

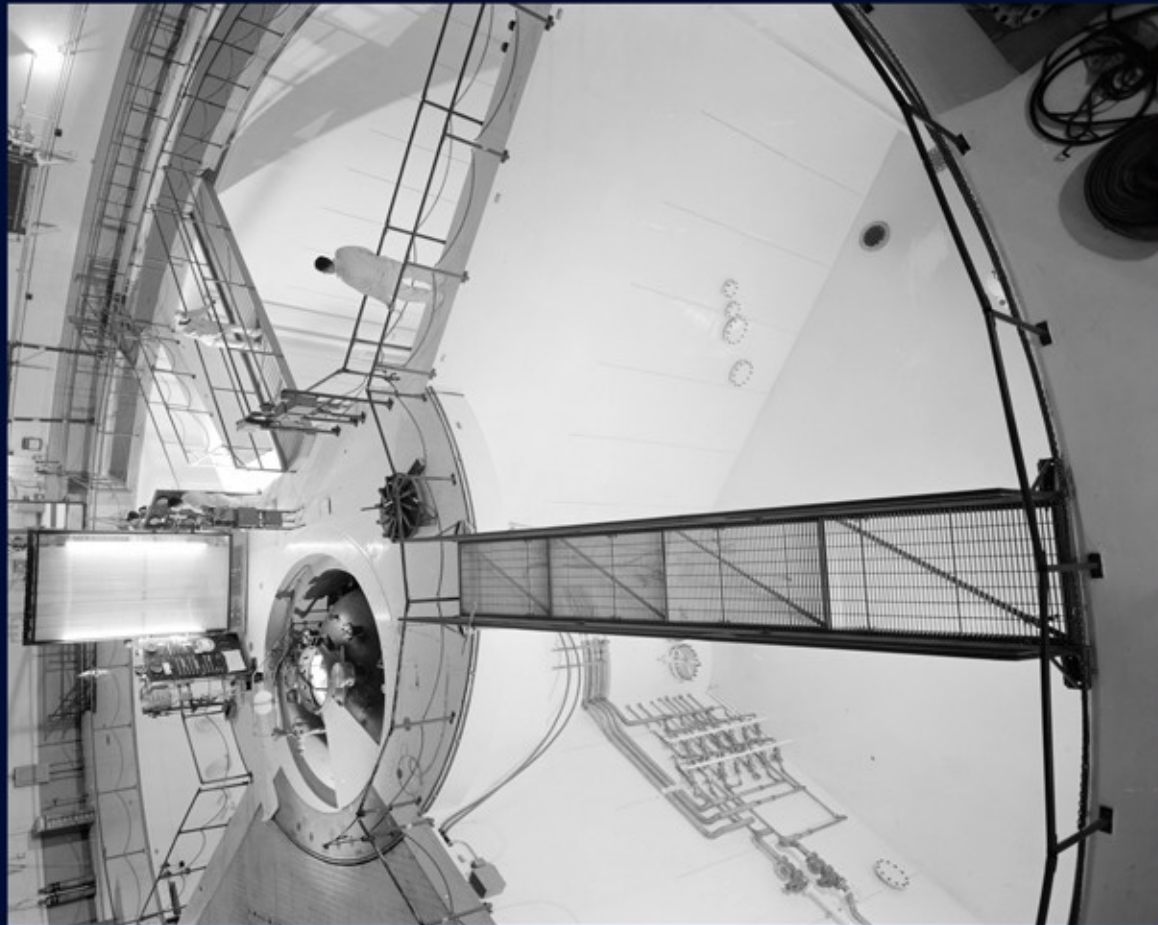


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AWARD WINNER

Science in Flux won the prestigious 2005 American Institute of Aeronautics and Astronautics History Manuscript Award. This award is presented each year for the best historical manuscript dealing with the science, technology, and/or impact of aeronautics and astronautics on society.



The Plum Brook nuclear test reactor in 1961. (NASA C-1961-55851)

National Aeronautics and Space Administration

NASA History Division
Office of External Relations
Washington, D.C.
June 2006

Science in Flux

NASA's Nuclear Program at Plum Brook Station 1955 – 2005

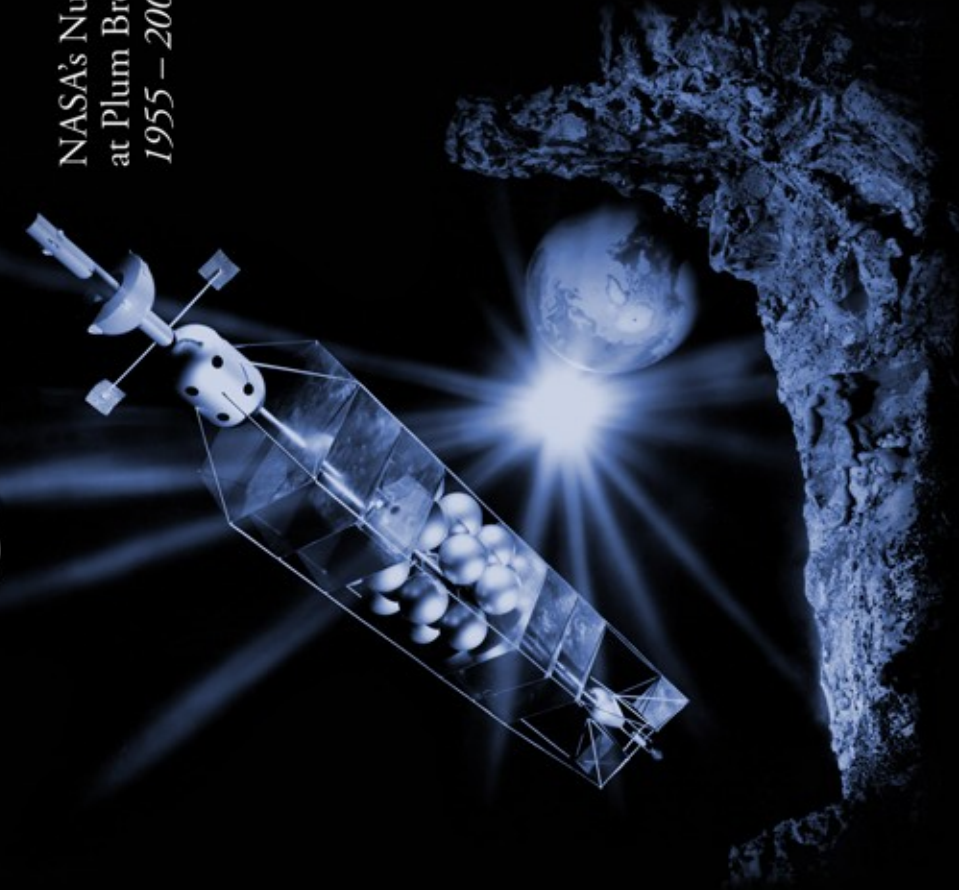
Mark D. Bowles



NASA
SP-2006-4317

Science in Flux

NASA's Nuclear Program
at Plum Brook Station
1955 – 2005



Mark D. Bowles

Science in Flux: NASA's Nuclear Program at Plum Brook Station 1955 – 2005

Science in Flux traces the history of one of the most powerful nuclear test reactors in the United States and the only nuclear facility ever built by NASA. In the late 1950s NASA constructed Plum Brook Station on a vast tract of undeveloped land near Sandusky, Ohio. Once fully operational in 1963, it supported basic research for NASA's nuclear rocket program (NERVA).

Plum Brook represents a significant, if largely forgotten, story of nuclear research, political change, and the professional culture of the scientists and engineers who devoted their lives to construct and operate the facility. In 1973, after only a decade of research, the government shut Plum Brook down before many of its experiments could be completed. Even the valiant attempt to redefine the reactor as an environmental analysis tool failed, and the facility went silent. The reactors lay in costly, but quiet standby for nearly a quarter-century before the Nuclear Regulatory Commission decided to decommission the reactors and clean up the site.

The history of Plum Brook reveals the perils and potentials of that nuclear technology. As NASA, Congress, and space enthusiasts all begin looking once again at the nuclear option for sending humans to Mars, the echoes of Plum Brook's past will resonate with current policy and space initiatives.

ABOUT THE COVER

Artist's conception in 1959 of a manned nuclear-powered spacecraft capable of reaching Mars.
(NASA C-1059-52113)

Science in Flux

NASA's Nuclear Program
at Plum Brook Station
1955 – 2005

by
Mark D. Bowles



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For Nancy and Isabelle

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Science in *Aux*

Preface

In June 2001 I was part of a group of historians and archivists visiting NASA's idyllic-sounding Plum Brook Station, located in the rural countryside outside Sandusky, Ohio. I had been to this place before when I was writing a book on the history of the Centaur rocket and knew that the scientific community considered it one of the leading rocket-testing facilities in the world, where experiments on the Arienne rocket, Mars Pathfinder, and the International Space Station had been performed.¹ But the reason for my visit that day was the two nuclear reactors housed at Plum Brook, the only such facilities NASA had ever built. I was going to write the history of these reactors and tell the story of why the government built them and was now in the process of tearing them down.

Plum Brook is an intriguing place that inspires an air of mystery. In 2001 the facility played a role in Dan Brown's best-selling thriller *Deception Point*, as a site for a scientific cover-up. His protagonist, Rachel Sexton, was an intelligence analyst who was "hardly able to believe she was going to talk about . . . a private test facility called Plum Brook Station."² In this fictional world, the secrets of Plum Brook were not to be revealed to the public. But Brown's story about the mysteries of the hidden region was familiar to local residents who told rumors about unexplained lights, weather-altering devices, secret research, and even stories about UFO sightings beyond the guarded fences.³ One Plum Brook director told a newspaper reporter in 1998 that many believed that the reason he would not let the public into Plum Brook was

¹ Virginia P. Dawson and Mark D. Bowles, *Taming Liquid Hydrogen* (Washington, DC: NASA SP-2004-4230, 2004). John Mangels, "NASA Testing Facilities Count Rivals Among Customers," *Newhouse News Service* (27 July 1999): 1. David Herman, "Following the Bouncing Ball on Mars," *Mechanical Engineering* 118, 5 (May 1996): 106. James Ewinger, "NASA Glenn Powered Research into Solar Cells for Space Station," *The Plain Dealer* (28 November 2000): 1B.

² Dan Brown, *Deception Point* (New York: Pocket Books, 2001), pp. 371–373, 493.

³ One Plum Brook UFO sighting in 1967 was published in Brad Steiger and Sherry Hansen Steiger, *UFOs Are Here!: Unmasking the Greatest Conspiracy of Our Time* (Citadel, 2001), p. 78.

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because NASA was doing “something secret” like “housing a flying saucer.”⁴ Radioactive research often spawns tales of fear and conspiracy among its neighbors. I was eager to explore beyond the Plum Brook fences and enter its dormant and nearly deserted nuclear reactors that had sat unused for a quarter-century.

On the first day of research, once inside Plum Brook’s main gates, we drove down a narrow road through what scientists consider to be one of the best examples of natural prairie and forest in the Midwest. Its other important natural feature is that it sits on the alluvial plain and has the lowest level of seismic activity in the entire United States—an important geological feature for nuclear research.⁵ There were few people on site that day, and once we were away from the guardhouse and administration buildings, it was rare to see anyone else about. Plum Brook had once employed nearly 700 people, but by the late 1990s there were only 12 civil servants on site. When we finally emerged from the trees, we entered a grassy area to see the nuclear facility—once the second most powerful in the United States.

Typically one thinks of the massive hourglass-shaped cooling towers that define power reactors. But nothing of the exterior of the Plum Brook reactor indicated what was inside. There was only a low, domed structure tucked into a 117-acre site with a water tower, several adjoining office buildings, and temporary trailers housing workers. As we parked the car in the gravel lot, we had to verify that this was the right place.

I would later read accounts of others who had researched nuclear facilities and discovered that my first impression was not out of the ordinary. Hugh Gusterson, who wrote a study on the Lawrence Livermore National Laboratory, experienced a similar initial reaction. He wrote, “When I first saw the laboratory, I was disappointed. Instead of the conspicuous high security, industrial landscaping, and impressive modern architecture I had expected, I found a ragged, non-descript sprawl of scrubland and trailers punctuated by the occasional modern concrete-and-dark-glass building.”⁶ The public perception of nuclear facilities and the true nature of life behind their fences are often at odds with each other. Plum Brook was much like the place that Gusterson described. Trees dominated a landscape disturbed only by sporadic, drab buildings, temporary worker trailers, and a domed building that hid inside its potential for unique scientific research.

⁴ Robert Kozar, quoted in Ulysses Torassa, “10,9,8,7 . . . Little-Known Ohio NASA Facility Tests New Rockets, Jet Engines,” *The Plain Dealer* (19 April 1998): 1J.

⁵ Michael Mecham, “Big Room, Big Vacuum,” *Aviation Week & Space Technology* 159, 1 (7 July 2003): 46.

⁶ Hugh Gusterson, *Nuclear Rites: A Weapons Laboratory at the End of the Cold War* (Berkeley: University of California Press, 1996), p. 25.

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There were two reactors at Plum Brook, the main “test” reactor, and a smaller “research” reactor. Our plan was to actually go inside the main reactor and try to envision what it used to do when it housed a vibrant nuclear research program in the 1960s. Before we could enter, protocol dictated that we listen to a lecture given in the trailers and read through a procedures manual about radiation safety. To ensure that we understood what we were told, we had to take a multiple-choice test, my first since my undergraduate days. After we passed the test, an engineer led us into the reactor security building, where we affixed pen-shaped dosimeters to our jacket pockets. These gauges could tell us if we were exposed to any unexpected sources of radiation. With a final warning not to eat or drink anything in the reactor (eating a meal next to a nuclear reactor was the last thing on our minds), our guide led us inside.

As we entered, the reactor we felt as if we had stepped back in time into the 1960s. It was like a modern-day ruins, an eerie Pompeii-like place where the material culture of its final days lay untouched, with papers still on desks, equations on blackboards, and tools left on workbenches. All Plum Brook nuclear research had ended abruptly in 1973, when the government canceled the program without warning, forcing nearly 700 scientists and engineers to begin looking for new jobs. A skeleton crew consisting of only a few individuals ensured that the closed reactor remained environmentally safe for the next several decades. The government kept the reactor in this standby condition until 1998, when NASA finally allocated the funds and received the Nuclear Regulatory Commission’s (NRC) approval to decommission it. (The NRC’s *Code of Regulations* defines decommissioning as the “safe removal of a facility from service and reduction of residual radioactivity to a level that permits termination of the NRC license.”)⁷ The decommissioning team established an interconnected series of trailers just outside the reactor, which served as the base for their efforts. They informally called this trailer region “Timmy Town,” in reference to Tim Polich, the leader of the decommissioning team. He managed a group of experienced workers in the slow process of tearing down the reactors and transporting truckloads of contaminated waste to landfills in Utah and South Carolina.⁸

Tom Junod, a former “health physics” officer at the facility, told me that he

⁷ John L. Minns and Michael T. Masnik, “Staff Responses to Frequently Asked Questions Concerning Decommissioning of Nuclear Power Reactors,” Nuclear Regulatory Commission, June 2000, Box 8, Folder 6, Plum Brook Archives.

⁸ John C. Kuehner, “NASA Reactors Take Final Voyage,” *The Plain Dealer* (27 June 2002): B10.

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always had an eerie feeling when he walked back inside the building.⁹ (“Health physics” was a term developed by Manhattan Project scientists during World War II to describe the mission of individuals whose job was “radiation protection.”) He said, “You almost feel like the place is haunted.”¹⁰ At the very least, it is like walking into an abandoned museum or a time capsule from the past. Posters from J. Edgar Hoover and the FBI reminded the employees, “A theft from your government is a theft from YOU!” The engineers had built ashtrays into the walls next to each of the hot laboratory manipulator arms, because smoking during the handling of radioactive materials was then a common practice. The massive control panel consisted of row after row of identically shaped buttons, with no apparent thought to ergonomic organization. It looked like the control room of the *Star Trek Enterprise*—the way the future looked as depicted by the original series back in the 1960s. It reminded me that visions of the future have an unusual way of becoming dated. The Plum Brook reactor was once state of the art. It now looked like a cannibalized museum relic.

As the *Star Trek* characters voyaged into the final frontier, we were exploring what once represented the leading edge of NASA’s nuclear frontier. Though obviously one was fictional and the other real, the two had one other element in common—rockets and the exploration of space. Inside the dome was the containment vessel, where for 11 years NASA had performed experiments on materials and devices to support the development of a nuclear rocket and nuclear electric power supplies for space exploration. One hoped-for application of this research was a planned nuclear rocket to transport humans to Mars.

Once we finished walking the empty halls, viewing the dry canals, and investigating the abandoned instruments, we walked toward the exit. On our way out we entered a room with two full-body radiation counters. Down the center of the room was a piece of tape. One side was contamination-free and the other was for all people or things exiting the reactor. Though the tape comically reminded me of Les Nesman from the 1970s sit-com *WKRP*, who defined his office walls in tape, the engineers stoically assured me that no one inadvertently crossed it—and neither did the contamination. Safety was a very serious issue, and no one seemed to appreciate the pop-culture reference. Even though our dosimeters read that we had encountered no radiation, we each stepped into full-body radiation machines to measure any minute traces of contamination that might be clinging to us. Alarmingly, my machine beeped when I was inside, and the electronic diagram of my body

⁹ Len Ackland, *Making a Real Killing: Rocky Flats and the Nuclear West* (Albuquerque: University of New Mexico Press, 1999), p. 102.

¹⁰ Interview with Tom Junod by Mark D. Bowles, 25 September 2002.

Preface

indicated potential high levels of contamination in the cranial region. Before I could utter, “What does THAT mean?” the engineer guide reassured me that I had simply not placed my body properly in the device. I repositioned myself and was given the OK sign. I tried to pretend that this was a normal occurrence in my life.

I was ready to begin investigating the significance of the facility and telling the story of its life and death. But I left with many unanswered questions. Why had NASA built these reactors at Plum Brook? What did they do? Despite now being closed and inoperable for over 30 years, the main Plum Brook reactor is still today the eighth largest nuclear test facility that the United States has ever built. Why had the nuclear research ended so abruptly? What had the scientists and engineers accomplished with their experiments? Why was Plum Brook itself shrouded in mystery that made the conspiracy stories of Dan Brown seem plausible and the tales of mystery behind its fence common? And why was the government now spending over \$150 million (and likely much more when the project is finally completed) to tear them down when it cost only one-tenth that amount to initially build them? I was ready to begin my journey into the history of this nuclear relic from NASA’s golden age of space exploration.

As I finish writing this preface it is September 2005, fifty years to the month since Plum Brook broke ground on its nuclear reactor. Over the past half-century NASA’s reactor program at Plum Brook has had a compelling history, even though the reactors were engaged in research for approximately one-fifth of this time. The telling of this story has required the assistance of a great number of people. I would first like to express my gratitude for the dedicated work of Robert Arrighi, who was my co-author on an earlier monograph on the Plum Brook nuclear reactor, *NASA’s Nuclear Frontier*.¹¹ Although that book was primarily a photographic history, I used much of the research and oral interviews that we performed as a springboard for writing this book, *Science in Flux*. I also thank Dr. Virginia P. Dawson at History Enterprises, Inc., for her valuable insight into NASA history and her comments on successive drafts of the manuscript. Both Virginia and Robert also assisted with the interviews for this book.

Kevin Coleman, of NASA-Glenn Research Center, was indispensable for his coordination of this project and his advice throughout all phases of the research, writing, and photograph gathering. He is a true NASA asset. I also acknowledge the valuable assistance of Deborah Demaline, Jan Dick, Jim Polaczynski, Quentin Schwinn, and Bruce MacGregor of InDyne, Inc.; Michael Blotzer, chief of the

¹¹ Mark D. Bowles and Robert S. Arrighi, *NASA’s Nuclear Frontier: The Plum Brook Reactor Facility* (Washington, DC: NASA SP-4533, 2004).

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Glenn Research Center's Environmental Management Office; Rich Kalynchuk at Science Applications International Corporation; Project Manager Timothy J. Polich and Senior Engineer Keith M. Peacock of the Plum Brook Reactor Facility Decommissioning Team; Steve Dick, NASA Chief Historian; Stephen Garber at the NASA History Division; Roger Launius at the National Air and Space Museum; Galen Wilson and Scott Forsythe at the National Archives; Nan Card at the Ruth-erford B. Hayes Presidential Center; Deborah A. Macdonell of the United States District Court Northern District of Ohio (Toledo); Linda Gattshall at the Milan Public Library; Margaret Baughman of the Cleveland Public Library Photograph Collection; Joanne Cornelius at the Cleveland State University Special Collections Department; Jerome Cooke at the Department of Energy; Judith A. Scalf and Patricia Bonecutter at the Northeastern Cooperative Regional Library Depository; Will Currie at the Firelands College Library; 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 transcriptions for all of the interviews conducted for this book, as well as data entry services for some of the charts. She has been an important colleague of mine for nearly ten years.

A talented group of professionals handled the production of this book. Heidi Pongratz at Maryland Composition oversaw the copyediting of this book. Tom Powers and Stanley Artis at NASA Headquarters acted as invaluable coordinating liaisons with the graphic design group at Stennis Space Center. At Stennis, Angela Lane handled the layout with skill and grace, Danny Nowlin did an expert job proofreading, and Sheilah Ware oversaw the production process. Headquarters printing specialists Jeffrey McLean and Henry Spencer expertly handled this last and crucial stage of production.

A special debt of gratitude is owed to the manuscript reviewers (anonymous peer reviewers and NASA and former Plum Brook reactor employees) who provided important suggestions for this and the previous monograph. They include H. Brock Barkley, Jack Brooks, Earl Boitel, Bill Brown, Don Johnson, Jack Ross, Dean Sheibley, and James A. Dewar. A special recognition goes to Olga M. Dominguez, Deputy Assistant Administrator for Management Systems at NASA Headquarters in Washington, DC. Without her support, dedication, and foresight in the preservation of the history of this facility, this book would not have been possible.

This book is dedicated to my wife and daughter. My wife, Nancy, has always given me the freedom and support to follow my dreams, and we have been on a wonderful journey together for the past 15 years. Our five-year-old daughter, Isabelle, is a magical joy in our lives. Each night before bed she peers out her window, excitedly trying to find out what the Moon, or Luna as she affectionately calls it, looks like that evening. This joy and passion to explore the unknown of space, if even with the naked eye, is a common thread that unites all those who gave their lives and careers

Preface

to NASA—an agency of critical importance to the United States. May those dreams never be extinguished.

MARK D. BOWLES
Cuyahoga Falls, Ohio
September 2005

Introduction

In 1970 Robert Earle wrote a science fiction novel called *Hot Lab*, the plot of which centered on the use of radioactivity as a scientific research tool. It took place at the fictitious Pine Valley Laboratories, a remote rural facility, where engineer Richard Rendfel, the book's protagonist, moved with his young family to work. This was a reactor that produced streams of neutrons for experimentation, not power for energy consumption. These "neutron fluxes" were very intense beams of radiation that experimenters directed at various materials in the hopes of learning new secrets about their atomic makeup. Researchers exposed the objects to the radiation near the reactor core for a specified length of time and then moved them via underwater canals to the "hot laboratories" for investigation. These were shielded cells aligned in a row where the engineering operators stood side by side, peering into them through thick plate-glass, oil-filled windows. They interacted with the materials through the deft use of robotic manipulator arms, which were huge claw-like devices that enabled the engineers to perform experiments on the materials without exposing themselves to high levels of radiation. After Rendfel's first day on the job, his supervisor told him: "We get nearly everything you can imagine—bottles of irradiated calf's liver, elastomers, transistors, timing devices, sledge hammer handles, and static eliminators for tape recorders. It seems that everybody wants to irradiate everything they can lay their hands on in hopes of a scientific or commercial breakthrough."¹

The term "irradiation" refers to the placement of materials near a radioactive source such as a nuclear reactor. After World War II, irradiation studies became a new and exciting field of science. The narrative in *Hot Lab* reflected this importance, and Rendfel's fictional experiences were typical of those who worked inside and lived on the outskirts of a test reactor devoted to irradiation experiments. Rendfel participated in the scientific research and devised ways to maintain and repair various aspects of the facility. He learned about the history of the laboratory, which was as an old munitions factory, and worked daily in its "dreary glamor." He helped

¹ Robert Earle, *Hot Lab* (New York: Vantage Press, 1970), p. 18.

