

NATIONAL ACADEMY OF SCIENCES

ISADORE PERLMAN

1915—1991

A Biographical Memoir by

GLENN T. SEABORG AND FRANK ASARO

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Biographical Memoir

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WASHINGTON D.C.



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Perlman

ISADORE PERLMAN

April 12, 1915–August 3, 1991

BY GLENN T. SEABORG AND FRANK ASARO

PROFESSOR PERLMAN HAD outstanding success in six major careers. He pioneered many advances made in nuclear medicine prior to World War II, particularly the use of radioactive iodine and phosphorus in physiological tracer studies. He played a key role in the development of plutonium production facilities for World War II, and was a leader of research in an intensely important project with a very tight schedule. His research contributed greatly to an understanding of the nuclear structure of the heavy elements, and he was considered a world leader on the systematics of alpha decay. He developed high-precision methods of neutron activation analysis at the Lawrence Berkeley Laboratory, developed procedures to determine the origin of ancient pottery and other artifacts from the data, and was regarded as a top expert in the field of archaeometry. He developed a new neutron activation analysis facility at the Hebrew University of Jerusalem, which became one of the top laboratories in the world for determining the origin of ancient artifacts, and which also produced some outstanding contributions in the field of geology. After returning to Berkeley, he helped develop handling procedures for measuring iridium abundances in large numbers of samples

used in testing the asteroid impact hypothesis of Alvarez et al.

In addition to these accomplishments, his versatility, brilliance, quick wit, and unselfishness impressed all who knew him.

YOUTH

Isadore (Iz) Perlman was born in Milwaukee, Wisconsin, on April 12, 1915, and after a long illness he died on August 3, 1991, in Los Alamitos, California, near Long Beach. His early life was marked by many changes, and these may have developed his capability to adjust to new concepts, facilitating the outstanding scientific contributions he made in later years to so many different disciplines. When he was very young his father Harry Perlman, his mother Bella Karpman Perlman, and his brother and three sisters moved to Brainard, Minnesota. The family lived in town while his dad raised cattle on a rented farm. Two of his sisters moved to California, and in 1930 the rest of the family followed. They lived in South Gate in southern California, where they ran a cattle-feeding yard. Perlman started his undergraduate work at the University of California, Los Angeles, then transferred to the University of California, Berkeley, in 1934 for his junior and senior years and obtained his bachelor's degree in chemistry in 1936.

Perlman worked at the Pabco Linoleum Company for six months and then decided the world must have more to offer—and it did. He met Labelle (Lee) Grinblat in 1937; they married the same year and subsequently had three daughters, Judy, Alice, and Paula.

FIRST CAREER: PHYSIOLOGY

In 1937 Perlman became interested in the use of radioactive tracers in physiology and began graduate studies under

Professor Israel L. Chaikoff at the University of California, Berkeley. Perlman suggested to Chaikoff that radioactive tracers could be used to study metabolism. Nuclear chemist Sam Ruben joined the team and they studied the rate of formation and destruction of phospholipids with ^{32}P prepared by deuteron bombardment of ^{31}P . The authors demonstrated that as little as 10^{-11} gram of ^{32}P could be quantitatively traced in the tissues of an animal. While a graduate student, Perlman was awarded a Rosenberg Fellowship, and after obtaining his Ph.D. in physiology in 1940, he continued research with the aid of an Upjohn Fellowship.

Isadore Perlman pioneered many advances made in nuclear medicine prior to World War II, particularly the use of radioactive iodine and phosphorus in physiological tracer studies. From 1937 to 1943 he published nineteen papers in this field and demonstrated the usefulness of radioactive tracers of phosphorus, bromine, and iodine to physiology. Radioiodine (iodine-131) is now basic in the diagnosis of thyroid activity and treatment of thyroid cancer, and radiophosphorus is generally used in decoding the nucleic acid code of the human genome. Chaikoff wanted Perlman to attend medical school after he obtained his doctorate, but with the turmoil in Europe, Perlman felt that his talents could best serve his own and his country's interests in a more direct way.

