NASA's Nuclear Frontier

The Plum Brook Reactor Facility

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Robert S. Arrighi

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The Plum Brook Reactor Facility, 1941—2002

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Image 1 (cover): Plum Brook reactor control room as engineers prepare to "take it critical" for the first time in 1961. (NASA C1961–55813)

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Introduction

In 1953, President Eisenhower delivered a speech called "Atoms for Peace" to the United Nations General Assembly. He described the emergence of the atomic age and the weapons of mass destruction that were piling up in the storehouses of the American and Soviet nations. Although neither side was aiming for global destruction, Eisenhower wanted to "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 towards peace and happiness and well-being."[1] One way Eisenhower hoped this could happen was by transforming the atom from a weapon of war into a useful tool for civilization.

Many people believed that there were unprecedented opportunities for peaceful nuclear applications. These included hopeful visions of atomic-powered cities, cars, airplanes, and rockets. Nuclear power might also serve as an efficient way to generate electricity in space to support life and machines. Eisenhower wanted to provide scientists and engineers with "adequate amounts of fissionable material with which to test and develop their ideas."[2] But, in attempting to devise ways to use atomic power for peaceful purposes, scientists realized how little they knew about the nature and effects of radiation. As a result, the United States began constructing nuclear test reactors to enable scientists to conduct research by producing neutrons.

American scientists and engineers carried out the "atoms for peace" initiative at the nearly 200 research and test reactors built in the 1950s and 1960s. These types of reactors are very different from power reactors, which are built to produce power by converting radioactive heat into electricity. In contrast, research and test reactors are used for scientific and technical investigations. Research reactors help engineers design experiments and build better reactors, while test reactors generate powerful radiation fields that enable scientists to

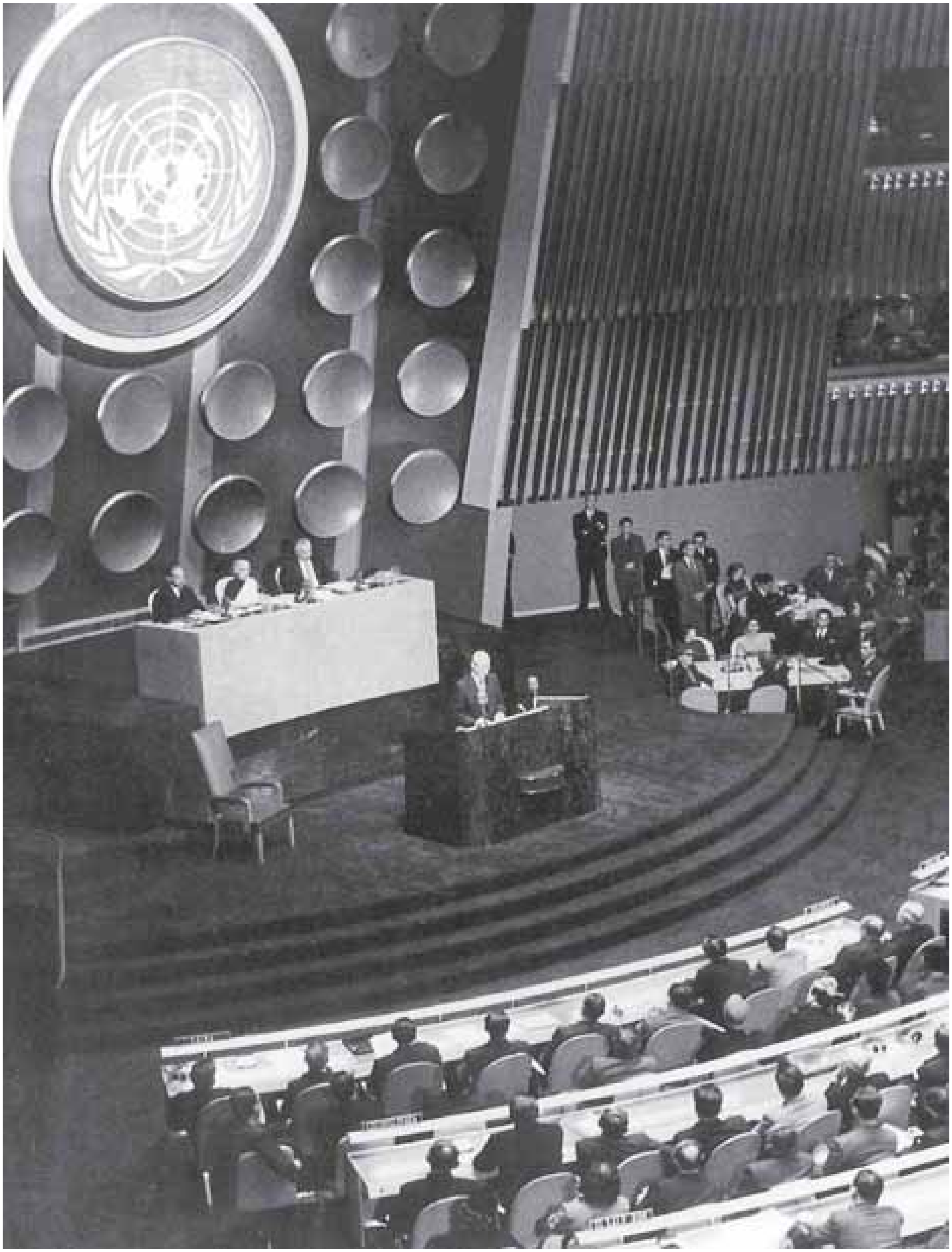

Image 2: In his 1953 “Atoms for Peace” speech at the United Nations General Assembly, President Eisenhower called for an international atomic agency so that “experts would be mobilized to apply atomic energy to the needs of agriculture, medicine, and other peaceful activities.” (International Atomic Energy Agency)

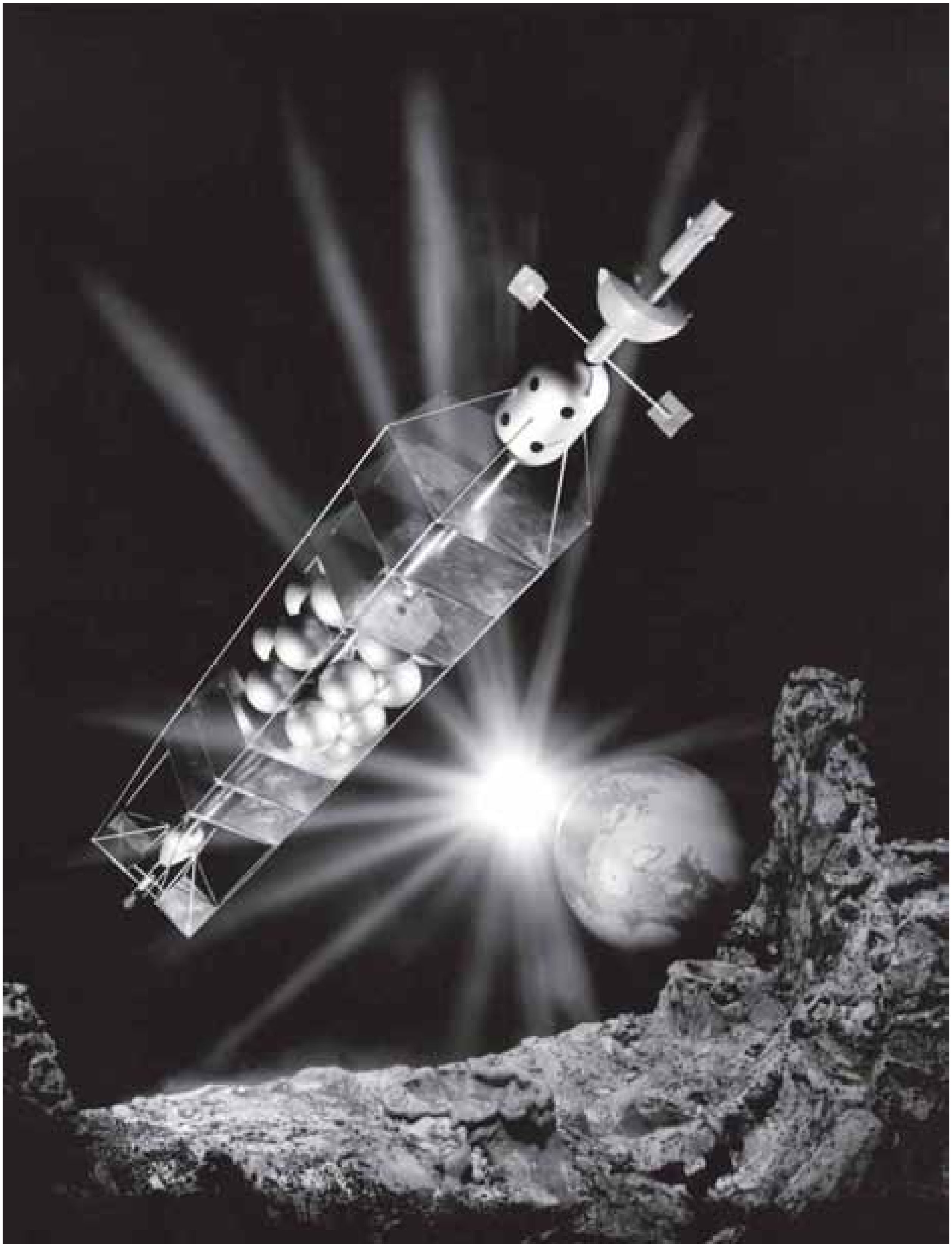

Image 3: Artist's conception of a piloted nuclear-powered spacecraft capable of exploring the solar system. (1959) (NASA C–1959–52113)

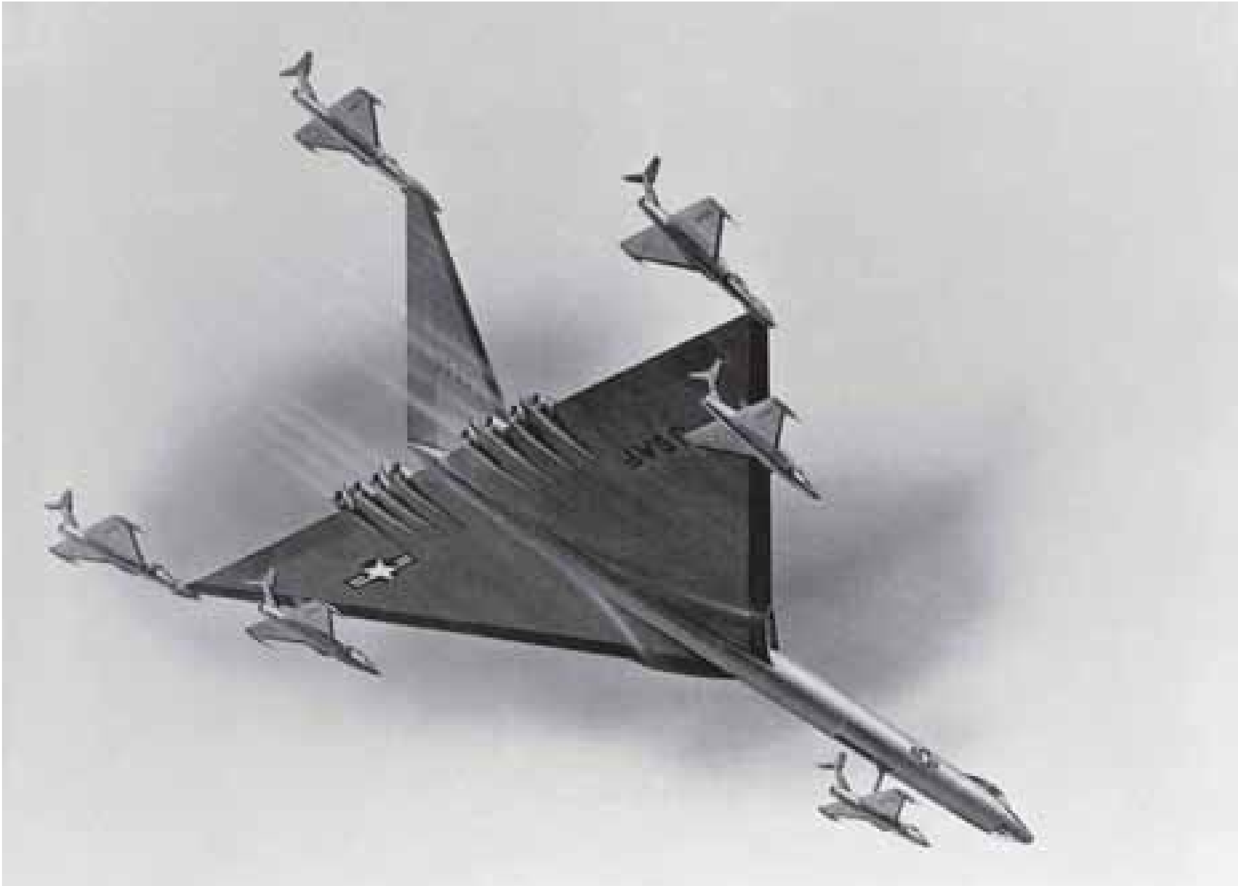

Image 4: Artist's conception of an atom-powered bomber capable of carrying its own fighter escort. The plane was described by Lee A. Ohlinger, atomic specialist for Northrup Aircraft, at a meeting of the Society of Automotive Engineers in New York (10 April 1956). Called "Project Opossum," the bomber would carry six fighters at subsonic speeds, cutting them loose and shifting into high in case of attack. (Copyright and permission courtesy of Bettmann/CORBIS)

study how materials respond to radioactive environments. Though commercial and academic institutions built some research and test reactors, the government supported the large majority of them. One of the most powerful in the world was the National Aeronautics and Space Administration (NASA) test reactor, located at Plum Brook Station in Sandusky, Ohio, near Lake Erie. From 1961 to 1973, this reactor was home to some of the most advanced nuclear experimentation in the United States. Engineer A. Bert Davis said of the work at Plum Brook, "We were young and eager and we felt like we were pushing back the frontiers of science."[3] The Plum Brook reactor became NASA's nuclear frontier—the boundary between what was known and unknown about the effects of radiation on materials.

This book is a visual history of the Plum Brook reactor, including numerous images and captions, a narrative history, and selected primary documents. It begins with the acquisition of the Plum Brook farmland by the government at the start of World War II and discusses its use as a significant ordnance works for the war effort. At the same time, scientists worldwide were making tremendous progress on a roughly fifty-year investigation of the mysterious world inside the atom and the enormous reserve of power it appeared to contain. This work culminated in the atomic bomb. After the war, as Plum Brook's ordnance factories went silent, scientists continued their pursuit of nuclear knowledge by constructing test reactors. One specific aim for this research in the 1950s was to build a nuclear-powered airplane. To support this effort, in 1956 NASA's predecessor, the National Advisory Committee for Aeronautics (NACA), began to design and build a massive test reactor at Plum Brook. By the time the reactor was completed in 1961, President Kennedy had suspended the nuclear

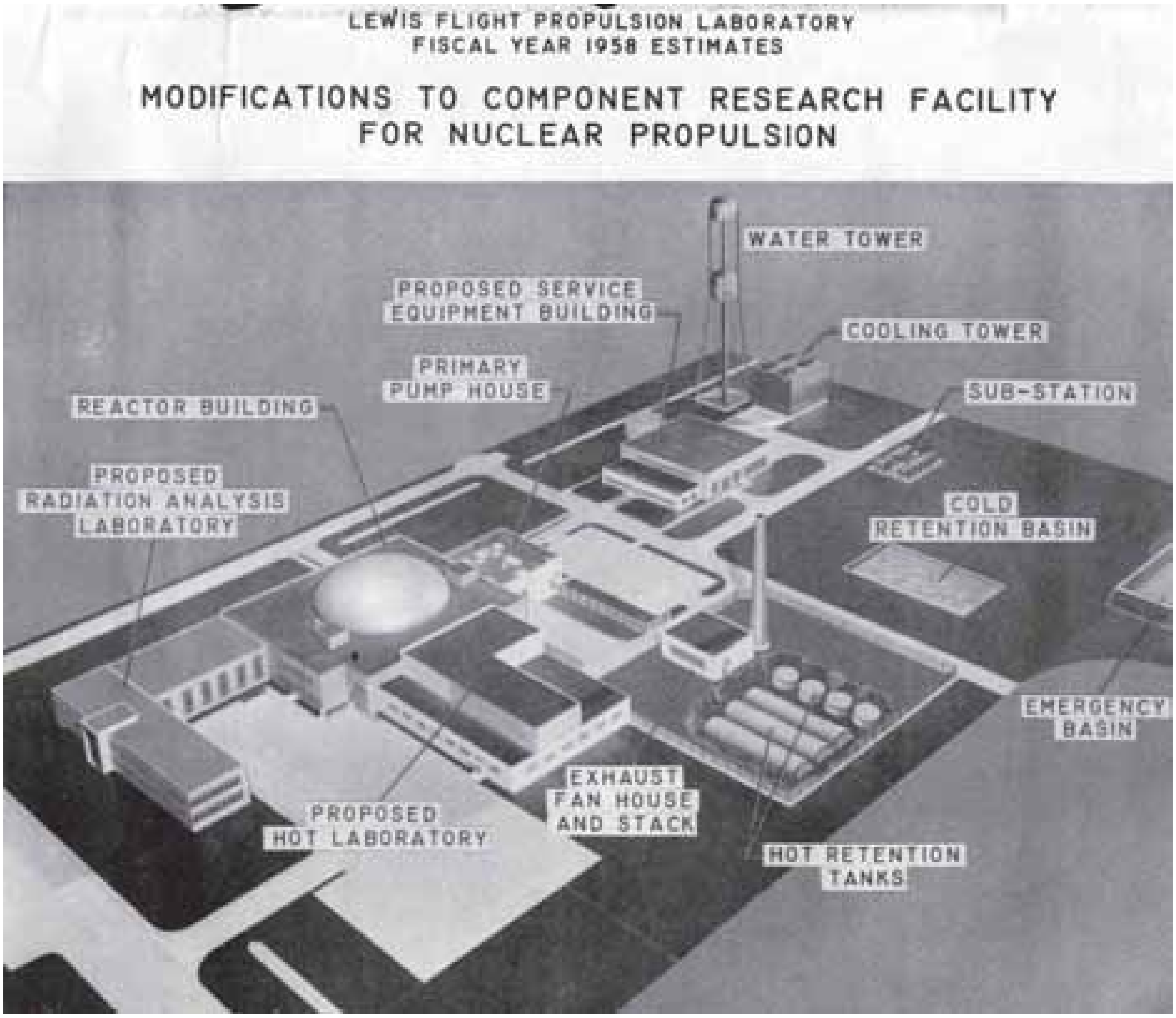

Image 5: Artist's drawing showing the layout of other Plum Brook support buildings and laboratories. At the time, several key buildings had yet to be built. (1957) (NASA C–2003–818)

aircraft program for safety and technical reasons. However, in its place he advocated an even bolder plan—a nuclear rocket. The Plum Brook Reactor Facility became one of the primary research facilities to test materials for this rocket. Working with contractors from Lockheed, Westinghouse, General Dynamics, and General Electric, scientists and engineers conducted ground breaking nuclear experiments.

Despite the promise of their work, many of the experiments were never concluded. In 1973, just over a decade after Kennedy first extolled the nuclear rocket's importance, the project shared the fate of the nuclear airplane. In the post-Apollo era, NASA terminated costly, long-term, nonreusable projects like the nuclear rocket in favor of programs that appeared to have greater immediate payoff like the Space Shuttle. Two weeks after Apollo's last mission, Plum Brook was ordered to shut down its reactor. The entire facility was maintained in a standby mode (under a "possess but do not operate" license) for nearly a quarter century. In 1998, a decommissioning plan was formulated to demolish the reactor piece by piece, until nothing would be left but bare land, suitable once again for farming. Despite now being closed for over thirty years, it remains the eighth-largest test reactor that the United States has ever built.

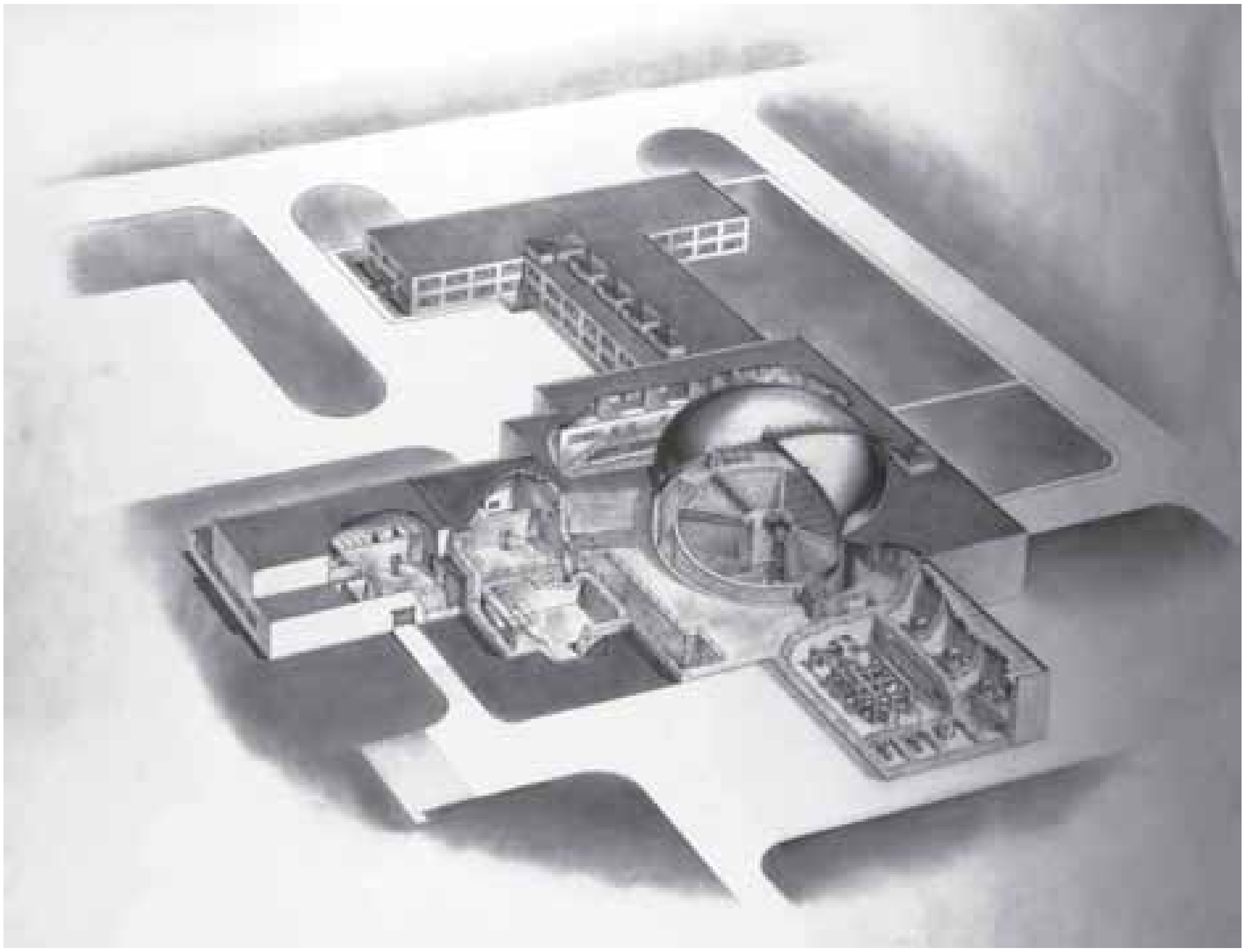

Image 6: Plum Brook reactor primary buildings with a cutaway of the containment vessel revealing the quadrants, the reactor pressure tank, and the lily pad. It was called the lily pad because, with water in the quadrants, the circular center resembled "a lily pad floating on water." (1956) (NASA C–1956–42673)

Archivist Robert S. Arrighi gathered a photographic database, collected artifacts for a museum display, and assembled documents in a collection destined for the National Archives and Records Administration. Historian Mark D. Bowles interviewed many of the people who had worked at the reactor, analyzed the documents, and began writing a scholarly book-length history of the facility (the forthcoming *Reactor in the Garden*). The authors hope that their combined efforts have resulted in a visually exciting and intellectually accessible monograph that recounts the pioneering research of a committed group of NASA scientists and engineers working in the nuclear frontier.

