Chapter

12

U.S. World War II U^{235} isotope separation: E. O. Lawrence and Philip H. Abelson.

Chapter 11 published two corresponding sets of 1943-1949 U^{235} production data obtained 5 December 1980 from the U.S. Department of Energy Enrichment Office Division at Oak Ridge, Tennessee, and the U.S. Department of Energy Office of Uranium Resources Enrichment, Planning and Analysis Branch in Washington, DC. Those two data sets show that during 1943 the Manhattan Project did separate either 74 or 59 kg of U^{235}. In the years since those 1943 U^{235} production data were provided by DOE many critics have disputed, and several have denied, the validity of those DOE data.

To sustain my argument that sufficient separated U^{235} had been produced by 17 July 1944 to enable a nuclear fission weapon detonation on that date at the Port Chicago Naval Magazine it has been necessary to discover corresponding documentary attestations to authenticate that either 74 kg or 59 kg U^{235} had been separated during 1943. Study of the many published books of the Manhattan Project historical literature yields no attestation that any quantity of U^{235} had been separated during 1943. The author's task has been to satisfactorily confute that universally accepted precept of the Manhattan Project historical literature. Information published in this chapter will show that Philip H. Abelson, working at the United States Naval Research Laboratory with the liquid thermal diffusion uranium isotope separation method, did

separate the U^{235} isotope during 1943 in quantity sufficient to permit the detonation of at least one Mark II bomb utilizing 9 kg U^{235} by 17 July 1944.

Beginning in 1940 at the U.S. Bureau of Standards in Washington, DC, with his first essentially bench-scale demonstration of the liquid thermal diffusion method Philip Abelson did achieve his first measureable uranium isotope separation in April 1941. That achievement was such a significant achievement in progress of the United States Navy's early interest in the development of nuclear fission energy as a means of ship propulsion that two months later, in June 1941, the Naval Research Laboratory (NRL) provided funding for further development of Abelson's uranium isotope separation by the liquid thermal diffusion method. Accordingly, Abelson moved his work from the Bureau of Standards to the NRL at Anacostia, also in the District of Columbia. Between March 1941 and December 1942 at the NRL Abelson designed and constructed the NRL liquid thermal diffusion pilot plant, which came on-line with successive improvements during 1942. During the six months following January 1943, namely February through July 1943, the NRL pilot plant "produced 236 pounds of UF6 [uranium hexafluoride] possessing isotope separation. The quantity and the separation were greater than had been obtained by the gaseous diffusion method at that time."

That information published by Dr. Abelson in 1998 is the first published verification that U^{235} separation had been accomplished in quantity during 1943. Additional information provided by a declassified letter dated 15 September 1943 from James Conant, alternate civilian member of the Atomic Bomb Military Policy Committee, to Rear Admiral William Purnell, the Navy member of that committee, also verifies that U^{235} separation in quantity had been accomplished during 1943 by the Naval Research Laboratory. That letter also shows that by 15 September 1943 all the enriched uranium hexafluoride ("hex") produced by Abelson at the NRL during, at least, those six months of 1943 had been, or immediately would be, transferred by the Navy to the Manhattan Project.

The per cent U^{235} concentration of that material, at least 236 pounds (107 kg), has not been disclosed in declassified documents but, as shown below, that material included defined quantities of varying, but known, U^{235} concentration. That material in possession of the Manhattan Project was available for immediate enhanced enrichment, if necessary, by Ernest O. Lawrence's electromagnetic method to the 20 per cent U^{235} concentration necessary to permit the detonation of at least one 9 kg U^{235} Mark II weapon by 17 July 1944.

James Conant's letter of 15 September 1943 to Admiral Purnell reads in the paragraph numbered (3):

15 September 1943 letter of James Conant to Rear Admiral William R. Purnell.

"We understand that there is still available at the Naval Research Laboratory approximately 80 pounds of hex, made up of several lots of different known composition. If this material, together with the analyses of the several samples, can be made available to those now engaged on the project under the general direction of the Military Policy Committee for experimental purposes, the favor will be deeply appreciated, and an equivalent amount of base material will be supplied in exchange. The arrangements for this would be made through General Groves' office."

The liquid thermal diffusion and electromagnetic isotope separation methods will be discussed in detail later in this chapter, but presently a brief review of several typical assessments of the success of World War II uranium isotope separation method that are pervasive in the Manhattan Project historical literature will introduce a fraction of comic relief into an otherwise sedating historical discourse.

Assessments of U^{235} separation accomplished during World War II.

