The Taming of “49”

Big science in little time

Recollections of Edward F. Hammel

During the Manhattan Project, plutonium was often referred to, simply, as 49. Number 4 was for the last digit in 94 (the atomic number of plutonium) and 9 for the last digit in plutonium-239, the isotope of choice for nuclear weapons. The story that unfolds was adapted from *Plutonium Metallurgy at Los Alamos, 1943–1945*, as Edward F. Hammel remembers the events of those years.

The work in plutonium chemistry and metallurgy carried out at Los Alamos (Site Y) between 1943 and 1945 had a somewhat controversial history. The controversy was about who was going to do what. At the time Los Alamos was being organized, most of the expertise in plutonium chemistry resided at Berkeley, where plutonium was discovered in December 1940, and at the Met Lab in Chicago. Consequently, most of the original Los Alamos chemistry staff came from these two laboratories. At the Met Lab, the existing body of information on plutonium was constantly being upgraded and extended to optimize the plutonium extraction processes,[1] which were initially carried out at Oak Ridge (Site X) and finally at Hanford (Site W). At the Met Lab, attention was also being given to the production and properties of plutonium metal.

When Los Alamos began operations in April 1943, the division of labor between its chemical and metallurgical R&D programs and similar programs under way elsewhere in the Manhattan Project (particularly those at the Met Lab) had not been agreed upon. The issue was not settled until May of that year, when a special review committee appointed by General Groves and chaired by W. K. Lewis of the Massachusetts Institute of Technology recommended that the final purification of plutonium, the reduction to its metallic state, the determination of the metal's relevant physical and metallurgical properties, and the development of the necessary weapon-fabrication technologies be carried out at Los Alamos. This recommendation was triggered by two main reasons: First, the Los Alamos Project was responsible for the correct functioning of the weapon, and second, a considerable amount of plutonium reprocessing and repurification work was an inevitable consequence of the nuclear and physical research that was still to be conducted on the metal. It would clearly have been inefficient and time consuming to ship small amounts of plutonium metal back to Chicago for repurification and refabrication into different sizes and shapes for the next-scheduled nuclear physics experiment.