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gauge the power of the reactor by measuring its neutron flux. He studied problems of corrosive fuel and the concerns about radiation damage to the reactor itself. He witnessed the protests by antinuclear activists and speculated that the nuclear industry had brought some of the attacks upon itself by its own self-criticism. In awe he watched the proficiency of hot laboratory engineers who used their master-slave, robotic claw arms to manipulate the irradiated materials removed from the reactor core. During quiet moments he saw them practice their craft by attempting incredibly meticulous tasks like threading a string through the eye of a needle in their radioactive cells. The engineers performed this demonstration of their skills for the frequent visitors to the laboratory, and especially for the “red carpet” tours by astronauts. Rendfel also attended the numerous laboratory parties and quickly felt the tight collegial bonds between the engineers and technicians.

With safety an ever-present concern, Rendfel frequently interacted with “health physicists” whose job was to take air samples and monitor the amount of radiation each employee received. Since many people speculated that radiation effects accumulated slowly over time in people, he helped enlist volunteers to work in high-radiation areas for short periods of time to perform critical tasks. Rendfel always carried a dosimeter with him to register the radiation that his own body received, and when he was exposed to too much, health physicists sent him to the Radiation Control and Treatment Laboratory for immersion in the whole-body radiation counter. Safety was on the minds not just of employees at the reactor but also of the country itself, because the United States was locked in an “atomic stalemate” with its rival superpower. The nuclear standoff between the nations created a “world based on fear.”

For the employees at the fictitious Pine Valley there was a more immediate concern. There were rumors that the government was about to cancel all work on nuclear-powered aircraft and rockets. If this were to happen, the entire Pine Valley Laboratories would be vulnerable, because this was one of their primary areas of research. Rendfel realized, “The place could be shut *down*.” Despite the importance of Pine Valley’s research for the nuclear aircraft and rocket program, Rendfel knew that his job was in constant jeopardy. He said, “The final irony . . . is that . . . the entire Pine Valley Plant could be *completely* closed down without anyone being the wiser—or really caring if it never reopened.”²

Robert Earle, the author of *Hot Lab*, was not a professional writer, nor did he even exist. The name was a pseudonym chosen by Robert Oldrieve, an engineer who wrote the book while he was the hot laboratory supervisor at NASA’s Plum

² Earle, *Hot Lab*, pp. 56–57.

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Brook nuclear test reactor in Sandusky, Ohio, from 1959 to 1965.³ Though the plot of his science fiction story was a fabrication, he based all of the surrounding elements on fact. After World War II, the government, universities, and private industry built numerous nuclear research facilities to study the effects of radiation. The experiments included irradiating materials used to construct future power reactors, develop nuclear weapons, and study radioisotopes in medicine. Research reactors also played pivotal roles in developing future propulsion systems for nuclear submarines, airplanes, and rockets. Other elements of Oldrieve's story were also true. The munitions factory, radiation damage, volunteers, antinuclear protesters, hot lab manipulator-arm operators, public demonstrations, astronaut visits, professional bonding, health physicists, personal radiation safety, the Cold War, nuclear fear, and the research on nuclear rockets were all things that he experienced while at Plum Brook.⁴ The science of the book accurately portrayed a thriving United States test reactor in the 1960s, and his concerns about the impermanence of nuclear rocket research were predictive of the future.

The Importance of the Neutron Flux

Testing and research reactors as scientific tools are more common than most people realize, and their history remains largely untold. There is an important distinction between these two types of reactors. A test reactor is one that operates above the 10-megawatt thermal power range, whereas a research reactor operates between 10 kilowatts and 10 megawatts.⁵ Power reactors that generate electricity (and operate at much higher power levels) frequently appear in newspaper headlines and are conspicuous because of their size and potential for disaster, whereas research reactors can be quietly tucked away, even located in the midst of a college campus. 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 was the most prolific research reactor-building nation, with 227 sites, followed by the former Soviet Union with 97. These American reactors were constructed by national laboratories (Argonne, Oak Ridge, Brookhaven, and Los Alamos), univer-

³ Robert E. Oldrieve, "Plum Brook Reactor Hot Laboratory Facility," Box 252, Folder 12, Plum Brook Archives.

⁴ Interview with Rosalie Oldrieve by Mark D. Bowles, 26 September 2002.

⁵ National Academy of Sciences, Subcommittee on Research Reactors Committee on Nuclear Science, National Research Council, "Survey of Research Reactors," 1970, Box 252, Folder 2, Plum Brook Archives.

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sities (North Carolina State, Penn State, MIT, etc.), private industry (Westinghouse, General Electric, etc.), and the military. In 1961, the year that the Plum Brook reactor went “critical” (meaning that it was ready to conduct research with a sustained nuclear reaction), there were 120 nuclear research and test reactors in operation in the United States. At 60 megawatts of power, the Plum Brook facility (along with its 100-kilowatt mock-up research reactor) was the second most powerful test reactor in the country, at the time second only to the Engineering Test Reactor at the National Reactor Testing Station near Idaho Falls, Idaho. Worldwide, only the Soviet Union, Britain, and Canada possessed more powerful test reactors than Plum Brook before it went critical.⁶

The World’s Most Powerful Test Reactors prior to June 1961⁷

Rank	Country	Reactor	1st Criticality	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 1956	70,000
5	Soviet Union	27/BT	1 Jan 1961	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

The Plum Brook Reactor Facility was important not just for its power capabilities, but even more so for its neutron flux. Plum Brook could pass 420 trillion neutrons per second through an area of one square centimeter.⁸ Only the Engineering Test Reactor in the United States had a neutron flux equal to that of Plum Brook. Earl Boitel, an engineer at the reactor, said, “The Plum Brook Reactor was designed such that it could enable you to expose materials to very, very high radia-

⁶ The Plum Brook reactor went critical at low power on 14 June 1961. Harold W. Giesler, Harry J. Reilly, and William A. Poley, “Low-Power Tests of the Plum Brook Reactor,” February 1963, Box 252, Folder 14, Plum Brook Archives.

⁷ Data compiled from International Atomic Energy Agency, “Nuclear Research Reactors in the World,” <http://www.iaea.or.at/worldatom/rrdb/>. Accessed June 2002.

⁸ Hugh Murray (Nuclear Experiments Section), “Comparison of PBR Fast Flux with that Obtained in Other Reactors,” 25 June 1963, Box 252, Folder 4, Plum Brook Archives.

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tion levels—high radiation fluxes . . . Experiment sponsors from around the country came to the Plum Brook Reactor because of this ability.”⁹ This was one of the key factors that made the Plum Brook reactor such an important research facility. Boitel said that comparable fluxes were not possible at other reactors, and for the few that could equal or better this performance (Engineering Test Reactor or Dounreay), the sponsors had to wait so long in line to get their experiments run that they almost became outdated before researchers could complete the tests.

The wait to perform experiments with radiation demonstrated the growing demand for research reactors after World War II. These facilities evolved quickly because the United States and other emerging nuclear powers believed that they would play a key role in developing more massive nuclear weapons and propulsion systems. One observer wrote, “After the war, the development of reactors, with their ability to produce neutrons in unheard-of quantities, even *beams* of them, promised to revolutionize nuclear physics, solid-state physics, and any field in which radioisotopes could be used.”¹⁰ In an age of increasing specialization, both professional and technological, the research and test reactors became unusually versatile instruments. In 2005 the Nuclear Regulatory Commission stated that these reactors made significant experimental contributions to almost every scientific discipline, including physics, chemistry, biology, medicine, geology, archeology, and the environmental sciences.¹¹

The neutron flux became a basic science tool for a wide range of disciplines. Nuclear physicists used reactors’ neutrons to help understand subatomic behavior. Solid-state physicists and chemists used neutrons to discover the properties of matter and materials. Biologists and physicians used neutrons to study radiation’s effect on tumors and organic tissues. Engineers used neutrons to design better nuclear reactors and electrical components. Environmentalists and geologists used a powerful technique called “neutron activation analysis” to measure trace elements like pollutants in air, water, and soil. But it was in the area of nuclear propulsion and nuclear rockets where some scientists and aerospace engineers believed that research and test reactors would make the greatest contribution.¹² Nuclear engineers

⁹ Interview with Earl Boitel, 22 January 2002.

¹⁰ Robert P. Crease, *Making Physics: A Biography of Brookhaven National Laboratory, 1946–1972* (Chicago and London: The University of Chicago Press, 1999), pp. 11, 153.

¹¹ “Fact Sheet on Research and Test Reactors,” U.S. Nuclear Regulatory Commission, found at www.nrc.gov/reading-rm/doc-collections/fact-sheets/research-reactors.html. Accessed 11 May 2005.

¹² L. Kowarski, “Report on Research Reactors,” in *Nuclear Reactors for Research*, ed. Clifford K. Beck (Princeton, NJ: D. Van Nostrand Company, Inc., 1957), p. 3–27. L. D. P. King, “What a Reactor Can Be Used For,” *Nucleonics* (April 1954): 11.

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required a tremendous amount of research in order to make nuclear rockets a reality. Government support of facilities like NASA's Plum Brook nuclear reactor promised to make the dream of a nuclear rocket possible, as long as it received long-term political support.

The Changing Politics of Flying Reactors

In 1955 the National Advisory Committee for Aeronautics (NACA) began designing Plum Brook to help support the goal of a nuclear airplane with a nuclear test reactor to enable engineers to conduct materials testing. The advantages of having nuclear propulsion for an airplane were numerous. Most importantly, in an era before ICBMs and conventionally fueled planes that could circumnavigate the globe, a nuclear airplane promised the first chance for the American military to fly from the United States, drop bombs over the Soviet Union, and then return home. But technical and environmental problems overwhelmed the political and military potential of this program. Although John F. Kennedy helped to inspire the dream of nuclear rockets, ironically he also terminated the research program Plum Brook was originally intended to carry out. Kennedy suspended the nuclear airplane program in March 1961, after over \$1 billion and 15 years of work. Less than 3 months before the reactor was to start operation, Plum Brook's main research program lost its political support. The public perceived nuclear airplanes as too costly and dangerous, and chemical fuels began providing many of the advantages once thought possible only with nuclear propulsion. This would be the first time that politics dramatically shaped the future of Plum Brook's scientific work. It would not be the last.

Although the government had terminated the nuclear airplane program, Plum Brook and the research potential of its neutron flux still represented a valuable capability. Just 20 days before the Plum Brook reactor began experimentation, in May 1961, Kennedy delivered his famous "Urgent National Needs" speech before a joint session of Congress. He talked about his dream of putting a man on the Moon, but he also talked about pushing the envelope further into the solar system itself. This, he believed, could be done only with a nuclear rocket.¹³ Although government and industry organizations would become involved in the nuclear rocket program, Plum Brook became one of the primary centers for conducting experimentation on materials and devices for the project. A great deal of research had to be done to

¹³ John F. Kennedy, "Urgent National Needs," 25 May 1961 (Washington: Department of State, 1961). For an excellent history of the nuclear rocket see James Dewar, *To the End of the Solar System: The Story of the Nuclear Rocket* (Lexington, KY: University of Kentucky Press, 2004).

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develop nuclear propulsion systems and atomic batteries. Scientists and engineers also needed to learn how various materials would respond to radioactivity over time. Plum Brook's powerful neutron flux facility promised to be an essential experimental test site for this research.

The motivation behind this program was political as well as scientific because America was in a "race" to accomplish its goal. Politically this was the era of the Cold War and was shaped by the real and imagined U.S. confrontation with the Soviet Union and the ideological struggle between capitalism and communism.¹⁴ Nuclear capability represented one component of this conflict and was one way to evaluate who was winning the race between the two nations. A month and a half prior to Kennedy's "Urgent National Needs" speech the Soviet Union had achieved its latest visible scientific and engineering success, when Yuri Gagarin became the first human to orbit the Earth. In 1957 the Soviets had also placed the first unmanned satellite into orbit when they launched Sputnik. It appeared to observers in the West that the Soviet scientists and engineers might be amassing not only the technology and skill to dominate space, but also the world.

An important element of this Soviet potential was the opening in 1956 of a facility called "27/BM," a massive research reactor at the Institute of Physics & Power Engineering. Five years later the Soviets finished construction on SM-3, with a 5,000-trillion neutron flux. Just months after Plum Brook went critical, the Soviets also opened another test reactor with the largest neutron flux capability in the world. The Scientific and Research Institute of Atomic Reactors operated this 100,000-megawatt facility, and it had the potential of producing ten times the neutron flux possible at Plum Brook. The Soviet nuclear research capability, as well as rumors that had been circulating for years about its possible nuclear airplanes, left Americans increasingly concerned. The Moon and the universe beyond represented a second chance to redeem the American scientific and space initiative and secure a symbolic and potentially strategic victory on a new frontier. But many questions needed to be answered. For example, what type of energy source could be used to propel astronauts to the Moon and sustain their life systems while on the surface? The answer, according to some, was nuclear power. One nuclear scientific journal promised, "Nuclear rockets will get him there . . . Nuclear rockets will sustain him there."¹⁵

The Plum Brook reactor was completed and went critical just in time to play a role in Kennedy's vision for the future. The 11 years of nuclear research conducted

¹⁴ Walter LaFeber, *America, Russia, and the Cold War, 1945-1996*, 8th ed. (New York: McGraw-Hill Companies, Inc., 1997).

¹⁵ "Special Report on Nuclear Energy in Space," *Nucleonics* (April 1961).

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at Plum Brook's reactor facilities provided important insights into irradiated materials and helped increase the American nuclear knowledge base. However, nuclear power was not the propulsion of choice for the Apollo program, and the Nixon administration eventually recoiled from taking long-term financial risks in space and implemented a reduced, flat budget. These cuts forced NASA to shut down the entire Plum Brook facility because the government no longer supported work on nuclear rockets.¹⁶ This announcement devastated the 700 NASA scientists and engineers who suddenly lost their jobs. They first learned of the plans to shut the reactor down at noon on 5 January 1973, when Bruce Lundin, director of NASA's Lewis Research Center in nearby Cleveland, Ohio, called them all into the Plum Brook auditorium and told them about the nation's new post-Apollo vision for space. This vision included a new initiative called the Space Shuttle, but not a nuclear rocket. Without a nuclear rocket there was no need for NASA's only large-scale nuclear test reactor. The closure was to take place immediately.¹⁷

The government had spent nearly \$120 million constructing the various facilities at Plum Brook (see Appendix D). This included over \$15 million for the reactor, \$30 million for the Space Power Facility, \$14.5 million for a spacecraft propulsion research facility, \$6 million for a hypersonic tunnel facility, \$.5 million for a cryogenic propellant tank laboratory, and \$50 million for other capital improvements and research facilities. After the Lundin announcement all of these facilities, including the reactor, were going to be shut down.¹⁸

The stunned and dejected Plum Brook employees returned to their reactor in a somber mood. They felt like they were witnessing the reactor's funeral, and yet there they were inside a facility that continued to operate at peak performance. It was still conducting the same experiments that earlier that morning the engineers thought were vital to the national space program. That afternoon they gathered together in the control room and shut the reactor down for the final time. One Plum Brook engineer recalled, "That was a very traumatic experience. There were a lot of tears in people's eyes."¹⁹ Lundin described his own reaction: "You suffer a shock that you can't quite believe it, a feeling of pain and anguish, of course, and then you lick your

¹⁶ Harold M. Schmeck, Jr., "NASA Cuts Programs to Save \$200 Million in Current Budget," *New York Times* (6 January 1973): 11.

¹⁷ Bruce Lundin, audiotaped Shut Down Speech, 5 January 1973, Plum Brook Archives.

¹⁸ "Plum Brook Station Research Facilities," 10 January 1986, Box 106, Folder 1, Plum Brook Archives.

¹⁹ Interview with Earl Boitel, 22 January 2002.

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wounds for a day or two.”²⁰ It took 6 months for the reactor to be safely sealed up in what was called a “mothball” condition, and it remained vacant for nearly 25 years. As the engineers began looking for other jobs, they lamented that one of the most powerful test reactors in the world, with one of the highest neutron fluxes, was closed in the midst of some of its most important experimental cycles. Ironically, Oldreive’s fictional world from his science fiction novel *Hot Lab* had become a reality. Much like his character Richard Rendfel, Oldreive likely speculated: Would anyone even care if Plum Brook never reopened?

A Commitment to Science

This book traces the history of Plum Brook and examines the relationship between government support and the success of long-term basic science. It is devoted to more than just the intricacies of nuclear experimentation. The Plum Brook reactors were in operation for just over a decade, and this book reflects the extraordinary effort that spanned four other decades to conceive, build, suspend, maintain, and demolish those reactors.

The story begins when the government first appropriated the Plum Brook land from local Ohio farmers to use as an ordnance works during World War II (Chapter 1). Then, in the 1950s, NACA (NASA’s predecessor organization) decided to construct a test reactor on these lands and use it for research on nuclear airplanes (Chapter 2). When national goals shifted from a nuclear airplane to a nuclear rocket, the Plum Brook reactor and its nuclear facilities remained a vital tool of basic research in support of the nuclear rocket or NERVA program (Chapter 3). Scientists and engineers commenced their experimental program at Plum Brook in the 1960s, using the reactor’s radiation to test materials and power systems for space and environmental applications (Chapter 4). Several of the appendices expand upon some of the technical and scientific details associated with nuclear experimentation (Appendices A-C). One problem in operating this reactor was its proximity to rural residential communities, and health physicists carefully established precautions to help prevent the possibility of accidents and ensure the safety of the population (Chapter 5). Even its excellent safety record could not prevent rumors of dangerous radiation escaping into the air and water around Plum Brook, and the fears of increased deaths and incidence of cancer.²¹

Despite efforts to produce valuable experimental results and protect the public,

²⁰ Bruce Lundin, audiotaped Shut Down Speech, 5 January 1973, Plum Brook Archives.

²¹ Tim Sowecke, “Radiation-Death Claim Repeated,” *Sandusky Register* (26 July 1973): 1.

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the government shut Plum Brook down in 1973 before it was able to conclude much of its research (Chapter 6). The reactor lay dormant for nearly a quarter-century before the Nuclear Regulatory Commission finally decided to decommission and tear down the reactor, a project that continues today (Chapter 7). When the decommissioning team finishes its work, it will cost ten times more to dismantle the reactor (low estimates are between \$150 million and \$160 million for ongoing work) than it did to construct it (\$15 million), and the effort to demolish it will last nearly as long as the time the reactor was operational.²² Had NASA decided to decommission the reactor in 1976 it would have cost the government only \$1.2 million.²³ This story of the cost of nuclear cleanup and the time required to safely dispose of it is an important one in our nuclear past.²⁴

The history of the Plum Brook reactor is important for several reasons. First, there has been virtually no historical analysis of the development of research and test reactors in the United States. The twentieth century represented the beginnings of the atomic age, and various histories have explored its cultural, scientific, and political meanings. The “atoms for war” authors tell about the development of the bomb, the Manhattan Project, the Cold War arms race, nuclear fear, and political negotiation of atomic weapons reduction. The “atoms for peace” authors discuss the rise of the Atomic Energy Commission (AEC), the emergence of nuclear energy, the fight of antinuclear protestors, the environmental movement, and the concern over accidents at places like Three Mile Island. One story about the twentieth century’s atomic age has not been told: the use of nuclear reactors for basic research in science and technology. Today there are 36 research and test reactors in operation in the United States; 5 more are in a “possess but do not operate mode,” and another 13 are in the process of being decommissioned.²⁵ Two of these in-process decommissioning reactors are at Plum Brook.

Because nuclear reactors that produce electricity often generate significant environmental controversy, they are often confused with research reactors. Research

²² Reactor costs found in AEC, “Quarterly Report on Status of Reactor Construction,” 7 November 1961, Box 1, Folder 5, Plum Brook Archives. “New Reactor Started in Ohio,” *New York Times* (18 July 1963): 16. John Mangels, “NASA to Dismantle Two Ohio Reactor Devices at Plum Brook,” *The Plain Dealer* (30 October 1999): 11B.

²³ “Review of Plum Brook Station Standby Statutes,” (28 September 1976), Box 106, Folder 3, Plum Brook Archives.

²⁴ Michael D’Antonio, *Atomic Harvest: Hanford and the Lethal Toll of America’s Nuclear Arsenal* (New York: Crown Publishers, Inc., 1993), p. x1.

²⁵ “Fact Sheet on Research and Test Reactors,” U.S. Nuclear Regulatory Commission, found at www.nrc.gov/reading-rm/doc-collections/fact-sheets/research-reactors.html. Accessed 11 May 2005.

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reactors have nothing to do with power generation. They are in fact a research tool comparable to other tools used in basic engineering and scientific research. Although these reactors do sometimes appear in the official histories of national laboratories like Brookhaven, Argonne, and Oak Ridge, they are a sidelight to the story of the institutions that built them. One history of Los Alamos fails to mention the subject of research reactors at all.²⁶ While the Plum Brook history is a study of only one test reactor and one research reactor, it is hoped that it will reveal important elements common to similar types of reactors and stimulate further interest in the subject. And the subject of our nuclear past is one that is now becoming more interesting to scholars. For example, Gabrielle Hecht's award-winning *The Radiance of France* (1998) and Paul R. Josephson's *Red Atom* (2000) describe the nuclear histories of France and Russia.²⁷ Ignoring the research and testing reactors has left a void in our understanding of our nuclear past.

Second, the Plum Brook story is important because it describes a culture of scientists and engineers on the frontier of an emerging science. According to Howard E. McCurdy, "The frontier mentality is very much a part of NASA's technical culture."²⁸ This mentality in many ways defined the experience for the scientists and engineers who also worked at NASA's largest nuclear reactor. Plum Brook Facility Chief A. Bert Davis said, "We were young and eager and we felt like we were pushing back the frontiers of science."²⁹ The Plum Brook reactor became the home of NASA's nuclear frontier—the boundary between what was known and unknown about the effects of radiation on materials and the performance of devices. Taming a frontier requires long-term support, commitment, patience, and cultivation. Without it no scientific pioneer can survive.

The design of the Plum Brook reactor began as a NACA government project, the precursor to NASA. The NACA culture was one that preferred taking on complex tasks in-house, with limited use of contractors (NASA emerged in 1958 out of the demise of NACA, though it did not continue its model of in-house research over

²⁶ Jo Ann Shroyer, *Secret Mesa: Inside Los Alamos National Laboratory* (New York: John Wiley & Sons, Inc., 1998).

²⁷ Gabrielle Hecht, *The Radiance of France: Nuclear Power and National Identity after World War II* (Cambridge, MA: MIT Press, 1998). Paul R. Josephson, *Red Atom: Russia's Nuclear Power Program from Stalin to Today* (New York: W. H. Freeman and Company, 2000).

²⁸ Howard E. McCurdy, *Inside NASA: High Technology and Organizational Change in the U.S. Space Program* (Baltimore and London: Johns Hopkins University Press, 1993), p. 72.

²⁹ Interview with A. Bert Davis by Mark D. Bowles, 27 February 2002.

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contractors).³⁰ The responsibility to build the Plum Brook reactor fell upon the shoulders of the Lewis Research Center's scientists and engineers, who had little to no nuclear experience. Engineers like Sam Kaufman, Benjamin Pinkle, and Alan "Hap" Johnson scoured the non-secret nuclear engineering textbooks to literally teach themselves how to build a reactor. They helped create not only one of the world's largest nuclear facilities, but also a place with a thriving organizational culture. The successful operation of Plum Brook was due to the round-the-clock work by hundreds of scientists, engineers, administrators, safety officers, technicians, and maintenance crew who devoted 15 years of their lives to their work. They were able to transform a remote piece of government land into an active research center and used the reactor's neutrons for a variety of experimental purposes, most importantly the nuclear rocket program. That nearly all of these workers had to cease work, relocate their families, and find other employment in a matter of a few months reminds us all that there is a human side to every policy decision.

Finally, the Plum Brook story is significant because it reveals an essential truth about the scientific process. Basic science requires commitment: it requires the commitment of scientists and engineers who are willing to invest their lives and careers into their research; it requires the commitment of time to allow for uncertain speculation and experimentation into new frontiers of research; it requires the commitment of tolerance to accept false starts and missteps; and it requires a political commitment that has the patience and the funding to see what was started appropriately concluded. Without these areas of commitment, the value of basic science and research goes unrealized. The Plum Brook story demonstrates what happens when political conditions change and commitment evaporates, revealing the Achilles heel of government funded science. It becomes *science in flux*.

This double entendre is intentional. "Science in flux" describes the history of the Plum Brook reactor in two ways. First, its scientific results came from the value of experimenting with its high-powered nuclear flux. "Flux" in this physics terminology relates to the rate of flow and the number of nuclear particles passing through a space. The Plum Brook reactor facilities used this flux to determine how materials would respond to a nuclear environment in space. But the Plum Brook nuclear science was ultimately in flux (as more commonly used to mean a state of change), not because of the merits of the scientific investigation, but instead because of a changing political climate, with its commitment to long-term space goals in flux.