The authors would like to thank Dr. Virginia P. Dawson at History Enterprises, Inc., for her valuable insight into NASA history and her comments on successive drafts of this manuscript. They also thank Kevin Coleman of NASA Glenn Research Center for his coordination of this project and his advice and assistance throughout all phases of the research, writing, and photograph gathering. The authors also acknowledge the valuable help of Deborah Demaline, Jim Polaczynski, Quentin Schwinn, Mark Grills, and Bruce MacGregor from Indyne Inc.; Michael Blotzer, chief of the Glenn Research Center Environmental Management Office; Rich Kalynchuk from Science Applications International Corporation; Project Manager Timothy J. Polich and Senior Engineer Keith M. Peecook from the Plum Brook Reactor Facility Decommissioning. Steve Dick, NASA Chief Historian, Stephen Garber, Jennifer Troxell, and Katrina Thompson from the NASA History Office; Galen Wilson and Scott Forsythe from the National Archives and Records Administration; Nan Card from the Rutherford B. Hayes Presidential Center; Deborah A. MacDonell from the United States District Court

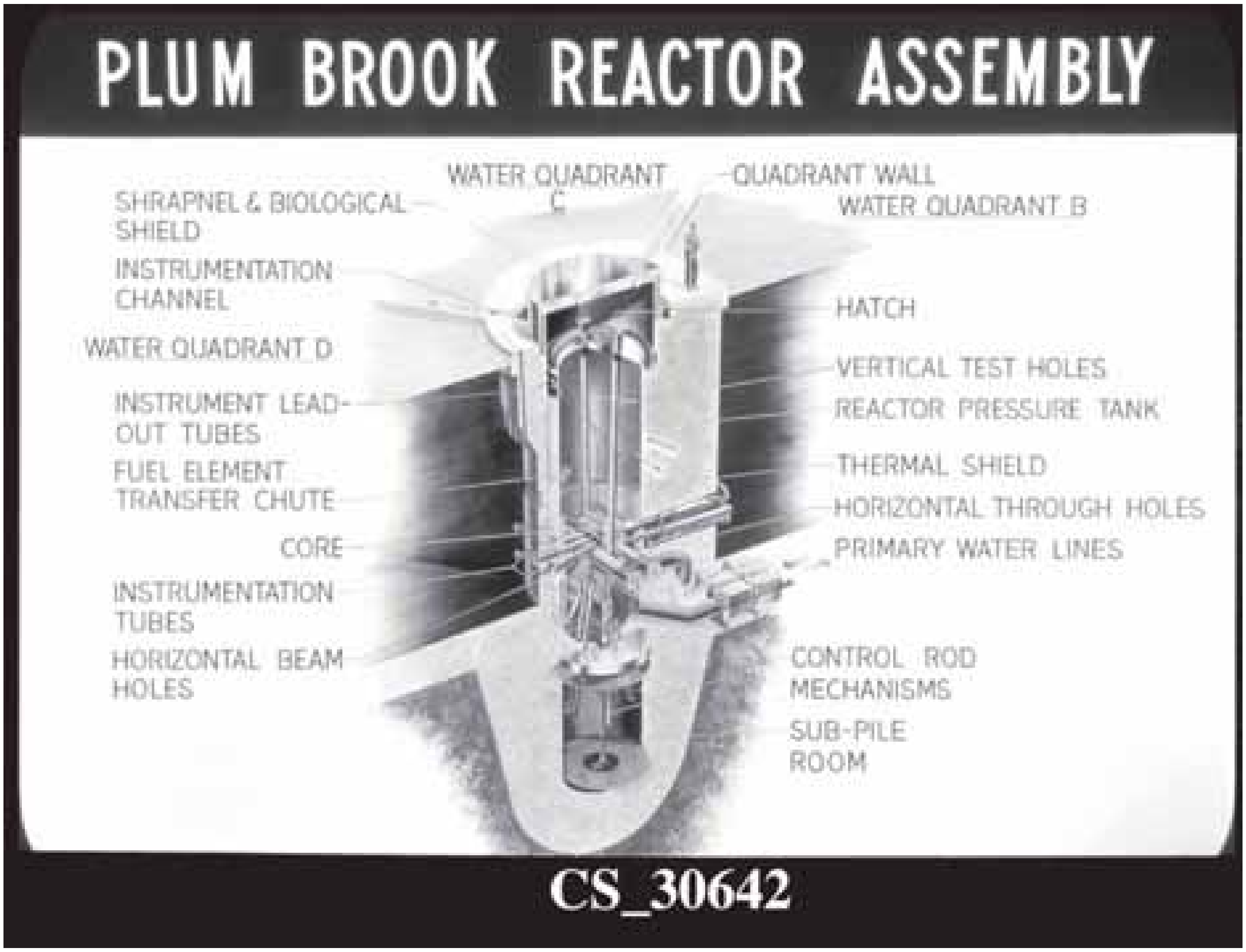

Image 7: Cutaway drawing of the Plum Brook reactor assembly within the pressure tank. The drawing reveals an array of test holes, the core, subpile room, control rods, water lines, etc. The tank was surrounded by four shielding quadrants, three containing water. Quadrant B was constructed with extra concrete shielding so the water was not necessary. This construction provided unique capabilities for handling experiment packages. Despite the significance of this feature, the artist erroneously depicts Quadrant B as being filled with water. (NASA CS–30642)

Northern District of Ohio (Toledo); Linda Gattshall from the Milan Public Library; Margaret Baughman from the Cleveland Public Library Photograph Collection; Joanne Cornelius from the Cleveland State University Special Collections Department; Jerome Cooke from the Department of Energy; and all of the retirees from the Plum Brook Reactor Facility who graciously gave their time to be interviewed for the history projects. Lynn Patterson provided excellent transcriptions for all the interviews conducted in this book. Melissa Kennedy at NASA Headquarters created an initial design, at NASA Glenn, Kelly Shankland redesigned and laid out the complete monograph, Patty McCredie was the editor, and Lorraine Feher was the proofreader. A special thank-you goes to Hap Johnson, H. Brock Barkley, and Harry Finger, who supplied documents and photographs from their personal files.

A debt of gratitude is extended to the manuscript reviewers (anonymous peer-reviewers and NASA and former Plum Brook reactor employees) who provided important suggestions to improve this manuscript. The NASA and reactor employees included H. Brock Barkley, Earl Boitel, Bill Brown, Jack Crooks, Don Johnson, Jack Ross, and Dean Sheibley.

A special recognition goes to Olga M. Dominguez, Deputy Assistant Administrator for Institutional and Corporate Management at NASA Headquarters in Washington DC, who without her support, dedication, and foresight to preserve the history of this unique facility, this document would not have been possible.

Obtaining the Land

In early 1941, Fred C. Baum was working on his 110-acre farm in Erie County, Ohio, just like he had every day for the previous twenty years. He was a typical small farmer, raising cows, cultivating his fields, and tending to his 120-tree apple orchard. He and his family lived in an idyllic country house near his crops and livestock. Several acres of beautiful shade trees surrounded the area and a babbling stream named "Plum Brook" ran through the center of the property. Though Baum's farm was a thriving enterprise providing a good living for his family, his career as a farmer ended unexpectedly that spring, before he could even harvest the year's crop. His fields were destroyed, buildings razed, and livestock slaughtered, as the United States government acquired his property in the name of military preparation. For compensation the government land agents offered the Baum family $18,375 and told them to vacate immediately.[4]

With World War II spreading throughout Europe, American political and military leaders began to prepare the United States for the material demands of conflict. It was still many months before the bombing of Pearl Harbor, but the government began laying the infrastructure for the war. This infrastructure took the form of seventy-seven ordnance factories built throughout the country, primarily on the land of former farmers. In the span of just a few months in the spring of 1941, the government's land agents took possession of 44 million acres of land (roughly the size of all the New England states) formerly owned by private citizens. In Erie County the government exercised its power of eminent domain and forced over 150 Ohio farming families, including the Baum family, to sell 9,000 acres of land. Baum's farm became part of the future home of the Plum Brook Ordnance Works.

The United States military designated Plum Brook as one of its most important sites for the development of gunpowder. It became one of the three largest suppliers of trinitrotoluene (TNT) for

Image 8: Descendants of original 1812 Firelands settlers owned much of the property that became Plum Brook Station. Years of commitment and investment in the land had resulted in abundant crops and a strong community. In early 1941, federal agents arrived, and in April, 150 families were forced to sell out and leave the land that had been theirs for generations. Courtesy of Henry Pfanner.

Image 9: Plum Brook Station seen in the context of Sandusky's unique location near Lake Erie. It is in the heart of some of the region's most fertile farmland. However, access to five highways, in addition to its secure distance from the borders, made it a perfect location for an ordnance facility. (NASA C–1960–55682)

Image 10: The Plum Brook Ordnance Works administrative building, medical services building, guard tower, and other structures during World War II. Just months prior to this photograph, this had all been farmland. Courtesy of Corps of Engineers, U.S., Army. (No. 1238–12, 1944)

Primary Document #1

The following document is Fred C. Baum's protest in a district court that the government was not providing fair compensation for the forced acquisition of his lands. The government was offering $18,500 and Baum believed that a fair price would be $35,929 for land that included a two-story brick home with ten rooms, two barns, milk house, hog pen, 120-tree apple orchard, thirty-one cows, twenty-two hogs, two acres of woods, and diversified crop production in his fields. Ten families went to court to get more money. Baum's was the only case in which the jury ruled in favor of the defendant; it awarded him $31,700, just $4,000 less than he was seeking. No other defendants were awarded anything close to what they held their land to be worth. The government believed that Baum won his case because of a disposition on the part of the jury to favor the landowner without giving just consideration to the testimony presented by government experts. This jury decision was eventually upheld and Baum received his money. These documents can be found at Record Group 21, Records of the District Courts of the United States, Toledo, Civil Case 4627, U.S. vs. 1140.375 Acres of Land, et al., National Archives-Great Lakes Region (Chicago).

September 19, 1941

IN THE DISTRICT COURT OF THE UNITED STATES FOR THE NORTHERN DISTRICT OF OHIO, WESTERN DIVISION

Fred C. Baum presents to the Honorable Court that on or about the 21st day of June, 1941, the United States of America instituted condemnation proceedings as herein entitled, seeking to acquire certain land in Erie County, Ohio, for federal building site purposes, more specifically designated as the Plum Brook Ordnance Site, a portion of which land designated as Parcel I, and fully described in the petition referred to, was in the name of this applicant; and that on or about the 23d day of June, 1941, by order of this Court, the immediate possession of this land referred to was taken by the United States of America.

The applicant further states that subsequently negotiations were entered into for the payment of said land with representatives of the United States Government, but that a price judged to be fair compensation for the taking of said property could not be agreed upon and that consequently the fair value of said property is to be determined at a later date by this Honorable Court and a Jury impaneled for such purposes.

The applicant further states that the United States of America considered that Eighteen Thousand, Five Hundred Dollars ($18,500.00) was a fair and reasonable price for the taking of said land as aforesaid, and has deposited with the Clerk of this Court said amount to the credit of this applicant.

This applying defendant has been ordered to vacate said premises by officials of the War Department of the United States, but is without sufficient funds to purchase or lease other lands and housing facilities to which he might move his family and his furniture and equipment.

IN THE UNITED STATES DISTRICT COURT
FOR THE NORTHERN DISTRICT OF OHIO
WESTERN DIVISION

UNITED STATES OF AMERICA, Petitioner,	:	CIVIL ACTION NUMBER 4627
vs.	:	SUPPLEMENTAL BRIEF ON MOTIONS FOR NEW TRIAL FILED BY ANNA BOOT, AMELIA KROMER, CARL KROMER, GEORGE D. BEATTY AND EMMA KROMER.
1140.375 acres of land, more or less, in Erie County, Ohio, E. A. Druckenmiller and Carrie Druckenmiller, et al., Defendants.	:	

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WAR DEPARTMENT

WASHINGTON

The Honorable,
The Attorney General,
Washington, D. C.

AUG - 9 1941

Dear Mr. Attorney General,

Reference is made to letter from this Department, dated June 17, 1941, requesting institution of condemnation proceedings for the acquisition of 1,140.375 acres of land located in Erie County, State of Ohio, for use in connection with the expansion of the Plum Brook Ordnance Plant.

Pursuant to the provisions contained in the Act of Congress approved February 26, 1931 (46 Stat. 1421; 40 U. S. C. sec. 258a), and under the further authority of the Act of Congress approved August 18, 1890 (26 Stat. 316), as amended by the Acts of Congress approved July 2, 1917 (40 Stat. 241), and April 11, 1918 (40 Stat. 518; 50 U. S. C. sec. 171), which acts authorize the acquisition of land for military purposes, and the Act of Congress approved April 15, 1941 (Public No. 29 - 77th Congress), which act appropriated funds for such purposes, it is requested that you cause the enclosed declaration of taking to be filed in condemnation proceedings now pending for the acquisition of the fee simple title to the land above referred to, subject, however, to all existing easements for public roads, highways and public utilities.

Said lands are more particularly described in the enclosed declaration of taking, executed by the Secretary of War on August 8, 1941. The declaration of taking sets forth the names of the purported owners of the land and the amount ascertained as just compensation for the taking, namely $9,950.00, check for which amount, payable to the order of the Clerk of the United States District Court for the Northern District of Ohio, Western Division, is enclosed for deposit in the Registry of said Court.

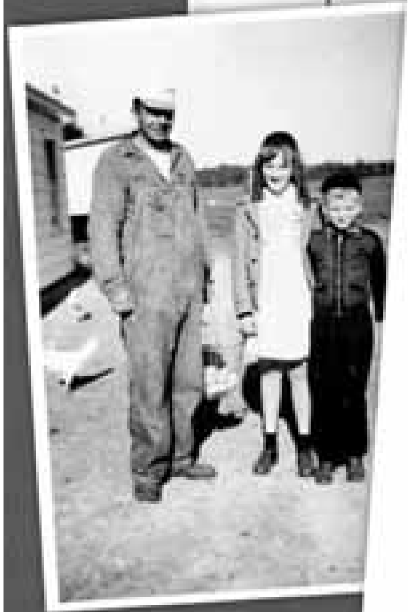
Attention is invited to the fact that the enclosed declaration of taking covers only a portion of the lands involved in the pending proceeding.

Sincerely yours,

HENRY L. STIMSON

Secretary of War.

2 Incls.
1 - Check
2 - Dec. of Tak. (4)



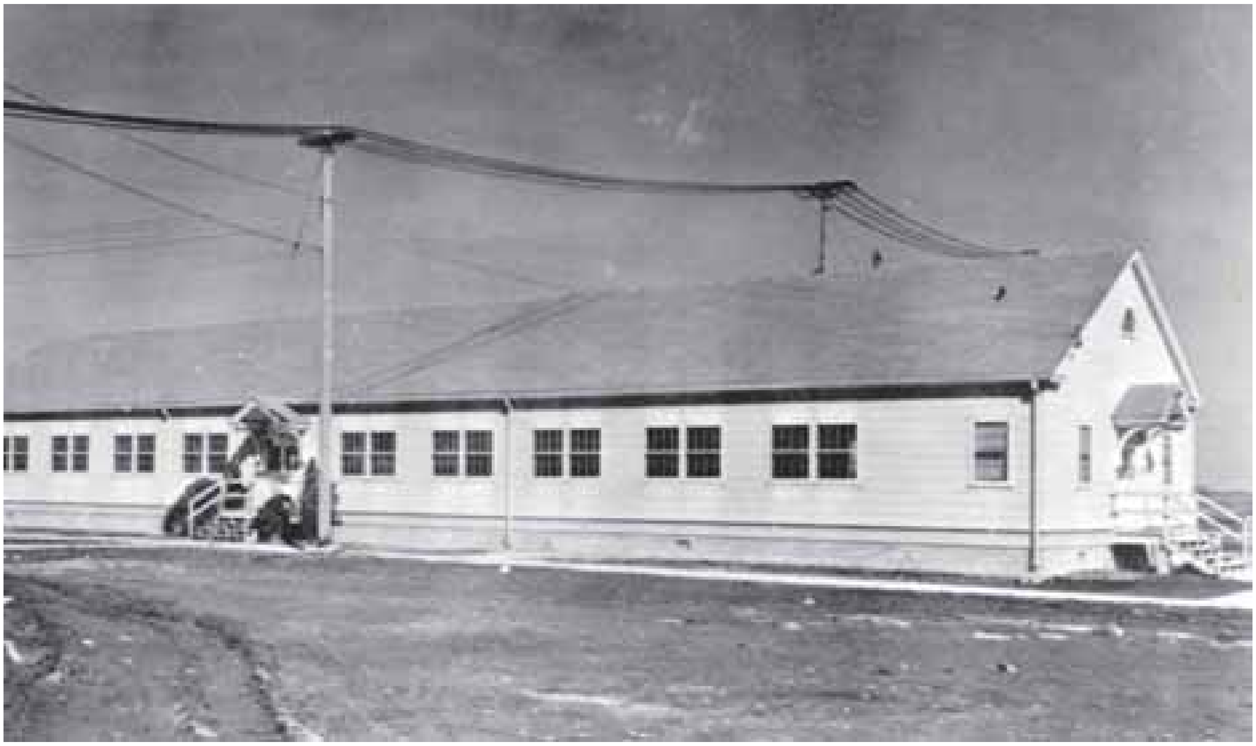


Image 11: The Plum Brook cafeteria building, a typical Ordnance Works structure. Plum Brook's ordnance buildings were built for functionality, not style. Although these structures were built to last five years, many survived much longer, and this building is today used by the Perkins School District. Courtesy of Corps of Engineers, U.S. Army. (No. 3–42, 1944)

Image 12: The Plum Brook cafeteria in the basement of Building 1. A painting of the Plum Brook Trojanair appears on the far wall. The B-17 bomber was built with war bonds purchased by Plum Brook Ordnance Works employees during one of their numerous bond drives. Courtesy of Corps of Engineers, U.S. Army. (No. 21748, 1944)

Image 13: One of ninety-nine bunkers used to store powder at Plum Brook's southwest corner. These structures function today as naturally climate-controlled warehouses for federal records. Courtesy of Corps of Engineers, U.S. Army. (No. 21762, 1944)

the nation, producing nearly one billion pounds between 1942 and 1945. Aesthetics, not surprisingly, were not considered important in the construction of most ordnance facilities. "There are to be no high falutin gargoyles on these buildings,"[5] remarked Major General Charles M. Wesson, chief of ordnance, in July 1940. Emphasis was placed on functionality, stability, and speed in construction. Most of the buildings at Plum Brook were considered temporary, with an expected lifespan of five years.[6] All in all, eight major buildings were erected at a cost of $7,851,335.[7]

While most of the buildings at ordnance facilities were hastily built with inexpensive construction materials, the igloos were a notable exception. The igloos (so named because they looked like Eskimo shelters) were solidly built storage facilities that Plum Brook used to house its explosives. They were concrete with reinforced steel structures, shaped like half-barrels lying sideways in the ground, and covered with a thick layer of sod. Two lightning rods protected them during electrical storms. Though they were designed to explode upward and not sideways, all ninety-nine of them had to be isolated from each other by at least 400 feet on each side and 800 feet from the front and rear to prevent a dangerous chain reaction if one of them ignited.

Plum Brook's first line production of TNT began on 15 November 1941, just twenty-two days before the Japanese unleashed a surprise attack on Pearl Harbor.[8] The prime operating contractor was the Trojan Powder Company of Allentown, Pennsylvania. Once operational, Plum Brook produced over 400,000 pounds of explosives per day.[9] The workers did everything that they could to support the war effort. Not only were they committed to performing their jobs, but they also pooled their money together to buy war bonds. One Plum Brook bond campaign set a goal of raising enough funds to purchase a $350,000 military airplane. The plane, a flying fortress, was christened "The Plum Brook Trojanair" before its first flight.

Sandusky, Ohio PBOW NEWS November 21, 1942

TROJAN TRIUMPHS!

$396,000 WAR BOND PURCHASES BY EMPLOYEES ENDS SEVEN MONTHS' CAMPAIGN TO BUY FLYING FORTRESS

RECEIVE PRAISE FOR ACHIEVEMENT

DOWN PAYMENT ON HAND FOR SECOND 'FORT'

Police Get Indian Fielder

BY DIRECT WIRE FROM

WESTERN UNION

Image 14: The Plum Brook Ordnance Works (PBOW) News was published every Saturday for the duration of the war. It emphasized exemplary work habits and kept employees up to date on the social comings and goings. Plum Brook employees ranged from sixteen to eighty years old and came from all around the country. They were tied together by a common sense of purpose to assist the Allied victory. There were also social events, sports teams, and holiday functions that created a strong and closely knit culture. Courtesy of Milan Public Library.

Image 15: Abbott & Costello appeared at the Plum Brook Ordnance Works in August 1942 to encourage workers to buy war bonds. Other campaigns included the display of a captured Japanese submarine, a visit by General MacArthur's ranger troop, and several all-Plum Brook days at Cedar Point, an amusement park in Sandusky. (Permission courtesy of the Charles E. Frohman Collection at the Rutherford B. Hayes Presidential Center, Freemont, Ohio)

In August 1942 the film and comedy duo Abbott & Costello visited Plum Brook to encourage the workers to purchase even more war bonds. The pair entertained the audience on a stage erected behind the administration building. After making jokes and imitating the sound of steam engines, Costello became serious and shouted, "We're going to put the three louses, Hitler, Hirohito, and Mussolini, in their place. We're going to send them right to a good seat—the hot seat!"[10] They spent the remainder of the day at Cedar Point, a local amusement park. Seven months later the bond campaign came to a successful conclusion with most employees setting aside 10 percent of their total salary for bond purchases.

It was difficult to keep morale strong. The labor was demanding and the conditions were harsh. Because buildings were considered temporary, they lacked adequate insulation from the cold Ohio winters. In December 1942 nearly all of the employees worked in their heaviest coats and hats as "icy blasts tore through warped window casings."[11] Most people pulled down their office shades in hopes of deflecting the cold winds. Typewriters became sluggish, and the secretaries forced their numb fingers to press the frozen keys. It was not unusual for twenty-foot icicles to form on the 110-foot-tall water tower. One office manager said that he spent most of the day brushing snow off his desk. Many of the employees rode bicycles to

Image 16: A typical Plum Brook Ordnance Works office building. Rooms like this looked relatively warm and comfortable, but their functional military construction left occupants vulnerable to the Ohio winter weather. Courtesy of Corps of Engineers, U.S. Army. (No. 21747, 1944)

work because of conservation efforts, which also proved to be quite challenging in the winter. While the conditions were difficult, employees endured them, knowing that loved ones were probably risking their lives in far more dangerous and demanding situations abroad.

Plum Brook emphasized safety and conservation. Supervisors had regular safety dinners where they discussed concerns or problems that they thought might threaten their workers. Plum Brook employees were also subject to strict conservation and rationing for the war. They saved gas by carpooling or biking to work. Many families planted "victory gardens" around their houses to help supply their own food needs.

As was typical in most industry during the war, women represented a large proportion of the workforce at Plum Brook.[12] Women held jobs as nitrator operators, wash-house helpers, packers, box factory operators, truck drivers, and clerical workers. There were numerous stories of patriotic women working for the war effort. For example, June Franklin's job was to nail the wooden bottoms onto TNT boxes. She had fourteen close relatives fighting in the war, and when she learned that her husband had been wounded in action in North Africa, she immediately walked into the Plum Brook payroll office, bought a war bond, and signed her name to the bottom of a TNT box. She vowed never to miss a minute of work and said, "Every time I drive a nail into the bottom of a TNT box I feel that I'm driving a nail into the Axis coffin."[13]

In 1945, World War II came to an end. In early May, Germany surrendered, and three months later, after the devastating atomic bomb attacks, Japan surrendered. President Harry Truman announced

P.B.O.W. NEWS October 17, 1942

BEAUTY AND THE BADGE

What with the frills of female finery, the badge of admittance to the reservation is not always shown to best advantage.

The drawings reproduced here are the work of Carol Barnhart, 19, mail messenger for Ordnance Department. The styles are creations actually worn by misses on the grounds and in the offices, according to the all-observant Carol.

The miss with the stack of-shall we say A.V.O.'s-in her left arm, wears her badge in a proper and very conspicuous position. The most myopic guard could readily see it and identify her. The gal in the center has her badge high on the left shoulder and it is almost obscured by the fancy lapel of her blouse. The almond-eyed attraction on the right has deigned to bury her badge in the folds of the material gathered on her left hip.

The NEWS dislikes belaboring, bedeviling and badgering you with talk about badges and their proper display. It all helps the police department, however. And it all spells safety!

Image 17: A drawing from the Plum Brook Ordnance News reminding women of the proper placement of their identification badges. Courtesy of Milan Public Library.

that the war was over via a radio broadcast that night, and proclaimed the next two days as a national holiday. Simultaneous celebrations spontaneously erupted through the United States. In nearby Akron, Ohio, nearly the entire city celebrated on Main Street, which was filled with "people yelling and hugging each other and mothers of G.I.s crying."[14] At Plum Brook the celebrations were more muted. One observer said, "There was quiet elation of course, and here and there especially among female employees there were misty eyes and tears of happiness because their loved ones were safe at last."[15]

After the Japanese surrender, the production at Plum Brook came to an end. For three-and-a-half years it had operated twenty-four hours a day, seven days a week, with only a few work stoppages.