SECOND CAREER: DEVELOPMENT OF METHODS OF SEPARATING
PLUTONIUM FROM URANIUM AND FISSION PRODUCTS

Isadore Perlman first met Glenn T. Seaborg, one of the authors of this memoir, in the fall of 1933 when they were undergraduate students at UCLA, and this contact continued in Berkeley. In January 1942 immediately after the United States entered World War II, Perlman began his second career when he joined Seaborg's research group in Berke-

ley, which had discovered the element plutonium and was investigating the development of chemical methods for the separation of plutonium from uranium and fission products. Seaborg already considered Perlman to be an outstanding scientist and thought he would also help in the overall direction of his group. Perlman, working with Beppino J. Fontana, began by separating a minute amount of ^{234}Th (UX1) from 500-1,000 pounds of uranyl nitrate hexahydrate. ^{234}Th , the daughter from the alpha decay of ^{238}U , decays with a 24.1-day half-life to an isomer of ^{234}Pa , which then decays to ^{234}U with a 1.17-minute half-life. By quickly separating out and purifying the ^{234}Th and then allowing it to decay to ^{234}U , they isolated 0.1 micrograms of ^{234}U , which was used to determine the ^{234}U slow neutron fission cross section. After accomplishing his first task Perlman then began studying ways of separating plutonium from neutron-irradiated uranium in preparation for research Seaborg planned to do as part of the Metallurgical Laboratory at the University of Chicago.

Scientists in Europe and the United States, intensely aware of the innovations of the German scientists in nuclear chemistry and the danger of Nazi Germany, had pleaded with the U.S. government for support of a program to develop atomic weapons before Germany did. One of the results was the start of the Plutonium Project in Chicago. The Berkeley scientists involved, who felt the work they were doing then would be the most important they would ever do, had voluntarily delayed publishing their own work to prevent Germany from using the information, and then they raced at breakneck speed to achieve large-scale production of plutonium before Germany would be able to do so.

Perlman arrived with Seaborg at the Metallurgical Laboratory of the University of Chicago on April 19, 1942, and the intent was to organize and set up chemical facilities

(starting with nothing but empty rooms) to eventually achieve large-scale production of ^{239}Pu .

Perlman was just twenty-seven years old and Seaborg just thirty. Nuclear reactors had not yet been built. Their problem was to develop procedures to extract plutonium from tens of tons of uranium metal and decontaminate it from fission products by a factor of 10 million. In the first year, they had very little to work with except minute amounts of cyclotron-produced plutonium and not much equipment. The originally limited laboratory facilities and groups working with them both grew as time went on. The team was working on a test tube scale with tracer radioactivity and was feeling its way to isolate plutonium. The selected method was to co-precipitate plutonium and some of the fission products with an inorganic compound while the plutonium was in a reduced oxidation state. Next the precipitate (e.g., lanthanum fluoride) would be dissolved and then the plutonium would be oxidized to a higher oxidation state. The inorganic compound was then re-precipitated, which again would co-precipitate the fission products, but it would leave behind the oxidized plutonium in aqueous solution. The entire process was then repeated through several cycles. Although the group worked with lanthanum fluoride in the beginning, towards the end of 1942 Stanley G. Thompson developed a new way to co-precipitate plutonium with bismuth phosphate, and this method was superior in many ways to the lanthanum fluoride precipitation. Perlman, working at the laboratory bench level and as deputy chief of the Plutonium Chemistry Section, contributed in many ways to working out the chemical separation process.

On December 2, 1942, the first-ever nuclear reactor was operated at the University of Chicago campus. The Du Pont engineers, who had been brought in to design and build the production reactors and to design and build the engi-

neering aspects of the chemical processing, wanted to have a scaled-up version of the reactor and chemical separation plant at an intermediate level, and the decision was reached to build such a reactor and chemical plant at the Clinton Laboratories at Oak Ridge, Tennessee. Perlman was sent down to Clinton Laboratories in the fall of 1943 to be chief of the Plutonium Chemistry Section, and he was eventually in charge of some forty-five scientists whose goal was to work out the process of separating plutonium from irradiated uranium and fission products on a scale of tons of uranium. The first runs were made in December of 1943, and by February of 1944 the laboratory staff was working up a ton of uranium per day and getting out several grams of plutonium. This was in itself a remarkable feat and attributable not only to Perlman but to many other people on the project. Just three years, almost to the day, from the first identification of this element from a few atoms of ^{238}Pu in Berkeley many grams of this element were being made and isolated in Tennessee in a place that later became the Oak Ridge National Laboratory. Meanwhile, the Du Pont company was building big production reactors at the Hanford Engineer Works in the state of Washington on the Columbia River, and these reactors were ultimately put into use in September of 1944. At the same time they were building the huge concrete-shielded chemical facilities for handling this highly irradiated uranium by remote control. Many scientists and engineers went to Hanford to make some final tune-ups of this chemical process and to serve as standby troubleshooters in case the Du Pont engineers got into any difficulty. Perlman played a key role as a consultant to Du Pont management.