It should be pointed out that the term "science" in the title of this book is deliberately used in the most general sense, e.g., systematized knowledge gained through

³⁰ "For Advancement of Space Travel," *Los Angeles Times* (4 June 1958): B4.

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testing or experimentation.³¹ Plum Brook was an engineering reactor that was built and operated not by scientists, but by engineers. Furthermore, one of the ultimate goals of NASA itself, building and flying a nuclear rocket, was far more of an engineering dream than a scientific one. As Vannevar Bush once said, "...when we sent the first astronaut to the moon, the press hailed it as a great scientific achievement. Of course it was nothing of the sort; it was a marvelously skillful engineering job."³² Plum Brook was like a wind tunnel, a huge test rig, or a giant experimental tool.³³ It was not, by contrast, similar to a university scientific research facility. Nevertheless, "science" appears in the title of the book. I am sure that many who have studied the shades of distinction between what scientists and engineers do will find fault with this terminology.³⁴ But "science" was chosen purposely to convey a concern for the larger pursuit of knowledge, and in this sense I allow science to subsume the pursuit of engineering knowledge as well. As a result, science (and engineering) in flux, along with the ramifications of this often unstable pursuit (for both the people involved and the infrastructure that supports them), is the central theme of this book. This theme is explored through the lens of the Plum Brook reactor.

U.S. Representative Charles A. Mosher, the local Sandusky, Ohio, Republican congressman, took great interest in the Plum Brook reactor. He served in Congress for 16 years, from 1961 to 1977, and was a strong advocate for the reactor as the ranking minority member of the Science and Astronautics Committee of the U.S. House of Representatives. He also served as the executive director of the House Science and Technology Committee.³⁵ In a private letter written after the reactor closed, he expressed his dismay over the lack of long-term commitment and vision to government-supported science. He wrote, "Among the major mistakes we make in government are our very wasteful, erratic ways of 'on and off,' firing up programs for short periods and then cooling them down. NASA's Plum Brook facility at Sandusky is a costly example of that." He argued that efficiency, cost control, and

³¹ *The Wordsworth Dictionary of Science and Technology* (Cambridge: Cambridge University Press, 1995), p. 789.

³² Vannevar Bush, *Pieces of the Action* (New York, 1970): 53-54.

³³ Correspondence with Virginia Dawson, author of the history of Lewis Research Center, *Engines and Innovation* (Washington, D.C.: NASA SP-4306, 1991).

³⁴ Edwin Layton, "Mirror Image Twins: The Communities of Science and Technology in 19th-Century America," *Technology and Culture* 12, no. 4 (October 1971): 562-580. Eugene S. Ferguson, *Engineering and the Mind's Eye* (Cambridge, Mass.: The MIT Press, 1993). Walter G. Vincenti, *What Engineers Know and How They Know It: Analytical Studies from Aeronautical History* (Baltimore and London: The Johns Hopkins University Press, 1990).

³⁵ Harry J. Lorber, "Mosher Says He Won't Run Again," *Sandusky Register* (12 December 1975).

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productivity in science required a stable and long-term commitment by government. Mosher concluded, "Persistence is imperative to the productive search for new knowledge . . . I suggest that all of human history proves the wisdom of investing generously, daringly, persistently in that vigorous search for new knowledge."³⁶

Plum Brook's engineers, local politicians, and NASA officials did all that they could to win back a commitment to continue research at the reactor. Even a last-ditch effort to redefine the reactor as an environmental test facility for the Environmental Protection Agency failed to materialize.³⁷ Because the government could not make a long-term commitment, Plum Brook lost its final opportunity to stave off its death sentence. Mosher questioned the wisdom behind this decision. Why construct a costly government facility, only to suspend its operations and release its workforce when the temporary political winds changed? Mosher predicted that the government would be restarting this work again in the 1980s, and by that point the over \$100 million invested in the Plum Brook infrastructure would be for naught. Mosher was correct that the political winds would once again support the efforts for nuclear propulsion, but this would not come until the new century.

Studying the importance of commitment is especially relevant today as the nation considers a new future of nuclear activity in space. It appears that Kennedy's goal of building nuclear rockets might have been a dream deferred, but not a forgotten vision. NASA in particular is once again revisiting the advantages of designing and constructing nuclear rockets for space exploration and an eventual voyage of humans to Mars. George W. Bush's administration has also outlined a new vision for NASA that includes a gradual phasing out of the Space Shuttle program in favor of future nuclear-powered voyages to the Moon and Mars.³⁸ Now that this historical topic of nuclear propulsion is relevant today, it offers us a chance to learn from past lessons. Perhaps the most important lesson is the necessity of establishing political continuity and support for any government-sponsored program in the basic sciences. If the nation once again explores the development of nuclear rockets, it should attempt to secure such a commitment, or else it will again risk wasting billions of taxpayer dollars and the skills of numerous scientists and engineers with little return on its scientific investment.

Thus the history of the Plum Brook reactor encompasses a significant yet mostly forgotten story of government's interaction with basic nuclear science in the last half

³⁶ Charles A. Mosher to Donald J. Pease, 3 February 1978, Box 106, Folder 15, Plum Brook Archives.

³⁷ George M. Low's testimony before the House Subcommittee on Manned Space Flight, 6 March 1973, Box 106, Folder 15, Plum Brook Archives.

³⁸ Jeffrey Kluger, "Mission to Mars," *Time* (26 January 2004): 43–50.

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of the twentieth century. It is a tale of nuclear research, political change, and the professional culture of the scientists and engineers who devoted their lives for over 15 years to the facility. It is a cyclical story of farmland giving way to gunpowder production in the 1940s, nuclear construction in the 1950s, research in the 1960s, standby from the 1970s through 1990s, and decommissioning today in NASA's "resident farmer scenario." Underneath the attempt to develop nuclear rockets, and the challenge to clean up the radioactive ruins from the site that housed the search, lies the story of one of the most powerful test reactors of its day. Its history reveals the perils, potentials, and challenges of that nuclear quest and science in flux.

Removing the Farmers

*I*n 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 20 years. He was a typical small farmer, raising cows, tending to his 120-tree apple orchard, and cultivating wheat, field corn, soybeans, squash, tomatoes, cabbage, potatoes, and alfalfa. He and his family lived near his fields in an idyllic country residence consisting of a two-story brick, slate-roof home with ten rooms, a bath, running water, electricity, and hardwood floors. Near the house were two large frame barns with a silo. Additional structures on his property included a milk house, a chicken coop, a stone hog pen, a two-car garage, and various equipment sheds. The entire area was surrounded by several acres of beautiful shade trees, with a babbling stream named Plum Brook running through the center. Although Baum's farm was a thriving enterprise providing a good living for his family, his crops were about to be destroyed, buildings razed, and livestock slaughtered. It was not an act of nature that destroyed the Baum



A Plum Brook farming family on the front porch of their house. c. 1930s. Courtesy of Henry Pfanner.

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farm, but an act of government. The United States acquired his property in the name of military preparation for World War II. For compensation the government's land agents offered the Baum family \$18,375 and ordered them to vacate immediately.¹

It was on lands like these that a conflict between the U.S. military/industrial complex and its agricultural community occurred throughout the country in 1941. The tension began when the government exercised its power of eminent domain and forced over 150 Ohio farming families, including the Baums, to sell 9,000 acres of land. With war spreading throughout Europe, American political and military leaders began to prepare the United States for the material demands of conflict. Those military needs were supplied in large part by 77 ordnance factories built throughout the country, primarily on the lands of farmers. In the span of just a few months in the spring of 1941, land agents took possession of 44 million acres of land (roughly the size of all the New England states) formerly owned by private citizens. Baum's farm became the future home of the Plum Brook Ordnance Works.

In May 1943, in the midst of World War II, Ohio Congressman Alvin F. Weichel reflected upon the dramatic transition that this land had undergone. He reminisced about what the area had been like before the government transformed it into a munitions factory. He said, "Just about two years ago, this very ground was a peaceful countryside and one of the garden spots of America." For decades farmers had measured the worth of this land by the production of apples, crops, and livestock. Preparations for war imposed a harsh new reality. In a matter of months, the government acquired it, cleared it of farms, and transformed it into a massive industrial war production site. This transformation, according to Weichel, demonstrated the virility of America itself, whose strength was measured by Plum Brook's "huge quantities of lethal products which it pours forth . . . to bring destruction and dismay to the enemies of our beloved country."²

This chapter explores the government's effort to transform the Plum Brook land by removing the resident farmers and building a massive ordnance works that became one of the three largest suppliers of trinitrotoluene (TNT) for the United States (producing nearly one billion pounds for World War II). Although it devastated the farmers, the Plum Brook Ordnance Works was successful because the government had a specific need for the land as well as a political commitment to

¹ Fred Baum petition, 29 October 1941, 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).

² Congressman Weichel, quoted in "Colorful Ceremony Marks Presentation of Honors to Plum Brook Employees," *Sandusky Star Journal* (1 May 1943).

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keep the facility operating until the nation achieved its military goals. This is a story of a clearly defined government mission, a national need, and the commitment to see its goals achieved. The scientists who later inhabited these same lands with a mission to carry out basic nuclear reactor research for the government would not be as fortunate.

Enforced Migration

Several Native American tribes originally populated the Plum Brook region, including the Erie (from which the county where Plum Brook is located takes its name), Wyandotte, Ottawa, Chippewa, Delaware, Seneca, and the Iroquois Confederacy. The first white men to venture into the territory were French traders, who transferred their claim to the land to Great Britain in 1763. However, after the U.S. victory in the Revolutionary War, ownership passed to the fledgling American nation. The Erie County land initially belonged to the state of Connecticut, which called it its “Western Reserve.” Connecticut citizens who had lost their homes during the war to the torches of British soldiers were rewarded with new land in this reserve. The land came to be known as the “Fire Lands” or “Sufferers’ Lands.”³ Ironically, there was another reason that these were the Firelands. Native Americans would burn the entire prairie each spring to help rejuvenate the lands. This caused new grasses to grow and brought migrating deer and elk from 100 miles away to eat the rich vegetation.⁴ As one early pioneer named Ruth recalled in 1839, the first settlers found fertile land and “fine fields free from timber.”⁵ Because of the “annual fires of the Indians,” these fields became an ideal place to farm.

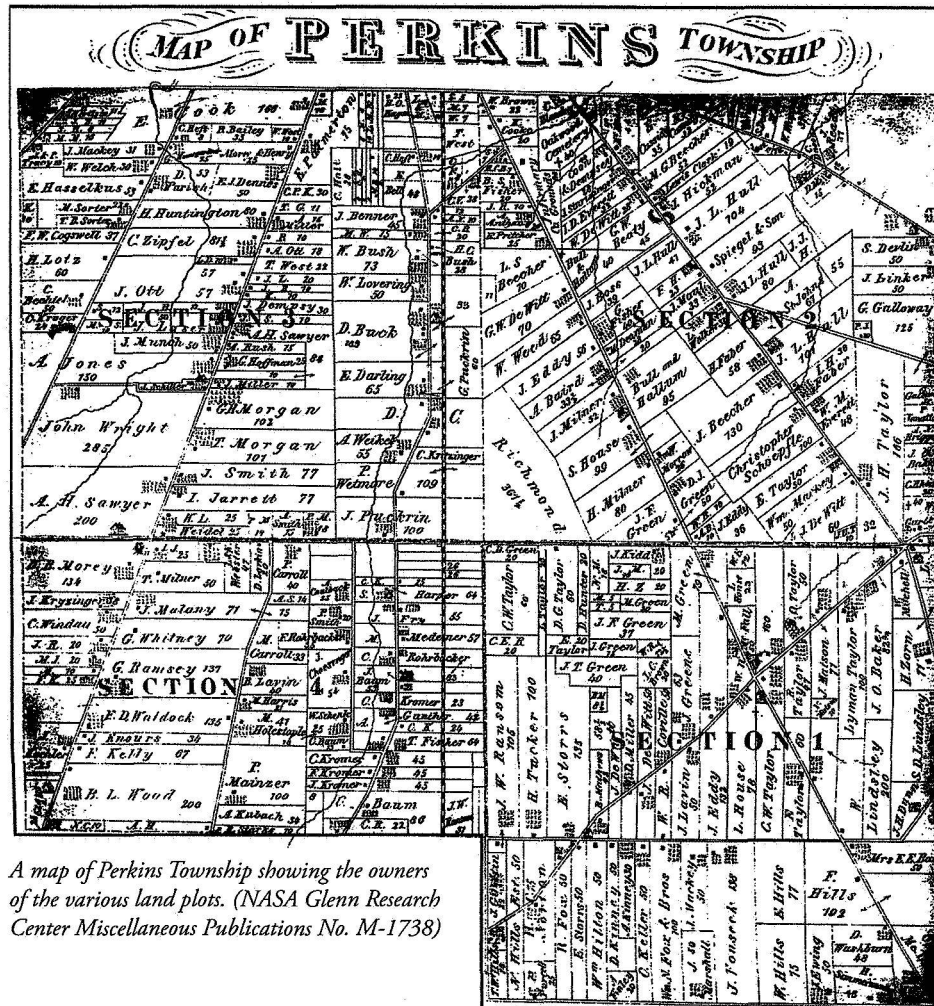
However, the government did not immediately award land to these Revolutionary War families from Connecticut. It was not until the 1820s, two generations later, that the tracts became available. Nearly all of those who were given lands sold off their property to speculators who quickly settled the area. In 1838 settlers established Erie County, 25 years after Ohio had become a state, and the city of Sandusky became an important commercial area in the center of what was then the western part of the United States. The Erie Canal linked the industrialists to both Lake Erie

³ Elisha Whittlesey, Address given before the Fire Lands Historical Society, 1857, *The Fire Lands Pioneer* (June 1858): 18.

⁴ Interview with John Blakeman by Virginia Dawson, 26 September 2002.

⁵ Ruth, “Scattered Sheaves,” *The Fire Lands Pioneer* (September 1860): 3.

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A map of Perkins Township showing the owners of the various land plots. (NASA Glenn Research Center Miscellaneous Publications No. M-1738)

and the Hudson River and made northern Ohio accessible to East Coast markets.⁶

Diverse peoples came to the area. The first to settle were the Puritans and the Congregationalists from Connecticut. What these settlers found were great prairie lands. Most of Perkins Township was covered with tall grasses and 6-foot wildflowers. To their pleasant surprise, once they cut back the grasses and plowed the land, they found soil richer than any they had ever seen before. Compared with the rocky

⁶ Soil Survey of Erie County, Ohio, February 2002 Interim Report, found at <http://www.ohiodnr.com/soilandwater/soils/soilsurveys/ErieInterimReport.pdf>. Accessed on 30 May 2003.

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soils that made farming a challenge in New England, the Firelands were a farmer's dream come true.⁷

Nearly all of those who settled in this area farmed the land. The careful tending of the soil and crop rotation improved its quality, and successive generations of families remained on the same plots of land for over 100 years.

While the succeeding generations of farmers continued to cultivate this land, tremendous military, political, and industrial changes transformed the nation. The mobilization efforts for World War I had presented extremely difficult logistical problems for American industry.⁸ Those who tried to ready the nation for war did so without knowing what production facilities were at their disposal. There was no single agency in charge of preparing the wartime inventory, and "more than 150 War Department purchasing committees were competing with each other for scarce supplies in the open market."⁹ Without central control of production, soldiers in the field soon realized that they often had too much of one interlocking part and not enough of another.¹⁰ It was not until 1918 that the United States attempted to balance the production of parts. In the meantime American troops in Europe often had to obtain missing supplies from France and Britain to make up for the haphazard shipment of weapons from home.¹¹

Although little could be done during World War I to solve this problem, after the war the government vowed never to find itself in a similar situation, and in 1920 the National Defense Act was passed. This reorganized the War Department and gave control to the assistant secretary of war to coordinate all arms production, so that the various military branches would never again compete with each other for supplies. The Ordnance Department itself was part of a larger supply chain for the American military. Other departments, prior to World War II, included the Air Corps, the Chemical Warfare Service, the Quartermaster Corps, and the Signal Corps. After World War I the Ordnance Department maintained a relationship with industrial

⁷ Interview with John Blakeman by Virginia Dawson, 26 September 2002.

⁸ Kimberly L. Kane, *Historic Context for the World War II Ordnance Department's Government-Owned Contractor-Operated (GOCO) Industrial Facilities, 1939–1945* (U.S. Army Corps of Engineers, 1995).

⁹ James E. Hewes, Jr., *From Root to McNamara: Army Organization and Administration, 1900–1963* (Washington, DC: Center of Military History, U.S. Army, 1975), p. 29.

¹⁰ Constance McLaughlin Green, Henry C. Thomson, and Peter C. Roots, *The Ordnance Department: Planning Munitions for War* (Washington, DC: Center for Military History, United States Army, 1955), p. 25.

¹¹ Gregory Hooks, *Forging the Military-Industrial Complex: World War II's Battle of the Potomac* (Urbana: University of Illinois Press, 1991), pp. 76–77.

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contractors, preserved weapons-making knowledge, and planned how future plants could be constructed should a world war ever come again.

Despite the planning, by 1940 the nation felt ill prepared for a new conflict. Secretary of War Henry L. Stimson recalled that the United States lacked even the basic raw materials to go to war, especially explosive powder. He recalled, "We didn't have enough powder in the whole United States . . . for anything like a day's fighting. And, what is worse, we didn't have powder plants or facilities to make it; they had all been destroyed after the last war."¹² In 1941 the Office of Production Management published a report titled "An Appeal to Every American Manufacturer," discussing the industrial wartime needs of the nation and lamenting the atrophied munitions production capability. It stated, "For more than 20 years the Nation concentrated its energies and genius for mass production upon the output of automobiles, ice boxes, radios, and a thousand and one other useful peacetime products—the fruit of a free and vigorous democracy. Our facilities for making munitions dwindled to an insignificant level."¹³

The United States Ordnance Department responded by establishing 77 facilities to supply ordnance (weapons, ammunition, vehicles, tools, and equipment) for the U.S. Army, Navy, Coast Guard, Marines, and 43 allied nations.¹⁴ Although the government owned all of these sites, contractors actually operated them; thus they were designated by the acronym GOCO (government-owned contractor-operated). These facilities were of two types: plants and works. The 43 "plants" existed to fabricate and assemble materials such as tanks, guns, and small-arms ammunition. The 34 "works" developed basic materials for production, such as powder, explosives, and chemicals. The government built all 77 facilities in a remarkably short period of time from August 1940 (marking the beginning of construction of Chickasaw Ordnance Works) to November 1942 (the beginning of construction of the Detroit Cup Plant).

¹² Henry L. Stimson, "America is Ready," *Army Ordnance Magazine*, XXIV, No. 137 (March–April 1943), 275. Ralph Elberton Smith, *The Army and Economic Mobilization* (Washington, DC: War Department, 1959), p. 437.

¹³ "Defense Contract Service: An Appeal to Every American Manufacturer," Folder 1, Box 6, Harold H. Burton Papers, Mss. No. 3828, Western Reserve Historical Society.

¹⁴ Levin H. Campbell, Jr., *The Industry-Ordnance Team* (New York: McGraw-Hill, 1946), p. 33.

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Seventy-seven Government-Owned, Contractor-Operated Ordnance Works Constructed During World War II¹⁵

Construction Date	Facility Name	Construction Date	Facility Name
Aug 1940	Chickasaw Ordnance Works	Nov 1941	Jayhawk Ordnance Works
Sept 1940	Detroit Tank Arsenal	Nov 1941	Oklahoma Ordnance Works
Oct 1940	Baytown Ordnance Works	Dec 1941	Kings Mill Ordnance Plant
Oct 1940	Indiana Ordnance Works	Jan 1942	Keystone Ordnance Works
Oct 1940	Radford Ordnance Works	Feb 1942	Lake Ontario Ordnance Works
Oct 1940	Ravenna Ordnance Plant	Feb 1942	Longhorn Ordnance Works
Nov 1940	Kankakee Ordnance Works	Feb 1942	Nebraska Ordnance Plant
Dec 1940	Elwood Ordnance Plant	Feb 1942	Wabash River Ordnance Works
Dec 1940	Gadsden Ordnance Plant	Mar 1942	Buckeye Ordnance Works
Jan 1941	Iowa Ordnance Plant	Mar 1942	Badger Ordnance Works
Jan 1941	Kingsbury Ordnance Plant	Mar 1942	Dickson Gun Plant
Jan 1941	Lake City Ordnance Plant	Mar 1942	Ozark Ordnance Works
Jan 1941	Morgantown Ordnance Works	Mar 1942	Pennsylvania Ordnance Works
Jan 1941	Weldon Spring Ordnance Works	Mar 1942	West Virginia Ordnance Works
Feb 1941	Denver Ordnance Plant	Apr 1942	Bluebonnet Ordnance Plant
Mar 1941	New River Ordnance Plant	Apr 1942	Cornhusker Ordnance Plant
Mar 1941	Plum Brook Ordnance Works	Apr 1942	Green River Ordnance Plant

¹⁵ Chart from Kane, *Historic Context for the World War II Ordnance Departments*, p. 45. "OP" refers to "Ordnance Plant" and "OW" refers to "Ordnance Works."

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Construction Date	Facility Name	Construction Date	Facility Name
Mar 1941	Redstone Ordnance Plant	Apr 1942	Kentucky Ordnance Works
Mar 1941	St. Louis Ordnance Plant	Apr 1942	Pilgrim Ordnance Works
Mar 1941	Wolf Creek Ordnance Plant	Apr 1942	Sangamon Ordnance Plant
Apr 1941	Hoosier Ordnance Plant	May 1942	Allegheny Ordnance Plant
May 1941	Alabama Ordnance Works	May 1942	Evansville Ordnance Plant
May 1941	Coosa River Ordnance Plant	May 1942	Lowell Ordnance Plant
May 1941	Ohio River Ordnance Works	May 1942	Milwaukee Ordnance Plant
Sept 1941	Arkansas Ordnance Plant	May 1942	New York Ordnance Works
Sept 1941	Kansas Ordnance Plant	May 1942	Oak Ordnance Plant
Sept 1941	Lone Star Ordnance Plant	May 1942	Pantex Ordnance Plant
Sept 1941	Louisiana Ordnance Plant	May 1942	Vigo Ordnance Plant
Sept 1941	Maumelle Ordnance Works	Jun 1942	Cactus Ordnance Works
Sept 1941	Utah Ordnance Plant	Jun 1942	Gulf Ordnance Plant
Oct 1941	Des Moines Ordnance Plant	Jun 1942	Scioto Ordnance Plant
Oct 1941	Dixie Ordnance Works	Jul 1942	Gopher Ordnance Works
Oct 1941	Illinois Ordnance Plant	Aug 1942	Eau Claire Ordnance Plant
Oct 1941	Mississippi Ordnance Plant	Aug 1942	Holston Ordnance Works
Oct 1941	Missouri Ordnance Works	Aug 1942	Sunflower Ordnance Works
Oct 1941	Twin Cities Ordnance Plant	Nov 1942	Cherokee Ordnance Works
Oct 1941	Volunteer Ordnance Works	Nov 1942	Detroit Cup Plant
Nov 1941	East Tennessee Ordnance Works		

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Each of these facilities required many thousands of acres for its specialized military production, and thus the entire mobilization effort hinged upon the acquisition of land. Prior to World War II the American government owned roughly two million acres within the continental states. By the end of the war it had acquired nearly 44 million additional acres, or 72,000 square miles.¹⁶ What made this acquisition process so difficult was that very little of it existed in the public domain. Private citizens owned the vast majority of the lands, which the government had to purchase or condemn.¹⁷ Although some of the land was leased, the government paid \$360 million for nearly six million acres (roughly the size of Massachusetts). One report estimated that “Thousands of families lost their land and entire communities were eradicated.”¹⁸ Midwestern farmers were the group most affected.

Although the acquisition policy was to take little used cropland or unused wasteland first, areas designated especially for ordnance works required valuable farmland that was in close proximity to larger cities. Farmland in the Midwest was an attractive option for the government because it was located away from the ocean coasts and the Mexican and Canadian borders. These interior locations helped safeguard against ground invasion. Moreover, the characteristics that made the land itself attractive to farmers were the same qualities that made it good for industrial production—level ground, a plentiful water supply, and access to railways and roads. Farmers were often forced off land that had been worked by the same family for multiple generations. The prospect of starting over somewhere else was inconceivable to many of them, and a great many of these displaced farmers left under protest, never again to work in agriculture. One historian has argued that this was a significant factor in the 17 percent reduction in U.S. farmland during World War II.¹⁹

The purchase of this land was an extremely difficult and emotional saga for those involved. One official War Department history documented the farmers’ plight and stated, “The emergency acquisition of land was accompanied by hardship and confusion not ordinarily experienced in peacetime.”²⁰ Farmers and landowners of this

¹⁶ U.S. Department of Agriculture, Bureau of Agricultural Economics, *Acquisition and Use of Land for Military and War Production Purposes, World War II* (War Records Monograph 5, August 1947), p. 5. Smith, *The Army and Economic Mobilization*, p. 441.

