was cut.

"Since it's difficult now for anyone to find wood as old as Sampson is supposed to be, we'll assume that Sampson was carved within a few years after the tree stopped living."

"How do you measure the amount of carbon-14 in Sampson?" asked Bill.

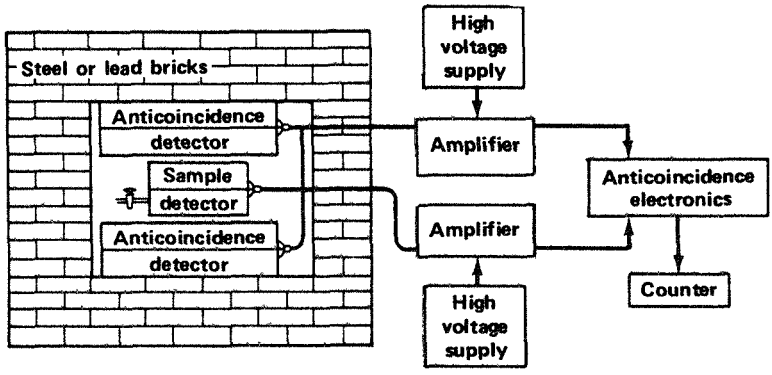
"There are two general methods in use," answered the scientist. "One of these—liquid scintillation counting—is best when large samples are available. I'll use a gas-proportional counter for your piece because it's rather small and I can't take much without disfiguring it."

Bill and Dad watched the scientist drill a hole into the bottom of Sampson. He carefully collected the wood chips and, weighing them from time to time, stopped when he had about 2 grams.*

"For liquid scintillation counting, we would want 5 to 10 times as much or more," remarked Dr. Gordon.

He burned the wood chips in a stream of oxygen gas inside a glass tube connected to a

*A gram is approximately $\frac{1}{30}$ ounce. A new dime has a mass of a little more than 2 grams.



A gas proportional counting system for the measurement of small amounts of carbon-14. A sample, prepared in the form of carbon dioxide or methane, is used to fill the sample detector in the center of the shield. While the shield protects the detector from much of the natural radiation from materials in the laboratory or cosmic rays (background radiation), it is also necessary to use the anticoincidence system shown. This works by automatically cancelling the detection of any radiation that comes from the outside and thus triggers an anticoincidence detector and the sample detector at the same moment. Actually the system is not perfect and a small amount of the background gets through.

complicated apparatus. He then went through a series of manipulations that he explained would result in nearly all the carbon in the wood being converted to carbon dioxide in a very pure form. A metal cylinder, the gas-proportional detector, was then filled with the pure carbon dioxide gas.

"The detector consists of this metal cylinder and a fine wire that stretches down the middle and is electrically insulated from the cylinder," continued Dr. Gordon. "A high

voltage is applied to the center wire. Any ionizing radiation, such as the beta rays from the carbon-14 in the gas, produces electrons that are collected by the electrically charged wire. Whenever that happens, a pulse of electricity is produced that registers as a count on the counter."

"Sounds simple," said Bill.

"There are complications," answered the scientist. "Cosmic rays and natural radioactivity (in the ground under us and in the building material around us) also produce counts. These would interfere with the small number of counts we should get from your sample.

"We minimize these by placing the detector inside a heavy shield of steel bricks. These absorb most of the external radiation but that isn't enough. We also use a method called 'anticoincidence counting' to cancel out the unwanted signals. Inside the shield, and surrounding the detector containing our sample, is a ring of counters that detects most of the radiation that gets through the shield.

"Now, whenever a cosmic ray, for example, registers in the sample detector, it must also have passed through the ring of counters a fraction (less than a millionth) of a second before. The electronic equipment is set up to reject any counts from the sample detector that occur at the same time as a count from the ring. Thus, only the radioactivity that originates inside the ring is measured. The small amount of radioactivity that still regis-

ters (in addition to that from the sample) is called the 'background' and consists of some external radiation that manages to get through the ring (or in the open ends) and some natural radioactive contamination in the materials of which the detector is constructed.

"The net result of all this is that the background of this counter is reduced from several hundred to approximately two counts per minute."

Dr. Gordon placed the detector containing the gas produced from Sampson in the shield, connected it, and turned on the counter.