Atomic bombs were dropped on Hiroshima (uranium-235) and Nagasaki (plutonium-239) in August of 1945. Opinions about the need for the bombs have been hotly debated

in recent years, but this was not true in 1945. The main concern was the safety of Allied troops. Frank Asaro, one of the authors of this memoir, was an undergraduate student at the time and remembers how grateful he and other students felt when it appeared the United States had a weapon that could defeat the Japanese without a continuation of the terrible casualties the U.S. troops had suffered in recapturing one Japanese-held island after another in the Pacific.

Playing a key role in the development of plutonium production facilities for World War II had been another career for Isadore Perlman the physiologist, in which he became a radiochemist, nuclear chemist, chemical engineer, and a leader in an intensely important project with a very tight schedule.

THIRD CAREER: NUCLEAR CHEMISTRY AND PHYSICS

Immediately after the end of the war, Perlman returned to Berkeley, first as an associate professor and then a full professor of chemistry (1949), thus beginning a third career. (He continued to be a consultant to the Du Pont company, serving as a resource in Du Pont's postwar nuclear program, such as the operation of the Savannah River plant in South Carolina for production of plutonium.) Perlman helped Seaborg direct the newly established Nuclear Chemistry Division in the Radiation Laboratory (now the Ernest Orlando Lawrence Berkeley National Laboratory), where the research on transuranium nuclides led to the synthesis and identification of ten more new elements. In the fall of 1947 he and his student Louis B. Werner were the first to isolate a compound of curium in macroscopic quantity.

In 1947 he began publishing experimental and theoretical papers on the systematics of alpha decay and was considered a world leader in this field for the next twenty years. The Aage Bohr-Ben Mottelson collective model and the later

Sven G. Nilsson unified model of the nucleus owed much to Perlman's experimental research program.

In the next two decades Perlman concentrated on the alpha decay process, nuclear energy level studies, and the identification of new isotopes. He worked with Stanley G. Thompson and Frank Asaro, for example, on nuclear structure; Frank S. Stephens on odd parity rotational states; Richard M. Diamond and Frank S. Stephens on multiple Coulomb excitation; Albert Ghiorso, John O. Rasmussen, and Frank Asaro on alpha decay systematics; and Glenn T. Seaborg, Jack M. Hollander, Donald Strominger, and C. Michael Lederer on compilations of tables of isotopes. He published two books with Earl K. Hyde and Glenn T. Seaborg, *The Nuclear Properties of the Heavy Elements. I. Systematics of Nuclear Structure and Radioactivity* and *The Nuclear Properties of the Heavy Elements. II. Detailed Radioactive Properties*.

An instance that demonstrates Perlman's originality was the development of an alpha particle spectrograph at the Radiation Laboratory in 1950. Many new alpha-emitting isotopes had been discovered at the Radiation Laboratory, and their energies had been measured by Albert Ghiorso and his associates with ionization chambers. These devices had very high efficiency, which was extremely useful when only a few atoms of radioactive material were available. If, however, conversion electrons were emitted nearly simultaneously (in coincidence) with an alpha particle, as often happened, their energies would add to that of the alpha particle in the ionization chamber, smear out its energy spectrum, and make the data less useful for nuclear structure studies. Other laboratories in the past had used magnetic spectrographs for measurements of alpha particle energies, but because of the trauma and aftermath of World War II, they were not yet operating again. The magnetic spectrograph had a much lower efficiency than a grid chamber, but its resolution could

be better, and its alpha particle energies would not be smeared by coincident conversion electrons. Perlman felt that with the increasingly larger amounts of recently discovered alpha-emitting elements that were being produced in reactors, it was feasible to make some of the measurements with an alpha particle magnetic spectrograph, but none was available. There were, however, magnetic mass spectrographs that had been constructed by Fred L. Reynolds in the Nuclear Chemistry Division at the Radiation Laboratory. In 1950 there was a new mass spectrograph that had been completed except for its source. It was of the Nier type and had a 60° sector magnet with a 75-cm radius of curvature. Perlman reasoned that such a large radius of curvature would produce excellent separation between alpha groups if it were used as an alpha particle spectrograph. So he told a new graduate student of his (Asaro) to see what he could do with the instrument with alpha particles while the mass spectrograph source was being constructed.

