Historical Mitigation Report:

Deactivated MH-1A Nuclear Power Reactor and Barge STURGIS,

Fort Eustis, Isle of Wight County, Virginia

Project Sponsor:

U.S. Army Corps of Engineers
Baltimore District
10 South Howard Street
Baltimore, MD 21201-1715

Prime Contractor:
APTIM Federal Services, LLC
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USACE Contract No. W912DY-10-D-0014/DA05

July 2019

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

REDUCED COPIES OF AS-BUILT AND DESIGN DRAWINGS

PHOTOGRAPHS

SUPPLEMENTAL INFORMATION

Virginia Department of Historic Resources

2801 Kensington Avenue

Richmond, VA 23221

Location: Fort Belvoir, Virginia (1968), Panama Canal Zone, Panama (1968 -1976); Fort Belvoir, Virginia (1977 - 1978); James River Reserve Fleet (1978-2015), Virginia; Port of Galveston, Texas (2015-2018); International Shipbreaking Limited, LLC, Brownsville, Texas (2018-2019)

Type of Craft: Z-EC2-S-C5 boxed-airplane cargo ship; converted to nuclear power generating barge

Trade: World War II-era emergency cargo transport, converted to serve as a military and civilian electrical power supply barge

Class: Liberty class Z-EC2-S-C5 boxed-airplane transport (1945-1963); converted to an unmanned barge greater than 400-feet in length (1963-2018)

Principal Dimensions:

Length (overall):	441 feet, 6 inches
Beam:	65 feet
Operating Draft:	18 feet
Displacement:	9,400 tons
Required Towing Power:	1,500 to 2,000 horsepower
Design Towing Speed:	8 knots

(the dimensions shown are for the MH-1A *STURGIS* floating nuclear power barge;[1] prior to its conversion, the *STURGIS*' predecessor, *SS Charles H. Cugle,* was originally recorded by Lloyds Registry with dimensions 422 feet, 8 inches (length), 57 feet (max. beam), 34 feet, 8 inches (draft), and 7,176 tons (displacement),[2] reflecting its modification as a Type Z-EC2-S-C5 boxed airplane transport from standard Liberty class ship dimensions of 441 feet- 6 inches (length), 57 feet (max beam), and 7,180 gross tonnage.[3])

Dates of Construction:

Keel Laying:	23 June 1945 (*SS Charles H. Cugle*)
Launching:	31 August 1945 (J.A. Jones Construction, Wainwright Shipyard, Panama City, Florida)[4]
Delivery:	24 September 1945 (Fort Eustis, James River Reserve Fleet)

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[1] FACT SHEET, The "Sturgis" Floating Nuclear Power Plant, 13 December 1966. Archived in USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents Archive, Box 2, File 10-Hist Documents.
[2] 1945-46 Lloyd's Register lists the *Charles H. Cugle* as vessel No. 37110, http://www.plimsollshipdata.org/pdffile.php?name=45a1168.pdf, accessed 8 October 2018. The U.S. Maritime Administration, Status Card lists the *Cugle's* total carrying capacity as 10,800 dead weight tons, https://www.marad.dot.gov/sh/ShipHistory/Detail/5496, accessed 8 October 2018.
[3] Reardon, Donald V., editor, *Design Z-EC2-S-C5 Airplane Transport Stowage and Capacity Booklet,* 1946, U.S. Maritime Commission. Archived at San Francisco Maritime National Historical Park, Maritime Research Center, San Francisco, California. See Reardon Drawings in Appendix A of this report.
[4] U.S. Maritime Administration, Status Card, https://www.marad.dot.gov/sh/ShipHistory/Detail/5496, accessed 15 Aug 2018.

Modifications: April 1963 to April 1966 (vessel converted to the unmanned, floating nuclear power plant and barge MH-1A *STURGIS)*
Delivery: July 1968 (Fort Belvoir, Virginia)

Designers: *SS Charles H. Cugle* - Gibbs & Cox, Naval Architects, for the U.S. Maritime Commission
MH-1A *STURGIS* - Martin-Marietta Corporation, Nuclear Division (MH1-A power plant) and J.J. Henry Corporation, naval architects, for U. S. Army Nuclear Power Program

Builders: *SS Charles H. Cugle* - J. A. Jones Construction, Wainwright Shipyard, Panama City, Florida
MH-1A *STURGIS* **-** Alabama Dry Dock and Shipbuilding Company (ADDSCO), Mobile, Alabama

Owners: U.S. Maritime Administration (*SS Charles H. Cugle*), 1945 - 1963
U.S. Army Corps of Engineers (MH-1A *STURGIS*), 1963 - present

Disposition: Deactivated 1978 (Fort Belvoir, Virginia); decommissioned 2015-2018 (Galveston, Texas), dismantled and scrapped 2018-2019 (Brownsville, Texas).

Significance: When evaluated for National Register of Historic Places (NRHP) eligibility in 2013, the MH-1A *STURGIS* was less than 50-years old but was determined eligible for NRHP listing under NRHP Criterion A and Criteria Consideration G for its exceptional significance in the areas of military history, invention, and engineering. Under Criterion A, the MH-1A *STURGIS* is directly associated with the United States' leadership in promoting and developing peaceful applications of nuclear power during the Cold War. Its service in support of the United States' Panama Canal Zone operations between 1968 and 1976 helped realize President Dwight D. Eisenhower's "Atoms for Peace" vision by successfully providing electrical power for peaceful, non-military needs at time when drought conditions were threatening the continued operation of that vital waterway.

When completed in 1968, the MH-1A *STURGIS* represented the U.S. Army's peak achievement in post-World War II nuclear power generating technology and demonstrated that nuclear power technology could reliably replace traditional petroleum-based fuel sources for generation of electricity in remote locations around the world. Designed and built by the U.S. Army's Nuclear Power Program (ANPP) and Martin-Marietta Corporation, the MH-1A nuclear power plant was unique and innovative and proved to be the most powerful of nine nuclear power plants developed by the ANPP. The design of MH-1A *STURGIS* was further distinguished as the world's only fully operational floating nuclear power plant, specifically designed and built for mobility within the converted hull of a World War II-era Liberty-class cargo ship.

At the time of its evaluation, the MH-1A *STURGIS* retained integrity of association, design, feeling, material, setting and workmanship - aspects that enabled the MH-1A *STURGIS* to convey a strong sense of the vessel's historical significance. The earlier World War II-era Liberty ship *SS Charles H. Cugle*, which was converted to support the MH-1A nuclear power plant, was so extensively reconfigured that it no longer retained sufficient integrity to represent the historical significance of World War II-era Liberty-class cargo ships that contributed greatly to the success of the Allied war effort.[5] Consequently, the historical significance of the MH-1A *STURGIS* is best represented as it was designed, built, and operated between 1963 and 1976.

Historians: Eugene Foster and Kathryn St. Clair, Horizon Environmental Services, Inc.
Carrie E. Albee and Christopher Polglase, Gray & Pape, Inc.

Project Information: This historic documentation report has been prepared to mitigate adverse effects to the National Register of Historic Places-eligible nuclear power plant and barge MH-1A *STURGIS* caused by radiological decommissioning and dismantling of the vessel by the U.S. Army Corps of Engineers (USACE). The USACE's Baltimore District (Baltimore District) was assigned responsibility for implementing the final decommissioning and disposal plans for the *STURGIS*' MH-1A nuclear power reactor under Army Reactor Council permit MH-1A-1-14.[6] Historic American Engineering Record (HAER)-quality documentation was one of several stipulations specified in a Memorandum of Agreement (MOA) between the Baltimore District and the Virginia State Historic Preservation Officer (VA SHPO) to mitigate adverse effects of the MH-1A *STURGIS*' decommissioning and dismantling. This historic documentation report was prepared by the Baltimore District for purposes of fulfilling the USACE's obligations under Section 106 of the National Historic Preservation Act, as amended, and the specific terms of the MOA.

Brenda Barber, P.E. served as the Baltimore District's Project Manager responsible for decommissioning and dismantling of the MH-1A *STURGIS* with the assistance of Hans Honerlah, The Baltimore District's Deactivated Nuclear Power Plant Program (DNPPP) Program Manager. APTIM Federal Services, LLC served as the prime federal contractor responsible for carrying out the vessel's decommissioning and dismantling under USACE Contract No. W912DY-10-D-0014, Delivery Order DA05. Horizon Environmental Services, Inc. of Austin, Texas served as APTIM's lead historic documentation consultant responsible for completing the HAER-quality documentation program specified in the MOA with sub-consulting support of Gray & Pape, Inc.'s Cultural Heritage Practice Group of Richmond, Virginia. Darrel Thornley provided technical editing and consulting support

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[5] Virginia Department of Historic Resources, letter dated July 9, 2013 to Hans Honerlah, U.S. Army Corps of Engineers, Baltimore District. see Appendix C - Supplemental Materials, VDHR Consultation documents appended to this report

[6] Section 91(b) of the Atomic Energy Act of 1954 authorized the Department of Defense to operate the MH-1A nuclear power plant as a utilization facility and Section 110(b) authorized its utilization without a license. From its conception, the U.S. Army Nuclear Power Program (ANPP) designed, constructed, and operated the MH-1A plant until the ANPP ceased operations and the U.S. Army began regulating deactivated nuclear power plants through permits. Permit MH1A-1-14 was the final permit issued by the Army Reactor Council to USACE Headquarters on May 9, 2014, with the Baltimore District assigned to implement final decommissioning and disposal plans for the MH-1A nuclear power plant.

for descriptions of nuclear power generating systems. Copies of this historic documentation report will be on file at the Virginia Department of Historic Resources (VDHR) in Richmond, Virginia, the Isle of Wight Public Library, the Baltimore District, and at the USACE Headquarters Office of History in Alexandria, Virginia. This report and digitized records related to the history of the MH-1A *STURGIS* will be published online by the Baltimore District via its MH-1A *STURGIS* Mitigation Records Archive website, http://www.nab.usace.army.mil/Missions/Environmental/Sturgis.aspx.

HISTORIC BACKGROUND

Liberty Ship *SS Charles H. Cugle* (1936-1945)

Prior to formally entering the World War II, the United States made a key decision to devote considerable resources to expand the nation's industrial infrastructure - a strategy to support its allies and win the war by out-producing Germany and the Axis powers. This allocation of substantial funds spanned numerous industries, including automotive, aircraft, and the massive ship building endeavors, and created millions of jobs for civilians pulling out of the Great Depression. As World War II loomed inevitable for the Allies, Franklin D. Roosevelt's administration recognized that the stagnant state of the shipbuilding industry put the nation at a competitive and military disadvantage. President Roosevelt and the U.S. Congress intervened with new legislation to aid the maritime industry by passing the Merchant Marine Act of 1936. Created by this Act, the U.S. Maritime Commission superseded the U.S. Shipping Board, and became a central force in the nation's development and construction of merchant marine and military ships during World War II.

In 1937, as Europe and Asia were moving toward war, the U.S. government gradually increased its capacity for shipping cargo overseas. The U.S. Maritime Commission developed a long-range program for building 500 ships that were both modern and economical over a ten-year period. The primary objective was to subsidize construction of hundreds of ships and then lease them to private American shipping companies while the government paid for U.S. Navy-approved additions that would enable ships to serve as naval auxiliaries in wartime.[7] The Commission was originally authorized to construct fifty vessels a year, but as the country's involvement in the war progressed it became apparent that this number would not support the nation's defense needs domestically and the nations' allies abroad.

After war broke out in 1939 British yards were still producing merchant ships at twice the U.S. rate, despite the recent increase in U.S. shipbuilding. Yet Germany was destroying British ships even faster. In 1940, a British Merchant Shipbuilding Mission arrived in the U.S., with ship plans in hand, to ask if they could purchase new cargo ships built in American yards, even suggesting that they pay to build the yards.[8] In response to Britain's request, President Franklin Roosevelt established the Emergency Shipbuilding Program to facilitate efficient production of wartime vessels under the direction of the U.S. Maritime

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[7] Bill Lee, "The Liberty Ships of World War II - Their Union County and Other Carolina Connections," http://jajones.com/pdf/Liberty_Ships_of_WWII.pdf, accessed 8 August 2018, page 4.

[8] Fred L Quivik, Rosie the Riveter National Historical Park, Ford Assembly Plant. HAER No. CA-326-H, 2002. Library of Congress, HABS/HAER/HALS Collections, http://cdn.loc.gov/master/pnp/habshaer/ca/ca3300/ca3339/data/ca3339data.pdf, accessed 8 December 2018, pp 46, 47.

Commission. The Commission was armed with funding and authority to expand the size of the country's fleet of merchant vessels and the capacity of the shipbuilding industry. As part of the Emergency Program, President Roosevelt declared that the U.S. would begin mass-production of a standardized 11-knot cargo ship, later called the "Liberty Ship."[9]

In 1941, two private shipyards, one on each coast, started building the sixty commercial ships requested by Great Britain. However, the war in Europe and the success of the German U-boat campaign against English shipping were causing increased concerns in the United States, particularly since American steamship companies traded with England and France. In addition, there was concern that Germany might shift its focus to American ships and trade routes. In response, the U.S. Maritime Commission raised the 1940 shipbuilding goal to 200 ships per year, a goal set to ensure the U.S would be "building ships faster than the enemy could sink them." [10]

In 1941, President Roosevelt proclaimed the need for even more merchant ships stating that Germany was sinking merchant ships at a rate twice that at which American and British shipyards combined were able to produce them. The U.S. Maritime Commission began organizing as much of the existing private shipping capacity in the U.S. that could be reallocated to supplying Britain. This massive ship construction plan utilized new and existing shipyards across the United States. Large shipyards that survived the nation's recent economic depression received as many private and Maritime Commission contracts as they could handle. In addition to utilizing existing shipyards, the government authorized construction of a series of new, medium-sized shipyards primarily in coastal areas not already congested with other shipbuilding or industrial pursuits in support of the war effort.[11] In 1940, seven new yards opened, three on the Gulf Coast and four on the West Coast. In addition, several smaller yards received contracts to build large cargo ships for the Maritime Commission. At the end of 1940, there were nineteen American shipyards building private cargo ships or standardized vessels for the U.S. Maritime Commission.[12]

The shipyards operating in the U.S. during this time were defined as either "permanent" yards (those existing prior to the war or exclusively for shipbuilding) or emergency yards (also referred to as "multiple" yards), which had been built on parcels of vacant waterfront with no intention of operating beyond the war. The Navy relied on the permanent yards to produce its large ships, like cruisers, battleships, and aircraft carriers. The permanent yards also executed some Maritime Commission contracts for standardized cargo ships. However, these long-established facilities were less suited for mass-production of the Commission's new standardized cargo ships. The multiple yards primarily handled contracts for the new standardized ship designs, especially the Maritime Commission's C-type cargo vessels, Liberty ships, and warships like destroyers, destroyer escorts, and landing craft because their yards were specifically laid out to accommodate mass-production of parts and pre-assembly of components.[13]

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[9] Clayton, Brian, *Arthur M. Huddell*, HAER No. VA-132, 2011. Library of Congress, HABS/HAER/HALS Collection, http://cdn.loc.gov/master/pnp/habshaer/va/va2000/va2040/data/va2040data.pdf, accessed 8 December 2018.
[10] Ibid.
[11] Quivik 2002,27.
[12] Quivik 2002,21
[13] Quivik 2002, 28.

Production of Liberty ships began in April 1941, and the *SS Patrick Henry* was the first Liberty ship launched on 27 September 1941. Between 1941 and 1945, 2,710 Liberty ships were built, with construction averaging about 42 days per ship.[14] During production many design changes and technological improvements to the basic Liberty ship design were made. Prefabrication and welding methods were refined, and a steel cold-rolling process was developed.[15] Of the Liberty ships completed, 200 were destroyed during World War II while others, including the *SS Charles H. Cugle*, were still being constructed in the final months of the war and never saw any action at all. Following World War II, several Liberty ships served in the Korean War. Others were retired in reserve fleets, sold to private companies, or disassembled for scrap metal.[16]

Though production of standardized ship designs had been undertaken by individual American shipyards during World War I, the World War II emergency shipbuilding program was the first to pre-fabricate components and simultaneously construct standardized ships at multiple shipyards across the nation. The efficiencies gained through use of standardized designs and prefabrication of parts for these ships resulted in mass-production of more than 2,700 Liberty ships in the U.S. shipyards between 1941 and 1945. Roosevelt's emergency ship building program has been credited with offsetting the German U-boat threat in the Atlantic campaign - a major American contribution toward the Allied war effort.[17]

U.S. Army Nuclear Power Barge MH-1A *STURGIS* – 1945-1977

The origins of floating nuclear power generation for both military and civilian applications, as eventually achieved with the U.S. Army nuclear power barge *STURGIS* (1963-2019), date from World War II when in 1945 the United States dropped nuclear bombs on the Japanese cities of Hiroshima (August 6) and Nagasaki (August 9), together resulting in the instantaneous death of an estimated 100,000 people and effectively ending World War II. With the help of its allies, the U.S.-led Manhattan Project had developed nuclear weapons at breakneck pace: it was just 31 months from the first successful man-made self-sustaining nuclear chain reaction at the University of Chicago on 2 December 1942 (Chicago Pile-1) to the Trinity test of 16 July 1945. U.S. military involvement in the Manhattan Project was centralized with the establishment of the Manhattan [Engineer] District of the Army Corps of Engineers in June 1942, initially under the direction of Colonel James C. Marshall (June 1942 – September 1942), followed by Brigadier General Leslie Groves, who remained Commanding General until the formal disbanding of the District in August 1947.

While the immediate response among the Allied nations was relief and jubilance at the end of the war, this soon gave way to a period of public awe and fear – rational and irrational – of nuclear technology that defined American culture for the next four decades. In the months after the Japanese surrender on 15 August 1945, political and military leaders in Washington, D.C. grappled with the overwhelming challenge of managing and further developing "atomic energy" during peacetime – in particular, whether nuclear technology should be under military or civilian control. On 1 August 1946, President Harry S. Truman

[14] "Liberty Ships and Victory Ships --Reading 1." National Park Service, U.S. Department of the Interior, www.nps.gov/nr/twhp/wwwlps/lessons/116liberty_victory_ships/116facts1.htm.
[15] Ibid.
[16] Ibid.
[17] Clayton 2011.

signed into law the Atomic Energy Act of 1946 (Public Law 79-585), which created the Atomic Energy Commission (AEC), a federal body composed of five civilians appointed by the President, ratified by Congress, and charged with the responsibility to oversee research and development of atomic energy on behalf of the U.S. government. As a declaration of policy, the law stated:

> It is hereby declared to be the policy of the people of the United States that, subject at all times to the paramount objective of assuring the common defense and security, the development, and utilization of atomic energy shall, so far as practicable, be directed toward improving the public welfare, increasing the standard of living, strengthening free competition in private enterprise, and promoting world peace.[18]

Among its purposes, the law aimed to foster "private research and development to encourage maximum scientific progress" in support of "the practical industrial application of atomic energy." The AEC was given "control of the production, ownership, and use of fissionable materials to assure the common defense and security and to insure the broadest possible exploitation of the fields." The language of the law hints at two underlying themes of importance at the time: concern about the U.S. maintaining technological superiority in the field of atomic energy; and the attempt to reframe the public's understanding of nuclear technology as a positive, constructive force rather than a destructive one. When the Atomic Energy Act of 1946 became law, most Americans knew of only one application – nuclear weapons.

Under the leadership of David E. Lilienthal, the AEC's first Chairman (1946-1950), the AEC focused on two main priorities – maintaining the U.S. preeminence in nuclear weapons technology and harnessing nuclear power to generate electricity. Lilienthal came to the AEC after 13 years as an executive with the Tennessee Valley Authority (TVA), the ambitious and ground-breaking Works Progress Administration (WPA)-era program that aimed to elevate the standard of living in the impoverished Tennessee Valley through hydroelectric power. As director and then chairman of the TVA, Lilienthal demonstrated his commitment to developing new and cheaper ways to deliver electricity to the public, consistent with his belief that providing public access to utilities was a basic responsibility of a democratic society.[19] His negotiation tactics with utility companies and his eastern European background led detractors to accuse him of Communist sympathies. Renowned architect Le Corbusier, however, upon meeting Lilienthal during his tenure with the TVA, described him as "the guiding spirit of that harmonious plan, sponsored by President Roosevelt, which built the dams on the Tennessee River and the new towns, rescued American agriculture and gave it new life."[20]

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[18] Atomic Energy Act of 1954, PL 79-585, section 1[a], https://www.gpo.gov/fdsys/pkg/STATUTE-68/pdf/STATUTE-68-Pg919.pdf, accessed 9 November 2018.

[19] "David E. Lilienthal," Atomic Heritage Foundation, available online at https://www.atomicheritage.org/profile/david-e-lilienthal, accessed 9 November 2018. David E. Lilienthal, *Democracy on the March*, Harper & Brothers Publishers: New York, 1944, available online at https://archive.org/stream/LilienthalDavidTVADemocracyOnTheMarch/Lilienthal%2C%20David%20-%20TVA%20Democracy%20on%20the%20March_djvu.txt, accessed 9 November 2018.

[20] "A Reign of Harmony," TVA Heritage Series, available online at https://www.tva.gov/About-TVA/Our-History/A-Reign-of-Harmony, accessed 9 November 2018.

Lilienthal's involvement in nuclear power began with his selection in January 1946 by Undersecretary of the U.S. Department of State, Dean Acheson, to lead a special committee to develop a strategy for international control of nuclear weapons.[21] Although the recommendations in the Acheson-Lilienthal Report were rejected, later that year President Truman appointed Lilienthal as the Chairman of the AEC. Under his leadership during the formative years of the AEC, Lilienthal oversaw the organization and expansion of the AEC and determined goals and priorities. The AEC's 1948 semiannual report to the Congressional Joint Committee on Atomic Energy placed strong emphasis on the development of reactors for power generation for both military and industrial uses, and underscores the importance of the Federal government, through the AEC and its activities, accelerating advancements in nuclear technology to the point where "the initiative, technical skill and managerial ability of American business are brought to bear with maximum effect on the problems of atomic energy development."[22] To this end, the AEC established an Industrial Advisory Group to "explore opportunities for increased individual participation for profit and methods of developing incentives for industry to get into the field."[23]

During the war, development of nuclear technology to generate electricity had been a low priority, although there were many who saw the potential, including Major General Kenneth D. Nichols, Manhattan District Engineer under Commanding General Groves.[24] It was the U.S. Navy, however, that first successfully applied the technology to nondestructive military purposes. The Navy's post-war nuclear reactors program recruited its greatest advocate, Admiral Hyman G. Rickover, in December 1945 by assigning him to work with General Electric on the development of nuclear propulsion. When the Navy established its Reactors Branch within the Bureau of Ships in 1949, then a collaboration between the Navy and the AEC, Rickover was selected to lead it, a position that he held for 33 years. Under his direction, the Navy designed and built the world's first nuclear-powered submarine, the *U.S.S. Nautilus* (SSN-571), which became operational in March 1953. By the time the Army's MH-1A reactor went critical [25] in January 1967, the Navy had 68 nuclear-powered vessels in service - 65 submarines (SSNs and SSBNs) including *Nautilus*, 1 cruiser (CGN) *U.S.S. Long Beach*, 1 aircraft carrier (CVAN) *U.S.S. Enterprise*, and 1 frigate (DLGN) *U.S.S. Bainbridge*.[26]

In the fall of 1951, when the Army created its Office of Research and Development (R&D), the realization of the nuclear Navy was still a few years off.[27] The Air Force was also working on its Aircraft Nuclear Propulsion (ANP) program, but its Convair NB-36H never advanced beyond the experimental phase before

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[21] Ibid.
[22] United States Atomic Energy Commission, Chairman David E. Lilienthal, "Letter from the Chairman and Members of the United States Atomic Energy Commission transmitting pursuant to law the third semiannual report of the United States Atomic Energy Commission," referred to the Joint Committee on Atomic Energy on 2 February 1948.
[23] Ibid.
[24] Lawrence Suid, *The Army Nuclear Power Program*, Praeger, 1990, https://www.bookdepository.com/publishers/ABC-CLIO, page 2.
[25] The use of the term "critical" in this context refers to a state of operation in a nuclear reactor when fission reactions within the reactor core become self-perpetuating and will to increase to a potentially dangerous level unless control measures are applied to limit the reactivity.
[26] Atomic Energy Commission report on reactors, December 1969.
[27] Suid,1990, 3

the cancellation of the program in 1961. With the appointment of former Manhattan District Engineer Kenneth Nichols as Chief of the new unit in January 1952, the Army began in earnest its post-war exploration of nuclear power for nondestructive military purposes.[28] For the Army, nuclear power offered an opportunity to significantly reduce, if not eliminate, the primary logistical challenge of conventional power: maintaining an adequate supply of fuel. This was particularly a concern in remote areas where the distance, terrain, or climate made regular delivery of fossil fuels (i.e., oil and coal) difficult or impossible. Nuclear reactors could operate for years on one load of fuel, thereby drastically reducing the time and cost required to transport, handle, and extract the fuel. These factors made nuclear power an appealing prospect for the Army, especially if such a plant could be compact enough that it was easily moved from one site to another.

Over the next year and a half, Nichols focused on the task of building a compelling justification for an Army nuclear power program and securing support from key players in critical sectors – military, private industry, scientific research, and the AEC. Perhaps the most significant challenge that Nichols faced was selling the Army nuclear program to the AEC. The AEC not only controlled the fissionable materials that fueled nuclear reactors, it also inherited the technology, and much of the personnel, from the Manhattan Project after the war. Despite the close kinship, the relationship between the Armed Forces and the AEC was a complicated one. There was inherent tension between the military that had controlled nuclear technology during wartime and the AEC, which was to be a civilian agency. As Congress formulated the Atomic Energy Act of 1946, the military lobbied unsuccessfully for control of atomic energy, largely because of the vehement objection of the scientific research community, which had worked on the Manhattan Project during wartime but in peacetime sought to maintain their independence from government - and military - control.[29] Enrico Fermi, the physicist whose research efforts produced the Chicago Pile-1 reactor, expressed this in no uncertain terms when he stated "It is not that we will not work for the government but rather that we cannot work for the government. Unless research is free and outside of control, the United States will lose its superiority in scientific pursuit."[30] As ultimately codified in the Act, military interests were represented by a Military Liaison Committee (MLC) that provided counsel directly to the AEC, and the Division of Military Application, one of six divisions overseen by the AEC. Military leaders who had directed the development of nuclear weapons with minimal interference during the war, such as Leslie Groves, former commander of the Manhattan Project, now had to accept a limited advisory role on the MLC. These tensions played out during the early years of the AEC in the well-known contentious relationship between Lilienthal and Groves.

At the time of his appointment to head the Army Office of R&D, Nichols had succeeded Groves as the Army representative to the AEC's Military Liaison Committee, so he already had direct access to the AEC.[31] Nichols' preliminary discussions suggested that a program with only military application would not be readily supported by the AEC or the scientific community, particularly given the existence of two other

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[28] Ibid.
[29] https://www.atomicheritage.org/history/atomic-energy-commission, accessed 8 November 2018.
[30] Richard G. Hewlett and Oscar E. Anderson, Jr., *The New Work, 1939/1946 Volume I A History of the United States Atomic Energy Commission*, The Pennsylvania State University Press: University Park, Pennsylvania, 1962, p. 422.
[31] Suid,1990, 3

military programs, albeit focused on nuclear propulsion. However, if the program could be shown to advance the goals of the Atomic Energy Act of 1946 and the AEC by contributing to the development of commercial nuclear power, then it might receive support.[32]

While the Atomic Energy Act of 1946 was intended to encourage investment from the private sector, the "Government monopoly provided by law," proved a significant obstacle.[33] Through the Industrial Advisory Group and representative professional organizations, including the Nuclear Energy Application Committee of the American Society of Mechanical Engineers to whom Nichols spoke directly, the industry laid out its interests and concerns in taking on nuclear power on a commercial scale. According to Lawrence Suid's *The Army Nuclear Power Program*:

> … the power industry believed "the time was approaching when they should enter vigorously into the development of a power plant using an atomic reactor as a source of heat and as a source of replacement fuel… At the same time, the lack of nuclear engineering expertise made private investment "a very considerable risk." According to Nichols, as an alternative to the problems involved in a private approach, industry representatives proposed that the government build a nuclear reactor with a primary purpose of producing fissionable material for military use and secondarily to provide power for private sale.[34]

Nichols received a similar message from John Dunning, Dean of Engineering at Columbia University, whom he approached to explore the University's interest in undertaking research in support of the Army's program.[35] The University of Chicago was one of only a few elite academic institutions where nuclear research was taking place, but Dunning was not interested in pursuing research with only military application. The University would, however, support the Army program if their work more broadly advanced the field of nuclear science. The two men discussed the concept that would serve as the basis of the Army's nuclear power program for two decades: the Army would explore the feasibility of nuclear power in remote areas where the logistics of conventional power (e.g., transportation of fossil fuels) were highly problematic if not prohibitive, and in so doing would contribute to the development of nuclear technology to the point where private industry was willing to invest.[36] In essence, the Army program would be a government subsidy of commercial nuclear power, and as such was consistent with the role that the AEC was already playing.

