A Global Forum for Naval Historical Scholarship

International Journal of Naval History

Volume 2 Number 1 April 2003.

"We had the hose turned on us!" Ross Gunn and The Naval Research Laboratory's Early Research into Nuclear Propulsion, 1939 – 1946.

Joseph – James Ahern,

American Philosophical Society Library

The United States Navy's development of a nuclear powered submarine is generally associated with Admiral Hyman Rickover's post-World War II initiative. What many are unaware of is that the Navy's research into the use of nuclear power predates Rickover's work by almost ten years, and the creation of the Manhattan Engineering District by three years. Between 1939 and 1946 the Naval Research Laboratory conducted research to determine the feasibility of using nuclear energy for submarine propulsion. During this time Navy scientists developed methods for the production of Uranium hexafluoride, and for isotope separation using liquid thermal diffusion. Both of these methods were vital to the production of Uranium 235, and were used in the creation of the atomic bomb. However, the Navy's research was carried out in an environment of isolation from and in competition with the Manhattan District. Ross Gunn, with the support of the Naval Research Laboratory, struggled with Manhattan to get the supplies the program needed and to show the potential of the research to the overall program. This paper argues that the Navy, not the Army, deserves credit for laying the groundwork for nuclear energy in the United States. Although the atomic bomb was built by the Manhattan Engineering District under General Leslie Groves, the little-known and nearly suppressed story of the

Navy's prior work in this field gives credence to Dr. Ross Gunn's claim that the Navy got hosed. How and why the Navy was cut out of nuclear research and how the story was ignored illuminates another side of the first military applications of nuclear energy.

The U.S. Navy's interest in developing a nuclear powered submarine originated in the separate quests to find an ideal means of submarine propulsion, and a new power source for naval vessels in general. For fleet submarines the important issue became finding the best means of propulsion to meet their mission requirements. The Navy adopted diesel-electric engines for submarine use in 1912, with the inherent limitation that the submarine had to carry both fuel and oxygen to operate when submerged, restricting its range and speed. Inside the Navy, Gun was alarmed at the nation's disappearing coal and oil reserves. To him, the Navy had an obvious interest in new forms of power given its position as one of the world's largest consumers of petroleum.[1]

During the early 1930s NRL's Mechanics and Electricity Division, headed by Gunn, was looking into new power plants for submarine and torpedo propulsion. The central limitation in all of the methods under consideration was providing an adequate oxygen source for propulsion that the submarine could carry with it, and a means of regeneration when running on the surface. The 1938 announcement and confirmation of German scientists Otto Hahn and Fritz Strassmann's experiment to deliberately split Uranium atoms by bombarding them with neutrons accelerated scientific interest in atomic energy. Gunn felt this was an answer to the submarine propulsion problem by simultaneously removing the oxygen problem, and providing the submarine with a long cruising range. Gunn's division had numerous discussions about the application of the nuclear energy to naval problems, and creating a tentative research program. However Gunn's group decided not to present such a theoretical program to the no-nonsense Navy bureau chiefs until they had significant data to back it up.[2]

While scientists at NRL had theorized about the use of nuclear energy, it was not until Enrico Fermi met with Navy representatives that nuclear energy research got underway. The meeting with Fermi took place on March 17 the Navy Department

building, and was attended by representatives from the Navy's Bureaus of Engineering, Ordnance, and Construction and Repair, NRL, and the Army's Ordnance Department. In a little over an hour Fermi gave a briefing on the success of Hahn and Strassman, focused on the potential of an atomic bomb, and briefly discussed the possibility of using it as a power source. While Fermi came away feeling the meeting had yielded little, it in fact had an impact on the NRL representative, Gunn, by providing the evidence that he needed for his division to take their idea before the Bureau of Engineering. Three days after the meeting Gunn and Captain Hollis M. Cooley, director of the NRL, approached Admiral Harold G. Bowen, director of the Bureau of Engineering, with a request for $1,500 to start Uranium research. When Gunn and Cooley left Bowen they had their funding and within a week were conducting research. NRL's work began almost seven months before President Franklin D. Roosevelt received Albert Einstein's famous letter about the potential for an atomic bomb. [3]

As work began at NRL there were a number of problems to solve. Physicist Neils Bohr had theorized that Uranium 235 would be an ideal source for a chain reaction. NRL needed to determine a method to separate that isotope from Uranium, and develop a method for producing the chemicals needed for separation. At this early stage the Navy was not focused on using fission as a weapon. In addition, he felt that the United States would not have a cause to use such a horrible weapon.[4]

Before separation research could begin NRL needed to find a method to supply adequate amounts of Uranium hexafluoride (UF6 or "hex"). UF6 was considered the principle material for use in isotope separation methods since its ability to exist in either a gaseous or liquid state allowed its use in the various methods under consideration. R.R. Miller of NRL's Chemistry Division and T.D. O'Brien of the University of Maryland began working in April 1939 on the production of UF6. The method they developed used a reaction of fluorine gas and a powdered Uranium-nickel alloy that proved to be expensive and time consuming.[5] While the Miller and O'Brien method allowed NRL to supply UF6 for research, it was not able to produce adequate quantities to meet all research and production requirements because of the rarity of Uranium-nickel alloy. Physicist Philip Abelson

at the Carnegie Institution of Washington required more than a kilogram, or ten times this amount, of UF6 for his experiments. Abelson set out independently to find a method of UF6 production that did not require the metal. He was able to devise a rather straightforward method using a common salt of Uranium that could inexpensively produce nearly a kilogram of Uranium hexafluoride per day by July 1941.[6] Eventually production was moved from NRL to the Harshaw Chemical Company of Cleveland, OH.