Perlman's idea worked marvelously well and produced high precision and accurate alpha particle energy measurements for many of the new alpha-emitting isotopes that had been discovered recently, as well as re-measurements for many of those discovered long ago. The instrument was used continuously for many years as an alpha particle spectrograph; so much so that the mass spectrograph source was never completed.

Between 1946 and 1975 Perlman and his collaborators, including forty graduate students, published ninety-two papers in the nuclear field, with fifty-eight in the *Physical Review*. Perlman was always a great friend to those starting their research careers, and their names usually appeared first on the papers.

In 1952 Perlman received the California Section Award of the American Chemical Society, and was a Guggenheim

fellow in 1955 and 1963. In 1957 he served as chairman of the Department of Chemistry of the University of California, Berkeley, and in 1958 he became head of the Nuclear Chemistry Division and an associate director of the Lawrence Radiation Laboratory. Perlman received the Ernest O. Lawrence Award from the Atomic Energy Commission in 1960. He was a member of the National Academy of Sciences, the American Academy of Arts and Sciences, and the Danish Royal Academy.

FOURTH CAREER: DEVELOPMENT OF HIGH PRECISION NEUTRON
ACTIVATION ANALYSIS FOR ARCHAEOMETRY

In 1967 Perlman became interested in a completely new field, the determination of the origin of ancient pottery by elemental analysis of the pottery fabric. The basic concept was that individual clay beds would have distinctive chemical "fingerprints." Thus, any ancient pot whose chemical fingerprint matched that of a known clay bed in a data bank could be assigned the same origin. H. W. Catling and coworkers^{1,2} in England had elegantly proposed the concept. Because their technique of measurement (emission spectroscopy) did not measure enough elements with good precision to determine pottery origin with the degree of certainty Perlman wanted, he decided to develop a new method. He initially tested out X-ray fluorescence as a measurement technique for several months, but with the methodology available then it also did not give satisfactory results. Another elemental analysis technique (neutron activation analysis) had been used to study the origin of ancient pottery.^{3,4} The abundance measurements, however, were only considered to be precise to 10%-15%, and Perlman felt those precisions would not be adequate for confident assignments of origin.

Perlman was Frank Asaro's research director when the

latter was a graduate student and the two subsequently collaborated on nuclear structure studies for fourteen years. Perlman asked Asaro to share in the development of a high precision neutron activation analysis technique that would be suitable for determining the origin of ancient pottery with a high degree of certainty. Asaro consented with the intent of spending three months on the project. (Perlman's idea worked so well that the work continued for the next thirty years.)

Perlman's group had been making gamma ray spectroscopic measurements for nuclear structure studies for many years with sodium iodide detectors and then with germanium detectors with lithium diffused into their surfaces. Perlman felt that the same gamma ray techniques used for nuclear structure measurements with the then new germanium detectors would make great improvements in the neutron activation analysis process and result in much higher precision of measurement for many elements. He believed that enough was known about the physics of the process to make measurements accurate to the 1% level, which should be good enough to make the distinctions between clay fingerprints from different clay beds.

This program, which started Perlman's fourth career, became very successful. There were problems initially, as the same 10%-15% errors that had beset earlier workers appeared in Perlman's work, but Perlman and his group were able to determine the cause. It was the variation of the relative neutron-capture cross sections for different isotopes with position in the reactor and with time. This could have been a stopping point. It would have been proper science to publish the explanation for the cause of the problem and then continue with other work. But this was not Perlman's way. He not only wanted to find out what was wrong; he also wanted to find the solution.