Wartime U^{235} production data was one of the most closely guarded secrets of the Manhattan Project, and the U.S. Department of Energy (DOE) has not yet administratively released the U^{235} production data for the years 1943-1949. During late 1996 and early 1997 DOE Secretary Hazel O'Leary toured the country to promote the DOE's "Openness Initiative," part of which was "a commitment to informing the

public on information regarding the total figures for United States highly enriched uranium production, acquisition, and utilization." That information was scheduled for publication in September 1997 as the "Highly Enriched Uranium Report: The First 50 years." The report was advertised to "provide information regarding uranium enriched in the U-235 isotope to a level of 20% or greater" for the years 1945-1996.

In a January 1997 meeting with Secretary O'Leary in San Francisco I gave to her the 1943-1949 U^{235} production data I had obtained in December 1980 from the two DOE offices and said those data should be basic to the forthcoming DOE "Uranium Report." One month later DOE announced that publication of the "Uranium Report" was indefinitely suspended because, "It is taking considerable time to locate, identify, and access the huge quantity of highly enriched uranium data which includes production, blending, shipment, etc. Further, analysis, verification, and validation of this data are taking considerable effort." At the time of this writing, 17 April 2002, the DOE "Uranium Report" has not been published.

The Government has withheld publication of those data with the result that anecdotal accounts of World War II U^{235} production, which lack any authentic documented basis, have become established by repetition in the historical literature and consequently credited in the public perception as fact. The Government has not published false information to mislead public perception of the actual amount of U^{235} production accomplished during the war, but since World War II the Government has tacitly permitted the promulgation and general acceptance of fiction in that matter. Appropriately critical reading of all hitherto published accounts of wartime U^{235} separation plainly shows that one author following another has creatively paraphrased the same few anecdotal assertions that have persisted in the literature since the first official account of the Manhattan Project was published in 1945 by Henry DeWolf Smyth, *Atomic Energy for Military Purposes*. Examples from current and recent Manhattan Project historical literatures illustrate how bizarre and antic those accounts of wartime U^{235} production can be and which are, despite their absurdity, generally credited as competent historical record.

The Nuclear Weapon Archive has posted at this web site,

http://nuclearweaponarchive.org/Usa/Med/Med.html,

that "September 1944 marked a difficult period: . . . The total production of highly enriched uranium to date was only a few grams." The FAS Web site provides no basis of documented fact for that assertion. That same assertion has been repeated in the literature since the end of World War II. Because Government records of U^{235} production that would substantiate or refute that assertion are classified that assertion is unverifiable; nevertheless FAS offers that information without the cautionary admonishment of competent science that customarily is made in circumstances of unverifiable fact, and FAS is satisfied to offered the public, as useful information, an indefinite number: A "few" is an indefinitely small number that conveys a qualitative sense of quantity, but not quantitative fact.

Richard Rhodes' 1986 book, *The Making of the Atomic Bomb,* which won the National Book Award for its elephantine literary accomplishment, offers information that should be—but is not—instructively correspondent to the FAS assertion that "September 1944 marked a difficult period: . . . The total production of highly enriched uranium to date was only a few grams." Richard Rhodes reports on page 600, "A minimum of 100 grams per day—3.5 ounces—of 10 percent U235 came through beginning in late September 1944." Rhodes specifically refers to production of the Oak Ridge, Tennessee, electromagnetic plant, Y-12, but the information provided by Rhodes for September 1944 is no more factually quantitative than the information provided by the FAS for the same period.

A one-day "minimum" production of 100 grams of 10 per cent U^{235} equates to 10 grams of U^{235}. Ten grams of U^{235} is reasonably the equivalent of "only a few grams" that the FAS asserts were produced during September 1944. But if two days at Y-12 in late September 1944 produced a minimum of ten grams, the total minimum September production was 20 grams, which is twice more than a few grams. Five days minimum production in late September would have produced 50 grams, which is five times more than a few grams, and might also be expressed as an indefinite number that is approximately several times

more than a few, but not many times more than a few. In fact, we don't know how many days in "late September" Y-12 did produce a minimum of 10 grams. We don't in fact know how many days constitute the period of "late September." We don't know if any day's production at Y-12 in late September perhaps exceeded the minimum daily production of 10 grams; if the daily 10-gram minimum was exceeded, we do not know how many grams in excess of the 10 grams minimum might have been produced.