The Navy next turned to the problem of isotope separation. A method was needed that could effectively separate U235 from Uranium on a manufacturing scale. NRL contracted research out to laboratories at some of the nation's top universities and research institutions, including Columbia University, the University of Virginia, and the Carnegie Institution of Washington. Of the dozen methods initially proposed and researched, four methods (gaseous diffusion, ultra centrifuge, mass spectrograph, and liquid thermal diffusion) were developed to the point where they could be included into a manufacturing plant. The program was financed by both the Navy's Bureau of Ordnance and Bureau of Ships, and with Army Ordnance, with the work coordinated by NRL.[7]

Lyman J. Briggs, director of the National Bureau of Standards and chair of the Uranium Committee, recommended to Bowen that NRL enter into a contract with the Carnegie Institution to support Abelson's research. The basis of the method is that lighter isotopes have the tendency to diffuse to a hotter area, where as heavier isotopes diffuse towards cooler areas. As such, the Uranium 235 enriched material would move to the top of a column where it could be collected. Abelson began by building and testing a few basic columns at the Carnegie Institution, which proved successful and encouraged further research. He formally suggested using liquid thermal diffusion in September 1940. Eventually an arrangement was reached where Carnegie Institution was paying Abelson's salary, NRL was furnishing the equipment, and the Bureau of Standards was providing laboratory space and a chemist. This lasted until June 1, 1941 when Abelson became a NRL employee, and all of Abelson's work was officially transferred to NRL's Anacostia Station. Abelson felt that the main advantage of the process was its simplicity and low startup cost.

This simplicity was shown by the speed with which the first plant was constructed after authorization. The main disadvantage was the large steam requirement.[8]

In June 1941 the decision was made to proceed by constructing a small pilot plant with 36-foot columns next to the Boiler House at NRL. Construction of the equipment was completed in November. Over the next six months NRL staff experimented with the spacing for the interior of the columns and their continuous operation, learning the optimum spacing and ease of operation. Encouraged by these findings NRL decided to expand their research by constructing a pilot plant with fourteen 48-ft. long columns. The plant was authorized in July 1942, and was substantially completed by November.[9] Since the Navy was focused on submarine propulsion they chose to use an enrichment method that would provide quantity over quality, and decided to pursue liquid thermal diffusion. It was acknowledged that liquid thermal diffusion was not the best method for ultimate performance because of its high consumption of power. At the same time it was seen as a feasible method for producing large amounts of material.[10]

The Laboratory had 10 to 15 columns up and running by November 15, 1942, and producing accurate, usable data by December. On December 10 General Leslie R. Groves and representatives of the Army's Manhattan Engineering District visited the NRL plant to inspect the setup. They were given a briefing on Abelson's separation method and a complete report of the Naval Research Laboratory's work. NRL provided all of the information they had, and recommended the potential importance of their program on Uranium production. It was at this time that NRL was informed that MED had been placed in charge of isotope production by order of the President. Gunn's comments following the visit indicate he was not happy with the situation. What most disagreed with Gunn was the Navy's lack of representation, since the navy was not directly represented on any of the research committees. An advisory committee from MED followed up Groves' visit in early 1943, and had a favorable view of NRL's work. However, the use of liquid thermal diffusion by MED was vetoed. Groves felt that liquid thermal diffusion was unsuitable as an independent process due to its large requirement of steam. According to Groves the size of the Navy project and its lack of urgency did not impress him. Finally, it was

also felt that to transfer the Navy program to MED would have major administrative and security problems.[11]

Despite Groves' views, an order by President Roosevelt was what kept the Navy outside the nuclear research program. When Vannevar Bush, director of the Office of Scientific Research and Development (OSRD), heard that Groves intended to visit NRL he felt this was "a mistake." Bush had insisted to Roosevelt that the Navy should be excluded from nuclear research, and that the work should be given to the Army. It is quite likely that Bush wanted the work given to the Army since he had influence over the War Department leadership, as well as a respect for Secretary of War Henry Stimson. In contrast Bush had run into conflict with the Navy . Bowen had criticized Bush and OSRD's work as supplanting those of the service laboratories, and taking needed funding from NRL. Bush in turn had no qualms about making an example of Bowen and NRL. Roosevelt, who trusted Bush's advise, was made aware of the potential for using atomic energy for military purposes at the end of 1939 through Albert Einstein's letter and Briggs' Uranium Committee report. Only a few naval officers and civilian engineers were sent from the Navy to MED. When the Uranium Committee became the S-1 Committee of OSRD, all Navy personnel were removed from membership. This further isolated the Navy's work. Finally, the fact that Abelson's findings were not available until February 1943 contributed to Roosevelt's decision to have the Army pursue nuclear research – leading to the creation of MED in September 1942.[12]