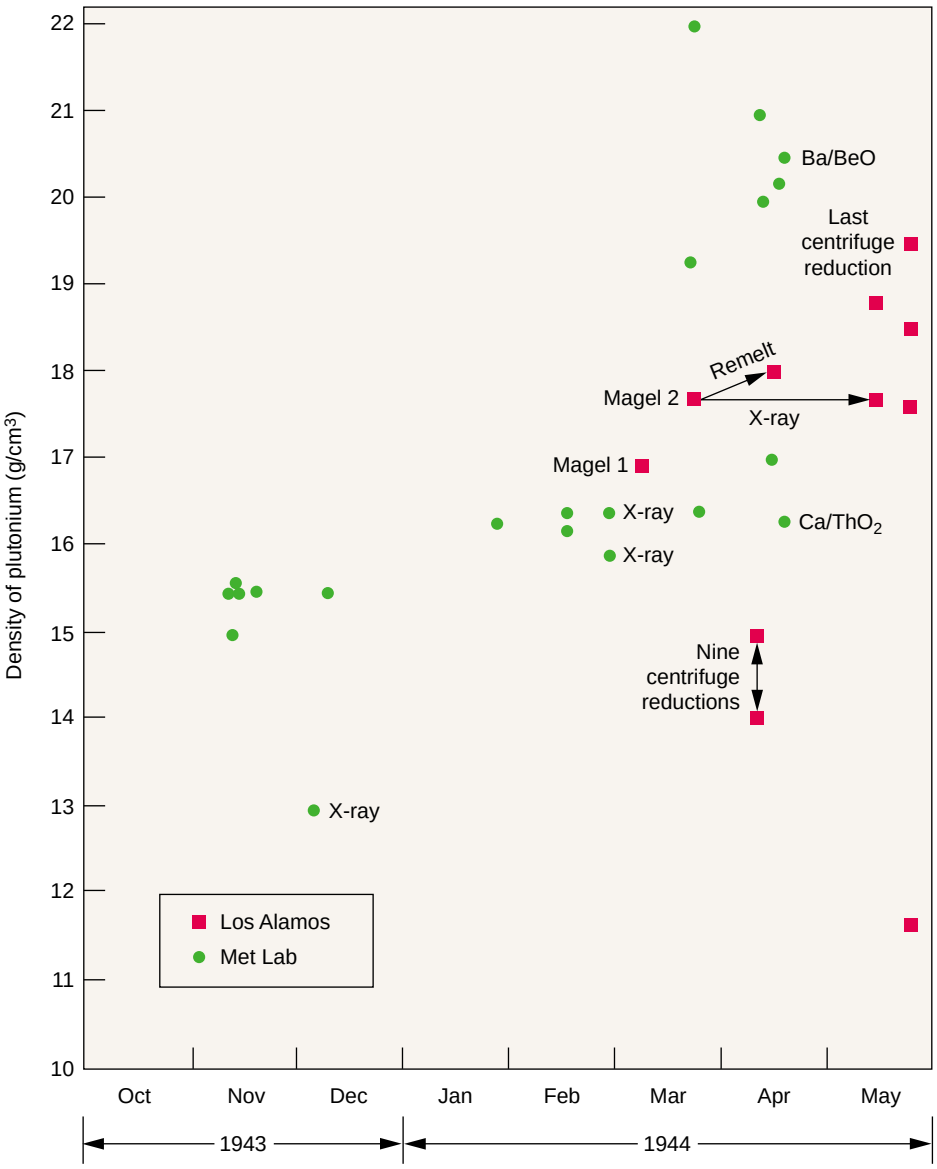
Minimizing the time spent to solve weapons R&D problems was a constant concern for the Los Alamos staff. Many of us had already participated in the costly uranium isotope separation or the plutonium production projects (at sites X or W or at their parent university laboratories), and we therefore knew that their engineering and construction phases were proceeding more or less on schedule. We also knew when their production phases were likely to begin and what the expected production rates would be. Our primary task was to make sure that, after enough active material had been delivered to Los Alamos to fabricate a weapon, the weapon could and would be built without further delay and then would be either tested or delivered to the Air Force for combat use. For the Chemistry and Metallurgy (CM) Division personnel, these concerns were intensified because important questions about plutonium's chemical and metallurgical properties had to be answered before the metal could be fabricated into satisfactory weapon components. In addition, not until January 1944 did the first few milligrams of pile-produced plutonium arrive at Los Alamos. The first 1-gram shipment arrived in February 1944, and quantity shipments of plutonium did not begin to arrive at Los Alamos until May 1945.

Ed Hammel in 1944

From the outset, it was clear that the purification of plutonium was the most important task of the CM-Division staff at Los Alamos. Achieving the impurity limits originally specified (on the order of a few parts per 10 million by weight for each of the lightest impurity elements) was essential for the success of the project. But this task was expected to be extremely difficult. To avoid a predetonation, we needed highly purified plutonium. The emission rate for plutonium α-particles is very high, well over 1000 times that of enriched-uranium α-particles. When the α-particles collide with an impurity nucleus (especially with that of a light element), neutrons are created. Unless each of the impurities is reduced to about 10 percent of the already very low levels specified before, the resulting neutron background will increase the chance of initiating a fission chain reaction in the plutonium well before the planned postfiring condition of maximum supercriticality is attained. The result will be a predetonation, or a "fizzle," in which little of the active material fissions before the entire assembly is blown apart.

Although we were fully aware of the impurity problem, we conducted little research on it during the first eight or nine months because adequate supplies of plutonium were nonexistent during that period. One project undertaken almost immediately, however, was the design and construction of a facility in which the projected chemistry and metallurgy work could be carried out with minimal contamination of the active materials by light-element dust particles settling out from the air. This facility was designated "D-Building." In May 1943, after the committee chaired by

[1] In addition to many other assignments, the Met Lab had prime responsibility for developing processes for separating plutonium from the uranium and the radioactive fission products in the reactor (pile) fuel elements.



Variations in measured plutonium metal densities finally provided convincing evidence for the high allotropy found in plutonium (six allotropes).

Lewis decided on the construction of this facility, some of the important tasks of the senior CM-Division staff, in collaboration with the architect and, in particular, with C. A. Thomas,[2] were to help set specifications for the building, participate in the design work, and subsequently, monitor the construction phase. The result was a laboratory as nearly dust-free as the air-conditioning technology available at that time permitted. The building was occupied in December 1943.