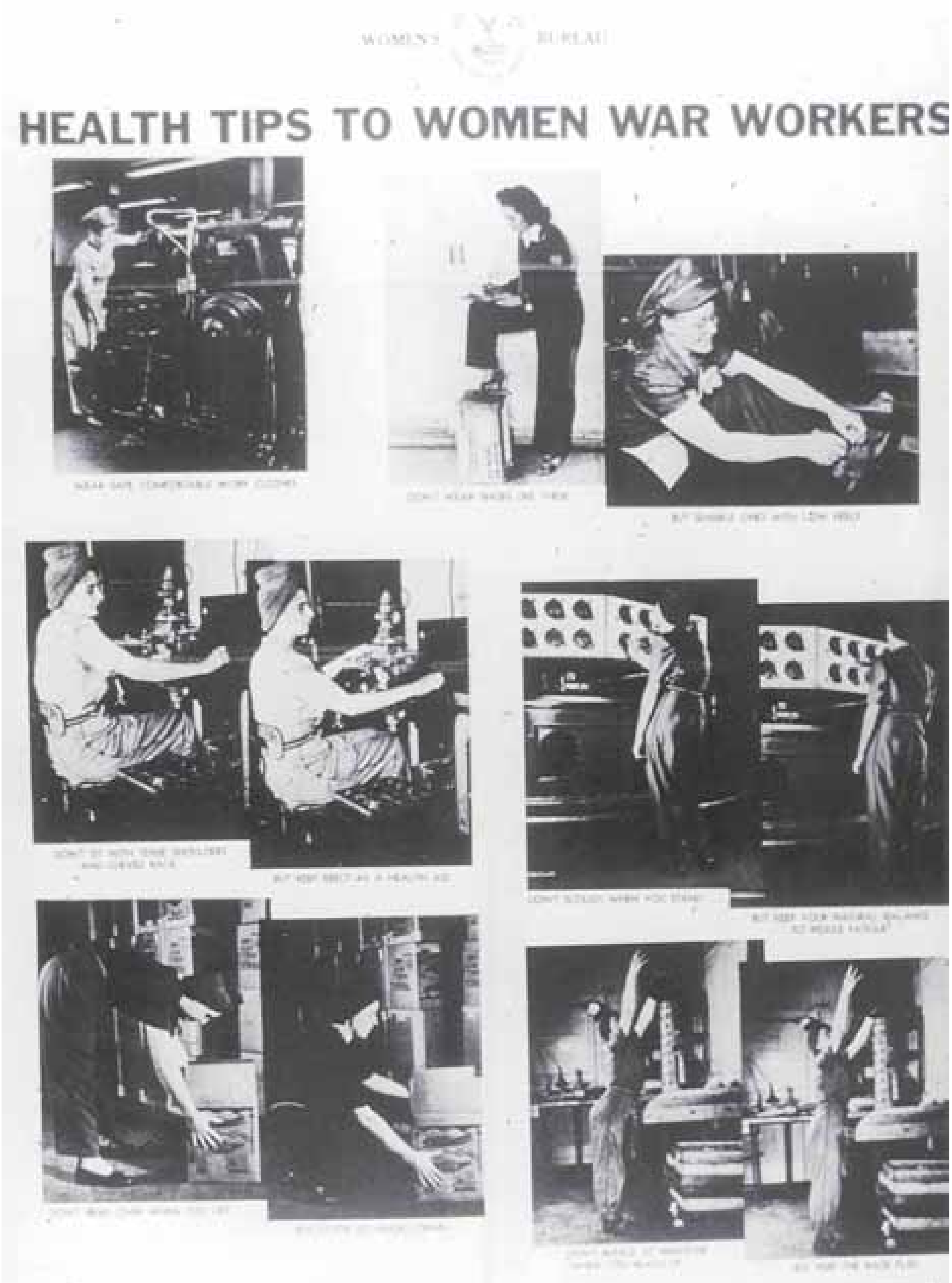


Image 18: This poster was issued by the Women's Bureau to help ensure that women workers did all they could to remain healthy and safe while on the job. (National Archives and Records Administration. NWDNS–44–PA–946)

Image 19: Employees at Oak Ridge National Laboratory celebrating the end of World War II. Spontaneous celebrations erupted all over the country when Japan surrendered. (1945) (Department of Energy Photo 946–26)

Eighteen million hours of labor had produced nearly one billion pounds of explosives, with no fatalities. Several months were needed to close and "decontaminate" the facility, so that the entire site could be returned to the government.[16] Suddenly, Plum Brook was silent again. Some observed a return to nature as they left the plant for the last time. For four years, since ground was first broken, peace and quiet had been absent from these lands. Now there was a "gloriously blue sky overhead" and sounds of "what seemed like a thousand birds throating a medley of songs just as if the feathered songsters knew that peace had come at last to the world of men."[17]

As Plum Brook went quiet, the nation began to wrestle with the realities of the new atomic age. The war ended with the detonation of an atomic bomb, but could the technology that enabled this deadly device be used for other applications? This quest became the goal for scientists working at an increasing number of research and test reactors built throughout the United States.

Image 20: Workers dig up transit lines, flumes, and buried TNT at Plum Brook. The explosive remains were then detonated safely elsewhere. Despite claims that there would be no long-term damage to the land, by 1948 it became evident that the Plum Brook site had suffered considerable contamination. During the early 1950s the land became a subsidiary of the nearby Ravenna Arsenal and was subjected to even more contamination. The NACA attempted to clean up the area in the mid-fifties. The United States Army Corps of Engineers is still working on the project today. (1956) (NASA C–2003–826)

The Dream of a Flying Reactor

After World War II, the United States military began envisioning ways to take advantage of nuclear technology for its weapons arsenal. Since the Army had already developed an atomic bomb, it hurriedly began working on even more destructive applications, namely, a nuclear warhead for a missile, while the Navy successfully built the USS Nautilus, a nuclear-powered submarine. The Air Force began its nuclear initiative on 10 October 1945, when J. Carlton Ward, Jr., president of Fairchild Engine and Airplane Corporation, testified before Congress on behalf of the post-war aviation industry. He claimed that the nation that first developed an atomic airplane would have an unparalleled tactical advantage in future conflicts.[18] Thus was born a fifteen-year, billion-dollar quest to put a nuclear reactor into an airplane for use as a fuel source. The apparent benefits appeared well worth the risk. Some believed that nuclear airplanes would be able to fly for months without the need to refuel. With the heightening tension of the Cold War and the increasing rumors that the Soviets were close to developing their own nuclear airplane, the American government quickly launched a massive effort to close the perceived gap.

A great number of technical problems needed to be solved.[19] For example, the crew would have to be shielded from the onboard reactor for obvious safety reasons. Traditional shielding was so thick and heavy that it would significantly complicate liftoff. Another safety problem was the danger to people on the ground. Should the plane crash, many observers thought that the effect would be similar to the detonation of a hydrogen bomb. Others in the nuclear field tried to reassure the skeptics that these predicted dangers were unrealistic. Lesser concerns consisted of finding materials that could withstand the high operating temperatures of the reactor.[20] Despite the controversy, Pratt & Whitney, Convair, the U.S. Air Force, Lockheed, and General Electric all began developing reactor testing technologies to try to solve the myriad technical problems associated with the nuclear airplane.

Image 21: Abe Silverstein, director of Lewis Research Center, addresses an audience about the benefits of nuclear propulsion. In the background is a display titled "Nuclear Energy Research Technology" that features images of nuclear rockets and uses for thermoelectric power. (1961) (NASA C–1961–58359)

Image 22: Launched on 21 January 1954, the USS Nautilus was the world's first nuclear submarine. The nuclear engine enabled the craft to remain submerged for weeks. After its success, the U.S. government became interested in constructing atomic-powered airplanes, which, it hoped, would have the potential to remain in flight for weeks without refueling. (National Archives and Records Administration, NWDNS–80–G–709366)

Image 23: NACA officials inspect Plum Brook Ordnance Works buildings to determine if they could be used for the NACAs purposes. When the inspectors opened up many of the buildings, they found rooms with calendars, coffee mugs, and papers as they had been left the day the Ordnance Works closed down. An eerily similar scene would be encountered forty years later by the decommissioning team in the Plum Brook Reactor Facility. (1958) (NASA C–1958–47291)

In 1951, the NACA began to explore the possibility of developing its own nuclear reactor to assist in the development of the nuclear airplane. The NACA was uniquely qualified to take the lead in the endeavor because of its expertise as an aeronautics laboratory. This government agency was also important because it willingly shouldered the risks associated with creating innovations. Virginia Dawson wrote, "By assuming the costs of research and testing, the government could pursue promising new technology, regardless of blind alleys and false starts."[21] The NACA selected the Lewis Flight Propulsion Laboratory in Cleveland, Ohio, to design and build the reactor. Representatives from the laboratory examined nineteen sites in Ohio and Pennsylvania for the reactor facility. The sites were judged with a predetermined list of criteria based on safety, cost, and accessibility. Lewis representatives finally chose the Plum Brook Ordnance Works because it was near to Cleveland and already had much of the infrastructure required to operate a nuclear reactor.[22]

Not just at Plum Brook, but throughout the United States, the government took the lead in developing test reactors. These projects exemplified the "big science" era. Big science was a new trend in research characterized by expensive programs massively funded by external agencies and patterned after the Manhattan Project.[23] The government made big science possible through its willingness to spend large amounts of money to develop projects whose outcomes were unknown. This activity took place at national laboratories like

Primary Document #2

The following document is an excerpt from a report that selected Plum Brook as the ideal site to construct the NACA test reactor.

SITE SURVEY FOR NACA RESEARCH REACTOR
September 13, 1955
Prepared for NACA by the Nuclear Development Corporation of America
White Plains, New York

This report summarizes the studies and evaluation of nineteen sites considered for location of a high-flux nuclear research reactor facility which is being designed by the Lewis Flight Propulsion Laboratory of the National Advisory Committee for Aeronautics. The research facility is to be used primarily for engineering studies and performance test evaluation of aircraft reactor power plant systems and components…simulating actual operating conditions.

The location of nineteen possible sites which have been considered includes: Altoona, Pennsylvania; Ashtabula, Ohio; Confluence, Pennsylvania; Cumberland, Maryland; DuBois, Pennsylvania; Fairport, Ohio; Indiana, Pennsylvania; Johnson Island, Ohio; Kittanning, Pennsylvania; Lorain, Ohio; Perrysville, Ohio; Plum Brook Arsenal; Portage, Pennsylvania; Ravenna Arsenal; Saxton, Pennsylvania; Seward, Pennsylvania; Strongsville, Ohio; Susquehanna Ordnance Depot; Twinsburg, Ohio.

It is concluded, as a result of this survey, that the most desirable site is in Plum Brook Arsenal, which is located in a sparsely populated area three and one-half miles south of Sandusky, Ohio. From a technical standpoint, this is among the best of the sites surveyed. Its favorable safety characteristics are inherited directly from the Arsenal's own requirements for both intra- and extra-site safety. Site development costs and the cost of maintaining security should be a minimum, since it is an active Government-owned facility with security fences and patrols, roads, and other services already established. The proximity to the Lewis Flight Propulsion Laboratory (fifty miles, one hour travel by car) will permit full utilization of the administrative and technical personnel and the extensive facilities of the Laboratory. This situation should contribute greatly to the reduction of the cost of establishing and operating the facility.

NDA Plum Brook NACA Nuclear Research Facility 1955

SITE SURVEY FOR

NACA RESEARCH REACTOR

September 13, 1955

SITE EVALUATION CHART

SAFETY	Weighting Factor	Indiana, Pa.	Johnson Island, Ohio	Kittanning, Pa.	Lorain, Ohio	Perryville, Ohio	Plum Brook Arsenal
Good Waste Disposal Possibilities - Air	4	8	8	8	4	8	8
Good Waste Disposal Possibilities - Water	4	4	8	0	4	4	4
Isolated From High Population Density	4	8	4	8	8	8	8
Closeness to Disaster Control Agencies							
Fire Department	3	3	0	0	3	0	6
Hospital	2	4	2	4	2	2	2
Police or Military	2	2	0	2	2	0	4
Protection From Sabotage	2	2	2	2	2	2	4
Dependable Services							
Electricity	3	6	3	6	6	3	6
Water	4	4	8	4	8	4	12
Communications	2	4	0	2	4	2	4
Good Roads	2	4	2	2	4	2	4
Large Area	4	4	8	4	4	8	8
COST							
Lan							
Lan			0	2	1	1	3
Zon			1	2	1	2	2
Dev			1	2	2	2	2
			1	1	2	1	2
			0	0	2	0	2
			2	0	2	2	2
			2	2	2	2	1
			2	2	2	1	1
			1	2	1	1	2
			2	0	1	1	2
			2	2	1	2	1
			2	0	6	2	6
			3	0	9	3	9
			64	57	83	63	107

d; 1, Fair; 0, Poor]

- 77 -

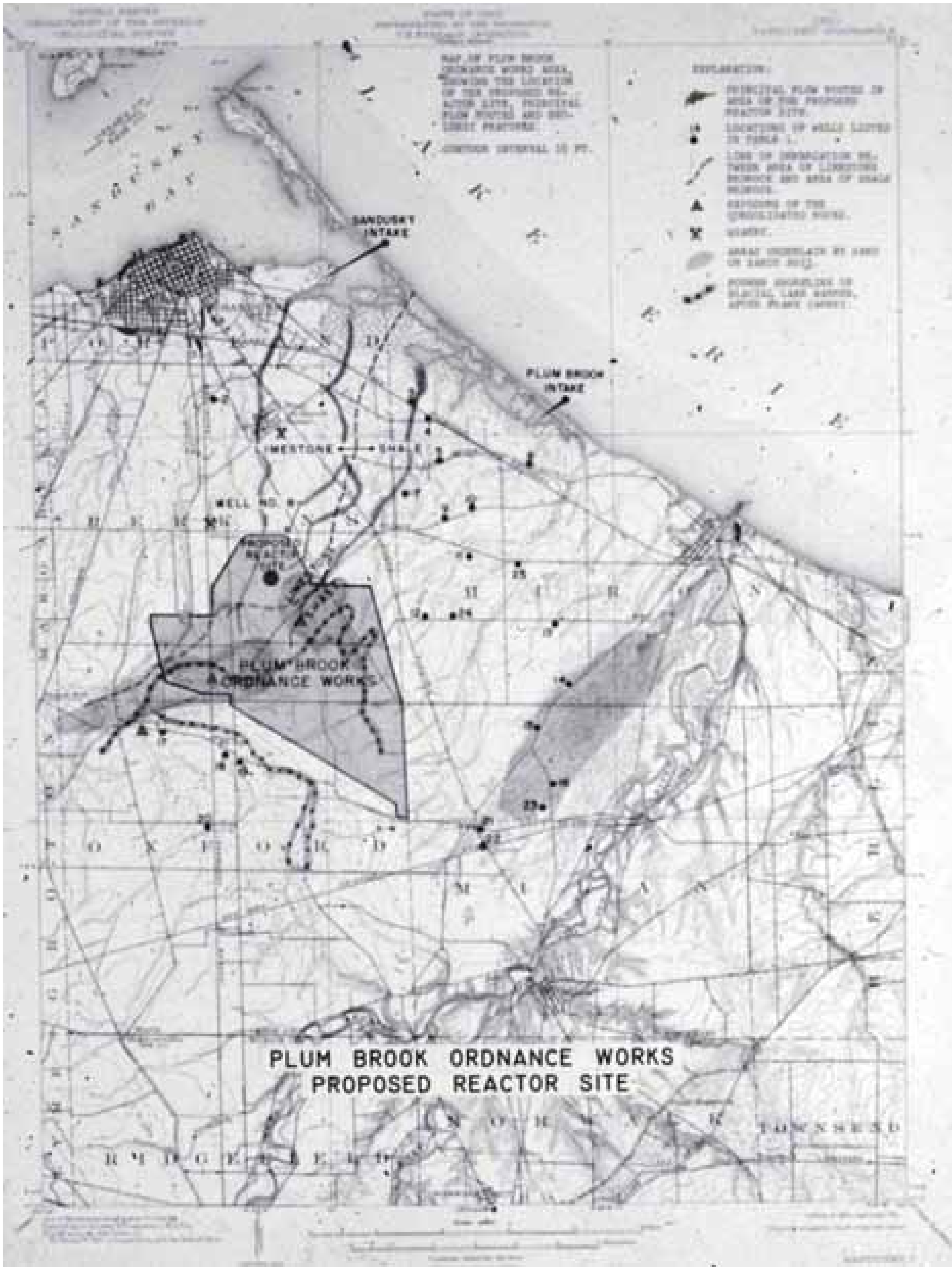


Image 24: This map shows Plum Brook's location relative to Lake Erie and several Northern Ohio cities. Plum Brook's only disadvantage was the relatively large population in nearby Sandusky. However, it was decided that any experiment deemed too risky would be sent to more remote test reactors in Idaho Falls like the Materials Test Reactor or the Engineering Test Reactor. (NASA CS–12374B)

Image 25: Argonne National Laboratory-West. Argonne's western site opened on 18 February 1949 in Idaho to serve as a testing ground for different types of reactors. Similarly to NASA Lewis and Plum Brook Station, Argonne's basic research was conducted at the main laboratory near Chicago, and nuclear facility testing and development was performed at the Idaho site. In December 1951, the Experimental Breeder Reactor I (EBR-1), the world's first nuclear power plant, produced the world's first nuclear-derived electricity. Other Argonne facilities included the Materials Test Reactor (1952–1970), the Engineering Test Reactor (1957–1982), and the Advanced Test Reactor (1967–present). (Department of Energy Photo 2001951)

Argonne, Oak Ridge, Brookhaven, and Los Alamos. Nuclear research was given a high priority, and these laboratories took the lead in developing test reactors. Between 1942 (when the first research reactor was built) and 1962 (when Plum Brook was in operation), the government constructed seventy-seven research and test reactors.

There were two other reasons why the U.S. government led the exploration into nuclear research. The first was secrecy. While much of the research generated at governmental facilities was eventually declassified for transfer to industry, as it was being produced it remained classified. The restricted environment of the typical government laboratory was essential when research was directly tied to national security issues. Second, national laboratories had the luxury of assembling a wide variety of specialists who could be brought together for a common goal. The prime example of this was the Manhattan Project's grouping of talent to achieve a vast, complex, yet single-minded goal that would have been far beyond the capabilities of any university laboratory or corporation. Since these specialists were all under the control of a single entity, such as the Atomic Energy Commission (AEC), their focus could be redirected at the government's discretion.

Image 26: The aircraft in these photos, a B-36 bomber converted to run a nonpropulsive test reactor during flight, flew forty-seven times between 1955 and 1957 over Texas and New Mexico. A nuclear-powered airplane was never flown. Engineers were aware of the multiple problems associated with an atomic plane, but they remained excited about the long-term possibilities. (Department of Energy)

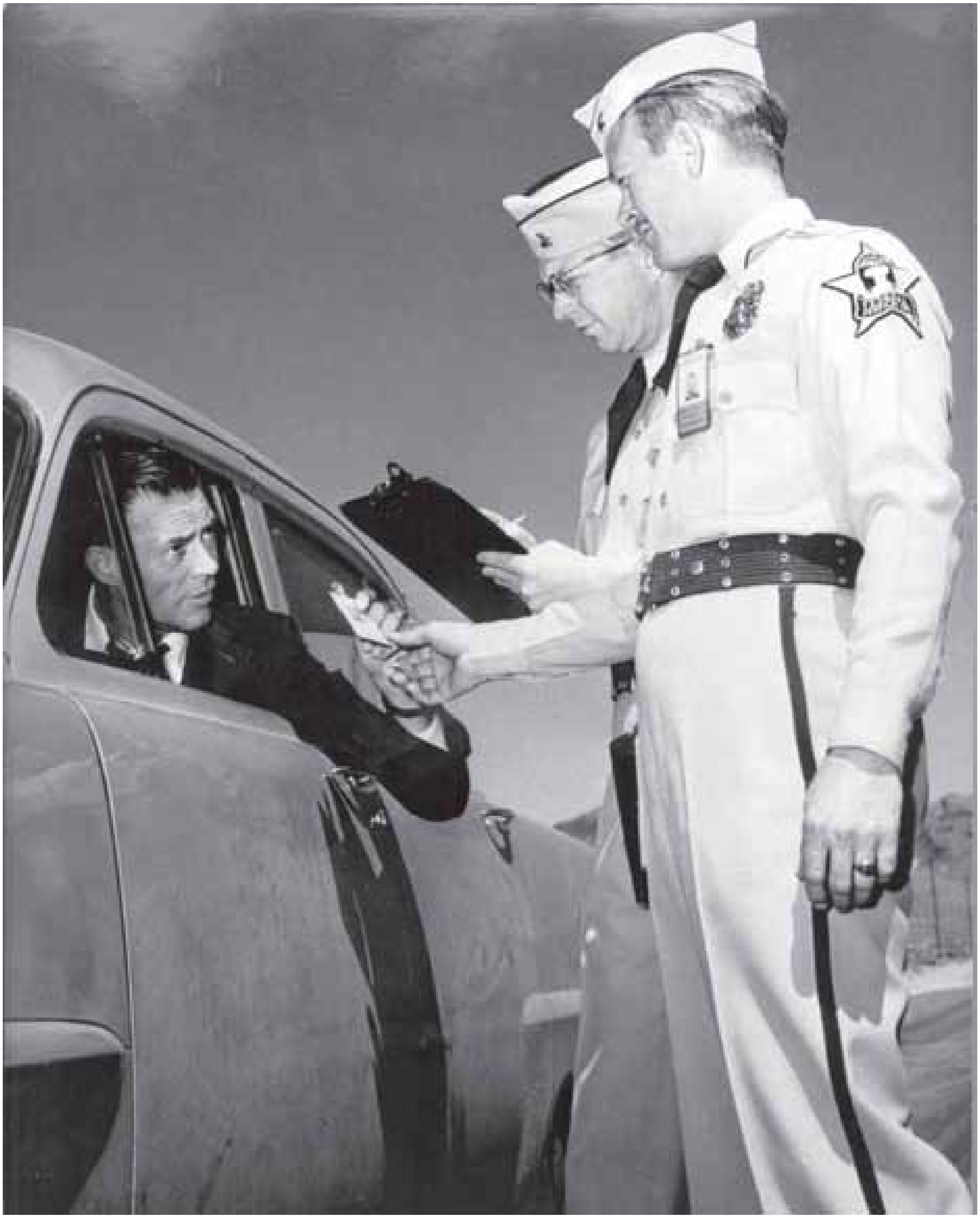


Image 27: Guards Milton Miller (left) and John Metcalf inspect the badge of Frank Waters of the Joint AEC Department of Defense (DOD) Information Office. Notice the mushroom cloud on the shoulder patch. Although the mission of the security forces has not changed over the last forty-two years, uniforms, communication equipment, and vehicles are substantially different. (1960s) (Department of Energy, Nevada Operations Office)

Designing the Plum Brook Reactor

Engineers already working at the Lewis laboratory were given the task of designing the reactor. Dr. Theodore "Ted" Hallman had a Ph.D. in nuclear engineering and was the first division chief of the Plum Brook reactor. He worked on the reactor design and managed the startup test programs at Plum Brook. Most of his colleagues had no background in the nuclear field and taught themselves by studying nuclear engineering textbooks from the library.[24] Sam Kaufman, an engineer, also worked with Hallman on the design, though he had little nuclear training. His right-hand man was Alan "Hap" Johnson, who eventually became the head of Plum Brook Station itself. These men also augmented their studies by visiting other test reactor facilities at Oak Ridge, Lockheed, and Idaho Falls. Through this process they were able to master the concepts and build a unique and powerful test reactor that had an unparalleled emphasis on experimental facilities. Abe Silverstein also established a nuclear training school at Lewis to provide broad training in nuclear applications. Though few of the high-level attendees actually went to work at Plum Brook, teachers like Jim Blue consulted during its development and operation.[25]

In the simplest terms, a nuclear reactor creates energy by literally splitting atoms, the basic building blocks of matter. Atoms were once thought to be indivisible, but in the twentieth century, scientists discovered that they could be artificially split or fissioned. Nuclear fission occurs when a neutron collides with the nucleus of an atom. Once this division occurs, the nucleus releases a large amount of kinetic energy, which is the source of the power found in atomic bombs and nuclear reactors. All nuclear reactors generate energy through this fission process.

At the center of both power and test reactors is the active core, which is where the nuclear fuel, or fissionable material, is located. It is here that the chain reaction occurs and all the energy is released.

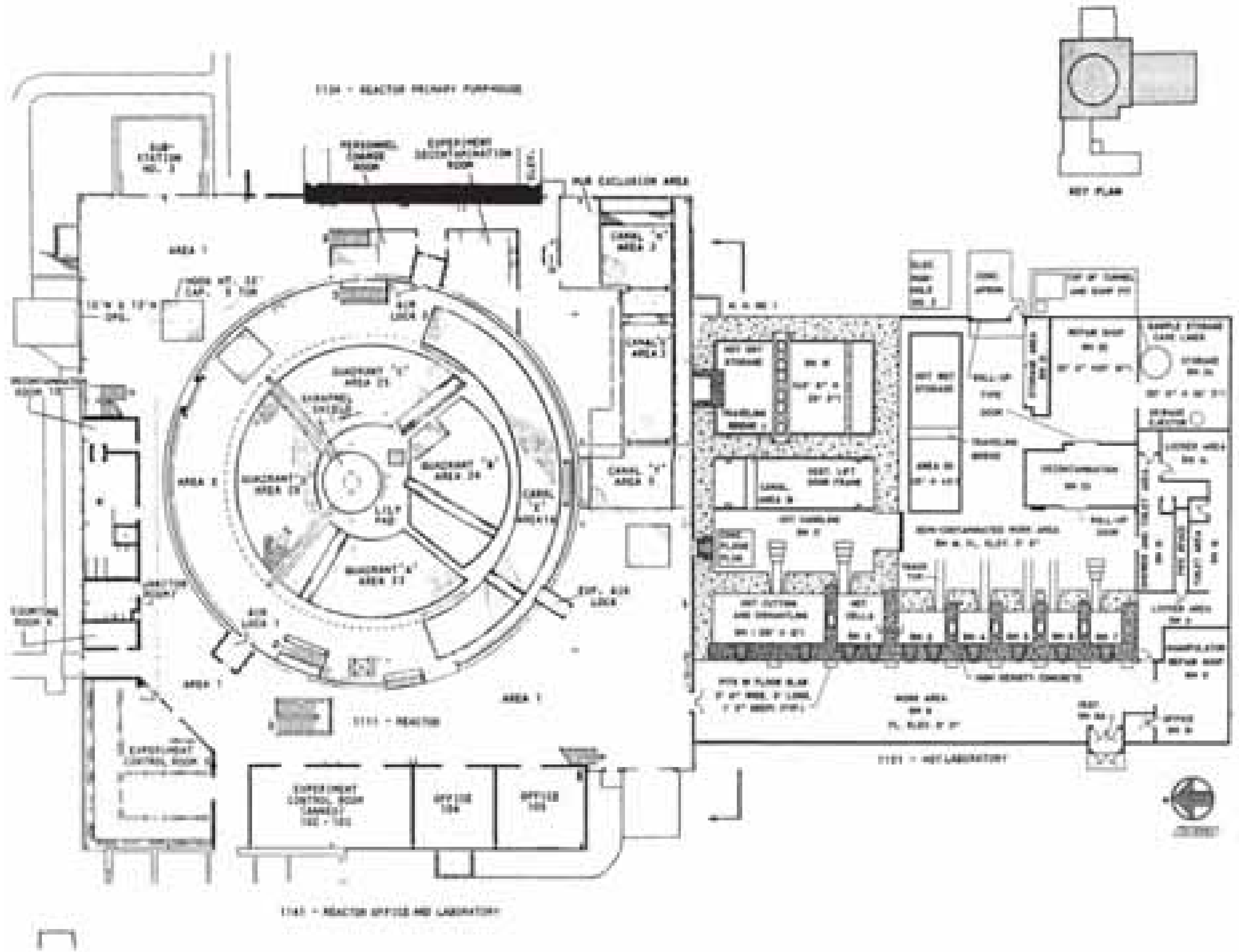


Image 28: First-level floor plan for the reactor building (no. 1111) at the Plum Brook Reactor Facility. (Plum Brook Reactor Facility Archives)

The fuel comes primarily from uranium isotopes, which are atoms that are chemically equivalent but different in mass. Uranium-235 is the principal isotope for the fission process; though uranium-238 is also present, it contributes very little to the process. The reactor becomes extremely hot during the chain reaction. A coolant mechanism is used, normally water, to carry away the heat. A reflector made of a material that prevents neutrons from leaving the pile surrounds the core. It gets its name from the fact that neutrons leaving the reactor core hit the reflector and are returned to the core. While the reflector can save a majority of these neutrons, some do escape and leak out of the pile. Shielding, usually constructed with steel, water, and concrete, is used to contain the radiation around the reactor core and protect people from the dangerous effects of radiation. The shielding materials effectively block the gamma, beta, and neutron radiation produced by the chain reaction. The shielding can also get very hot from the radiation (though much less so than the reactor), and the coolant helps to cool it as well. Reactor components called "moderators" enable scientists to control the speed of the neutrons so they will move at the proper velocity to split the nucleus. The moderator can be a solid, such as graphite, or a liquid, such as water.