¹⁷ L. Fine and J. A. Remington, *The Corps of Engineers: Construction in the United States* (Washington, DC: Office of the Chief of Military History, United States Army, 1972), p. 510.

¹⁸ Kane, *Historic Context for the World War II Ordnance Departments*, p. 188.

¹⁹ Gerald D. Nash, *The Great Depression and World War II: Organizing America, 1933–1945* (1979). M. C. C. Adams, *The Best War Ever: America and World War II* (Baltimore: Johns Hopkins University Press, 1994), p. 119.

²⁰ Smith, *The Army and Economic Mobilization*, pp. 441–444.

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“enforced migration” were ordered to evacuate without delay, often without being given the opportunity to find a new place to live and work. The poorer farmers did not even have the funds required to move their families, store their equipment, and house their animals. The older farmers suffered more from the severing of their emotional attachments to the land than the economic sacrifice. All farmers who were able to move and purchase other lands, at the very least, lost a year’s income because they were unable to plant new crops in time for the growing season. One Minnesota farmer said: “It was a rude . . . awakening to the people of a rural community that had never been disturbed. Life was so tranquil and peaceful. All of a sudden it was just blown to smithereens and we had no foundation.”²¹

Although many of these landowners fought to retain ownership, few ever succeeded in keeping the government from taking control of their properties. And though they were deeply patriotic, most farmers were angered over the lack of control they had over the process, the amount of money offered, and the perceived uncaring nature of the government. One farmer recalled his sentiment when the Indiana Army Ammunition Plant took his land. He said, “I was in a state of unbelieving shock . . . there was a deep feeling that perhaps, I might wake up and realize I had a horrible dream. It was hard to accept that [a neighbor], so proud of his home, his farm, his heritage, was crushed . . . I made up my mind irrevocably that if Clark County was going to have the powder plant and bag-loading plant—I didn’t want to be near it nor in sight of it.”²² The United States was preparing for war, and military/industrial plans took precedence over many private agricultural enterprises. A similar story occurred among the farmers in northern Ohio.

Acquiring Plum Brook

By 1940 agriculture in Ohio was a huge business. Nationally the state ranked 4th in gross farm income (\$390 million), 8th in the number of farms (255,146), and 18th in total farmland acreage (23 million acres). These figures demonstrate that one of the central features of Ohio agriculture was that it was made up of numerous small farms. Of a total state population of seven million people, one million lived and worked on farms. Transportation to and from these lands was better in Ohio than in any other state, since a majority of its farms could be reached by

²¹ Patricia L. Dooley, “Gopher Ordnance Works: Condemnation, Construction, and Community Response,” *Minnesota History: The Quarterly of the Minnesota Historical Society* 49, 6 (Summer 1985): 219.

²² Kane, *Historic Context for the World War II Ordnance Departments*, p. 189.

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An aerial view of the Plum Brook region showing farm plots. Lake Erie is visible in the upper left corner. (NASA C-1960-55682)

hard-surfaced roads.²³ While this was an important feature for distributing crops, it was also essential for transporting munitions in a time of war, and the land became prime real estate for the War Department.

On this farmland, near Lake Erie in Perkins, Erie, and Oxford townships, the government selected a 9,000-acre site for a new ordnance works. In early January 1941 government officials announced that this site would become the home of a new \$11 million munitions works and TNT plant. It selected the area primarily because of its rural location. But even more important was its accessibility by water, railroad, and highway. By water, the site was near two ports (Sandusky and Huron) that would enable ships to transport raw materials and TNT from the facility. Five major railroads also intersected near this site, including the Baltimore & Ohio (to the west of the land), the New York Central (east and south), Wheeling and Lake Erie (south), Nickel Plate (west), and the Pennsylvania (west). Major highways were

²³ "Farm Facts," Harold H. Burton Papers; Folder 2, Box 16, Mss. No. 3584, Western Reserve Historical Society.

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An aerial view of some of the Plum Brook farmhouses before the U.S. government took possession of them prior to the start of World War II. (NASA C-2004-102)

also nearby for overland transport by truck. This was important because the new facility was designed to supply powder for shell-loading facilities like the Ravenna Arsenal, located just outside Akron, Ohio, less than 100 miles away.²⁴

Before the government made any official decision, landowners gathered together for what they called an “exchange views” discussion. L. C. Hill was one of the farmers who led the meeting. He advised his neighbors to be cautious when considering the sale of their lands and to negotiate only with accredited federal government representatives. Some at the meeting expressed their reluctance to sell. They had spent their lives working the land and were “influenced by their pride in the community’s accomplishments” and feared that the government would not only take their lands, but also fundamentally change the character of their city.²⁵ Although

²⁴ “State and County Extension Agents to Aid Farmers in TNT Area,” *Sandusky Star Journal* (4 January 1941); “5 Railroads Located in Plant Area,” *Sandusky Star Journal* (6 January 1941).

²⁵ “5 Railroads Located in Plant Area,” *Sandusky Star Journal* (6 January 1941).

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the government claimed on 7 January 1941 that the decision for the site was still “not definitely settled,” just one day later local papers reported that the site selection was finalized and that “speed is essential to the defense program” in moving ahead with the project.²⁶

Speed meant getting the farmers off their land as quickly as possible. Logistically this was not an easy task, and the farmers were concerned that the government would not understand the difficulty of relocating a working agricultural enterprise. Moving an entire farm, including machinery, animals, tools, and personal belongings, under a limited time schedule was extremely demanding and was not an item that government land agents considered a reimbursable expense.

Although the government had decided to take the land, it had not yet told the residents. The War Department hired two men, Major Edward Ostendorf and William Morris of the Ostendorf and Morris real estate firm, to inform the community.²⁷ Ostendorf summoned the farmers to a meeting at the Perkins Grange Hall, the site where the TNT works was to be built. The farmers had not been told the purpose of the gathering, and rumors quickly circulated that they would learn the official news that they were to be forced to vacate their lands. The farmers sat in silence, waiting in the old brick building for Ostendorf and the other government agents to arrive. Ostendorf announced that the rumors in the local papers were correct: the Perkins Township site had been selected, and the government would purchase 7,200 acres of land. He assured them, “No high-pressure methods will be used.”²⁸

More than just farmlands were going to be taken over. Numerous buildings, many of which were central to Perkins Township community life, were also to be razed. These included the Perkins Grange Hall (where many of the farmers gathered to discuss the sale of their lands), Strickfaden’s Store and Nursery, the Brick Tavern (a popular nightclub), the Central Erie Supply and Elevator Association, Yost’s Store, and St. John’s Evangelical Church. In total, 159 families who resided in the area would have to sell their properties and move to another location.²⁹ Not only were the farmers to be relocated, but also the final resting places of many of their deceased parents and grandparents. One of the most contentious aspects of the government’s plan was the relocation of Perkins Township Cemetery and its 450

²⁶ “TNT Plant Site Revealed,” *Sandusky Star Journal* (8 January 1941).

²⁷ “War Department Picked Ostendorf & Morris, of Cleveland,” *Sandusky Star Journal* (7 January 1941).

²⁸ “Representatives of Both Trojan Powder Co. and Boston Firm Expected,” *Sandusky Star Journal* (9 January 1941).

²⁹ “Ostendorf & Morris Co. Begins Work and Trojan Power Co.’s Contractors Expected Soon,” *Sandusky Star Journal* (13 January 1941).

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graves.³⁰ This was what many believed to be the first time that the government had moved a cemetery to make room for a factory.³¹ The farmers called a special meeting of all of the individuals who had family members buried in the cemetery, and the government assured them that it would pay for all of the moving costs.³² Ironically, the government was willing to pay the moving costs for the dead, but not the moving costs incurred by the living descendants leaving their farms.

William Morris said that he and the other government agents were taking their time to explore all of the difficulties of the relocation, including the farmers' understandable sensitivities to the destruction of their church, and the exhuming of their loved ones' remains. He said, "We are giving as much time as possible to study the individual farmer problem with such a view expected to increase the early acquisition of the land." But he said that though the government wanted to deal fairly with everyone and financially compensate them for their cooperation, "the government . . . does not intend to be made a 'Santa Claus.'"³³

Despite the government's emphasis on good intentions, the farmers were angered by what they believed was an inequitable monetary compensation for their lands. They accused the government representatives of having an "arbitrary and dictatorial attitude" in their attempts to purchase their property and argued that they did not understand the intensity of their relationship to the land.³⁴ Through over a century of work, multiple generations of families had transformed the area into abundant farmland with a strong surrounding community. By late January 1941 the government had acquired several large properties, but there was still strong local opposition to the amount of compensation offered. Furthermore, if forced to move, roughly half of the displaced farmers said that they would not start new farms elsewhere, but would look for other lines of work.³⁵ At the same time, President Franklin D. Roosevelt was calling for the United States to become "the great arsenal of democ-

³⁰ "Removal of Bodies Also Provided," *Sandusky Star Journal* (17 January 1941).

³¹ "Perkins Cemetery Trustees Tell Lot Owners About Removal Plans," *Sandusky Star Journal* (27 January 1941).

³² "Perkins Cemetery Trustees Call Meeting of Lot Owners," *Sandusky Star Journal* (20 January 1941).

³³ William Morris, quoted in "W.L. Morris Reports Good Progress," *Sandusky Star Journal* (14 January 1941).

³⁴ "Protest Land Acquisition in Federal Court," *Sandusky Star Journal* (27 May 1941).

³⁵ "Representatives of Both Trojan Powder Co. and Boston Firm Expected," *Sandusky Star Journal* (9 January 1941).

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A Plum Brook farming family prior to World War II. Courtesy of Henry Pfanner.

racy.”³⁶ To the farmers this democracy was being tainted by the dictatorial powers of eminent domain.

Hank Pfanner was a child then, but he clearly remembers today what it was like when the government came to purchase his grandfather’s and father’s land. His grandfather grew corn and potatoes and raised chickens and cows. He recalled, “I remember how the [government] came. They treated the landowners very rudely and most landowners were not as upset about the fact of selling the land as . . . how they were treated.” For example, Pfanner’s father protested to one of the land agents about how much money they had offered him. The agent’s response was to take the money, throw it on the floor, and say, “That’s what you’re going to get.”³⁷ The Plum Brook farmers’ disappointment over the amount of money paid to them by the government was not unusual. At the Gopher Ordnance Works, a smokeless powder facility in Minnesota, farmers told a similar story. One said that she had been paid \$35 per acre for her land even though she had paid \$90 per acre for a large

³⁶ Franklin D. Roosevelt, “Arsenal of Democracy” address, 29 December 1940.

³⁷ Interview with Hank Pfanner by Mark D. Bowles, 26 September 2002.

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portion of it 15 years earlier. Another farmer from the same region recalled, "When we objected to the price . . . they said we should be glad they weren't taking a son, or the men in the family didn't have to go into service. We should be happy it was just the land we were losing."³⁸

On 15 January 1941 the first trainload of construction machinery rolled into Sandusky. This came from the E. H. Badger and Sons Company, located in Boston. It sent a variety of machines like tractors and graders over the Baltimore & Ohio Railroad to destroy the farmers' crops and help transform the land. Even as the trains came in, the local farmers mounted a protest. The local papers reported the "determined efforts by property owners to have the plant placed elsewhere."³⁹ They watched as their farmland was destroyed, community buildings demolished, churches torn down, a cemetery moved, and homes razed or occupied by military officers. Pearl Harbor was still a half-year away, and many wondered if the United States would even enter the war. Meanwhile the military sent machinery and materials, widened roads to accommodate the influx of trucks, and began construction on hundreds of buildings and bunkers. The local residents who remained coexisted with the influx of factory workers and voiced concerns over chemical runoffs into their drinking water. The industrial war machine had invaded their quiet rural community.

At a subsequent town meeting, Harold Burton, Republican Senator from Ohio, and local Republican Congressman A. D. Baumhart voiced the farmers' grievances.⁴⁰ Burton had often emphasized the importance of the farmer in his bid for U.S. Senator in 1940. He warned that agricultural research was disproportionately reduced in favor of "pork barrel items such as munitions."⁴¹ Baumhart was also a

³⁸ Interview with Mary McAndrews Hynes by Teresa Seliga and Helen Davis, 30 June 1976, in Dooley, "Gopher Ordnance Works," p. 220.

³⁹ "Major Ostendorf Told in Letter No Change to Follow Objections Filed," *Sandusky Star Journal* (22 January 1941).

⁴⁰ Burton was a Harvard-educated lawyer who had served in the Army during World War I. In the 1920s he taught law at Western Reserve University and started his own firm. By the end of the decade he became interested in politics, holding several community positions, until he became mayor of Cleveland from 1935 to 1940 as an independent Republican. In 1940 he turned from local to national politics and became a senator from Ohio, serving until 1945. President Truman then selected him as associate justice of the Supreme Court, and he held this position for 13 years. "Harold H. Burton Register Biography," Harold H. Burton Papers, Mss. No. 3828, Western Reserve Historical Society.

⁴¹ "Harold H. Burton for U.S. Senator," Harold H. Burton Papers, Folder 3, Box 16, Mss. No. 3584, Western Reserve Historical Society.

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A Plum Brook farmer in his fields. Courtesy of Henry Pfanner.

vocal advocate for the farmers who were his primary constituents.⁴² In 1941 they both gave several reasons why the land should not be used for the powder factory. First, the government's use of the site would remove thousands of acres of vital farm production, which would be critical if the nation were to enter the war. Second, they argued that there were more suitable lands for the ordnance works that were nonproductive in terms of farming. Third, through decades of work the land had become so fertile that it produced what many considered the best sweet corn and seed available in the United States. Fourth, the land was nearly unparalleled in the production of tomatoes, cabbages, and other vegetables suitable for canning, which were also essential in time of war. A fourth argument made on behalf of the farmers was that the munitions site would ruin the area's robust tourist trade at the local

⁴² Baumhart focused his career primarily upon local politics. After earning his master's degree from Ohio University in 1931, he served in the Ohio State Senate (1937–1940) until he became the Republican congressman representing the Plum Brook region. He served only from 1941 to 1942, when he accepted a commission with the United States Navy. After the war he became director of the Republican National Committee in 1953 and 1954 and returned to local politics from 1955 to 1961, when he again became a congressman.

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beaches, like the nearby Cedar Point resort, which had been in operation since the 1880s.⁴³

Another problem was environmental. Many local residents were concerned that the area's streams, waterways, and even Lake Erie itself could be contaminated by wastewater flowing from the powder plant. Although this was only a rumor, it spread quickly and caused "considerable unrest in the city." The E. H. Badger construction company issued a report to silence these anxieties, arguing that residents "need have no fear of contamination or pollution of waters . . . from the powder plant."⁴⁴ Specifically the company said that the water used in the manufacture of explosives was for cooling purposes and that it would not come into contact with acids or other chemicals, which might later pollute the area.

The delays presented by the petitions and environmental concerns managed to slow progress in the clearing of the farmland. The government argued that these obstacles were "hazardous to the national defense program."⁴⁵ More speed was needed in facilitating the transfer of lands and the construction of buildings. The entire ordnance works needed to be completed by the end of 1941, so that it would be ready to supply explosives to the shell loading plants in both Ohio and Indiana. Many of the farmers cooperated with the government more out of a sense of patriotism than a desire to leave their homes, but there remained a group staunchly committed to staying put. The government responded, "We wish to be as lenient as possible, but if the landowners do not respond better in the near future, other action is contemplated."⁴⁶ They gave no indication at that time as to what this more forceful action might entail.

The government's land agents at Plum Brook promised to finish all land acquisition by February 1941. This allowed less than 2 months to contact 159 separate landowners and convince them that they had no alternative but to leave their homes. By the first of the month the Army had appointed Captain Jermain Rodenhauser as representative in charge of the ordnance works. His first task was to urge all of the remaining landowners to sell their property to the government. Only 45 percent of the total 7,200 acres had been acquired, and he was given until 1 March to complete the job. He sent a letter to all of the farmers, stating:

⁴³ "Committee Learns Reasons for Selecting Erie-Co TNT Site in Washington Visit," *Sandusky Star Journal* (3 February 1941).

⁴⁴ "Representative of Construction Company Dissipates Story of Acid Waste Damaging Territory," *Sandusky Star Journal* (24 January 1941).

⁴⁵ Ibid.

⁴⁶ Ibid.

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A number of owners have held back from commencing or concluding negotiations with us because of a false hope that has been gained that the plant might still be relocated. The Federal Government and Army officials now have stated emphatically that there can be no change in the selection of this site. Whether these owners have been influenced by a false impression as to the uncertainty of the location of the site or a desire to get more than the fair value, the result is the same—delay in completing a critically important link in the national defense chain.⁴⁷

The letter helped convince those still holding out that they had no other option. If they did not agree to the fair value price and tried to press for more, their cases would have been sent to the Department of Justice, where the ultimate outcome might be less favorable. When one of the owners of the largest and most respected farms sold his land on 25 February, a majority of the other holdouts conceded and also signed.⁴⁸ By 1 March most of the 159 families had signed the papers, and the government promised them \$1.6 million in total for compensation.⁴⁹ Checks to the former farmers began arriving by the end of the first week of March.⁵⁰ James Rea, an attorney for the Department of Justice, gave the remaining families a deadline of 15 April to vacate their homes. Some of the houses of the first farmers to sell were being razed, some were transported off the site on rolling logs, and others were converted into residences for ordnance personnel.⁵¹ On 8 March, hundreds of these family members gathered together in the Perkins Grange Hall to say goodbye to each other, enjoy local entertainment, and sing.⁵² Ostendorf and Morris closed their office on 15 March.⁵³

⁴⁷ "Letters to Owners Ask More Speed," *Sandusky Star Journal* (11 February 1941).

⁴⁸ "Report One of Largest Farms Sold," *Sandusky Star Journal* (25 February 1941).

⁴⁹ "Payment in 10 Days for First Land," *Sandusky Star Journal* (13 February 1941).

⁵⁰ "Checks are Brought By Jas. W. Rea," *Sandusky Star Journal* (3 March 1941).

⁵¹ "Production to Begin Soon at Plum Brook Powder Plant," *Cleveland Plain Dealer* (26 October 1941).

⁵² "TNT Options Completed by Tonight," *Sandusky Star Journal* (8 March 1941).

⁵³ *Sandusky Star Journal* (8 March 1941).

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The Army did not destroy all of the homes. Some were moved to different locations at Plum Brook and used for officer housing. U.S. Army Corps of Engineers, US Army. (No. 54)

Condemnation Hearings

However, not all of the farmers agreed to the price, even though they had no choice but to abandon the lands. The government “condemned” their properties and initiated legal proceedings.⁵⁴ Condemnation hearings were provided for by an Act of Congress on 26 February 1931, most commonly referred to as the Declaration of Taking Act.⁵⁵ This enabled the government to immediately take possession of contested lands before the issue went to court. Thus, even though the Plum Brook landowners refused to sell, they were forced off their property and their compensation was deferred until the case went to trial.

⁵⁴ “Labor Call at TNT Job 4 Weeks Off,” *Sandusky Star Journal* (4 March 1941).

⁵⁵ The 1931 act is defined as 46 Stat. 1421; 40 U.S.C. sec. 258a). Previous acts defining this power include 18 August 1890 (26 Stat. 316), 2 July 1917 (40 Stat. 241), and 11 April 1918 (40 Stat. 518; 50 U.S.C. sec. 171). The congressional act on 15 April 1941 approved funds for the acquisition of the land. Henry L. Stimson to the Attorney General, 9 August 1941, 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).

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The power to appropriate private property for public use is known as eminent domain. Although this power is not explicitly defined in the Constitution, the Fifth Amendment does assume its existence and places limitations on its action. The amendment states that no person shall be deprived of property without due process of law, and furthermore no private property could ever be taken "without just compensation." This issue of fair compensation was often contested. If the landowners did not agree to the price set for their property by the government, they had the right to take the case to court and let a jury of their peers decide the fairness of the compensation. To avoid a lengthy trial, it was in the best interest of both the government and the landowner to agree to the initial terms, accept the money, and move off the land. But this did not always happen, and many cases dragged on for years. One hundred forty-nine of the families accepted the government's initial offer for the land, but ten families refused and argued that they deserved better compensation. This was the catalyst for the start of a four-year condemnation hearing that took place before a jury in a U.S. district court.

The following table lists the ten primary defendants, describes their land, what the government offered for it as fair compensation, and what the defendants believed they were entitled.

Name/Location	Offered	Seeking	Main Features of Property
Fred C. Baum, 110 acres, parcel 1	\$18,375	\$35,929	Two-story brick home with ten rooms. Two barns. Milk house. Hog pen. 120-tree apple orchard. 31 cows. 22 hogs. Two acres of woods. Diversified crop production.
Anna Bouy, 43 acres, parcel 2	\$14,900	\$36,875	Two-story stucco stone home with 14 rooms. Two barns. Hog pen. Chicken coop. 20-tree apple orchard. 47 cows. 18 hogs. Diversified crop production.
Amelia Kromer, et. al., 37 acres, parcel 3	\$9,900	\$21,325	Two-story frame home with seven rooms. One newly shingled barn. Cattle shed. Pig pen. Milk house. Chicken coop. Small orchard of peach and plum trees. 13 head of cattle. Diversified crop production.
Carl V. Kromer, 35 acres, parcel 4	\$8,650	\$15,607	Two-story brick home with 12 rooms. Stone smokehouse. Chicken coop. Large barn. Small barn. Two-acre vineyard. Two acres of woods. Apple orchard. Diversified crop production.

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Name/Location	Offered	Seeking	Main Features of Property
George D. Beatty, 156 acres, parcel 5	\$11,500	\$49,075	Entirely farmland with his home residence on attached property not condemned by the government. Without the farmland he claimed his barns and equipment were rendered "almost valueless."
William Kromer, 83 acres, parcel 6	\$14,850	\$29,850	Two-story frame, slate-roof home with ten rooms. Attached summer kitchen. Large frame barn. Steer and cow shed. Concrete silo. Chicken coop. Corn crib. Milk house. Peach and apple orchard. Small sawmill. Diversified crop production.
Emma A. Hermes, 79 acres, parcel 7	\$12,350	\$29,977	Two-story frame, slate-roof home with ten rooms. Large metal roof barn. Six outbuildings. Large silo. Milk house. Cherry and apple orchard with 44 trees. 13.5 acres of molding sand land. Dairy farm. Diversified crop production.
Joseph and Martha Michel, 18 acres, parcel 8	\$6,700	\$12,590	Two-story frame and shingle-roof home with six rooms. One large newly sided barn. Two sheds. Corn crib. Grain bin. Newly planted 104-tree peach orchard.
Frank J. Bouy, 133 acres, parcel 9	\$17,850	\$42,982	Two-story frame and shingle-roof home with nine rooms. Small milk house. Chicken coop. Large tool shed with steel roof. Large barn. 40-fruit tree orchard. 22 acres of wooded land. 47 cows. 18 hogs. 16 acres of field cord. 9 acres of soybeans. 6 acres of corn stalks. 16 acres of alfalfa. 50 bushels of apples. 20 bushels of potatoes.
Frank and Pauline Radde, 50 acres, parcel 10	\$9,850	\$17,430	Two-story frame shingle-roof home with seven rooms. Large barn. Large tool shed. 40-tree apple, cherry, and pear orchard. 12 cows. 12 steers. Diversified crop production.

Removing the Farmers

The court proceedings dragged on for two years through various motions and re-filings. By June 1943 the jury issued its rulings heavily in favor of the government's original offer.⁵⁶ Fred C. Baum's land (the farmer described at the start of this chapter) was the only property for which the original jury ruled in favor of the defendant. The original offer was \$18,375, and the jury awarded Baum \$31,700, just \$4,000 less than he was seeking. No other defendants were awarded anything close to what they believed their land was worth. The government lawyers argued that "the verdict was greatly excessive and greatly showed a disposition on the part of the jury to favor the land owner without giving just consideration to the testimony presented by the government experts."⁵⁷

The other disputes dragged on until 2 April 1945, just 28 days before Hitler committed suicide, thus hastening the end of the war.⁵⁸ The conflict over the compensation for the Plum Brook lands and the construction of an ordnance works for the war lasted as long as the war itself. Although the jury returned a mixed result, one thing was very clear. The process of providing compensation for land forcefully obtained is a difficult and subjective process. The government, working to settle thousands of similar cases, attempted to save as much as it could on each property. The property owners themselves, heavily invested both emotionally and financially in their land, naturally sought to gain as much as they could for what they had spent their lives building. In the meantime, while the legal battle was being fought, Plum Brook played a central role in winning the world war against dictatorship.