Working in temporary quarters through March 1944, when the division was more formally organized, CM-Division members were engaged in a variety of tasks, most of which have already been described in other accounts of the Laboratory’s early days. It may be of interest, however, to comment on the general modus operandi during the first eight to ten months of the division’s existence. April, May, and June 1943 were spent primarily on the acquisition of personnel, equipment, and materials; on organizational details; and on getting highly specialized laboratories in operation. J. W. Kennedy was appointed as acting leader of the CM-Division, and C. S. Smith served as acting associate division leader for metallurgy. Initially, there were about 20 chemists and metallurgists in this division, who would soon be assisted by roughly an equal number of technicians (by the end of the year, the division’s size had approximately doubled). During this same period, the functional structure of the division began to emerge. The two main organizational entities were obviously chemistry and metallurgy, but within those categories, small specialized groups were soon established. In the chemistry area, for example, a clear need arose for expertise in radiochemistry, analytical chemistry, purification chemistry, and general or service-related chemistry. Then, in addition to synthesizing materials requested by other parts of the project, CM-Division staff had to fabricate those materials into various shapes. The physical and chemical properties of those materials were specified and had to be confirmed. These tasks—including the reduction of purified plutonium compounds to plutonium metal and the final remelting, casting, and fabrication of the plutonium metal into the desired shape—were carried out by the metallurgical and analytical groups.

Because of the informality of the division’s organizational structure, its early accomplishments were recorded in a series of Los Alamos series reports, each dealing with a problem assigned to and reported on by an individual member (or members) of the division. Very brief (one- or two-page) semimonthly or monthly memoranda were also filed by the division leader. They summarized the results of those topical reports. It is also worth noting that

[2] Thomas, Research Director of the Monsanto Chemical Company, had been appointed by General Groves as coordinator for all the plutonium purification work being carried out throughout the Manhattan Project.

essentially all the technical personnel in CM-Division were experimentalists. Not surprisingly, much of their work had a strong empirical content.

Summary of Events between March 1944 and August 1945

In this section, I summarize plutonium metallurgy research, development, and production in D-Building by providing an abbreviated time line of the events that unfolded from March 1944 until the end of World War II. This time line also lists some of the associated problems that occurred and were solved by CM-Division personnel. The graph on the next page spread will assist you in achieving a better perspective of these events. Each numbered paragraph below refers to the corresponding number under the ordinate axis of the graph, and the short vertical line above each number points to the date when each event occurred.

1. Before any plutonium became available at Los Alamos, experience was sought with reduction techniques on related materials. Uranium and other plutonium “stand-ins” were used. But as it eventually turned out, such experience proved to be neither relevant nor very helpful. When it became fairly certain that the first macroscopic amounts (50 milligrams to 1 gram) of plutonium would be arriving at Project Y in late February or early March 1944, the metallurgists realized that they would first have to deal with the scaling problem. In other words, they would have to apply procedures and techniques that worked well on “large-scale” uranium reductions (>10 grams of uranium) to very small samples of plutonium. And it became immediately obvious that those techniques were not likely to work well at all on the first plutonium samples, which would be considerably smaller. In January 1944, therefore, Los Alamos staff conducted experiments to explore small-scale reductions, but these attempts were unsuccessful. The only individuals known to be familiar with such reductions were T. T. Magel and his assistant N. Dallas, who had been using centrifuge techniques to solve similar problems at the Met Lab in Chicago. Arrangements were therefore made for their immediate transfer to Los Alamos, and they arrived at the Laboratory in early February 1944.

2. Using their centrifuge to help force the coalescence of the molten metal produced into a single well-formed button, Magel and Dallas produced their first 50-milligram button of metallic plutonium on March 9, 1944.

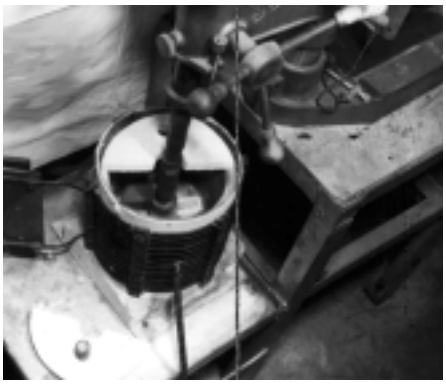
3. Using their centrifuge, Magel and Dallas produced the first 1-gram specimen of plutonium metal on March 23, 1944.