In a July 1952 draft memorandum prepared for Army Chief of Staff, General Lawton J. Collins, Nichols presented the case for the Army Nuclear Power Program. He proposed that the goal be to develop

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[32] Ibid., 3,4
[33] United States Atomic Energy Commission, Chairman David E. Lilienthal, "Letter from the Chairman and Members of the United States Atomic Energy Commission transmitting pursuant to law the third semiannual report of the United States Atomic Energy Commission," referred to the Joint Committee on Atomic Energy on 2 February 1948.
[34] Suid,990, 5
[35] Ibid.,3
[36] Suid,1990, 3, 4

solutions to the Army's requirement for a "mobile or semi-mobile [atomic] power plant that is essentially free of the present logistic support requirements for fuel."[37] Such a program would:

> … make a major contribution to advancement of the state of the art and to an ultimate industrial power industry, because the Army sponsored effort would permit proceeding vigorously prior to amending any restrictions imposed by the Atomic Energy Act, and, further, the initial engineering and economic risk inherent in such an enterprise could be absorbed justifiably by the Army.[38]

General Collins presented Nichols' recommendation in a subsequent letter to the Secretary of the Army, Frank Pace, Jr., along with a request for $1,250,000 to build the program.[39] Collins further proposed that the project be unclassified to the extent possible under the Act, writing that the program offered "a fruitful source of effective publicity on Army support of peaceful applications of atomic energy."[40] Pace agreed, and in November 1952 the Army Nuclear Power Division was activated in the Office of the Chief of Engineers under the direction of Colonel James B. Lampert, who had served as Executive Officer to Leslie Groves for the Manhattan Project.[41]

Pace and Nichols followed the lead of the Navy and Air Force in securing a "dual assignment" for Lampert in the AEC Reactor Division to ensure that the Army kept abreast of the latest technological developments.[42] Nichols continued to work through channels to negotiate a working agreement with the AEC, soliciting additional support from Admiral Lewis Strauss, former AEC commissioner and advisor to then President-elect Eisenhower on nuclear affairs.[43] In July 1953, Strauss was appointed by President Eisenhower to be the Chairman of the AEC, and he selected Nichols to be his General Manager.[44] Nichols left the Army Nuclear Power Division with a definitive recommendation that the program "support the design of a prototype nuclear plant that would produce about 1,000 kilowatts of electrical power and sufficient additional steam to heat an arctic installation having a 200-man garrison."[45] This became the basis for the program's first nuclear reactor: the stationary, medium-power SM-1 prototype at Fort Belvoir, Virginia.

On 8 December 1953, President Dwight D. Eisenhower delivered his "Atoms for Peace" speech to the United Nations (UN) in which he laid out his vision for the development and use of nuclear technology for peaceful civilian benefit at home and abroad. It was in the early years of the Cold War, when tensions between the U.S. and the U.S.S.R. were rapidly intensifying as the two nations positioned themselves on opposite sides in political and military clashes across the globe. It was also a period of economic growth:

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[37] Ibid.,6
[38] Ibid.
[39] Ibid.,6, 7
[40] Ibid.,7
[41] Ibid.,10, 11
[42] Ibid.,5, 9
[43] Ibid.,11
[44] Ibid.,15
[45] Ibid.,16

following an initial post-war recession, the U.S. was in its fourth consecutive year of substantial gains in the gross domestic product and optimism was high. Families were growing and buying homes, automobiles, and consumer goods, and the nation's demand for energy increased accordingly. U.S. consumption of petroleum and natural gas increased 54% and 103%, respectively, between 1945 and 1953: the combined consumption of petroleum, coal, and natural gas increased 16% from 30 quadrillion BTU in 1945 to 34.9 quadrillion BTU in 1953.[46] Within this context, nuclear power was viewed by many as a promising new source of energy: it was cleaner than conventional fossil fuels, renewable through breeder reactors (i.e., produce more fissionable material than they consume), and could bring the U.S. closer to the elusive goal of energy independence.

Eisenhower's address was just over 25 minutes long, delivered in the first year of his two-term presidency and on the twelfth anniversary of U.S. entry into World War II with a declaration of war on Japan. In it he laid out his personal philosophy regarding the peaceful use of atomic energy, and in doing so, the policy of the United States for the next seven years. First addressing the topic that loomed large on the minds of the assembly, Eisenhower assured the Soviet Union and other would-be enemies that should "an atomic attack be launched against the United States, our reactions would be swift and resolute… the retaliation capabilities of the United States are so great that such an aggressor's land would be laid waste."[47] However, he tempered this by stating that "all this, while fact, is not the true expression of the purpose and the hopes of the United States." Rather,

> … my country's purpose is to help us move out of the dark chambers of horrors into the light, to find a way by which the minds of men, the hopes of men, the souls of men everywhere, can move forward towards peace and happiness and wellbeing… The United States would seek more than the mere reduction or elimination of atomic materials for military purposes. It is not enough to take this weapon out of the hands of the soldier. It must be put into the hands of those who will know how to strip its military casing and adapt it to the arts of peace. The United States knows that if the fearful trend of atomic military build-up can be reversed, the greatest destructive forces can be developed into a great boon, for the benefit of all mankind. The United States knows that peaceful power from atomic energy is no dream of the future. The capability, already proved, is here today. Who can doubt that, if the entire body of the world's scientists and engineers had adequate amounts of fissionable materials with which to test and develop their ideas, this capability would rapidly be transformed into universal, efficient and economic usage?[48]

To "hasten the day when fear of the atom will begin to disappear from the minds of the people and the governments of the East and West," Eisenhower proposed the formation of a body that was essentially

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[46] U.S. Energy Information Administration, "History of energy consumption in the United States, 1775-2009," available online at https://www.eia.gov/todayinenergy/detail.php?id=10, accessed 11 November 2018.
[47] President Dwight D. Eisenhower's "Atoms for Peace" address to the United Nations, 8 December 1953, available online through the Eisenhower Presidential Library website at https://www.eisenhower.archives.gov/research/online_documents/atoms_for_peace/Binder13.pdf, accessed 12 November 2018.
[48] Ibid.

an international version of the AEC to control fissionable material and direct its use for "agriculture, medicine, and other peaceful activities."[49] Having seen the impact of a project like the TVA, Eisenhower hoped that such an organization would "provide abundant electrical energy in the power-starved areas of the world." His idea fully manifested four years later as the International Atomic Energy Agency (IAEA), which adopted the "Atoms for Peace" slogan and message.

In the time between the "Atoms for Peace" address and the formation of the IAEA, the Eisenhower Administration worked with the AEC under Chairman Strauss to develop the President's agenda into a highly visible international public relations campaign for peaceful applications of nuclear technology with promotional videos, coffee table books, and press releases. An important step came in August 1954 when the President signed the Atomic Energy Act of 1954, a rather lengthy amendment to its predecessor that aimed to "encourage widespread participation in the development and utilization of atomic energy for peaceful purposes to the maximum extent" by loosening the more onerous restrictions to private enterprise.[50] The AEC continued to direct and support research in government, academic, and industrial sectors, but Eisenhower felt that it would take more than this to convince the world of the potential benefit of nuclear power. Under the "Atoms for Peace" campaign, President Eisenhower supported, and the federal government partially funded, two demonstration projects: the Shippingport Nuclear Power Station in Shippingport, Pennsylvania, and the merchant ship *N.S. Savannah*.

Shippingport Nuclear Power Station
In the 1948 AEC report to Congress, Lilienthal had estimated "from 8 to 10 years to overcome the technical difficulties and have a useful, practical demonstration plant in operation," and as many as 20 years for the industry to have developed to the point "when nuclear energy can make a significant contribution to the supply of power now available from other sources." [51] Although Lilienthal had left the AEC by the time, he was correct about the demonstration plant. As a joint venture between the AEC and the Duquesne Light Company, the Shippingport Nuclear Power Station incorporated a large-scale light water reactor that had been in development by Westinghouse Electric Corporation for the AEC's Division of Naval Reactors under the direction of Admiral Hymen G. Rickover.[52] The ground-breaking ceremony was in September 1954: in a symbolic gesture, President Eisenhower initiated construction from Denver, Colorado by passing "a neutron wand over a neutron counter, which flashed an electronic signal 1,200 miles to Shippingport, activating a large high-lift excavator which moved forward and scooped the first dirt in the ground breaking ceremony."[53] The first commercial nuclear-powered, large-scale, electric-generating station came on line 18 December 1957.[54] Designated a National Historic Mechanical Engineering Landmark in

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[49] Ibid.
[50] Atomic Energy Act of 1954, available online at https://www.gpo.gov/fdsys/pkg/STATUTE-68/pdf/STATUTE-68-Pg919.pdf, accessed 13 November 2018.
[51] Lilienthal 1948.
[52] American Society of Mechanical Engineers, "Shippingport Atomic Power Station National Historic Mechanical Engineering Landmark Presentation Ceremony, May 20, 1980 Program," available online at https://www.asme.org/wwwasmeorg/media/ResourceFiles/AboutASME/Who%20We%20Are/Engineering%20History/Landmarks/47-Shippingport-Nuclear-Power-Station.pdf, accessed 10 November 2018.
[53] Ibid.
[54] Ibid.

1980, the coming online of Shippingport Nuclear Power Station is widely recognized as a seminal moment in the history of nuclear power. Other nuclear power plants soon followed, including Commonwealth Edison's Dresden Nuclear Power Station (1959) in Grundy County, Illinois, and the Yankee Rowe Nuclear Power Station (1960) in Rowe, Massachusetts, which was a joint venture formed by ten New England utility companies. Nevertheless, Lilienthal's 20-year estimate proved overly optimistic. It took close to 30 years for nuclear power generation to reach production levels derived from hydroelectric power – roughly 12% of commercially produced electricity in the U.S. in 1979 – and it was not until the 1980s that nuclear power permanently surpassed hydroelectric and approached its current output of roughly 20 percent.[55]

N.S. Savannah
The other high-visibility demonstration project was the *N.S. Savannah,* a collaboration between the AEC and the U.S. Maritime Administration (MARAD) and the Department of Commerce. With the *U.S.S. Nautilus* as an example of the successful use of nuclear power for propulsion, and plans for expanding the nuclear Navy well underway, President Eisenhower envisioned a "nuclear powered 'peace ship,' or roving goodwill ship, to build world-wide support for the non-military benefits of nuclear power."[56] As constructed, the *N.S. Savannah* was a combination passenger/cargo merchant vessel built by the New York Shipbuilding Corporation with a Babcock & Wilcox Company nuclear reactor and operated by the States Marine Lines, Inc.[57] The keel was laid in May 1958 by Pat Nixon using an "atomic wand" like that used at Shippingport.[58] The ship was accepted by MARAD in May 1962 and began demonstration service in August.[59] By that time the Navy had added several nuclear submarines as well as the *U.S.S. Long Beach* and *U.S.S. Enterprise* to its fleet, and the Army Nuclear Power Program had awarded a $16.9M contract to Martin-Marietta for the design, construction, and testing of a high-powered mobile reactor that would be mounted on a floating barge, the MH-1A *STURGIS*.

SM-1 Army Nuclear Power Plant, Fort Belvoir, Virginia
Just a few months after Eisenhower's UN address, in January 1954 the Army Nuclear Power Branch, the Corps of Engineers field agency, was activated at the Engineer Research and Development Laboratories (ERDL) at Fort Belvoir, Virginia.[60] It was here that the Army's first reactor, the stationary medium power prototype (SM-1), was built with joint funding from the Department of Defense and the AEC. At the outset,

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[55] U.S. Department of Energy, "The History of Nuclear Energy," available online at https://www.energy.gov/sites/prod/files/The%20History%20of%20Nuclear%20Energy_0.pdf, accessed 10 November 2018. U.S. Energy Information Administration, "History of energy consumption in the United States, 1775-2009," available online at https://www.eia.gov/todayinenergy/detail.php?id=10, accessed 10 November 2018. World Nuclear Association, "Nuclear Power in the USA," available online at http://www.world-nuclear.org/information-library/country-profiles/countries-t-z/usa-nuclear-power.aspx, accessed 10 November 2018.
[56] Robie S. Lange, "N.S. Savannah," Maritime Heritage of the United States NHL Theme Study – Large Vessels, August 1990, https://npgallery.nps.gov/NRHP/GetAsset/NHLS/82001518_text, accessed 12, November 2018.
[57] Ibid.
[58] Ibid.
[59] Ibid.
[60] The Army Nuclear Power Branch was under the supervision of the Army Nuclear Power Division in the Office of the Chief of Engineers. See Suid, 1990, page 20.

the prototype was to be directed towards "the possible application of nuclear power to meet other power requirements of the Army than those of fixed land installations," including land-based vehicles, trains, and seagoing vessels.[61] Although the Army was focused on using nuclear power plants at remote facilities, Fort Belvoir was chosen as the project site because it was felt that the first reactor prototype should be more accessible for research and training.[62] In December 1954 the Army awarded a firm fixed price contract to design, construct, and test the prototype to the American Locomotive Company (ALCO) out of Schenectady, New York, with a delivery date of December 1957.[63] The "first military nuclear power plant built for the generation of electrical power," the SM-1, was a pressurized water reactor with 38 fuel rods and seven control rods, first went critical on 8 April 1957, and was put into regular operation shortly thereafter.[64] At the dedication ceremony, Admiral Strauss linked the SM-1 to the "Atoms for Peace" program, and stated that the reactor demonstrated the feasibility of "compact, efficient, and readily transportable power plants for remote outposts where electrical energy would be unattainable, except under conditions of extreme logistical strain."[65]

Operating accident-free from 1957 to 1973, the SM-1 was the first and longest-running reactor of the ANPP. Designed to produce 2MW of electricity, the SM-1 is believed to be the first nuclear reactor to be linked to a public utility grid (Virginia Electric and Power Company [VEPCO]).[66] It incorporated design features and innovations that informed subsequent projects, and was used for research, experimentation, and training in support of the MH-1A *STURGIS* and other ANPP reactors, as well as a minor power source for Fort Belvoir. When the SM-1 was deactivated in 1973 all the ANPP reactors had ceased operations except for the MH-1A. Among the factors that played a part in the Army's decision to deactivate the SM-1 were the rising costs for operation and maintenance, and the need to modify the plant to meet updated AEC safety standards.[67] Decommissioning of the SM-1 was completed in 1975 following the removal of fuel, control rods, and associated nuclear materials, and decontamination of the remaining reactor components.[68]

SM-1A Army Nuclear Power Plant, Fort Greely, Alaska

In anticipation of the SM-1 completion, the Army was ready to move forward with the goal of developing a nuclear reactor in the field. The Army retained ALCO in June 1956 to design a nuclear reactor to supply electricity and steam heat at the Army's remote Fort Greely, Alaska, facility.[69] The subsequent construction contract was awarded to Peter Kiewit Sons' Construction Company out of Seattle, Washington, who subcontracted the reactor to ALCO.[70] Construction on the SM-1A - the 'A' denoting the

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[61] Suid,1990,24
[62] Ibid.,24, 25
[63] Ibid.,26, 27
[64] Ibid.,37
[65] Ibid.,37
[66] AEC December "Nuclear Energy," The National Museum of the United States Army, available online at http://thenmusa.org/nuclear-1.php, accessed 20 November 2018.
[67] Suid,1990,113
[68] Ibid.
[69] Ibid.,50
[75] Ibid.

first field plant of a type - began in June 1958 and the reactor first went critical four years later in March 1962.[71] A pressurized water reactor with 38 fuel rods and seven control rods like the SM-1 prototype, the SM-1A was also designed to produce 2 MW of electricity at full power.[72] It provided power and steam to the Fort Greely facility until 1972, when the Chief of Engineers determined that it had "successfully completed its mission of demonstrating the feasibility of building and operating a nuclear power plant in a remote arctic environment."[73] Decommissioning was completed in 1973, including removal of nuclear materials, decontamination of the reactor components, and *in situ* entombment of the remaining reactor structure in concrete.[74]

SL-1 ANPP Prototype Plant, Idaho Falls, Idaho

The third stationary reactor built by the ANPP was the stationary low power prototype (SL-1). Unlike the SM-1 and the SM-1A, the SL-1 was a boiling water reactor with a core that could accommodate up to 59 fuel rods and nine control rods to produce a range of 300KW to 1MW of electricity.[75] A joint project of the AEC and the ANPP, the SL-1 reactor was designed by AEC's Argonne National Laboratories and contained within a plant constructed at the National Reactor Testing Station (NRTS) near Idaho Falls, Idaho, by the Pioneer Services and Engineering Company of Chicago.[76] This type of reactor was of interest to the Army because of its more compact and easily-transportable size, and its incorporation of aluminum alloy fuel elements - an innovation that would subsequently become standard in reactor design.[77] The reactor first went critical in August 1958, but it did not lead to derivative field reactors, in part because of a fatal accident that occurred on 3 January 1961.[78] In an attempt to manually dislodge a stuck control rod, the operator lost control of the rod and the sudden movement to supercritical position caused a nuclear excursion - uncontrolled nuclear fission chain reaction - resulting in instantaneous fuel melt and vaporization that exceeded the capacity of the pressure vessel, forcing the vessel upwards and ejecting metal components.[79] Later that year following intensive investigation of the accident site, the reactor pressure vessel was removed, the plant demolished, and contaminated components buried.[80] The SL-1 accident is the only nuclear accident to occur in the United States that resulted in immediate fatalities (i.e., from physical trauma rather than radiation). Constructed for experimental purposes at a time when nuclear power technology was still in early stages of development, the SL-1 accident did not have the significant negative impact that the 1979 partial core meltdown at the Three Mile Island (TMI) General Public Utilities Corporation nuclear generating station near Harrisburg, Pennsylvania, did on public perception of the industry. TMI is widely cited among the three most significant accidents in the history

[71] Ibid.,51-53
[72] Ibid., 53
[73] Ibid.,111-112
[74] Ibid.,112
[75] Ibid.,81
[76] Ibid.,82
[77] Ibid.,83
[78] Ibid.,82
[79] AEC, "The SL-1 Accident Briefing Film Report," 1961, available online at https://www.osti.gov/sciencecinema/biblio/1122857, accessed 20 November 2018.
[80] Suid,1990,86

of nuclear power along with Chernobyl (1986) and Fukushima (2011), and the point at which anti-nuclear sentiment in the United States reached critical mass.

ANPP Portable/Mobile Reactors

In addition to the stationary (S) class of reactors, the Army also produced portable (P) and mobile (M) reactors. Portable reactors were designed to be "prefabricated to the maximum extent possible to minimize the time for construction at the site" and "preassembled into shipping units compatible with all modes of transportation, including airlift, and capable or being handled with routine construction equipment, which must meet the same requirement for transportability."[81] The first of these to be placed into service was the portable medium power (PM) 2A, which operated at Camp Century, Greenland from 1960 to 1962. The pressurized water reactor was designed and fabricated by ALCO, the secondary system designed by Peter F. Loftus Corporation, steel plant framework by the Bristol Steel and Iron Works, and the balance of the plant constructed by Metcalf & Eddy Engineers.[82] Construction began in 1959 and in November 1960 the PM-2A became the first nuclear reactor to supply electricity (1 MW capacity) and heat to a remote military installation.[83] Of the nine ANPP reactors, the PM-2A operated for the shortest duration – less than three years – in large part because of continued problems with the conventional aspects of the plant.[84] However, the modular construction and methods developed to ship the components were innovations in the field of portable nuclear power.[85]

Two other portable reactors – the PM-1 and PM-3A – were built under the ANPP but the end users were other branches of the military. The PM-1 prototype was a 1 MW capacity pressurized water reactor designed by the Martin Company (later Martin-Marietta Corporation) that operated at the Sundance Air Force Radar Station, Wyoming, from 1962 to 1968.[86] It performed two primary functions: to provide power and heat for the 731st Radar Squadron of the North American Air Defense Command (NORAD); and to provide data that would inform the development of nuclear power plants for NORAD's Distant Early Warning (DEW) and other remote Air Force stations.[87] NORAD began in 1957 as Cold War-era air and sea monitoring program that would help to protect the U.S. and Canada from foreign threats, including nuclear weapons, through early detection. The DEW line was a line of radar stations within the Arctic Circle, the part of the North America geographically closest to Russia. The Martin Company also designed and fabricated the PM-3A field reactor, a pressurized water reactor similar to the PM-1 that operated from 1962 to 1972 at the Navy Air Facility at McMurdo Sound in Antarctica in support of the international scientific research program based there.[88] The PM-3A was a joint project of the AEC, ANPP, and the U.S. Naval Nuclear Power Unit that was established at Fort Belvoir to oversee the work: similarly, the ANPP and the Naval Nuclear Power Unit worked together to staff and train the operating crews of the PM-3A.

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[81] Ibid.,58
[82] Ibid.,60
[83] Ibid.,67
[84] Ibid.,71
[85] Ibid.,69
[86] Ibid.,73
[87] Ibid.
[88] Ibid.,76

[89] Parts were designed to be airlifted to Antarctica, but were ultimately shipped to McMurdo Sound on the *U.S.S. Arneb* and assembled in 71 days within a plant constructed by the Navy Seabees.[90] The only reactor of the ANPP to operate at a remote facility in true isolation for months at a time, the PM-3A was also one of its most successful projects.[91] It produced up to 1.5 MW of electricity and steam for heat and to run the salt water distillation plant at the 150-person McMurdo Station for ten years.[92]

The ANPP only constructed two mobile nuclear reactors – the experimental mobile low power prototype (ML-1) at NRTS and the mobile high-power field reactor (MH-1A) mounted on board a converted World War II-era Liberty ship. However, an important step in the development of the ANPP's mobile reactors was the Gas-cooled Reactor Experiment prototype (GCRE-1) at the NRTS Army Reactors Experimental Area. Whereas the other ANPP reactors in development in the late 1950s, and ultimately 7 of the 9 ANPP reactors, were water-cooled, gas-cooled reactors offered advantages of low volatility, simpler fuel processing, and greater range in pressure and temperature that were desirable for compact, mobile reactors. Accordingly, the GCRE-1 – a heterogeneous, water-moderated, nitrogen-cooled reactor – was designed, built, and operated by Aerojet-General Corporation as an experimental prototype to "test reactor components and fuel elements in support of the development of a mobile nuclear power package."[93] As originally designed and fabricated, the GCRE-1 was to be combined with a gas-cooled systems experiment (GCSE) in a single experimental unit, the gas-cooled reactor facility (GCRF).[94] However, the GCSE was modified into the ML-1, a skid-mounted prototype, and the use of the GCRE-1 was subsequently limited to fuel element testing.[95]

The ML-1 was a closed-cycle, gas-cooled light water reactor designed by Aerojet-General Corporation in response to the Army's continued interest in combining the mobility of a diesel generator with the logistical merits of a nuclear reactor.[96] As explained by Suid,

> The goal was to build a mobile, low-power nuclear plant that could accompany troops from place to place and provide power to command and communications centers, evacuation hospitals, depots, and radar and weapons systems. Initial plans called for a plant with a capacity of several hundred kilowatts that would be shock-mounted and transported on low-bed trailers… The ML-1 was designed to produce 300 to 500 kilowatts and to operate for 10,000 hours between fuel changes and 50,000 hours between

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[89] Ibid.,76, 78
[90] Ibid.,77
[91] Ibid.,77, 78
[92] Ibid.,6, 78
[93] Aerojet-General Nucleonics, "Army Gas-Cooled Reactor Systems Program, Progress Report, 1 July through 31 October 1965," San Ramon, California: January 1966, pp. 1-2, available online at https://www.osti.gov/servlets/purl/4541739, accessed 21 February 2019; and Aerojet-General Nucleonics, Military Projects Division, "Army Gas-Cooled Reactor Systems Program: Utilization of the GCRE-1 in Support of the ML-1A Program," 6 May 1960, p. 2, available online at https://www.osti.gov/servlets/purl/4186534, accessed 21 February 2019.
[94] Aerojet-General Nucleonics, 1960.
[95] Ibid.
[96] Suid,1990,89

> overhauls. The Army expected to mount ML-1-type power plants on six skids and transport them as an integrated package by military semi-trailers, railroad flatcars, or barge. The plant was designed to be set up and ready for operation within 12 hours after its arrival or prepared for removal within 6 hours.[97]

During its period of operation from 1961 to 1966, the ML-1 suffered from numerous technical problems and breakdowns.[98] However, Suid points out that the ML-1 was the smallest nuclear power plant to produce electricity and the first reactor to be coupled with a closed-cycle, gas-driven turbo-generator.[99]

The MH-1A Floating Nuclear Power Plant
In contrast to the other reactors developed by the ANPP, the MH-1A had the greatest electrical-generating capacity of all (Table 1). According to Lawrence Suid, the U.S. military had utilized vessel-mounted conventional power plants prior to and during World War II, proving that it could be done successfully. So much so that the Army initiated the design of another floating conventional power plant in 1952. However, many of the logistical challenges that the Army sought to resolve with nuclear power limited these as well as land-based plants. In 1959, with the SM-1 and SL-1 already in operation and the PM-2A nearing completion, the ANPP prepared specifications for a 10MW floating nuclear power plant to provide "beachhead and invasion support, supply of power for civil defense or civil affairs, and support of missile tracking or testing facilities." Additionally, the reactor was to be located on a waterborne vessel and as such would need to operate "under various combinations of list, trim, and roll" within a plant that was in constant motion. This is worth noting given the mechanical precision required to control a nuclear chain reaction within the reactor core. In 1961 a contract was awarded to the low bidder, the newly formed Martin-Marietta Corporation, a merger between the Martin Company, which was already working on the Army's PM-1 and the PM-3A, and the American-Marietta Corporation.

Table 1: Summary of ANPP Reactors

Long Name	**Location**	**End User**	**Designer**	**Type**	**Capacity**	**First Criticality**	**Last Criticality**
SM-1 Stationary medium power prototype	Ft. Belvoir, Virginia	Army	ALCO	Pressurized water reactor	2MW	1957, Apr 8	1973, Mar 16
SL-1 Stationary low power prototype	NRTS, Idaho	Army	Argonne National Labs	Boiling water reactor	1MW	1958, Aug 11	1961, Jan 3
GCRE-1 Gas-cooled reactor experiment	NRTS, Idaho	Army	Aerojet-General Corp.	Gas cooled light water reactor	N/A[1]	1960, Feb	1962

[97] Ibid.,90, 91
[98] Ibid.,91
[99] Ibid.

PM-2A Portable medium power field reactor	Camp Century, Greenland	Army	ALCO	Pressurized water reactor	1MW	1960, Oct 3	1962, Jul 9
ML-1 Mobile low power prototype	NRTS, Idaho	Army	Aerojet-General Corp.	Gas cooled light water reactor	500KW	1961, Mar 30	1966, Jun 30
PM-1 Portable medium power prototype	Sundance, Wyoming	Air Force	Martin Company	Pressurized water reactor	1MW	1962, Feb 25	1968, Apr 11
PM-3A Portable medium power field reactor	McMurdo Station, Antarctica	Navy	Martin Company	Pressurized water reactor	1.5MW	1962, Mar 3	1972
SM-1A Stationary medium power field reactor	Ft. Greely, Alaska	Army	ALCO	Pressurized water reactor	2MW	1962, Mar 13	1972, Mar 14
MH-1A Mobile high power field reactor	Ft. Belvoir, Virginia	Army	Martin-Marietta Corp.	Pressurized water reactor	10MW	1967, Jan 25	1977

[1] Electrical generation capacity data not available for this experimental prototype.

MH-1A STURGIS Development

In the spring of 1960 Contract DA-36-109-ENG -7454 for Design and Construction of Floating Nuclear Power Plant, was put out for bid by the U.S. Army Corps of Engineers' Philadelphia District Engineer, with staff assistance provided by the ANPP at Fort Belvoir, Virginia.[100] Coordination of funding and construction directives passed from the Office of the Chief Engineer (OCE) to the Philadelphia District. Direction of ANPP staff support was provided by the ANPP Project Manager. The U.S. Coast Guard reviewed all design and construction, leading to eventual certification of the vessel. The American Bureau of Shipping (ABS), a private organization under contract to the District, reviewed all hull designs - ABS review being acceptable by the Coast Guard for certification. The AEC also reviewed the project at steps normal for reactors whether under Article 91B of the 1954 Atomic Energy Act or not: prior to construction, prior to operation, and possibly after some period of test operation. [101]

[100] Untitled report dated 22 January 1967, compiled by Major Robert M. Bunker. Archived in USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents Archive, Box 2, File 11-Admin Files.

[101] *Historical Site Assessment for the MH-1A Nuclear Power Reactor and STURGIS Barge*, prepared by Integrated Environmental Management, Inc. (IEM) for the U.S. Army Corps of Engineers, Baltimore District. USACE Contract No. W912DR-08-D-0022, Delivery Order 003. Final (Revision 1), November 14, 2013.

The New York Shipbuilding Company, along with six other firms, responded to the Philadelphia District's request for proposals in August 1960, drawing upon its history designing and building some of the nation's first nuclear powered naval vessels and submarines.[102] However, the Philadelphia District selected Martin Company (later Martin-Marietta Corporation), which was teamed with J.J. Henry Marine Architects as Martin Company's subcontractor for naval architecture and marine engineering design.[103]

As originally contracted in 1961, MH-1A program costs were awarded in eight optional phases of work:

A. Design - $644,000
B. Construction of Plant - $14,674,000
C. Construction of core - $789,000
D. Test Operations - $346,000
E. Repair parts and tools - $304,000
F. Training - $65,000
G. Technical manuals - $172,000
H. Documentary Film - $30,000[104]

The design phase of the project was completed in December 1962 and optional phases for construction of the Army's floating nuclear power plant were also awarded to the Martin Company, which continued working with J. J. Henry Co. of Philadelphia as the marine architecture and engineering design subcontractor. The Martin Company subcontracted with Alabama Drydock and Shipbuilding Co. (ADDSCO) of Mobile, Alabama as its construction subcontractor, which had a long history of building Liberty ships during World War II. With changes orders, the original contract amount increased from $16,235,789.00 to a final cost of approximately $17,200,000, an increase of approximately 6.25%.[105]

Naming of the STURGIS

During the summer of 1964, as the ship that would become the *STURGIS* was being converted, the Army explored a range of possible names for the vessel out of the "six classes of names appropriate for floating nuclear power plants: (1) Surnames of deceased prominent CE [Corps of Engineers] personnel. (2) Geographical features. (3) Historical names. (4) Technical terms. (5) Surnames of prominent logistics personnel (deceased). (6) Surnames of deceased nuclear scientists."[106] The consensus among Army personnel was that the vessel should be named after Lieutenant General Samuel D. Sturgis, who had died

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[102] "Proposal FLOATING MOUNT 10,000 KWe (NET) FLOATING NUCLEAR POWER PLANT (MH-1A)," New York Shipbuilding Corporation, Camden, New Jersey. August 18, 1960. Archived in USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents Archive, Box 1, File 28.