The Plum Brook Ordnance Works

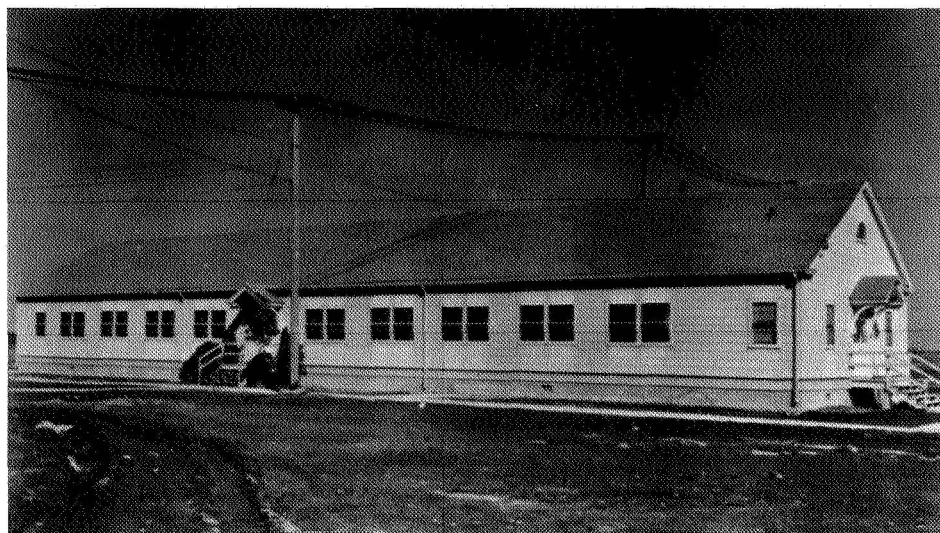
While the condemnation hearings were just starting, the Army began construction on the "Plum Brook Ordnance Works," retaining the name of a local brook and perhaps subtly emphasizing environmental preservation of the area. The first

⁵⁶ "Supplemental Brief on Motions for New Trial," 28 June 1943, 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).

⁵⁷ "Memorandum Supporting Motion for a New Trial," 25 March 1943, 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).

⁵⁸ "Final Judgement," 2 April 1945, 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).

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The cafeteria building at the Plum Brook Ordnance Works. Its construction style was similar to all of the structures at the facility. Courtesy U.S. Army Corps of Engineers, U.S. Army. (No. 3-42 1944)

task was to improve the infrastructure by widening the road access.⁵⁹ Some of the larger machinery began to be purchased for the plant, including four diesel electric locomotives. Six miles of wire fence was erected around the entire land, and stakes marking the future location of buildings were driven into the ground.⁶⁰ Captain Rodenhauser returned from Washington, DC, with the plans for construction of the entire plant.⁶¹ The headquarters' building would be the first erected, followed by the various other factory buildings and storehouse bunkers.

By May 1941 significant progress had been made. Conflict was worsening in Europe, and President Roosevelt addressed a worldwide audience via radio announcing that the United States pledged its full military support to stop Hitler and his plans for "world domination" by the Axis. Roosevelt proclaimed an "unlimited national emergency," and the Plum Brook workers intensified their preparations. One report noted, "Following closely upon President Roosevelt's appeal for united efforts to stop the dictators, the Plum Brook Ordnance plant today took on a new

⁵⁹ "Await Word After Visits to Capital," *Sandusky Star Journal* (20 February 1941); "Plan Roads Around TNT Plant Site," *Sandusky Star Journal* (21 March 1941).

⁶⁰ "6 Miles of Wire Fence to be Used," *Sandusky Star Journal* (10 March 1941).

⁶¹ "Start Still Uncertain," *Sandusky Star Journal* (15 March 1941).

Removing the Farmers



A manufacturing shop at Plum Brook Ordnance Works. U.S. Army Corps of Engineers, US Army. (No. 21739, 1944)

meaning and efforts to comply with that request were forthcoming immediately.”⁶² The Army hurried the administration, hospital, fire, police, and cafeteria buildings to completion. Fifteen hundred men were also scheduled to begin work the first week of June.

Progress on the cemetery move was also being made. The Army moved half of the bodies to the Bogart Cemetery Annex. It made special provisions to allow family members who still had relatives buried at the old Perkins Cemetery to be able to visit and decorate their graves for the upcoming Memorial Day. This was also a significant date, because at 7:00 p.m., as the last of the visitors left the cemetery, the Plum Brook guards closed the gate, sealing off for the first time the over 9,000 acres of land to the community. The local paper marked the occasion, stating, “Whether that section of this country will ever again become a farming region [is] unknown, but for the immediate future all efforts will center on manufacturing.”⁶³

Aesthetics were not considered important in the construction of most of the ordnance facilities built for World War II. Army engineers placed emphasis upon speed in design, functionality, and stability. Major General Charles M. Wesson,

⁶² “1,500 Men on Job by Next Week,” *Sandusky Star Journal* (28 May 1941).

⁶³ “Perkins Cemetery Visited for Last Time Memorial Day by Relatives; Gates of TNT Area Closed to Public,” *Sandusky Star Journal* (31 May 1941).

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Chief of Ordnance, said in July 1940, "There are to be no high-fallutin' gargoyles on these buildings." He then explained, "We will have simple but durable plants. We figure that this emergency is not here today and gone tomorrow, and that these facilities should be built on a basis that would make them available for the next twenty years."⁶⁴ There were eight major buildings at the facility costing a total of \$7,851,335.⁶⁵

Facility Name	Building Cost
Administration Area	\$827,957
TNT Area "A"	\$1,036,569
TNT Area "B"	\$735,483
TNT Area "C"	\$1,040,415
Acid Area #1	\$2,060,674
Acid Area #2	\$1,011,692
Acid Area #3	\$1,039,858
Pentolite Area	\$98,684

The most solidly built structures at the ordnance works were the "igloos," which were storage facilities that Plum Brook used to house its explosives. One observer said that these facilities have a "unique place in architectural and engineering design."⁶⁶ The igloo (named after the Eskimo shelter it resembled) was a concrete and reinforced steel structure shaped like a half-barrel lying sideways in the ground.⁶⁷ Two lightning rods protected them during storms, and they were covered with a thick layer of sod. The igloos were equally spaced in a grid (400 feet on each side and 800 feet in front) throughout the facility so that if one exploded, it would not ignite the next closest one, thus preventing a dangerous chain reaction. Plum Brook had a total of 99 igloos, all of which were used to store TNT.

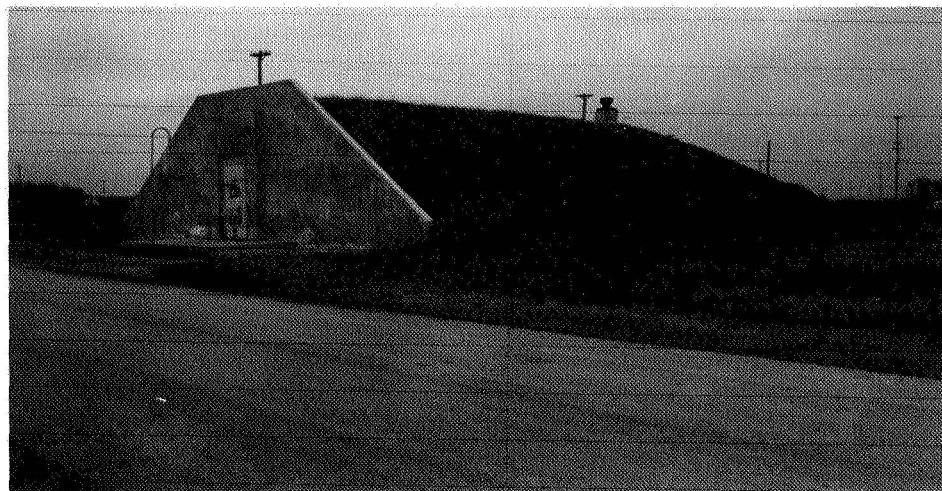
⁶⁴ Charles M. Wesson, quoted in Fine and Remington, *The Corps of Engineers*, pp. 165, 325. John C. Everett (Chief, Plant Services Division) and L. Marcus (Head, Structural Design Section) to Chief, Technical Services Division, 16 May 1958, Folder: Evaluation of Buildings and Structures, Box: 7, NASA-Glenn Archives.

⁶⁵ "Evaluation of Plum Brook Ordnance Works," July 1958, Folder: Evaluation of PBOW, Box: 7, NASA-Glenn Archives.

⁶⁶ Kane, *Historic Context for the World War II Ordnance Departments*, p. 109.

⁶⁷ Harry C. Thomson and Lida Mayo, *The Ordnance Department: Procurement and Supply* (Washington, DC: United States Army, 1991), p. 360.

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One of 99 bunkers or "igloos" used to store power in Plum Brook's southwest corner. Courtesy U.S. Army Corps of Engineers, U.S. Army. (No. 21762, 1944)

Other structures at Plum Brook included administrative, housing, manufacturing and chemical processing, processing support, shipping and storage, worker support, utilities, and landscaping buildings. Some of the large structures at Plum Brook included an administration building, a cafeteria, and a tall water tower. In the "acid area" the facility had massive sulfuric acid tanks constructed with linings of asbestos, lead, and brick to prevent their destruction.

The first time the community had an opportunity to revisit the area was in September 1941 for the flag-raising ceremonies and the public dedication of the Plum Brook Ordnance Works. By this time over 4,000 employees were working daily at the facility. The Army suspended all work at noon, so that the employees could be on hand for the dedication festivities, which included music from the American Legion and visits by high-ranking military officials from Washington, DC. Many believed that the public would be surprised when it saw the transformation of the lands that just a few months earlier were still producing crops. One reporter noted, "When the public views the project next Saturday it will see a small city which has mushroomed on the farmlands."⁶⁸ Perhaps what was most unsettling for the visitors was to once again see their old family homes, many of which were preserved and occupied by ordnance workers. Not only were Army personnel living in the old residences, the structures themselves had been moved to a new location, away from the manufacturing areas. The ordnance officers towed over 100 homes by tractor on

⁶⁸ "Flag Raising Ceremonies on Program," *Sandusky Star Journal* (21 September 1941).

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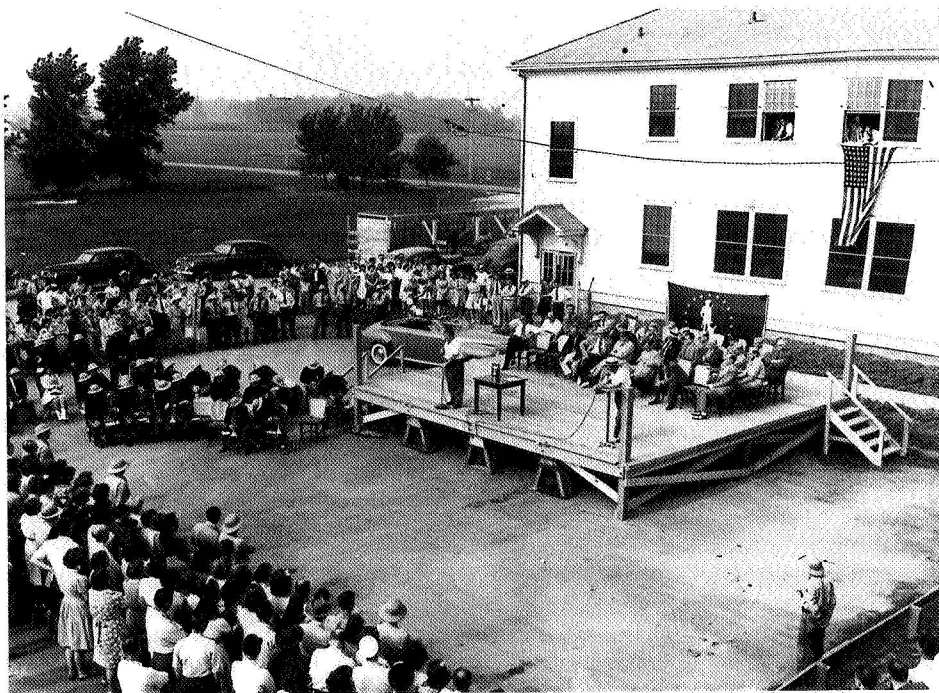


Chemical storage containers at Plum Brook Ordnance Works. (NASA 2005-1199)

Removing the Farmers



Staff quarters for Army officers converted from farmhouses taken by the U.S. Government. U.S. Army Corps of Engineers, US Army. (No. 21754, 1944)



Abbott & Costello visited Plum Brook in August 1942 to encourage workers to purchase War Bonds. (Permission courtesy of the Charles E. Froman Collection at the Rutherford B. Hayes Presidential Center, Fremont, Ohio)

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rollers up to five miles from their original foundations.⁶⁹

Major Jermain Rodenhauser, commanding officer at Plum Brook, spoke at the ceremonies and dedicated the facility to the “people of the nation.” He said, “This is your plant . . . The Plum Brook Ordnance plant was conceived and built in the interests of, for, and by the American nation, as a whole.”⁷⁰ Rodenhauser’s eloquent and patriotic words masked the fact that several of the farmers were still mounting protests.

Plum Brook was now ready for operation. The farmers had been removed from the land, the U.S. government owned all of the property (though some litigation on the settlements was far from over in the courts), the facilities were in place, and the work force was learning the task of manufacturing gunpowder. The government completed the effort just in time. The first of the 12 TNT production lines began operation on 15 November 1941, just 22 days before the Japanese unleashed a surprise attack on Pearl Harbor, thrusting America inexorably into World War II.⁷¹ Plum Brook became one of the three largest TNT plants in the country. It eventually encompassed over 10,000 acres of land, and the road around the entire facility was about 20 miles in length.⁷² It was a major component of America’s arsenal of democracy. Throughout the war Plum Brook sent its explosives less than 100 miles away to the Ravenna Arsenal, which was the largest combined shell loading and ammunition storage depot in the world.⁷³

In January 1941 the United States had less than 11 million pounds of powder and explosives.⁷⁴ Once operational, Plum Brook was producing 400,000 pounds of explosives per day.⁷⁵ In less than a month it produced more explosives than the entire United States had in its storehouses before the war began. TNT (trinitrotoluene) was the most widely produced explosive for World War II. Ordnance facilities at Chickasaw, Kankakee, Kentucky, Keystone, Lake Ontario, Longhorn, Okla-

⁶⁹ “Production to Begin Soon at Plum Brook Powder Plant,” *Cleveland Plain Dealer* (26 October 1941).

⁷⁰ “Plum Brook TNT Plant Dedication Underway Today,” *Sandusky Star Journal* (27 September 1941).

⁷¹ “Production to Begin Soon at Plum Brook Powder Plant,” *Cleveland Plain Dealer* (26 October 1941).

⁷² “Trojan’s Explosives Help Speed War’s End,” *Sandusky Star Journal* (7 May 1945).

⁷³ “Ohio in the War: Arsenals of the Army,” *Sandusky Star Journal* (24 December 1945).

⁷⁴ “Workers Praised by Congressional Investigator,” *PBOW News* (7 July 1944), The Charles E. Frohman Collection, Rutherford B. Hayes Presidential Center Archives.

⁷⁵ “Plum Brook Station Review,” 30 December 1976, Plum Brook box, NASA Glenn Archives.

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One of the factories in operation at Plum Brook Ordnance Works. U.S. Army Corps of Engineers, US Army. (No. 201-142, 1944)

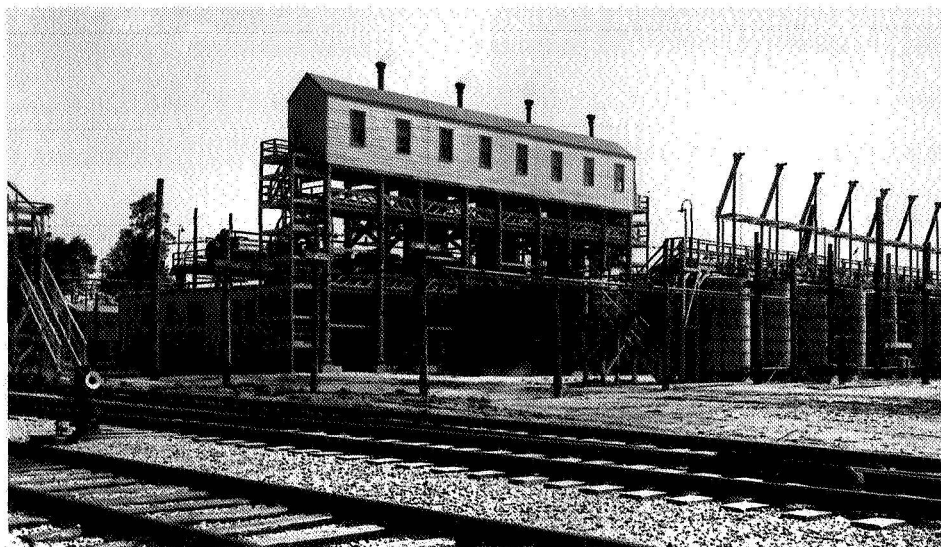
homa, Pennsylvania, Plum Brook, Radford, Virginia, Volunteer, Weldon Springs, and West Virginia made TNT. Only five ordnance facilities produced dinitrotoluene, including Alabama, Chickasaw, Kankakee, Plum Brook, and Weldon Springs. Pentolite was considered the most sensitive of all explosives. The Army made it from a mixture of TNT and pentaerythritol tetranite and used it in bazooka rockets, detonators, rifle grenades, boosting devices, and shaped charges for high-explosive antitank shells. Only Plum Brook and Radford had the capability to manufacture this type of explosive. Only Plum Brook manufactured all three.

One other important feature of the Plum Brook Ordnance Works was that it was temporary. Its workers knew that they would not be spending the rest of their lives manufacturing powder. These jobs would end with the cessation of war. In the first week of May 1945 Germany surrendered. On 6 and 9 August the United States dropped atomic bombs on Hiroshima and Nagasaki. Five days later President Harry Truman announced the war's end via a radio broadcast, proclaiming the next two days to be a national holiday. In nearby Akron, Ohio, everyone gathered to celebrate on Main Street, which was soon filled with "people yelling and hugging each other and mothers of G.I.'s crying."⁷⁶ At Plum Brook one observer also noted the "misty eyes and tears of happiness because their loved ones were safe at last."⁷⁷

⁷⁶ "Memoirs of Donald L. Bowles," author's private collection.

⁷⁷ "War's End Taken Quietly," *PBOW News* (18 August 1945), The Charles E. Frohman Collection, Rutherford B. Hayes Presidential Center Archives.

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Plum Brook Ordnance Works transportation facility for loading explosives. U.S. Army Corps of Engineers, US Army. (No. 20956, 1943)

After the Japanese surrendered to the Allies on 17 August 1945, the production at Plum Brook came to an end. For 2.5 years it had operated 24 hours a day, 7 days a week, with only a few work stoppages. Nearly 1 billion pounds of explosives had been made through the expenditure of 18 million hours with no fatalities. The government spent over \$11 million on the land purchase and the construction of the Plum Brook Ordnance Works. The total cost was \$16 million. The Army needed several months to close and “decontaminate” the facility so that the entire site could be returned to the government.⁷⁸ On 23 August the government placed the Plum Brook Ordnance Works on a surplus list along with 251 other plants. These assets totaled nearly \$1.5 billion, not including another 134 facilities owned by the Navy. All of these eventually became available for private industry to purchase.⁷⁹

By the beginning of September, Plum Brook administrators announced that roughly 900 people would lose their jobs immediately. Major J. H. Ellett, its commanding officer, congratulated his workers because they remained dedicated to their task even during the final days of the war, when they knew that they would

⁷⁸ “Production at Plum Brook Ordnance Works Stops and High Praise is Expressed,” *Sandusky Star Journal* (17 August 1944).

⁷⁹ “Ordnance Plant Here is Placed in Surplus List,” *Sandusky Star Journal* (23 August 1945).

Removing the Farmers



Children watch huddled under a tree as most of the Plum Brook buildings are intentionally burned to the ground at the end of the war. Over 600 buildings were demolished, while NACA retained 41 structures. (NASA 2005-1202)

soon lose their jobs.⁸⁰ During its last week in operation, one worker wrote: “All over Plum Brook this week were ample evidence that many friendships that have been made will endure for life. . . . Through the dark days of the war, through the war-weary years, through spring, summer, fall and winter we ate and worked together. On many a night we had fun and relaxation together. Friendships, solid friendships were brought into being—never to be severed, never to be forgotten. . . . The saga of the Plum Brook Ordnance Works as a World War Two explosives-producing facility was ended.”⁸¹

Suddenly Plum Brook was quiet again. Many observed a return to nature as they were leaving the plant for the last time. Some said that peace and quiet had been absent from these lands for four years since ground was first broken. There was a

⁸⁰ “Maj. Ellet Announces Closing; Praises Trojan and Employees,” *Plum Brook News* (18 August 1945), The Charles E. Frohman Collection, Rutherford B. Hayes Presidential Center Archives.

⁸¹ “Auld Lang Syne,” *Plum Brook News* (18 August 1945), The Charles E. Frohman Collection, Rutherford B. Hayes Presidential Center Archives.

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“gloriously blue sky overhead.” There were 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.”⁸² The government returned to farmers over 3,000 acres of land that had been used as a buffer zone.⁸³ As the industrial production faded away, nature began to reassert its presence, but a tremendous amount of industrial pollution still remained. For ten years, from 1945 to 1955, the land lay dormant. The Ravenna Arsenal took over administration, burning many of the unneeded buildings to the ground by putting straw and oil inside and igniting them with flames. To the community onlookers this brought to mind once again the image of the Firelands. Plum Brook remained in this condition until 1955, when the government discovered a new use for the area. It emerged as the prime location for one of the largest nuclear test reactors ever conceived to study the effects of radiation upon materials that could be used to construct a nuclear airplane. Would the government again exhibit the same ability to successfully carry out its objectives on these lands?

⁸² “The Saga of Plum Brook Ordnance Works,” *Plum Brook News* (18 August 1945), The Charles E. Frohman Collection, Rutherford B. Hayes Presidential Center Archives.

⁸³ “Plum Brook Station Retention Plan,” 1976, Box 106, Folder 11, Plum Brook Archives.

Building for a Nuclear Airplane

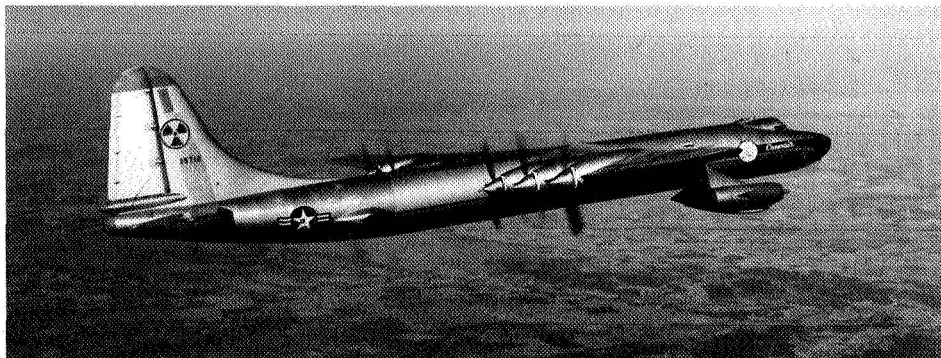
On September 17, 1955, just outside Carswell Air Force Base in Fort Worth, Texas, a strange airplane flew overhead in the morning sky. To a casual observer from the ground it looked like a typical B-36 bomber, but the plane itself was anything but ordinary. The first clues to its significance were the insignias on its outer shell. Painted on its side was the symbol of the atom, and on the nearly 50-foot tail was the emblem for radioactivity. These images hinted at the plane's unusual payload. Inside its bay door was a 1000-kilowatt nuclear reactor, and the flight that morning marked the first time that a nuclear reactor had ever flown inside an airplane. Although the reactor did not power the craft and was used primarily to test shielding and other precautions associated with nuclear flight, those involved with the project believed that this represented the first step in creating a fleet of nuclear-powered airplanes that would ensure American air power dominance during the Cold War.¹

Just three days after this flight E. R. Sharp, director of the Lewis Flight Propulsion Laboratory in Cleveland, Ohio, made an announcement that NACA had selected Lewis to construct a new and powerful test reactor. The reactor's mission was to conduct materials research in support of the nuclear airplane project. Though Lewis would manage the construction, the reactor was to be located 50 miles away, at the site of the former Plum Brook Ordnance Works. Sharp described the important role that the reactor would play in the military preparedness for the nation. He said, "The performance capabilities to be realized from harnessing nuclear energy for aircraft propulsion would be nonstop flight to any point on the face of the earth and return The new reactor will be the most useful in the solution of the complex problems on which the NACA is working."²

¹ "47 Tests Made of A-Plane," *The Washington Post* (29 January 1959): B4; Mark Wolverton, "Winged Atom" *American History Magazine* (February 2003).