This is the kind of nonsensical numbers jumbling that recalls Medieval speculations that disputed the number of angels that could dance on the head of a pin. Information that would be historically meaningful is not the daily minimum or daily maximum potential output of the Y-12 plant, but the actual quantity of material that was produced during the late days of September 1944—the results. The actual results are, of course, classified data and the result of that ignorance has been that authors, like the weaver of cloth for the "Emperor's New Clothes," weave an imaginary fabric and the world admires the design. Few readers would be satisfied with an historical account of the 1944 Kentucky Derby which reported only that a minimum of two horses had run the Derby in early May 1944. A satisfactory historical record would report the race results. The 1944 Kentucky Derby was won by Pensive, owned by Calumet Farm, trained by Ben A. Jones, and ridden by one of the greatest jockeys of the mid-century, C. McCreary, in a time of 2:04 1/5. The maximum number of horses that can run the Kentucky Derby is 20; the actual number that ran in 1944 was 20, and the fastest Derby time, 1:59 2/5, was run by Secretariat in 1973. That's useful historical information.

On page 602 Rhodes reports the anecdote that has been repeated since the end of the war, "Early in 1945 Oak Ridge began shipping bomb grade U235 to Los Alamos." This report is as comprehensive as a report that Santa Claus began delivering Christmas toys to deserving boys and girls in late December 1945. Santa Claus and his Elves had spent most of the year 1945 producing those toys, but Santa didn't distribute those toys until the appropriate time. I am decidedly persuaded that Los Alamos scientists received bomb grade U^{235} at the time and in quantities that General Groves determined appropriate. General

Groves had no practical reason to provide any of the U^{235} produced during 1943 and 1944 to the scientists at Los Alamos in quantity above what was immediately necessary to experimental purposes or, when useful, bomb construction.

General Groves had more than one compelling reason to withhold any and all U^{235} that had no immediate experimental or weapon use. That deliberate procedure of dispensing only the amount of U^{235} useful at any time did guarantee that the actual amount of U^{235} available at any time during the war was unknown to the scientists working at Los Alamos, which ignorance limited the possibility that information might leak to the enemy and allow some military advantage to the Japanese, the Germans or even to our ally, the Russians.

Furthermore, General Groves was a very much experienced personnel manager, on a mammoth scale; he'd gotten the Government's Pentagon Building in Washington, DC, completed in less time than anyone hoped it could be done, and he knew that people will work more diligently, and with more dedication and resourcefulness, if the purpose to be accomplished is urgent, or is represented to be urgent—a race against time or, as the title of one book of Manhattan Project history characterized that urgency, "Scientists Against Time." The programs of the Manhattan Project were urgent, but by creating the exaggerated impression that timely production of the fissionable material for the Mark I U^{235} bomb was always in doubt General Groves spurred the scientists at Los Alamos to greater urgent effort to complete a workable plutonium Mark IV bomb, which for several years General Groves and others in the military and at Los Alamos knew would be necessary to the postwar development of the hydrogen fusion bomb.

The Mark IV technology and plutonium would be the basis of the trigger mechanism for the hydrogen bomb. General Groves was concerned that if the Mark IV were not successfully completed before the end of the war Government funding in peacetime for that development might not materialize. The hydrogen bomb would certainly be developed eventually by the Russians, and military preparedness required that the U.S. also have the H-bomb to counter that expected Russian threat. Successful completion of the Mark IV, focused

spherical plutonium implosion technology before the end of the war was of very, very great importance to the postwar national defense. The scientists at Los Alamos were kept in ignorance of the fact that the prototype Mark II bomb had been successfully proof fired at Port Chicago, and they were kept in ignorance of the actual quantities of U^{235} that had been produced. The urgency of scientists working against time to produce the Mark IV plutonium weapon gave a very great impetus to that effort.

Uranium isotope separation methods, 1943-1944.

Centrifugal uranium isotope separation.

Early in the U.S. atomic bomb development program some theoretical and experimental studies were made to evaluate the potential of centrifuges to separate the uranium isotopes. Theory and experiment proved that the lighter and heavier uranium isotopes would segregate in distinct bands from an originally homogenous natural uranium material subjected to centrifuge rotation at high speed. Thousands of centrifuges would have been required to separate the U^{235} isotope in bomb quantity, and no efficient means of extracting the separated isotopes from the experimental centrifuges was immediately practicable. Furthermore, rapidly spinning machines have a notorious tendency to spontaneously disintegrate which, in the case of a uranium isotope separation centrifuge, results in the loss of the contained material. The centrifugal method was abandoned very early in the U.S. program; the history of that method has been well reported in the literature and will not be repeated here.

Of contemporary interest, Iraqi President Saddam Hussein's efforts in the late 20th century to produce U^{235} for weapon use employed the centrifugal method; German manufacturers sold those machines, in pieces, to Iraq in violation of an applicable United Nations embargo. Saddam Hussein was frustrated in that undertaking by the same problems the U.S. had encountered in 1940 and 1941: the required machines are fragile and often disintegrate in high speed operation, and it's difficult to remove the useful isotope from a centrifuge without significant contamination by the dominant but useless U^{238} isotope.