[103] "Fact Sheet, MH-1A FLOATING NUCLEAR POWER PLANT," undated, with handwritten note indicating original was given to Mr. Wilhelm, GAO on 16 May 1966. Archived in USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents Archive, Box 2, File 11-Admin Files.

[104] "Quarterly Report. Floating Nuclear Power Plant," 10 October 1966, Archived in USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents Archive, Box 21, File 14.

[105] The approximate final cost reported here is from Page 1, "Floating Nuclear Power Plant, 'Sturgis,' Arrives at Fort Belvoir," *Belvoir Castle*, Friday, April 29, 1966. Archived in USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents Archive, Box 10.

[106] USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents Archive, Box 2, File 10-Hist Documents.

of Parkinson's disease in July of that year at the age of 66.[107] The obituary in the *Washington Post* described Sturgis as "a lifelong student of engineering… an aggressive builder-fighter in both World Wars and foresighted planner in peacetime," and a decorated officer.[108] On 5 October 1964, Chief of Engineers, Lieutenant General W. E. Wilson, Jr., sent a letter to Sturgis's widow requesting her permission to name the "world's first floating nuclear power plant" after her husband.[109] Wilson wrote:

> [Lieutenant] General Sturgis was Chief of Engineers during the period when responsibility for electrical power production by nuclear energy was assigned to the Corps of Engineers [1953-1956]. Through his interest and direction, great progress was made in the field… I am heartily in favor of this action as one means of providing recognition of your husband's important contributions to the defense of our nation. It is, I believe, appropriate for the inspiration that he provided to all of us to live on through the use of his name on this monumental engineering achievement, the MH-1A.[110]

Mrs. Sturgis expressed her approval just a few days later in a letter to Lieutenant General Wilson in which she wrote that "I feel sure that [Lieutenant] General Sturgis would like it very much if the MH-1A were named for him."[111]

MH-1A STURGIS Goes Critical at Fort Belvoir
The MH-1A reactor was brought to criticality for the first time on 25 January 1967 while moored at Fort Belvoir, prompting the Army to print notices in military publications and issue press releases to external media outlets announcing the world's first floating nuclear power station, designed to provide "emergency electric power to communities hit by earthquakes, hurricanes and other peacetime disasters."[112] James Lampert, now a Lieutenant General and the Deputy Assistant Secretary of Defense, acknowledged the importance of the event in a congratulatory letter to Lieutenant Colonel H.S. Smith of the Army Corps Nuclear Power Division, writing "I will always maintain a strong interest in your program, and I share, to a degree, the gratification which I know you and your associates experienced when you passed this milestone. I hope for an opportunity to visit the plant one day."[113]

Following the Army's acceptance of the MH-1A from Martin-Marietta in July 1967, the *STURGIS* provided power to Fort Belvoir through the VEPCO grid while awaiting an assignment.[114] In preparation, the Chief of Engineers activated the 535th Engineer Detachment (Floating Power Plant, Nuclear), to be comprised

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[107] Obituary for Lieutenant General Samuel D. Sturgis III, *Washington Post*, 6 July 1964. On file in USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents Archive, Box 2, File 10-Hist Documents
[108] Ibid.
[109] USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents Archive, Box 2, File 10-Hist Documents.
[110] Ibid.
[111] Letter from Mrs. Samuel D. Sturgis, dated 9 October 1964. Archived in USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents Archive, Box 2, File 10-Hist Documents.
[112] "Sturgis Exhibit for Smithsonian," *Information Bulletin Office of the Chief of Engineers*, 6 February 1967, Vol. 12, No.5. In USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents Archive, Box 2, File 10-Hist Documents.
[113] Letter from J.B. Lampert to H.S. Smith dated 13 February 1967. In USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents Archive, Box 2, File 10-Hist Documents.
[114] Suid,1990,100.

of up to 68 men, two-thirds of whom were skilled nuclear power technical specialists trained at Fort Belvoir.[115]

MH-1A STURGIS in the Panama Canal Zone

The formal order for deployment of the *STURGIS* to the Panama Canal Zone (PCZ) was issued by the U.S. Army Chief of Staff on April 12, 1968 following a study by the OCE, to be "most beneficial to the Army and would demonstrate its feasibility."[116] The April 1968 monthly operating report for the MH-1A, prepared by Lieutenant Colonel R.H. Shultz, Jr., notes that the reactor is undergoing "Downtime for pre-deployment maintenance and Turbine repairs," suggesting that the decision to deploy the *STURGIS* had been made by that time.[117] The assignment was initially expected to be two to three years to "assist the Panama Canal Company in meeting a serious power shortage," but was later extended "based on the successful operation of the *STURGIS* and a continued need for its output."[118]

The PCZ was a territorial unit of the U.S. established in 1903 (treaty ratified by Congress in 1904) when the U.S. took over the construction of the Panama Canal from the French *Compagnie Nouvelle du Canal de Panama*. The desire for a navigable canal through Central America that would eliminate the need to sail south around South America had been a subject of discussion since the early period of European navigation. U.S. interest intensified during the gold rush of the mid-19th Century and a cross-isthmus railroad through the Republic of New Granada (now Panama), the Panama Railroad Company, was built by American investors in 1855. Having successfully directed the construction of the Suez Canal in Egypt, completed in 1869, French diplomat Ferdinand de Lesseps spearheaded what he believed would be a similar effort in Panama under the financing of the *Compagnie Universelle du Canal Interoceanique* in 1881. Plagued by technical challenges and a workforce weakened by malaria, the company was bankrupt by 1889. While serving as Assistant Secretary of the Navy, Theodore Roosevelt became a supporter of the isthmus canal concept and when he became President in 1901, he advocated for the U.S. government to acquire the French assets and complete the project. Following the Panamanian declaration of independence from Columbia in 1903, the U.S. signed the Hay-Bunau-Varilla Treaty with the new republic, giving the U.S. rights over a 20-mile wide strip of land bisecting Panama for the purpose of canal construction.

Construction of the 51-mile long Panama Canal resumed under U.S. control in 1904 and was completed in 1914 at a cost of $352M, plus the $287M investment made by their French predecessors.[119] Unlike the earlier Suez Canal, which is a sea-level structure located in a flat desert region, the Panama Canal uses locks to raise ships 85 feet above sea level for access to a 32-mile reach across a large man-made lake

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[115] Ibid.
[116] "Fact Sheet," no date. Archived in USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents Archive, Box 2, File 10-Hist Documents.
[117] Monthly operations report, April 1968. Archived in USACE Baltimore Digitized MH-1A STURGIS Historical Documents Archive.
[118] "Fact Sheet," no date. Archived in USACE Baltimore Digitized MH-1A STURGIS Historical Documents Archive, Box 2, File 10-Hist Documents.
[119] "The American Era: Construction Period," Panama Canal Museum website, available at http://cms.uflib.ufl.edu/pcm/timeline/americaneraconstruction.aspx, accessed 1 December 2018.

(Gatun Lake) in the country's interior and across the Continental Divide via the Culebra Cut. As originally constructed (i.e., before the addition of a third channel), the Panama Canal consisted of two channels and locks in three locations: on the Atlantic side, the three-chamber Gatun Locks; the single-chamber Pedro Miguel Locks on the far side of the Continental Divide; and the two-chamber Mira Flores Locks on the Pacific side (Figure 1). The entire system depended upon a large-scale, year-round supply of water to operate the locks, necessitating the creation of Gatun Lake by damming the Chagres River and flooding a 164 square-mile area with 5.2 cubic kilometers of water.[120]

At the time of its construction, Gatun Lake and Dam were the largest of their kind in the world. Secondary benefits of Gatun Dam included hydro-electric power, storage of potable water, and infrastructure that helped to control flooding. Nevertheless, by the 1920s concerns about water supply, especially during the dry season, resulted in the construction of a second reservoir to feed the Canal. The Chagres River was dammed upstream from Gatun Lake to create Lake Madden (now Lake Alajuela), completed in 1935, significantly increasing the reservoir capacity of the Canal.

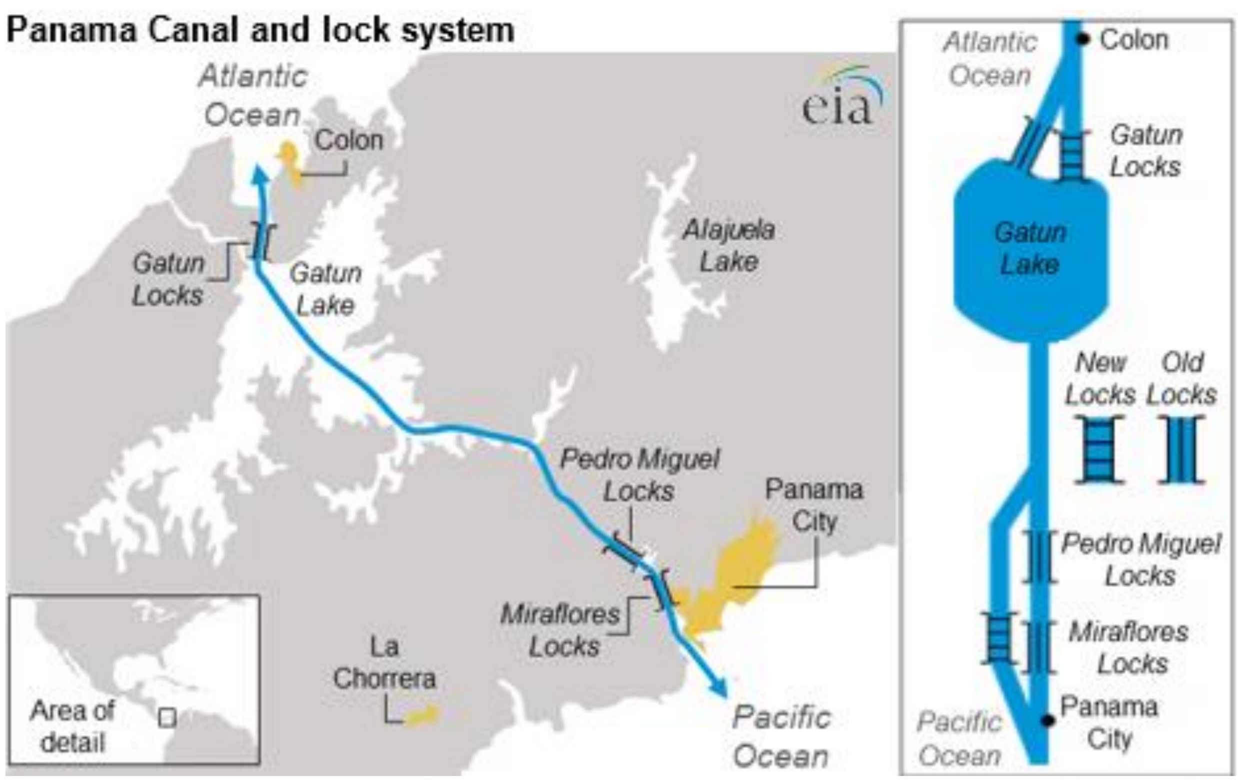

Figure 1. Panama Canal and Lock System (U.S. Energy Information Administration 2018)

[120] "Gatun Lake," https://en.wikipedia.org/wiki/Gatun_Lake, accessed 1 December 2018; and "Interesting Facts About the Panama Canal," Panama Canal Museum website, http://cms.uflib.ufl.edu/pcm/facts.aspx, accessed 1 December 2018.

The PCZ was initially governed by the U.S. Secretary of War and the Isthmian Canal Commission, followed by an entity named The Panama Canal under the direction of the Secretary of War. In 1951 governance was reorganized under the Canal Zone Government, with the Panama Canal Company, the successor of the Panama Railroad Company, in charge of operating the canal. From 1904 to 1979, the PCZ functioned as an entity set apart from the country that it bisected, with its own U.S.-funded infrastructure – housing, schools, hospitals, roads, sewers and water treatment facilities, and electricity that was consistent with the living standards and health requirements of the Zonians (residents of the PCZ) and supported Canal operation. Because the existing conditions in Panama were determined to be substandard, the U.S. government invested in numerous large-scale infrastructure improvement projects inside the PCZ and in neighboring communities including Panama City on the Pacific side of the Canal and Colón on the Atlantic side, to maintain a healthy, productive, and safe workforce to operate the Canal. One of the first infrastructure projects undertaken by the Panama Canal Company, initiated in 1904, was to overhaul the water and sewer system in the oldest part of Panama City, which was outside of the PCZ.[121] One of the last major U.S. projects, completed in 1962, was the construction of the Bridge of the Americas to carry the Pan-American Highway over the Pacific entry to the Canal.

In the first few years of operation, traffic on the Panama Canal jumped from about 1,108 transits (i.e., individual trips) in 1915 to over 7,000 by the late 1920s.[122] Following the end of World War II, the number of transits on the Panama Canal rose sharply, a trend that continued into the 1960s.[123] By 1970 the number of annual transits exceeded 15,523, with net tonnage at 115.5M generating $100.8M in tolls.[124] The U.S. ranked fourth in percentage of annual net tonnage through the Canal – Liberia accounted for 17%, Great Britain for 12%, and Norway for 11%.[125] Coal and coke made up the largest percentage of cargo tonnage at 18%, followed by petroleum and petroleum products at 15%, and iron and steel products at 7%.[126] Indirect benefits to the Panamanian economy, derived from employment of citizens in the PCZ, goods and services sold to the PCZ and users of the Canal, and expenditures by visitors, were considerable.[127] In April 1968, right around the time that the orders were being prepared for the deployment of the MH-1A *STURGIS* to Panama, the *Washington Post* reported record traffic on the Panama Canal despite political unrest leading up to the May 12 presidential election.[128]

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[121] Ashley Carse, "An Infrastructural Event: Making Sense of Panama's Drought," *Water Alternatives*, Vol. 10, No. 3, 2017, p. 898.
[122] Panama Canal Company, *General Comparative Statistics, Panama and Suez Canals*, 1 June 1971, available online at http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=17&ved=2ahUKEwiIofvD5f_eAhWumeAKHZr_CKcQFjAQegQIABAC&url=http%3A%2F%2Fbdigital.binal.ac.pa%2Fbdp%2Fdescarga.php%3Ff%3Dpanamasuezcanal.pdf&usg=AOvVaw0dftk44zNLChOKtKSmIMrz, accessed 1 December 2018.
[123] Ibid.
[124] Ibid.
[125] Ibid.
[126] Ibid.
[127] Sandra W. Meditz and Dennis M. Hanratty, ed., *Panama: A Country Study*, Washington, DC: GPO for the Library of Congress, 1987, available online at http://countrystudies.us/panama/, accessed 1 December 2018.
[128] William Montalbano, "Canal Sets Record for Ship Traffic," *Washington Post*, 20 April 1968.

> Last week, the Canal established a two-day record of 110 transits by ocean-going ships of more than 300 tons, and a three-day record of 155 transits. Average transits in the last two weeks, during the height of political unrest, have been at a near record of about 44 ships a day… The record for single-day transits was set Feb. 29 when 65 crossed from ocean to ocean. It came after a Japanese freighter had gone aground, blocking the waterway for two days. Traffic was so heavy at one point that a scheduled overhaul of Gatun Locks had to be suspended.[129]

However, direct economic benefit to Panama beyond the annual annuity from the U.S. required by treaty was limited and consequently became a source of resentment on the part of Panamanians that heightened with the rise of Panamanian nationalist sentiment in the 1950s and 1960s.[130] Concurrent with the increase in canal traffic within the PCZ was a period of unprecedented industrial growth in Panama spurred by liberal government incentives and tariffs, investment in infrastructure, and foreign investment in oil refining, food processing, and utilities that prompted a building boom.[131] An additional boost came from the Remon-Eisenhower Treaty of 1955 between Panama and the U.S. that "phased out a number of manufacturing activities in the Canal Zone and opened a market for such Panamanian products as bakery goods, soft drinks, meats, and bottled milk."[132]

These factors resulted in an increased demand for energy that exceeded the capacity of the existing power infrastructure in Panama, a deficiency that was projected to worsen if additional power generating capability was not developed. Prior to 1958, electric power in Panama was generated and distributed by private companies, the most significant of which was the *Cia Panamena de Fuerza y Luz* (CPFL), a General Electric subsidiary established to provide power for the Canal construction. In 1961 the *Instituto de Recursos Hidraulicos y Electrificacion* (IRHE) was created as a government agency charged with coordinating power development in Panama, but the process was slow and only one major project – the 7 MW *La Yeguada* hydroelectric plant – had been completed by 1968.[133] An analysis of Panama's electric power industry prepared in 1970 by the International Bank for Reconstruction and Development, part of the World Bank, characterized energy consumption in Panama as follows:

> In the developed power market areas, the growth of energy consumption over the past ten years has been rather uniform and steady, at a rate of about 11% per annum. Prospects are for continued economic expansion and parallel growth of energy consumption. The energy consumption is concentrated in the Panama City and Colon metropolitan areas, which form the principal power market and together account for

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[129] Ibid.
[130] Meditz and Hanratty 1987.
[131] Ibid.
[132] Ibid.
[133] International Bank for Reconstruction and Development International Development Association, "Appraisal of the Second Power Expansion Project of the *Instituto de Recursos Hidraulicos y Electrificacion Panama*," 19 February 1970, http://documents.worldbank.org/curated/en/303761468059333500/pdf/multi-page.pdf, accessed 8 November 2018.

> approximately 85% of the national consumption… Load factors are high, due to intensive use of air-conditioning in urban centers.[134]

The report noted that in the late 1960s existing facilities in Panama, exclusive of the PCZ, barely had the capacity to meet energy demand under the best conditions, to say nothing of a plant going off line due for maintenance or in a weather event.[135] The most important and largest of the regional systems was the Metropolitan System, serving the metropolitan areas of Panama City and Colon immediately adjacent to the PCZ. Approximately 60% of Panama's 155 MW capacity came from the Metropolitan System.[136]

The estimated 100 MW capacity required by the PCZ was supplied by the Panama Canal Company through the hydroelectric plants at the Gatun and Madden Dams and additional plants at Cocoli and Miraflores.[137] The PCZ grid and the Metropolitan System were connected "primarily for the exchange of emergency power," although it did allow the PCZ to sell surplus power when available to the urban areas outside of the PCZ, just as it sold potable water collected from the Chagres River basin and stored in PCZ reservoirs.[138] The increased Canal traffic and corresponding demand for energy within the PCZ in the 1960s eliminated the availability of surplus power to be sold outside the PCZ. Prior to the arrival of the MH-1A *STURGIS* nuclear power barge, the diesel- and gas-powered barge *Andrew Weber* in 1968, and the expansion of the Miraflores plant in 1971, the PCZ capacity was estimated at 105.5 MW, which would have been sufficient, again, under the best conditions but not during peak times.[139] During the dry season from December through April, output at the hydroelectric dams, which accounted for 46.5 MW (44%) of the PCZ capacity, declined while temperatures remained constant year round. This put a strain on the grid that was further exacerbated when a plant was taken offline for maintenance or due to weather events.

Two measures helped to relieve the power shortage in the PCZ – the deployment of the Army's power barges MH-1A *STURGIS* and *Andrew Weber* in 1968, together adding 29.5 MW of capacity, and purchase of an additional 30 MW from IRHE beginning in 1969.[140]

The MH-1A *STURGIS* left Fort Belvoir on 26 July 1968 and arrived in Panama on 7 August 1968.[141] It was moored on the northwest shore of Gatun Lake on the Atlantic side of the Canal, 250 meters from the Gatun Dam and the adjacent hydroelectric plant. This site was practical because it allowed the MH-1A *STURGIS* to tie in easily to the existing electricity infrastructure, but it also met several important safety requirements. As with stationary nuclear power plants, sites were to be located in sparsely populated areas to minimize the human impact of an accident. There were no residences within 800 meters of the

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[134] Ibid.
[135] Ibid.
[136] Ibid.
[137] Ibid.
[138] International Bank for Reconstruction and Development International Development Association 1970 and Carse 2017, p. 897.
[139] International Bank for Reconstruction and Development International Development Association 1970.
[140] Ibid.
[141] Suid 1990,101.

STURGIS mooring site, and an "acceptably low population distribution" within 1,600 meters.[142] The site was also on the downstream side of the lake and close enough to the dam that the current was strong enough to pull contaminated water in the direction of the spillway, rather than allowing the water to spread throughout the lake.[143] The *Andrew Weber*, a 20MW conventional floating power plant, had arrived about a month earlier and was moored in Balboa on the Pacific side of the Canal.[144]

The MH-1A *STURGIS* was readied for operation and on 5 October 1968 began supplying power to the PCZ grid. Information included in the annual reports for the MH-1A from 1968 to 1976, summarized in Table 2, suggest that operations during the eight-year deployment were ordered and routine.[145] They also show that safe operation of the nuclear reactor required constant problem solving through close observation, analysis, and modification. The majority of malfunctions were categorized as mechanical (i.e., mechanical failure of a part or process), instrumental (i.e., the failure of instrumentation used to monitor the reactor), or problems with the Panama Canal Company electrical grid that interrupted power and triggered a reactor "scram" (automatic shut-down).[146] According to Charles Harmon, in all but one case during his time on the MH-1A *STURGIS* (1972-1974) the operators in the reactor control room knew what caused the unscheduled scrams, and the anomalies were readily corrected.[147] He stated that it took 7 to 8 hours to get the reactor back on line and generating power after a scram. Review of the description of malfunctions and modifications show that there were a few chronic mechanical problems that were elevated up the chain of command for permanent solutions that could include redesign by Corps engineers, and or redesign and/or replacement by the original manufacturer.

Table 2: Summary of *STURGIS*' Performance in the PCZ, 1968-1976[1]

Category	1968*	1969	1970	1971	1972	1973	1974	1975	1976*
Plant Availability[2]	36%	84%	70%	83%	63%	65%	46%	65%	48%
Operating Hours, Total	2934	7,362	5,097	7,041	5,505	5,993	3,953	5,702	4,150
Standby Hours, Total	-	-	1,001	227	7	162	115	10	7
Downtime Hours for Maintenance[2]	30%	13%	16%	12%	33%	13%	33%	30%	50%
Downtime Hours, Unscheduled[2]	34%	3%	14%	5%	4%	22%	21%	5%	2%

142 Atomic Energy Commission, *Safety Evaluation by the Division of Reactor Licensing in the Matter of Sturgis (MH-1A) Floating Nuclear Power Plant, Project No. 370*, USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents.
143 Ibid.
144 Suid,1990,101.
145 Annual Reports for the MH-1A Nuclear Power Plant, prepared in accordance with AR 385-80 by the U.S. Army Engineer Reactors Group (after 1971, the U.S. Army Facilities Engineering Support Agency), 1968-1977; USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents.
146 The Nuclear Regulatory Commission defines "scram" as "the sudden shutting down of a nuclear reactor, usually by rapid insertion of control rods, either automatically or manually by the reactor operator. Also known as a 'reactor trip' ".
147 Telephone interview with Mr. Charles Harmon, conducted by Carrie Albee and Kathryn St. Clair, 15 November 2018.

Electricity Produced, Gross (GWh)	24.9	64.1	43.0	66.8	57.2	58.6	31.4	35.2	20.6
Electricity Produced, Net (GWh)	22.4	57.3	37.3	59.1	51.5	52.3	25.8	28.8	15.7
Core No.	1	1, 2	2	2, 3	3, 4	4	4, 5	5	5
No. of Malfunctions	20	40	27	31	28	64	30	44	27
No. of Unscheduled Scrams	6	10	4	12	3	28	8	8	2
No. of Modifications	1	38	34	16	24	31	36	22	17
Crew Size, Average	55	58.5	59.2	54	62	64	68	67	71
Occurrences of Radiation Exposure in Excess of 1.25 rem/yr[3]	0	14	3	0	0	0	9	1	0

(1) Numbers are either directly provided or derived from the MH-1A Annual Reports. Remainder minutes have been dropped from the table (e.g., if the Annual Report indicates 2934 hours and 2 minutes, the table will show 2934 hours). Percentages are therefore approximate.
(2) Based upon 8,760 hours in a calendar year. Numbers are approximate.
(3) Rem per year. OSHA currently uses a quarterly limit of 1.25 rem, and yearly maximum of 5.00 rem.
*Numbers are for the entire year; the *STURGIS* was in Panama only part of the time.

The annual reports also include detailed information about radioactive waste and monitoring of radioactivity levels of staff and in the environment surrounding the *STURGIS*. Spent fuel assemblies were placed in purpose-built containers and sent to AEC/ Nuclear Regulatory Commission (NRC) facilities for reprocessing. Other solid radioactive waste was placed into drums and transferred to one of several AEC/NRC disposal sites. Liquid and gaseous radioactive waste that did not exceed safety thresholds could be discharged into the environment (i.e., Lake Gatun or the atmosphere): otherwise it was treated (e.g., diluted) within the *STURGIS* until it could be discharged safely.

The MH-1A *STURGIS* shut down once a year for annual maintenance. As shown in Table 2, the MH-1A reactor was refueled four times during its ten years of operation.[148] Refueling required taking the plant down for a period of time, generally concurrent with annual maintenance. The first four cores were refueled through the removal of 16 of the 32 fuel assemblies at a time. The final core consisted of 32 new fuel assemblies grouped together as a batch – all 32 were intended to be installed and removed together. The MH-1A *STURGIS* was dry-docked only once during its deployment, in September 1972, at Fort Davis in the PCZ, consistent with the Federal requirement that a vessel operating in fresh water be dry-docked every 60 months.[149]

MH-1A STURGIS Withdrawal from the PCZ, July 1976

On 1 July 1976, the MH-1A was shut down for annual maintenance, but before the MH-1A was returned to active duty as it had been in previous years the decision was made to discontinue the *STURGIS*' mission in the PCZ.[150] Press releases issued by the Army and other administrative records from the period of the

[148] Annual Report for the MH-1A Nuclear Power Plant, prepared in accordance with AR 385-80 the U.S. Army Facilities Engineering Support Agency, 1975; USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents.
[149] "Drydocking of the Sturgis (MH-1A), Ft. Davis, Canal Zone," USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents.
[150] U.S. Army Corps of Engineers – Baltimore District, "Decommissioning Plan for the MH-1A Nuclear Power Reactor and STURGIS Barge," 14 November 2003, p. 2, in USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents.

MH-1A *STURGIS*' withdrawal from the PCZ state that the supplemental power was no longer needed due to "construction of additional power sources in the Canal Zone."[151] In 1970 and 1971 annual reports record periods when MH-1A *STURGIS* was available but not exporting power due to there being "ample power in the Canal Zone."[152] But likely the single greatest factor was the completion in 1976 of the Panamanian government-backed 150MW *Bayano* Hydroelectric Plant, fulfilling a long-held promise of Panamanian nationalists to develop the country's power infrastructure.

Also contributing factors were the cost of continued operation and the effort required to meet the safety standards of the NRC, the AEC's successor agency. As summarized in a 1977 fact sheet on the *STURGIS*,

> In August 1976, the Office of the Chief of Engineers evaluated a number of possible sites where the Sturgis could be effectively used when no longer needed in the Canal Zone. We were unable to identify an operational requirement which would justify the continued utilization of the Sturgis and the cost of supporting the crew of 70 military personnel. While nearly two years worth of nuclear fuel is in the nuclear reactor, it would cost several million dollars to return the plant to a safe operating condition because of the additional work necessary to modify the nuclear system to comply with the latest Nuclear Regulatory Commission's Standards for Nuclear Safety.[153]

The same document noted that the MH-1A *STURGIS'* 10MW output capacity was "quite small and relatively costly to operate when compared with other forms of power generating equipment of comparable size," a reoccurring theme for the ANPP, which justified its existence in part based upon the cost savings afforded by nuclear power – not in the design, construction, or operation of the plants but in the diminished cost of acquiring and transporting conventional fuels.[154] Indeed, one of the reasons cited by Suid for the decline of the ANPP is the elimination in the 1960s of fuel transportation from the cost-benefit analysis formula used by the Office of the Secretary of Defense.[155]

The commercial nuclear power industry was dealing with many of the same issues, but the cost of compliance had not yet reached the point of deterring private investment as it would do later in the 20th century. When the Energy Reorganization Act of 1974 passed into law, the commercial nuclear power industry was just starting to see the results of the planning and investment undertaken since the Atomic Energy Act of 1954. By 1971, 22 nuclear power plants were online in the U.S. and a record number of 41

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[151] "Fact Sheet Floating Nuclear Power Plant Sturgis," ca. 1977. Archived in USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents, Box 2, File 10-Hist Documents.
[152] Annual Report for the MH-1A Nuclear Power Plant, prepared in accordance with AR 385-80 by the U.S. Army Engineer Reactors Group, 1970; USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents.
[153] "Nuclear Power Barge to Return to Fort Belvoir for Decommissioning," ca. January 1977. Archived in USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents, Box 2, File 10-Hist Documents.
[154] "Fact Sheet Floating Nuclear Power Plant Sturgis," ca. 1977. Archived in USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents, Box 2, File 10-Hist Documents.
[155] Suid,1990, 78.

nuclear power plants were ordered by American utility companies in 1973.[156] But with the expansion of the industry came increased public scrutiny and heightened concerns about nuclear safety. The NRC explains:

> … as the number of plants being built, and the size of those plants rapidly increased during the late 1960s and early 1970s, reactor safety became a hotly disputed and enormously complex public policy issue. Often bitter debates over the reliability of emergency core cooling systems, pressure vessel integrity, quality assurance, the probability of a major accident, and other questions received a great deal of attention…[157]

The enacting of the National Environmental Policy Act (NEPA) in 1969 reflects the increasing public concern over the impact of large-scale federal infrastructure and civil projects on the surrounding populations and the environment. As a Federal agency, the AEC/NRC was responsible for legitimately considering these impacts and for providing an opportunity for public input. Concerns about nuclear power focused on several key issues: thermal pollution, or the increase in temperature of riparian ecosystems from plant discharge of water; radiation and radioactive waste disposal; and a core melt, colloquially called a nuclear meltdown, when the temperature of the core increases beyond the melting point of the fuel, potentially breaching the containment vessel and allowing the escape of radioactive material.