"It will take at least till tomorrow to register enough counts for an accurate answer," he said. "I'll call you later in the week."

"Just one more question," said Bill. "How does the liquid scintillation counter work?"

"There are a few more chemical reactions to carry out during which the carbon dioxide is converted to benzene. Then certain other chemicals are dissolved in the benzene. These chemicals have the property of emitting light when radiation is absorbed. The light is detected by a special electronic tube called a photomultiplier, and once again electrical pulses are produced and counted. The background is much higher—tens of counts—but because a large sample can be used, there are even more counts from the sample and useful data is obtained."

"Thanks very much," said Bill. "I'll be waiting for your call."

Bill and Dad said goodbye and left the laboratory.

The Results: A Few Methods for the Future

During the next week or so, more answers came in.

The thermoluminescence data on Harley's pottery showed that the natural radiation dose rate was 200 millirads per year*, while the amount of light obtained upon heating corresponded to a total dose of 480 rads. That meant that the pottery was 2400 years old with an uncertainty in the measurement of 200 years. That was just right for the piece if it was Etruscan as the archaeologists believed. Everyone agreed that the date was a pretty convincing argument and that the piece was genuine.

The curator of the museum said it was a fine specimen and offered to have it cleaned. Harley generously donated it to the museum and it was accepted. It would go on display with an engraved plate stating that Harley had donated it.

Sampson, Bill's wooden figure, was also genuine. Carbon-14 dating had set its age at

*The rad is a unit of radiation dosage. A millirad is $\frac{1}{1000}$ of a rad.

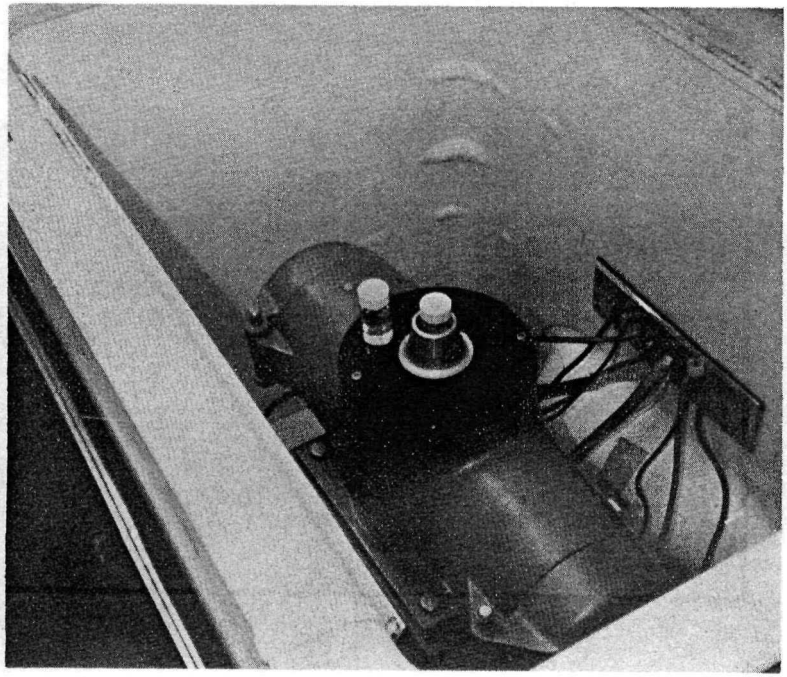
2000 years, plus or minus a hundred years. It was in pretty bad shape, however, since it had been very wet when found. Bill decided to keep it and wondered how it could be repaired.

Dad said, "There are a number of methods for 'fixing' water-logged wood. The trick is to dry it out somehow without warping it or otherwise damaging it. These methods are all slow and not completely satisfactory. They generally consist of replacing the water with a chemical that doesn't dry out, or that hardens and thus strengthens the wood.

"There has been one nuclear method proposed that has interesting possibilities. This is a method that was originally developed (and is still being used) for making a wood-plastic combination that looks like wood but is much stronger and more resistant to moisture changes than wood alone. To use it to stabilize wood artifacts that are already wet, one would begin by replacing the water in the wood with a substance called a 'monomer'. Then, by irradiating the monomer-soaked wood with gamma rays from radioisotopes like cobalt-60, the monomer molecules link up with each other to form a plastic (or polymer) right in the pores of the wood."