To determine if NRL research would be of any use to MED, it was recommended that NRL begin a series of experiments to determine if thermal diffusion can provide consistent results. There was concern that NRL research could have a negative effect on MED. As such, it was recommended that NRL continue its work as a small-scale problem.[13]

While Manhattan was not interested in liquid thermal diffusion, it remained the Navy's primary means of isotope separation. By 1943 MED had expended over two million dollars on their project, where as the Navy's work had only cost $60,000. The general feeling was that NRL should be included in further research since the Laboratory had significantly contributed in the beginning. Since NRL had been

involved up to that time Gunn felt that it was not "in the best interest of progress" to be excluded from further work. As he saw it NRL was "a military laboratory entitled to have access to any information in the country available on this subject."[14] Gunn was not alone in his views. Admiral Alexander H. Van Keuren, who became director of NRL in 1942, was equally outraged over the Army's expenditure of "astronomical sums" while the Navy had "independently carried forward a fruitful research program" at considerably less cost."[15]

By January 1943 research had proven that the set-up was dependable and capable of continuos operation. This indicated that use of the thermal diffusion method of isotope separation on a large scale was achievable. However, additional research was needed before a production plant could be designed. Between February and July 1943 NRL constructed 18 columns, which were operated for 1,000 days. During this period NRL realized its steam facilities were inadequate to expand research using larger columns, resulting in the search for a new steam source. The Naval Research Laboratory made a review of several naval facilities and came across the Naval Boiler and Turbine Laboratory at the Philadelphia Navy Yard.[16]

NRL proposed the construction of a pilot plant at the Philadelphia Navy Yard in June 1943. On July 24 Van Keuren, Gunn, and Abelson visited NBTL to determine if steam production and available facilities would meet their research needs. Eleven days later at a meeting between representatives of both laboratories it was agreed that NRL's research would move to the Philadelphia facility. One stipulation of the set up was that the NRL research could not interfere with turbine testing. NRL stressed the need for team work, requesting that both the Public Works Office at the Philadelphia Navy Yard and NBTL be instructed that this project have "priority" and to "collaborate" with the NRL in the plant's construction and operation. These requests were most likely a result of the NRL's growing difficulty in getting assistance from the Army, and to insure against problems within the Navy. on 17 November 1943 the order was signed that authorized NRL to construct a 300-column pilot plant in Philadelphia, with the stipulation that they not use technical personnel possibly needed by MED. Construction on the Philadelphia plant began on January 1, 1944, and by February work was progressing well.[17]

In addition to putting NRL on the back burner, MED hindered their access to information and materials. By the beginning of 1942 NRL had stopped receiving information from the S-1 Committee. Despite Abelson's reports being sent to the Committee through Gunn, he was unable to garner the interest of the Committee, and eventually was no longer in liaison with them. While the Navy did not place limitations on the development of their work, they were unable to proceed further without information from the Army. Gunn was unwilling to spend money on research that was potentially being conducted by other government scientists. To do otherwise held the potential for senseless expenditures. Van Keuren supported the idea of the NRL having access to nuclear research information that would benefit both the Navy's interest in submarine propulsion and weapon's development. Despite the best efforts of the Navy, NRL and MED were completely out of contact with each other between September 1942 and April 1943.[18]

Once MED took over nuclear research NRL began to have difficulty in acquiring material. As early as January 1943 NRL was informed that in order to obtain supplies of UF6 it would have to go through the Army. When the S-1 Committee reviewed the Navy's work before Labor Day 1943 it decided that NRL would be cut off. As a result NRL was not to receive new supplies of Uranium hexafluoride to conduct experiments. When NRL requested additional supplies of UF6 in October, Groves refused. MED informed NRL on October 11 that it would not be able to supply them with the material "for an indefinite period." NRL pointed out that it was Abelson who had developed the current method of producing Uranium hexafluoride, and that NRL had freely shared this information. As a result, the Army reluctantly supplied the material. At this point, all information exchange between the two projects stopped again. In November MED ordered the War Production Board to withhold UF6 supplies from NRL that were necessary for the Philadelphia plant. At that point NRL sought to restart its own production of UF6, until it realized that the Army controlled the nation's entire raw Uranium supply. Furthermore, Abelson learned from Richard Lund at the Rare Minerals Division of the War Productions Board that Army officers had previously informed him not to give NRL additional Uranium. Gunn saw such actions as "unwarranted, unjustified and manifestly an

attempt to override the best interests of the Navy in this work." Gunn and the other scientists did not see how their request for a mere 2,000 pounds could effect or jeopardize the Army's project. Van Keuren directly contacted Groves to remind him that the S-1 Committee had decided that NRL should continue its research "on a small scale," which was "being undertaken as an insurance against the failure of the isotope separation project." In pointing out the Navy's need for the Uranium hexafluoride, Van Keuren stated that "[t]his material is essential for the completion of the present phase of the Navy's work on isotope separation," and that the Army's attitude was "not understood."[19]