These and other concerns, including the possibility of nuclear material falling into the hands of hostile nations or terrorists, resulted in the abolition of the AEC under the 1974 Act and the creation of the NRC and its Office of Nuclear Reactor Regulation to license nuclear reactors and "review the safety and safeguards of all such facilities, materials, and activities," including "monitoring, testing and recommending upgrading of systems designed to prevent substantial health or safety hazards."[158] Although the NRC retained many of the responsibilities of the AEC, there was a clear shift from the optimistic, proactive AEC of the 1950s and 1960s that sought first and foremost to promote the industry, prompting one critic to compare it to "letting the fox guard the henhouse," and the NRC of the 1970s that operated for the primary purpose of ensuring public safety.[159] The perceived conflict of interest with respect to the AEC is hinted at in the declaration of purpose for the 1974 Act which states "Congress finds

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[156] U.S. Department of Energy, "The History of Nuclear Energy," available online at https://www.energy.gov/sites/prod/files/The%20History%20of%20Nuclear%20Energy_0.pdf, accessed 15 November 2018. U.S. Energy Information Administration, "History of energy consumption in the United States, 1775-2009," available online at https://www.eia.gov/todayinenergy/detail.php?id=10, accessed 15 November 2018.
[157] Nuclear Regulatory Commission, "History: Reactor Safety," available online at https://www.nrc.gov/about-nrc/history.html, accessed 15 November 2018.
[158] Energy Reorganization Act of 1974, PL93-438, Section 203.
[159] J. Samuel Walker and Thomas R. Wellock, *A Short History of Nuclear Regulation, 1946-2009*, Report prepared for the United States Nuclear Regulatory Commission, October 2010, p.49.

that it is in the public interest that the licensing and related regulatory functions of the Atomic Energy Commission be separated from the performance of the other functions of the Commission."[160]

MH-1A *STURGIS* ship supervisor (1972-1974) Charles D. Harmon confirmed that the level of effort required to be in compliance with the NRC requirements was indeed a major factor, given that the MH-1A reactor was designed in 1964.[161] In particular, he cites the lack of an emergency core cooling system in the MH-1A *STURGIS*, a safety feature that became standard in later years. Harmon also noted the increasing political instability in Panama in the mid-1970s and concern that security of the MH-1A *STURGIS* and its nuclear reactor, and to a lesser degree its companion vessel in the PCZ, the conventional power barge the *Andrew Weber*, might be difficult to maintain. An undercurrent of resentment on the part of Panamanian citizens of the U.S. presence had begun in 1903 and was exacerbated by the stark contrast between the living conditions within and outside the PCZ, which bisected the country, and by the perceived exploitation of Panamanian labor and resources for American profit. Student-led anti-U.S. protests and rioting in January 1964 resulted in the death of 21 Panamanians and four American soldiers, and extensive damage to PCZ property. Thereafter, the U.S. and Panama entered into formal negotiations culminating in the signing of the Torrijos-Carter Treaties in September 1977 that laid out the framework for the U.S. withdrawal from the PCZ and transfer of the Panama Canal to the Panamanian government. An information package prepared by the Army in response to a Senate inquiry in early 1977 confirms Harmon's conclusion, stating "National security reasons dictated that the *STURGIS* be removed from the Canal Zone by a specified date."[162]

At the conclusion of its mission, the Army reported that the *STURGIS* produced over 357 million kilowatt hours of electricity to the Panama Canal Company grid over eight years of deployment.[163] In January 1977 following the departure of the MH-1A *STURGIS* the Governor of the Panama Canal Zone and President of the Panama Canal Company from 1975 to 1979, Major General Harold Robert Parfitt sent a letter of appreciation to Colonel James R.C. Miller, Director of the U.S. Army Facilities Engineering Support Agency at Fort Belvoir for the MH-1A *STURGIS* and the *Andrew Weber* "having completed eight years of outstanding and valuable service for the Panama Canal Company."[164] Parfitt commended the crew members for their "admirable cooperation in helping us solve many of our electrical support problems. The officers and men who manned the barges have been a real credit to the Corps of Engineers, and we are grateful for the assistance they furnished."[165]

[160] Energy Reorganization Act of 1974, PL93-438, Section 2(c).
[161] Charles D. Harmon, telephone interview with Carrie Albee and Kathryn St. Clair, 15 November 2018. A summary of this oral history interview is provided in Appendix C - Supplemental Materials, Historical Documentation appended to this report.
[162] Charles D. Smith, "Proposed response to inquiry from Senator Hayakawa," ca. November 1977, in USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents.
[163] "Possible Questions on the Sturgis Relocation," Admin files. In USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents, Box 2, File 10-Hist Documents.
[164] USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents, Box 2, File 10-Hist Documents.
[165] Ibid.

Nevertheless, the Army was not successful in identifying a suitable mission for the MH-1A *STURGIS* upon its return from the PCZ. Administrative records show that at least one option was considered: the Department of Commerce & Economic Development for the State of Alaska contacted the Chief of Engineers in October 1976 to communicate interest in "studying the feasibility of relocating the *STURGIS* and/or *WEBER* to Alaska under mutually advantageous conditions," citing Alaska's "insufficient reserve capacity in some areas while our continued rapid growth required more and more electrical power which our private utilities are having difficulty meeting."[166] However, correspondence from the U.S. Energy Research and Development Administration (ERDA), later the Department of Energy, dated May 1977 laid bare the most significant challenge to civilian use of the MH-1A *STURGIS* – the cost, which was prohibitively high compared to conventional plants.

> … civilian use of the STURGIS plant would appear to be limited to very special cases. You mention an annual operating cost alone of $2 million for operation by the U.S. Army. At 70 percent capacity factor this amounts to almost 33 mills per kilowatt hour. Operating costs could be expected to be even higher under utility management if manpower levels were maintained. Even under the assumption that the civilian user did not have to pay fixed charges on the STURGIS investment, its economics would not be attractive compared to national averages. The Atomic Industrial Forum has reported that for the first half of 1976 U.S. electric utility total generating costs averages 15 mills/KWh for nuclear power plants, 18 mills for coal-fired plants and 36 mills for oil-fired plants. Of course, individual circumstances can belie conclusions based on averages. It would appear, though, that any civilian application of the STURGIS plant will require a combination of a relatively small system where 10,000 KW represents a significant addition to capacity, high system generation costs, and probably an isolated - but ship accessable [sic]-system without appropriate interconnections to other systems.[167]

Suid cites a general decline in support for the ANPP by the mid-1960s that was reflected in, or perhaps a result of, a shrinking budget that demonstrated a shift in priorities on the part of the military.[168] The U.S. formally entered the Vietnam War in 1965 and within three years increased combat troop presence on the island from an initial fighting force of 3,500 to just short of 550,000 in 1968. The Vietnam War continued to dominate military resources and political discourse until the U.S. withdrawal in 1973, leaving few surplus resources to divert towards the ANPP. Noting that the AEC's initial support of the ANPP was based upon the benefits of developing the technology for both military and commercial uses, one source observed that "Cutbacks in military funding for long-range research and development because of the Vietnam War led the AEC to phase out its support of the program in 1966. The costs of developing and

[166] Letter to J.W. Morris, Army Corps of Engineers from Langhorne A. Motley, State of Alaska Department of Commerce & Economic Development," 21 October 1976. Archived in USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents, Box 2, File 10-Hist Documents.
[167] Letter from Douglas C. Bauer, Director, Division of Nuclear Research and Applications, ERDA, to Mr. William B. Taylor, Sr.," 4 May 1977, Archived in USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents, Box 2, File 10-Hist Documents.
[168] Suid,1990, 102.

producing compact nuclear power plants were simply so high that they could be justified only if the reactor had a unique capability and filled a clearly defined objective backed by DOD." [169]

In 1968 the Chief of Engineers recommended to the Army Chief of Research and Development that an ad hoc group be formed to evaluate the Army's need for nuclear power.[170] In February 1969 at the first meeting of the group, the Chief of Engineers gave a briefing that pointed to a weak justification for the program from the beginning stating that it had

> … suffered continually from a lack of firm requirements. Essentially, as has been said before, nuclear power is a solution in search of a problem. Certainly this is an apt description of the ANPP. One of the major program efforts has been to try to define the need for nuclear power. Intuitively, we in the program feel that there is a need, but we have been unsuccessful to date in conveying it to the rest of the Army – or the other services – or the DoD.[171]

By the time of the briefing, only four of the ANPP's nine reactors were still in operation (SM-1, SM-1A, PM-3A, and the MH-1A), and no new projects were in the works. Over the next eight years, while the MH-1A *STURGIS* served in Panama, the remaining three reactors were decommissioned, most notably the one that had started it all, the SM-1, in 1973. Concurrently, the mission of the Engineer Reactor Group, under which the ANPP operated, shifted from "an elite, research and development organization," focused on nuclear power development to "essentially a reactive, emergency support agency."

DESIGN

SS Charles H. Cugle (1945-1963)

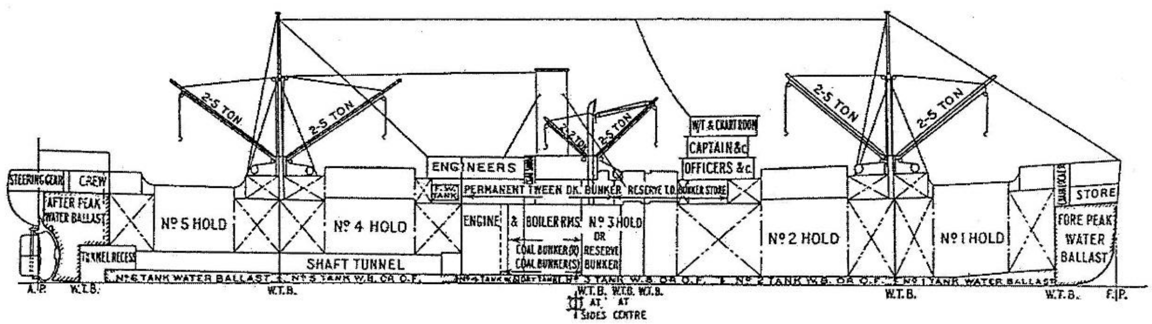
The *SS Charles H. Cugle* was one of 2,710 standardized emergency cargo ships mass-produced in the U.S. between 1941 and 1945. Nicknamed the 'ugly ducklings,' the American Liberty-class emergency cargo ship design was derived from a 1930s-era British tramp freighter designed by the firm of Joseph L. Thompson and Sons in Sunderland, United Kingdom. Thompson and sons based the design on a basic freighter with a displacement around 10,000 tons and service speed of 10 knots (Figure 2). As the U.S. Maritime Commission was initially planning its emergency shipbuilding program in 1940, the Thompson and Sons freighter design was favored because it could be easily modified and had a proven track record of service in the Atlantic Ocean.[172] Among many factors and alternatives considered at the time, Admiral Howard L. Vickery (Vice Chairman of the U.S. Maritime Commission) favored the British design in part because the frame bending on these vessels could be easily handled at our shipyards.[173] As the Commission presented

[169] Robert A. Pfeffer and William A. Macon, Jr., "Nuclear Power: An Option for the Army's Future," 2001, available via the U.S. Army website at https://almc.army.mil/alog/issues/SepOct01/MS684.htm, accessed 4 April 2019.
[170] Ibid.,103
[171] Ibid.,104
[172] Clayton 2011
[173] "Liberty Ship History," http://www.ssjohnwbrown.org/blog/2015/12/9/liberty-ship-history, accessed 16 August 2018.

its request for funding to Congress, the emergency ship design was described as "…the best that can be devised for an emergency product to be quickly, cheaply, and simply built." [174]

The U.S. Maritime Commission had previously developed and built standardized merchant ship designs, but nothing compared to the scale of the design-build program required for its World War II emergency fleet. Under the intense time constraints that prevailed in January 1941, the American naval architecture firm Gibbs & Cox was contracted to alter the British design to be compatible with American shipyards and to allow for mass production in an assembly-line manner. The process to determine how to adapt Britain's design included several attempts to use previous designs. Before the British ship plans were even brought to the U.S., the Director of Merchant Shipping in the Admiralty, Sir Amos L. Ayre, had removed most of the double curves at the bow and stern so that the production process would be quicker. Gibbs & Cox further streamlined the design, replacing the wide hull used in British ships with a straight-sided hull to provide quick movement. Gibbs & Cox designers, Alan Osbourne and F.E. Reed, suggested the use of the design for the *Los Angeles*, a mass-produced ship with the same deadweight as the British ships, with slightly smaller dimensions. [175]

It was concluded that the *Los Angeles* design would be too time consuming to produce. Several more designs were considered, until it was determined to proceed with the original plan to modify the design already in use by the British. A new division, the Division of Emergency Ship Construction, was organized



Length overall	440 ft. 6 in.	Machinery	Triple Expansion	Aux. Boiler	Scotch
Beam extreme	56 ft. 2½ in.	Cylinders	23½ in., 40 in., 68 in.	Diameter	13 ft. 6 in.
Load draught	24 ft. 9½ in.	Stroke	48 in.	Length overall	11 ft. 6 in.
Load displacement	12,635 tons			Pressure	220 lb. per sq. in.
Block coefficient	0 - 749	Boilers	2 S.E. Scotch	Draught	Forced
Max. designed loaded speed	10½ knots	Diameter	15 ft. 6 in.	Steam	Saturated
Gross tonnage	5,484	Length overall	11 ft. 6 in.		
Net tonnage	3,220	Pressure	220 lb. per sq. in.		
		Draught	Forced		
		Superheat	225° F.		
		Heating surface	5,020 sq. ft.		

Figure 2. Typical British Tramp Freighter, 1934 (Bourneuf 2008).

[174] Gus Bourneuf Jr., *Workhorse of the Fleet,* American Bureau of Shipping, 2008 edition, Houston TX, https://issuu.com/abs.eagle/docs/workhorseofthefleet, accessed 15 August 2018, page 54.
[175] Ibid.,75

to oversee efficiency in production and approve design plans. The massive task of preparing a comprehensive set of working drawings fell to Gibbs & Cox. Their challenge was to produce a comprehensive, standardized set of plans that could be used to manufacture identical vessels at the rapidly expanding array of shipyards on the East, West, and Gulf coasts. Once drafted, each sheet of the working plans, and each revision to those plans, had to be reviewed and approved by the American Bureau of Shipping.

The resulting Liberty ship design developed by Gibbs and Cox was referred to as EC2, an acronym for a medium-size emergency cargo ship between 400 and 450 feet at the waterline.[176] Production of Liberty ships began in April 1941 and the first Liberty ship to be launched was the *SS Patrick Henry* on September 27, 1941. Between 1941 and 1945, 2,710 Liberty ships were built, with construction averaging approximately 42 days per ship.[177] During the production of Liberty ships many design changes and technological improvements were made. Prefabrication and welding methods were refined, and a steel cold-rolling process was developed.[178] Of the Liberty ships completed, 200 were destroyed during World War II while others never saw any action at all. Following World War II, several Liberty ships served in the Korean War. Others were retired in reserved fleets, sold to private companies, or disassembled for scrap metal.[179]

As a class, the American World War II emergency ships, or EC2 ships as they were officially designated,[180] maintained the general hull form of their British predecessor with a deep displacement hull, an inverted or raked bow, and a pronounced vee-shaped stem that tapered aft to a long, straight mid-section with vertical sides and a flat bottom. The vertical sides tapered aft to a rounded "cruiser" stern that extended over and beyond the ship's propeller and rudder. This hull form created a box-like mid-section that was well suited accommodating large volumes of cargo stowage in five holds below the main deck. The most apparent change to the British hull design was a technological one, with the hull plates welded together rather than riveted. This change actually increased the man-hours required to complete construction of these large, mass-produced ships, though greater efficiency of construction was achieved as American shipyards gained experience with this construction technique.[181]

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[176] National Park Service, U.S. Department of the Interior, "Liberty Ships and Victory Ships --Reading 1," www.nps.gov/nr/twhp/wwwlps/lessons/116liberty_victory_ships/116facts1.htm.
[177] Ibid.
[178] Ibid.
[179] Ibid.
[180] Marijan Žuvić's article "The Story of the Liberty Ships," *Transactions On Maritime Science*, (2(2), pp. 133-142, 2013 indicates that the American-made emergency cargo ships were identified by type codes in accordance with an official classification system introduced by the United States Maritime Commission's 1936 Merchant Marine Act. The letter E was allocated exclusively to Emergency "Liberty" ships. C2 is for Cargo ships between 400 and 450 feet long. The letter S represents steam propulsion. Designations C1 through C5 were for particular variations on the basic E-C2-S design. The prefix "Z" was used for some specialized design variants, including the Z-EC2-S-C5 boxed airplane carriers.
[181] Bourneuf 2008, page 10 notes that average man-hours required to produce the early Liberty-class in the United States ships was reduced from 600,000 hours to 375,000 hours, page 10.

Throughout their history of production, EC2 emergency cargo ships continued to rely on the British North Eastern triple-expansion steam engine, which produced 2,500 horsepower to drive a large 4-blade propeller, 18 feet-6 inches diameter, and achieve a rated speed of 11 knots.[182] Otherwise, several key design modifications became characteristic of the American-built EC2 ships, including replacement of coal with fuel oil for firing the ship's boilers, and the use of water-tube boilers rather than the bulkier Scotch fire-tube boilers.

Gibbs and Cox' first emergency cargo ship design, coded EC2-S-C1, was a basic cargo ship design that could be adapted to different wartime needs. Among the earliest EC2-S-C1 variants was a bulk cement carrier intended to provide material for a third series of locks at the Panama Canal. However, by June 1942 the Panama Canal expansion plans were modified and Gibbs & Cox were redirected by the U.S. Maritime Commission to develop EC2 tank carriers, which were given the designation Z-EC2-S-C2. By December 1942 the critical shortage of oil tankers prompted the Commission to further authorize Gibbs & Cox as well as Delta Shipbuilding Company to develop plans for conversion of EC2s to serve as bulk oil carriers.[183] Eventually the popular name "Liberty Ship" was coined and became widely used as a result of a wartime public relations campaign undertaken by President Roosevelt's administration. Though the less glamorous term "Ugly Duckling" has been widely attributed to President Roosevelt, some sources trace it instead to newspaper coverage by the New York Times. [184]

Though the Emergency Cargo or Liberty class design program was intended to achieve simplicity and ease of construction, countless design modifications became a matter of necessity as the war progressed. By the summer of 1944 an airplane transport variation was designed which was, in fact, an alteration of the earlier EC2 tank carrier design, with the effect being to bring the vessel closer to Gibbs & Cox' basic EC2-S-C1 design. The airplane transport (sometimes referred to as "boxed airplane carrier") was given the special designation Z-EC2-S-C5 (Figure 3).[185]

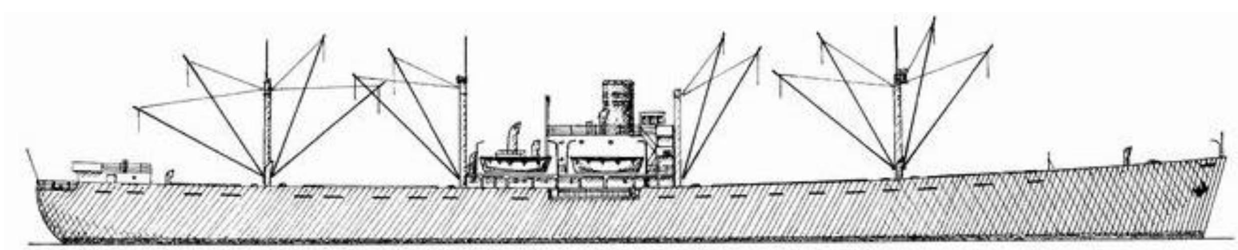

Figure 3. Outboard Profile of Type Z-EC2-S-C5 Emergency Cargo Vessel (Karsten-Kunibert Krueger-Kopischke, http://drawings.usmaritimecommission.de/drawings_ec2.htm).

The plan of the Z-EC2-S-C5 airplane transport ships differed from the standard five-hold configuration typical of most other EC2 vessels, most evidently in the use of four masts, two forward and two aft of the

[182] Reardon, Donald V., editor, *Design Z-EC2-S-C5 Airplane Transport Stowage and Capacity Booklet.* U.S. Maritime Commission, 1946. Archived at San Francisco Maritime National Historical Park, Maritime Research Center, San Francisco, California.
[183] Bourneuf 2008, 10.
[184] Žuvić 2013.
[185] Bourneuf 2008, 103.

central bridge, each fitted with cargo winches and booms rated for lifting 10 tons into two forward and two aft cargo holds. The ship's bridge was located centrally with a large vent stack centered over the engine, boiler room, and fuel oil settling tanks. Forward of the vent stack and atop the upper deck were the wheel house and the officers mess. Behind the vent stack were the gyro room, the main galley, officers and steward quarters, various passageways, and a hospital (Figure 4). Accommodations were originally provided amidships for as many as 45 ship's crew, with up to 36 gunners accommodated in separate

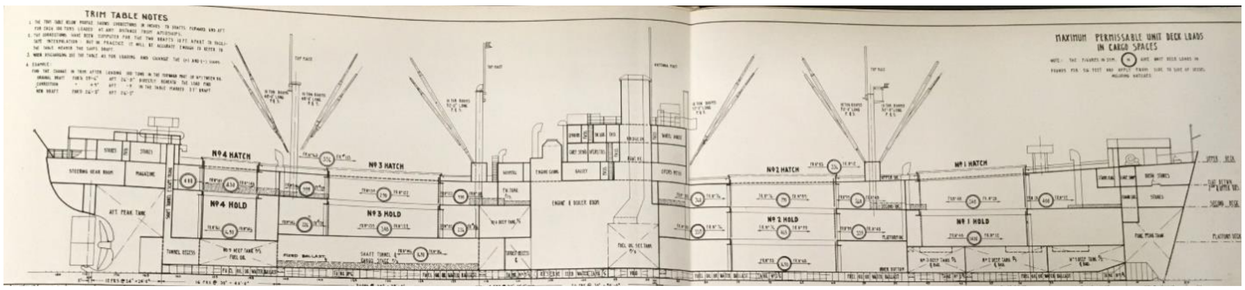

Figure 4. Internal Profile of the Z-EC2-S-C5 Airplane Transport
(Reardon 1946 - see Reardon drawings in Appendix A for a digital copy of this image)

quarters. There were four lifeboats, two with capacity for 25 people and two with a capacity for 31 people. At first one, then later both, of the 25-man boats were provided with a motor.[186]

The rear or "fantail" portion of the main deck included a low deck house that accommodated small storage needs and supported a gun emplacement atop the rear deck house. Additional weapons were typically positioned on the port and starboard sides of the bridge deck. A single three-inch gun would often be fitted on the bow. Many variants on this typical arrangement existed, with additional guns fitted in other areas. As with all ships during the war, the armament tended to increase as the war progressed.[187]

Structurally, the steel hull was to be reinforced by a series of vertical watertight bulkheads extending laterally from the port to starboard sides of the hull. Additional structural reinforcement was provided by dividing the below-deck spaces horizontally into three sub-decks and a variety of storage compartments and tanks. Below the main deck from top to bottom was a second deck, a platform deck, and an inner bottom deck, each of which was further divided into cargo holds and compartments for a variety of functions, including boxed-airplane storage. Cargo Holds 1 and 2 would be located forward of the central engine and boiler room with cargo holds 3 and 4 located aft of the central engine and boiler room. Each hold was accessible by a large hatch on the main deck and the fore and aft cargo handling masts with their laterally swinging booms.

[186] Bourneuf 2008, page 80 indicates that Liberty ships were generally designed to carry an operating crew of 52, with up to 29 additional gun crew.
[187] James Davies, "Liberty Ship Briefing", http://www.ww2ships.com/usa/us-os-001-b.shtml, accessed 8 November 2015.

Foremost in the ship's bow was the Bosuns[188] storage area, general storage, and anchor chain storage compartments. Several sealed storage tanks were also located deep in the ships bow and below the floor of Hold 1. General cargo was stored on three sub-decks between Holds 1 and 2. Just aft of the central engine and boiler room a freshwater tank was located directly beneath the Hospital. General cargo storage compartments aft of the engine and boiler room were accessible via Hold 3 and Hold 4, though the lowest level below Holds 3 and 4 included an long tunnel to accommodate the propeller shaft that connected the engine to the propeller. Above the propeller, the second deck included a steering gear room and a magazine for munitions storage.

Otherwise, a variety of storage tanks, typically for fuel oil or ballast water, were located at the lowest levels of the ship, below Holds 3 and 4 and in the space between the inner and outer hulls. Apart from the fixed ballast locations shown in Figure 4, liquid ballast tanks were distributed throughout the lower levels of the ship's hull and connected to pumps to enable trimming of the ship fore-and-aft and side-to-side according to towing demands and other variable conditions at sea.

U.S. Army Nuclear Power Barge MH-1A *STURGIS* (1963-2019)

In response to the Army's specification calling for conversion of a World War II Liberty ship to a nuclear power plant barge, one of the first design challenges involved replacing the mid-section of a typical Liberty ship with an entirely new mid-section approximately one-half the overall length of the ship.[189] The new mid-section, called a floating mount, was specifically designed to safely and effectively accommodate a compact but independently functional nuclear power plant (Figure 5). Accordingly, the original power plant and propeller drive mechanisms of the Liberty ship were to be removed and the new mid-section structurally joined with watertight bulkheads to the original Liberty ship's bow and stern sections.

In designing the new mid-ship section to contain the nuclear reactor and related components, the ANPP and the Martin Company recognized that safety for the crew and the environment surrounding the floating nuclear power plant, wherever it may be deployed, were of prime concern. The fundamental problem they sought to prevent was an unplanned release of radioactivity under worst-case conditions or catastrophic events the ship might encounter. The Martin Company's naval architecture contractor, J.J. Henry Company, focused on protecting the central nuclear power plant from potentially catastrophic

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[188] The Bureau of Navy Personnel Instructions, http://buperscd.technology.navy.mil/bup_updt/508/OccStandards/CHAPTER 14.htm, accessed 10/1/2018, defines the role of Boatswain's Mates (or Bosun) as an officer who trains, directs, and supervises personnel in ship's maintenance duties, in all activities relating to marlinespike, deck, boat seamanship, painting, upkeep of ship's external structure, rigging, deck equipment, and boats. They take charge of working parties; perform seamanship tasks; act as petty officer-in-charge of picket boats, self-propelled barges, tugs, and other yard and district craft. They maintain discipline as master-at-arms and police petty officers; serve in, or take charge of, gun crews or damage control parties; and operate and maintain equipment used in loading and unloading cargo, ammunition, fuel, and general stores.

[189] On page 3 of *The Design and Construction of a 10,000 KWe Floating Nuclear Power Plant for the U.S Army.* George A. Johnson and Gerald W. Chase, hereafter cited as Johnson and Chase 1964, identify the length of the new mid-section as 212 feet. See Appendix C - Supplemental Materials, Historical Documentation, Technical Reports for a complete copy of this report.

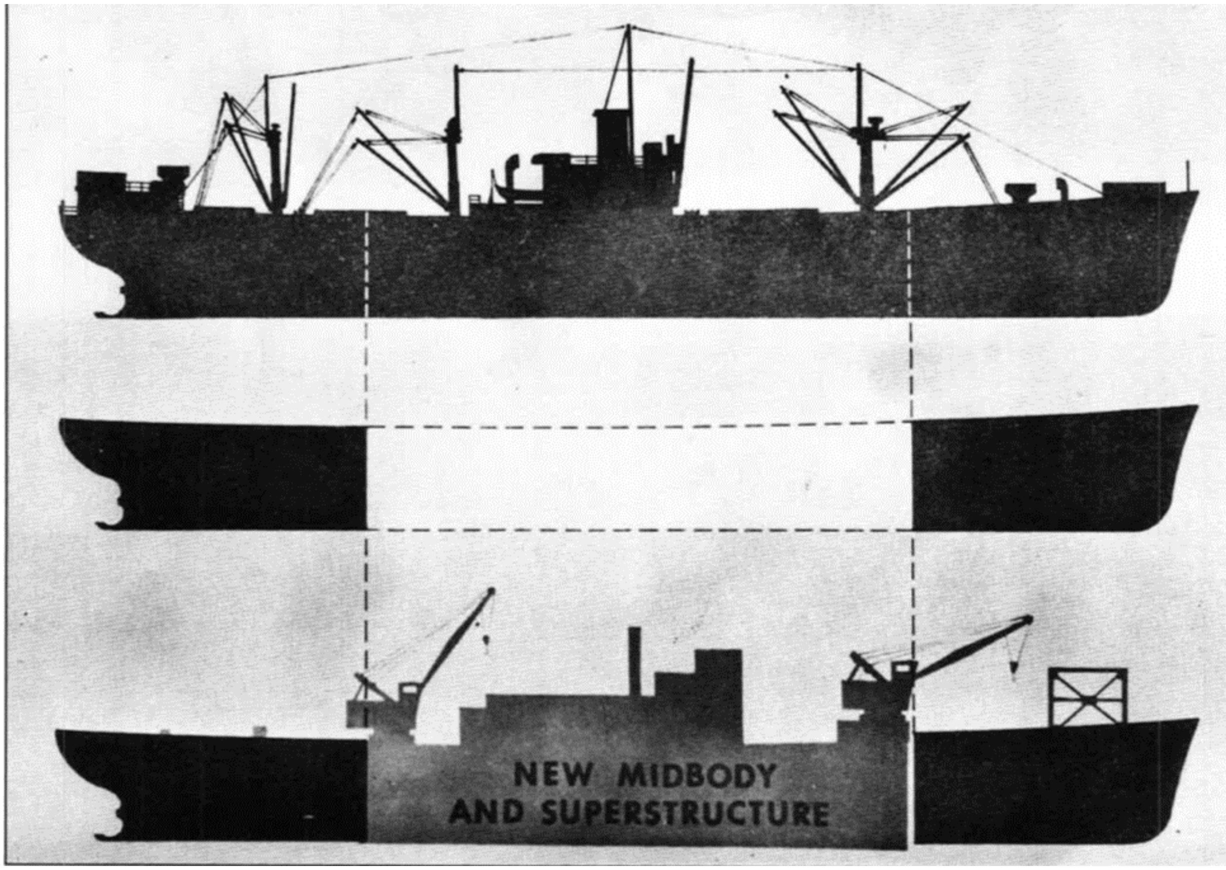

Figure 5. *Concept for replacement of Liberty Ship mid-body for conversion to nuclear power production barge* (Johnson and Chase 1964).

impacts, such as might occur with a severe grounding of the vessel or a broadside collision with another large vessel, and consequential sinking of the vessel.