"Can we do that to Sampson?" asked Bill.

"Not yet, but perhaps someday we will when the techniques are all worked out," answered Dad. "A scientist in the Netherlands, R. A. Munnikendam, has been working on this problem, and the French have recently



A liquid scintillation counter used for counting carbon-14. One sample bottle is about to be lowered into the counter so that it can be "looked at" by the photomultiplier tubes. Another is resting on the rim of the shield. The entire assembly is in a freezer cabinet because cold temperatures reduce the electronic "noise" that may interfere with the measurement.

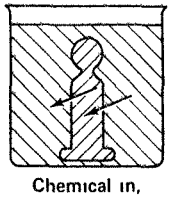
exhibited a wooden statue that was treated in this way."

"We certainly have learned a lot about the way nuclear techniques help with archaeological problems," commented Harley.

"Are there any more being studied?" asked Martin.

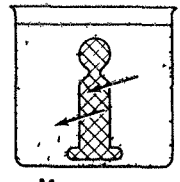
PROPOSED SCHEME FOR TREATING WATERLOGGED WOOD BY CREATING A COMBINATION OF WOOD AND PLASTIC

① Soak waterlogged piece in chemical to replace water.



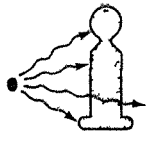
Chemical in, water out

② Soak chemical-soaked piece in monomer to replace chemical.



Monomer in, chemical out

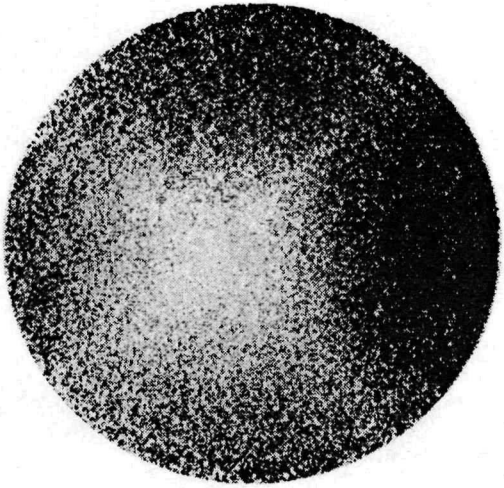
③ Irradiate monomer-soaked piece with gamma rays from radio-active source.



④ This produces wood-plastic combination

which is tougher, harder and more moisture resistant than the best seasoned wood alone

This 14th century wooden madonna and child was preserved by monomer impregnation and radiation polymerization by the French Commissariat a l'Energie Atomique and the Conseil International des Musees in France.



An "X-ray" picture of a pyramid. This photograph was produced by computer from the information obtained by detecting many mesons arriving at a detector beneath the pyramid of Chephren in Egypt. (Mesons are one of a class of medium-mass, short-lived elementary particles with a mass between that of the electron and that of the proton.) The four corners of the pyramid are apparent, but there is no shadow corresponding to a possible hidden chamber in the rock.

"Yes, there are," answered Dad. "Mass spectrometry is being studied in a number of ways as a possible identification method. One way* is to look at the variation of stable isotopes of certain elements like lead and oxygen in nature to see if the source of a sample of material used in an artifact can be

*Robert Brill at the Corning Museum of Glass is conducting research in this area.

identified. Another method* is the use of mass spectrometry to analyze the composition of metal objects, with high sensitivity, so as to 'fingerprint' them.

"And a very special technique called Mossbauer effect spectrometry, has been used to study the compounds of iron in certain kinds of pottery.† Scientists believe they might be able to tell at what temperature the clay was fired with this method.

"Finally, a technique using special cosmic-ray detectors was employed by Luis Alvarez to 'X-ray' a pyramid in Egypt using a part of the cosmic rays as if they were from an X-ray machine."

"Sounds like nuclear scientists will be helping archaeologists in lots of ways from now on," commented Bill.

"And I'm glad they are!" exclaimed Harley admiring his pitcher.

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*This work is being done by Thomas Cairns at the Los Angeles County Art Museum.

†D. R. Cousins and K. G. Dharmawardena are using this in England.

Reading List

About Atomic Power for People, Edward and Ruth S. Radlauer, Childrens Press, Chicago, Illinois 60607, 1960, 47 pp., $2.75. Grades 5–9.

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