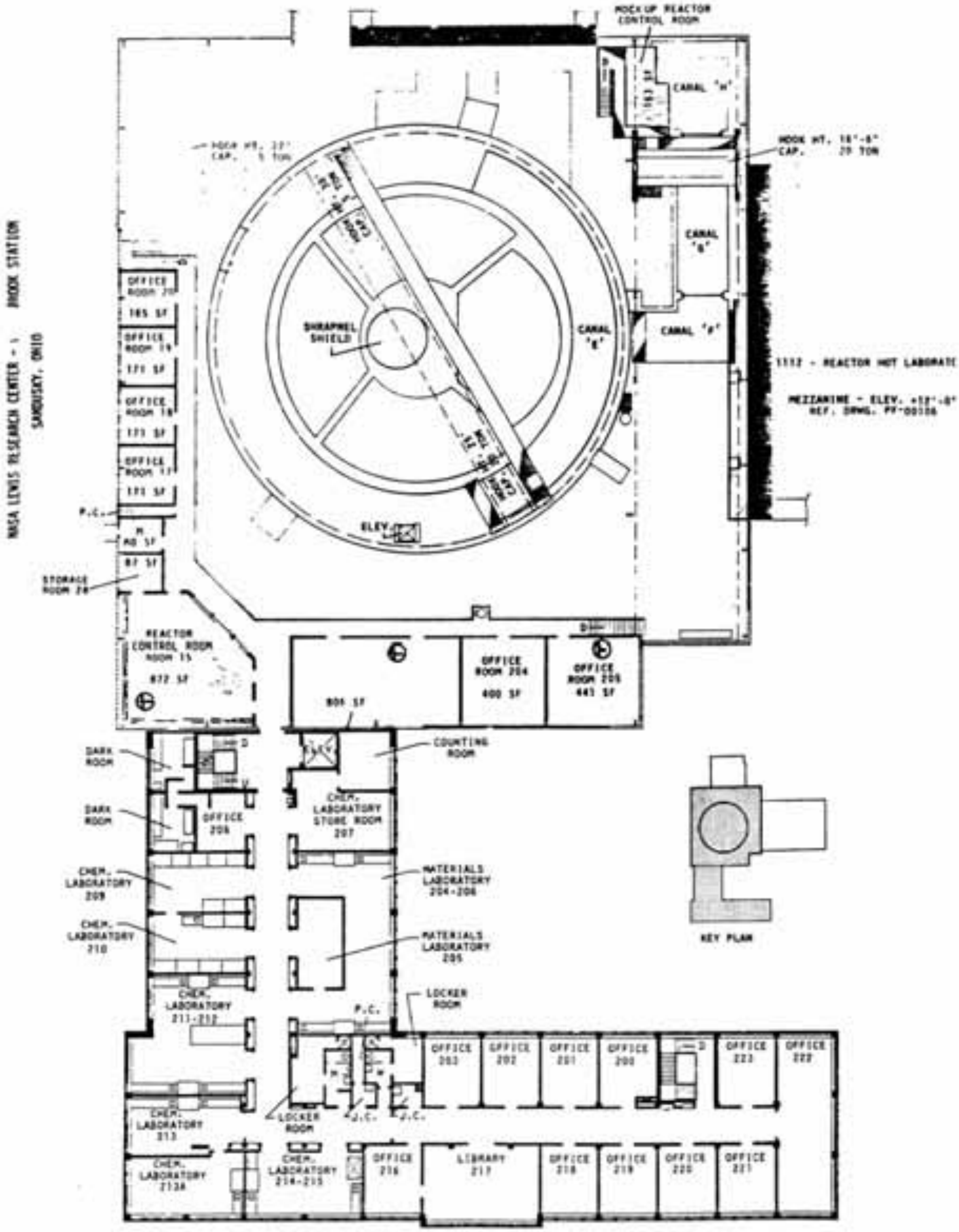


Image 29: First-level floor plan for the hot laboratory (no. 1112) at the Plum Brook Reactor Facility. (Plum Brook Reactor Facility Archives)

Image 30: One of the rare women physicists at NASA Lewis Research Center, working on an atomic laboratory experiment that pushed a gas at low pressure through a high-voltage discharge. (1957) (NASA C–1957–45726)

Another important part of the reactor are the control rods. If the reaction becomes unbalanced, with either too few or too many neutrons causing fission, then it could either die out or accelerate to dangerous proportions. Scientists use the control rods to regulate the process. These are usually made of boron or cadmium, elements that absorb the extra neutrons. Lowering or raising the rods into the core is a way of fine-tuning the reaction; the level of the rods controls the neutron absorption rate. The deeper they are in the core, the more neutrons are absorbed and the slower the reaction. The further they are pulled out, the more reactions take place.

There are three main types of nuclear reactors: power, research, and test. Research and test reactors as scientific tools are more common than most people realize. While power reactors frequently appear in newspaper headlines and are conspicuous because of their size and power, research reactors can be quietly tucked away, even in the midst of a college campus. Power reactors generate heat, which can easily be converted to other useable

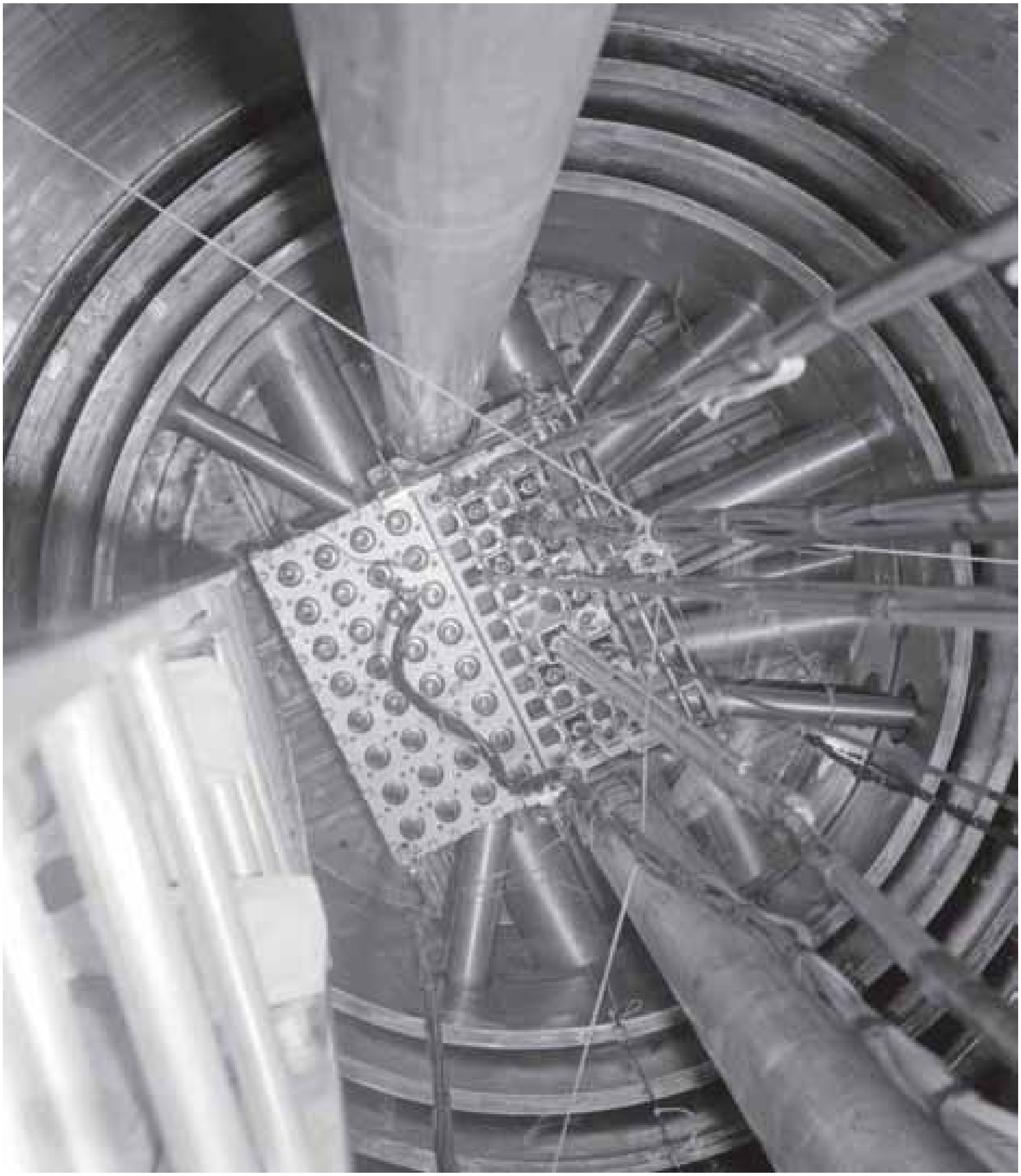


Image 31: The reactor core area from the top of the pressure tank. The reactor core (right side of the box) comprises a uranium-fueled section (a center array of three holes by nine holes for fuel control rods) surrounded by reflector material or experiments, to compose the complete four- by eleven-hole core array. The fueled core contains twenty-two stationary rods and five moveable cadmium and fuel control rods. The reflector material on three sides includes two cadmium and beryllium moveable regulating rods, three similar shim safety rods, and twelve fixed reflector plugs or experiments. The fueled core housing has reflector plates on the right and left sides and aluminum end-plates. Alongside the fueled section is a large four- by eight-hole reflector section (left side of the box), which provides facilities for inserting up to thirty-two experiments, one for each hole. The whole core structure sits on a stainless steel rack in the stainless-steel-lined pressure vessel (nine feet in diameter by thirty-one feet high). Three thermal shields are visible (the three rings) around the core. Two large vertical test holes run next to the ends of the core. One large tube runs through the large reflector section and another runs next to the fueled section. Three smaller beam tubes abut the right side of the core and three others are on the reflector side (left). (1961) (NASA C–1961–55533)

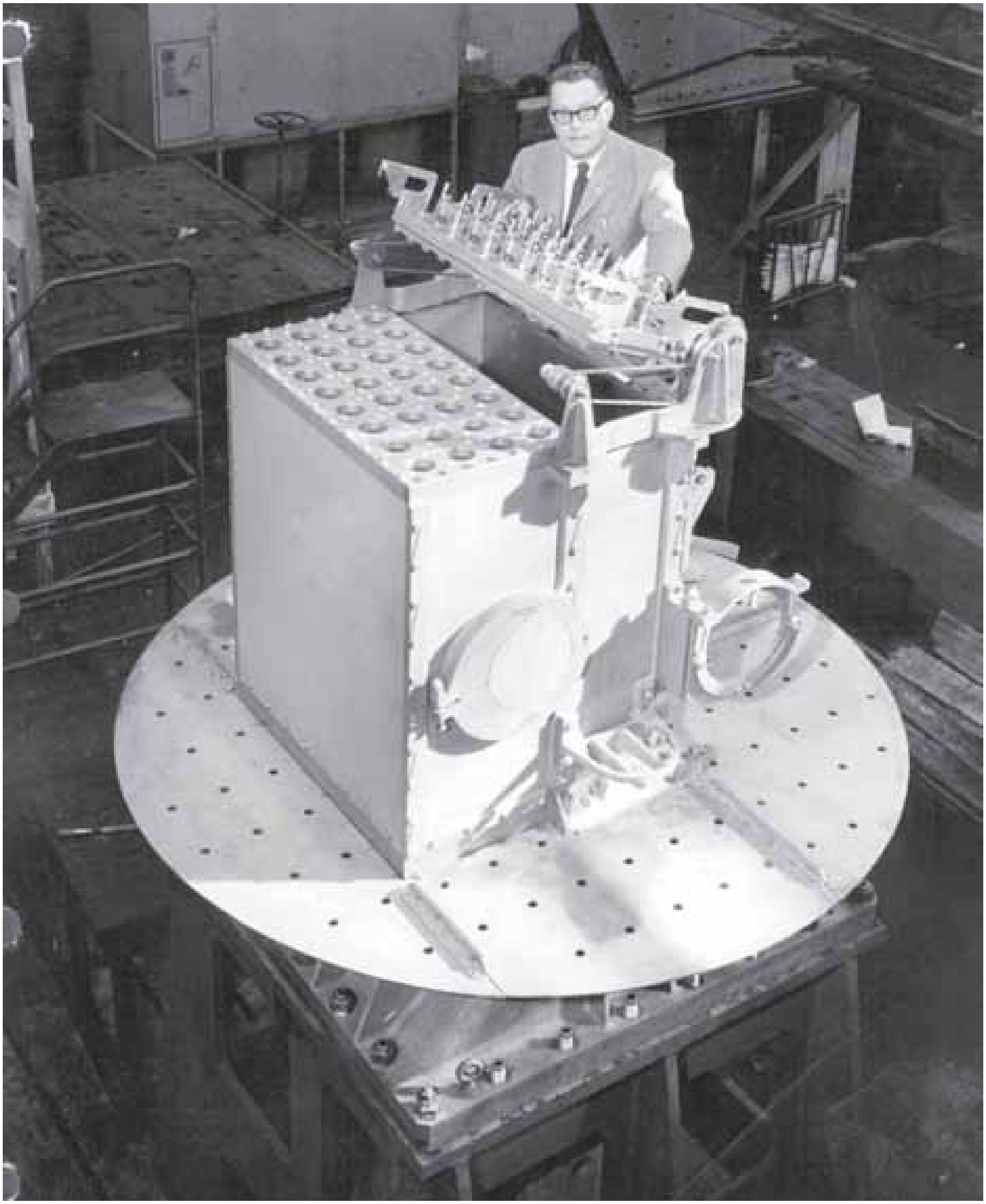


Image 32: The Plum Brook reactor's core, as demonstrated by the manufacturer prior to installation in the reactor pressure tank. (NASA C–2003–828)

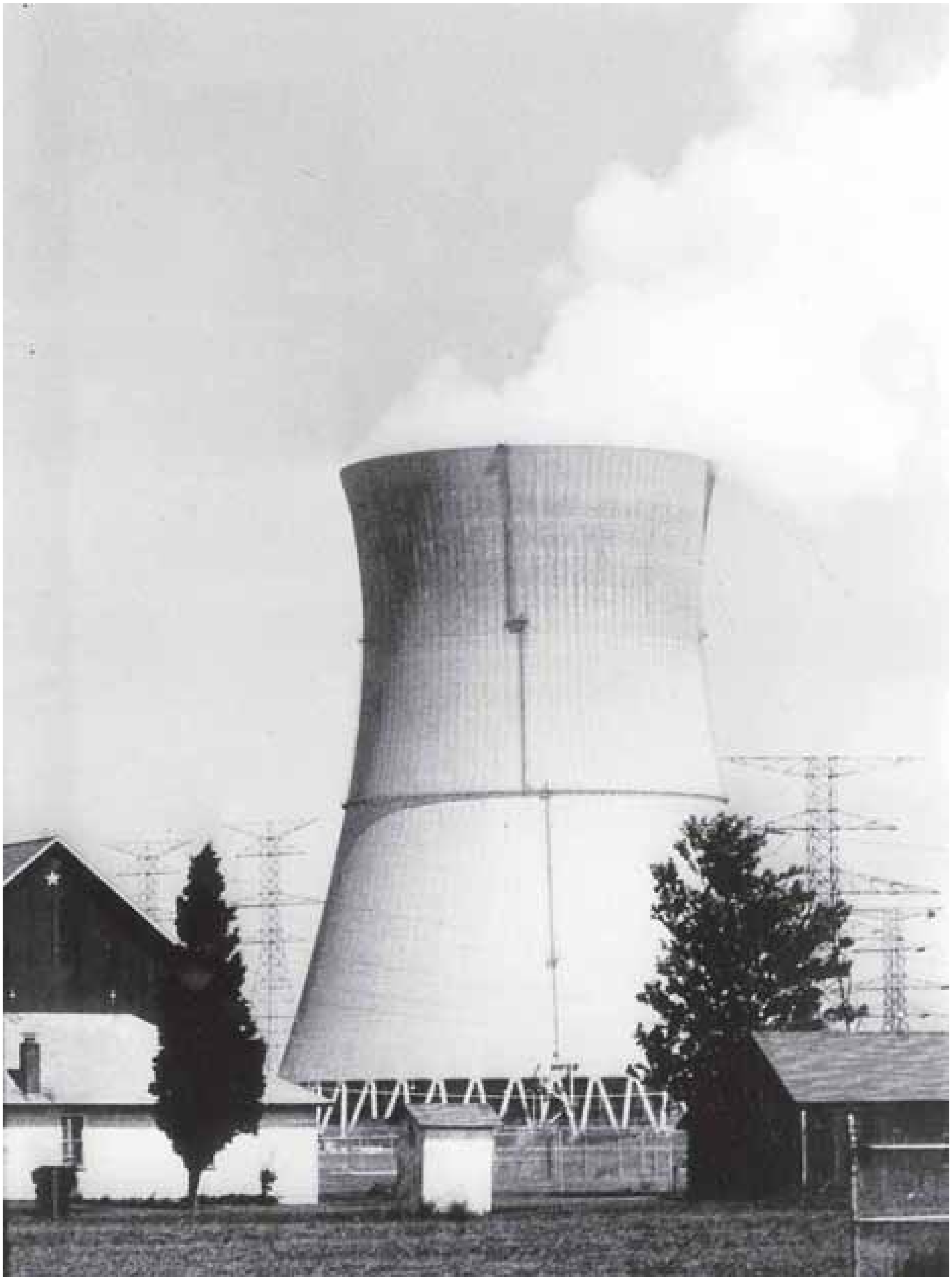


Image 33: Before construction began on the nearby Davis-Besse nuclear power reactor (pictured here), community leaders examined the safety of the Plum Brook facility for reassurances that a nuclear reactor could coexist within a populated area. (Cleveland Press Photo Collection—"Atomic Energy Facilities: Davis-Besse")

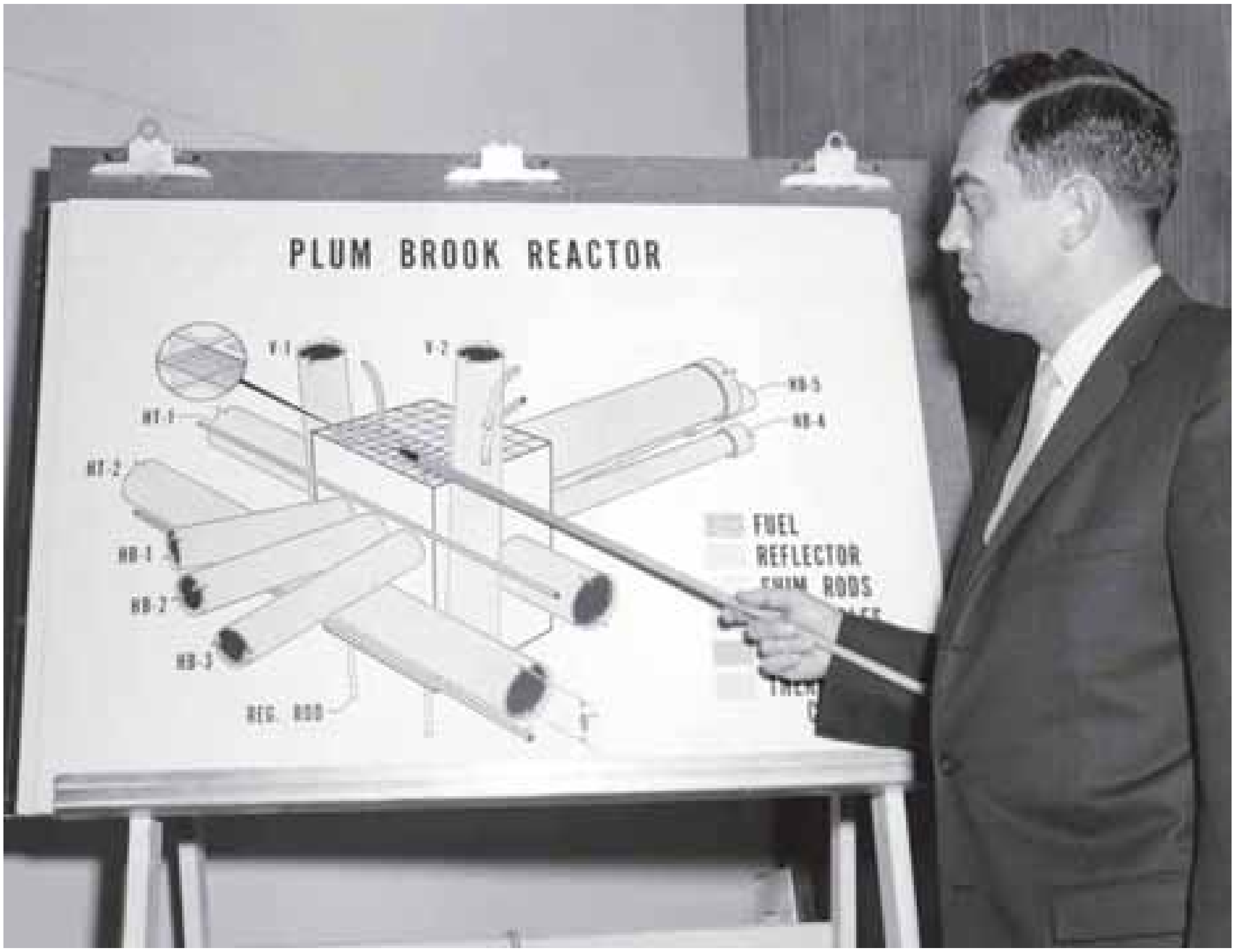


Image 34: A Plum Brook representative explains a diagram showing the main elements of the Plum Brook reactor core. The numerous test holes and rabbit tubes were what made the Plum Brook reactor unique. Few other test reactors in the United States had the ability to irradiate as many test materials simultaneously. (NASA C–2003–1039)

forms of energy, such as electricity. Research reactors operate at very low thermal power levels—so low, in fact, that they do not even require any type of forced cooling. They are used to measure nuclear parameters and other characteristics, which can then be used to build other reactors or to design experiments for test reactors. Test reactors are more powerful than research reactors and are able to produce much more intense radiation fields. Though they are still much less powerful than the power reactors, they generate enough heat to require a closed-loop forced-circulation coolant system. This system will remove the heat from the reactor by transferring it to a secondary cooling system, which releases it into the atmosphere through cooling towers.

Radiation is produced for research in the form of controllable neutron fluxes, which are very intense fields into which hardware components or electronic, structural, or fuel materials are placed. Objects are tested to determine the effect of radiation on physical properties such as strength, brittleness, or elasticity. Items are exposed to neutron radiation for a specified length of time, removed, and transferred to hot laboratories, which are shielded cells where engineers and technicians can safely analyze the irradiated experiments. Hot laboratories are important because materials exposed to nuclear radiation become radioactive and emit gamma rays. Operators peer through thick glass windows and use claw-like robotic manipulator arms to carry out chemical and physical tests without being exposed to the deadly radiation.