Their approach to this design challenge was to place the nuclear plant centrally within the vessel and surround it with watertight bulkheads and "collision barriers," including steel-reinforced concrete walls, beside and below the power plant to absorb major impacts and leave the nuclear plant undamaged. After analyzing the depth or "draft" of the converted vessel as well as the maximum allowable impact of a large Mariner-class cargo vessel colliding with the new mid-section under various scenarios, the Martin Company's architects and engineers determined that adequate collision barrier protection around the nuclear power plant required the maximum width or "beam" of the typical Liberty ship to be increased. Consequently, the maximum beam of the new mid-body was designed to be eight- feet wider than the original, with the beam of the new mid-body tapered fore and aft to match up with the Liberty ship's bow and stern sections.

Similarly, the architects and engineers designed additional bottom hull protection by designing an inner hull bottom. The space between the inner and outer hulls would provide additional protection against catastrophic hull rupture in the event of a severe grounding. Designed to exceed safety guidelines established by Lloyds of London's, the space between the inner and outer hulls was increased to provide 7 feet of separation beneath the floor of the nuclear reactor deck. By further adding saltwater, freshwater, and fuel oil compartments as ballast compartments within the bottom hull spaces and by distributing the liquid ballast in the various ballast compartments, the trim or "balance" of the ship could be adjusted to compensate for potentially dangerous conditions the ship might experience while being towed or during other destabilizing sea conditions. [190]

Removal of the ship's original mid-section, containing its steam engine and boilers as well as its propulsion system, essentially converted the vessel from a self-propelled ship to a non-propelled barge. Conversion of the ship's system from steam power to modern electro-mechanical technology also necessitated modifications to the ship's steerage system and extensive changes to its operational equipment and safety systems. For example, the original rudder was replaced with a larger rudder to help maintain directional control of the barge while under tow at slower speeds – 8 knots rather than the Liberty ship design speed of 11 knots. The ship's original steam-driven rudder controls and anchor handling equipment would also be upgraded with new electro-hydraulic equipment. The ship's original anchors, anchor chains, and hawse pipes were among the few original components that would be retained for future use.

Removal and replacement of the ship's mid-section also necessitated a complete reconfiguration of the Liberty ship's decks and internal spaces. The entire main deck would receive a new multi-story deck house over the central nuclear power plant and the former multi-boom masts fore and aft would be replaced with two rotating single-boom Skagit cranes rated to lift 15 tons. Additionally, a large electrical transmission frame would be mounted prominently near the ship's bow to facilitate connection of electrical transmission cables from ship-to-shore. Below the main deck and just aft of the electrical transmission framework a vertical water screen would be installed to screen debris from seawater used in the ship's ballast and cooling systems. These two components would be retrofitted within the original bow section of the Liberty ship (Figure 6).

Also located in the ship's original bow, just aft of the new water screen, a diesel generator room and switchboard/electrical distribution room would be placed below the main deck to provide start-up power and switching controls when bringing the nuclear power plant online and to provide a base level of non-nuclear electrical power for shore-based applications. Just aft of the diesel generator and the switching/electrical distribution room, a new Main Machinery Room would be positioned within the forward portion of the ship's new mid-body to provide operational and maintenance support to the diesel generator room as well as a new turbo-generator that would serve to convert thermal energy output from the nuclear power plant into electrical power for onboard and shore-side applications.

Beneath the ship's new mid-ship deck house, containing the Pilot House and quarters for a 15-man "riding" crew, a central Control Room would be situated strategically below the main deck and between the turbo-generator and the nuclear reactor spaces to provide coordinated control of those key power

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[190] Johnson and Chase, 1964, pages 7-12, describes the collision barrier and grounding protection system designs in greater detail. See Appendix C - Supplemental Materials, Historical Documentation, Technical Reports appended to this report.

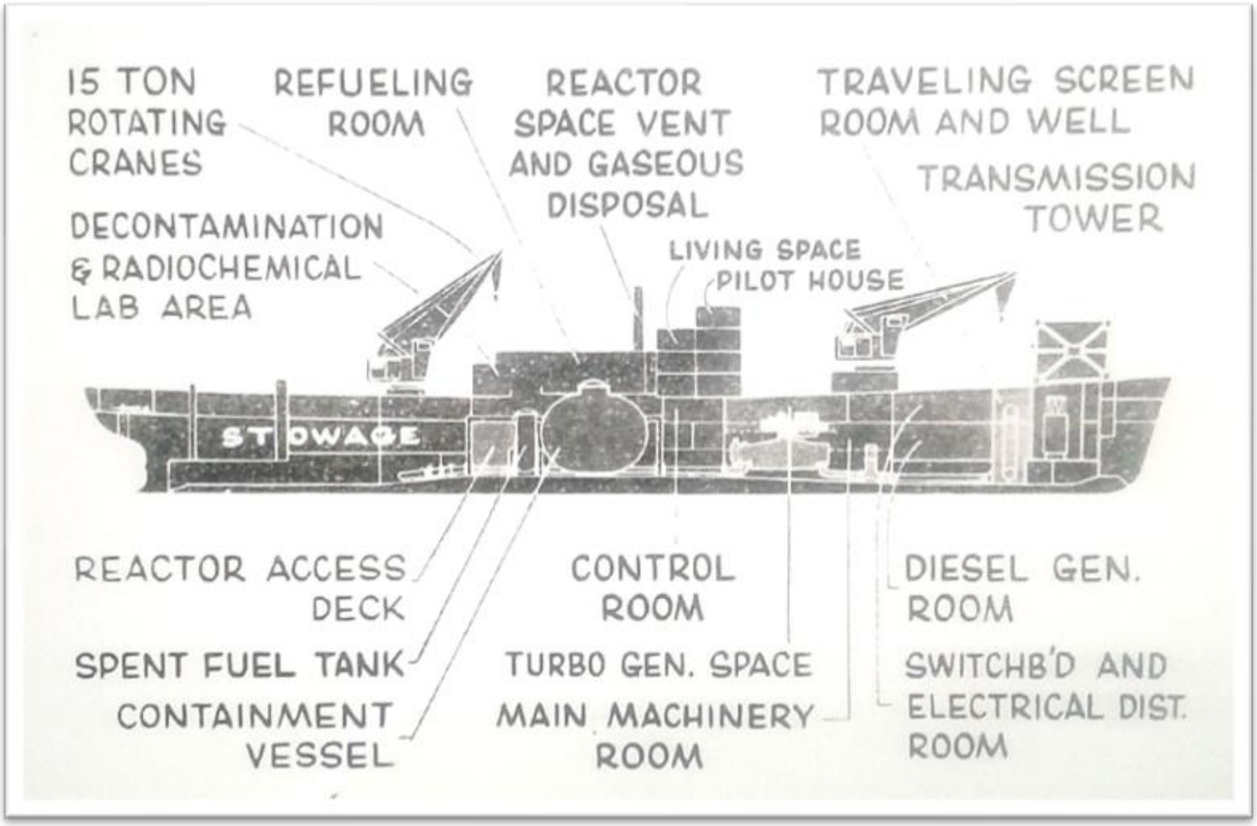

Figure 6. Inboard Profile of the MH-1A Nuclear Power Barge (Johnson and Chase 1964).

production components. The nuclear reactor spaces would be situated centrally within the new mid-body structure and would include the MH-1A reactor within its ovoid containment vessel as well as a spent fuel storage container that could be accessed via a large hatch on the main deck for loading and unloading nuclear fuel. The ovoid reactor containment vessel would be securely cradled in a steel framework that would be welded to the new inner bottom hull to maximize protection of these vital nuclear power plant components.

Personnel access to the central reactor components would be accommodated by way of a reactor access room, located immediately aft of the spent fuel storage container (see Figure 6). Refueling of the reactor would be accomplished by means of a 15-ton overhead hoist located in the refueling room which would lift the access hatch on top of the reactor containment vessel and thereby gain access to remove the cover of the reactor core and replace the fuel elements and control rods inside. The crane was designed to remove the spent fuel assemblies and move them to a separate, adjacent spent fuel storage cask in the reactor access room. Radiochemical laboratory and decontamination facilities would be placed immediately aft of the refueling room, also at the main deck level. Aft of the new mid-body deck house, the reconfigured main deck of the ship included a large single-boom crane positioned for removal of the spent fuel storage cask as well as a variety of below-deck stowage compartments in the rear third of the ship. Throughout the vessel, stowage spaces were provided for spare parts, etc., that would be necessary for the MH-1A *STURGIS* to operate self-sufficiently when on mission assignments at remote locations.

<u>MH-1A Nuclear Power Plant</u>

In response to the Army's design specifications for safety and continual operational availability over the period of one-year, the ANPP and Martin Company's nuclear power plant engineers selected a low enriched, pressurized, water-cooled reactor design already proven safe and capable in the other U.S. military nuclear power plants. The MH-1A system was designed to operate with multiple layers of containment, monitoring, and treatment systems surrounding the radioactive core of the reactor. As described above, the mid-body structure, or floating mount, was itself a water-tight structural enclosure designed to provide collision protection around the MH-1A reactor containment vessel. Additional layers of protection within the floating mount included a primary shield of cooling water surrounding the reactor core and a secondary shield of reinforced concrete (up to 4 feet thick), lead (5 inches), and polyethylene (8 inches) surrounding the reactor containment vessel and the spent fuel storage cask. The multi-layered shielding system was designed to provide both collision protection around the power plant and to absorb radiation emanating from the radioactive fuel elements and control rods inside the reactor core and in the spent fuel storage tank.

Further safety measures designed and incorporated into the MH-1A nuclear power plant included a reactor cooling water system that was itself designed with redundant layers of protection surrounding the plant's radioactive core elements. Operational safety zones and operational procedures were established to limit crew exposure to radiation in areas of moderate and high radiation. Radioactive wastes in the form of liquids and gases from the reactor core and the containment vessel, were collected, analyzed, treated, and disposed or stored as necessary to prevent release of radioactivity into the environment surrounding the ship. [191]

Reactor Core

The innermost component of the MH-1A nuclear power plant, the reactor core, was designed as a stainless-steel pressure vessel, known as the reactor pressure vessel (RPV). Operationally, heat produced within the RPV would be absorbed by a constant flow of cooling water and carried away to a steam generator where high pressure saturated steam was used to drive a combined turbine and generator system, called the turbo-generator, to produce electricity. Figure 7 illustrates the primary and secondary systems as they were designed for the MH-1A nuclear power plant. Together the reactor, pressurizer, coolant pumps, and steam generator equipment comprise the primary system and were designed to fit as a group within a large ovoid stainless-steel pressure vessel called the MH-1A containment vessel (Figure 8). At 31-feet diameter, 43-feet long, and weighing 350 tons, the containment vessel was a specially constructed pressure vessel that was mounted centrally within the ship's new mid-body structure and

[191] Johnson and Chase 1964, page 29, provides a more detailed description of the radiation protection measures and safe-exposure parameters designed for the MH-1A nuclear power plant. See Appendix C - Supplemental Materials, Historical Documentation, Technical Reports appended to this report.

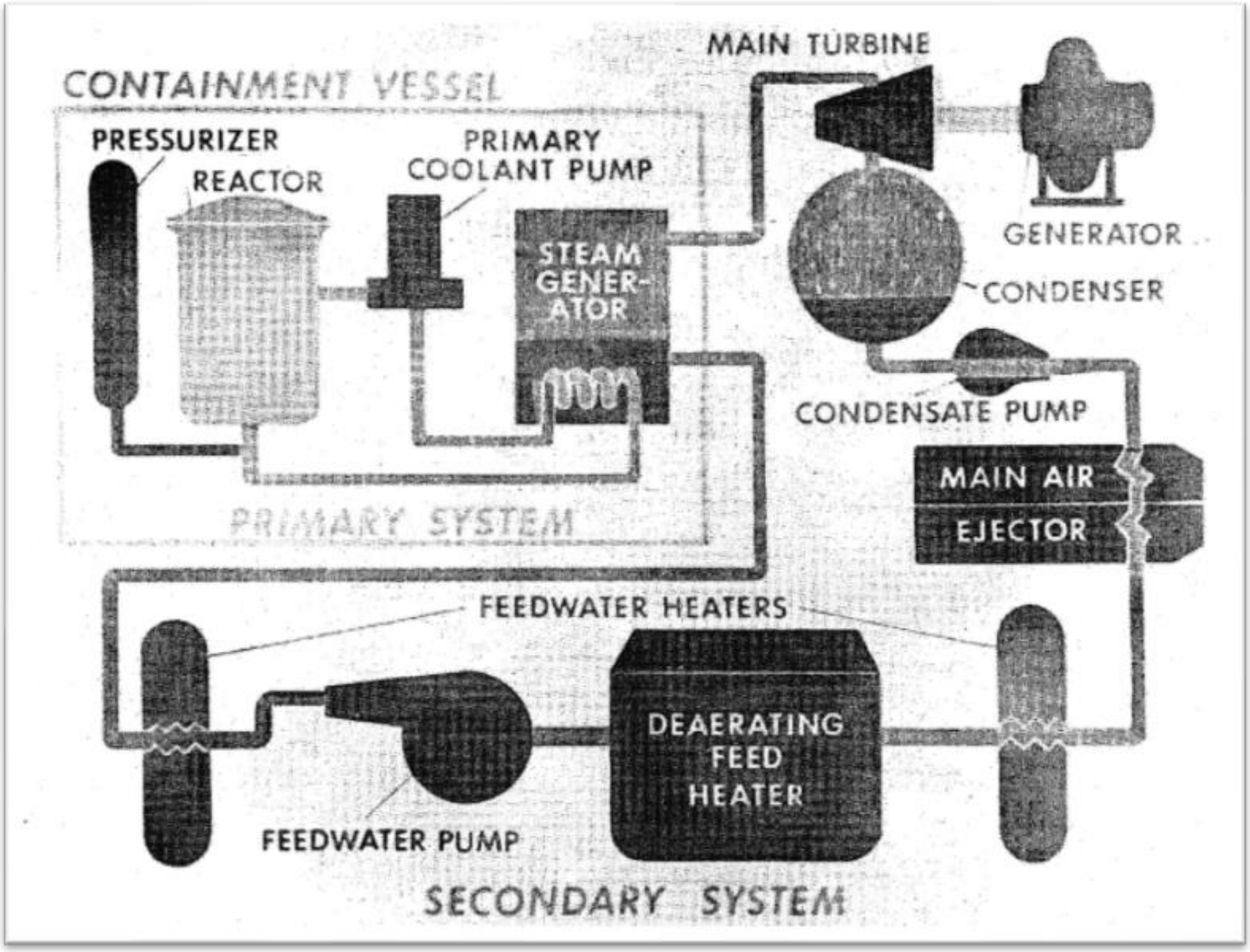

Figure 7. Schematic Diagram of MH-1A Nuclear Power Plant (Johnson and Chase 1964).

designed to withstand maximum credible accident pressures from inside and out.[192] The containment vessel had removable but sealed hatches for personnel access and for loading and unloading fuel assemblies from within the reactor core. Given the number of smaller electrical, plumbing, and other penetrations through the containment vessel wall, each opening was fitted with special seals designed to control the amount of leakage that could escape during a possible accident or equipment failure within the containment vessel. To further control the level of risk to the system and personnel, the MH-1A containment vessel was fitted with internal air filtration and firefighting systems.

[192] Johnson and Chase 1964, pages 31-32, provides more detailed descriptions and illustrations of the primary system designed for the MH-1A nuclear power plant. See Appendix C- Supplemental Materials, Historical Documentation, Technical Reports appended to this report.

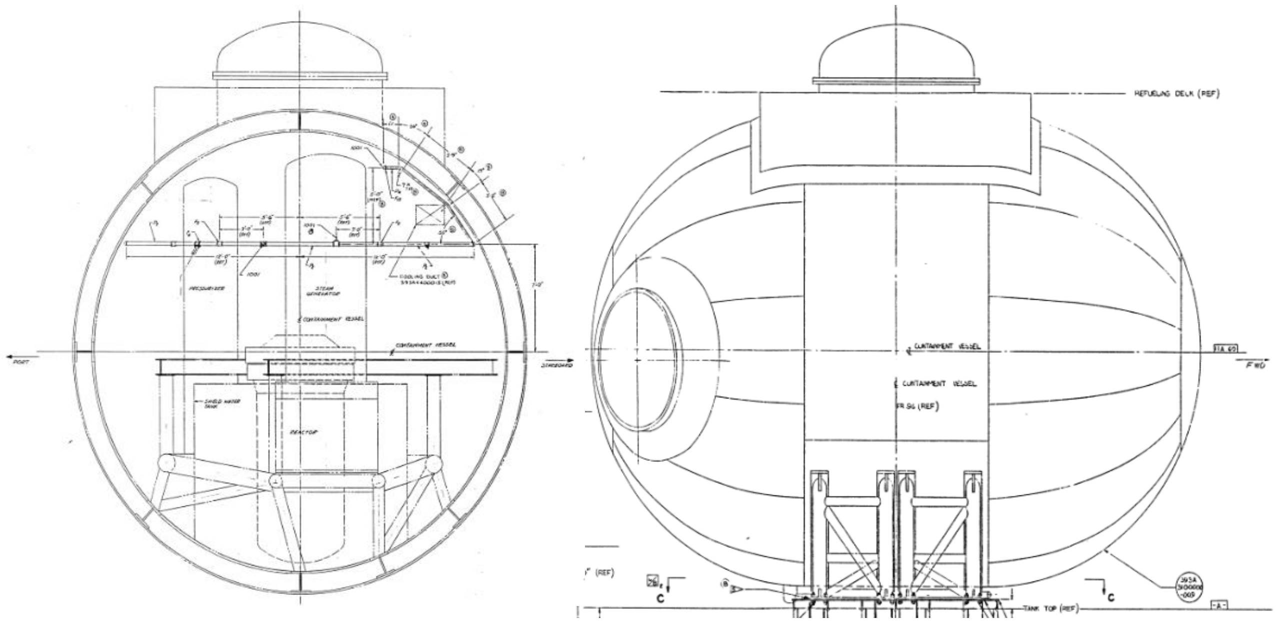

Figure 8. MH-1A Nuclear Reactor Containment Vessel, circa 1963
(Reproduced in U.S. Army Corps of Engineers *Historical Site Assessment – Final (Rev 2*), 2013).

Uranium 235 (U-235) was selected as the radioactive or "fissile" material for the MH-1A nuclear reactor. When combined with Uranium dioxide (UO_2) at a low-level (5% U-235) and formed into fuel pellets (Figure 9), 2,918 kilograms of this low-enriched nuclear fuel could generate 45 megawatts of thermal energy over the one-year minimum duration required by the Army's design mandate.[193] [194] The extreme levels of heat generated by the fission chain-reaction within the reactor core would be controlled by inserting specially designed control rods of Boron and stainless steel that absorbed or "poisoned" the radiation emanating from the fuel elements. Special hydraulic lifting mechanisms called "fingers" were designed to raise or lower the control rods to a position adjacent to the fuel elements – thereby maximizing the absorptive effect of the control rods and controlling the heat generated by the fuel rods inside the reactor core. The lifting mechanisms were designed to insert the control rods automatically in the event of emergency, thereby limiting the reactive power of the fuel rods. As described by the Martin-Marietta Corporation in

[193] Johnson and Chase 1964, page 24, indicates that 2,918 kilograms of Uranium fuel for one year of MH-1A operation equates to 9,740,000 gallons of fuel oil used by a conventional oil-fired power plant. See Appendix C-Supplemental Materials, Historical Documentation, Technical Reports appended to this report.
[194] Current naval reactors are designed for 93-97% enrichment, which allows for smaller reactors and refueling every 10 or more years over their 20-30 years lifetime; whereas, land-based reactors use fuel enriched to 3-5% and need to be refueled every 1 – 1-1/2 years, M. Rahgeb, Nuclear Marine Propulsion, 9/11/2018, http://mragheb.com/NPRE%20402%20ME%20405%20Nuclear%20Power%20Engineering/Nuclear%20Marine%20Propulsion.pdf, page 4.

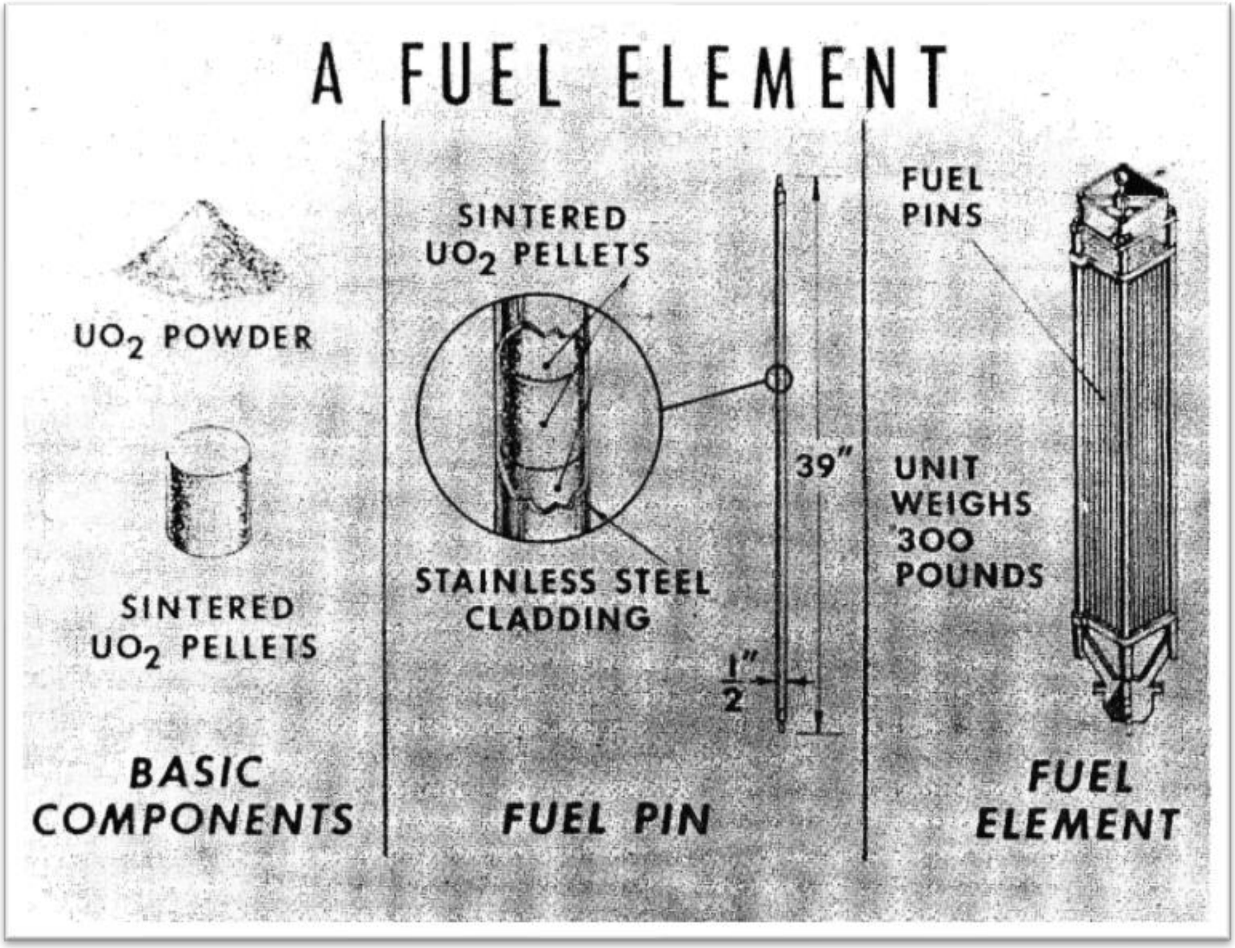

Figure 9. Schematic Diagram of MH-1A Fuel Element.

1965[195] the interior of MH-1A reactor core was designed to include a circular array of 32 fuel elements or "cells" arranged in a grid, with each fuel cell loaded with 104 stainless steel-clad "pins", 39 inches long and 0.507 inches diameter, containing specified quantity of low-enriched uranium dioxide pellets (Figure 10). Also inserted into the grid among the fuel cells were twelve cruciform control rods, with each arm or blade constructed of a 0.25-inch thick layer of enriched boron that serves to absorb and thereby "poison" the radiation released by the U-235 fuel elements. Other reactor core components included one centrally located fuel "source" pin and twelve stainless steel dummy rods filling the vacant cells in the grid.

As noted above, the MH-1A reactor pressure vessel (RPV) was designed as a stainless-steel barrel, 200-inches tall and 73-inches in diameter, to contain the reactor's Uranium dioxide fuel elements and Boron control rods. A specialized alloy called Austenitic stainless steel was specified for the RPV construction to maximize resistance to internal corrosion. The top of the RPV was capped with a shallow dome, also of

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[195] Martin-Marietta Corporation, *MH-1A Final Design Report, Nuclear Analysis MND-3238*, September 1965, pages 45-50. See Appendix C- Supplemental Materials, Historical Documentation, Technical Reports appended to this report.

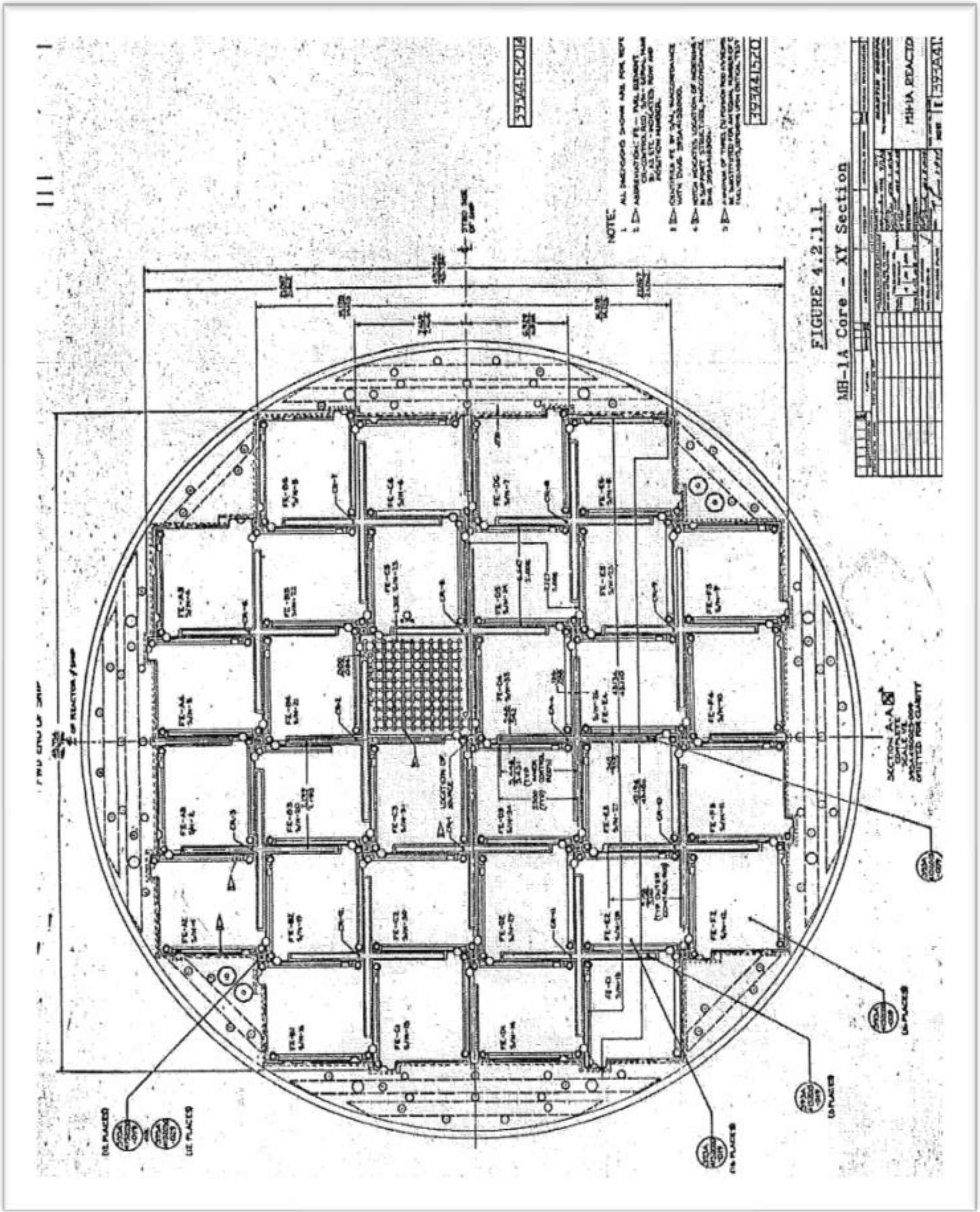


Figure 10. Horizontal cross-section of MH-1A Reactor Core with 32 fuel cells and 12 control rods. (Martin-Marietta Corp. 1965, page 46). Note: only one fuel cell is shown with its 104 fuel pins.

special stainless steel, that was perforated with twelve openings to allow for raising and lowering of individual reactor control rods. The inner wall of the RPV was fitted with multiple layers of radiation and thermal shielding designed to absorb radiation and heat that would otherwise be absorbed by the vessel wall. The outer wall of the RPV wall was designed with in-flow and out-flow ports near the top to allow pressurized coolant water to be circulated into the RPV, completely submerging the radioactive fuel elements and control rods, and out of the RPV on its way to the steam generator (Figure 11).