To cure the problem Perlman and his group decided it was necessary to calibrate the neutron-capture cross section for every isotope of interest in every neutron irradiation for every sample position. To do this it was desirable to have a multielement homogeneous standard that could be placed in various positions in the reactor in every irradiation. But there were no multielement standards available whose abundances were precisely known. So Perlman decided to prepare such a standard of fired clay and have it accurately calibrated for over thirty elements. It took over a year to prepare and calibrate the standard, called standard pottery, and it became one of the most highly regarded multielement standards in the field of neutron activation analysis. It was also necessary that samples of pottery be prepared in such a way that they all were of almost exactly the same shape and size. When this was all done it was found that neutron activation analysis could indeed be done as accurately as about 1% for the best elements. This was another possible stopping point. But when Perlman presented the data to an archaeological associate, the response was "What am I going to do with it?" So Perlman and his group decided it was not only necessary to develop the new method, but also to implement it.

One of the major efforts in Perlman's work was the development of a data bank of reference clay sources whose fingerprints could be compared with those of ancient pottery. Unfortunately, clay beds accessible in the present often did not correspond in composition to the pottery produced by the ancient potters. But sherds deformed in the firing process (called "wasters") were usually disposed of close to the kiln in which they were made and could serve as excellent reference sources. Other reference sources could be clay objects used in the operation of the kiln, handmade pottery used as kitchenware, or other common wares that

were not likely to be exported. Perlman's research infused new vigor into the determination of origin by chemical analysis and effectively opened up a new field. Neutron activation laboratories specializing in the origin of ancient pottery with procedures similar to those used in Berkeley were eventually spawned in France, Israel, and Germany. Other scientists, such as Edward Sayre and his collaborators at the Brookhaven National Laboratory in New York, developed independent methodologies for using germanium detectors to determine the origin of ancient glass⁵ and pottery^{6,7} by neutron activation analysis.

One of the first archaeological projects tackled by Perlman and Asaro was a study of second millennium B.C. pottery from Cyprus. This project was chosen because the archaeology for that period in that area was rather confused, and Perlman felt that in order to impress the archaeological community, the new technique had to solve problems that could not be solved otherwise. Perlman had help in this choice because two of his daughters, Alice and Paula, were participants in the University of California, Berkeley, Graduate Program in Ancient History and Mediterranean Archeology. Through the efforts of the Swedish archaeologist, Professor Einar Gjerstad, 1,200 pottery sherds from the second millennium B.C. that had been excavated by the Swedish Cyprus Expedition in 1927-31⁸ were loaned to Perlman's group, which analyzed them by the new method of high precision neutron activation analysis.

One of the most important results from the Swedish samples was achieved with a graduate student from Brandeis, Michal Artzy. A distinctive pottery called "Bichrome Ware," which had been first found in Tel Ajjul in Palestine by the archaeologist Sir Flinders Petrie,⁹ was thought to have originated in Palestine and been exported to Cyprus and other sites in the eastern Mediterranean. It was made on a fast

wheel and was well decorated in two colors with drawings of animals and birds. It was so unusual that it was thought to be the work of a new painter or a new school of painting. It was considered to be a classical Palestinian pottery ware.¹⁰ The work of Perlman's group showed instead that the chemical composition of the pottery matched that of pottery known to have been made in Cyprus and also that of Cypriot clay. The pottery became known as classical Cypriot Bichrome Ware. This completely reversed the known trade patterns for this ware, as it was shown to have been made in Cyprus and exported to Palestine, Egypt, and other sites in the eastern Mediterranean instead of originating in Palestine. There were extensive ramifications of this work in the archaeology of the eastern Mediterranean. It was found that the fast wheel was used in Cyprus in the second millennium B.C. (which was not known before) and that many types of pottery previously assigned to Ras Shamra (in what is now Lebanon), because they were made on a fast wheel, had actually been made in Cyprus. It was found in addition that poorly painted Bichrome Ware, which had been assumed to be a precursor to the beautiful classical product, was actually a local imitation of the Cypriot pottery.

Besides many studies on pottery, Perlman's group also made studies of obsidian artifacts. Obsidian is a volcanic glass that fractures with very sharp edges. It was used by ancient civilizations as a cutting tool before the development of metal knives. It was so prized that it was exported over long distances and its distribution could be used to gauge the commercial interactions between ancient societies. The origin of an obsidian artifact is usually more easily determined than a pottery sherd, because a given volcanic flow is often very homogeneous, and its chemical profile appears in all artifacts made from that flow. Perlman's neutron activation methodologies were so well developed that

artifacts measured five years after the source determinations (with completely new detector systems and electronics) would agree with a source profile within 2% on the average for the sixteen best measured elements.