After excluding the Navy from the main program, the Army decided to use the electromagnetic and gaseous diffusion processes for isotope separation and constructed two plants in Oak Ridge, TN. As the Philadelphia plant neared completion in spring 1944, MED only had the electromagnetic plant in operation with the gaseous diffusion plant still months away from completion. Looking at other separation methods they had discarded earlier, J. Robert Oppenheimer, MED's scientific director, started to take renewed interested in liquid thermal diffusion after reviewing two one-year old reports on Abelson's work, and getting oral reports from Captain William S. Parsons. The estimates of the Philadelphia plant led Oppenheimer to consider using slightly enriched Uranium as a feed material for the other processing plants to speed up production. Oppenheimer appraised Groves of this possibility, to which Groves responded that he was not sure if the Army would use the Navy's process. A review committee went to Philadelphia in mid-June 1944, and recommended the construction of a liquid thermal diffusion plant at Oak Ridge. On 26 June Groves arrived at NRL to obtain the blueprints for the Philadelphia plant. The Army broke ground on 6 July for the plant, labeled S-50, and had the first columns ready by September 15.[20]

As construction of S-50 progressed, the Army sent personnel to the Philadelphia for training. On September 4, a week after arriving, an explosion occurred at the Philadelphia Plant when a cylinder of UF6 overheated and exploded, fracturing nearby steam pipes. The mixture of UF6 and steam created hydrogen fluoride, a very caustic acid, which injured thirteen men, of which two died. The

accident halted the training in Philadelphia, and sent all of the Army trainees and fifteen men from the Naval Research Laboratory under Abelson to Oak Ridge. A thorough investigation was conducted to rule out faulty designs at the Philadelphia plant. Instead of poor construction work on the part of the Navy, it was found that the cause of the accident was the result of the tanks, and the lack of cooperation on the part of Manhattan. The Army's control of nickel production had prevented the Navy from constructing seamless nickel tubes for UF6 storage. Instead, the Navy had to build tanks with a thin nickel liner. When the meeting turned to discussing the safety procedures that the Army had developed, Gunn asked how they had arrived at their calculations. Only to have an Army representative state he was ordered not to disclose that information. Gunn's anger at the Army must have been greatly increased by this time. Not only had the Army excluded the Navy from nuclear research in terms of material and information, but now it was unwilling to share safety information following two deaths.[21]

Repairs were quickly made to the Philadelphia plant, and production of enriched Uranium continued. In excess of 5,000 pounds were turned over to MED to feed the electromagnetic isotope separator, which contributed to the construction of the first nuclear bombs.[22] The Philadelphia plant was used even after the S-50 plant was shut down. Plans were made for the plant to be shut down by January 1, 1946. It was not until September 1946 that the decision was made to dispose of the Philadelphia plant.[23]

With the end of World War II NRL scientists were eager to continue with their research into nuclear propulsion. However, as a result of the security restrictions placed on nuclear work, NRL was still blocked from getting information on Manhattan research. Bowen felt that if the Navy was going to pursue the creation of nuclear propulsion, it needed to control all of the related activities. The Navy would need to create its own capabilities in both basic nuclear science and propulsion. In his plea for the Navy's re-inclusion into nuclear research, Gunn noted that submarine propulsion was at the top of the list for the Navy's prime interest. Gunn felt an obligation to make the Navy aware of the potential of nuclear energy. Despite the security blackout, he was able to organize a symposium at NRL on

November 19, 1945 for submarine leaders to discuss the facts of nuclear propulsion. The interest generated by this symposium eventually lead to a report prepared by Abelson, and other Navy scientists that was issued on March 28, 1946.[24] Abelson did not hesitate to point out that the Navy's work on submarine propulsion had been deferred first to conduct the preliminary work on isotope separation, and then to assist in completing the atomic bomb. Furthermore, the Navy clearly saw the lack of cooperation between NRL and MED as an obstacle. The report stated that NRL needed adequate support from the Navy, the President, and the Manhattan District to continue its research.[25]

It is undeniable that Gunn was proud of his efforts, especially in terms of cost. For Gunn it was the Army's dog-in-the-manger control of the nuclear research program that prevented NRL from actually producing a nuclear submarine sooner. He saw the flow of information between the NRL and MED as one way. In 1945 he noted that even though the Navy was represented in the beginning of the atomic energy research it did not have "access to the technical developments of the Army since the middle of 1941." Gunn felt the close relationship between the Army and the Uranium Committee had "jeopardized the Navy's interest in the work" and put NRL "years behind in knowledge and details of operation of atomic power plants." Gunn felt that, "[t]he Manhattan District missed no opportunity to scuttle the NRL program and no useful assistance was ever obtained from them." As such, Gunn goes on to state, "[i]t is my view that this action prolonged the war by many months."[26] NRL being cut off from Uranium between November 1943 and June 1944 was another sign that the Army wanted to sidetrack the NRL's work until it became apparent it would be of use to them. It was Gunn's opinion that MED only renewed interest in the NRL's work when confronted by possible failure.[27]