Gaseous diffusion uranium isotope separation method: Oak Ridge, K-25.

The gaseous diffusion uranium isotope separation method or process, also known as the screen diffusion method or process, and constructed at Oak Ridge as the K-25 plant, has been adequately reported in the available Manhattan Project literature and will not be reviewed here. This gaseous diffusion method made no contribution to U^{235} separation during 1943 and 1944.

Electromagnetic uranium isotope separation: Ernest O. Lawrence, Oak Ridge, Y-12.

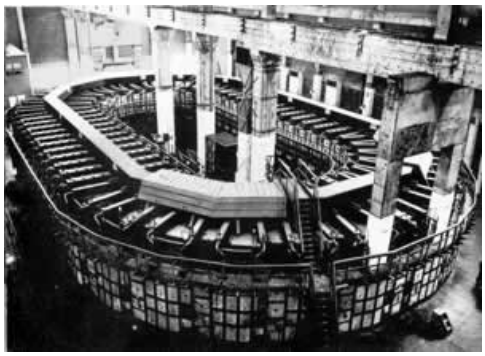
Ernest O. Lawrence, Director, University of California Berkeley Radiation Laboratory (1901-1958).

In 1939 A. O. C. Nier at the University of Minnesota had separated a minuscule amount of U^{235} by mass spectroscopy and immediately Ernest O. Lawrence, Director of the University of California Berkeley Radiation Laboratory, calculated that improvements to a machine he had invented would enable large scale separation of the U^{235} isotope. That machine was the cyclotron. In 1939 Lawrence received the Nobel Prize in physics "for the invention and development of the cyclotron and for results obtained with it, especially with regard to artificial radioactive elements."

The cyclotron—later in the war known as the calutron, for **Cal**ifornia **U**niversity cyclo**tron**—utilized a huge electromagnet and the associated prodigious magnetic field between the magnet's poles to accelerate atomic particles. A monoenergetic beam of ions of naturally occurring uranium when passing between the poles of the calutron magnet, in a vacuum, splits into several streams according to their momentum, one per isotope, each characterized by the particular radius of curvature induced by the magnetic field. Collecting cups at the ends of the semicircular trajectories caught homogenous streams of the different uranium isotopes.

Lawrence's 1939 cyclotron magnet was inadequate to more than experimental isotope separation and a gargantuan magnet enclosed in a comparably-sized calutron would be required to separate the U^{235} isotope in quantity greater than laboratory samples. Electromagnets of the size necessary to the purpose had never before been made. Production of U^{235} in quantity sufficient to the requirement of an atomic bomb by this, the electromagnetic isotope separation method, would require many such prodigious magnets each in a separate calutron.

In April 1940 the Rockefeller Foundation pledged $1.4 million to the cost of Lawrence's proposed 184-inch cyclotron magnet. In November 1941 a committee of the National Academy of Sciences reported that Lawrence's proposed method of separating the U^{235} isotope should be pursued by the Manhattan Project (then known as the S-1 project) as well as several other methods that seemed less certain. The Office of Scientific Research and Development (OSRD) then contributed $400,000 to Lawrence's development of the calutron. Two years later, in March 1942, Lawrence successfully enriched the U^{235} isotope in a sample of uranium by a factor of five; General Groves ordered construction of an industrial scale plant at Oak Ridge, Tennessee, code named Y-12, that would employ Lawrence's calutrons to separate U^{235} in weapon quantities.



Oak Ridge, Tennessee,
Y-12 Alpha electromagnetic isotope separation "racetrack"

During 1942 Lawrence and his associates at Berkeley worked pretty much night and day to refine the calutron design to multiply the demonstrated factor of five enrichment. The first calutrons constructed at Oak Ridge were built in a large oval configuration and officially designated Alpha units but, in code talk, were soon referred to as Lawrence's "racetracks," an important recurrent term. General Groves initially had ordered construction of 96 calutrons at Oak Ridge to be combined into each of five production racetracks, but in March 1943 the General authorized construction of a second installation of calutrons known as Beta units, which were to receive the slightly enriched uranium product of the Alpha units and to increase the U^{235} concentration produced by the Alpha units to bomb grade

enrichment. Ground was broken at Oak Ridge on February 18, 1943 for the electromagnetic isotope separation plant designated Y-12. In a letter to General Groves dated 3 August 1943, Lawrence wrote, "The first racetrack [designated "XA"] will go into operation November 1 and succeeding racetracks follow at monthly intervals."