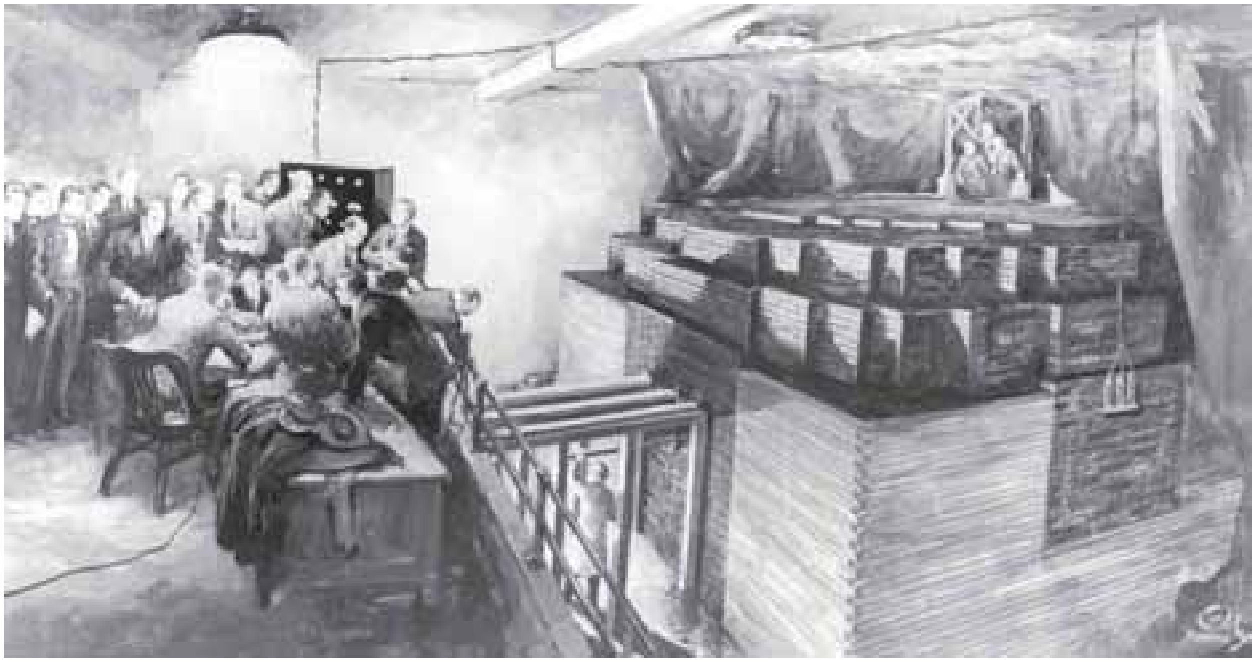


Image 35: Artist's rendering depicting the group of scientists, which included Enrico Fermi, gathered around the first chain reaction on 2 December 1942. The team began work at 8:30 a.m. Slowly, over the course of the morning, they pulled out several of the control rods and monitored the graphs. When an automatic rod accidentally shut down the reaction, Fermi abruptly broke for lunch. The slow, tense operation resumed with rods being withdrawn inches at a time at Fermi's command. At 3:25 p.m., they had achieved the first self-sustaining chain reaction. Twenty-eight minutes later, Fermi ordered Walter Zinn to insert the "zip" rod and the reaction was shut down. (National Archives and Records Administration NWDNS–326–DV–4 [4])

Since the completion of the first nuclear research reactor in 1942 at the University of Chicago, 672 facilities have been built throughout the world. The United States has built the most research and test reactors worldwide, with 227 sites, followed by the former Soviet Union with 97. National laboratories, universities, private industry, and the military constructed these reactors and were responsible for the golden age of research and test reactors in the 1950s and 1960s. During these decades, 193 research facilities became operational, compared to a combined total of only 34 reactors in the years before 1950 and after 1969. These reactors were the centerpiece of the American nuclear initiative after World War II, and invaluable research tools for American scientists who were using radiation for diverse fields of experimentation.

Plum Brook's main nuclear facility was a light-water-cooled and moderated sixty-megawatt test reactor. Additionally there was a 100-kilowatt research Mock-Up Reactor (MUR), which was used to design experiments for the main reactor. In this kind of reactor, the fuel elements were in a pool and the water functioned as a reflector, moderator, and coolant. The AEC recognized that there were such significant differences between research and test reactors that they began to issue separate licenses for them. The Plum Brook Test Reactor was given the number TR-3, which signified that it was the third test reactor licensed in the United States.

The emphasis on testing was what made Plum Brook different from other reactors at the time.[26] The reactor itself had two horizontal holes,

Image 36: View into the reactor core of the Materials Test Reactor (MTR) at Idaho Falls. The 30,000-kilowatt test reactor first went critical on 31 March 1952 and operated until 23 April 1970. The core designs and fuel elements of virtually every American nuclear reactor, including Plum Brook Reactor, were influenced by studies at the MTR. (Department of Energy Photo 1002147)

six horizontal beam holes, and forty-four in-core test locations. Experimental materials could be sent hydraulically into the holes in tiny capsule devices called "rabbits," or they could be irradiated from the neutrons emanating from the beam holes. The engineers would determine the effects on the materials subjected to radiation and this basic research could then be used to help design various components for the nuclear airplane program. The entire facility cost $15 million to build.[27]

In 1956, the NACA sought AEC approval for the construction of the test reactor. The NACA planned that the facility's main area of research would be testing materials for a nuclear airplane. This included the effects of radiation on aircraft components, shield refinement, and related nuclear and solid-state physics. The pump loop experiments were to be the most important. This research would all take place under simulated aircraft reactor conditions. The AEC granted its approval, and in September 1956 the groundbreaking ceremony took place in Sandusky.[28] Congressman A.D. Baumhart, Abe Silverstein, and several NACA leaders spoke at the ceremony, praising the local leadership and stating that Plum Brook was selected in part because of its progressive, forward-thinking community.[29]

Image 37: Control rods for Plum Brook's Mock-Up Reactor, which entered the core from above. In the Plum Brook reactor, the control rods entered the core from below. Three types of control rods were used in the Plum Brook reactor: two hydraulically controlled regulating rods to provide precise control of the reactor power level; three mechanically controlled reflector rods to provide a coarser level of control (the reflector rods had a quick release to allow them to drop and scram the reactor, if necessary); and five fueled shim rods, which performed the same functions as the reflector rods. (NASA PS63–0007)

Image 38: Atomic Energy Commission (AEC) officials with Abe Silverstein (front row, sitting third from left), working out the final reactor licensing issues. It is said that Silverstein told AEC Director Glenn Seaborg that the officials could not leave until a deal was struck. Because Plum Brook was a federal facility, it was not required to file for an AEC license, but to promote peace of mind in the nearby community and maintain safety, NASA officials decided to work through the commission. They received the AEC designation Test Reactor 3 (TR-3). (NASA C–1964–69271)

Primary Document #3

The following document is an excerpt from a local newspaper article reporting on the groundbreaking ceremonies at the Plum Brook reactor in September 1956.

"BREAK GROUND FOR REACTOR HERE"
The Sandusky Register Star-News
September 26, 1956

Silver pick, shovel start work on Lab.

Nuclear Project at Plum Brook ready in 3 years.

Dr. Edward Sharp, director of the NACA Lewis Laboratory at Cleveland, using a silver shovel, and Congressman A.D. Baumhart, Jr., Vermillion, with a silver pick, loosened the ground to mark the formal start of construction of the reactor which is scheduled to be completed within three years and be staffed by approximately 50 aeronautical scientists and 100 other employees.

Dr. Sharp explained that NACA's primary interest in atomic power is conversion of the energy generated in a reactor to useful thrust in the most efficient manner possible… He added that the airplane powered by the atom will be capable of flying non-stop to any point on earth without refueling, and its flight endurance will be limited only by the endurance of its crew.

Abe Silverstein, associate director of the Lewis Laboratory, said of the reactor: "Despite recent important advances in aerodynamic efficiencies for aircraft at supersonic speeds, nuclear power still is the 'shining hope' for increasing the range of aircraft at high speeds and for increasing aircraft ranges to values obtainable with conventional special chemical fuels. A long range bomber may carry 100,000 pounds or more of fuel. A piece of Uranium 235 with the same energy content would weigh less than one ounce."

LEWIS FLIGHT PROPULSION LABORATORY NACA

WING TIPS

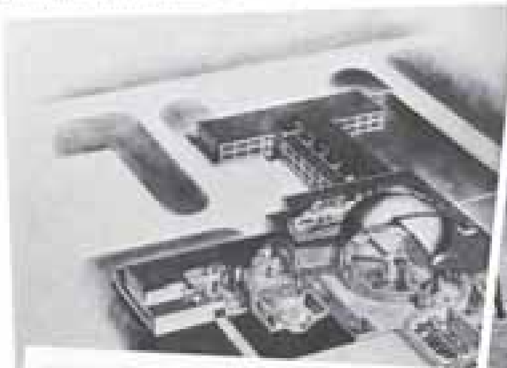
Vol. XV — Cleveland, Ohio, September 26, 1956 — No. 2[illegible]

PLUM BROOK RESEARCH REACTOR FACILITY CONSTRUCTION BEGUN

Another forward step in aeronautical progress was made on Wednesday, September 26, 1956 as ground was broken for construction of the NACA's Plum Brook Research Reactor Facility near Sandusky, Ohio. This will be a key link in America's search for the practical solution to the harnessing of nuclear energy to drive the commercial and military aircraft of tomorrow.

Dr. Edward R. Sharp headed a list of government and local officials and civilian guests at the ceremonies. Among the speakers were Dr. John F. Victory, Executive Secretary, and Addison M. Rothrock, Assistant Director for Research.

The NACA is consulting closely with the Atomic Energy Commission in the design of the facility, which will contain elaborate safeguards against any possible hazards to employees or to residents of the area. Safety features include precautions against nuclear contamination of drainage water, and air currents over the facility.



Art
at right
and its
vessel
materi

Constructing the Reactor

The construction of Plum Brook required a great deal of effort between the first groundbreaking in 1956 and first criticality in 1961. During this span of five years, construction efforts reshaped the land and resulted in a powerful nuclear test reactor. The following photographic section documents this effort.

Image 39: Congressman Baumhart watched as Lewis Laboratory Director Dr. Edward Sharp dug the first shovel of dirt at the September 1956 groundbreaking ceremony for the Plum Brook Reactor Facility. The silver pick and shovel are the same ones used for the 1941 groundbreaking of the NACA Lewis Laboratory in Cleveland, Ohio. (NASA C–1956–43032)

Image 40: Controlled fire to demolish unwanted Ordnance Works structure. Upon taking possession of Plum Brook, the NACA inventoried all the Ordnance Works structures and decided to retain forty-one of them, demolishing over 600 other buildings. In addition, three TNT areas and underground waste disposal lines had to be destroyed and decontaminated. (NASA C–2003–829)

Image 41: The Plum Brook Ordnance Works' Pentolite Area was demolished and decontaminated. It was on these 117 acres of land that the reactor facility was constructed. (NASA CS–18957)

Image 42: The Plum Brook Reactor Facility construction began when crews excavated a hole in the ground for the pressure tank. The tank extended approximately thirty-two feet under ground. The steel containment vessel, which was more than 100 feet high (fifty-five feet above grade and fifty-six feet below grade), surrounded the reactor tank area and the surrounding quadrants and canals. It was designed to prevent any radioactivity from being released if an accident were to occur in the reactor. This safety precaution was essential because of the nearby communities. Many other large reactors did not have such safety features. For example, the Materials Test Reactor in Idaho Falls had no shield because small amounts of contamination could be released into the atmosphere without endangering the public. (1958–60) (NASA C–2003–830)

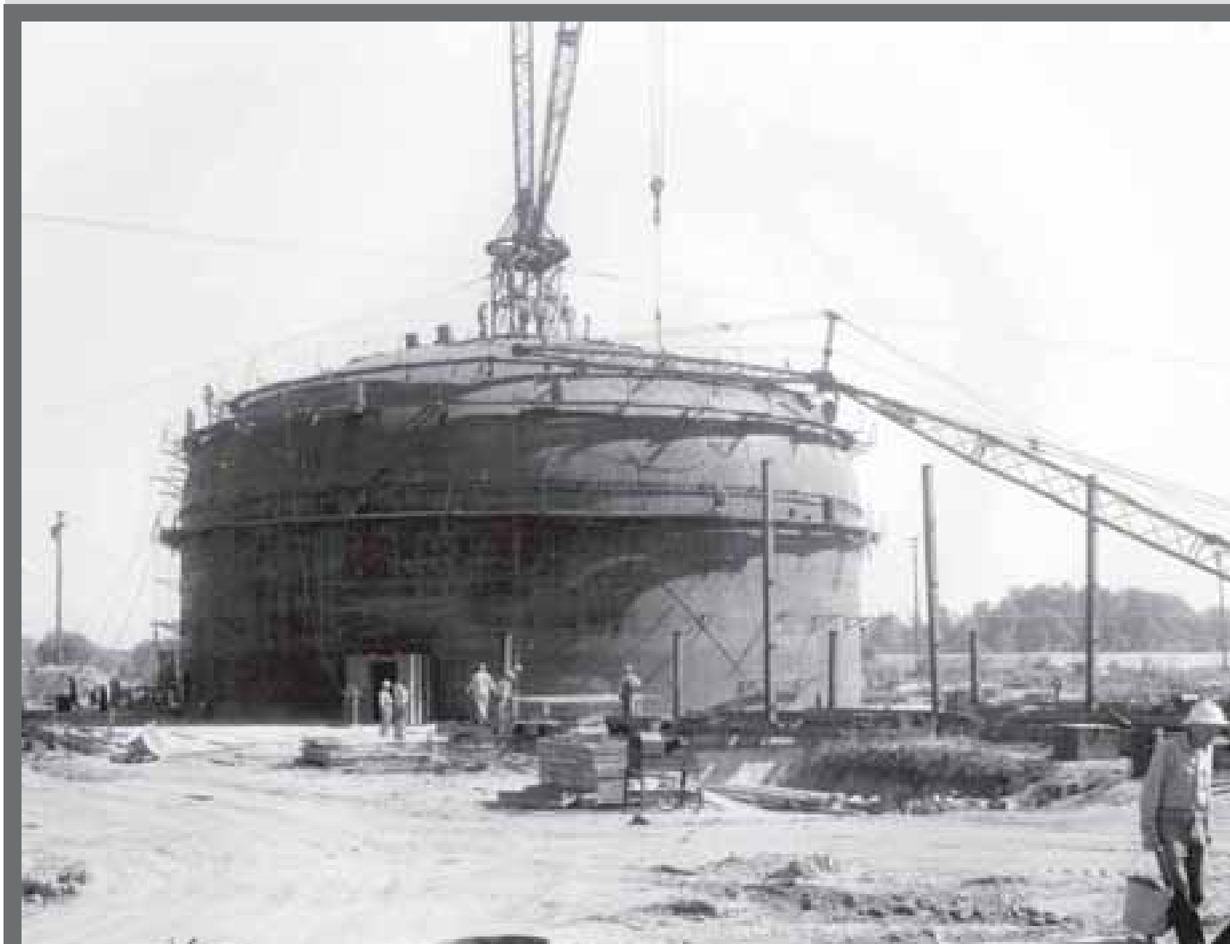


Image 43: Exterior of the containment vessel during construction. (NASA C–2003–831)

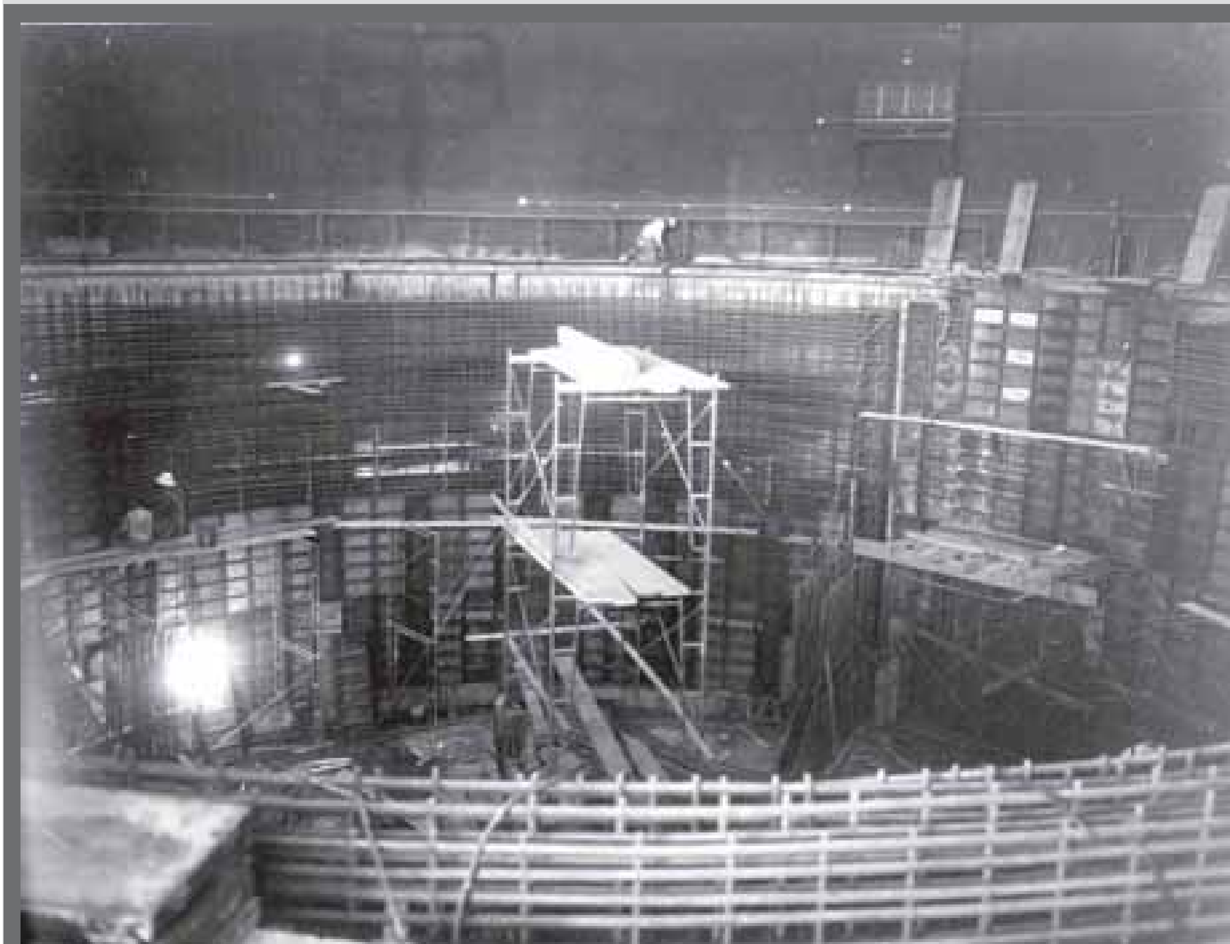


Image 44: Inside the containment vessel during construction. (NASA C–2003–832)

Image 45: The pressure tank was shipped to Plum Brook via railway, and transported to the reactor facility on a flatbed truck. The tank was then rolled to a crane, which lifted it into place at the center of the unfinished quadrant area. Several pipes jutted out from the tank. These "test holes" would be used to transport experiments to the reactor core for radiation during its operating cycles. (c. 1959) (NASA C–2003–833)

Image 46: The pressure tank delivered by truck. (NASA C–2003–834)

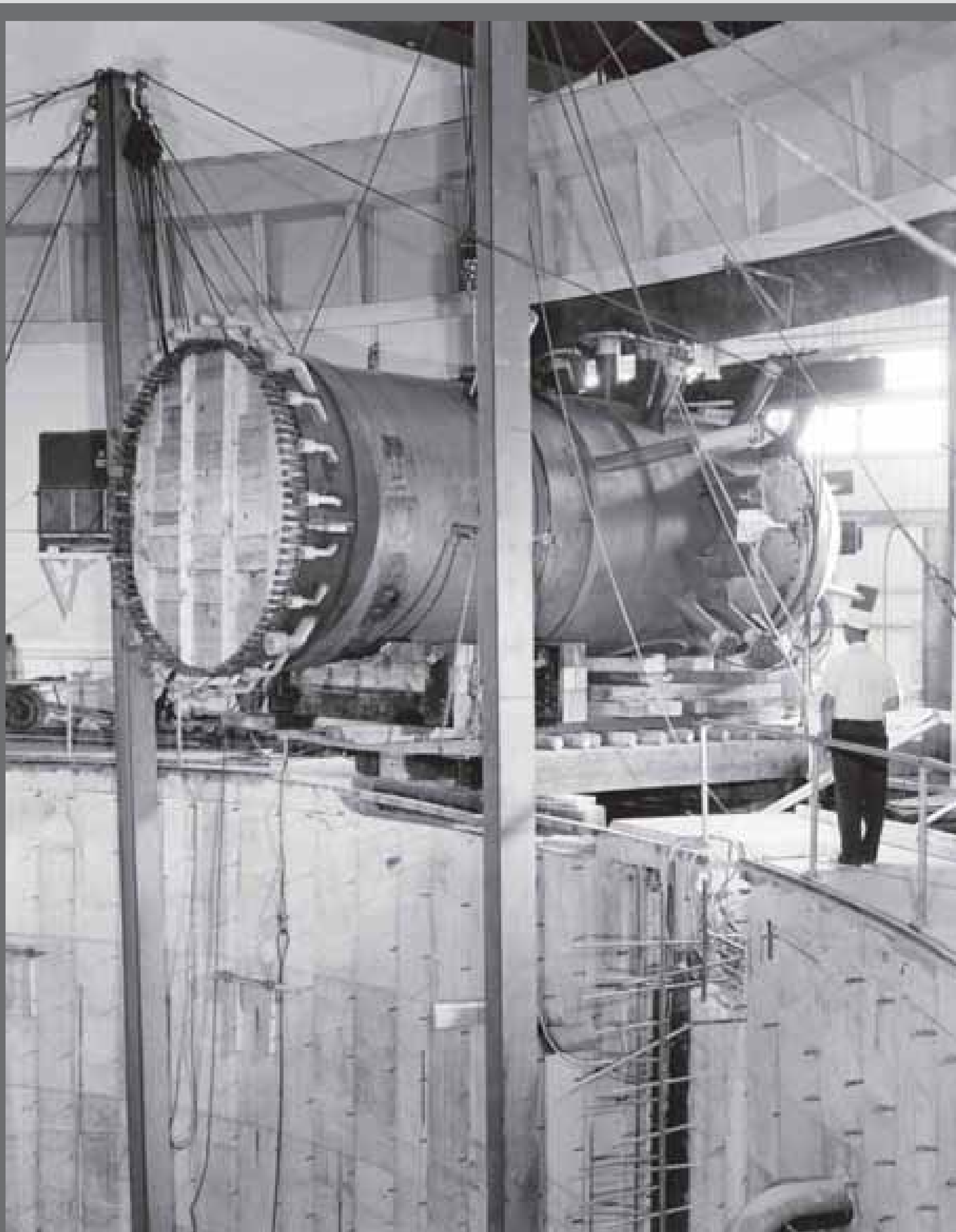


Image 47: Pressure tank being lowered into the containment vessel. (NASA C–2003–835)

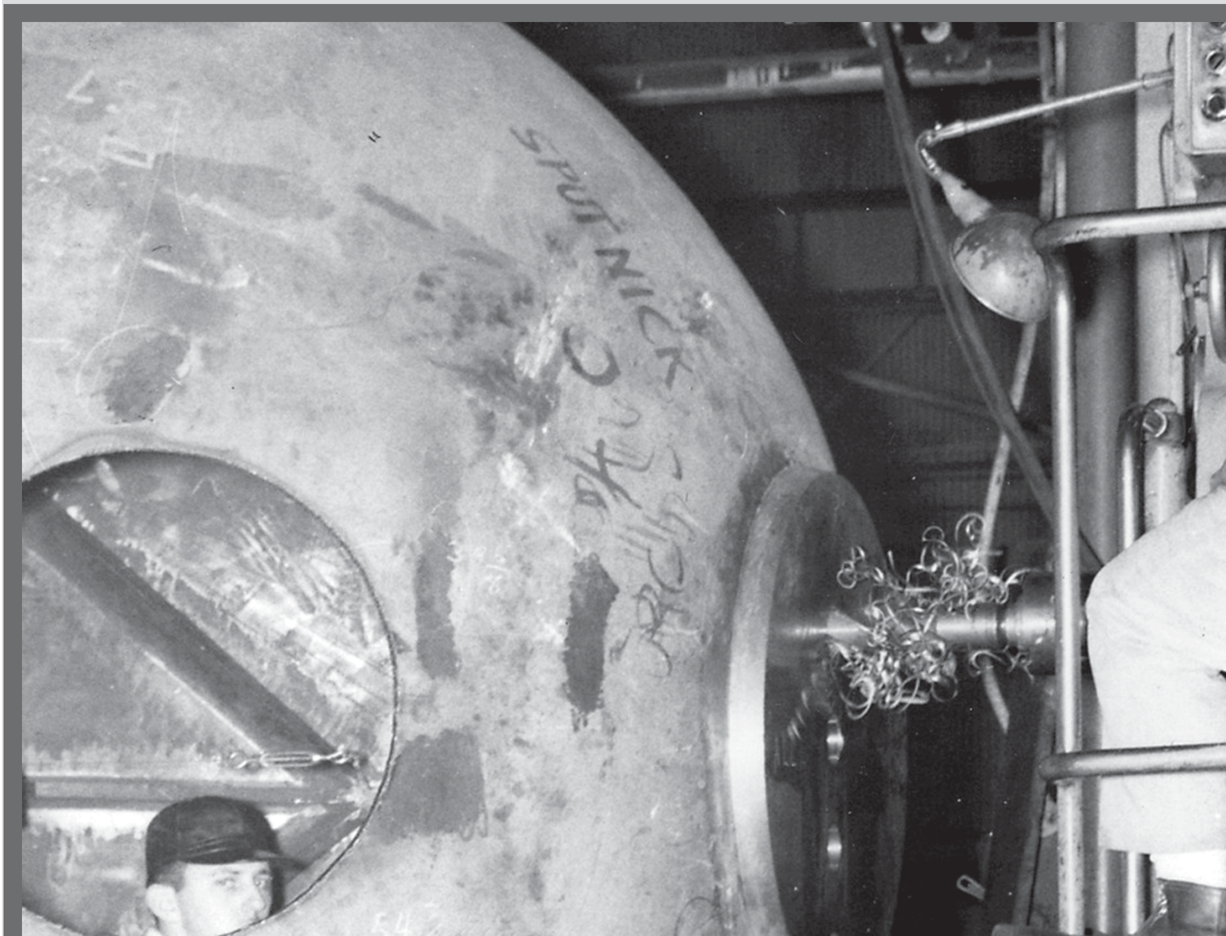


Image 48: Because it bore a resemblance to the Soviet's first orbiting satellite, engineers scrawled the word "Sputnick" into the side of the pressure tank. Though misspelled, this was perhaps a not-so-subtle reminder of the Cold War space race. It was hoped that the basic experimental science conducted at Plum Brook would play a vital role in the development of a nuclear rocket. (NASA C–2003–835)