Gunn's feelings towards the treatment of NRL were expressed in a 1954 letter to Bowen. In it he states that he was "puzzled" as to why the NRL method was not adopted earlier then 1944 since "it certainly fitted in very well indeed with available facilities during the war." Gunn expressed the opinion that Groves and Oppenheimer had ignored the Navy's work in order to promote their own programs. Overall, Gunn believed that the separation between the work of the Army and Navy "had its roots in

partisan Presidential politics." Gunn wrote that, "Roosevelt had no business appointing an independent political group to be responsible for atomic energy when there was already established, under forward-looking Navy management, a team and program designed not only to produce a bomb, but who were dedicated to its long range utilization as a military tool and implement of public welfare." Obviously Gunn felt the rug had been pulled out from under him, as he was the one who had initiated the first research into atomic energy, only to have control placed in the hands of the S-1 Committee, with the limelight being given to the Army. Gunn's overall opinion was summed up in the statement, "I think we had the hose turned on us!"[28]

It is undeniable that Ross Gunn and the Naval Research Laboratory made significant contributions to nuclear research in the United States. NRL contracts initiated the first practical research into isotope separation, and Navy funding was behind Abelson's method for Uranium hexafluoride production (a process still used today). Therefore, Gunn's view that NRL's work was sidelined and redirected by the Manhattan District is understandable. However, it is more likely that the real reason NRL's work was sidetracked by the Army was its goal – nuclear propulsion. From the beginning of Gunn's work a nuclear powered submarine was the primary goal, with a nuclear weapon as a far second. Those in the Navy did not begin to view their work as contributing to a weapon until 1943. The Army, on the other hand, believed they were in a race to produce an atomic bomb before the Germans, and did not want the NRL taking personnel and material they needed. Unfortunately, rather then seeing NRL as contributing to nuclear research the MED saw them as competing for resources. After the war, the Navy was further blocked by Grove's unwillingness to release information without authority from either the president or the passage of the Atomic Energy Act. This further delayed the Navy's nuclear reactor program until 1947. Once the Navy did begin work on a nuclear powered submarine, Rickover was able to build a support base that allowed him to control the Navy's nuclear program for over thirty years. In that time, Rickover's ability to get the *Nautilus* and other boats in the water overshadowed the early efforts of Gunn and NRL. Ross Gunn and the NRL got caught in the wake of the two major military history events of the nuclear age – the atomic bomb and the *Nautilus*.

[1] Ernest Andrade, Jr., "Submarine Policy in the United States Navy, 1919 – 1941," (*Military Affairs*: Vol. 35, No. 2) 50; Norman Polmar, *Rickover*, (New York: Simon and Shuster, 1981), 117; U.S. Senate Special Committee on Atomic Energy, *Atomic Energy: Hearings Pursuant to S. Res. 179,* 79th Cong., 1st sess., 13, 14, 19, and 20 December, 1945, 364-365, 367 (hereafter Senate COA); Ross Gunn, "Notes prepared for the Senate, 13 December 1945", 1, Navy's Role in Development of Atomic Energy, Operational Archives, Naval Historical Center, Washington, D.C. (hereafter Atomic Energy, Operational Archives, NHC).

[2]Senate COA, 364 – 365; Ross Gunn, "The Early History of the Atomic Powered Submarine at the U.S. Naval Research Laboratory March 1939 to March 1946." Revised 1959. Unpublished manuscript, 7 Gunn, Ross Biographical File. Niels Bohr Library, American Institute of Physics, College Park, MD. 1 – 2 (hereafter Gunn, "The Early History …," AIP).

[3] Ross Gunn had to request funds from Admiral Harold Bowen since the Bureau of Engineering controlled funding for NRL. Philip Abelson, "Early History of Uranium Power for Submarines," (Washington, D.C.: Naval Research Laboratory, 1 May 1946), 1; Lewis L. Strauss, *Men and Decisions*, (New York: Doubleday and Co., 1962), 236*;* Memorandum for File, 17 March 1939 [Box 1 / Folder 1] S-1 Files, Naval Research Laboratory Correspondence, 1939-1946, Records of the Office of Scientific Research and Development, RG 227, National Archives and Records Administration at College Park, College Park, MD (hereafter S-1 Files, RG 227, NACP); Laura Fermi, *Atoms in the Family: My Life with Enrico Fermi* (Chicago: University of Chicago Press, 1954), 163; Richard G. Hewlett and Oscar E. Anderson, Jr, *The New World, 1939/1946: Volume 1 A History of the United States Atomic Energy Commission*, (University Park, PA: Pennsylvania State University, 1962), 15; Richard G. Hewlett and Francis Duncan, *Nuclear Navy, 1946-1962*, (Chicago: University of Chicago Press, 1974), 16 – 17;

Gunn, "The Early History …," AIP, 2; Ivan Amato, *Pushing the Horizon: Seventy-five Years of High Stakes Science and Technology at the Naval Research Laboratory*, (Washington, D.C.: Naval Research Laboratory, 1998), 140 – 142; "World War II Nuclear Research at NRL," 1958, p.1, General Correspondence, Papers of Harold Gardiner Bowen, Manuscript Division, Library of Congress, Washington, D.C. (hereafter Bowen Papers, LoC).