Richard Rhodes' book on page 492 offers the claim that "At the end of 1943 Y-12 was dead in the water with hardly a gram of U235 to show for all its enormous expense," but apparently Y-12 was raised from the dead to productive life during the 31 days of January 1944, following the transfer of 236 pounds of enriched uranium hexafluoride from the Naval Research Laboratory to the Manhattan Project. An early February 1944 exchange of letters between Military Policy Committee alternate member James Conant and E. O. Lawrence documents that spontaneous vivification. On 11 February, in cryptic reference to the Y-12 Alpha "racetracks," Conant wrote to Lawrence at the Berkeley Radiation Laboratory, "I hear your horses are running well and all prospects for the future are rosy. Many congratulations and best wishes." Five days later Lawrence responded, "Many thanks for your kind words. Prospects are indeed rosy and there is every reason to expect that the job will go through in time to be a factor in the shape of things to come." By early February 1944, entirely as a consequence of the enriched uranium hexafluoride produced by the NRL that had been transferred to the Manhattan project during 1943, the Y-12 electromagnetic separation plant was not "dead in the water."

United States U^{235} isotope separation accomplished during 1943 and 1944 was the conjunct product of the Naval Research Laboratory liquid thermal diffusion pilot plant operated by Philip H. Abelson and E. O. Lawrence's Oak Ridge Y-12 electromagnetic Alpha racetracks. Uranium hexafluoride, enriched to various known but classified U^{235} concentrations, produced by the NRL during 1943 was accumulated by the Navy and when transferred to the Manhattan Project, before and after 15 September 1943, was converted to uranium tetrachloride and utilized as U^{235}-enriched feed stock for Lawrence's Alpha calutrons. Several sources in the Manhattan Project historical literature report that slightly enriched uranium tetrachloride was successfully enhanced to bomb quality U^{235} concentration, 93 per cent, in one pass through any

one of Lawrence's 96 Alpha calutron units; Dr. Abelson has confirmed that assertion during telephone conversations with me made during the mid-1990s.

The liquid thermal diffusion isotope separation method was greatly more efficient than Lawrence's electromagnetic method to double the 0.7 per cent occurrence of the U^{235} isotope in natural uranium to 1.4 per cent. Lawrence's Alpha calutrons were greatly more efficient than Abelson's liquid thermal diffusion method to increase 1.4 per cent U^{235} product to any higher degree of enrichment from 20 per cent up to efficient bomb grade enrichment of 93 per cent U^{235}.

Liquid thermal diffusion uranium isotope separation: Philip H. Abelson and the NRL.

Capt. William S. Parsons, USN, and Dr. Philip H. Abelson (1913-2004).

The most succinct description of the liquid thermal diffusion method and the history of the development of that method is provided by Philip Abelson in a Biographical Memoir of NRL scientist Dr. Ross Gunn published by the National Academy Press in 1998. Every reader is emphatically encouraged to go to the complete text of that memoir, for Ross Gunn was a scientist of extraordinary accomplishment in a wide range of scientific disciplines, especially in his service to the Navy and including his contributions to NRL development of the liquid thermal diffusion isotope separation method. Philip Abelson's Biographical Memoir of Ross Gunn is at:

www.nap.edu/html/biomems/r**gunn**.pdf

In the interest of more widely disseminating Dr. Abelson's tribute to Ross Gunn, as well as Dr. Abelson's account of the historical development of the liquid thermal diffusion method, several paragraphs of that Biographical Memoir are here carried forward to this readership.

"From 1927 to 1947 Gunn was a research physicist on the staff of the U.S. Naval Research Laboratory. In 1934 he was appointed technical adviser for the entire laboratory. In that role he interacted with important naval personnel. In March [June?] 1939 he wrote a memorandum to Admiral H. G. Bowen, chief of the Navy's Bureau of Ships, outlining the tremendous advantages that could be expected from the use of atomic energy in submarine propulsion.

"Immediately after the announcement of the discovery of uranium fission in early 1939, Ross Gunn became a keen observer of and participant in developments relevant to nuclear power. He was particularly interested in its possible application to propulsion of submarines.

"By mid-1940 it had become evident that the rare 235U was fissionable and that a chain reaction creating nuclear power was likely to be achieved. Gunn learned that I [Abelson] was conducting experiments on uranium isotope separation and arranged to provide me with financial support. I was then an employee of the Carnegie Institution of Washington. I obtained my first tiny isotope separation using equipment manufactured by me, but housed at the National Bureau of Standards. The method involved liquid thermal diffusion of uranium hexafluoride (UF6). The simple apparatus consisted mainly of three concentric tubes 12 feet long. The inner tube was heated by steam. A second tube was maintained at 65° C. The third tube served to contain the 65° C cooling water. The UF6 occupied the space between the walls of the inner and middle tubes. Runs on this column were made in April 1941, when a measurable isotope separation was obtained.