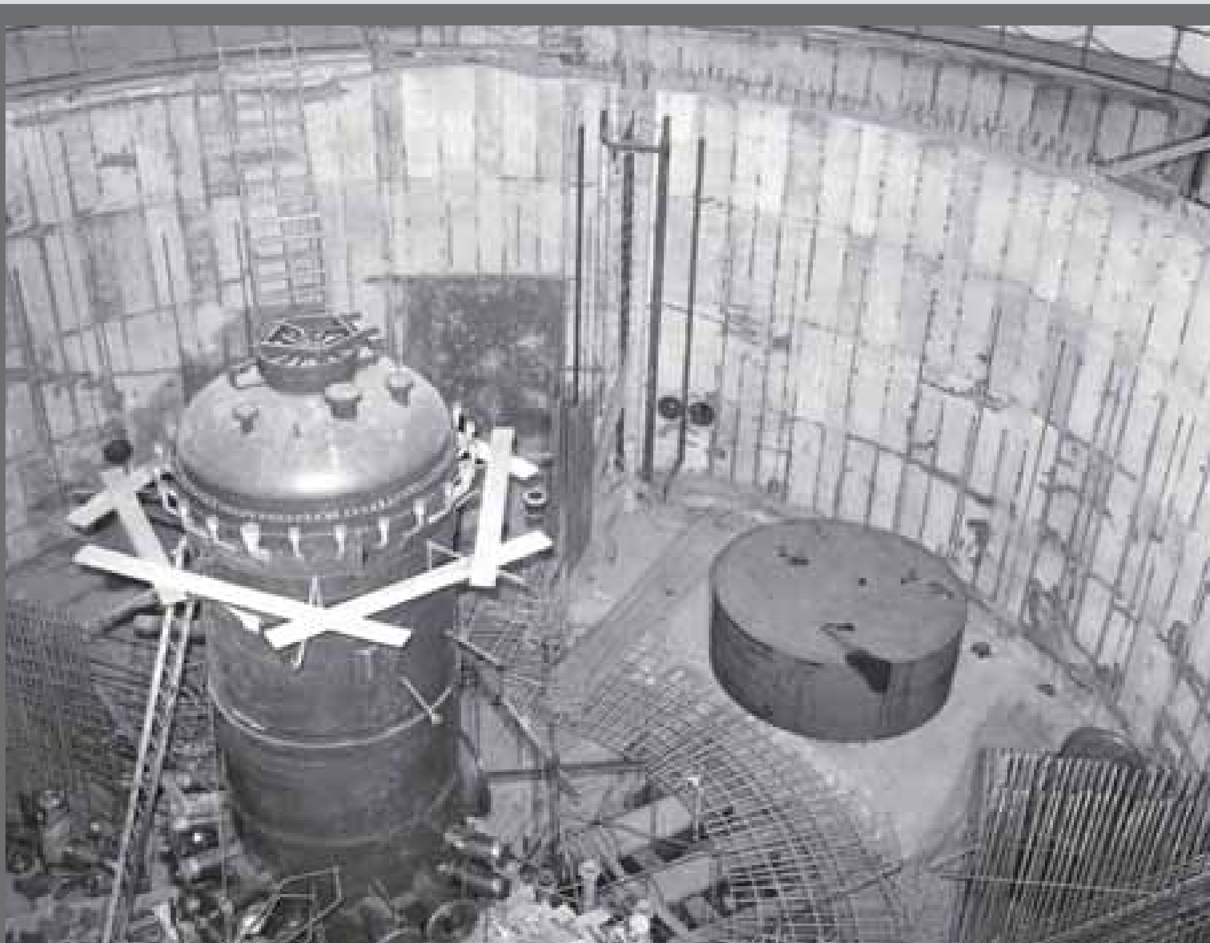


Image 49: The pressure tank in place inside the containment vessel. (NASA C–2003–836)

Image 50: A worker spray paints one of the quadrant walls and a shielding wall surrounding the reactor pressure tank. The quadrants were twenty-five to twenty-seven feet deep and filled with water. The water provided shielding for the radioactive materials that were transported along the canal basin. (NASA C–2003–837)

Image 51: Plum Brook had two pumping stations to obtain raw water from nearby Lake Erie. The reactor required one million gallons of water daily for cooling, shielding, and dilution of radiation. The main one was at Rye Beach (pictured) and the other was at Big Island. They were initially constructed in 1941 for the Ordnance Works and were closed in late 1945. In March 1958, NACA assumed control of both facilities, but it took several years of repairs and cleaning before both would consistently function properly. They were connected to Plum Brook by 5.9 miles of 24-inch steel piping. Together, they could pump 51 million gallons of lake water per day. (1983) (NASA C–2003–838)

Image 52: A diver emerges after working on the Plum Brook water pumps in Lake Erie. Divers had to flush the intake line and clear it of mud, silt, and debris regularly. (NASA C–1961–58167)

Image 53: The Plum Brook Guardhouse. (NASA C–2003–850)

Image 54: The Plum Brook reactor complex consisted of numerous research facilities and support buildings. The containment vessel's silver dome was at the center of the main reactor building. The reactor office and lab building was located in the immediate foreground, and the hot laboratory was adjacent on the right. Across the road to the left was the reactor office building, and assembly, test, and storage building. Behind it was the large, white helium storage structure. Behind the reactor building were the service equipment building, the cooling tower, and the water tower. The fan house and waste-handling building were behind the hot laboratory. (1969) (NASA C–1969–10920)

Primary Document #4

The following document is a report detailing the potential radioactive hazards posed by the Plum Brook reactors. It was first submitted to the AEC in October 1956 and then revised in 1959. The following is an edited excerpt from the over-400-page summary.

FINAL HAZARDS SUMMARY NASA PLUM BROOK REACTOR FACILITY, December 1959, edited A.B. Davis, B. Lubarsky, and T.M. Hallman

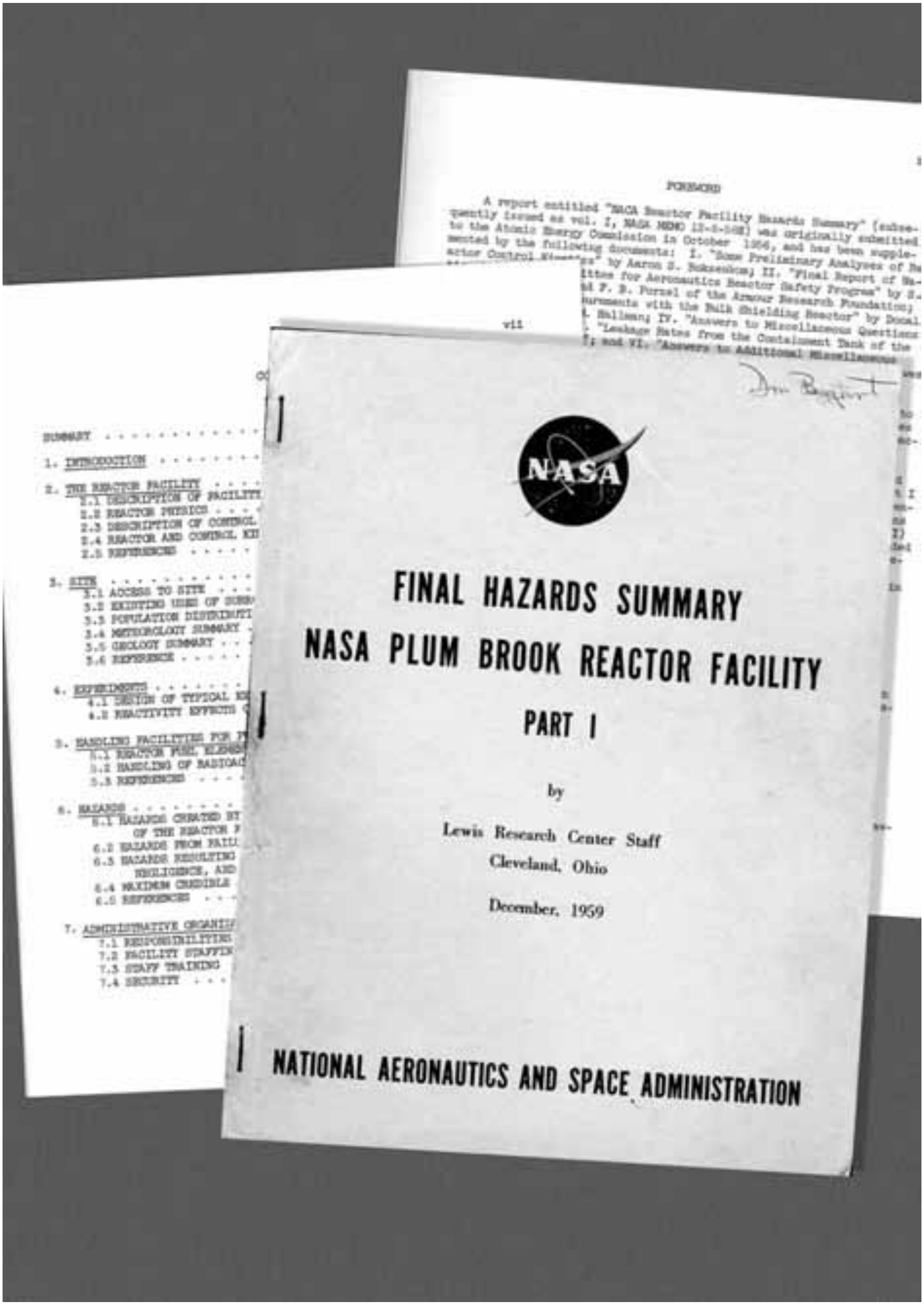
The Lewis Research Center of the National Aeronautics and Space Administration has built a nuclear research reactor at the NASA Plum Brook Research Facilities (formerly known as the Plum Brook Ordnance Works) near Sandusky, Ohio. The purpose of this report is to provide information to the U.S. Atomic Energy Commission concerning the design of the reactor facility, the characteristics of the site, the hazards of operation at this location, and general operating and emergency procedures.
To achieve good coordination of the reactor research with programs on the other propulsion system components, the reactor was constructed at the NASA Plum Brook Facilities. The reactor facility is located 3000 feet from the closest border of the site, three miles from Sandusky, a city of 35,000 people, and fifty miles from the Lewis Research Center in Cleveland, Ohio.

During the period when the site for the NASA reactor was selected, consideration was given to a more remote site such as the NRTS [National Reactor Testing Station] site in Idaho. The NASA Plum Brook Facilities offered a number of advantages compared to a site of this type.

The surrounding population density is the chief disadvantage of the Plum Brook Site compared to a more remote location. This factor may prohibit the performance of a few very hazardous experiments at this site. Any experiment vital to the progress of scientific knowledge or nuclear propulsion which is deemed too hazardous for the Plum Brook Site, could readily be carried out at MTR [Materials Test Reactor] or ETR [Engineering Test Reactor]. This fact minimizes this disadvantage of the Plum Brook Site.

An analysis of the consequences of failure or malfunction of equipment has been made for the purpose of estimating the consequences of the unplanned release and dispersion of radioactive materials. The analysis deals with accidents which may introduce hazards from the following sources: (1) Failure or malfunction of component parts of the reactor or of component parts of the reactor cooling, electrical, or control system. (2) Failure or malfunction of experiments in any of the radiation facilities of the research reactor. (3) Acts of God, sabotage, negligence. (4) Maximum credible accident.

[A maximum credible accident] is the excursion resulting from the inability of the control system to compensate for the addition of a large step-increase in reactivity to the reactor. In this excursion, the reactor power and temperatures increase rapidly until some inherent self-limiting process in the reactor stabilizes the situation or until the reactor disassembles itself. The runaway to destruction in a reactor of this type would probably include the melting of the fuel plates, an explosion in the reactor pressure tank, and the scattering of radioactive materials. It is an event which could create a considerable hazard both for the operating personnel and the general populace.


FOREWORD
NASA
FINAL HAZARDS SUMMARY
NASA PLUM BROOK REACTOR FACILITY
PART I
by
Lewis Research Center Staff
Cleveland, Ohio
December, 1959
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Kennedy's New Dream

During the five years of Plum Brook's construction, both the government and the U.S. Air Force lost their enthusiasm for the nuclear airplane program. It turned out that the reports stating that the Soviet Union was close to building its own nuclear airplane were untrue. Also, progress on traditionally fueled airplanes enabled them to begin performing at levels that were once thought achievable only by a nuclear airplane. Bombers were now able to fly to Moscow and back, and intercontinental ballistic missiles (ICBMs) armed with small nuclear warheads could be launched from the United States and accurately hit targets in the Soviet Union. In March 1961, President John F. Kennedy delivered a message to Congress on the defense budget, which became known informally as the "kiss of death for the atomic plane." He said that despite the time and money (fifteen years and $1 billion) that had been sunk into the project, "the possibility of achieving a militarily useful aircraft in the foreseeable future is still very remote." As a result he planned to "terminate development effort" on the nuclear airplane.[30]

Suddenly, just months before the Plum Brook reactor was to go critical (meaning that it would be able to sustain a nuclear reaction or reach criticality), its primary research objective was eliminated. But the Plum Brook engineers, still finishing construction on their facility, did not have to wait long to have a new assignment handed to them. Despite the end of the nuclear airplane, Kennedy did not lose his enthusiasm for nuclear technology. The nation had also been working on a nuclear space initiative since 1955, and this was the brave new world that Kennedy wanted to explore. Less than two months later he delivered his famous "Urgent National Needs" speech before a joint session of Congress about landing a man on the Moon before the decade was out. He said, "Now it is time to take longer strides—time for a great new American enterprise—time for this

Image 55: President Kennedy emerges from a tour of the nuclear rocket test facilities at Jackass Flats, Nevada. At his right is the head of the Atomic Energy Commission, Glenn Seaborg, and in front of him is Harold Finger, the head of the joint AEC-NASA Space Nuclear Propulsion Office. (Harry Finger Collection)

nation to take a clearly leading role in space achievement, which in many ways may hold the key to our future on Earth." He wanted the entire nation to commit itself to achieving this goal quickly and efficiently as before its rival superpower, the Soviet Union, could do so. What is often forgotten about this speech is that Kennedy also advanced an even more compelling dream. Though just months before he had cancelled the nuclear airplane, now he called for increased funding to develop a nuclear rocket. He said, "This gives promise of some day providing a means for even more exciting and ambitious exploration of space, perhaps beyond the Moon, perhaps to the very end of the solar system itself."[31]

The development of a nuclear rocket was a highly complex undertaking (even more so than the nuclear airplane), and advanced research facilities like Plum Brook would play a role in its development. One important advantage of the nuclear rocket was its high specific impulse (a measure of the miles per gallon that would be possible with hydrogen fuel propellant, which

Image 56: President Kennedy operates a remote manipulator like the ones found in the hot laboratory at Plum Brook. This one was used to disassemble radioactive parts from a nuclear rocket reactor that had been sent to Los Alamos from the Nuclear Rocket Development Station at the Nevada Test Site. Harold Finger accompanied him on the trip and recalled, "There's no question about it. [Kennedy] enjoyed seeing the equipment. He actually played with some of the remote manipulators and I can tell you he was beaming as he was doing it. After meeting these outstanding scientists at Los Alamos and seeing the facilities in Nevada, he was really excited about the whole thing."[32] (Harry Finger Collection)

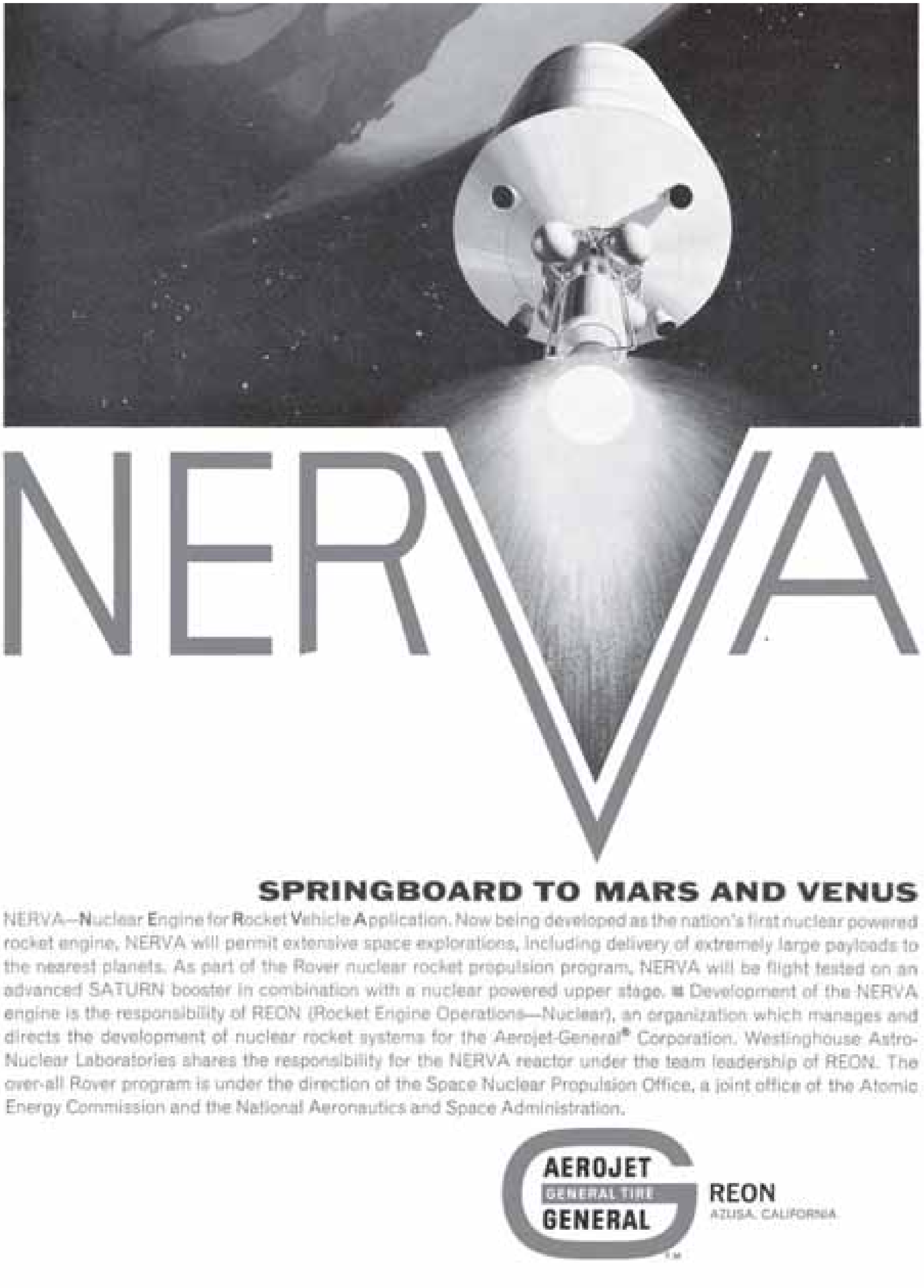


Image 57: An advertisement for NERVA, the Nuclear Engines for Rocket Vehicle Applications program. Aerojet General Corp. and Westinghouse were primary contractors who operated under NASA–AEC's Space Nuclear Propulsion Office. (Harry Finger Collection)

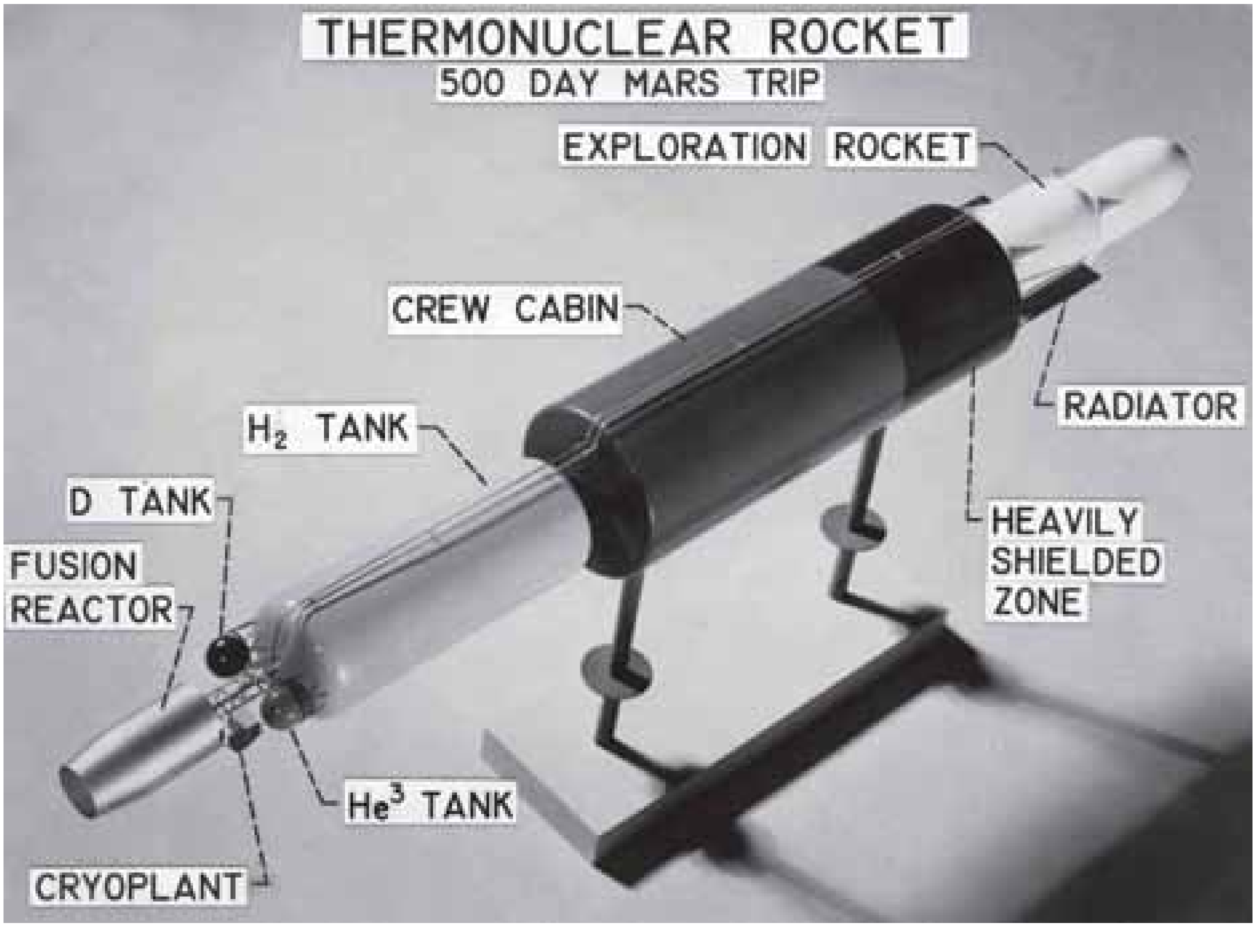


Image 58: A model of a thermonuclear rocket capable of interplanetary exploration. The reactor was used to heat up liquid hydrogen for thrust similarly to traditional rocket engines. The large heavily shielded zone between the reactor and the crew cabin protected the astronauts from the radiation. (1963) (NASA C–1963–63470)

would be used in tandem with a nuclear rocket), due to the high operating temperature of the reactor. Though scientists had harnessed the power of the atom for nuclear bombs twenty years earlier, there was still much to learn about the effects of radioactivity. Building a nuclear rocket presented many scientific, technical, and human questions. For example, how quickly would materials exposed to radiation (both from space and the reactor itself) become weak and deteriorate? What types of materials endured best in these environments? Which of these materials provided the greatest radiation-shielding capabilities to ensure the safety of the astronauts traveling with it? Important questions also surrounded temperature. For example, what would be the effects of radiation and high temperatures on the reactor and the rocket's engines? Did cryogenic temperatures also have an effect upon performance? The search for these answers became the responsibility of scientists and engineers working at nuclear research and test reactors around the country.[33] Just twenty days after Kennedy gave his speech, the Plum Brook reactor went critical and became the second most powerful American test reactor facility.

Primary Document #5 and #6

Just seven days before President Kennedy officially canceled the atomic airplane, Plum Brook held a massive open house to demonstrate the reactor that was constructed to support development of this project. More than sixty members of the print media and radio and television news services met at the site to talk with community leaders and NASA and AEC representatives. To see the dramatic change of focus for the reactor, compare the following two excerpted newspaper reports. The first article, "Reactor for A-Plane Gets Okay," appeared in early March when the Plum Brook reactor was set to support the atomic airplane. The second article, "Plum Brook Atomic Lab Brings Space Closer," appeared less than two weeks later and made no mention of the atomic airplane,although it discussed space and nuclear rocket research.

"REACTOR FOR A-PLANE GETS OKAY"
Chillicothe Gazette
8 March 1961

The Plum Brook research nuclear reactor, to be used in efforts to develop an atomic airplane, has received the Atomic Energy Commissions approval to go into operation. The reactor, the nation's second largest with power equivalent to 60 million watts, is a facility of Cleveland's Lewis Research Center, which operates under the National Aeronautics and Space Administration… Scientists hope to develop a fuel, a couple of pounds of which would enable an airplane to fly many times around the world.

NASA has said the entire installation was designed to withstand any foreseeable accident without releasing any hazardous materials or gases. The reactor is contained in a steel tank three-quarters of an inch thick. The tank is encased in three feet of concrete for more protection. Surrounding the tank is a pool 70 feet in diameter that will be filled with water for further protection.

"PLUM BROOK ATOMIC LAB BRINGS SPACE CLOSER"
The Cleveland Press
21 March 1961

U.S. effort to harness nuclear power for rockets and space flight takes a giant step today with completion of the Plum Brook Reactor Laboratory three miles south of Sandusky. This is the first laboratory of its kind built by the space agency and the only nuclear reactor in Northern Ohio…

Civic officials of Sandusky and top scientists from Lewis participated in opening ceremonies at the laboratory today. Lewis officials described an extensive program to guarantee that the facility and its environs will be kept free from radioactive contamination.