[4] Harold G. Bowen, *Ships Machinery and Mossbacks*; *the Autobiography of a Naval Engineer*, (Princeton, N.J.: Princeton University Press, 1954), 182 – 183; Abelson, "Early History …," 2; Ross Gunn to Director, NRL; 1 June 1939; Subject: Submarine Submerged Propulsion – Uranium Power Source – Status of as of this date, Gunn, Ross Biographical File. Niels Bohr Library, American Institute of Physics, College Park, MD.; Senate COA, 366, 371; Gary E. Weir, *Forged in War: The Naval-Industrial Complex and American Submarine Construction, 1940 – 1961*, (Washington, DC: Naval Historical Center, 1993), 155.

[5] Gunn, "The Early History …," AIP, 4; Abelson, "Early History …," 1; J. B. Cochran, "History of Uranium Project at the Naval Research Laboratory," (Washington, D.C.: Naval Research Laboratory, 9 August 1945), 1; Director NRL, "Uranium Project, Memorandum of Progress 1940 – 1941." 8 April 1942, Bureau of Ships, RG 19, National Archives and Records Administration at College Park, College Park, MD (hereafter RG 19, NACP); Bowen, 183 – 184; Ross Gunn to George Pegram 27 November 1939, Gunn to Jessie Beams 27 November 1939, Pegram to Gunn 9 December 1939, Gunn to Pegram 19 December 1939, Gunn to Pegram 10 January 1940 [Box 1 / Folder 1], S-1 Files, RG 227, NACP.

[6] Philip H. Abelson, "An Exciting Era in Nuclear Physics" (talk presented at the Washington Academy of Sciences, 15 March 1951), 7 – 8, Archives of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, D.C.; R. Briscoe to Lyman J. Briggs 9 July 1941 [Box 1 / Folder 2] S-1 Files, RG 227, NACP.

[7] Gunn, "The Early History …," AIP, 3; Hewlett, *The New World*, 22 – 23; Philip Abelson, "Progress Report on Liquid Thermal Diffusion Research," (Washington, D.C.: Naval Research Laboratory, 3 January 1943), 1; Bowen, 184; Senate COA, 367; Director NRL, "Uranium Project, Memorandum of Progress 1940 – 41," RG 19, NACP.

[8] Briggs to Bowen 10 September 1940 [Box 7 / Folder NRL] Briggs Alphabetical Files, S-1 Files, Records of the Office of Scientific Research and Development, RG 227, National Archives and Records Administration at College Park, College Park, MD (hereafter Briggs Files, RG 227, NACP); Philip H. Abelson, "An Exciting Era in Nuclear Physics" (talk presented at the Washington Academy of Sciences, 15 March 1951), Archives of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, D.C. 4, 6 – 7, 8; Abelson, "Progress Report ...," 2, 3; Richard Rhodes, *The Making of the Atomic Bomb*, (New York: Simon & Schuster, 1986), 550; R.E. Ruskin, "Separation of Isotopes," September 1947, 2; Henry DeWolf Smyth, *Atomic Energy for Military Purposes: The Official Report on the Development of the Atomic Bomb Under the Auspices of the United States Government, 1940 – 1945*, (Princeton: Princeton University Press, 1945), 68, 161 – 162; Senate COA, 367, 371; Amato, 144; Bowen, 184 – 185; Gunn, "The Early History …," AIP, 2-3; Weir, 156.

[9] Abelson, "Progress Report …," 4 – 5; Philip Abelson, *Liquid Thermal Diffusion*, (Washington, D.C.: Naval Research Laboratory, 1946), 23; Notes on Statements by Abelson and Gunn, Naval Research Laboratory, November 9, 1944, Series I, Henry DeWolf Smyth Papers, American Philosophical Society; Jones, 173.

[10] Philip J. Abelson Memorandum for Director and Files: "Present Status of Uranium Problem – Centrifugal Separation of Isotopes" 27 March 1942, Abelson Memorandum for Director and Files: "Present Status of Uranium Problem – Centrifugal Separation of Isotopes" 14 July 1942 [Box 1 / Folder 4], Harold G. Bowen to Briggs 2 September 1942

[Box 2 / Folder 5] S-1 Files, RG 227, NACP; Rhodes, 551; Jones, 172 – 173; Abelson, "Progress Report …," 20 – 21.