"When Gunn learned that I had achieved a small separation of uranium isotopes, he invited me to join the staff of the Naval Research Laboratory, where enhanced supplies of high-pressure steam could be made available. In June 1941 the move was made. A series of experiments was conducted to determine the optimum spacing between the hot and cool walls. In June 1942 a column 36 feet long heated by 100 psi of steam produced an isotope separation factor of 1.11. This success led to an expanded effort that included authorization to build and operate fourteen columns 48 feet long. It also led to the procurement of a propane-fired boiler capable of delivering 1,000 lb/in^2 of steam. For a time, the facility at the Naval Research Laboratory was the world's most successful separator of uranium isotopes.

[Interpretive note for the paragraph below: The Manhattan Project predecessor agency, code named the S-1 project, was headed by University of Chicago physicist Arthur H. Compton who was widely then perceived as an ineffective and ineffectual leader. Many wartime documents composed after the August 1942 establishment of the Man-

hattan Project continued to refer to the S-1 project rather than the Manhattan Engineer District (MED) project, as S-1 was reorganized after 17 September 1942 by Army Colonel Leslie Richard Groves within the Manhattan, New York, District Office of the Army Corps of Engineers.]

"Ross Gunn, who was a member of the federal government's S-1 uranium committee, communicated results of the isotope experiments to committee chairman Lyman J. Briggs in August 1942. This led in October 1942 to a visit to the Naval Research Laboratory by General Leslie R. Groves and Admiral W. R. Purnell. Later, in January 1943, a special committee assembled by the Manhattan District inspected the installation. The committee was impressed by the simplicity of the equipment and commented favorably. A Naval Research Laboratory report submitted to the Bureau of Ships by Gunn in January 1943 pointed to the advantages of using enriched uranium in nuclear reactors. It would be a necessary step in creating a nuclear-powered submarine. The report also stated, 'A liquid thermal diffusion plant costing one to two million dollars could provide the necessary separated isotopes.' "


Liquid thermal diffusion uranium isotope separation columns, Philadelphia Navy Yard.

"During the next six months, improvements were made in the construction of the separation columns. At the same time, the pilot plant produced 236 pounds of UF6 possessing isotope separation. The quantity and the separation were greater than had been obtained by the gaseous diffusion method at that time.

"Gunn decided that an expansion of production capabilities of the liquid thermal diffusion method was warranted. Doing so would provide an alternative if the Manhattan District's magnetic and gaseous diffusion methods failed. A survey of naval establishments showed that large-scale sources of high-pressure steam could be made available at the Naval Boiler and Turbine Laboratory at the Philadelphia naval base. Authorization to build a 306-unit plant at Philadelphia was obtained on November 27, 1943.

Rear Admiral Earle Mills, assistant chief of the Bureau of Ships, signed the project order.

"In June 1944 the Philadelphia plant was approaching completion. J. Robert Oppenheimer learned of the progress and recognized that a supply of partially separated uranium would increase the production of an electromagnetic plant at Oak Ridge. He communicated with General Groves, who sent a reviewing committee to the Philadelphia plant. Its report was favorable and led to the decision to build a 2,142-column plant at Oak Ridge. Construction there was rapid. The $20-million facility [named S-50 and built in less than three months] achieved production that shortened the duration of World War II by eight days.

"Secretary of the Navy James Forrestal presented the Navy Distinguished Civilian Service Award to Ross Gunn on September 4, 1945. The citation included:

> " 'For exceptionally distinguished service to the United States Navy in the field of scientific research and in particular by reason of his outstanding contribution to the development of the atomic bomb . . . For his untiring devotion to this most urgent project, Dr. Gunn has distinguished himself in a manner richly deserving of the Navy's highest civilian award.'

"Immediately after the end of the war Gunn returned to the concept of the nuclear submarine. Methods of detecting diesel-powered submarines had advanced greatly. In the latter part of World War II large numbers of German submarines had been destroyed. I was tasked with becoming familiar with the current state of nuclear reactors, particularly those using enriched uranium. I was provided with access to experimental programs at Oak Ridge and Argonne, and I participated in criticality experiments of enriched uranium assemblages.

"Gunn also took part in obtaining blueprints of the most advanced German submarine. Analysis showed that the energy system of the submarine could be replaced by a shielded nuclear reactor. In September 1946 a report on the feasibility of a nuclear submarine was submitted to the Bureau of Ships. Later, Admiral Hyman Rickover

directed a highly successful development and construction of nuclear submarines. However, some part of the credit for nuclear submarines belongs to Ross Gunn."