4. From these first metallic buttons, many of the first estimates of the physical properties of plutonium were obtained. By far, the most significant and inexplicable property exhibited by both of these samples, as well as the others that followed, was widely differing densities (see graph on page 50). This phenomenon had already been observed at the Met Lab, but the samples used were so small that the results were simply indicative of a problem, without an explanation for it.

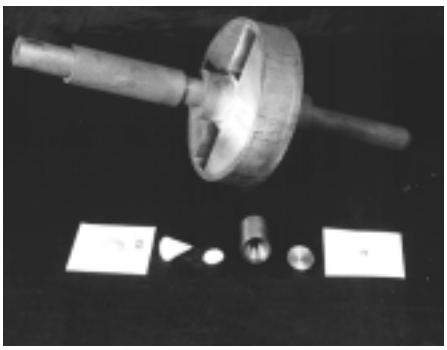
5. At Los Alamos, F. Schnettler made the first tentative suggestion that the conflicting density results might be attributable to allotropism.[3]

6. By the end of May 1944, R. D. Baker had solved his reduction problems for the “stationary-bomb” approach to small (0.5- to 1.0-gram) plutonium samples. Because his technique appeared equally efficient and intrinsically safer, the centrifuge program was phased out. Shortly thereafter, Magel and Dallas left Los Alamos. Important physical properties still remained to be determined. Among them were ductility, tensile strength, melting point, thermal-expansion

[3] A similar suggestion had previously been advanced at the Met Lab in Chicago.



The centrifuge used by Magel and Dallas for small-scale reductions of plutonium compounds.



Components of Magel and Dallas’s centrifuge.

The plutonium compound was placed inside a graphite crucible and was then reduced in the centrifuge. The longitudinal cross-section view above shows the button of plutonium metal obtained after reduction.

One of the famous weekly colloquia held at Los Alamos during the Manhattan Project.

D-Building, the facility for all the plutonium chemistry and metallurgy work done at Los Alamos during the Manhattan Project.

Open hood in D-Building.

coefficients, compressibility, metallographic properties, and others. From the outset, nuclear physics requirements for plutonium purity levels were so high that they were previously unheard of. This problem was being studied by high-temperature, high-vacuum remelting of the metal in various new and exotic crucibles believed to be incapable of adding refractory-derived impurities to the molten metal. Also during May, M. Kolodney demonstrated that the melting point of plutonium was less than 660°C, far below previous estimates.

7. In June 1944, using careful dilatometric measurements, F. Schnettler unambiguously demonstrated that transformations into at least two different allotropic forms were associated with the progressive heating of plutonium and that the transition temperature was in the range of 130°C–140°C.

The infirmary

8. Later in June, two additional phase changes were identified.

9. In July 1944, Segrè and his group confirmed the expectation of many nuclear physicists that the plutonium produced in the Hanford piles would contain substantial amounts of plutonium-240, an isotope whose spontaneous-fission rate was very high and would result in a high neutron background and therefore a predetonation, or fizzle, of the bomb.

10. Therefore, on July 20, 1944, R&D work on the plutonium gun program was formally terminated.

11. By the beginning of August 1944, the Laboratory had been reorganized to facilitate the design, construction, testing, and deployment of a plutonium implosion weapon, which would compress so rapidly that

DP-Site, the location of the postwar facility for the fabrication and recovery of plutonium.

Guard checking trucks on the way to the Trinity Test.