² "Plum Brook Ohio Ordnance Site Chosen by NACA for Research Reactor," *Wing Tips* 13, 18 (30 September 1955), NASA-Glenn Research Center Archives.

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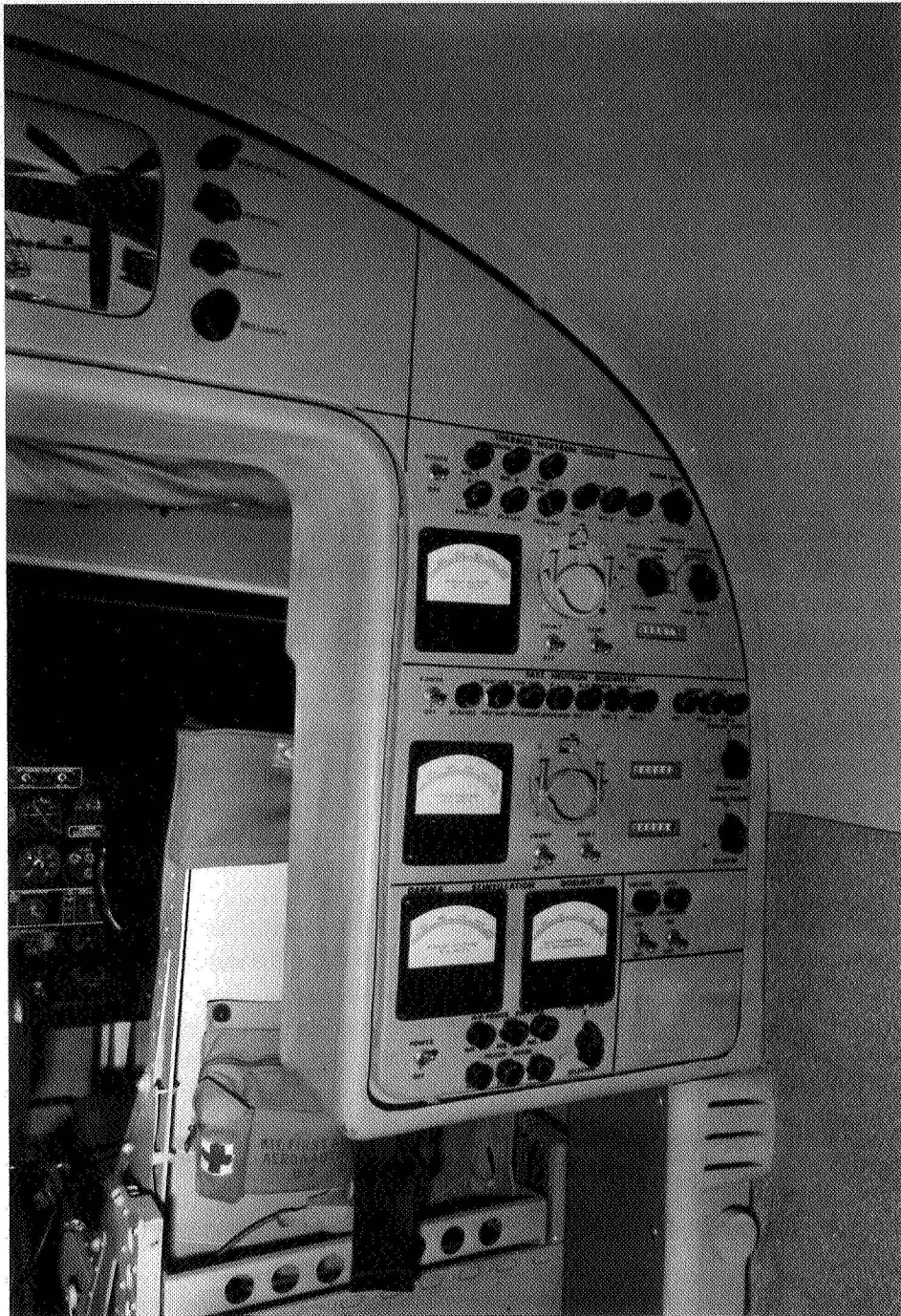
A Convair B-36 bomber converted to operate a nonpropulsive test reactor during flight. It flew 47 times between 1955 and 1957 over Texas and New Mexico. (Department of Energy)

Groundbreaking occurred one year later in September 1956 with a large ceremony attended by politicians, NACA leadership, and the public. Abe Silverstein, Sharp's successor as director of Lewis, and local congressional representatives hailed the reactor as an important part of the "atomic future," and the nuclear airplane was praised as the "shining hope" of supersonic aircraft.³ However, over the next five years while NACA built the Plum Brook reactor, this optimism died away. The first major change was the transition from NACA to NASA in 1958 and an increased national priority on developing projects for space and not aviation. Then with the Plum Brook reactor weeks away from going critical in 1961, President John F. Kennedy officially terminated the nuclear airplane program. Though the project cost the United States over \$1 billion and provided the rationale for the Plum Brook reactor's construction, the flights of the B-36 were the closest that America would come to realizing the dream of an atomic-powered airplane.

Why did the United States allocate so much time, money, and human resources to develop a nuclear airplane whose outcome was always questioned by leading authorities? One answer was that atomic politics quickly followed the discovery of atomic power in World War II. The Soviet Union was narrowing the gap in its nuclear capability and demonstrated its growing prowess with the detonation of its first atomic bomb in 1949. Furthermore, throughout the 1950s rumors circulated about a Russian nuclear airplane that was making test flights over Moscow. For America to remain strong in the Cold War world it had to continue to solidify its capabilities in the nuclear realm. One such challenge became the application of

³ Abe Silverstein and Congressman A. D. Baumhart's remarks at the Plum Brook reactor groundbreaking, in "Break Ground for Reactor Here," *The Sandusky Register Star-News* (26 September 1956).

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Interior control of the B-36 bomber with an onboard reactor. (Department of Energy)

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atomic power for aircraft propulsion. Whichever nation first perfected such technology would have a devastating advantage in any coming wars, with airplanes capable of circumnavigating the globe without the need to refuel.

Because of these atomic politics the United States actively pursued all things nuclear that might significantly improve the nation's capabilities compared with the Soviet Union. This chapter tells the story of the ill-fated nuclear airplane and the innovative test reactor NACA constructed to help build it. During this five-year period, changes to the political and technological environment fundamentally altered the future of this facility and the dreams of a flying reactor. By the time the Plum Brook reactor was completed, both NACA and the nuclear aircraft program would no longer be in existence. Would Plum Brook itself be able to survive in the wake of these changing national commitments?

The Birth of the Nuclear Airplane

After World War II the U.S. military began envisioning new ways to take advantage of nuclear technology for its weapons arsenal. Since the Army had already developed an atomic bomb, and the Navy was successfully working on the *Nautilus* (a nuclear-powered submarine), the Air Force looked for its own application. It began its nuclear initiative on October 10, 1945, when J. Carlton Ward, Jr., president of Fairchild Engine & Airplane Corporation, testified before Congress on behalf of the postwar aviation industry. He said that the nation that first developed an atomic airplane would have an unparalleled tactical advantage in future conflicts.⁴ Thus was born the quest to put a nuclear reactor into an airplane.

In May 1946 the Air Force established the Nuclear Energy for the Propulsion of Aircraft (NEPA) program. It also selected the Fairchild Engine & Airplane Corporation to develop feasibility studies for the development of nuclear powered aircraft. The Massachusetts Institute of Technology carried out further investigations under the guidance of the Atomic Energy Commission (AEC). The result was a consensus among engineers that nuclear-powered aircraft were possible. In 1948 the *New York Times* cited Oak Ridge engineer David M. Poole, claiming that the "theory of an atom-driven airplane" was 99 percent perfected.⁵ NEPA urged Congress to give this research its highest priority, and the Massachusetts Institute of Technology, on the recommendations of its Lexington Report, projected that success was pos-

⁴ John Tierney, "Take the A-Plane," *Science* 82 (January/February 1982): 46–55.

⁵ "Atom Plane Ready 99% in Theory, Engineer at Oak Ridge Reports," *New York Times* (16 October 1948): 1.

Building for a Nuclear Airplane

sible within 15 years.⁶ Because of these findings, in 1951 the Aircraft Nuclear Propulsion program began. Its goal was to “develop strategic weapons systems which would eliminate the limitations of conventional power plants as to range and endurance.”⁷

To achieve this dream, a great number of environmental and technical problems had to be solved.⁸ 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. For example, biological shields on the ground were typically made up of a five-foot-thick concrete shell surrounding the reactor core, or a ten-foot-diameter sphere.⁹ Another safety problem was the danger to people on the ground. Should the plane crash, there was the real danger of spreading radiation to a populated area. The AEC tried to dispel fears about radiation associated with the nuclear airplane. In 1959 an AEC physician, Dr. Payne S. Harris, stated that dangers to the public posed by nuclear airplanes were minor ones that could be controlled. Furthermore, he claimed that the fallout from the crash of an atomic plane would be much less than that produced by a nuclear bomb.¹⁰

There were also numerous technical problems, like the choice of materials best suited to manufacture the plane and the reactor. At the start of the program no one knew what materials could endure high-intensity radiation, resist corrosion due to the hot air that the reactor created, and prevent leakage of the radioactive fission products into the air.¹¹ Because of these environmental and technical concerns, in 1953, President Eisenhower’s secretary of defense, Charles Wilson, argued that the entire Aircraft Nuclear Propulsion program should be canceled. He derogatorily compared it to a “shitepoke” (a Texas nickname for a lanky, awkward-looking bird), because even though it might fly, it would likely lumber above the marshes with barely enough speed to keep it aloft.¹²

⁶ Herbert F. York, *Race to Oblivion: A Participant's View of the Arms Race* (New York: Simon & Schuster, 1970), p. 62.

⁷ Excerpt from “Aircraft Nuclear Propulsion Program,” Report of the Congressional Joint Committee on Atomic Energy, September 1959, in “Aircraft Nuclear Propulsion,” *Metal Progress* (December 1959): 93.

⁸ John Tierney, “Take the A-Plane,” *Science* 82 (January/February 1982): 46–55.

⁹ E. D. Reeves, “Atomic Powerplants,” *SAE Journal* (March 1958): 69.

¹⁰ Harry Nelson, “Atomic Plane Radiation Dangers Called Minor,” *Los Angeles Times* (30 October 1959): 22.

¹¹ T. M. Hallman and B. Lubarsky. “NACA Reactor Facility Hazards Summary” (October 15, 1956), p.1-1.

¹² Wolverton, “Winged Atom.”

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Despite the criticisms there were many proponents in the nuclear field who assured the skeptics that the fears were unrealistic and the technical hurdles were solvable. The Joint Committee on Atomic Energy and others in the government were strong supporters of the project, and funding continued. Pratt & Whitney, Convair, the Air Force, Lockheed, and General Electric all began developing reactor-testing technologies to try and solve the myriad technical problems associated with the nuclear airplane. These organizations worked with the goal of building a nuclear airplane that could stay aloft for 96 hours straight without refueling, and then at the end of that period make a Mach 2.2 assault on a military target, flying just over treetop level.¹³ But the motivating forces behind the project were political and military. The government was willing to undertake this costly, dangerous, and uncertain program because of the Cold War. With the heightening tensions between the superpowers, and the increasing rumors that the Soviets were close to developing their own nuclear airplane, the U.S. government quickly launched a massive effort to close the perceived gap.

The Soviet Atomic Plane Illusion

In the 1950s the technological “race” with the Soviet Union included many types of weapons systems, like missiles and tanks. Soon the nuclear airplane was added to the list. The genesis of the program emerged from a letter Anatolii Aleksandrov wrote to Igor Kurchatov. Aleksandrov earned his reputation with the Soviet nuclear submarine program and later lost much of his status because his government blamed him for the faulty design of the Chernobyl reactor. Kurchatov headed the Soviet atomic bomb project and established the Kurchatov Institute, which housed an important research reactor. On August 14, 1952, Aleksandrov wrote to Kurchatov, “Our knowledge in the area of atomic reactors allows us to raise the question of the creation of atomic engines in the coming years which can be applied to airplanes.”¹⁴ The Soviet government at first opposed the project because it believed nuclear airplanes to be too costly and technically difficult. The Soviets realistically acknowledged that the technological problems associated with the plane were daunting and that success would be at best 15 to 20 years away. They believed that a nuclear airplane could only be achieved with a long-term technological commitment and a great deal of funding.

¹³ Interview with Dick Schuh by Mark D. Bowles, 25 September 2002.

¹⁴ Aleksandrov, in, Paul R. Josephson, *Red Atom: Russia's Nuclear Power Program from Stalin to Today* (New York: W. H. Freeman and Company, 2000), p. 129.

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However, knowledge of this Soviet skepticism never made it to the West; only rumors of stunning progress. In 1953 the first reports of a Russian atomic plane surfaced in the United States. Soviet engineers were rumored to have solved the difficult shielding problem with a mysterious material called "LOSK," unknown to anyone else in the world. In 1955 newspapers across the United States began carrying reports about the Soviet atomic plane. One story told of a Communist broadcast from East Germany claiming that the Russian atomic-powered, supersonic airplane would make its maiden voyage in the near future. In January 1955 NACA Chairman Jerome C. Hunsaker claimed that the nation needed a strong effort in order to achieve a nuclear airplane, and that the United States was in "a technological race with the Soviet Union" to first achieve nuclear flight.¹⁵ In October 1955 a former AEC staff member said that because of these Soviet efforts, "the heat is on to get [the United States] an atom plane in the air."¹⁶ That same month, General Thomas D. White, Air Force vice chief of staff, became one of the first Air Force officials to publicly discuss progress on the Aircraft Nuclear Propulsion program. He confidently predicted that the "point of uncertainty" had been crossed and that the public would see an atomic plane flying "within the next decade."¹⁷

National magazines and newspapers in the United States began reporting on this development one year later. In January 1956 the *Washington Post* stated that the Eisenhower administration believed that "our national security may well depend on research in atomic energy for aircraft propulsion."¹⁸ In June, *Newsweek* ran a cover story on the "Coming Atomic Plane" and called it the "Fight for an Ultimate Weapon." While conceding that the "best brains" in the scientific community and the most powerful politicians in Washington had ridiculed it since its inception, the fear that the Soviet Union might actually create a nuclear airplane spurred the United States into costly research and development. *Newsweek* reported that if the "Soviet boast of a Russian A-Plane has any validity, the U.S. designers are obviously in a race, and working under the gun."¹⁹ The article listed several reasons why the Soviet claims should be taken seriously. First, Russian abilities in developing advanced aircraft had already been demonstrated by the Soviet Mig. Second, Soviet reactor design knowledge was improving. Third, the Soviets appeared to understand

¹⁵ Robert C. Cowen, "A-Powered Bombers Forecast," *Christian Science Monitor* (28 January 1955): 3.

¹⁶ "Heat on to Get A-Plane Up Into Air," *The Sandusky Resister-Star* (15 October 1955).

¹⁷ "AF Official Sees Flight in Decade," *The Sandusky Resister-Star* (8 October 1955).

¹⁸ "Ike Stresses A-Power for Planes," *The Washington Post* (24 January 1956): 6.

¹⁹ "The Fight for an Ultimate Weapon," *Newsweek* (4 June 1956): 57. *Newsweek* also published artists' conceptions of Russian and American atomic airplanes on 23 April 1956 on page 68.

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the urgency of developing an atomic plane more so than their American counterparts. Finally, *Newsweek* also speculated that the Soviets probably cared less for the safety of the pilots and civilians on the ground, and this enabled their scientists and engineers to make bolder technological advances.

The successful Soviet launching of Sputnik in October 1957 dramatically increased America's fears that it was falling behind the Soviets in the space race. Many believed that the first orbiting satellite would soon be followed by a second Soviet "first." Congressman Melvin Price, a Democrat from Illinois and chairman of the Joint Atomic Energy Subcommittee on Research and Development, made a personal visit to the Soviet Union in October 1957 and claimed that Russians would soon be flying an atomic-powered airplane. He said, "The Russians know the tremendous psychological value of startling military 'firsts . . . ' Their plane probably won't be perfect, but I have little doubt that it will be flying. The U.S. has been puttering along in the hope of eventually developing the perfect atomic plane."²⁰ An *Aviation Week* editorial said that Sputnik just represented another in a "long chain of Russian surprises in the development of atomic-airpower weapons ranging all the way from jet bombers [to] . . . hydrogen warheads."²¹

One year later *Aviation Week* claimed that the Soviets were already flight-testing a nuclear bomber. This was an exclusive story, and it generated a great deal of controversy over the ensuing years as politicians, the press, the public, and President Eisenhower debated its veracity. The article reported that a Soviet plane had been flying over Moscow for about 60 days. The sources of the story were unnamed "foreign observers" (though others claimed it originated from Air Force leaks) from both Communist and non-Communist countries who had apparently seen the airplane in flight.²² To increase the validity of the report, *Aviation Week* published schematic diagrams and an artist's conception of the airplane. It had a 195-foot fuselage and a 78-foot wingspan and was powered by two direct air-cycle nuclear reactors and two conventional turbojet engines. The plane weighed 300,000 pounds. Although American observers were unable to learn about the shielding system the Russians used, *Aviation Week* claimed, "Soviet technical literature has been studded with brief but positive references to a major 'breakthrough' in shielding techniques."²³ Many

²⁰ Melvin Price, quoted in Katherine Johnsen, "Congressmen Fear Second Soviet 'First,'" *Aviation Week* (28 October 1957): 29.

²¹ Robert Hotz, "Sputnik in the Sky," *Aviation Week* (14 October 1957): 21.

²² Arthur M. Squires, *The Tender Ship: Government Management of Technological Change* (Boston: Birkhäuser, 1986): p. 97.

²³ "Soviets Flight Testing Nuclear Bomber," *Aviation Week* (1 December 1958): 27-29.

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Western observers speculated that the Soviets would soon stage a nonstop, nonrefueled flight around the world to demonstrate its new military capability. A follow-up editorial in *Aviation Week* said that these developments were a “sickening shock” and that it was another example of the “technical timidity, penny-pinching and lack of vision that characterized our own political leaders.”²⁴ The editorial questioned, “How much longer can we ‘afford’ this kind of leadership and still survive as a free nation?”

There was widespread reaction to this story. The *New York Times* and the *Wall Street Journal* supported the article’s claims, and a Defense Department spokesman said that he was under orders “not to deny confirmations of the story.”²⁵ However, some government officials discredited the story and argued that the reports were untrue. Defense Secretary Neil H. McElroy said that he remained “highly skeptical.” In a news conference Merriman Smith from United Press International asked President Eisenhower about the *Aviation Week* story. Smith asked, “Do we have any reason to believe such a report and, second, how do you feel generally about these unofficial reports of rather extensive Russian accomplishments?” Eisenhower responded by saying, “There is absolutely no intelligence, no reliable evidence of any kind, that indicates that the Soviets have flown a nuclear-powered aircraft.”²⁶ While he said that America was a long way from flying an atomic airplane, he assured the reporters that “we do not abandon the basic research” that will enable a nuclear airplane to one day fly.

Of all the comments swirling around rumored Soviet flight, Eisenhower’s was the most accurate. The Soviet reports were all based on rumors by observers on the ground watching a plane fly overhead. Much like the also popular UFO sightings during the 1950s, there was also no direct evidence of a Russian atomic airplane. Likewise, the United States was no closer to its own atomic plane, and the focus of the effort in both countries was confined to basic research. The primary tool that scientists used in both nations to explore this potential was the research reactor.

²⁴ Robert Hotz, “The Soviet Nuclear-Powered Bomber,” *Aviation Week* (1 December 1958): 21.

²⁵ “Nuclear Plane Details Spur Wide Reaction,” *Aviation Week* (8 December 1958): 28.

²⁶ “Eisenhower’s Nuclear Bomber Comment,” *Aviation Week* (15 December 1958): 27.

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The Golden Age of Research Reactors

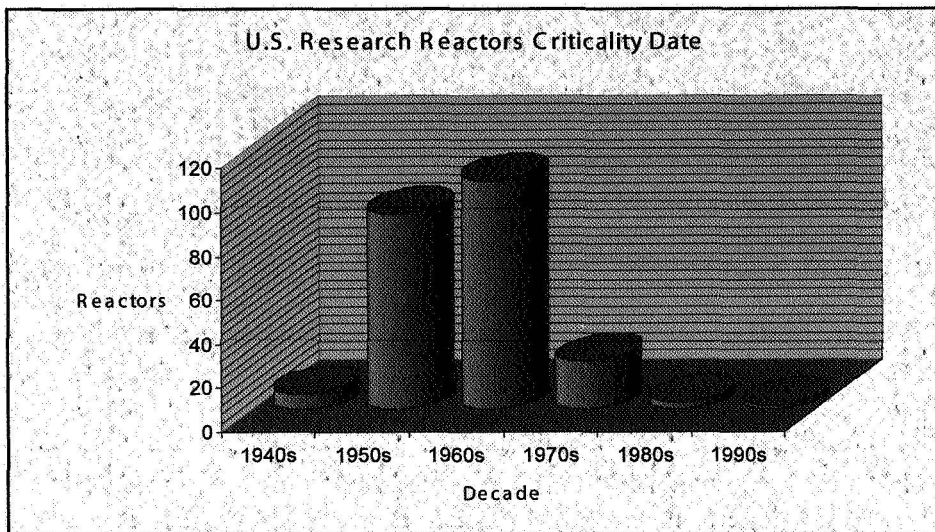
The 1950s and 1960s represented the golden age of American research reactors, with 193 facilities going critical, compared with only a combined total of 34 reactors in the years before 1950 and after 1969 (see chart). These reactors formed the centerpiece of the American nuclear initiative after World War II and provided invaluable research opportunities for American scientists, who began using radiation for diverse fields of experimentation. There were a variety of reasons why research reactors began to proliferate in the United States during this time. First was that the AEC relaxed many of its previously strict standards for those interested in building and operating a reactor. Second, new and more abundant supplies of uranium-235 were becoming available for use as reactor fuel. Third, regulations allowed reactor owners to reap the financial rewards from any discoveries made with the reactor. Fourth, there was a great desire to learn more about nuclear fission. Scientists knew that the true potential of the nuclear reactor could never be realized without a basic understanding of the fission process. Fifth, President Eisenhower's "Atoms for Peace" speech in 1953 called for mobilizing experts through an atomic energy agency to improve agriculture, medicine, and other peaceful incentives. This proved to be a stimulus to the creation of university research reactors. Finally, and perhaps most important, there was a remarkable optimism about the scientific results that were possible with these reactors. For example, one reactor operator enthusiastically said, "The most compelling reason for mounting interest [in research reactors] is...the research potential in physics, engineering, biology, and chemistry associated with reactor use."²⁷ These reasons combined to create a surge in momentum for research and test reactors.

This proliferation of reactors took place in government, academic, and private industrial settings. The government was by far the most prolific builder of research reactors, with 77 constructed between 1942 and 1962. The second largest sponsor was academia, with 41 reactors built on university campuses across the United States. Since this was still a new, secretive, and unproven technology, few corporations assumed the risk in building research reactors, although 18 were built during these years.

Research and test reactors were an example of the "big science" infrastructure that dominated postwar America. Big science came of age after 1945, patterned after the Manhattan Project. Scientists realized that the process of doing science was now fundamentally different. This difference was the "increasing prevalence of

²⁷ Joel W. Chastain, Jr., "The Research Reactor," *U.S. Research Reactor Operation and Use*, ed. Joel W. Chastain, Jr. (Reading, MA: Addison-Wesley Publishing Company, Inc., 1958), p. 1.

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expensive instruments and large externally funded research projects.”²⁸ The government made big science possible through its willingness to expend large amounts of money to develop projects whose outcomes were unknown. Congress made atomic energy a priority and a government enterprise. This activity took place at national laboratories like Argonne, Oak Ridge, Brookhaven, and Los Alamos, and these laboratories took the lead in developing research reactors.