NUCLEAR REACTOR'S CONTROL ROOM contains a vast assortment of instruments to ensure safe operation and shut-down of the atomic reactor. A licensed operator directs activities here in the nerve center, and from this console the staff expects to start-up the reactor for the first time this month.

Lewis to Control Sandusky Reactor

Unveil Sandusky Nuclear Reactor

Reactor for Atom Plane Project Will Be Started

50 Visiting Newsmen To See Reactor Here

More than 50 newspapermen, radio and television representatives will get a final look at the nuclear reactor south of Sandusky on Tuesday morning. The reactor, a facility of the National Aeronautics and Space Administration, is expected to be "fired up" with nuclear fuel in the near future.

Sandusky Reactor Key To Atomic Plane Try

For Atomic Flight Research

NASA Shows Off Its Plum Brook Reactor

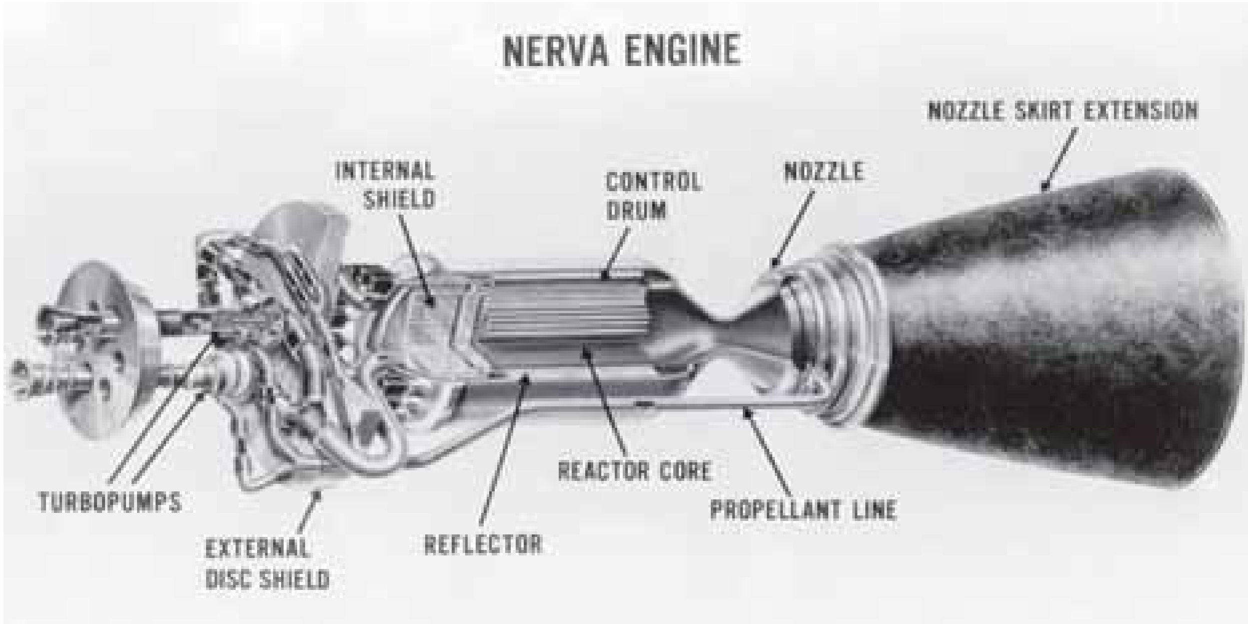


Image 59: The main components of a nuclear rocket engine with 75,000 pounds of thrust. The engine heated liquid hydrogen and exhausted it through the nozzle. (1970) (NASA C–2003–851)

Image 60: Reporters and government officials examine the NERVA engine as it stands on its railcar test platform at Jackass Flats, Nevada. This engine was used for ground tests only. The nozzle on top released heated liquid hydrogen into the air and the engine remained fixed on a railroad track. (Harry Finger Collection)

Plum Brook's Nuclear Facilities

Los Alamos Scientific Laboratory, in association with the Air Force, initiated work on the nuclear rocket development program in 1955. At the beginning, its primary focus was to develop a potential missile application for use in warfare. In 1961 these efforts evolved into the Nuclear Engine for Rocket Vehicle Application (NERVA). In theory, nuclear rockets produced propulsion by directing cold liquid hydrogen into a hot reactor. This caused the liquid hydrogen to expand into a high-pressure gas, which resulted in a very high specific impulse that was roughly twice as powerful as that produced by chemical rockets. By exhausting the gas through a nozzle, engineers believed that between 50,000 and 70,000 pounds of engine thrust was possible. This thrust level was later greatly improved when on 26 June 1968, the Phoebus 1B Reactor was operated at 4200 megawatts, which produced 200,000 pounds of thrust. A second nuclear space application program called the Space Nuclear Auxiliary Program (SNAP) also began during this period. SNAP was developing a nuclear generator to provide electrical power for a spacecraft or satellite. By the mid-1960s NASA and the AEC had spent an accumulated $584.5 million on the two programs.[34]

One of the main concerns affecting both of these programs was how the materials used to build the spacecraft would withstand the damaging effects of radiation. The answer to this question became the focus of the experimental program initiated at NASA's Plum Brook Station. The chief of the reactor division, H. Brock Barkley, said, "Although many experiments have been run in other facilities in the past, they have not yielded the kind of information that NASA needs for space applications. That is why our job and our programs are so vital to NASA's application of nuclear power to space."[35]

After Congress cancelled work on the nuclear airplane, Plum Brook's mission was quickly revised to support work on the nuclear rocket. When Plum

Image 61: Jack Crooks (right) and Jerold Hatton work inside the reactor tank in preparation for the initial startup of the Plum Brook Reactor. They are inserting dummy fuel elements into the core as part of the final hydraulic testing. (1961) (NASA C–1961–56897)

Image 62: Harold Geisler takes the Plum Brook reactor critical for the first time on the evening of 14 June 1961. This first self-sustaining chain reaction was conducted at very low power. It wasn't until the following April that the reactor reached its full potential of sixty megawatts. By July 1963, the reactor had completed its first experimental cycle while critical. (NASA C–1961–56899)

Brook first reached criticality in June 1961, it joined 120 other research and test reactors already in operation across the country.[36] The only research or test reactor in the United States that was more powerful at the time was the Engineering Test Reactor in Idaho. As one of the most powerful test reactors in the world, the NASA Plum Brook reactor became a leader on the emerging nuclear frontier.

Reaching criticality for the first time was a momentous occasion. People gathered around the control room, either inside or looking through the large glass windows from the outside walkway. They all anxiously awaited the announcement that the reactor was finally critical. Reactor operator Clyde Greer said, "It was breathtaking to see one instrument especially." An ink line drawing represented the power level of the reactor. Everyone knew that once it reached criticality it would begin to trace a straight line. Once it did, Harold Giesler and Bill Fecych announced, "We're critical," and everyone began clapping and cheering.[38] Nuclear engineer A. Bert Davis recalled, "That was a special day when it went critical… I stood outside the glass looking in the control room observing what was going on. After it went critical we had a great party that night at a winery in Sandusky."[39]

Image 63: The lily pad area atop the reactor pressure tank. For over ten years, engineers subjected materials to radiation within this vast, cathedral-like containment vessel. In this picture, the shrapnel shields have been removed from over the pressure tank and the hatch has been removed and placed on the lily pad, revealing the open reactor tank. Monitoring was performed and experimental equipment was often assembled in this area. (1961) (NASA C–1961–55851)

Though the Plum Brook reactor went critical in 1961, it was almost two years before it operated at its full sixty-megawatt power capacity. While the power of the reactor was important, it was the neutron flux that was the main attribute that enabled advanced experimentation. Myrna Steele, the only woman physicist at Plum Brook, recalled, "The neutron fluxes and the neutron currents from the reactor at Plum Brook were among the highest in the world at the time that it was built and running."[40] The Plum Brook reactor was capable of producing average neutron fluxes of 4.2×10^{14} neutrons/cm^2-sec. This meant that the reactor could transmit 420 trillion neutrons through a square centimeter of space every second. In the United States, Plum Brook's performance was second only to the Engineering Test Reactor's 500-trillion-neutron flux. Worldwide, only the Dounreay Fast Reactor in Britain had a higher flux at the time, 2,500 trillion. Even though the Chalk River Laboratories reactor in Canada had a much higher power rating—135 megawatts versus Plum Brook's sixty megawatts—it was only capable of a 400-trillion neutron flux.

On 15 August 1963, the main reactor completed its first experimental cycle. During the experimental cycles, when the reactor was operational, a plume of vapor would drift over the reactor cooling tower. This plume became a

Image 64: Two men standing on the lily pad guide a crane to remove the third of three large, white, twenty-ton shrapnel shields that nest over the pressure tank. The shields were then stacked off to the side until it was time to reposition them on top of the pressure tank. Since the support beams could rotate 365 degrees, the overhead crane could reach any location in the containment vessel. The pressure tank hatch is open. (1959) (NASA CS–18228)

symbol to the reactor operators that their systems were operating normally.

That same year, Plum Brook received its AEC license for the Mock-Up Reactor (MUR). The MUR significantly increased Plum Brook's experimental capability and assisted in the overall experimental program by saving both time and money for the experiment sponsors.[41] Benefits included being able to make flux and reactivity measurements on the MUR without tying up the main reactor. The MUR also could help the engineers determine where the experiments should be placed, how much irradiation they would receive from the core, and how the experimental materials would affect the reactor. Maintenance on the MUR occurred monthly for all of its electronic systems. It first went critical at 9:30 p.m. on 10 September 1963, and was considered a "major milestone" for the facility.[42] Dick Robinson was the senior operator and supervisor, and Bill Poley operated the control panel.

In December 1963, the hot laboratory, headed by Robert Oldrieve, became fully operational. After materials were irradiated in the core, some of them were transferred via underwater canal to the adjacent hot laboratory building for examination, while others were transported in lead casks above the water. The radioactive materials also

Image 65: The area just outside the containment vessel airlock (bottom right). The reactor control room on the second floor is visible to the left. The experiment control room is directly below it on the first level. On the second level to the right is a workarea that was later segmented and enclosed for office space. In this picture, three of the "Reactor On" signs are illuminated, indicating that the reactor is in operation. (1961) (NASA C–1961–55812)

The World's Most Powerful Test Reactors Prior to June 1961[37]

Rank	Country	Reactor	Critical Date	Power, kW
1	United States	Engineering Test Reactor, ETR	2 Sept 1957	175,000
2	Canada	Chalk River Laboratories, NRU	3 Nov 1957	135,000
3	Soviet Union	SM–3	10 Jan 1961	100,000
4	Soviet Union	27/BM	1 Jan 1961	70,000
5	Soviet Union	27BT	1 Jan 1956	70,000
6	Britain	Dounreay	1 Nov 1959	65,000
7	United States	SPERT–3, Phillips Petroleum	1 Jan 1958	60,000
8	United States	WTR, Westinghouse	1 Jan 1959	60,000
9	United States	NASA Plum Brook Test Reactor	14 June 1961	60,000

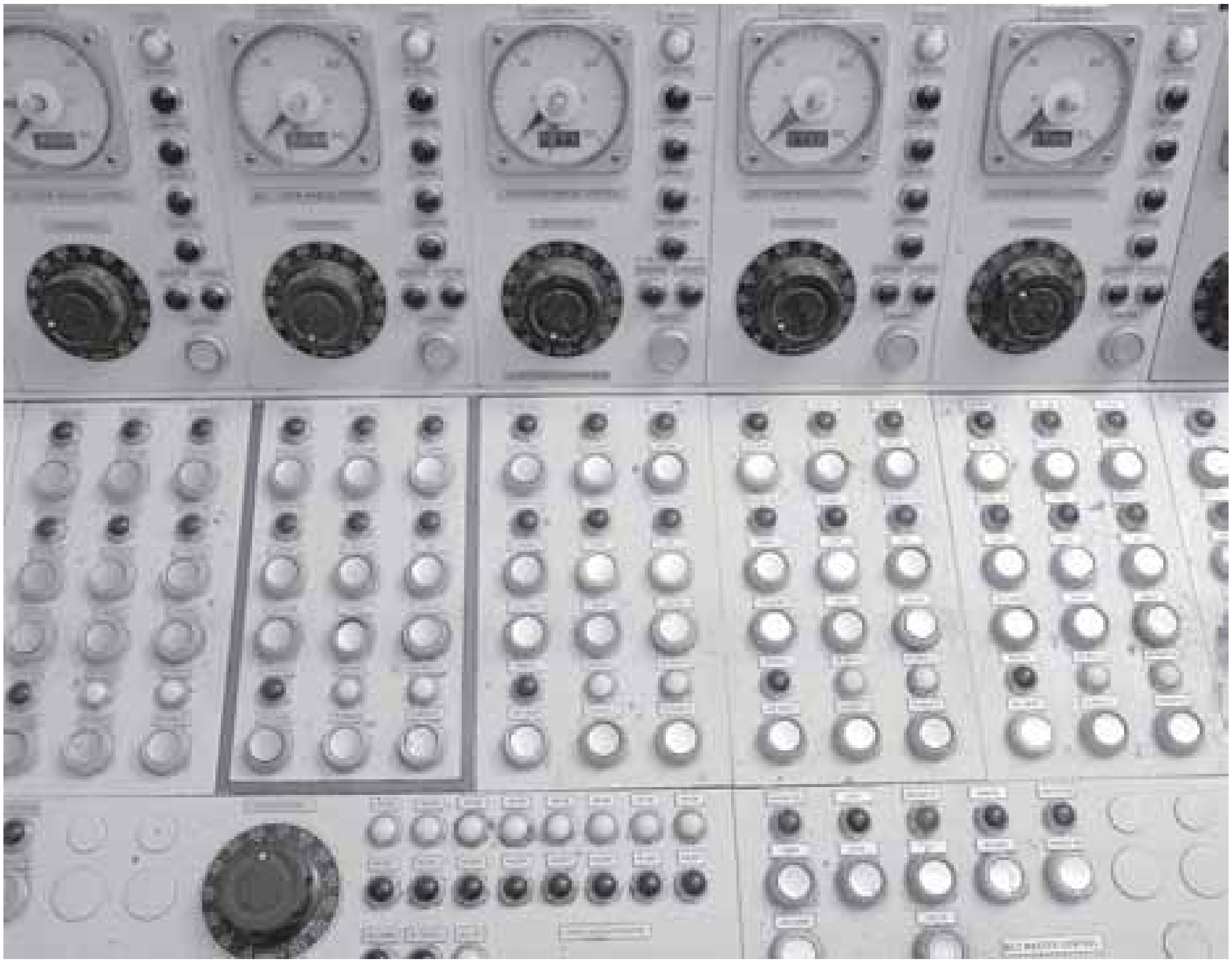


Image 66: This closeup of the right side of the control panel in the reactor control room shows the controls for the manual operation of the shim rods. Each rod has its own speed dial, meter, indicator lights, control buttons, and scram button. The buttons within the square on the left-hand side controlled the regulating rod that could activate a "junior" scram (a partial scram using only one regulating rod). It was designated within the box so that operators could quickly locate the rod's control buttons in case of emergency. The full scram buttons, which dropped all the control rods simultaneously, were set apart at the bottom of the console. (NASA C–2001–01229)

passed through a large room that shielded the rest of the laboratory from radiation. Then they could be examined in one of seven "hot cells." The walls of the hot cells ranged from forty-three to sixty-three inches thick and contained various tools and equipment to inspect and dismantle the experiments. In addition, "master-slave manipulators" allowed operators outside of the cell to work with materials. The Model A and Model D manipulators were both constructed by Central Research Labs, Inc., of Red Wing, Minnesota. Once the elements were disassembled, the irradiated materials were placed in rabbits (small metal capsules), which could be sent through pneumatic tubes to other laboratory rooms in the facility.

Public relations were very important, and most reactor operators considered it a "vital part of our job."[43] Tours were given to distinguished visitors from NASA, such as astronauts, and to the public and media. Some distinguished guests included Raymond Bisplinghoff (director of NASA's Office of Advanced Research and Technology), Harold Finger (manager of the Space Nuclear Propulsion Office (SNPO)), Glenn Seaborg (AEC chairman), the editors of *Nucleonics* magazine, officials from the Japanese Atomic Energy Commission, and professors from local universities who were considering the use of the reactor for their own experiments. In 1963, an aircraft landing strip was built in the southern portion of Plum Brook so

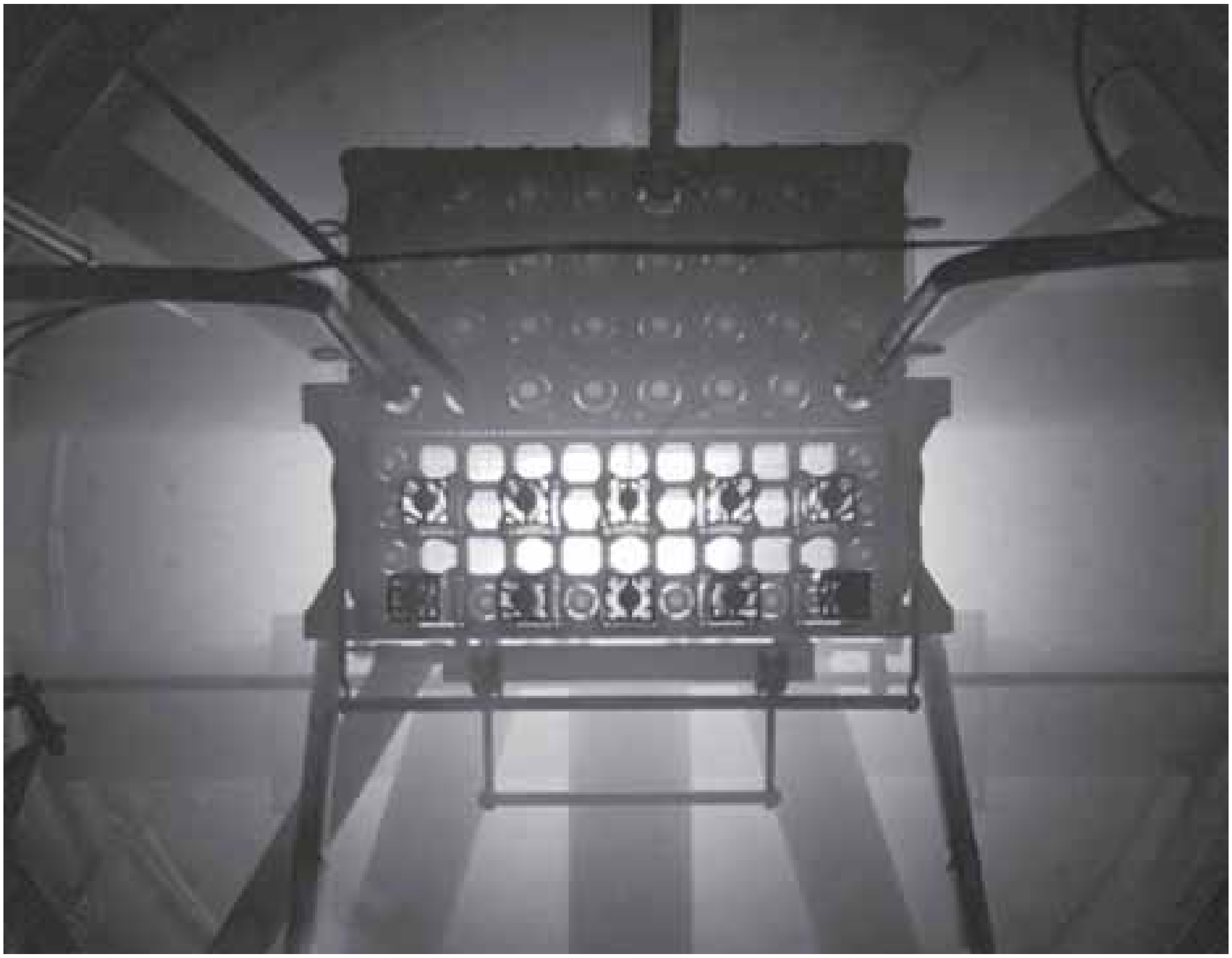


Image 67: During criticality, the Plum Brook Reactor core emitted an eerie blue glow known as Cherenkov radiation. This is common to all swimming pool reactors. The Cherenkov Effect is caused by high-energy beta particles moving at velocities faster than the speed of light in water. Pavel Alekseyevich Cherenkov first observed this phenomenon in 1934. Cherenkov's discovery helped with the detection of elementary particles and was significant for subsequent experimental work in nuclear physics and the study of cosmic rays. In 1958 he was awarded a Nobel Prize in Physics. (c. 1962) (NASA C–1996–03983)

that visits from important guests could be handled more efficiently. Frequent public tours were also given to demonstrate that the reactor was safe for the surrounding community, and also to let people know that the public funds were being properly utilized. After one tour for a Catholic school, Sister Mary Christopher wrote, "From the moment when the guards met us at the gate, all through the periods of explanation at the various stations, until the moment when we left, we were impressed by the willingness and competence of the personnel who helped to make our tour enjoyable and worthwhile."[44] General open houses were also held for the public. These were of tremendous interest to the community; over 1,600 people visited the reactor during an open house in October 1963. A speakers bureau was staffed by a group of reactor employees who traveled around to local schools and civic organizations talking about the reactor.

Though the reactor maintained its safety record, shutdowns, or "scrams," were relatively common and did not necessarily mean that there was a significant danger present. For example, in its second year of operation there were twenty-one unscheduled shutdowns.[45] These were most often due to operator errors, defective equipment, safety or control system malfunctions, and loss of

Image 68: Three technicians work on the core, inside the pressure tank, during one of the shutdown periods. Experiment cycles varied greatly. Some lasted months, while others only days. Each cycle consisted of two parts—the shutdown portion and the power portion. The shutdown periods were used to change fuel, perform maintenance, and work on experiments. (NASA C–1961–56897)

electrical power. Forced evacuations of the containment vessel were not common, but when they did occur they usually resulted from the presence of high levels of airborne radiation. Flooding within the vessel caused at least one evacuation. The majority of medical emergencies were common eye, hand, and bruise injuries. Individual employee radiation exposure was monitored daily and health physics managers used this information to keep track of monthly and annual accumulation. This radiation safety program ensured that employee exposures were kept below established safe limits. Throughout the Plum Brook reactor's entire history, there was never a case of personal injury or illness related to radiation exposure.[46]

However, accidents happened on occasion. For example, one evening during the second shift on 20 May 1964, three workers were removing control rod drive assemblies from the subpile room. Due to a simple mistake they were suddenly "drenched with primary water contaminating themselves and their protective clothing."[47] They were immediately taken to the decontamination shower and were closely monitored by health-safety personnel. After several showers they were cleaned of the radioactivity and airborne tests showed no other remaining contamination. These risks were considered worth taking because of the importance of the experimental program at Plum Brook.