Dr. Ross Gunn (1897-1966).

Ross Gunn made the first proposal to utilize uranium as a fuel for submarine propulsion in a 1 June (March?) 1939 memorandum to the NRL Director Admiral Bowen, "Submarine submerged propulsion: Uranium power source." Admiral Hyman Rickover is generally credited, and properly so, with the practical development of the Navy's first nuclear-powered submarine after World War II, but immediately following the war Rickover "was still an undistinguished, little-known captain doing the routine work of mothballing excess navy ships in the Pacific. Months would elapse before he found his way into the nuclear field. By then research on nuclear power for ships was already under way within Groves' Manhattan Project. [Admiral William S.] Parsons' close relations with Groves help explain the readiness of the general to undertake this research. As the chief nuclear advisor to [Admirals] Forrestal and Nimitz, Parsons helped promote nuclear power for ships as a high navy priority."

A discussion of the roles of Admirals Parsons and Rickover is found in Albert Christman's *Target Hiroshima: Deak Parsons and the Creation of the Atomic Bomb*, U.S. Naval Institute Press, 1998, from which the above quotation is taken.

Christman's biography of Admiral Parsons, described by one critic as an "in-house gloss" because of Christman's prepossessed opinions as a retired Navy employee, is nonetheless the only present comprehensive study of Admiral Parsons' life and naval career and is certainly recommended reading. Admirals Parsons and Rickover were members together of the Annapolis Class of 1922. Which of the two admirals deserves to be acknowledged the most accomplished technical officer of the 20th century U.S. Navy will be disputed for many years, but as more information will be published descriptive of the modest and reclusive Admiral Parsons' and his accomplishments I am confident

that history will accord that distinction which I have felt appropriate for 20 years.

By September 1980 I was aware that the liquid thermal diffusion method of uranium isotope separation had contributed significantly to U.S. wartime production of the U^{235} isotope in weapon quantities. In 1984 I began conversations and correspondence with Philip Abelson to learn the actual contribution of that method which he had developed beginning early in 1940; Dr. Abelson is editor emeritus of the American Association for the Advancement of Science journal *Science*. He has been very generous in correspondence and discussion of the technology and development of the process, but politely he always has declined to disclose the actual quantity of U^{235} that had been separated by that method during the war, citing the secrecy agreement he had accepted and signed during the war which established his continuing legal obligation to withhold that information.

In spring 1939, soon after it was announced that uranium fission had been achieved, Philip Abelson completed the requirements to receive his Ph.D. in physics from Berkeley where he worked with J. Robert Oppenheimer and E. O. Lawrence. That spring season on his office blackboard, with Abelson present, Oppenheimer drew a rough sketch of a U^{235} gun assembly weapon. Oppenheimer told Abelson that a weapon of that design was theoretically feasible but practically so only if an industrial scale method of separating the U^{235} isotope could be developed. With his Ph.D. awarded, Philip Abelson moved to the Carnegie Institution in Washington, DC, where he began development of the method for uranium isotope separation that would subsequently be accomplished entirely with U.S. Navy funding at the NRL and the Philadelphia, Pennsylvania, Navy Yard. The product of the Navy's liquid thermal diffusion uranium isotope facilities, which product was owned by the Navy, did in combination with the capabilities of Lawrence's first calutrons at Oak Ridge account for all the separated U^{235} available to the Manhattan Project during 1943 and 1944.

Significantly, Dr. Abelson writes in his Biographical Memoir of Ross Gunn that the liquid thermal diffusion isotope separation method "achieved production that shortened the duration of World War II by

eight days." Dr. Abelson, a modest man as was his mentor and colleague Dr. Gunn, does not report in that memoir that following the end of World War II he, Philip Abelson, was recognized by United States Congressional memorial for his development of that method of uranium isotope separation, which Congress somehow calculated did shorten the duration of the World War II by eight days. In discussion of that honor Dr. Abelson chuckles in perplexity, unable, as is the reader, to decipher any sensible meaning from that recognition.

On 12 September 1945 the Japanese representatives signed the official "Instrument of Surrender," and World War II ended that day. Is the implication of that Congressional recognition that the Japanese representatives would have surrendered eight days later, on 20 September, if the U^{235} produced by the Abelson method had not enabled the combat use of the U^{235} Mark I weapon at Hiroshima on 6 August? Lacking other more specific determined meaning, that recognition must be a figurative acknowledgment by the United States Congress that Philip Hague Abelson and the liquid thermal diffusion method of uranium isotope separation method did contribute uniquely and exceptionally to the successful termination of World War II.