The ability to fund these projects without the guarantee of scientific reward was the central reason that national laboratories spearheaded the nuclear research initiative. As one AEC commissioner wrote, “The nature and cost of the special equipment required for much of both the basic and applied work of interest to the AEC is such as to dictate [nuclear research] in Government-supported laboratories.”²⁹ Even though many academic centers sponsored their own research reactors, the financial requirements of large-scale nuclear research was well beyond what universities could afford. For example, the first reactor at the University of Chicago (funded through the government) cost \$1.5 million in 1942. However, this reactor was modest compared with the larger facilities built less than a decade later. A reactor built in 1950 at Brookhaven cost \$20 million, and another constructed by Argonne and Oak

²⁸ Pamela E. Mack, ed. *From Engineering Science to Big Science: The NACA and NASA Collier Trophy Research Project Winners* (Washington, DC: NASA, 1998), p. xi.

²⁹ Henry D. Smyth, “The National Laboratories—Their Role in Atomic Energy Development,” *Nucleonics* (January 1950): 6.

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Ridge in 1952 cost \$18 million.³⁰

There were two other reasons why national laboratories headed the exploration into nuclear research. The first was secrecy. Although much of the research generated at governmental facilities is eventually declassified for transfer to industry, as it is being produced it often remains classified. This restricted environment, which is best suited for a government laboratory, is essential when the research is directly tied to national security issues, and nuclear research was squarely in this category. American allies like Canada, Britain, and France also began a significant nuclear research effort, but the United States knew that the Soviet Union also coveted this technology. With scientific knowledge becoming a symbolic and practical weapon of the Cold War, any information resulting from nuclear research had to be protected. Although no facility was immune from spies, the U.S. government believed that its best chance for controlling the spread of nuclear secrets was at its own laboratories, and not at academic or industrial sites. Second, national laboratories also had the luxury of assembling a wide variety of specialists from different disciplines that could be brought together for a common goal. The prime example of this was the Manhattan Project. Such a vast, complex, yet single-minded goal would have been far beyond the capabilities of any single university laboratory. Furthermore, since nuclear specialists were all under the control of the AEC, their focus could be redirected at the discretion of the government.

The Soviet Union was quickly gaining a vast nuclear expertise with the help of its own research and test reactor program. The first went critical at the Russian Research Center at the Kurchatov Institute on December 25, 1946. The Soviets had founded this institute three years earlier to develop nuclear weapons, and it became the leading postwar Russian research and development organization in the field of nuclear energy.³¹ This reactor was in operation for over 57 years, and most of the work on the Soviet nuclear airplane took place there.³² From 1946 to 1961 (the year that Plum Brook went critical) the Soviet Union built 15 research and test reactors.

³⁰ J. A. Lane, "Technical and Cost Data for Reactor Design," *Nucleonics* (April 1954): 13.

³¹ "Russia: Kurchatov Institute," found at <http://www.nti.org/db/nisprofs/russia/reactor/research/with/kurchato.htm>.

³² Josephson, *Red Atom*, p. 129.

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Soviet Research And Test Reactors 1946–1961³³

Name	Owner	Operator	Years	Power (KW)	Criticality Date
F-1	Russian Research Centre, Kurchatov Institute	Russian Research Centre, Kurchatov Institute	57	24	12/25/1946
TVR	State Sci. Cntr of Russian Fed. Inst. of Th. & Exp Physics	Institute of Theoretical and Experimental Physics	37	2,500.00	1/1/1949
RPT	Russian Research Centre, Kurchatov Institute	Russian Research Centre, Kurchatov Institute	10	10,000.00	4/1/1952
AM-1	Russian Federation Atomic Energy Ministry	Institute of Physics & Power Engineering	49	10,000.00	6/15/1954
27/BM	Russian Federation Atomic Energy Ministry	Institute of Physics & Power Engineering	47	70,000.00	1/1/1956
SBR-2	Russian Federation Atomic Energy Ministry	Institute of Physics & Power Engineering	1	150	3/1/1957
BR-10	Russian Federation Atomic Energy Ministry	Institute of Physics & Power Engineering	45	8,000.00	6/1/1958
VRL-02	Research Institute of Scientific Instruments	Institute of Scientific Instruments	15	100	1/1/1959
WWR-M	Russian Academy of Sciences	Petersburg Nuclear Physics Institute	44	18,000.00	12/29/1959
IFR (IBR-1)	Russian Federation Atomic Energy Ministry	Russian Federation Atomic Energy Ministry	9	6	12/1/1960
27/BT	Russian Federation Atomic Energy Ministry	Russian Federation Atomic Energy Ministry	42	70,000.00	1/1/1961
FS-1	Institute for Physics & Power Engineering	Institute for Physics & Power Engineering	42	0.2	1/1/1961
VRL-03	Research Institute of Scientific Instruments	Research Institute of Scientific Instruments	8	100	1/1/1961
SM	Ministry on Atomic Energy of Russian Federation	Research Institute of Atomic Reactors	42	100,000.00	1/10/1961
IR-50	Russian Federation Atomic Energy Ministry	Research & Dev. Inst. for Power Engineering	32	50	2/20/1961

³³ Data compiled from International Atomic Energy Agency, "Nuclear Research Reactors in the World," <http://www.iaea.or.at/worldatom/rddb/>. Accessed June 2002.

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Unlike information about the Soviet nuclear airplane program, which American journalists based primarily on rumors and speculation, Russian nuclear expertise was well documented. For example, the *Journal of Experimental and Theoretical Physics of the Academy of Sciences of the USSR* was a scientific journal published in Russian and translated by researchers in the United States. A large majority of its articles discussed nuclear science. In 1961 this journal published a total of 324 articles, and roughly one-third of them explored nuclear topics.³⁴ One Russian scientist claimed that the “artificial production of beams of protons and electrons with enormous energy made it possible to investigate and discover a variety of phenomena of fundamental importance for nuclear physics and for all of science.”³⁵

Americans were well aware of the Soviet progress. In 1959, Walter Zinn, director of Argonne National Laboratory, evaluated Soviet progress in reactor technology for the journal *Nucleonics*. He wrote that Russian technical progress in developing power reactors was rapid. He concluded, “Practically all of the principal types of reactors under exploration in the USA also are being explored by the USSR.”³⁶ Just like the pattern of many other emerging technologies during this period (space satellites, nuclear weapons, nuclear aircraft), one measure of the success of the American research reactor was how well it compared with its Soviet counterparts. America clearly dominated in the sheer number of research and test reactors it had built—roughly 120 by 1961 as compared with only 15 in the Soviet Union. But the Soviet Union was making important advances with high-flux research reactors. The *New York Times* reported on a new Soviet research reactor that would test materials for long-range space voyages with an “intense flux of neutrons.”³⁷ The United States worked to keep pace and surpass Soviet achievements with the development of the Materials Test Reactor at Idaho Falls, a facility that became a model for the Plum Brook reactor.

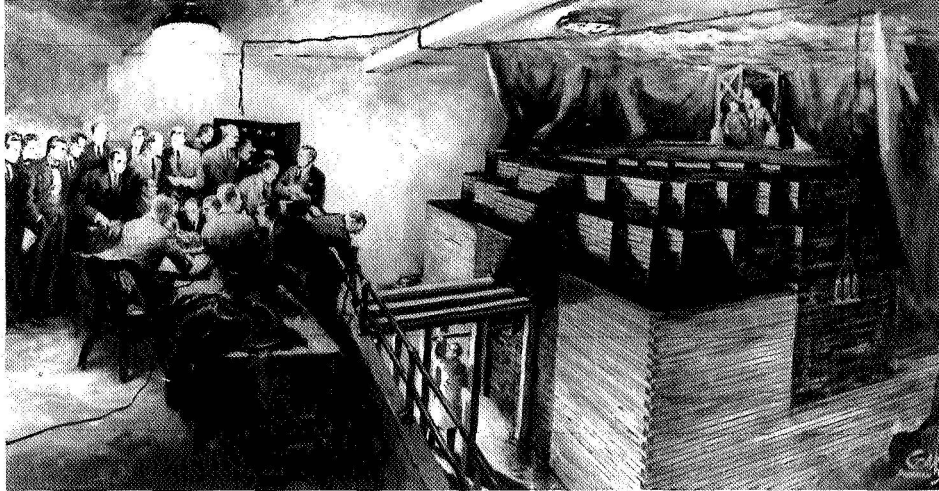
³⁴ “Analytic Subject Index to Volume 13,” *Soviet Physics JETP* 13, 6 (December 1961): 1334–1341, a translation of the *Journal of Experimental and Theoretical Physics of the Academy of Sciences of the USSR*.

³⁵ V. I. Veksler, “The Present State of the Problem of Acceleration of Atomic Particles,” *Soviet Physics Uspekhi* 66(1), 1 (September–October 1958): 54, translated by M. Hamermesh from *Advances in the Physical Sciences of the Academy of Sciences of the USSR*.

³⁶ Walter Zinn, “W. H. Zinn Evaluates Russian Reactor Progress,” *Nucleonics* (March 1959): 104.

³⁷ “Soviet at Work on New Reactor . . . Ultra-High Flux Device,” *New York Times* (22 March 1959): 68; Theodore Shabad, “Russian Reactor to Aid Space Trip,” *New York Times* (10 December 1967): 71.

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Artist's rendering of a group of scientists led by Enrico Fermi, gathered around the first nuclear chain reactor on 2 December 1942. (National Archives and Records Administration NWDNS-326-DV-4 [40])

From MTR to Plum Brook

America's first research reactor was built in 1942 at the University of Chicago. It was called the Metallurgical Laboratory, which was a code name to disguise the nuclear research that was being carried out.³⁸ There beneath the football field in the squash court Enrico Fermi built the world's first atomic pile, named Chicago Pile 1 (CP-1). Its research proved that an atomic bomb was indeed possible and eventually led to the successful creation of this weapon at Los Alamos.

In 1946 Argonne National Laboratory, 25 miles west of downtown Chicago, was the first government center established to assist in the effort to develop new energy sources and to conduct scientific research. Although created after the war, Argonne's nuclear lineage extended back to Fermi, who by this time was considered the "architect of the atomic age."³⁹ Those who worked with Fermi and his research reactor at the University of Chicago gained invaluable experience in the field, and these were some of the people who began working at Argonne. Inside its red brick buildings the Argonne Laboratory carried on the line of "CP" (Chicago Pile) reactors first conceived at the university. With this experience behind them and the new

³⁸ For an excellent overview of the Metallurgical Laboratory see Jack M. Holl, *Argonne National Laboratory, 1946-96* (Urbana and Chicago: University of Chicago Press, 1997), pp. 1-46.

³⁹ "Enrico Fermi: Architect of the Atomic Age," *Nucleonics* (January 1955): 70.

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designation as the lead nuclear laboratory by the newly formed AEC, Argonne was poised to shape the future of American nuclear research.

One essential ingredient to developing a strong nuclear program was the establishment of secluded and safe sites on which to build reactors. Argonne's director, Walter Zinn, wanted to establish a reactor "proving ground" in a remote western state. In 1948 he began trying to convince the AEC to support his plans. By March 1949 the AEC accepted Zinn's idea and began looking for locations in both Montana and Idaho, later settling on a 400,000-acre location at Idaho Falls. It was at Idaho Falls that the AEC assigned Argonne three reactor development projects. The most important defense project was the Mark II reactor for the Navy. The design of the project eventually shifted to Westinghouse engineers, and in June 1953 the first nuclear submarine traveled from the United States' eastern seaboard to Ireland.⁴⁰ A second reactor project was the Experimental Breeder Reactor (EBR-I), originally called CP-4, which was the first attempt to produce nuclear-generated power. On 20 December 1951 Zinn charted in his notebook, "Electricity flows from atomic energy. Rough estimate indicates 45kw."⁴¹ Many argue that this was the first time that electricity was ever generated from nuclear power.

Argonne's third reactor project was the Materials Testing Reactor, which became the first large-scale test reactor in the world at what was called the National Reactor Testing Station near Idaho Falls, Idaho. This was a huge reactor range that was half the size of Rhode Island.⁴² This effort was in collaboration with the Oak Ridge National Laboratory, which was responsible for the design of the reactor itself.⁴³ Oak Ridge was as important as Argonne for its development of nuclear reactors. The Oak Ridge, Tennessee, site was initially used during World War II for various atomic bomb-related activities, including plutonium production and the separation of uranium-235 from uranium-238. In 1948, it officially became known as the Oak Ridge National Laboratory. Eugene Wigner went to Oak Ridge in 1945 with the plan to build the nation's first peacetime research reactor. The Oak Ridge Laboratory later became known for being the home of the AEC's Reactor Training School.

⁴⁰ "Nautilus Awaits Reactor," *Nucleonics* (February 1954): 22.

⁴¹ Holl, *Argonne National Laboratory*, p. 99.

⁴² Robert K. Plumbs, "Big Idaho Reactor Shown by A.E.C.," *New York Times* (22 August 1954): 37.

⁴³ For a history of Oak Ridge see Charles W. Johnson and Charles O. Jackson, *City Behind a Fence: Oak Ridge Tennessee, 1942-1946* (Knoxville: The University of Tennessee Press, 1981); Leland Johnson and Daniel Schaffer, *Oak Ridge National Laboratory: The First Fifty Years* (Knoxville: The University of Tennessee Press, 1994); "History of ORNL Research Reactors," Box 252, Folder 1, Plum Brook Archives.

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By 1953 this school had a curriculum of six four-week courses and had trained over 700 people from all over the world.⁴⁴

In December 1945 Wigner and his team began the design of the reactor, which was eventually renamed the Materials Testing Reactor. Oak Ridge and Argonne completed the design in August 1946 as a joint project. While Oak Ridge was principally responsible for the design, Argonne managed the area surrounding the reactor tank. John R. Huffman led the Argonne effort, and by March 1950 he had finished nearly all of the design for the service buildings, experimental reactor ports, irradiated fuel element storage, and the coffins that transported the radioactive materials.⁴⁵ In July 1949 the Blaw-Knox Construction Company began the engineering work, and in May 1950 the Fluor Corporation, Ltd., broke ground. Later that year the Phillips Petroleum Company became the operating contractor for the reactor.

The 40-megawatt reactor went critical in March 1952, and it achieved full power in May. Its purpose was to test materials for future reactors by bombarding them with intense neutron radiation. It had roughly 100 holes for experiments, several of which could be used to irradiate reactor components. For example, fuel assemblies could be exposed to simulated conditions of temperature, pressure, and coolant.⁴⁶ Alvin Weinberg, who was at the time chief of physics at Oak Ridge, decided on an enriched uranium fuel reactor with river water used as moderator and coolant. The core was uranium, sandwiched between plates of aluminum. These plates were surrounded by beryllium, which reflected neutrons and ensured a high neutron flux for research purposes.⁴⁷ The beryllium was also used because there was a high-energy reaction with gamma rays that resulted in the production of neutrons.

One of the difficult challenges of the Materials Testing Reactor was its organization and staffing. After it went critical the Phillips Petroleum Company managed all of the reactor operations, including the job of finding qualified people to run it. One manager said this was difficult because “No one had previous experience in the field.”⁴⁸ The company tried to simplify the problem by reassigning current employees to tackle the challenges of the job. The administration started by filling

⁴⁴ Gordon Dean, *Report on the Atom: What You Should Know About the Atomic Energy Program of the United States* (New York: Alfred A. Knopf, 1953), p. 221.

⁴⁵ Holl, *Argonne National Laboratory*, p. 99.

⁴⁶ John R. Huffman, “The Materials Testing Reactor,” *Nucleonics* (April 1954): 21.

⁴⁷ Johnson and Schaffer, *Oak Ridge National Laboratory*, pp. 32–34.

⁴⁸ R. L. Doan, “Organization and Staffing the Materials Testing Reactor,” *Nucleonics* (March 1953): 10–13.

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the jobs for manager, assistant manager, and plant engineer. The three men chosen had an average of 18 years with Phillips. The operations branch included five shifts of personnel, with 14 people on each shift. Their job was to keep the Materials Testing Reactor running day and night. Each of the five shift supervisors had been with Phillips an average of ten years. Although the new staff had little experience in running a test reactor, they were able to quickly manage the Materials Testing Reactor's experiments. One year after the reactor went critical, there were 12 organizations sponsoring its work. These included Argonne, Oak Ridge, Brookhaven, General Electric Company, Westinghouse Electric Corporation, North American Aviation, Inc., University of California Radiation Laboratory, Los Alamos Scientific Laboratory, California Research and Development Company, California Research Corporation, Monsanto Chemical Company, and Tracerlab, Inc. After one decade in operation, it had run for 50,000 hours and had performed 20,000 neutron irradiations.

Perhaps most importantly, the Materials Testing Reactor was extremely influential for all of the test reactors that came after it. Engineers measured its experimental value in terms of its neutron flux, which was the number of neutrons a reactor could pass through a square centimeter of space. The *New York Times* praised the Materials Testing Reactor for having "a greater neutron flux than any machine in existence."⁴⁹ Jack M. Holl, author of the history of Argonne, wrote, "The design of cores and fuel elements of virtually every major nuclear reactor built after 1952 was influenced by studies conducted with the MTR."⁵⁰ One reactor influenced by the Materials Testing Reactor design was a new NACA reactor that was in the planning stages to support the Aircraft Nuclear Propulsion program. In the mid-1950s NACA was searching for a location for the reactor and found it at the home of the former Plum Brook Ordnance Works.

Finding a Location

The Naval Appropriations Bill of 1915 established the National Advisory Committee for Aeronautics (NACA). The rationale for its creation was a fear that if the government did not support aviation research, the nation might lose the initiative begun by the Wright brothers and fall behind its European rivals. Prior to World War II it did not receive a great deal of government funding or commitment. Walter

⁴⁹ Robert K. Plumbs, "Big Idaho Reactor Shown by A.E.C.," *New York Times* (22 August 1954): 37.

⁵⁰ Holl, *Argonne National Laboratory*, p. 114.

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McDougall argued, "From 1789 to 1941 the U.S. government stood relatively aloof from science and technology."⁵¹ Even though NACA's largest yearly budget was \$3.1 million in 1940, it still managed to inform the aviation community of the latest advances, as well as make contributions of its own (i.e., the Langley wind tunnel in 1931). Nevertheless, the development of new scientific knowledge was an area that the government largely stayed out of prior to 1941, instead letting individuals and institutions pave the way. But to compete in the new postwar political environment of an intensifying Cold War, and amid concerns about Soviet scientific and technological superiority, the United States government transformed itself into a key patron of research and development. NACA carried out the aviation arm of this work.

As soon as NACA considered constructing a nuclear test reactor, engineers at NACA's Lewis Flight Propulsion Laboratory began lobbying to take charge of the project.⁵² According to Lewis historian Virginia Dawson, "The Lewis staff were old hands at dealing with the opportunities and disappointments associated with the development of nuclear propulsion."⁵³ Even prior to the dropping of the atomic bombs during World War II, Bruce Hicks and Sidney Sheldon (a Lewis Ph.D. physicist and chemist respectively) began thinking about the possibilities of nuclear energy for aircraft propulsion. Although they were unaware of the Manhattan Project, they knew that the atom would soon be split, and they wrote a memo to NACA headquarters requesting permission to explore this new technology. They hoped to eventually have an entire nuclear team at Lewis.⁵⁴

Although Washington was initially reluctant to bring NACA into its inner nuclear circle, by 1948 it was clear that the government needed this organization. On July 15, 1948, the AEC and NACA agreed to a formal research program. Lewis personnel were sent to the Oak Ridge National Laboratory for training, and soon the Lewis Laboratory's strong reputation began spreading to the highest levels of

⁵¹ Walter A. McDougall, . . . *The Heavens and the Earth: A Political History of the Space Age*, New York: Basic Books, Inc., 1985), pp. 75, 132.

⁵² H. S. Bloomfield and R. J. Sovie, "Historical Perspectives: The Role of the NASA Lewis Research Center in the National Space Nuclear Power Programs," presented at the Conference on Advanced Space Exploration and Initiative Technologies, September 4-6, 1991, NASA Technical Memorandum 105196.

⁵³ Virginia Dawson, *Engines and Innovation* (Washington, D.C.: NASA SP-4306, 1991), p. 184.

⁵⁴ Bruce Hicks and Sidney Simon to Addison Rothrock (Acting NACA Executive Engineer), "Nature of AERL Research on Nuclear Energy Fuels," 11 June 1945, 34/17112, NASA Glenn Archives.

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government.⁵⁵ New funds became available for Lewis engineers to work with emerging nuclear technology. In 1949 Lewis built a cyclotron for research purposes. This was a machine that accelerated charged particles while a magnetic field confined them to a circular path. General Electric was the contractor and designed the 60-inch frequency cyclotron that produced 21-mega-electron-volt deuterons and 42-mega-electron-volt alpha particles.⁵⁶ With it Lewis engineers began studying the strength of materials that had been subjected to neutron fields. Harold Finger was an engineer at Lewis at the time who later became the head of the joint AEC–NASA Space Nuclear Propulsion Office (SNPO). He recalled, “There was no question that we felt we ought to be able to get involved with any application of nuclear energy related to aircraft propulsion.”⁵⁷ Lewis was the best qualified because of its propulsion and engine expertise, and there was a core of engineers eager to become more involved in nuclear propulsion applications.

Several Lewis employees had already been working on issues related to the Aircraft Nuclear Propulsion program. Frank Rom was an engineer at Lewis who started his career there in 1948 working on long-range aircraft. He was a member of a team that devised new ways for conventional aircraft to travel long distances, primarily for bombing purposes. His team experimented with jet engines and turbo-prop engines, but when the nuclear idea surfaced, Lewis reassigned them to work on the Aircraft Nuclear Propulsion project. They started by designing some reactors on paper to determine their size and weight. Like other researchers, they soon came to understand the daunting technical problems. They looked for ways to develop a shield that was light and able to protect the pilots and crew from radiation. The reactor also had to be crash resistant to ensure the safety of people on the ground. After Rom and his team defined the critical factors, they came to a disturbing conclusion—the plane would need to be one million pounds in weight. But, Rom said, “We could make any size airplane, we thought. So that didn’t bother us then.”⁵⁸

Because of the Lewis nuclear expertise, the Cleveland laboratory appeared to be the most qualified to take the lead in developing a new test reactor to support development on the atomic airplane. Benjamin Pinkel, then chief of the Materials and Thermodynamics Division, wrote a memo in 1952 to officially make the case for the Lewis involvement. He said that of the many organizations that were currently

⁵⁵ J. F. Victory (Executive Secretary) to Jerome C. Hunsaker (Chairman, NACA), 16 April 1947, NASA HQ, Nuclear Powered Aircraft series.

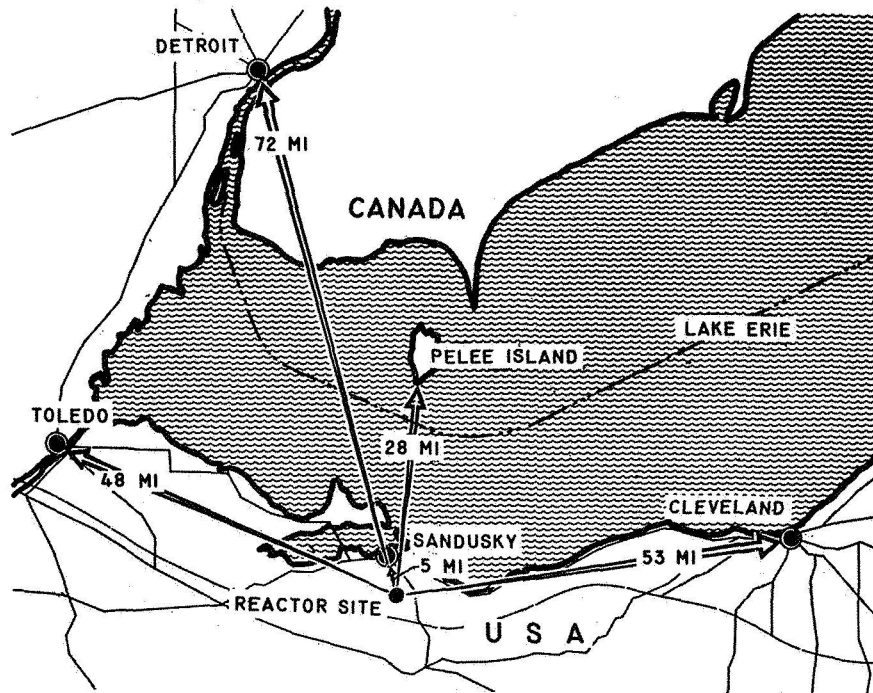
⁵⁶ Interview with Jim Blue by Mark D. Bowles, 11 February 2002.