In response to the U.S. Army's requirement that the MH-1A plant produce power that would be readily if not continuously available for a one-year period, the engineers developed a reactor refueling method that would maintain a balanced output of energy from the reactor core despite the gradual decay of the fuel rods and corresponding diminishment of energy production over time. The design solution was to shuffle fuel rods in and out of the reactor core in such a way that the reactor always contained a balance of partially decayed and newly installed fuel rods. Using this system, fully decayed fuel rods were removed from the central region of the reactor core and replaced by partially decayed fuel rods from the outer portion of the reactor core. New fuel rods were then installed in the outer portion of the reactor core. With this approach partially expended fuel is fully consumed before being removed for storage and disposal.[196]

Figure 12 illustrates the MH-1A refueling process whereby spent fuel rods were removed, placed in a spent fuel transfer cask, and the cask transferred to a spent fuel storage tank located on the reactor access deck, just aft of the reactor containment vessel (see Figure 6). Each transfer cask weighed 29,000 pounds and required a 15-ton capacity rolling hoist to lift the spent rods from the reactor core, out of the containment vessel, and place them within the spent fuel transfer cask. A special two-part refueling shield tank was designed to be erected on top of the containment vessel and filled with water to limit radiation emanating from the spent fuel rods as they were transferred to the spent fuel transfer cask. The spent fuel tank was designed as a vertical metal cylinder, 28 feet long and 7 feet six inches in diameter, to contain up to 36 spent fuel elements, equivalent to a one-year supply, submerged in 8,000 gallons of demineralized water. Additional shielding was placed around the spent fuel transfer cask to absorb any residual radiation emanating from the stored spent fuel elements inside the spent fuel storage tank.

Cooling System

The MH-1A reactor cooling system was designed to ensure safe operation of the system under normal as well as various emergency scenarios. The final design report for the MH-1A reactor coolant system[197] describes the normal operational and emergency backup systems, all of which were designed to operate completely and independently within the "floating mount," referring to the mid-body hull structure designed to contain the MH-1A nuclear power plant and float independently of the ship's bow and stern sections. Under normal operations "light," meaning non-radioactive, cooling water would be continuously pumped through the RPV, thereby cooling the hot core elements from normal operating temperatures of

[196] Ibid.
[197] Martin Marietta, *Final Design Report, MH-1A Reactor Coolant System,* 1964. See Appendix C- Supplemental Materials, Historical Documentation, Technical Reports appended to this report.

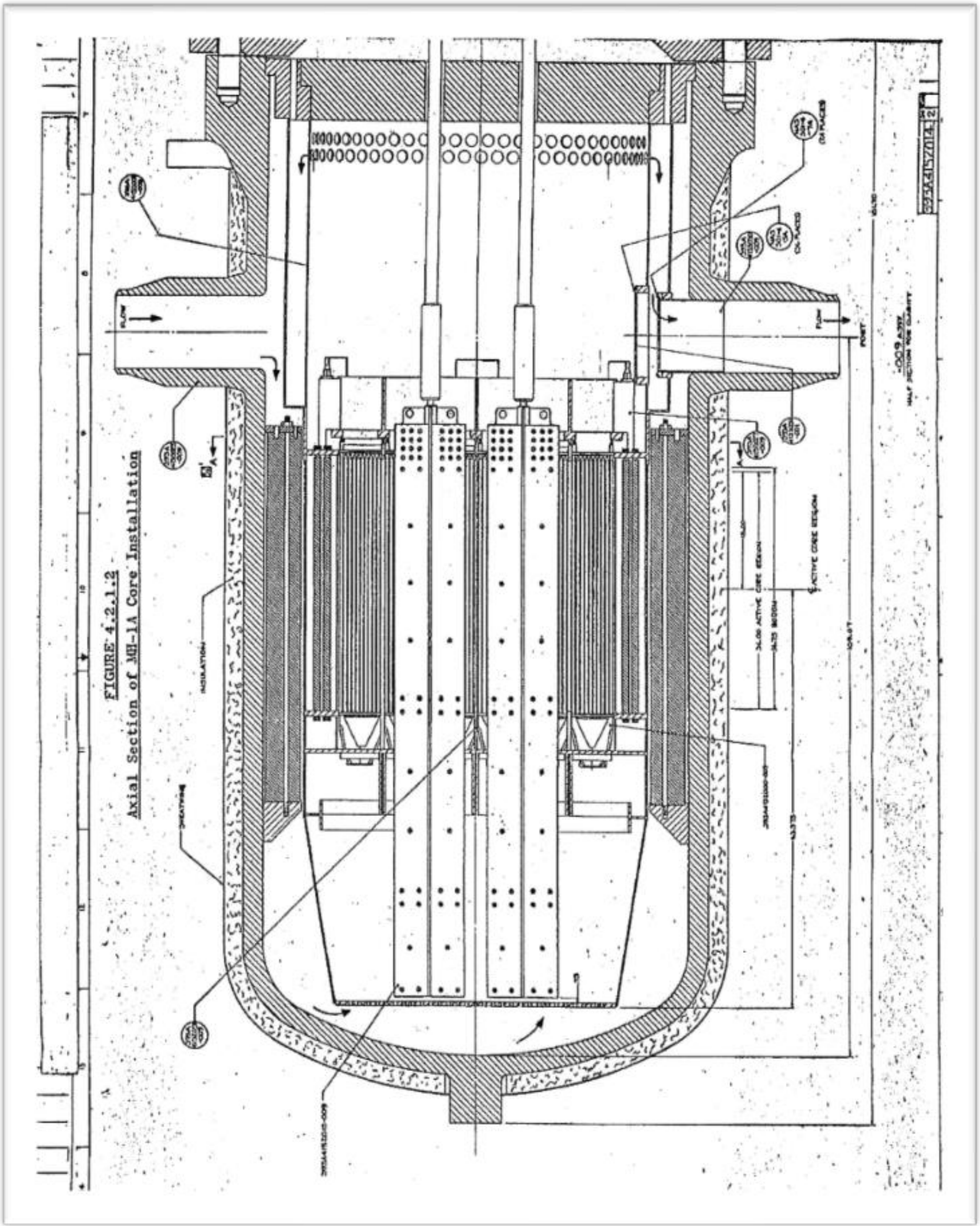


Figure 11. Reactor Core Vertical Cross-section Showing Fuel Cell and Control Rod Arrangement (Martin-Marietta Corp. 1965, page 47).

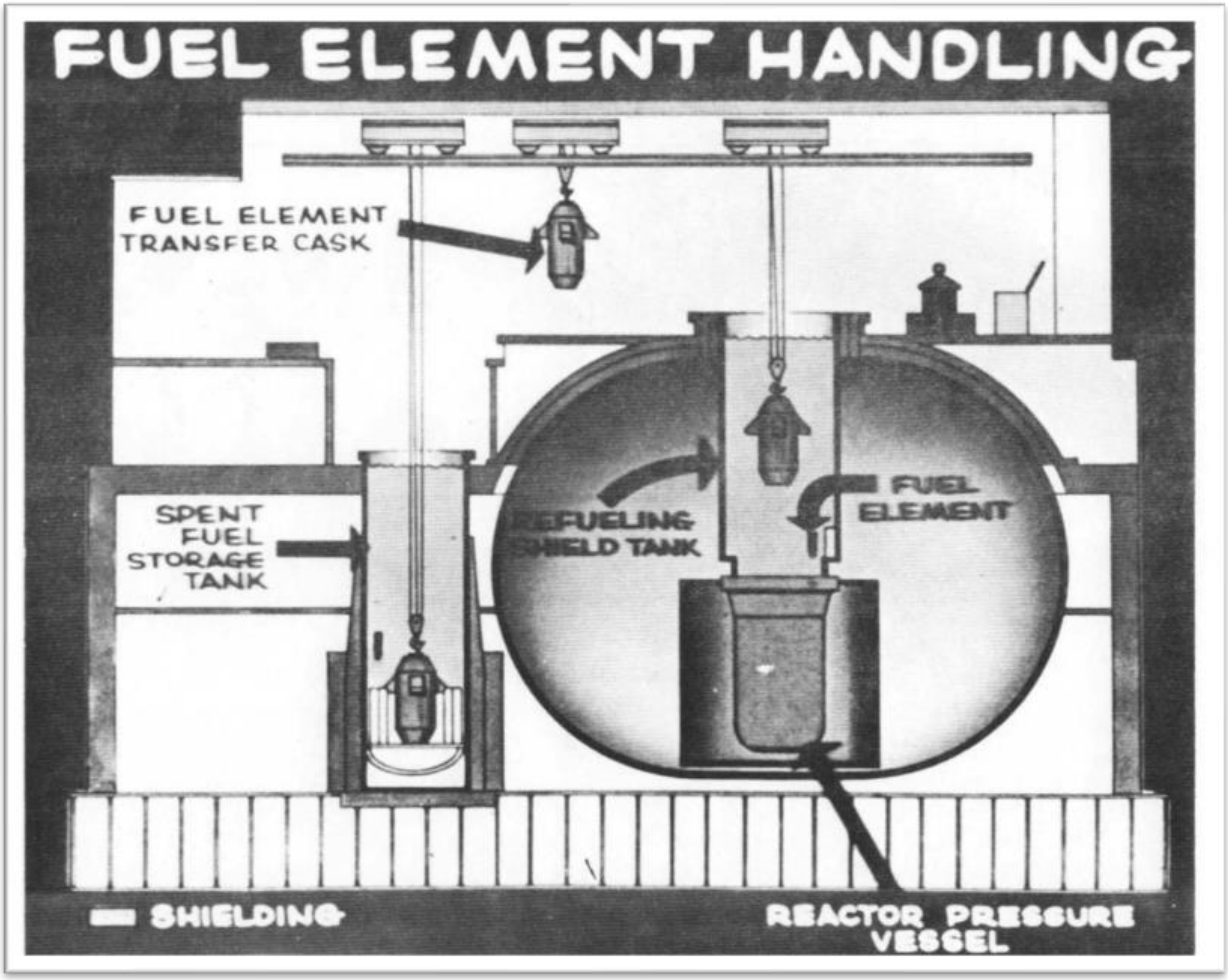


Figure 12. MH-1A Refueling Process Diagram (Johnson and Chase 1964, pp. 27-28).

510^0 F to 470^0 F. Non-pressurized cooling water was also circulated around the RPV in a primary shield designed to absorb excess heat radiating from the RPV.

The effectiveness of the pressurized cooling system was designed to be maintained at all times through simultaneous operation of primary and secondary water pumps, each providing 4,000 gallons per minute of circulation throughout the primary reactor coolant system (Figure 13). Both reactor cooling pumps were specified to be canned electro-mechanical rotary type pumps. The pumping and piping systems were designed to ensure the RPV was always filled with water, sufficiently to submerge the radioactive fuel elements and control rods, even in the event of pump failure or pipe rupture. A secondary or emergency water supply was also designed to inject cooling water into the reactor core during routine maintenance and decontamination procedures or during emergency events requiring repair or replacement of pumping equipment or water circulation pipes.

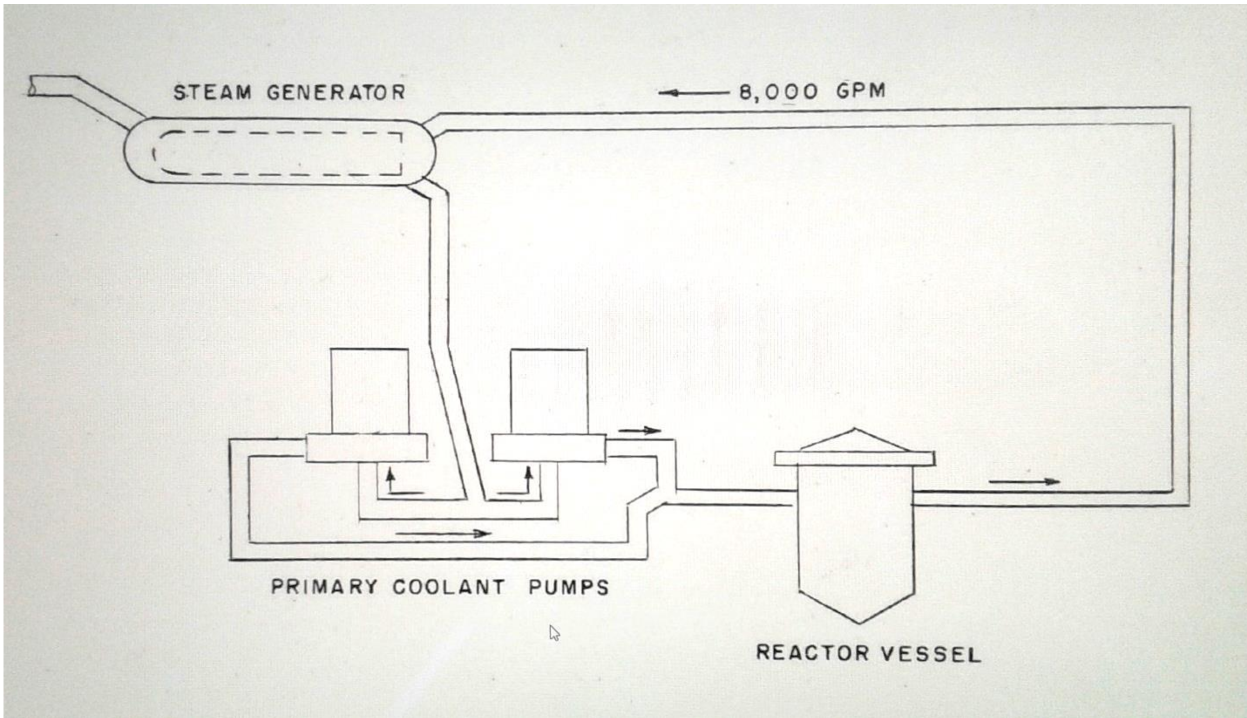


Figure 13. MH-1A Reactor Coolant System Diagram (Johnson and Chase 1964, pp 16-17).

The MH-1A coolant system was designed to reduce the reactor water and the primary shield water temperature to 120 degrees Fahrenheit (^{0}F) within 12 hours of a scheduled system shutdown or an unscheduled "scram" shutdown event. Notably, even in the event of complete electro-mechanical pump failure, the system was designed to provide natural or passive cooling of the reactor core whereby the cooling water would passively circulate through the reactor core and the steam generator to gradually reduce the temperature of the reactor core water from a maximum design temperature of 617^0 F to a safe level of 120^0 F over a period of five days.[198]

Water purification was also integral to the MH-1A pressurized reactor cooling system to remove minerals that would accumulate in the cooling water over time, thereby increasing acidity and promoting corrosion within the primary cooling system. Special non-corrosive materials, either Austenitic stainless steel or Inconel,[199] were specified for all equipment and components that would be in contact with reactor cooling water.[200] Also, as reactor cooling water tends to decompose into hydrogen and oxygen in the presence of

[198] Ibid, 2.
[199] Austenitic stainless steel is a special stainless steel alloy containing high percentages of nickel and chromium suitable for high pressure, high temperature applications requiring high levels of corrosion resistance https://www.collinsdictionary.com/dictionary/english/austenitic-stainless-steel. *Inconel* is a trademarked alloy of this type.
[200] Martin-Marietta 1965, page 17. See Appendix C- Supplemental Materials, Historical Documentation, Technical Reports appended to this report.

the reactor's radiation field, additional hydrogen was injected into the primary cooling water to bind with free oxygen and minimize oxygen's highly corrosive effects. Continual analysis of the reactor water quality was to be carried out in the radio-chemical laboratory to determine when the cooling system required treatment or replacement with fresh "light" water. All tanks, pumps and piping involved in the reactor cooling systems were designed to safely vent and drain with the contaminated water captured and stored in the floating mount until it could be safely transferred to an onshore disposal facility

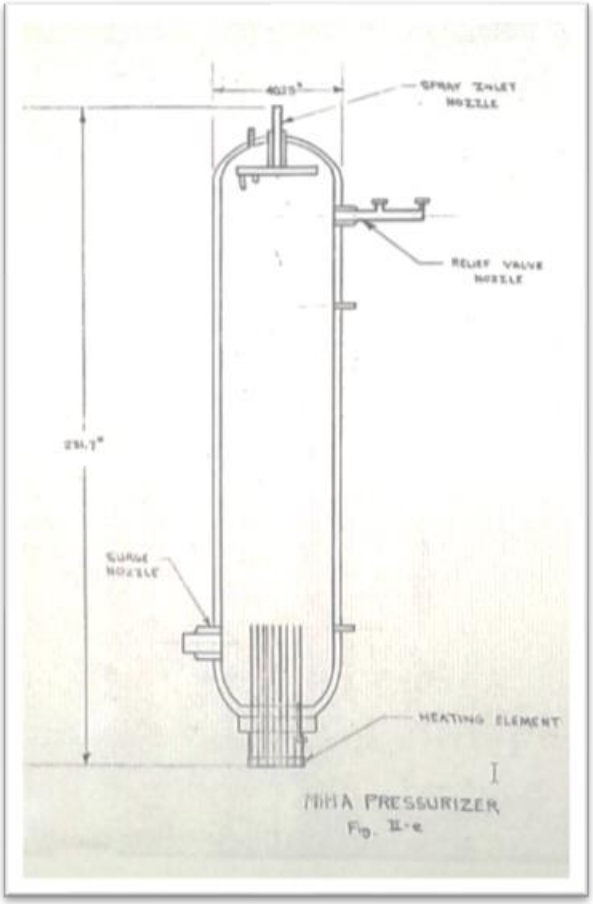
Pressurizer

The MH-1A pressurizer was designed as an integral component of the MH-1A nuclear reactor. Located within the reactor containment vessel and connected to the reactor's primary coolant water piping system, the pressurizer was designed to maintain pressure within the primary cooling system at 1,500 pounds per square inch absolute (psia).[201] Designed as a cylindrical pressure vessel with piping inlets and outlets as well as an internal spray nozzle and electrical heating element (Figure 14), the pressurizer maintained a volume of pressurized steam within the vessel. As pressures and temperatures varied within the overall reactor cooling system, the pressurizer buffered those variations, prevented boiling of the cooling water, and served as a self-regulating control for the temperature of the cooling water entering the RPV. Once the reactor had been brought online and the reactor control rods adjusted to achieve a steady state operating temperature of 510^0 F for the coolant water leaving the RPV, the pressurizer enabled the entire system to self-regulate with minimal mechanical manipulation of the control rods.[202]

Steam Generator

In addition to the primary cooling system pumps and piping, a key component of the MH-1A's operating system is the system's steam generator. The steam generator was a vertical stainless-steel cylinder, 65 inches diameter and 18 feet, 10 inches tall located inside the reactor containment vessel with a 16-inch personnel hatch, large enough to provide access for repairs to the tank's internal coolant circulation tubes (Figure 15). As described above, water heated during its passage through the reactor core would be circulated from the RPV to the Steam Generator where the reactor heat would be transferred to a secondary loop of "feed" water that flashed to steam before being pumped outside of the reactor containment vessel to the turbine-generator (turbo-generator) where electricity was produced. The MH-1A steam generator was designed to receive heated reactor water at 510^0 F and return it to the reactor at 470^0 F for another cycle of heating and cooling. The secondary feed loop was designed to circulate 170,960 pounds per hour of saturated steam at 430^0 F and 342 psia pressure.[203] Pressure relief valves and vents were provided throughout the system to prevent over pressurization and potential rupture of the cooling system components. As noted above, the steam generator was also designed to serve as a natural heat sink that enabled the cooling system to passively cool the reactor water in the event of pump failure. By containing the primary reactor cooling water within a closed loop and keeping it separate from the

[201] Martin-Marietta Corporation, *Final Design Report, MH-1A Reactor Coolant System,* 24 February 1964, page 4. See Appendix C- Supplemental Materials, Historical Documentation, Technical Reports appended to this report.
[202] Johnson and Chase 1964, p 20.
[203] Martin-Marietta 1964, page 8. See Appendix C- Supplemental Materials, Historical Documentation, Technical Reports appended to this report.



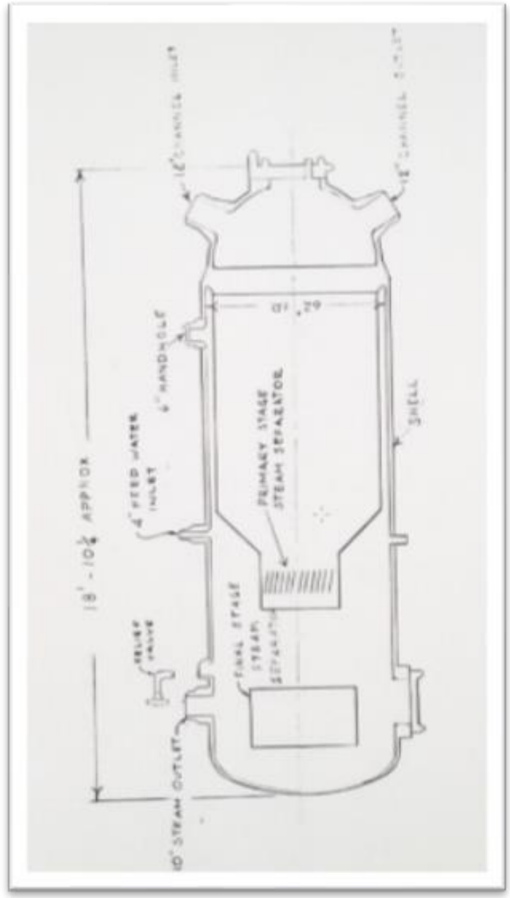


Figure 14. Pressurizer Diagram. Figure 15. Steam Generator Diagram.
Note: Figures 14 and 15 are from Johnson and Chase 1964, pp 20-21.

secondary loop of feed water for the turbo-generator electrical production system, irradiated reactor coolant water would not contaminate turbo-generator equipment, work spaces, and crew working outside of the sealed reactor access deck.

Electrical Generation System

As described above, the MH-1A electrical power generating turbine is a secondary system component that receives saturated steam from the steam generator (see figures 7 and 15) via a supply pipe at 430^0 F, 342 psia, and 170,960 pounds per hour. The pressurized steam is injected into the turbine – a horizontal high-pressure, impulse-reaction turbo-generator - located forward of the reactor containment vessel, outside the secondary shield wall of the reactor access area. The steam entering the turbine drives the turbine, which in turn drives an electrical generator that is directly connected to the turbine. From the turbine, the saturated steam is returned to the stream generator through a series of heaters, pumps and de-aerators for another cycle of steam-powered turbo-generation.

The MH-1A turbo-generator was designed to generate from 9,583 kilowatts (kW) to 11,500 kW of alternating current electricity at 50 to 60 cycles per second (Hertz or Hz) at 3,000 to 3,600 revolutions per minute (rpm), respectively. At 50 to 60 Hz, the voltage (V) output is 13,800 V to 11,500 V, respectively. Electrical power from the turbo-generator would then be distributed via insulated electrical cables to the system's high voltage switchgear and from there to any of three applications: to the ship's deck-mounted transmission tower for onshore distribution, to an onboard 1,500 kW frequency changer for the ship's auxiliary power systems, or to a 1,500 kilovolt-amp (kVA) transformer for to support MH-1A power plant loads.

The main transformer for onshore transmission was oil-cooled, rated for 15,000 kVA power output, and could be adjusted to step the line voltage up from 13.8 kV to 22.9, 33, 44, or 66 kV to match onshore system needs. The main transformer was located in an open well on the ship's forward deck, directly below the ship's electrical transmission tower. Aerial and submarine transmission cables could be connected from the onboard transmission tower to onshore transmission towers at distances up 250 feet and 1,200 feet, respectively.

When the reactor is not online, three 680 kW electrical diesel generators are also capable of producing electrical power for the ship's onboard auxiliary system needs, for MH-1A startup or shutdown, or for limited onshore transmission. An additional 150 kW electric diesel generator was also provided as an emergency backup for emergency loads and other vital onboard systems.

Instrumentation and Controls
Instrumentation and controls for the MH-1A power plant were located in a central control room, above and just forward of the reactor access room, within the central deck house. The instrumentation and controls were organized on a large control console such that one operator could monitor and control the performance of several systems required for the plant's safe operation (Figure 16).

- Nuclear - displayed and recorded power production in the reactor core by means of detectors in the primary shield tank measuring the amount of neutron flux occurring in the core
- Reactor Safety - monitored the control rod positions and controlled mechanical actuators to raise or lower the control rods as needed to maintain safe operating conditions within the reactor core. Abnormal conditions would be sensed by the reactor safety system and automatically shut-down or limit the reactor power as an emergency backup for the plant operator
- Radiation Monitoring – monitored a network of 31 sensors distributed throughout the plant to measure radiation levels in plant liquids, gases, and the environment
- Primary and Secondary Systems – monitored various sensors recording water temperature, pressure, flow, and level with indicators, controls, and alarms as needed for both primary and secondary cooling/heat exchange systems

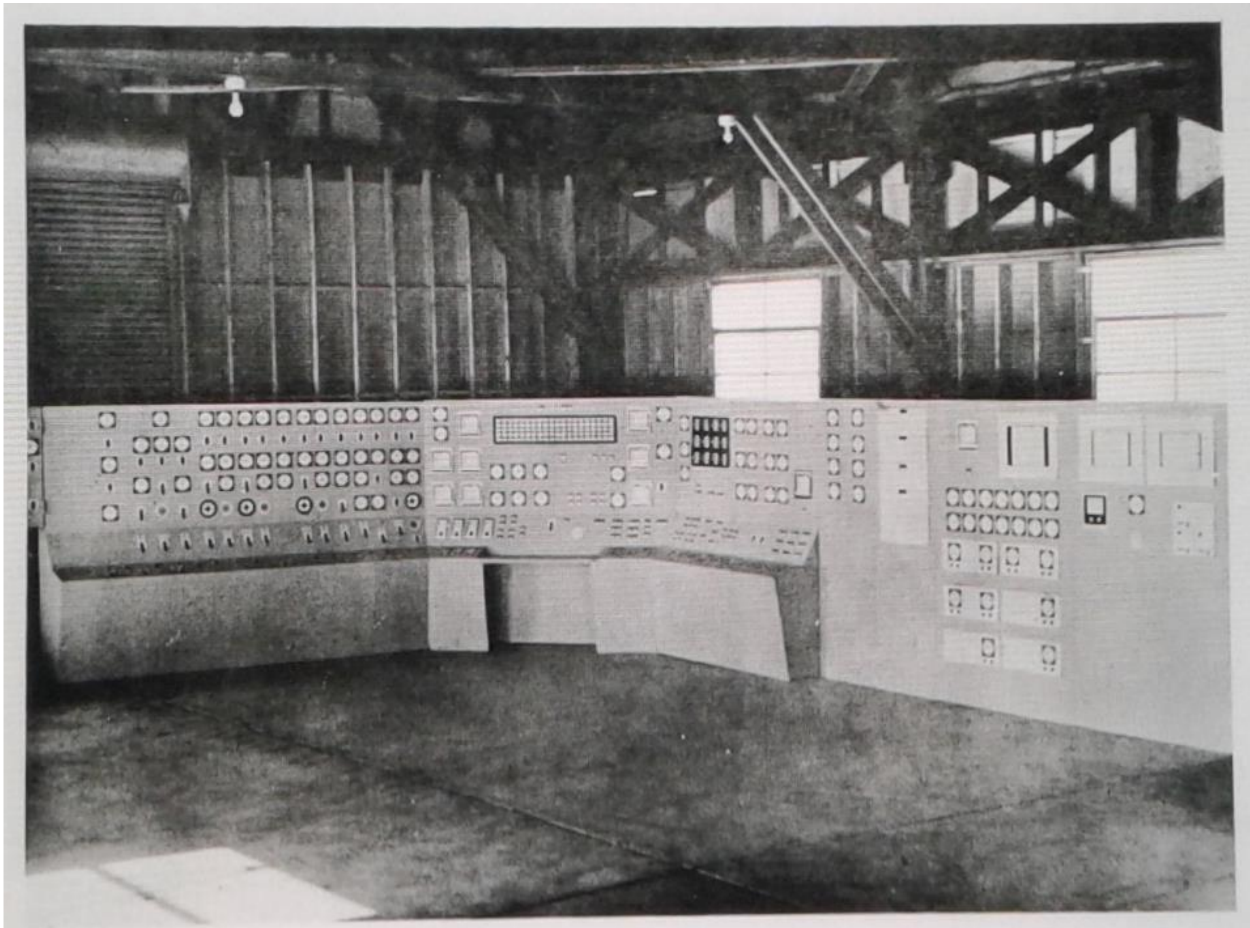


Figure 16. MH-1A Control Panel (Johnson and Chase 1964, pp 36-37).

More than 100 operational parameters were monitored and displayed in the control, with an automatic alarm system to notify the plant operator or automatically shut-down the plant in the absence of corrective actions by the operator. A central communications system enabled the operator to notify and coordinate with other personnel as needed in the plant. Together the control room operator and an equipment operator in the turbo-generator space could activate the reactor and bring it online for power distribution.