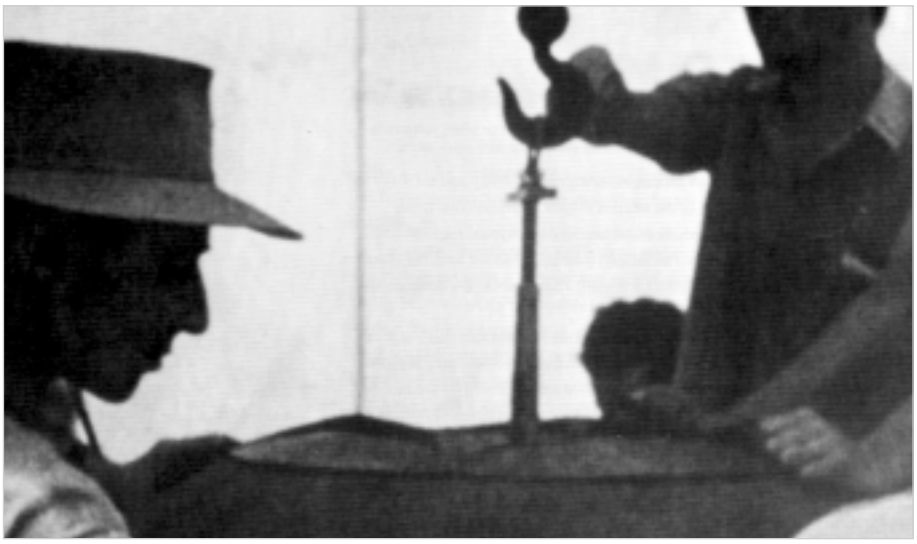
1945

the increased neutron background became irrelevant.

12. In a memorandum sent to J. W. Kennedy on August 8, 1944, C. S. Smith casually mentioned, perhaps as an afterthought, that consideration was being given to the addition of a small amount of some impurity to a plutonium melt with the hope that such an addition might retard the transformation to the α-phase. Smith subsequently noted that, if such a stratagem were found to work, one would, of course, be always dealing with a metastable state but that, nevertheless, it might be worth pursuing. Only long after the war was over did the scientists learn that δ-plutonium so stabilized was thermodynamically stable—or perhaps it was not (see the article “A Tale of Two Diagrams” on page 244). Despite Smith’s suggestion, no action was taken to initiate an alloy survey program until the end of October 1944, and it was not until mid-December that aluminum was found to retard the transformation to the α-phase.

Technical area near Ashley Pond

13. Beginning in August 1944 and continuing for the rest of that year, problems were encountered in fabricating plutonium specimens for various research activities. Attempting to fabricate the specimens at room temperature was hopeless because α-plutonium was much too hard and brittle at ambient temperatures, but the scientists had some success by carrying out the fabrication process at 250°C–300°C and retaining the forming pressure while the metal was cooling. Unfortunately, as the specimens fabricated became larger and more complicated, this technique became less reliable.



J. R. Oppenheimer at the Trinity Test

14. By the end of August, the research program on the corrosion, cleaning, and development of a permanent and impervious coating for plutonium metal moved into high gear. Although this research had been in progress for months with evaporative techniques investigated by the CM-6 group and electrolytic methods investigated by M. Kolodney and his section, little success had been achieved in solving the problem.

15. During September, an extensive R&D program was initiated to study the rates of transition between different adjacent phases of plutonium upon both the heating and the cooling of the specimen.

16. R. D. Baker successfully carried out the largest reduction of plutonium by the stationary-bomb technique to date (6.5 grams).

17. An extensive new series of crucible testing was initiated.

18. Phase transition studies were expanded and extended.

19. Toward the end of September 1944, the Alloy Survey Program was formally initiated.

20. During November, the Alloy Survey Program was significantly enlarged.

21. In December, aluminum was discovered to retard the $\delta \rightarrow \alpha$ transformation. Silicon was also found to be effective in this regard but not as effective as aluminum.

22. In early January 1945, additional aluminum alloys (with differing atomic percentages of aluminum) were made and tested for their ability to retain the δ-phase at low temperatures.

23. Preparations were under way during the first week of January for making two 0.9-inch-diameter hemispheres of δ-plutonium for multiplication measurements. After having been pressed, they were cooled under load and, upon removal from the die, appeared entirely satisfactory.

24. On January 18, 1945, the roof of C-Shop caught fire. Because C-Shop was only a few yards away from D-Building, where plutonium was being processed, Kennedy worried about the safety of the community and the workers should that building catch fire as well. He immediately enlisted C. A. Thomas's help for the design of a new plutonium-processing facility.

25. In early February, General Groves approved the construction of this new facility, which was called DP-Site.

26. The most complete and detailed set of measurements of the phase transition temperatures of plutonium was carried out in February. Dilatometry and electrical resistance measurements monitored the progression of the phase transitions at each temperature at which they occurred.

27. A number of aluminum and silicon alloys of plutonium were also prepared and tested in February.

28. At the end of February, the Christy core design (a solid plutonium sphere) for the newly proposed implosion device was approved.