One of the more spectacular obsidian studies by Perlman's group was the discovery of a source, near Borax Lake in northern California, where the abundances were not homogeneous, but varied greatly for different samples taken within the volcanic flow. But the abundances of pairs of elements were linear with respect to each other amongst the various samples. The group also found that the abundances of elements in rocks with somewhat higher silicon dioxide abundances than found in obsidian (dacites) also had linear relationships, and these were the same as those found in the obsidian. This study was inspired by Harry R. Bowman, an engineer who had been very active in nuclear chemical measurements. Subsequently, he joined Perlman's group and became interested in applications of nuclear methods to the field of geology. The cause of the linear relationships in the obsidian and dacite rocks was ascribed to the mixing of two magmas and eruption before the mixing was complete (magmatic mixing). The dacite and obsidian were considered part of the same eruption. The work was very controversial at the time of publication in 1973 in the *Journal of Geology*, but it is now regarded as a classic example of magmatic mixing.

Perlman and his group applied their techniques to other rock types, most notably the twin colossal statues, commonly known as the Colossi of Memnon, on the Plain of Thebes across the Nile River from Luxor in Egypt. They collaborated with Professor Robert Heizer and his staff and students from the University of California, Berkeley, Department of Anthropology and Archaeological Research Facility. These two statues, which were monoliths erected in the

early fourteenth century B.C. as guardians of the Mortuary Temple of the very powerful Pharaoh Amenhotep III, were made of a quartzose sandstone rock (quartzite) formed by quartz particles cemented with iron oxide. The upper half of one of the statues (the northern one) was known from the historical literature to have been knocked over in an earthquake about 27 B.C. and was reconstructed by the Roman emperor Septimius Severus about 197 A.D.

Before 1933 there had been considerable controversy about the origin of the stone of the colossi. Then Alexandre Varille,¹¹ in summarizing the earlier work, concluded that the stone came from a quartzite quarry near Cairo, over 400 miles away from its present location, and was taken upstream. In 1965 Labib Habachi¹² suggested that the stone came from quartzite quarries close to Aswan, which was only about 100 miles away, and was floated downstream. This later belief arose because there was an inscription near the Aswan quarries that indicated that great monuments had been moved to the north (i.e., toward the Plain of Thebes). This was the type of controversy Perlman enjoyed, because he felt the measurement skills that his group had developed could achieve solutions when other methods could not.

The neutron activation analysis measurements indicated that the rock from the unreconstructed part of the statues did indeed come from Gebel el Ahmar near Cairo, so the ancient Egyptians did quarry the quartzite there and take it over 400 miles upstream as Varille thought. Perlman's group and its collaborators found the Romans, on the other hand, reconstructed the north statue with small blocks from the much closer Aswan quarries. From the neutron activation studies, it could be deduced that the Egyptian pharaohs apparently did what was most esthetically pleasing or reli-

giously important to them, while the Romans did what was the most practical.

During these years Perlman was regarded as a top expert in the field of archaeometry and published twenty-one papers in the field.

FIFTH CAREER: ARCHAEOMETRY AT
HEBREW UNIVERSITY OF JERUSALEM

Perlman retired from the University of California, Berkeley, and the Lawrence Berkeley Laboratory in 1973 and began his fifth career. He obtained a dual professorship in archaeology and chemistry at the Hebrew University of Jerusalem in Israel. There with Joseph Yellin he built a neutron activation analysis laboratory for ancient pottery, which soon became one of the top-rated facilities in the world. In close association with archaeologists it provided new insight into many provenience problems. In this, his fifth career, he published with his students and coworkers many papers relevant to archaeology and geology.