CONSTRUCTION

SS Charles H. Cugle (1945-1963)

There were five waves of Liberty ship construction nation-wide between September 1941 and September 1945. By the end of the war the U.S. Maritime Commission had produced over 2,700 of the ships at eighteen emergency fleet shipyards around the nation.[204] One of the shipbuilding companies contracted by the U.S. Maritime Commission to produce Liberty ships was the J. A. Jones Construction company, which built its Wainwright emergency shipbuilding yard with 6 ways during the fifth wave of shipbuilding expansion, funded in part by a $13M investment form the U.S. Maritime Commission. Jones' Wainwright Shipyard constructed 108 Liberty ships during the nation's 1941-1945 emergency shipbuilding program. At its peak J.A. Jones' Panama City shipyard employed 15,000 people, many of whom were women directly involved in heavy construction trades[205]. While many of these were of the standard EC2-S-C1 Liberty ship design, many others received modification to facilitate the shipment of aircraft, army tanks, and other war materiel. Between April 1942 and January 1945, the U.S. Maritime Commission awarded J.A. Jones Construction three contracts for construction of 28 Type Z-EC2-S-C5 Boxed Airplane Carriers at its Wainwright Shipyard in Panama City, Florida. The third and final contract, Contract no. 34762, was awarded on January 3, 1945 to build twelve ships, hull numbers 3137 through 3148, including the *SS Charles H. Cugle* (Hull No. 3145*)*.[206]

The *Charles H. Cugle* was named in honor of Captain Charles Hurst Cugle (1881-1939). A Baltimore, Maryland, native, Cugle served in the Navy and then a private shipping company before accepting an appointment to the U.S. Steamboat Inspection Service in 1915. Cugle served as Assistant Inspector of Hulls at the Port of New Orleans, Louisiana, and Manager of the Sea Service Bureau of the U.S. Shipping Board in New Orleans before he was appointed to serve as a New Orleans Pilot, a role he performed from 1922 to 1939. According to a biography submitted to the U.S. Maritime Commission with a petition to name a Liberty ship after Cugle, he was

> "… deeply interested in simplifying the language of Navigation. He succeeded so well that one of his works in navigation, which has been revised and enlarged several times, remains one of the most popular text books of the United States Merchant Marine, and has found its way, not only to all the nautical book shelves of the ports of the United States, but also to most of the English speaking ports of the world." His work called "Cugle's Two Minute Azimuths" reduced the computation for Azimuths of Heavenly Bodies to a minimum, and, with the navigator's best interests ever in mind, was printed in type so large that it could be read easily in the poorest light. He was also the author of "Simple Rules and Problems in Navigation" and "Practical Advanced Navigation".[207]

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[204] The American Bureau of Shipping, The U.S. Maritime Commission, and other reputable sources place the total number of Liberty Ships produced at 2,710 with one additional ship reportedly burned on the ways.
[205] Florida Department of Veterans Affairs, "Wainwright Shipyard, Panama City Port Authority, http://www.museumoffloridahistory.com/exhibits/permanent/wwii/sites.cfm?PR_ID=174, accessed 12 August 2018.
[206] Jones Construction, Panama City FL, http://shipbuildinghistory.com/shipyards/emergencylarge/jonespanamacity.htm, accessed 10/9/2018.
[207] Letter to Mr. R.L. Sanford, director, Gulf-Great Lakes region, U.S. Maritime Commission, dated September 14, 1944, Archived in USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents Archive, Box 2, File 10-Hist Documents.

The keel for Type Z-EC2-S-C5 Liberty ship *Charles H. Cugle* was laid at Way #5 on June 23, 1945 with construction completed less than three months later on August 13, 1945.[208] When registered with Lloyds Registry of 1945-1946 the *SS Charles H. Cugle* received registry number 37110 and was listed with dimensions 422 feet, 8 inches (length), 57 feet (beam width), 34 feet, 8 inches (draft) and 7,176 (gross tonnage) (Figure 17).[209] The *Cugle*'s recorded dimensions varied from the standard Liberty class dimensions as a result of its modification to serve as a specialized type of Liberty ship – a boxed airplane carrier – designed to carry heavier loads than typical Liberty cargo and personnel transport ships. Also noted on its Lloyds Registry listing was the triple expansion three-cylinder steam engine that was typically used for Liberty class vessels. Though total cost for construction is not known specifically for the *Cugle*, records indicate that Liberty class vessels were constructed on average in 42 days for an average cost of approximately $2 million.[210] The *Cugle* was launched on August 31, 1945, less than 3 weeks after the U.S. dropped atomic bombs on Hiroshima and Nagasaki, Japan.

1 Numero d'Ordre. Numero Officiel. Signaux	2 3 Nom du Navire. Matériaux, Greement, etc. *Ex-nom, s'il y a lieu.* Visites Périodiques. Nombre de Ponts, &c.	4 Tonnage Officiel. Total. Sous le Pont. Net.	5 Détails de la Classification. Cote. ✠ Surveillance Spéciale. Date de la dernière Visite.	6 Port de Visite.	7 Terme assigné maintenant expiré. Lettre d'Equipement.	7° Date de la dernière visite de l'arbre porte-hélice.	8 Construit. Quand.	9 Par qui. Où.	10 Armateurs.	11 Dimensions de Douane. Superstructures, &c. Longueur.	Largeur.	Creux.	12 Port d'Armement. Pavillon.	13 Machines. No. & Dia. des Cylindres.—Course. Pression des Chaudières. NHP—Force en chevaux d'après les formules de la Société. RHP—Force en chevaux d'après les papiers du navire. Détails des Chaudières & Foyers. Nom du Constructeur des machines	14 Creux sur Quille Franc-bord au milieu du navire. Tirant d'eau correspondant. *pds. pc.*	15 Registres où coté, si ce n'est dans le L.R. Durée, Cert. B. of Trade
37110 248108 AORY	Charles H. Cugle *2Dks* D.F. E.S.D. GyC. *Fitted for oil fuel* *Elec.welded* *CruiserStern*	7176 — 4380					1945	J.A.Jones Const.Co.Inc PanamaCity, Fla.	UnitedStates WarShipping Administration	422·8	57·0	34·8	Pensacola, Fla. Utd.States	T.3Cy.24½",37"&70"-48"		R

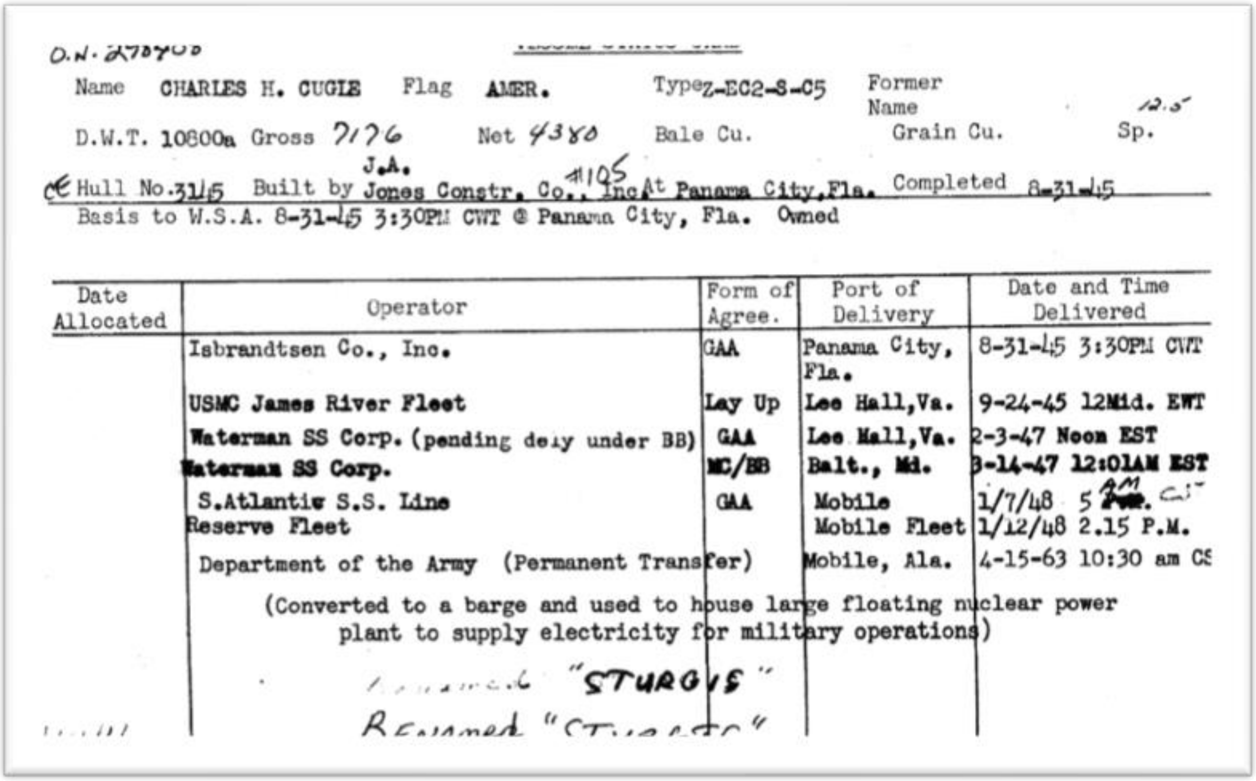
Figure 17. Lloyds Ship Registry for the Liberty Ship *Charles H. Cugle*
(http://www.plimsollshipdata.org/pdffile.php?name=45a1168.pdf).

Upon its completion, the *Cugle* was delivered to the War Shipping Administration at Panama City, Florida, on 31 August 1945 where it was moored briefly in the Mobile Reserve Fleet before being relocated to the James River Reserve Fleet, near Fort Belvoir, Virginia, where it arrived on 24 September 1945 (Figure 18). The *SS Charles H. Cugle* remained in lay-up status within the James River Reserve Fleet for just under three years before it returned to the Mobile Reserve Fleet, where it lay for an additional 15 years before it was permanently transferred to the U.S. Army Corps of Engineers on April 15, 1963 for conversion to "a barge…used to house a large nuclear power plant to supply electricity of military operations."[211]

<u>U.S. Army Nuclear Power Barge *STURGIS* – 1963-2019</u>

The Liberty ship *Walter F. Perry* was initially chosen for the MH-1A conversion project, but the SS *Charles H. Cugle*, then moored in the Mobile Reserve Fleet, was ultimately selected for the quality of its hull and its proximity to the Alabama Drydock and Shipbuilding Company (ADDSCO), which was Martin Company's

[208] Jones Construction, Panama City FL, http://shipbuildinghistory.com/shipyards/emergencylarge/jonespanamacity.htm, accessed 10/9/2018
[209] http://www.plimsollshipdata.org/pdffile.php?name=45a1168.pdf, accessed 10/8/18
[210] Bill Lee, *The Liberty Ships of World War II; Their Union County and Other Carolina Connections,* http://jajones.com/pdf/Liberty_Ships_of_WWII.pdf, accessed 11/26/2018, pages 8, 9.
[211] U.S. Maritime Administration, Status Card for SS *Charles H. Cugle*, 1963, https://www.marad.dot.gov/sh/ShipHistory/Detail/5496, accessed 15 Aug 2018



O.N. 247400

Name CHARLES H. CUGLE Flag AMER. Type Z-EC2-S-C5 Former Name

D.W.T. 10800a Gross 7176 Net 4380 Bale Cu. Grain Cu. Sp. 12.5

Hull No. 3145 Built by J.A. Jones Constr. Co. #105 Inc At Panama City, Fla. Completed 8-31-45

Basis to W.S.A. 8-31-45 3:30PM CWT @ Panama City, Fla. Owned

Date Allocated	Operator	Form of Agree.	Port of Delivery	Date and Time Delivered
	Isbrandtsen Co., Inc.	GAA	Panama City, Fla.	8-31-45 3:30PM CWT
	USMC James River Fleet	Lay Up	Lee Hall, Va.	9-24-45 12Mid. EWT
	Waterman SS Corp. (pending dely under BB)	GAA	Lee Hall, Va.	2-3-47 Noon EST
	Waterman SS Corp.	MC/BB	Balt., Md.	3-14-47 12:01AM EST
	S.Atlantic S.S. Line	GAA	Mobile	1/7/48 5 AM. CST
	Reserve Fleet		Mobile Fleet	1/12/48 2.15 P.M.
	Department of the Army (Permanent Transfer)		Mobile, Ala.	4-15-63 10:30 am CS
	(Converted to a barge and used to house large floating nuclear power plant to supply electricity for military operations)			
	Renamed "STURGIS"			
	Renamed "STURGIS"			

Figure 18. U.S. Maritime Administration, Status Card for *Charles H. Cugle* (MARAD 1963).

subcontractor for the ship's construction. As originally planned, the Martin Company, as the prime contractor for the MH-1A, would work under the direction of the ANPP and the Contracting Officer for the plant procurement. The US Army's Philadelphia Engineer District would work closely with the U.S. Coast Guard (USCG) and the U.S. Atomic Energy Commission (AEC) to insure construction of a safe, reliable, high quality plant. And when completed, the barge would be inspected and certified by the USCG with the nuclear plant's design and operation reviewed and approved by the AEC.[212]

Construction of the MH-1A *STURGIS* as originally planned required a complex sequence of concurrent events by a variety of different organizations working at different locations from Baton Rouge, Louisiana to Fort Belvoir, Virginia. Among many key milestones leading to the *STURGIS'* completed construction, the *Cugle* was towed from the Mobile Reserve Fleet to ADDSCO on 15 April 1963 to begin its conversion (Figure 19). Thereafter, the *Cugle* was dry-docked at ADDSCO from April 1963 to April 1966. During that

[212] "Fact Sheet, MH-1A FLOATING NUCLEAR POWER PLANT," undated with handwritten note indicating original was given to Mr. Wilhelm, GAO on 16 May 1966. In USACE Baltimore Digitized MH-1A STURGIS Historical Documents Archive, Box 2, File 11-Admin Files.

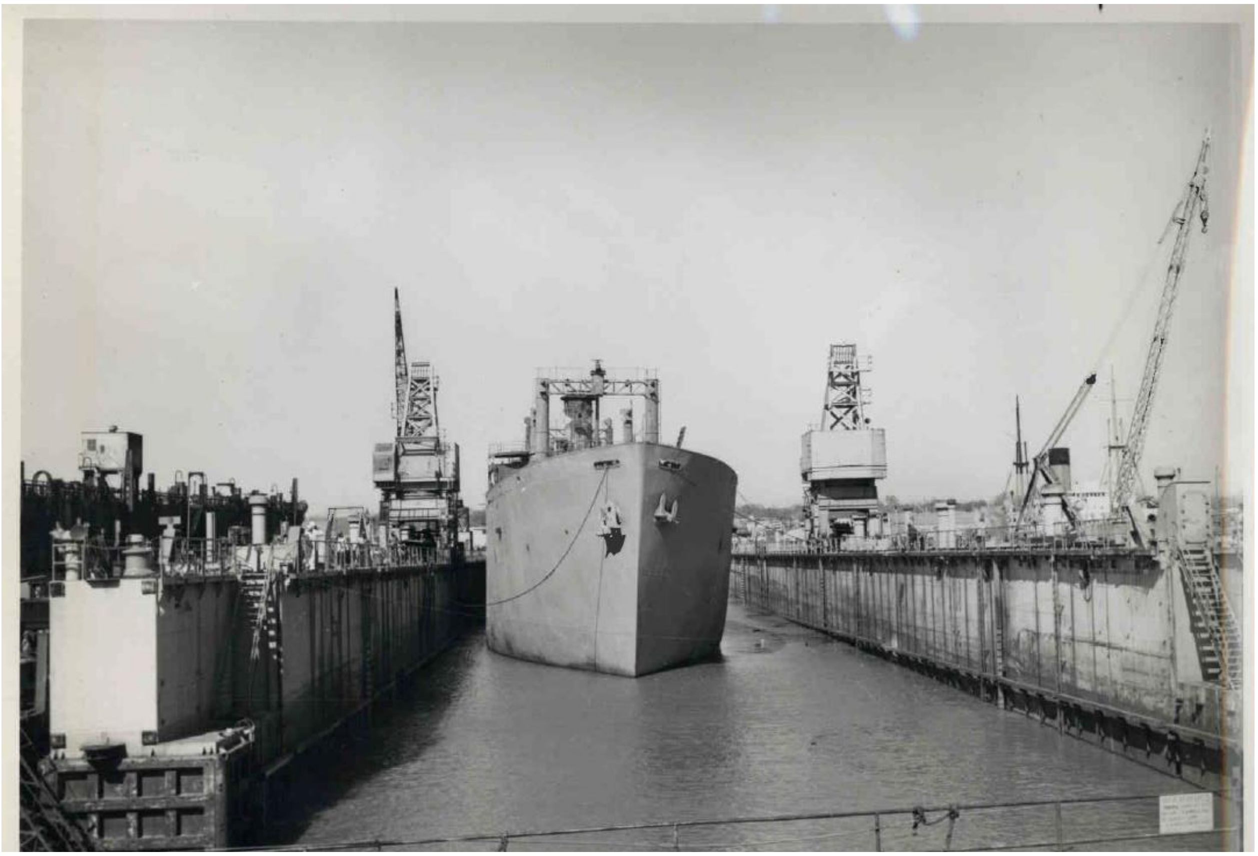


Figure 19. *SS Charles H. Cugle* at Alabama Drydock and Shipbuilding Company, 31 March 1964. (USACE Baltimore's MH-1A *STURGIS* Digitized Historical Documents Archive at http://www.nab.usace.army.mil/Missions/Environmental/Sturgis.aspx)

period, the U.S. Army's Philadelphia District assigned a Senior Engineer Representative to oversee and assist the Martin Company and its many subcontractors. [213]

As scoped under Phases B and C of the construction contract, the Martin Company's Nuclear Division fabricated and tested the MH-1A nuclear reactor in its "critical" manufacturing facility in Baltimore, Maryland. Concurrently, the new mid-body "floating mount" that would carry the MH-1A power plant was constructed at ADDSCO's shipyard in Mobile, Alabama (Figure 20). The MH-1A containment vessel was manufactured at a special metal fabrication plant in Baton Rouge, Louisiana and floated by barge down the Mississippi River to New Orleans, where a huge crane capable of lifting the 350-ton containment vessel and placed it within the new mid-body of the *STURGIS*, which had been be towed to New Orleans

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[213] Nuclear Power Field Office memo dated May 6, 1964 and entitled "Planning and Actions Needed to Integrate MH-1A into the ANPP System." Archived in USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents Archive, Box 2, File 11-Admin Files.

Figure 20. Completed MH-1A mid-body, ready for launching, 1 April 1964
(USACE Baltimore's MH-1A *STURGIS* Digitized Historical Documents Archive at
http://www.nab.usace.army.mil/Missions/Environmental/Sturgis.aspx)

from the ADDSCO shipyard in Mobile, Alabama.[214] Installation of all MH-1A reactor components, excluding radioactive fuel elements and control rods, was completed at ADDSCO before the *STURGIS* was towed once again to Fort Belvoir, where fuel elements and control rods were installed into the then complete MH-1A nuclear power plant.

In April 1966, following installation of the MH-1A containment vessel at ADDSCO, the completely converted barge *STURGIS* with the MH-1A containment vessel and nuclear plant components installed, was inspected and certified by the U.S. Coast Guard for its voyage, under tow, from Mobile, Alabama to Fort Belvoir, Virginia (Figure 21). The MH-1A *STURGIS* departed Mobile under tow on 14 April 1966 and arrived at Fort Belvoir, Virginia eight days later, on 22 April 1966 for operational testing and evaluation of the by Martin Company Nuclear Division engineers with ANPP oversight.[215]

In preparation for the *STURGIS'* arrival, the Army had designed and constructed a new pier at Whitestone Point, near the Army's first nuclear plant, the SM-1, at Fort Belvoir (Figure 22). Significant security measures had been planned and implemented to address safety concerns about the presence of floating nuclear power plant in a busy public waterway, with all non-military vessel movements restricted to a distance of more than 1,700 feet.[216]

The MH-1A was loaded with fuel and brought to its "critical" stage of self-sustaining nuclear reaction between the 24th and 27th of January 1967.[217] From this critical milestone of the MH-1A power plant's reactor system, further testing focused on assessments of the nuclear physics of the plant and its power generation capabilities.[218]

While the vessel and its nuclear power plant were constructed largely as initially designed, detailed operational testing of the MH-1A plant and other ship's systems revealed the need for modifications to various components of the MH-1A power plant as well as other operational systems throughout the *STURGIS*. MH-1A power plant modifications included minor changes to the degree of uranium enrichment to be provided for the fuel rods and the degree of boron enrichment for the control rods, done to improve the nuclear power plant's physical performance characteristics. Other adjustments were made to overcome problems in the plant's mechanical operability, including modifications to the mechanism used to raise and lower the control rods in the reactor core. A detailed report of the Phase "d" testing and

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[214] Martin-Marietta Corporation documentary film titled *MH-1A Floating Nuclear Power Plant STURGIS Construction Report*, produced for the U.S. Army Corps of Engineers, circa 1964. Digitized video http://youtu.be/i7t_AtWQazM, accessed 11/26/2018.

[215] FACT SHEET, FLOATING NUCLEAR POWER PLANT STURGIS, no date. In USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents Archive, Box 2, File 10-Hist Documents.

[216] Safety Analysis, *STURGIS (MH-1A) Floating Nuclear Power Plant, Revision A*, 2 October 1967, page 724. In USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents Archive, Box 15, File 5.

[217] This milestone date was achieved approximately 16 months beyond its originally scheduled date as outlined in a Nuclear Power Field Office memo dated May 6, 1964 and entitled "Planning and Actions Needed to Integrate MH-1A into the ANPP System." In USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents Archive, Box 2, File 11-Admin Files.

[218] Information Bulletin, Office of the Chief of Engineers, 30 January 1967. In USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents Archive, Box 10.

TREASURY DEPARTMENT
U.S. COAST GUARD
CG-841 (Rev. 9-59) dhm

VESSEL

FILE NO. V-7238

This Certificate Expires 11 May, 19 66.

UNITED STATES OF AMERICA
TREASURY DEPARTMENT
UNITED STATES COAST GUARD

Certificate of Inspection

VESSEL STURGIS (ex CHARLES H. CUGLE) OFFICIAL NO. (248108)
CLASS Seagoing Barge TONS: GROSS Est. 7,800 NET – LENGTH 441.6'
HOME PORT – OWNERS U.S.A. rep. by U.S. Army, Corps of Engrs.
OPERATORS U.S.A. rep. by U.S. Army, Corps of Engrs. Washington, D.C.

The inspection of the above-named vessel having been completed at Mobile, Alabama on the 11th day of April, 19 66, I hereby CERTIFY that the said vessel was built at Panama City in the State of Florida, in the year 1945, rebuilt in the year 1966; that the hull is constructed of steel; is provided with – staterooms, 15 berths; that the said vessel at the date hereof is in all things in conformity with the applicable vessel inspection laws and the rules and regulations prescribed thereunder; and is allowed to carry – passengers, – persons in addition to the crew.

The following complement of licensed officers and crew is required to be carried, included in which there must be – certificated lifeboatmen: UNMANNED.

– Master	– Second Mate	– Able Seaman	– Chief Engineer	– Firemen/Watertenders
– 1st Class Pilot	– Third Mate	– Ordinary Seaman	– 1st Assistant Engineer	– Oilers
– 2d Class Pilot	– Inland Mate	– Watchmen	– 2d Assistant Engineer	– Motorboat Operators
– Chief Mate	– Radio Officer	– Deckhands	– 3d Assistant Engineer	–

and also may carry – other persons in crew. Total number of persons allowed –

Vessel may carry a riding crew of three (3) persons not connected with the navigation of the vessel.

The said vessel is permitted to be navigated for one ~~XXXXXX~~ voyage, under tow, from Mobile, Alabama, to Fort Belvoir, Va.

DATA, PARTICULARS OF EQUIPMENT AND PERIODIC EXAMINATIONS

– Wooden lifeboats for – persons	11 Fire extinguishers, Class A—II	Stability letter issued – 19 –	Aux. BOILERS
– Oar prop. metal lifeboats for – persons	7 Fire extinguishers, Class B—II	Date drydocked March 1966.	Number 1 Year built 1965.
2 Hand-operated metal lifeboats for 62 persons	5 Fire extinguishers, Class C—II	Propelled by –	Mfr. Vapor Corporation.
– Motor lifeboats for – persons	1 Fire extinguishers, Semiportable, Class, B-V.	H. P. – Number of engines –	Minimum efficiency of weakest longitudinal section – percent
– Work boats for – persons	5 Fire extinguishing systems, Fixed CO2; OR, MIR; MO; FO; EGR, PL, LL; SR.	Tail shaft drawn –	Record in Office at Chicago, Ill.
1 Inflatable Liferafts for 10 persons	8 Fire axes 3 Fire pumps	–	Mountings opened New 12/65.
– Buoyant apparatus for – persons	Fire hose, total length 1950 ft.	Pressure vessels examined Jan. 1966.	–
1 Life floats for 10 persons	Inspected and approved for the carriage of inflammable or combustible liquids of grade –	–	Mountings renewed New 12/65.
18 Ring life buoys	–	–	–
50 Life preservers, adults'	–	Fuel –	Date hydrostatic pressure applied 12/65.
– Life preservers, children's	Capacity in barrels –		–
– Wood floats			Maximum steam pressure allowed 60#.
Rocket type, line-throwing apparatus			

W. D. Alley
(Acting) (Officer in Charge, Marine Inspection)
W. D. ALLEY, Commander, USCG.
Mobile, Alabama
(Inspection Zone)

PREVIOUS EDITIONS MAY BE USED

STURGIS (ex CHARLES H. CUGLE) OFFICIAL NO. (248108) GROSS TONS 7,800

Figure 21. U.S. Coast Guard Certificate of Inspection, 1966.

Figure 22. MH-1A *STURGIS* moored at Gunston Cove, Ft. Belvoir, VA, circa 1966
(reproduced in Honerlah and Hearty 2002).

operations at Fort Belvoir identified numerous technical problems and summarizes the testing methods and solutions that were implemented prior to its acceptance by the Army.[219]

A July 21, 1967 Information Bulletin from the Office of the Chief of Engineers reported that the testing period was complete and that the U.S. Army Corps of Engineers had accepted the MH-1A power plant from Martin-Marietta Corporation. Shortly thereafter in October 1967, the Army's Nuclear Power Field Office (NPFO) at Fort Belvoir issued a safety analysis report that detailed the final MH-1A design, construction, and operational safety specifications.[220] After being accepted by the Army, the MH-1A

[219] F.M. Black, *MH-1A Floating Nuclear Power Plant Report on Phase "d" Testing. Description of Tests Performed Prior to and During Initial Start-Up Period. Assembled and Complied from Available Data*, Engineering Division, USAERG for U.S. Army Corps of Engineers, Fort Belvoir, Virginia. 26 March 1969

[220] This report, dated 2 October 1967 and entitled *Safety Analysis STURGIS (MH-1A) Floating Nuclear Power Plant, Revision A,* was approved for publication by the Army's Chief of the Nuclear Power Field Office, Veikko E. Jardstrom, following review and approval by the Atomic Energy Commission. As the most complete record of the MH-1A *STURGIS*' as-built condition at the time of its completion in 1967, the first 212 pages of this 840+-page

STURGIS remained anchored at its Whitestone Point pier for 11 months before being towed out of Gunston Cove in July 1968 for its first duty assignment in the Panama Canal Zone (Figure 23).

Figure 23. MH-1A STURGIS arriving in Panama Canal Zone, 7 August 1968

The MH-1A *STURGIS* went on-line at Panama Canal Zone in early October 1968. Over the next 8 years of service, the MH-1A *STURGIS* was operated, refueled, and maintained with occasional need for repairs and design changes to the *STURGIS*' on-board systems as well as its MH-1A nuclear power reactor. For example, as early as July 1969, after the MH-1A *STURGIS*' first full year of deployed operation, the Nuclear Power Field Office at Fort Belvoir issued a detailed set of specifications for procuring improved, second generation fuel and control rod assemblies. Material specifications included changes to the degree of enrichment of the uranium dioxide powder and modifications to the design and manufacture of the boron control rods. Other changes involved mechanical modifications to the spatial tolerances within and between fuel system components, changes to the design of the control rod lifting mechanisms, and changes to the positioning of control rods within the fuel assemblies. Though the changes were detailed and sometimes subtle, all were intended to continually improve the operational reliability and safety

report are provided along with other as-built records in Appendix C-Supplemental Materials, Historical Documentation.

controls for the MH-1A reactor core.[221] Among many changes made to the *STURGIS'* peripheral systems a method was devised to eliminate whipping movements of the main steam pipe when operating under high pressure.[222]

Interviews with Charles Harmon and David Craig,[223] both former MH-1A *STURGIS* personnel, indicate that the crew of the *STURGIS* consisted of approximately 100 military personnel with various specialties. The crew size was just enough to cover all required maintenance. Maintenance of the vessel was an arduous task. It was a constant battle to remove rust and re-paint the vessel. The vessel was kept very clean while it was operating. Mr. Harmon indicates that the Army Engineer Reactor Group Training coursework lasted one year. As part of the operations training, everyone had to go through one of four specialty training: health physicist, electricians, mechanics, and instrumentation electronics. As an Instrumentation Electronic Specialist, Mr. Harmon indicates the reactor and power plant were operated by a crew of three: shift supervisor, control room operator, and equipment operator. Either the shift supervisor or control room operator were always in the control room. The equipment operator made rounds of the power plant. There was a crew of ten mechanics, ten electricians, and five Health Physicists to maintain the plant. Mr. Craig indicates that a typical 8-hour shift in the Control Room involved three operators and two trainees. There were three shifts per day. Turnover in the Control Room to the next shift typically took 10-15 minutes. During the shifts, one person worked on the floor operating mechanical equipment to transfer the steam to make electricity, and others worked in the control room. Those in the control room were responsible for operating and controlling the output of the reactor, which averaged 1 megawatt/hour; 24-hours a day. The electricity provided power directly to the Panama Canal electrical grid. Mr. Craig noted the MH-1 reactor was a very stable plant. The plant typically operated at its rated capacity of 10 MW and was most efficient when it ran at steady load.

Regarding the highly-intense refueling process, Charlie indicated he did have a role in this function. Charlie was completing qualification training, but also served on the refueling team. He noted it was a complex process to refuel the reactor. Some of the tasks included removing the spent fuel from the vertical tank, which was accomplished by removing the fuel from the reactor into another cask, and then hauling the cask to a storage rack. None of this process was automated, and it was all done by man-power (though utilizing tools to protect from radiation exposure, including cranes and poles). The process was described as lengthy but straight forward.