Dr. Abelson also writes in his biographical memoir of Dr. Gunn that Secretary of the Navy James Forrestal presented the Navy Distinguished Civilian Service Award to Ross Gunn on 4 September 1945. The citation included a recognition that will surprise careful readers of Richard Rhodes' *The Making of the Atomic Bomb,* who will find in the book's three indexed references to Ross Gunn no suggestion of Gunn's "outstanding contribution to the development of the atomic bomb." The Navy award citation reads in part that Dr. Gunn was recognized,

> "For exceptionally distinguished service to the United States Navy in the field of scientific research and in particular by reason of his outstanding contribution to the development of the atomic bomb . . . For his untiring devotion to this most urgent project, Dr. Gunn has distinguished himself in a manner richly deserving of the Navy's highest civilian award."

The significance of the Navy Distinguished Civilian Service Award to Dr. Gunn on 4 September 1945—even 8 days before the 12 September 1945 Japanese surrender—means Dr. Gunn was the first person of all those associated directly or indirectly with the Manhattan Project to receive Government recognition of his contribution to the development of the atomic bombs. The significance of the contributions made by Ross Gunn and Philip Abelson and the liquid thermal diffusion uranium isotope separation method developed with their direction to the successful conclusion of World War II will be truly comprehended only when the quantity of U^{235} produced that method shall be publicly known.

To augment this chapter that has been principally concerned with Philip Abelson's contributions to the successful termination of World War II by development of the liquid thermal diffusion uranium isotope separation method, other particulars of Abelson's exceptional role in the nation's atomic bomb program are of interest.

Early in the game, U^{235} separation in bomb quantity and quality required a license from Philip Abelson because he had been granted a U.S. patent on the only then feasible method of producing uranium hexafluoride (UF_6) in industrial scale quantities; UF_6 gas when appropriated heated enters its liquid phase, and it was liquid UF_6 that was the basis of Abelson's liquid thermal diffusion uranium isotope separation method. UF_6 in its gaseous phase, at about 60°C, was also essential to the gaseous diffusion uranium isotope separation method which, after January 1945, began undocumented but no doubt scanty separation of the isotope. The gaseous diffusion method conducted at the Oak Ridge K-25 plant did not, during the war, make a critical contribution to U^{235} production, although in the postwar decades the gaseous diffusion plant has been the only major U.S. facility to separate the isotope.

There is an apocryphal story which is probably true but has not yet been thoroughly documented that General Groves seriously blew his emotional relief valve when he had to acknowledge that the Oak Ridge K-25 gaseous diffusion plant would not be able to operate without a patent license from Philip Abelson, which license would legally permit Manhattan Project contractors to produce the vast quantities of UF_6 gas

necessary to operation of the K-25 plant. Without much delay Abelson was persuaded to sell his patent to the U.S. Government for $1.00, but it is alleged by usually reliable sources of rumor that one condition of the sale of that patent required General Groves to guarantee to the Navy, on demand, those quantities of refined uranium metal necessary to continued uranium isotope separation at the Navy's Philadelphia Yard liquid thermal diffusion facility, which facility was Philip Abelson's personal province. The Navy's interest in postwar U^{235} production at Philadelphia anticipated that uranium power reactors would be developed as a means of naval ship propulsion, especially submarines. Philip Abelson did lead the Navy's first feasibility study of nuclear-powered submarines.

Appendix A provides transcriptions of all those documents in my possession concerned with development of the liquid thermal diffusion uranium isotope separation method during the period 9 September 1940 through 21 September 1944. These documents, which will not be otherwise available to the reader interested in the detail these documents provide, also provide references to additional, comprehensive NRL reports on the process which I have been unable to locate.

Photographs and illustrations credits.

"15 September 1943 letter of James Conant to Rear Admiral William R. Purnell." Source: National Archives Microfilm Publications, "Bush-Conant File Relating to the Development of the Atomic Bomb, 1940-1945; Records of the Office of Scientific Research and Development Record Group 227," reel No. 10, frames Nos. 152, 153.

"Oak Ridge, Tennessee, Y-12 Alpha electromagnetic isotope separation 'racetrack' ." Source: U.S. National Archives.

"Liquid thermal diffusion uranium isotope separation columns, Philadelphia Navy Yard." Source: U.S. National Archives.

"Ernest O. Lawrence, Director University of California Berkeley Radiation Laboratory." Source: The University of California.

"Capt. William S. Parsons, USN, and Philip H. Abelson." Source: Philip H. Abelson.

"Dr. Ross Gunn." Source: U.S. National Archives.