SIXTH CAREER: COMING BACK HOME

Perlman “retired” from the Hebrew University of Jerusalem in 1985 and returned to the Lawrence Berkeley Laboratory for his sixth career. There he helped Frank Asaro organize a program of measuring the abundance of the element iridium in thousands of rock samples to determine the relationship (according to the concept of Alvarez et al.¹³) between massive extinctions of life on Earth in the past and the impact of large asteroids or comets. In this concept, a mass extinction of species that took place 65 million years ago resulted from the impact on the Earth of an asteroid 10 km in diameter. Alvarez et al. hypothesized that the resulting tremendous explosion of the asteroid produced a dust cloud that encircled the Earth, blocked out

the sunlight for a time, and caused the extinction of species starting with plants at the bottom of the food chain. The major indicator for impacts in geological sediments in the early 1980s was an anomalously high abundance of the element iridium. The focus of the Alvarez team at that time was twofold. One was on determining if unusual abundances of the element iridium (and hence impacts) occurred in sediments at about the same time as other mass or minor extinctions of species had been detected, and the other was to determine to what extent iridium anomalies occurred in sediments where no such extinctions were known. Thus, there was a need for a large number of iridium measurements. The Alvarez group had developed a spectrometer capable of measuring iridium abundances at the level of 30 parts per trillion, 500 times faster than had previously been possible by neutron activation analysis without chemical separations. It was necessary, however, to develop routines to handle the flood of samples. This was where Perlman's knowledge and organizational experience excelled, and he was a great boon to Asaro in handling the measurements.

At the Lawrence Berkeley Laboratory and the Hebrew University of Jerusalem, as at the University of California, Berkeley, Perlman was always a most conscientious teacher, and there were very strong bonds of affection between him and his students.

DISCUSSIONS WITH LABELLE PERLMAN, Isadore's wife, his children, colleagues, and former students were most helpful in the preparation of this memoir. Some material about Isadore's early career in physiology was taken directly from a write-up by Cornelius Tobias. A memorial speech for Perlman delivered by Earl K. Hyde contributed greatly to summarizing the plutonium years, as did the journals of Glenn T. Seaborg. The latter are included in the book *The Plutonium*

Story: The Journals of Professor Glenn T. Seaborg 1939-1946 (Columbus, Oh.: Battelle Press, 1994).

AWARDS AND PRIZES

- 1939 Rosenberg Fellowship
- 1940 Upjohn Research Fellowship
- 1952 California Section Award, American Chemical Society
- 1955 Guggenheim Fellow
- 1960 Ernest O. Lawrence Award, Atomic Energy Commission
- 1963 Guggenheim Fellow
- 1964 American Chemical Society Award for Nuclear Applications
in Chemistry

NOTES

1. H. W. Catling, A. E. Blin-Stoyle, and E. E. Richards. Spectrographic analysis of Mycenaean and Minoan pottery. *Archaeometry* 4(1961):31-38.
2. A. Millett and H. W. Catling. Composition patterns of Minoan and Mycenaean pottery: Survey and prospects. *Archaeometry* 10(1967):70-77.
3. E. V. Sayre and A. W. Dodson. Neutron activation study of Mediterranean potsherds. *Am. J. Archaeol.* 61(1957):35.
4. V. M. Emeleus. The technique of neutron activation analysis as applied to trace element determination in pottery and coins. *Archaeometry* 1(1958):6-15.
5. E. V. Sayre. Refinement in methods of neutron activation analysis of ancient glass objects through the use of lithium drifted germanium diode counters. In *Proceedings of the VIIth International Congress on Glass*, Brussels, 1965. Paper 220. New York: Gordon and Breach, 1966.
6. E. V. Sayre, L.-H. Chan, and J. A. Sabloff. High resolution gamma ray spectroscopic analyses of Mayan fine orange pottery. In *Science and Archaeology*, ed. R. H. Brill, pp. 165-81. Cambridge, Mass.: MIT Press, 1971.
7. J. S. Olin and E. V. Sayre. Compositional categories of some English and American pottery of the American colonial period. In *Science and Archaeology*, ed. R. H. Brill, pp. 196-209. Cambridge, Mass.: MIT Press, 1971.