[11] Abelson, "Early History of Uranium …" 3; Senate COA, 368; Gunn, Memorandum for File "Production of Separated Isotope 235" 10 December 1942 [Box 2 / Folder 5], S-1 Files, RG 227, NACP; The recommendation for the Lewis Group to visit NRL was made by Briggs on 9 December, Hewlett, *The New World,* 169 – 170; Gunn to Bowen 9 April 1952, Harold G. Bowen Papers, MC #033, Public Policy Papers/University Archives, Department of Rare Books and Special Collections, Princeton University Library (hereafter Bowen Papers, Mudd); Leslie R. Groves, *Now It Can Be Told: the Story of the Manhattan Project*, (New York: Harper and Brothers, 1962), 119; Jones, 172, 174; The follow up committee in January 1943 consisted of Briggs, Urey, E.V. Murphree, Karl Cohen, and W.I. Thompson, Abelson, *Liquid Thermal Diffusion,* 23.

[12] Robert William Love, *History of the U.S. Navy, Vol. 1*, (Harrisburg, PA: Stackpole Books, 1992), 271; Groves, 22 – 23; Statement of the Secretary of War, [Box 80, "Nuclear Physics" folder], Records of the Office of Naval Research, RG 298, National Archives and Records Administration at College Park, College Park, MD; G. Pascal Zachary, *Endless Frontier: Vannevar Bush, Engineer of the American Century*, (New York: The Free Press, 1997), p 119-128; Hewlett, *The New World,* 20; Hewlett, *Nuclear Navy,* 15, 18, 20; Cochran, p 2; Weir, 156.

[13] Leslie R. Groves to W. R. Purnell 27 February 1943 [Box 2 / Folder 5] S-1 Files, RG 227, NACP; Stephane Groueff, *Manhattan Project: The Untold Story of the Making of the Atomic Bomb*, (London: Collins, 1967), 338, 340; Briggs, Urey, Murphree & Lewis to James B. Conant 8 September 1943, James Conant to. Purnell 15 September 1943 [Box 2 / Folder 8] S-1 Files, RG 227, NACP; Jones, 175.

[14] Amato, 146; Gunn, Memorandum for Director, NRL "The Uranium Problem and the Utilization of Uranium Fission by the Navy" [Box 2 / Folder 5], S-1 Files, RG 227, NACP.

[15] Director of NRL to Chief of the Bureau of Ships, "The Uranium Problem and the Utilization of Uranium Fission by the Navy. Review of Present Status," 15 June 1943 [Box 2 / Folder 6], S-1 Files, RG 227, NACP.

[16] Abelson, "Progress Report on …," Abstract, 21; Abelson, "Memorandum for the Director, NRL" 4 January 1943 [Box 2 / Folder 5], Director NRL to Chief of Bureau of Ships, "The Uranium Problem and the Utilization of Uranium Fission by the Navy. Review of Present Status," 15 June 1943 [Box 2 / Folder 6],S-1 Files, RG 227, NACP; Philip Abelson, "Fourth Partial Report on Liquid Thermal Diffusion Research," (Washington, D.C.: Naval Research Laboratory, 30 July 1943), 1, 3.

[17] The design work for the Philadelphia plant was conducted between June and October 1943, and based on the 14-column plant at NRL. The main goal was to construct a unit that could be expanded to a production plant. Capt. C.A. Bonavillian of NBTL was concerned about the limited amount of time for the completion of the NRL facility. In addition, he was not sure that the boiler design would permit continuous operation. After a conference in Philadelphia on 20 October 1943 it was tentatively decided that a 100 column pilot plant would be installed and operated utilizing steam from the boilers originally intended for Annapolis. As for installation time, NBTL felt that they could have the facility up and running by 1 April 1944. Abelson, *Liquid Thermal Diffusion,* 60, 62; C.A. Bonavillian to Director, Naval Research Laboratory, "Proposed Chemical Reflux Installation at the Naval Boiler and Turbine Laboratory," 7 August 1943, S-1 Files, RG 227, NACP; Memorandum for File: "Reflux Heat Exchanger Test," 21 October 1943 [Box 2 / Folder 9], Gunn, Memorandum for the Files, "Uranium Problem – Steam and Facilities at Naval Boiler and Turbine Testing Laboratory, Navy Yard, Philadelphia" 24 July 1943, "Minutes of Meeting between Representatives of the NRL

and NBTL," 4 August 1943 [Box 2 / Folder 7], S-1 Files, RG 227, NACP; Abelson, "Early History of …," 3-4; Jeffery M. Dorwart, *The Philadelphia Navy Yard: From the Birth of the U.S. Navy to the Nuclear Age,* (Philadelphia: University of Pennsylvania Press, 2001), p.188; Director NRL to the Chief of the Bureau of Ships, "Uranium Project, Transfer of, To Naval Boiler Laboratory, Navy Yard, Philadelphia, Pa." 10 August 1943 [Box 2 / Folder 7], Gunn to Director NRL, "Erection of Isotope Separation Pilot Plant at the Naval Boiler and Turbine Laboratory, Philadelphia, Pa." 3 November 1943 [Box 2 / Folder 9], S-1 Files, RG 227, NACP; Abelson, *Liquid Thermal Diffusion*, 24 – 25; Weir, 156.