29. On March 9, 1945, CM-Division received a new set of impurity tolerances for the plutonium core of the implosion device.

30. CM-Division officially remained cautious and uncertain about guaranteeing the long-term stability of a weapon core fabricated from stabilized δ-phase plutonium.

31. Toward the end of March, it was recognized that the amount of aluminum required to stabilize δ-phase plutonium would exceed the latest impurity-tolerance levels and hence could not be used.

32. In early April 1945, barely four months before Nagasaki, it was decided that the substitution of gallium for aluminum should be investigated. Gallium was considered another element likely to be effective in stabilizing δ-phase plutonium because it was immediately below aluminum in the periodic table and hence should behave similarly in comparable chemical and physical situations. Simultaneously, gallium would more than satisfy the impurity-tolerance criteria. The substitution was totally successful. Nevertheless, at that time,

the weapon designers were still intending to use an α-phase plutonium core—density 19.8 grams per cubic centimeter (g/cm^3).

33. During the last week of April, the physicists requested four 2-inch-diameter α-phase plutonium hemispheres for neutron multiplication measurements.

34. Fabrication of the four hemispheres was completed by mid-May. Despite having been cooled under load, however, all the hemispheres transformed more completely to the α-phase upon removal from the die. And that transformation triggered serious warping and cracking of the diametral planes.

35. Within days, it was decided that the 3.0–3.5 atomic percent (at. %) gallium alloy should be used for the cores of the Trinity device and the combat weapon.

36. On June 1, 1945, an extensive, systematic, and rigorous long-time surveillance study of the gallium alloy was initiated.

37. On July 1, 1945, the hemispheres for the Trinity Test were completed and delivered.

38. On July 14, 1945, the Trinity Test was carried out, and the combat hemispheres were completed and delivered.

39. On August 1, 1945, additional hemispheres were completed and delivered.

40. On August 6, 1945, the plutonium bomb was dropped at Nagasaki.

A Final Comment

In retrospect, the plutonium delivery curve illustrated on pages 52–53 and the explanatory notes in the “Summary of Events between March 1944 and August 1945” present more dramatically than any words alone can convey how much science and technology were accomplished in so short a time and with so little material with which to work. Indeed, the immense body of data obtained could only have been accumulated by the recycling of every metal specimen immediately after every planned measurement had been completed. The used specimens went back through the Recovery and the Chemical Purification Groups, which in turn immediately proceeded to synthesize new plutonium tetrafluoride for Baker to reduce once again to more metal and for the rest of us to make new test specimens, carry out more tests, and measure more properties. ■

Edward F. Hammel completed all the formal requirements for a Ph.D. in physical chemistry at Princeton in 1941 (but actually received the diploma in the mail in 1944). He began working on the heavy-water portion of the S-1 Project (directed by the Office of Scientific Research and Development) in May 1941 at Princeton. During the first half of 1942, he served as the scientific representative of the Columbia/Princeton Substitute Alloy Materials (SAM) Laboratories at the Consolidated Mining and Smelting Corporation’s plant at Trail, British Columbia, where a new facility to produce heavy water in tonnage quantities had been constructed and was being brought on line. Deuterium was a candidate, along with graphite, for use as a neutron moderator in achieving the first controlled-fission chain reaction. After returning to Princeton, Hammel participated in diffusion barrier research and development for one of the uranium-235 separation plants at Oak Ridge, Tennessee. At the end of May 1944, Hammel transferred to Los Alamos and was assigned responsibility for the remelting, alloying, and casting of plutonium metal. After the end of the war, he and his group undertook a program to determine, with the highest precision, the physical properties of plutonium (among these were its very low temperature properties). While preparing to carry out these experiments, however, Hammel’s interests shifted to low-temperature physics research. In 1948, he and colleagues E. R. Grilly and S. G. Sydoriak were the first to liquefy and study many of the properties of pure helium-3. For 25 years Hammel headed the Los Alamos Low-Temperature Physics and Cryoengineering Group. In 1970, he moved to energy-related research and, for several years, directed the Los Alamos program in superconducting energy technology. Shortly thereafter, Hammel was appointed Associate Leader of the newly formed Energy Division. In 1974, he became the Laboratory’s Assistant Director for Energy. Hammel retired from Los Alamos in 1979 and has continued his association with the Laboratory ever since.