8. E. Gjerstad, J. Lindros, E. Sjöquist, and A. Westhom. *The Swedish Cyprus Expedition: Finds and Results of Excavations in Cyprus 1927-1931, vol. III, Text*. Stockholm: Victor Pettersons Bokindustriaktiebolag, 1937.
9. F. Petrie. *Ancient Gaza II*. London: The British School of Archaeology in Egypt, 1932.
10. C. Epstein. *Palestinian Bichrome Ware*. Leiden, Netherlands: E. J. Brill, 1966.
11. A. Varille. L'inscription dorsale du Colosse Meridional de Memnon. *Ann. Serv. Antiq. Egypt* 33(1933):85-94.
12. L. Habachi. Notes on the unfinished obelisk of Aswan and another smaller one in Gharb Aswan. *Mitt. Deut. Archaeol. Inst. Cairo* 20(1965):85.
13. L. W. Alvarez, W. A. Alvarez, F. Asaro, and H. V. Michel. Extraterrestrial cause for the Cretaceous-Tertiary extinction: Experiment and theory. *Science* 208(1980):1095-1108.

SELECTED BIBLIOGRAPHY

1937

With S. Ruben and I. L. Chaikoff. Radioactive phosphorus as an indicator of phospholipid metabolism. I. The rate of formation and destruction of phospholipids in the fasting rat. *J. Biol. Chem.* 122:169-82.

1941

With I. L. Chaikoff and M. E. Morton. Radioactive iodine as an indicator of the metabolism of iodine. I. The turnover of iodine in the tissues of the normal animal, with particular reference to the thyroid. *J. Biol. Chem.* 139:433-47.

1947

With others. Fission of bismuth, lead, thallium, platinum and tantalum with high energy particles. *Phys. Rev.* 72:352-2.
With D. H. Templeton and J. J. Howland. Artificial radioactive isotopes of polonium. *Phys. Rev.* 72:758-65.

1948

With G. T. Seaborg. Table of isotopes. *Rev. Mod. Phys.* 20:585-667.

1950

With A. Ghiorso and G. T. Seaborg. Systematics of alpha-radioactivity. *Phys. Rev.* 77:26-50.
With G. T. Seaborg. The synthetic elements. *Sci. Am.* 182(4):38-47.

1951

With L. B. Werner. First isolation of curium. *J. Am. Chem. Soc.* 73:5215-17.

1952

With F. Asaro and F. L. Reynolds. The complex alpha-spectra of Am^{241} and Cm^{242} . *Phys. Rev.* 87:277-85.
With F. Asaro. First excited states of even-even nuclides in the heavy element region. *Phys. Rev.* 87:393-94.

1953

With F. Asaro. Patterns in alpha spectra of even-even nuclei. *Phys. Rev.* 91:763-64.

1954

With F. Asaro. Decay properties of Am^{243} and possible rotational bands in the alpha spectra of odd-even nuclei. *Phys. Rev.* 93:1423-24.

1957

With F. Asaro. Isomeric state of uranium-235. *Phys. Rev.* 107:318-19.

1959

With F. S. Stephens, Jr., and F. Asaro. Classification of the energy levels of odd-mass nuclei in the heavy-element region. *Phys. Rev.* 113:212-24.

Nuclear spectroscopy. *Proc. Natl. Acad. Sci. U. S. A.* 45:461-71.

1960

With others. Anomalous electric dipole conversion coefficients in odd-mass isotopes of the heavy elements. *Phys. Rev.* 117:492-505.

With others. Isomers of Am^{242} . *Phys. Rev.* 120:934-43.

1969

With F. Asaro. Pottery analysis by neutron activation. *Archaeometry* 11:21-52.

1972

With F. Asaro and H. V. Michel. Nuclear applications in art and archaeology. *Annu. Rev. Nucl. Sci.* 22:383-426.

1973

With H. R. Bowman and F. Asaro. On the uniformity of composition in obsidians and evidence for magmatic mixing. *J. Geol.* 81:312-27.

With others. The Colossi of Memnon revisited. *Science* 182:1219-25.

With M. Artzy and F. Asaro. The origin of the "Palestinian" Bichrome Ware. *J. Am. Orient. Soc.* 93:446-61.

With M. S. Rapaport and F. Asaro. K-shell electron shake-off accompanying alpha decay. *Phys. Rev.* C11:1740-45.

1983

With J. Gunneweg and J. Yellin. The provenience, typology and chronology of Eastern Terra Sigillata. Monograph of the Institute of Archaeology, Qedem, no. 17. Hebrew University of Jerusalem.

1990

With D. Adan-Bayewitz. The local trade of Sepphoris in the Roman period. *Israel Expl. J.* 40:153-72.