Mr. Harmon described one of the biggest challenges of working on the Sturgis was the fact that it moved. "You had to be aware of the ship's lift, and not let it lift too far, or you would be faced with operating issues. Too much weight on one side could result in an increase in bearing temperatures." The moving ship factor was particularly a challenge during the refueling process, for example, when a person moved

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[221] NUS Corporation, *MH-1A Type II Procurement Specifications,* prepared for the U.S. Army Engineer Reactor Group 's Nuclear Power Field Office, dated March 1968. Archived in USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents Archive, Box 5, File 13.
[222] Suntac Nuclear Corporation, *Design of Pipe Whip Restraints fore the Main Steam Line on the MH-1A,* prepared for the Engineering Division, U.S. Army Engineer Power Group. Contract # DAAK02-72-D-0272, Task 0025. October 1974. Archived in USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents Archive, Box 5, File 18.
[223] Summaries of oral history interviews conducted with Charles Harmon and David Craig in 2018 are provided in Appendix C - Supplemental Materials, Historical Documentation appended to this report.

the spent fuel across the refueling room. Mr. Harmon recalled one incident when the lift crane wouldn't move due to the tilt of the ship, and they needed to remove spent fuel from the reactor. This was solved by pumping water into a bilge tank to counter-balance the ship and level out the floor.

Mr. Harmon also recalled challenges in paralleling the *STURGIS'* operations with the Panama Canal Company Power System grid. He noted the primary source of electricity was generated on the Pacific side of the isthmus. Electricity was supplied between the Atlantic to the Pacific, where power lines ran through the rainforest, where conditions could short out these transmission lines. This resulted in a sudden demand of power from the *STURGIS*, sometimes causing the reactor to shut down, which would then require a 7 to 8-hour cool-down period to get it up and running again. Mr. Harmon described the *STURGIS* as sluggish to respond to the energy demand following a "scram" or tripped power system. Often the operators could not keep the reactor online to maintain an adequate source of heat. If the *STURGIS* crew could break away from the grid in time, and only provide power to supply the ship and reactor, then they could maintain operations to supplement the Power Plant before the demand on the reactor tripped the safety shut-offs.

DECOMMISSIONING

<u>Liberty Ship *SS Charles H. Cugle* 1963 - 1966</u>

As noted above, the Liberty ship *SS Charles H. Cugle* was selected in 1963 from others in the U.S. Maritime Commission's reserve fleet for decommissioning as a Liberty class cargo vessel and conversion to a U.S. Army nuclear power production barge. Decommissioning and conversion of the *Cugle,* occurred between April 1963 and April 1966, including complete removal of 212 feet from the ship's mid-section along with its engine and propulsion systems. Decommissioning and conversion of the *Cugle* also included removal of older, technologically obsolete systems, such as steam-powered electrical generating systems, and steam-powered anchor windlasses. Deconstruction of the *Cugle* was accomplished at the Alabama Drydock and Shipbuilding Company's facility in Mobile, Alabama and coordinated with the ANPP's design of a self-contained nuclear power plant within a replacement mid-body section. As converted, the *Cugle* was renamed *STURGIS* in 1964. In April 1966 the *STURGIS* with its MH-1A nuclear power plant installed was approved by the U.S. Coast Guard for towing to Fort Belvoir, Virginia, where operational testing of the MH-1A nuclear reactor was conducted.

<u>U.S. Army Nuclear Power Barge MH-1A *STURGIS* – 1977-2019</u>

On 1 July 1976, the MH-1A was shut down and the *Sturgis* towed from Panama to Fort Belvoir, Virginia.[224] During transportation, the *STURGIS* encountered severe weather and was diverted to the Military Ocean Terminal at Sunny Point, North Carolina, where it subsequently underwent temporary structural repairs. Following repairs in March 1977, the *STURGIS* was taken under tow to Fort Belvoir, where the Department of Army (U.S. Army Facilities and Engineering Support Agency, Fort Belvoir) deactivated and defueled the reactor and placed it under safe store (SAFSTOR) configuration.

[224] U.S. Army Corps of Engineers – Baltimore District, "Decommissioning Plan for the MH-1A Nuclear Power Reactor and *STURGIS* Barge," 14 November 2003, p. 2, in USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents.

As with the decommissioning of its ANPP predecessors, the process to immediately decommission the reactor and prepare the *STURGIS* for long-term storage required: defueling and shipping of irradiated fuel and irradiated control rods; disposing of radioactive wastes/components and radioactive sources/samples; isolating the remaining radioactive materials from the public with appropriate physical barriers; and decontaminating all other plant areas to within prescribed limits for release as an unrestricted area.[225] Forty-seven long tons of gravel shielding were added to the reactor vessel shield tank, and the containment vessel penetrations for primary systems, secondary systems, electrical and instrumentation systems, and the external purge systems were all closed and sealed.[226]

James River Reserve Fleet (1978-2015)
The *STURGIS* was towed to the James River Reserve Fleet on 23 September 1978 where it remained in safe storage as part of the James River Reserve Fleet for more than two decades (1978-1998), under the USACE's responsibility for the safety of facility staff, the public, and the environment. During that time the Army Reactor Office, part of the U.S. Army Nuclear and Chemical Agency (USANCA), issued a series of Nuclear Reactor Possession Permits to the Corps' Environmental Division detailing what requirements must be met to protect workers, the public, and the environment.

The Army's original intent was for the *STURGIS* to "remain at anchor in the Reserve Fleet for a long time until the residual radioactivity in the reactor components decayed enough to allow the vessel to be economically scrapped."[227] However, in 1998, the USANCA funded a study to review the status of the Army's reactors and to develop decommissioning alternatives. The study concluded that the levels of contamination present within the reactors would not be reduced by decay sufficiently to allow for release of the facilities without significant decontamination being performed. The study also indicated that maintaining the reactor in a safe storage condition may not be the most cost-effective strategy due to escalating decommissioning costs, personnel/maintenance costs, waste disposal options, and changing regulations concerning decommissioning. These issues led the Army Reactor Office to recommend that an all hazards assessment be performed for the *STURGIS* to allow for development of a more accurate decommissioning cost estimate and to address projected changes in disposal options.[228] Accordingly, the Baltimore District initiated efforts to develop updated decommissioning and decontamination plans for the MH-1A *STURGIS*. USACE Baltimore District Health Physicist Hans Honerlah reports that he started work on the MH-1A *STURGIS* decommissioning project in 1998 and has been continuously involved since that time in a variety of technical and managerial roles.[229] In 2002, Mr. Honerlah presented a paper at the WM'02 Waste Management conference in Phoenix, Arizona that characterized the condition of the MH-1A *STURGIS* and outlined the Baltimore District's plans for its future decommissioning and decontamination.[230]

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[225] Hans B. Honerlah and Brian P. Hearty, U.S. Army Corps of Engineers, "Characterization of the Nuclear Barge *Sturgis*," presented at the WM'02 Conference, 24-28 February 2002, Tucson, Arizona.
[226] Ibid.
[227] Letter from J.R.C. Miller, Colonel, Corps of Engineers, Acting Director of Facilities Engineering to Honorable S.I. Hayakawa of the United States Senate, 8 November 1977, in USACE Baltimore Digitized MH-1A *STURGIS* Historical Documents.
[228] Honerlah and Hearty 2002
[229] Hans Honerlah and Brenda Barber, personal communications during telephone interview, December 12, 2018.
[230] Honerlah and Hearty 2002.

In 2001, the Baltimore District issued a contract to plan and implement a comprehensive hazards assessment and the corresponding 2006 *All Hazards Assessment* (AHA) report provided a detailed baseline of existing levels of radioactive and other hazardous materials contamination with recommendations for complete decommissioning and decontamination of the reactor and the reactor facilities prior to the Corps' eventual disposition of the vessel.[231] The Baltimore District's 2006 AHA provided a basis for a subsequent *Historical Site Assessment* (HSA) of the *STURGIS* that enabled the Corps to develop a detailed decommissioning and decontamination plan.[232] Phase I of the HSA identified five primary areas of radiological concern: the refueling room, reactor access compartment, containment vessel, spent fuel tank, and hull bottom tanks.

> *Refueling Room* – During the deactivation the refueling room was used as the primary work area for operations. Several pieces of equipment remain from the reactor operations and include the crane hoist used for reactor refueling operations, upper section of the refueling shield tank, new fuel rod storage cask, spent fuel storage cask, and the spent fuel transfer cask.
>
> *Reactor Access Compartment* – During the deactivation all piping connections were welded closed and the reactor access compartment was secured. The historical assessment indicated that several of the radioactive waste disposal tanks remained as well as significant piping for numerous systems associated with reactor operations. The reactor access compartment is also the point of entry for several of the hull bottom tanks, identified in the historical assessment, as potentially containing residual radioactive contamination.
>
> *Containment Vessel* – During the deactivation all piping connections were welded closed and the vessel was sealed/secured. The historical assessment indicated that much of the equipment associated with the reactor was still in place. The major components remaining are the reactor pressure vessel, steam generator, pressurizer, primary loop pumps, and lower section of the refueling shield tank.
>
> *Spent Fuel Tank* – During the deactivation all piping connections were welded closed and a steel cover was put in place over the tank prior to sealing/securing the tank (Figure 24). The historical assessment identified numerous contaminated components that were placed into the interior of the tank during the deactivation. The documentation for the material placed within the spent fuel tank, as well as the condition of the spent fuel tank, was sufficient for future decommissioning activities. Therefore, the decision was made not to open the tank for inspection.

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[231] *All Hazards Assessment Report. Hazard Assessment of the Nuclear Barge STURGIS*. James River Fleet, Fort Eustis, Virginia. USCACE Baltimore District January 2006.
[232] *Historical Site Assessment for the MH-1A Nuclear Power Reactor and STURGIS Barge*, prepared by Integrated Environmental Management, Inc. (IEM) for the U.S. Army Corps of Engineers, Baltimore District. USACE Contract No. W912DR-08-D-0022, Delivery Order 003. Final (Revision 1), November 14, 2013.

> *Hull Bottom Tanks* – There are several hull bottom tanks that run the length of the vessel. Several of these tanks were identified during the deactivation as containing residual radioactivity. The historical assessment indicated that all remaining liquids were removed and identified significant decontamination efforts with several of these tanks. All tanks were sealed upon completion of the deactivation.

The HSA also identified the potential for chemical hazards as; PCBs in electrical wiring, paints, equipment, and gaskets; asbestos in insulation, gaskets, and floor/ceiling tiles; lead shielding; metals in paints (i.e., barium, cadmium, chromium, and lead); mercury in fluorescent lights and monometers; chromium in

Figure 24. Refueling Room showing Spent Fuel Tank Lid and Access Plug (Honerlah and Hearty 2002).

chrome-plated fasteners; residual diesel in fuel tanks; and organo-tin antifouling agent of hull paint. The HSA also identified significant logistical challenges involved with the mobilization of equipment, daily site access, and environmental conditions that would be encountered during field activities.

Since 2011, Mr. Honerlah has worked with USACE Baltimore Project Manager Brenda Barber, P.E. to implement the Baltimore District's MH-1A *STURGIS* decommissioning and disposal (D&D) plan. Together Mr. Honerlah and Ms. Barber describe the MH-1A *STURGIS* decommissioning project as a one-of-a-kind undertaking that required intensive research into the USACE's MH-1A *STURGIS* records, including thousands of technical drawings and documents to develop methods necessary for accessing and removing materials and equipment that remained radioactive at low levels even after twenty years of safe storage. Though the Baltimore District decommissioning team relied on industry standards and best practices for removal of radioactive waste and other hazardous materials from industrial facilities, Mr. Honerlah noted that there were no existing templates or guides for executing the required work within the unique conditions present in the MH-1A *STURGIS*, a one-of-a-kind floating nuclear power plant.[233]

Based on the results and recommendations of the 2013 HSA, USACE undertook several further planning efforts in accordance with Army Regulation 50-7 before the proposed D&D plan could be fully implemented. In 2014, USACE published a Final Environmental Assessment (EA) in accordance with USACE's environmental planning requirements under the National Environmental Policy Act of 1969 (NEPA) which was approved.[234] The environmental impact and alternatives analyses presented in the Final EA served as a basis for a Final Finding of No Significant Impact (FNSI) in April 2014.[235] The Final EA and Final FNSI acknowledged that the proposed action would cause adverse effects to the National Register of Historic Places-eligible vessel *STURGIS* and summarized a mitigation plan to be implemented in accordance with Section 106 of the National Historic Preservation Act (NHPA) and a Memorandum of Agreement (MOA) between the USACE-Baltimore District and the Virginia State Historic Preservation Officer.[236] [237]

Decommissioning and Disposal, 2015-2019

Upon completion and approval of its environmental planning efforts, the USACE's analysis of facilities and firms capable of performing the necessary D&D work, the Baltimore District selected APTIM Federal Services, LLC (APTIM) and the Port of Galveston (POG) as the most appropriate firm and location for carrying out its planned D&D operations. The USACE and APTIM personnel had numerous interactions with local Texas and Galveston Area stakeholders prior to *STURGIS*' arrival in the POG. The timeline began with a kickoff meeting in Galveston in June 2014 and continued with the arrival of the *STURGIS* in the POG. Meetings and presentations were conducted to inform, plan, and coordinate with the local stakeholders. Informational and planning meetings occurred with local stakeholders, including representatives from the local State Representative's office, Galveston City Council, the City of Galveston, the Galveston Sheriff and

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233 Honerlah and Barber 2018.

234 *Final Environmental Assessment, Decommissioning and Dismantling of STURGIS and MH-1,* prepared by U.S. Army Corps of Engineers, Baltimore District, January 2014.

235 *Final Department of Defense, Department of the Army, Finding of No Significant Impact (FNSI) For Decommissioning and Dismantling of STURGIS and MH-1,* signed by J. Richard Jordan III, Colonel, Corps of Engineers, 21 April 2014.

236 *MH-1A Nuclear Power Reactor and STURGIS Barge Public Interpretation Mitigation Plan for the Virginia State Historic Preservation Office*, prepared by U.S. Army Corps of Engineers, Baltimore District, January 2014.

237 *Memorandum of Agreement Between The U.S. Army Corps of Engineers, Baltimore District, and the Virginia State Historic Preservation Office Pursuant to 36 CFR part 800 Regarding the Proposed Decommissioning of the MH-1A Nuclear Power Reactor and Barge STURGIS, Ft. Eustis, Isle of Wight County, Virginia,* signed by J. Richard Jordan III, Colonel, Corps of Engineers, 21 APR 14, and Julie V. Langan, Director, Department of Historic Resources, 5/2/14.

Fire Department, Texas Department of State Health Services, Texas Commission on Environmental Quality, Economic Development Partnership, and POG.

After receipt of approval from Galveston City Council, in 2015, the MH-1A *STURGIS* was towed to Malin International Shipyard in the POG for removal of the remaining MH-1A reactor components, including the Reactor Pressure Vessel (RPV) and the Spent Fuel Storage Tank. Given the unique construction of the MH-1A reactor containment vessel and its secure mounting deep inside the vessel hull, APTIM performed high-definition laser imaging of the entire vessel, inside and out, to aid in development of methods necessary to access and remove those components (Figure 25).[238]

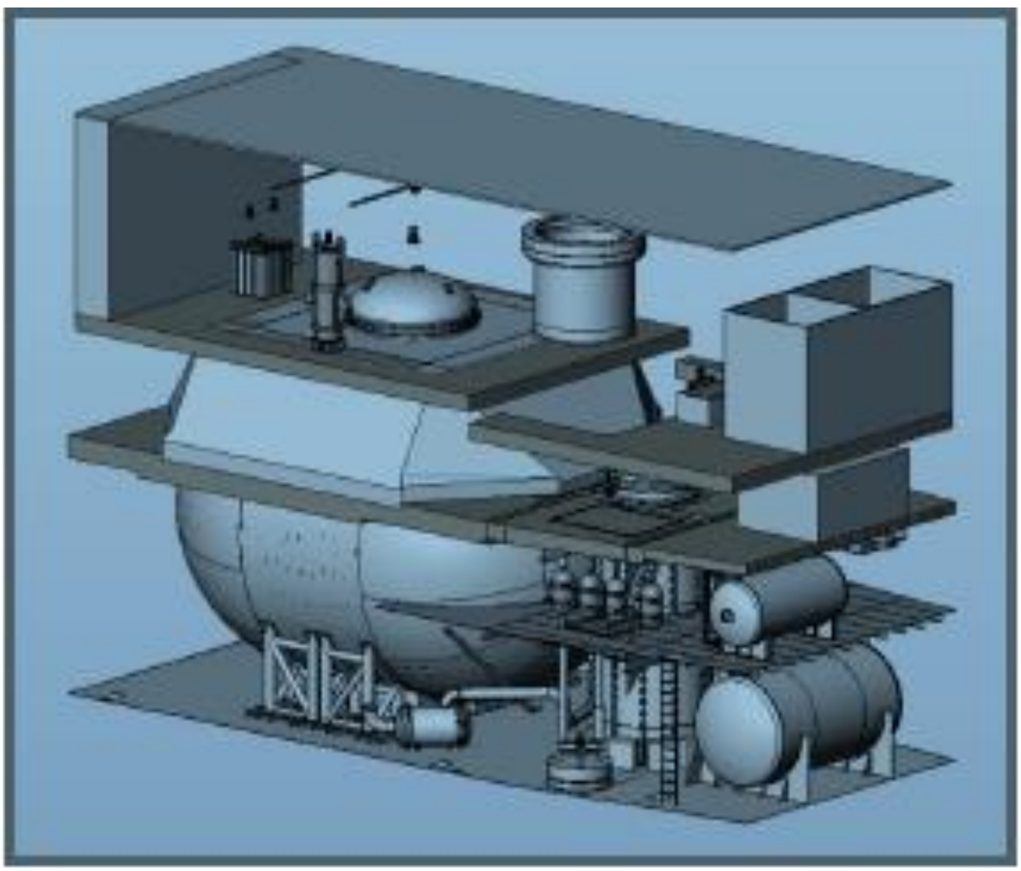

Figure 25. 3-D LiDAR image of the MH-1A reactor containment vessel and related components within the hull of the barge *STURGIS*, circa 2015.

In a telephone interview conducted in December 2018, Mr. Honerlah reported that 95% of the remaining radioactive contamination within the MH-1A *STURGIS* was in the RPV, which was removed and sealed in a special container before being trucked to a specially permitted low-level radioactive waste disposal site operated by Waste Control Specialists (WCS) in Andrews County, Texas (Figure 26).

[238] See Appendix C – Supplemental Materials, Decommissioning Documentation, 3-D MARSAME Drawings for examples of the 3-D imagery developed during this phase of work.

Figure 26. MH-1A Reactor Pressure Vessel being loaded for shipment at Port of Galveston, 2018.

Other MH-1A nuclear plant components that required similar disassembly and disposal included the MH-1A primary shield tank and stainless-steel piping that were contaminated at lower levels. Like the RPV, they too were sealed and disposed of at the WCS site under special state and federal permits.[239]

During the decommissioning operations, the team had to overcome several significant issues that were more complicated than had been anticipated. Additionally, the team encountered inclement weather conditions related to Tropical Storm Bill and Hurricane Harvey. USACE issued two modifications to APTIM to provide additional funding for shortfalls and delays as a result of the unique complexity of this project.

During the MH-1A STURGIS' three-year period of decommissioning at the Port of Galveston, more than 2.5 million pounds of liquid and solid waste with low levels of radioactivity were removed and disposed, most of that weight being from liquid ballast in the lower levels of the vessel's hull as well as lead and steel from the MH-1A *STURGIS*' mid-body mount and the reactor containment vessel.[240] Non-radiological

[239] Honerlah and Barber 2018.
[240] Matlapudi 2018.

hazards present during the decommissioning and shipbreaking of the STURGIS included asbestos-containing material (ACM) used in ceiling tiles, wall tiles, floor tiles, gaskets, and thermal system insulation, lead from shielding, and polychlorinated biphenyls (PCB) from paint that were used extensively throughout the MH 1A reactor containment and other areas of the vessel. In addition, small amounts of mercury were present in fluorescent light bulbs and old switches and thermostats located throughout the STURGIS as well as liquid PCBs in residual oils. During the decommissioning and shipbreaking activities, these materials were properly removed and disposed in accordance with applicable state, local, and federal regulations.

When the D&D process was completed at the POG in 2018, the remaining areas of the *STURGIS* were surveyed for residual radioactivity and results supported the free release of the vessel to International Shipbreaking Limited (ISL) in Brownsville, Texas, for shipbreaking. The hull of the *STURGIS* was subsequently prepared for relocation. In September 2018, as the *STURGIS* departed Galveston and arrived in Brownsville, documentary photographs (Figures 27 and 28) and videos were recorded to document the *STURGIS'* final voyage.[241] In March 2019, ISL completed the remaining disassembly work, cutting the *STURGIS'* hull into smaller pieces for recycling and reuse.

Figure 27. *STURGIS'* arrival at International Shipbreaking Limited, Brownsville, Texas (2018).

[241] Additional photographs and videos of the *STURGIS*' relocation from Galveston to Brownsville are included in Appendix C- Supplemental Materials, Decommissioning Documentation accompanying this report as well as the USACE Baltimore's MH-1A *STURGIS* Digitized Historical Documents Archive at http://www.nab.usace.army.mil/Missions/Environmental/Sturgis.aspx.

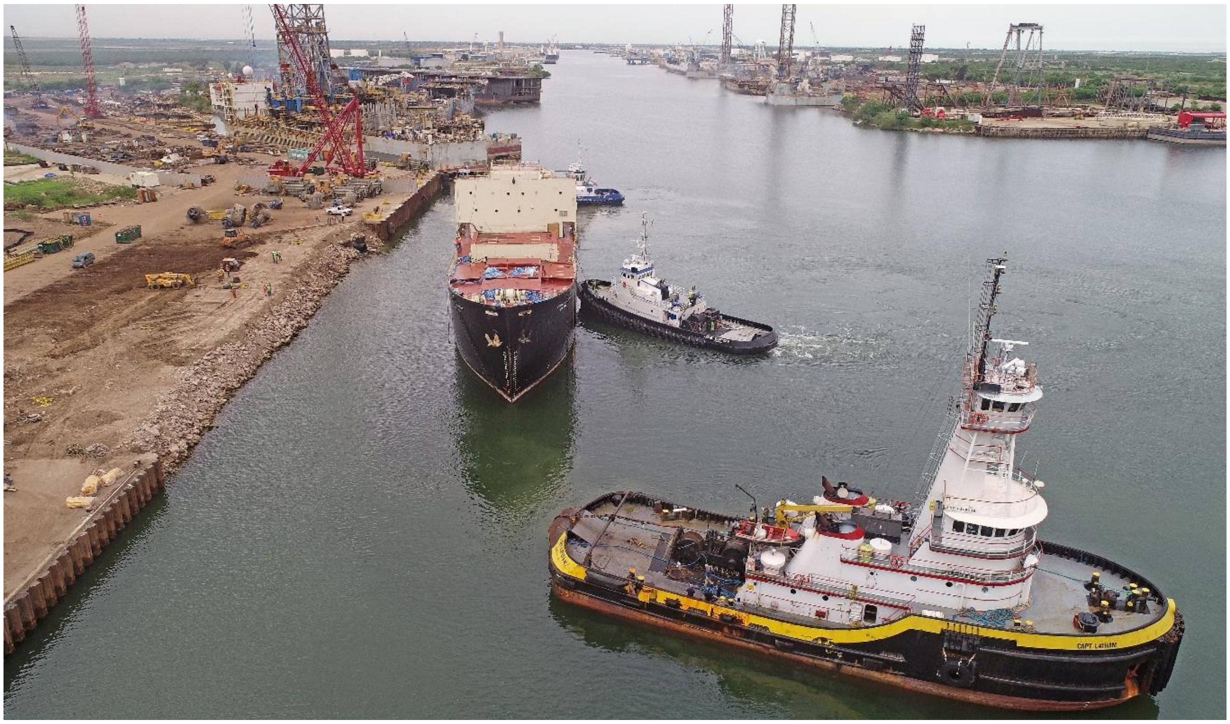

Figure 28. Mooring *STURGIS* at International Shipbreaking Limited,
Brownsville, Texas (2018).

APPENDICES

<u>A - Drawings (digital drawing images provided on electronic storage media (DVD-R) inside rear cover)</u>

LIBERTY SHIP DRAWINGS – 4 images, 1964, (MS Word with Captions, entitled "Reardon Drawings" (JPG images)

MH-1A *STURGIS* DRAWINGS – 36 images, circa 1964-1967 (Adobe.pdf)

<u>B - Photographs (digital photo images provided on electronic storage media (DVD-R) inside rear cover)</u>

LIBERTY SHIP *SS CHARLES H. CUGLE* – 1 captioned image, 1964

MH-1A NUCLEAR POWER REACTOR AND BARGE *STURGIS* – 33 captioned images, 1963-1965

DIGITAL IMAGES – 154 captioned and uncaptioned images, various dates

<u>C - Supplemental Materials (digital files provided on electronic storage media (DVD-R) inside rear cover)</u>

MH-1A *STURGIS* HISTORICAL DOCUMENTATION

FILMS – 3 internet web-videos, circa 1965 (You-Tube web-links)

HISTORIC DOCUMENT INDICES – 3 spreadsheets (MS Excel)

MISCELLANEOUS – 1 compiled folder of memos, correspondence, and newspaper articles, 1944-1977 (Adobe.pdf)

ORAL HISTORIES - 2 interview summaries, 2018 (Adobe.pdf)

TECHNICAL REPORTS – 7 report images, 1964-1969 (Adobe.pdf)

MH-1A *STURGIS* DECOMMISSIONING DOCUMENTATION

USACE REPORTS AND PRESENTATIONS – 2 report images (Adobe.pdf) and 1 Microsoft PowerPoint file, 2002, 2014, and 2018

PHOTOGRAPHS - 86 images (Adobe.pdf; JPG), circa 1978 – 2018

VIDEOS - 4 digital videos (.MP4; .WMV), 2015 - 2018

DRAWINGS- EM Final Drawings: 35 images (Adobe.pdf), c. 2015; 3-D Renderings- 14 images (.PNG files), date unknown

VDHR CONSULTATION - 3 survey forms, 1 letter, 1 agreement document, 1 planning document, 2013 - 2018 (Adobe.pdf)

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Public interest in the Liberty ships of World War II and the U.S. Army's applications of nuclear technology in the Cold War era has generated countless articles and websites that are readily accessible via the worldwide web. To assist those interested to conduct further research into those topics, the sources of information cited in the narrative report above have been compiled hereafter in bibliographic format. While the readily available sources of information specific to the *SS* C*harles H. Cugle* seem remarkably limited within a sea of publications and websites about World War II Liberty ships, the breadth and depth of information about the Army Nuclear Power Program (ANPP), its goals, its leaders, and its ultimate achievement, the nuclear power barge MH-1A *STURGIS*, are far more abundant. Several of the most relevant primary sources regarding the MH-1A *STURGIS* have been digitized by the U.S Army Corps of Engineers, Baltimore District and are provided, as noted below, in a series of appendices accompanying this report. Others are available via the USACE Baltimore's MH-1A *STURGIS* Digitized Historical Documents Archive at http://www.nab.usace.army.mil/Missions/Environmental/Sturgis.aspx.

It is important to understand, however, that the sources cited and provided herein represent only a fraction of the overall body of official records, scholarly publications, and avocational articles that are available on these topics in the nation's archives and libraries and via the internet. Among the most voluminous records are those of the U.S. Army Chief of Engineers, U.S. Army Secretary Frank Pace, the Records of the U.S. Maritime Administration, and the Atomic Energy Commission, all archived in the National Archives, the Library of Congress, and their regional records centers. For more focused research into the ANPP and its many achievements, the U.S. Army Corps of Engineers maintains the records of the ANPP, its leaders, and its successors in the USACE Headquarters Office of History in Alexandria, Virginia. Certainly, general internet sources such as Wikipedia can provide a convenient starting place for avocational research. But as a compilation of primary and secondary sources offering both general historical background of the *SS Charles H Cugle* as well as highly technical engineering documentation of the MH-1A *STURGIS,* the authors and sponsors of this report hope that this bibliography will serve as a useful and reliable starting point for further research into the nation's historic Liberty ships and Cold War-era nuclear technology achievements.

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ADDITIONAL SOURCES OF INFORMATION

Appendix C of this report contains the Baltimore District's Historical Documents Repository Index of historical, administrative, design, construction, operation, and maintenance documentation for the MH-1A *STURGIS* dating from circa 1960 to 1979. The indexed documents were digitized by the Baltimore District and stored at the Baltimore District's MH-1A *STURGIS* Digitized Historical Documents Archive, http://www.nab.usace.army.mil/Missions/Environmental/Sturgis.aspx. While the documents within this collection served as the primary source of information used in developing this historical mitigation report, this collection contains far more information than has been incorporated herein.

Army Nuclear Power Program "Virtual Exhibit": https://armyengineerhistory.dodlive.mil/anpp/. This online source, hosted by the U.S. Army Corps of Engineers, provides a user-friendly overview of the ANPP, including its inception and the associated reactors. Much of the textual information is derived from or duplicates information provided in Lawrence Suid's 1990 book on the ANPP. However, the Virtual Exhibit is enhanced with documentary photographs and other visual materials.

Wikipedia: https://en.wikipedia.org/wiki/Army_Nuclear_Power_Program.
While Wikipedia is not generally considered a scholarly source and is open to revisions based on unverified sources, the Wikipedia entry on the ANPP currently provides an overview of the program, with citations that serve as a reasonable point of departure for those seeking additional information on the program.

The U.S. Army Corps of Engineers, Baltimore District maintains an environmental division website on the MH-1A *STURGIS*: https://www.nab.usace.army.mil/Missions/Environmental/Sturgis.aspx. This website provides additional information on the environmental requirements associated with the decommissioning and disassembly of the *STURGIS*, including links to environmental reports and compliance documents. The site includes links to several historic-period videos available on YouTube that describe the ANPP, the MH-1A *STURGIS* and many aspects thereof. These primary-source videos are valuable for their period images and for providing a contemporary perspective (i.e., view of the program during the period in which it operated).