Image 69: The Mock-Up Reactor (MUR) was a 100-kilowatt reactor installed in the reactor building to test experiments at low power before inserting them into the more powerful sixty-megawatt reactor. This allowed operators to determine the best location for the experiments and it also helped them understand the effects each loading scheme had on the neutron flux. Though much smaller and less powerful than the main Plum Brook reactor, the MUR required its own annual AEC/NRC license, and today has its own separate decommissioning plan. (NASA C–2001–01204)

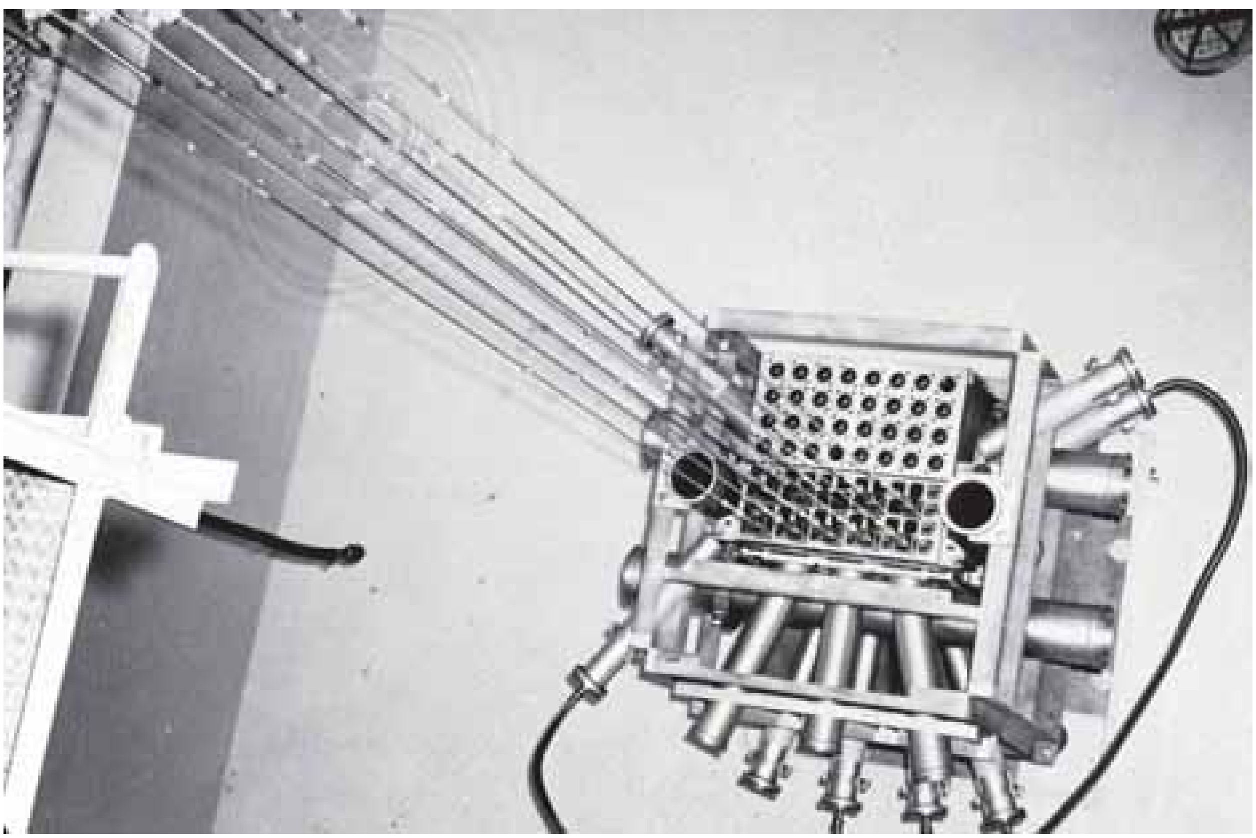


Image 70: The Mock-Up Reactor (MUR) core as seen from the control room. Since the MUR generated a very small amount of radioactivity, the "swimming pool" within which it was located provided sufficient shielding. A moveable bridge directly above the core allowed MUR operators to easily change fuel or manipulate experiments during shutdowns. (NASA PS63–0002)

Image 71: The control room for the Mock-Up Reactor was perched directly above its core. The large windows allowed the operators to view the controls and monitors, as well as the activity in the core below. (NASA PS63–0008)

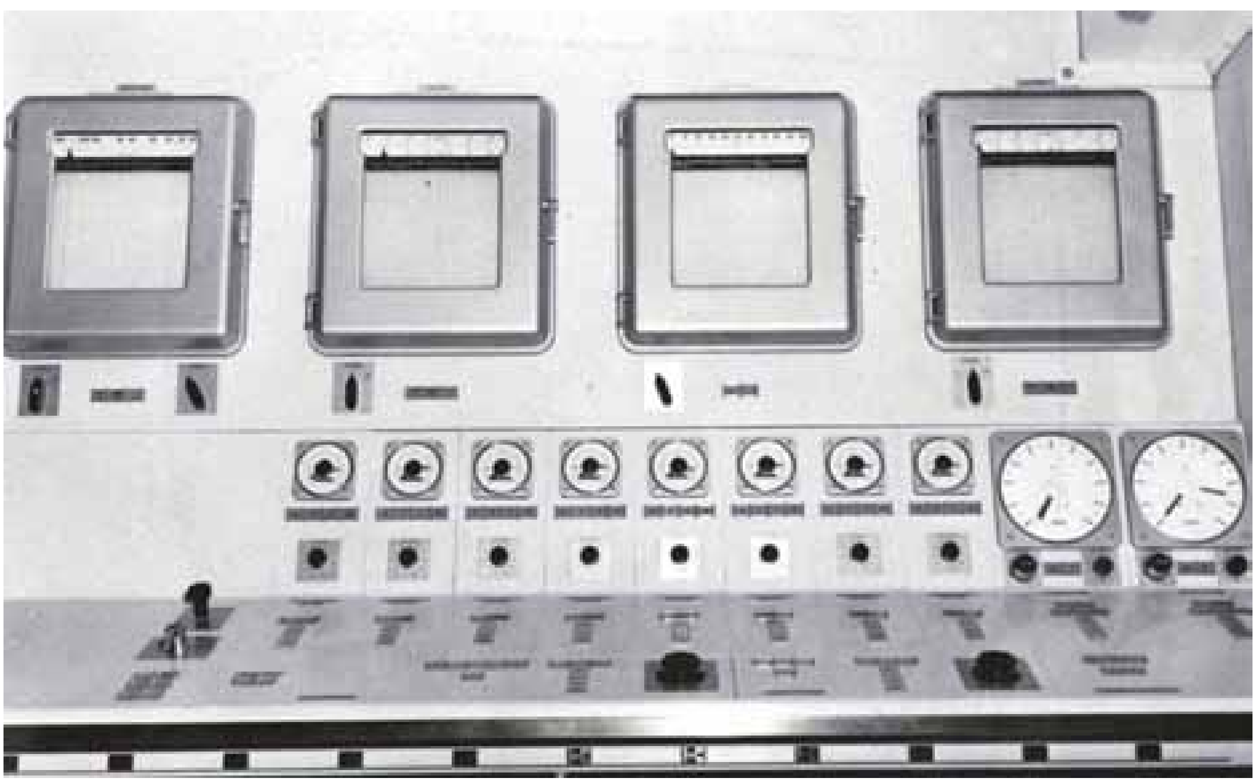


Image 72: Interior of the Mock-up Reactor control room. (NASA PS63–0005)

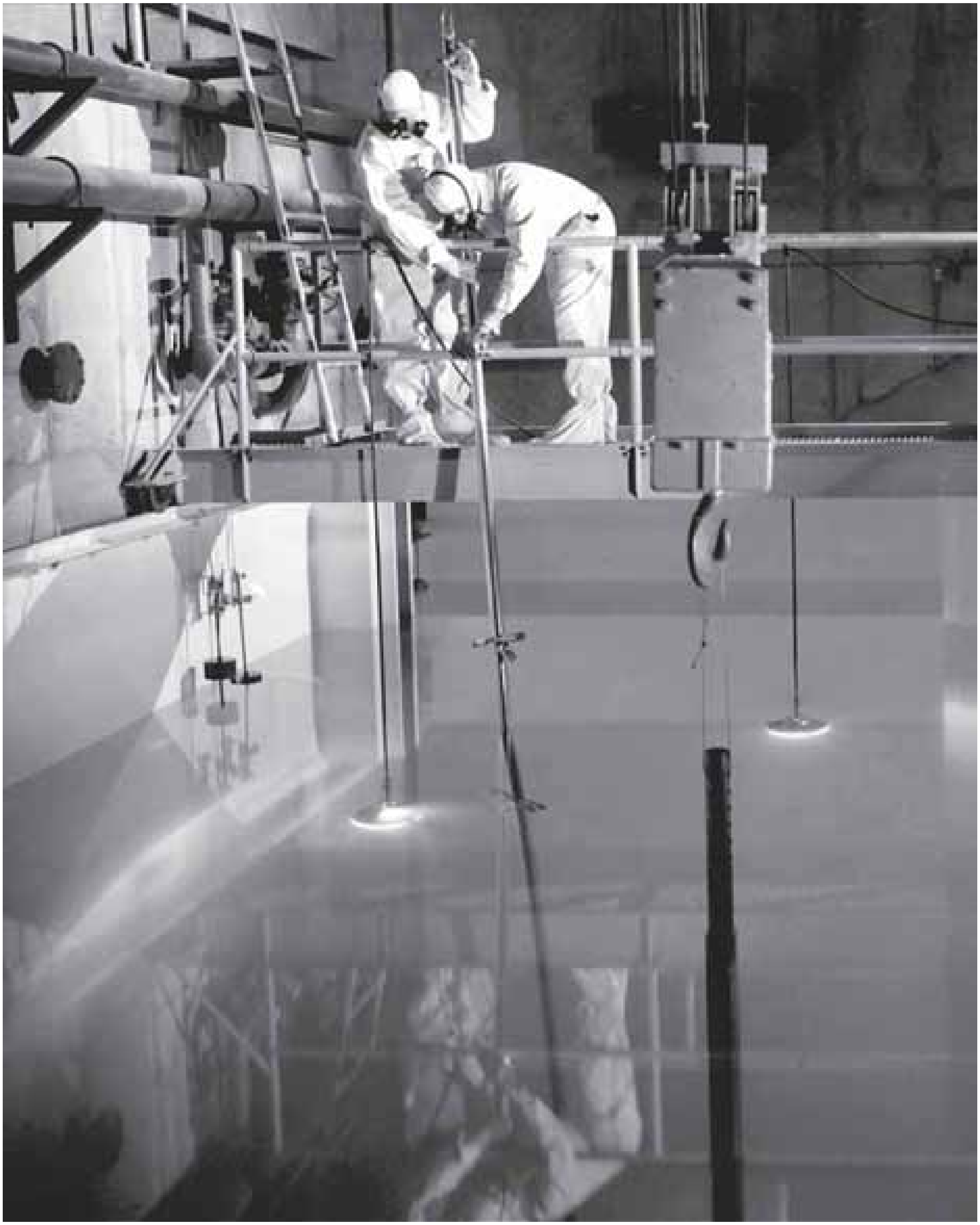


Image 73: Two technicians clad in anti-contamination clothing manipulate a shim safety control rod in a water canal in the hot laboratory. The twenty-five-foot-deep water provided shielding from radiation, yet still enabled visible contact with the research experiments. This water canal also allowed the underwater transfer of irradiated materials from the reactor to the hot laboratory for inspection. Moving materials by canal reduced the need for lead transfer casks, though they were still needed when the radioactive materials were taken out of the water. (1961) (NASA C–1961–55808)

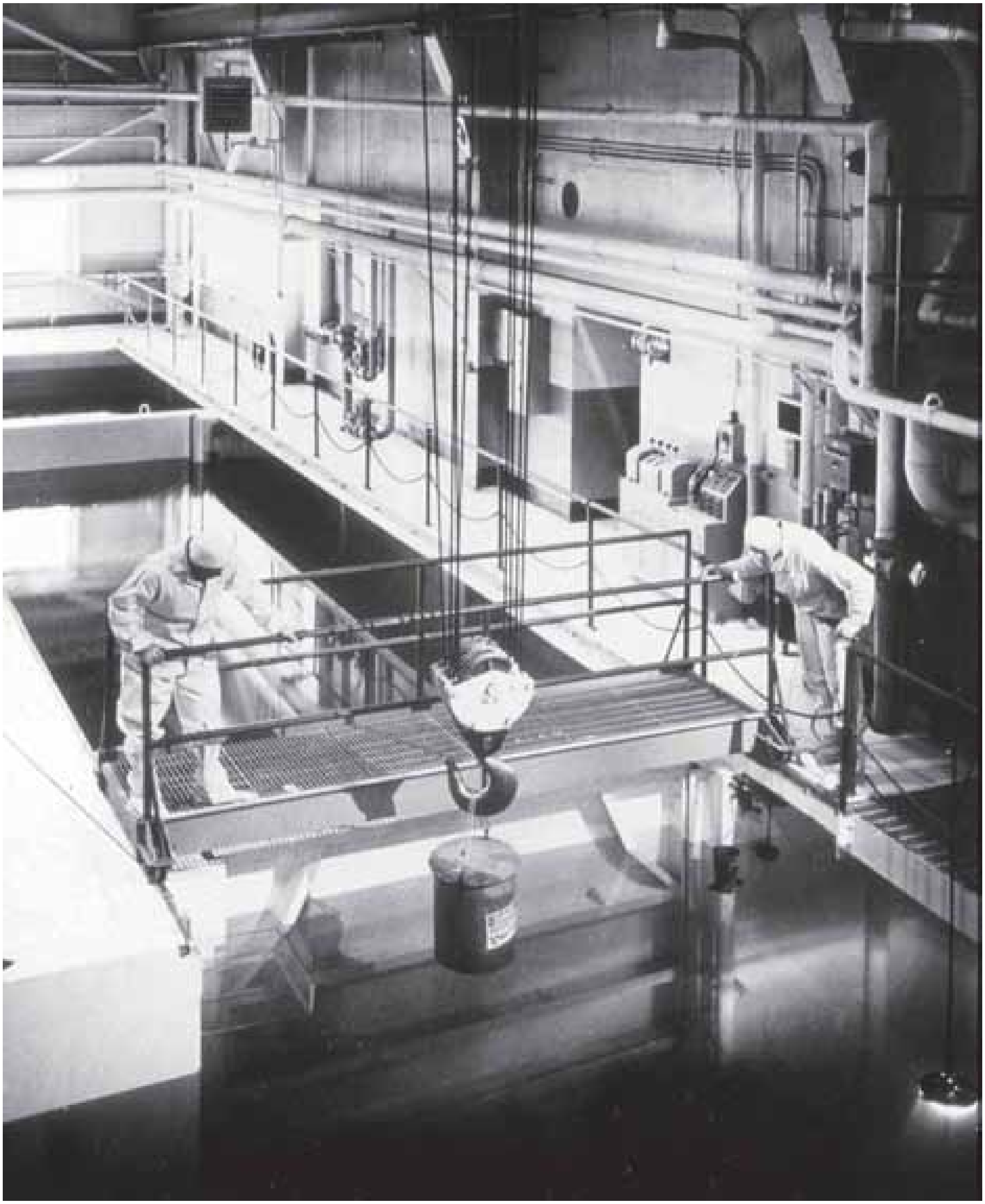


Image 74: Two Plum Brook employees use an overhead crane to lift a lead cask of low-level radioactive waste from Canal F. This was the first canal outside of the containment vessel. Canals G and H are visible behind the man standing on the bridge. The bridge was moveable so technicians could continually work above the objects as they moved through the canal system. The canal connected to the hot laboratory, which was adjacent to the south side of the reactor building. Radioactive materials were moved under water with vehicles, or remotely controlled cranes, between heavily shielded walls in the hot handling room and hot dry storage areas. Then they could be transferred to the hot cells. An eighty-ton lead door separated the hot handling room from the controlled workarea. (NASA CS–22209)

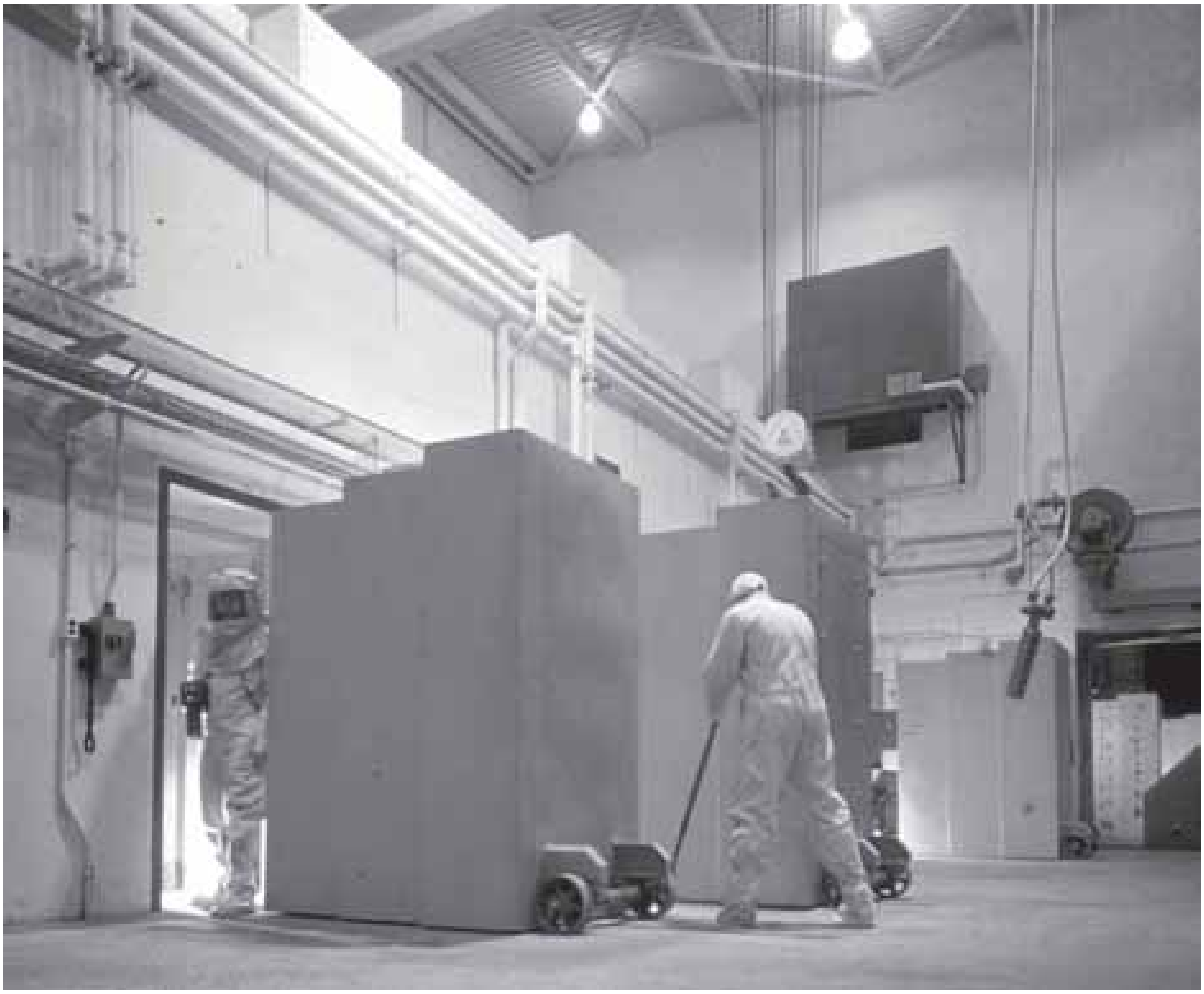


Image 75: A technician emerges from the rear of a hot laboratory cell in full protective gear carrying a "cutie pie" radiation detector. Another technician wheels open the massive sixty-three-inch-thick concrete door plug. (NASA CS–22203)

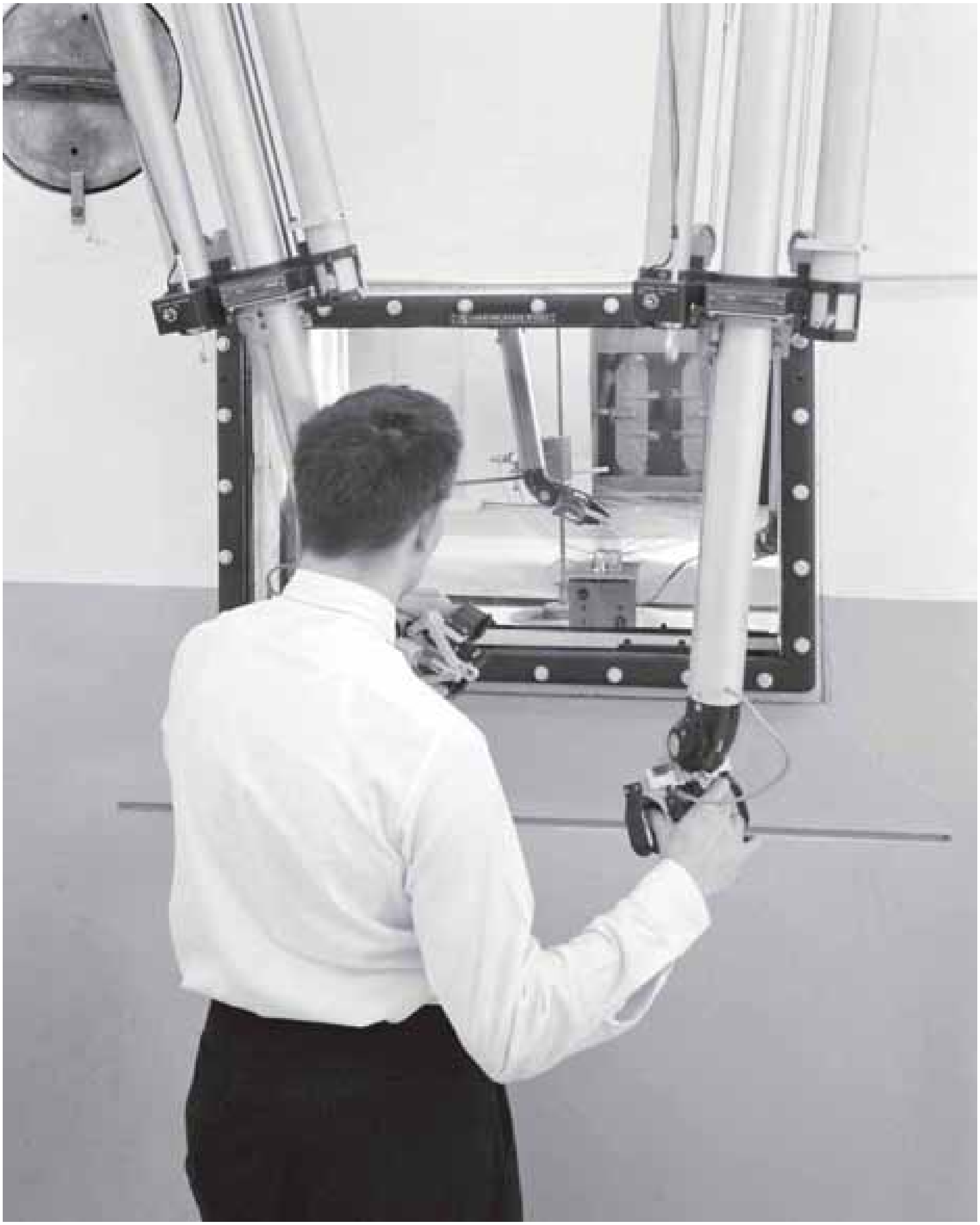


Image 76: Bob Oldrieve, a hot laboratory supervisor, uses manipulator arms to inspect radioactive materials within a hot cell. The pliers-type "hand" is visible inside the window. Operators became so skillful in operating the manipulators that some were even able to thread a needle with them. (1961) (NASA C–1961–55638)

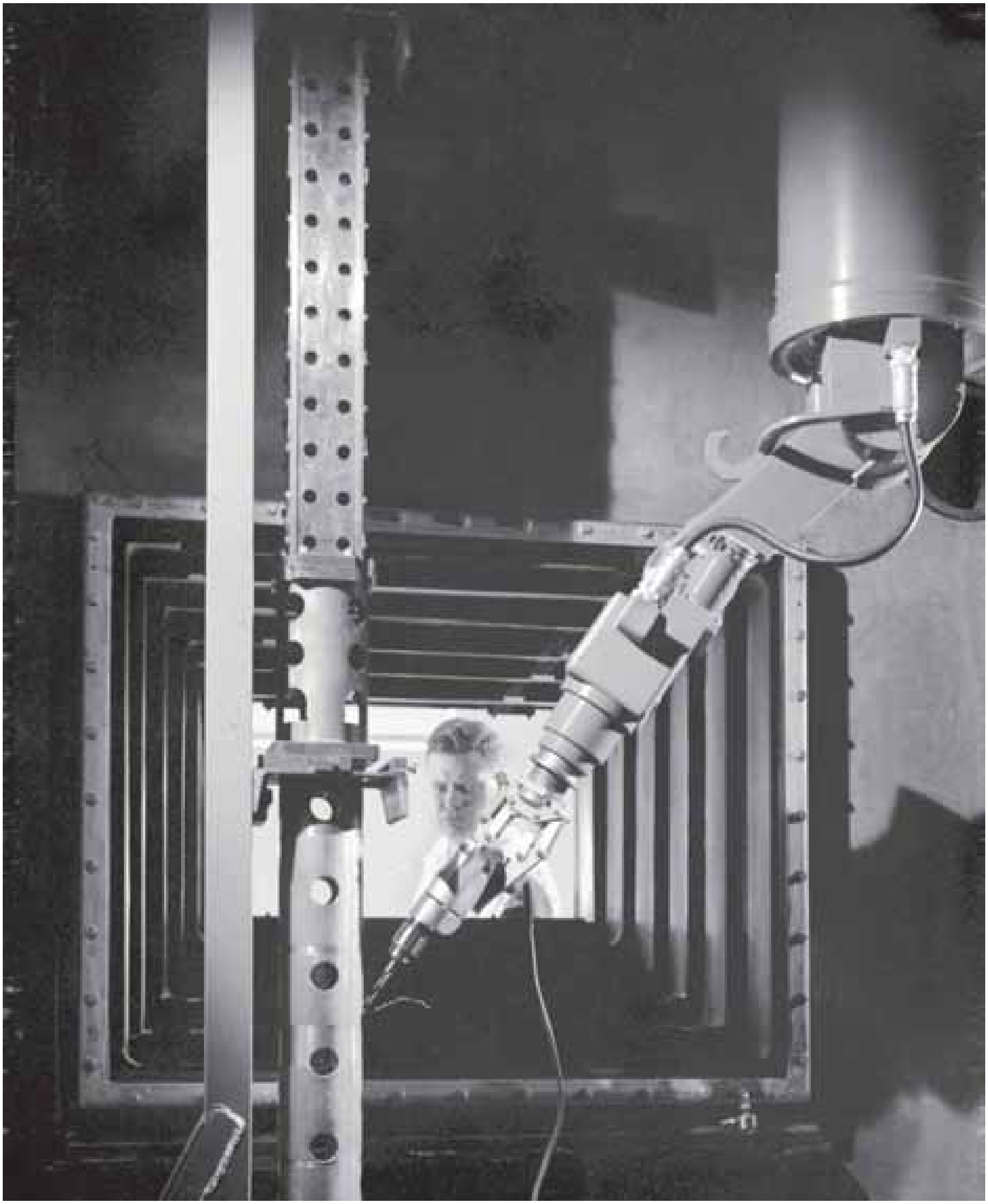


Image 77: View from inside a hot laboratory cell looking out. The manipulator arm is in the foreground; the engineer behind the glass, Dan Gardner, is operating it. A fifty-two-inch oil-filled glass window protected the operator from the radiation. The oil eliminated all of the window's distortion when looking through it. There were seven interconnected hot cells at Plum Brook—each with its own function. Cell 1 was over twice as large as the others. It was used for dismantling experiments when they entered the hot laboratory. Cell 2 had an engine lathe to machine materials. Cell 3 was a tensile testing facility with two sets of manipulator arms. Cell 4 was a preparatory area for Cell 5, where a variety of metallographic testing equipment was housed. Cell 6 was used for chemical analysis. Cell 7 had X-ray diffraction and analysis machinery. Each cell had filtered air, water, special vents, an intercom, and floor drains for liquid waste effluent. (1961) (NASA C–1961–55800)