[18] Hewlett, *The New World,* 169; Senate COA, 374; Abelson, "Progress Report …," 20 – 21; Van Keuren to Purnell 11 February 1943 [Box 2 / Folder 5], S-1 Files, RG 227, NACP; Jones, 175; Weir, 156 – 157.

[19] H.W. Elley to R.W. Dole 14 January 1943 [Box 2 / Folder 5], Gunn to Mills "Raw Materials for Isotope Separation Plant" 3 November 1943, Van Keuren to Groves, 10 November 1943 [Box 2 / Folder 9], S-1 Files, RG 227, NACP; Hewlett, *The New World*, 171; Gunn, "The Early History …," AIP, 4.

[20] Groves, 94, 120 - 121; Abelson, *Liquid Thermal Diffusion,* 25; Hewlett, *The New World,* 168, 172; Groves had selected the H.K. Ferguson Co. to be the prime contractor for the Manhattan Project's liquid thermal diffusion plant. It was decided against using the Philadelphia Plant as it would not be under Army control and that the Manhattan Project plant could be built quicker if not distracted by operation at the Navy's plant. Jones, 175 – 179; Smyth, 202 – 204.

[21] Amato, 149; Dorwart, 187 – 188; The log book listed the injured as E. Achutt, A. T. Young, N. Piscano, R Kendig, A. Wouch, Albert Pirolli, John Snyder, George Levefre (PFC - U.S. Army), Merlin Hanson (PFC - U.S. Army), John E. Tompkinson (PFC - U.S.

Army), Stuart B. Bloom (PFC - U.S. Army), Arnold Kramish (PFC - U.S. Army), Douglas Meigs (employee of H.K. Ferguson & Co.), and Peter Bragg. (employee of Naval Research Laboratory), 2 September 1944, October 1, 1941 – December 31, 1944, Log Book, Philadelphia Navy Yard, Records of Naval Districts and Shore Establishments, RG 181, National Archives and Records Administration – Mid-Atlantic Region (Philadelphia, PA);Jones, 179 – 180; *Manhattan District History: Book VI - Liquid Thermal Diffusion (S-50) Project* (National Archives Microfilm Publication A1218, Roll 10), Records of the Office of the Chief of Engineers, RG 77, National Archives and Records Administration at College Park, College Park, MD S12; Groves, 122; Gunn, "Meeting with the Army group interested in Uranium at the office of Major General L. R. Groves," 12 September 1944 [Box 3 / Folder 11], S-1 Files, RG 227, NACP.

[22] Notes on Statements by Abelson and Gunn, Naval Research Laboratory, November 9, 1944, Smyth Papers, APS; Gunn, "The Early History …," AIP, 5; Abraham, "Navy Yard Has its own Atom Secret," Atomic Activity File, Box 173A, Philadelphia Navy Yard Mounted Clippings, Urban Archives; Gunn to Chief, Office of Research and Inventions, "Review of the Navy's part in the utilization of atomic energy and necessity for re-evaluation of its bearing on Naval Problems" 21 August 1945 Draft, Bowen Papers, Mudd; Senate COA, 368.

[23] Memo to Director, NRL, Subj.: Naval Research Laboratory Project at U.S. Naval Boiler and Turbine Laboratory, Philadelphia - Future Work on. 12/13/45, RG 19, NACP; Philip Abelson, et al, "Atomic Energy Submarine," (Washington, D.C.: Naval Research Laboratory, 28 March 1946), cover memo; Groves, 385; Mills to Commander PNSY, Reflux Plant - Disposition of. 5 Nov 1946. (Box 74, Folder 600.12), Records of Office of the Commanding General, Manhattan Project, General Administration Files, General Correspondence, Manhattan Engineering District, Records of the Office of the Chief of Engineers, RG 77, National Archives and Records Administration at College Park, College Park, MD (hereafter RG 77, NACP).

[24] Carol O. Holmquist and Russell S. Greenbaum, "The Development of Nuclear Propulsion in the Navy" (*United States Naval Institute Proceedings*, Vol. 86, No. 9), 67; Hewlett, *Nuclear Navy*, 25; Gunn to Chief, Office of Research and Inventions; "review of the Navy's part in the utilization of atomic energy and necessity for re-evaluation of its bearing on Naval Problems" 21 August 1945 Draft, Bowen Papers, Mudd; Gunn, "The Early History …," AIP, 6.

[25] Abelson, et. al., "Atomic Energy Submarine," 1, 5.

[26] Gunn to Chief, Office of Research and Inventions, "Review of the Navy's part in ….," 21 August 1945 Draft, Bowen Papers, Mudd; Senate COA, 371; Gunn, "The Early History …," AIP, 4-5.

[27] Gunn to Bowen, 9 April 1952, Bowen Papers, Mudd; Gunn, "The Early History …," AIP, 5; Bowen, 189

[28] Gunn to Bowen 29 September 1954, General Correspondence, Bowen Papers, LoC.

The Editors
International Journal of Naval History
editors@ijnhonline.org