⁵⁷ Interview with Harold Finger by Virginia Dawson, 4 April 2002.

⁵⁸ Interview with Frank Rom by Virginia Dawson, 27 September 2002; Frank E. Rom, “Airbreathing Nuclear Propulsion: A New Look,” *Nuclear News* (October 1971): 79.

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Map of Western Lake Erie



This map demonstrates the proximity of local cities to the Plum Brook reactor. (NASA CS_12414)

sponsored by the Air Force and the AEC to develop a nuclear-powered aircraft engine, the Lewis organization had developed unique expertise in the nuclear field. Pinkel said, "The Lewis Flight Propulsion Laboratory now has an extensive program on this subject which covers heat transfer, cycle analysis, reactor analyses, materials, corrosion, radiation damage, and thermal distortion."⁵⁹ NACA agreed with Pinkel, and it assigned Lewis the lead role in designing a nuclear reactor facility to evaluate aircraft reactor power plant systems and components.

One of the first steps in the design process was to find a location for the reac-

⁵⁹ Benjamin Pinkel memo to Chief of Research, 29 February 1952, NASA-HQ unprocessed collection.

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tor.⁶⁰ On September 13, 1955, Lewis officials prepared an extensive site survey for NACA.⁶¹ Representatives from the laboratory and the Nuclear Development Associates of New York (an independent engineering firm that was consulted for its expertise in the use of nuclear energy) examined 19 sites in Ohio and Pennsylvania for the reactor facility. The site survey ranked 33 different factors in three main categories—safety, cost, and convenience. The decision was narrowed down to two facilities—the Plum Brook Ordnance Works and the Ravenna Arsenal.

Ravenna had also been an ordnance site during World War II and was located about 90 minutes east of Cleveland. Plum Brook and Ravenna were equally weighted in almost every category. The cost factors were identical, including land, availability, and development features. The safety factors were also nearly the same, including air and water waste disposal possibilities; isolation from high population areas; electricity, water, and communications services; adequate roads; relationship to disaster control agencies; protection from sabotage; large area; and a good burial ground (this was an unusual category, but nevertheless a human burial ground was a factor that was considered, though the reasons behind it were unstated). Ravenna actually scored more points in the safety category because it had much better hospital facilities than Sandusky. The final category was convenience, and this is where Plum Brook beat out its competition, because it was located slightly closer to the Lewis Laboratory. The final score was 98 points for Plum Brook and 95 points for Ravenna.⁶²

In September 1955 the *New York Times* reported on the proposed new facility and discussed the reasons for the NACA choice of Plum Brook: it was near Cleveland and the Lewis Flight Propulsion Laboratory (50 miles); it was in a moderately populated area; it had much of the infrastructure required to operate a nuclear reactor (roads and security fences left over from the ordnance works); and it was already a government-owned facility.⁶³ Sandusky newspapers also announced the news to the residents of the area. Reporters speculated that the reactor would cost \$4.5 million to construct and would be staffed by a team of 50 engineers. NACA emphasized that “elaborate safeguards” would be installed to reduce the dangers associated with radioactivity, including protecting the air and water supplies from contamination. For the most part the community welcomed the reactor. Congressman A. D. Baumhart, who 15 years previously failed in the fight to help farmers

⁶⁰ “Plum Brook Station Retention Plan,” 1976, Box 106, Folder 11, Plum Brook Archives.

⁶¹ “Site Survey for NACA Research Reactor,” 13 September 1955, Plum Brook Archives.

⁶² “Preliminary Site Evaluation Chart,” Plum Brook Archives.

⁶³ “Atomic Power for Planes,” *New York Times* (25 September 1955).

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keep possession of the Plum Brook land, was an active proponent in bringing the reactor to his district. He had worked for several months contacting NACA and other officials, promoting the site as an excellent choice for the reactor.⁶⁴ E. R. Sharp, director of the Lewis Flight Propulsion Laboratory, made the announcement official on September 20, 1955. He estimated that the design of the reactor, which was then in progress, would be finished by the end of the year, and then construction would start in 1956.⁶⁵

The AEC's Reactor Safeguards committee was responsible for reviewing each reactor application, and this included granting approval for site selection.⁶⁶ The AEC was reluctant to give NACA the go-ahead to build its reactor at Plum Brook because of nearby cities; in this respect Plum Brook was unlike the MTR, which was sparsely populated. Although it argued that a less populated site would have been better, finally it reluctantly granted its approval.⁶⁷ In comparison, the Materials Testing Reactor was located in an extremely desolate area of Idaho.

The NACA reactor would take its place alongside other leading organizations that were contributing to the nuclear aircraft program. These included the Convair Division of General Dynamics, which was developing an initial design for the airframe of a nuclear bomber. General Electric's Nuclear Propulsion Division was in charge of power-plant development. Convair worked with General Electric to solve engine and airframe problems. Pratt & Whitney was responsible for developing the atomic indirect cycle nuclear engines. The Air Force and Lockheed Martin also played a role in designing the airplane components, and the Lockheed Nuclear Laboratory performed experimental studies on the effects of radiation on materials.⁶⁸ The Plum Brook reactor was to be far more advanced than Lockheed's, and it was hoped it would provide a significant research tool in helping to realize the dream of atomic-powered airplanes.

⁶⁴ "Pick Plum Brook for Research Site," *Sandusky Register Star News* (20 September 1955).

⁶⁵ "Plum Brook Ohio Ordnance Site Chosen by NACA for Research Reactor," *Wing Tips* 13, 18 (30 September 1955), NASA-Glenn Research Center Archives.

⁶⁶ Plum Brook was similar to other nuclear sites. For example, the MTR Engineer Works manufactured plutonium during World War II. Manhattan Project officials selected this site of a "sparsely populated stretch of struggling orchards, farms, and ranches along the Columbia River" that was reminiscent in many ways of the land at Plum Brook prior to its ordnance works. At the MTR the government created a new kind of "atomic space," that it would later emulate in places like Plum Brook. Richard White, *The Organic Machine* (New York: Hill and Wang, 1995), pp. 81–82.

⁶⁷ George T. Mazuzan and J. Samuel Walker, *Controlling the Atom: The Beginnings of Nuclear Regulation, 1946–1962* (Berkeley: University of California Press, 1985), p. 221.

⁶⁸ "Nuclear Plane Contracts," *Aviation Week* (30 March 1959): 29.

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Designing the Reactor

The traditional view of engineering is that it is simply an applied science whereby the engineers inherit knowledge from scientists and use it to create a material artifact. Most engineers know, and historian Walter G. Vincenti has demonstrated, that this is a naive viewpoint because there is rarely a defined blueprint to follow in the process of designing and creating new technologies.⁶⁹ Engineering knowledge is not a handmaiden to science. It has a domain of its own, with intersecting tentacles into the scientific world. The design of the Plum Brook reactor was one such example of this unique type of engineering knowledge. Although nuclear science played an important role in the design of the reactor, engineers built the facility with an eye toward the utilitarian end of a working experimental facility. This divide and distinction between scientific and engineering knowledge was also evident within the Plum Brook work culture. Some believed Plum Brook engineers considered physicists to be “damned useless eggheads.”⁷⁰ This was a common divide with prejudice existing in both camps. Hugh Gusterson, in his history of Lawrence Livermore Laboratory, wrote that the “physician’s greatest insult [was] likening other physicists to engineers.”⁷¹ But, Plum Brook was an “engineer’s” reactor with few physicists around, and prior to its design the engineers knew little of nuclear science.

Though engineers dominated the group at Lewis, E. R. Sharp, the director of the laboratory from 1947 to 1960, was a lawyer. He served in World War I in the Navy, and then became an early employee at Langley Research Center, where he became a construction administrator. In 1924 he earned a law degree from William and Mary and arrived in Cleveland in 1941 when ground was broken at Lewis. As a lawyer his role at the facility was to be an administrator, and he left the engineers to themselves to do their work without meddling in the details of their research.⁷²

One of the most talented engineers on his staff was Abe Silverstein. He began his NACA career in 1929 as a mechanical engineer at Langley.⁷³ His early expertise was altitude wind tunnels, and he is credited with the conception, design, and con-

⁶⁹ Walter G. Vincenti, *What Engineers Know and How They Know It: Analytical Studies from Aeronautical History* (Baltimore and London: The Johns Hopkins University Press, 1990), pp. 3–6.

⁷⁰ Interview with Myrna Steele by Mark D. Bowles, 7 February 2002.

⁷¹ Hugh Gusterson, *Nuclear Rites: A Weapons Laboratory at the End of the Cold War* (Berkeley: University of California Press, 1996), p. 48.

⁷² Dawson, *Engines and Innovation*, p. 20.

⁷³ Robert W. Graham, “Four Giants of the Lewis Research Center,” NASA TM-83642, May 1984. “Abe Silverstein Biographical Data,” found at www.grc.nasa.gov/WWW/WPAO/html/abebio.htm.

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struction of some of the early supersonic wind tunnels. He was transferred to the Lewis Laboratory in 1943 as chief of the wind tunnel and flight division. By 1949 he was in charge of all Lewis research activities and became associate director three years later. Other engineers greatly respected (and some feared) his awesome abilities and his demanding presence. One engineer who later went on to become the head of Plum Brook called him “the renaissance man of aircraft.”⁷⁴ Silverstein was convinced that nuclear propulsion would become as revolutionary as the turbojet.

Silverstein was an active proponent of the atomic plane and welcomed a Lewis involvement in the project with the design and construction of the Plum Brook nuclear test reactor. NACA began the preliminary design for what became the Plum Brook reactor in August 1954 (before the site was selected) and completed it one year later.⁷⁵ Silverstein gave 12 engineers already working at the Lewis laboratory in the materials and stress division the task of designing the reactor. Few of them had any nuclear experience. Division Chief Benjamin Pinkel, upon learning of the new assignment, went to the library and checked out all of the latest textbooks on nuclear reactors he could find. After his intensive self-study he began teaching his supervisors.⁷⁶ Theodore “Ted” Hallman had a Ph.D. in nuclear engineering and was one of the few who had experience in this field. He worked on the reactor design and managed the startup test programs at Plum Brook; he later became its first division chief. 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 the MTR. Through this process they were able to master the concepts and design a unique and powerful test reactor, with an unparalleled emphasis on experimental facilities. Johnson confessed, “I didn’t know an alpha particle from a gamma ray when we started,” but through study and practical experience he learned the field quickly.⁷⁷

Jim Blue, who headed the Lewis cyclotron, recalled that while they were developing cyclotron experiments, the designs for the Plum Brook reactor were under way in the same building. When these designers got to the point where they needed

⁷⁴ Interview with Alan “Hap” Johnson by Mark D. Bowles, 20 March 2002.

⁷⁵ Atomic Energy Commission, “Quarterly Report on Status of Reactor Construction,” 7 November 1961, Box 1, Folder 5, Plum Brook Archives.

⁷⁶ Interview with Donald Bogart by Mark D. Bowles, 19 February 2002.

⁷⁷ Interview with Alan “Hap” Johnson by Mark D. Bowles, 20 March 2002.

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help with instrumentation, they selected Blue and some of his co-workers to assist.⁷⁸ John Acomb was head of the instrument development section at Plum Brook, and he recalled how important Jim Blue's expertise was in helping out at the reactor. He regarded Blue as a mentor. He said, "When I had problems that I couldn't solve, I always called Jim and he would come out to Plum Brook. He was very knowledgeable in nuclear physics."⁷⁹

While the reactor was being designed, Abe Silverstein also established a nuclear training school at Lewis to provide broad training in nuclear applications. At this time the universities were far behind the government in setting up programs to train nuclear physicists and engineers. Because there was no university program that taught advanced reactor technology, Silverstein designed the Lewis six-month training program to give current engineers the background necessary to work at a reactor facility. Though it is unclear exactly how many engineers went through the program, estimates are that there were 4 or 5 classes of 20 to 30 students each.⁸⁰ Lewis selected the students from experienced engineers already working in the compressor and turbine group and new "fresh outs" from college. Most of the recent graduates had little nuclear background. For example, Joe Savino, who eventually worked at the Plum Brook process systems section, had graduated from Purdue University in 1955 with a degree in fluid mechanics and heat transfer. When Lewis assigned him to go to the reactor training program, Savino said, "I didn't know a nuclear reactor from an auto engine."⁸¹

Ben Pinkel and Ted Hallman designed the program, and teachers like Jim Blue, Sam Kaufman, Donald Bogart, and Frank Rom contributed to its development and operation.⁸² Lecturers from the Case Institute of Technology were also invited to round out the students' education. Though it was not nearly as well known as nuclear schools at Oak Ridge, the nuclear school at Lewis produced its share of individuals who later became prominent in their fields: Harold Finger (head of the Space Nuclear Propulsion Office), Art Hansen (president of Purdue University),

⁷⁸ Interview with Jim Blue by Virginia Dawson, 26 September 2002.

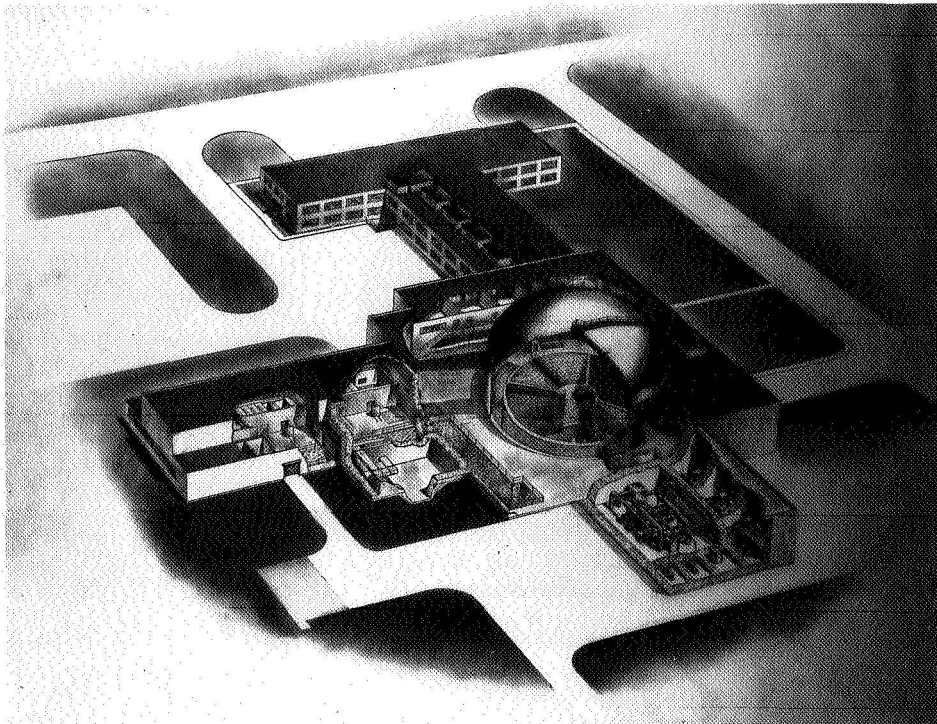
⁷⁹ Interview with John Acomb by Mark D. Bowles, 13 February 2002.

⁸⁰ Interview with Donald Bogart by Mark D. Bowles, 19 February 2002.

⁸¹ Interview with Joe Savino by Mark Bowles, 21 September 2002.

⁸² Interview with Jim Blue, conducted by Mark D. Bowles, 11 February 2002.

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Artist's conception of Plum Brook with a cutaway for the containment vessel showing the quadrants, reactor pressure tank, and lily pad area (1956). (NASA C-1956-42673)

and Edgar Cortright (director of Langley).⁸³ The final exam for the first class of 24 students was to design a nuclear reactor that operated in space (ironically predictive of Plum Brook's soon to be shifting focus).

Plum Brook's main nuclear facility was to be a 60-megawatt light-water-cooled and -moderated test reactor. There was also a 100-kilowatt Mock-Up Reactor (a research reactor), which was used to aid in the design of experiments that were going into the main reactor. The closest comparison to Plum Brook's main reactor was the Materials Testing Reactor. Both were test reactors that were built to produce neu-

⁸³ This first class was joined by Hubert Allen and Howard Herzig, who worked with Hansen on turbines; R. Cavicchi, E. Davison, and Robert English, who worked on fundamental turbines; Dan Bernatowicz, Ted Fessler, Sy Lieblein, and Carl Schwenk, who worked with Finger on compressors; Tony Diaguila, Pat Donoughe, Herman Ellerbrock, John Livinggood, and Henry Sloan, who worked on turbine cooling; and Tom Dallas, Irving Goodman, Eldon Hall, Jim Kramer, Herb Heppler, Bill Phillips, Lou Rosenblum, and Cortright, who were from various other divisions around Lewis. Dawson, *Engines and Innovation*, p. 172, n26.

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Abe Silverstein addresses an audience at the September 1956 groundbreaking ceremony for the Plum Brook reactor. The address was carried live on local radio stations. (NASA C-1956-43039)

tron beams for experimental purposes. The Plum Brook fuel elements were directly patterned on the Materials Testing Reactor's. They were approximately 4 feet long and had 14 plates with uranium enriched to 93.5% uranium-235.⁸⁴

Though there were similarities, Plum Brook did have unique features. It was more powerful than the MTR, with its 40 megawatts of power, compared with Plum Brook's 60 megawatts. Moreover, the emphasis on testing was what made Plum Brook different from other reactors at the time.⁸⁵ Specifically the difference was that aircraft engine components could be irradiated to the point of failure without causing any damage to the radiation source itself. Hugh L. Dryden, NACA director, said that while the Plum Brook reactor would never generate power, its significance would be its radiation source for testing fuels, coolants, structural mate-

⁸⁴ Interview with Robert Defayette by Virginia Dawson, 21 September 2002.

⁸⁵ Interview with Robert Defayette, conducted by Mark D. Bowles, 29 January 2002.

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rials and devices, and aircraft equipment.⁸⁶

Plum Brook also had much larger experimental facilities than the MTR that were adjacent to the core, so that bigger components could be experimented upon.⁸⁷ Hap Johnson recalled visiting the MTR several times. He said, "We looked at their designs . . . and looked at the shortcomings and didn't build anything like it."⁸⁸ He said that the final similarity was that both reactors were designed to produce neutron fields and not power. With the design complete, the Plum Brook nuclear test facility was ready for groundbreaking.

Building the Reactor

Several weeks before the official groundbreaking ceremonies, the Sandusky community began preparing for the event. Local notices advertised the much-anticipated occasion, which was to take place at 11 a.m. on September 26, 1956, behind the fences at Plum Brook.⁸⁹ The Sandusky Chamber of Commerce sponsored the ceremony. Local community leaders like Congressman A. D. Baumhart from Vermillion believed that the reactor facility would make Sandusky "one of the centers of the nation and world for the development and uses of atomic engines."⁹⁰

Richard Kruse, president of the Sandusky Chamber of Commerce, was the master of ceremonies for the occasion. It began with an invocation given by Reverend Raymond Etzel of St. Mary's Church and was followed by turning over of the symbolic first shovelful of dirt. Edward Sharp, director of the Lewis Laboratory, used a silver shovel, and Congressman Baumhart used a silver pick to officially break ground. The silver pick and shovel were the same ones used at the groundbreaking for the Lewis Laboratory on January 23, 1941.⁹¹ The tools had been on display in the Lewis cafeteria until they were used again at Plum Brook.

There was a large and distinguished guest list of government officials and civilians in attendance. After Sharp and Baumhart broke ground, several speakers discussed the role that the Plum Brook reactor would play in aeronautics research.

⁸⁶ "NACA Reactor to Test Engine Parts," *Aviation Week* (28 March 1955): 13.

⁸⁷ Interview with A. Bert Davis by Mark D. Bowles, 27 February 2002.

⁸⁸ Interview with Alan "Hap" Johnson by Mark D. Bowles, 20 March 2002.

⁸⁹ "Top Officials Expected at Nuclear Site," *Sandusky Register Star-News* (13 September 1956).

⁹⁰ A. D. Baumhart, found in, "Break Ground Soon for Nuclear Reactor at Ordnance Plant," *Sandusky Register Star-News* (10 September 1956).

⁹¹ "Ground Breaking at Plum Brook," *Wing Tips* (10 October 1956): 1.

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Sharp was the first to address the audience. He argued that for the United States to maintain its leadership in the skies, it needed to develop an atomic airplane. But this necessitated a great deal of research, and he was confident that the Plum Brook reactor would help solve many of the problems standing in the way of this development. It would achieve these research goals by simulating the temperatures, stresses, corrosion, and radiation conditions that material components would be exposed to in a nuclear reactor.⁹²

Abe Silverstein was the next person to address the audience. With great optimism he predicted the impact nuclear power would have on aviation. He said, "Despite recent important advances in aerodynamic efficiencies for aircraft at supersonic speeds, nuclear power is still the 'shining hope' for increasing the range of aircraft at high speeds and for increasing aircraft ranges to values unobtainable with conventional and special chemical fuels." He also illustrated the dramatic improvements that this would make for long-range bombers. Currently these bombers had to carry over 100,000 pounds of fuel for lengthy missions. However, Silverstein proclaimed that a "piece of Uranium 235 with the same energy content would weigh less than one ounce."⁹³ This analysis ignored the findings of Silverstein's own engineers that the plane itself would likely weigh over one million pounds because of the radiation shielding requirements. Nevertheless, Silverstein went on to espouse its merits. He said that the nuclear-powered airplane would have the capability of flying nonstop to any place on the earth and then returning. Silverstein and others believed that in the future flight durations would no longer be limited by technology, but instead would become solely a measure of the endurance of the crew.

Addison M. Rothrock, assistant director of propulsion research at NACA headquarters in Washington, DC, also spoke at the ceremony. He described how various nuclear engine components would be tested at the Plum Brook reactor to determine how effective they would be and what improvements were needed to power a nuclear airplane. He said that the reactor would be one of the first of its kind and that all of the data would be turned over to the Department of Defense. He further emphasized to the community members in attendance that the reactor would be safe and would not endanger local residents. The final speaker was Congressman Baumhart, who echoed these sentiments. He also emphasized safety and proclaimed

⁹² "Plum Brook Research Reactor Facility Construction Begun," *Wing Tips* (26 September 1956); 1, 4-5.

⁹³ Abe Silverstein remarks at the Plum Brook reactor groundbreaking, in "Break Ground for Reactor Here," *Sandusky Register Star-News* (26 September 1956).

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Aerial view of the construction of the containment vessel dome. (NASA 2005-1198)

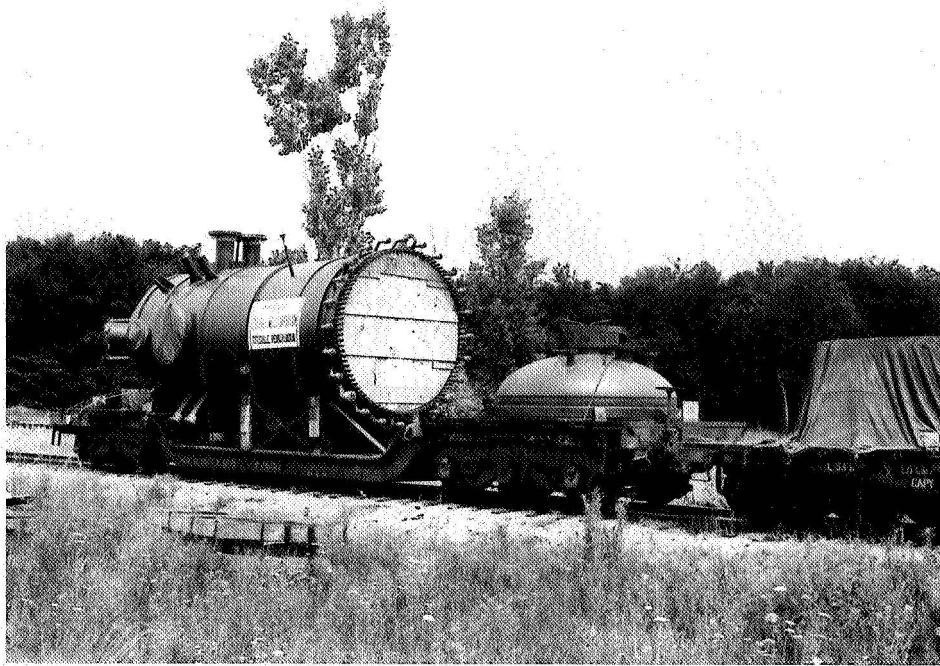
that the reactor would be a “firm step forward in the atomic future.”⁹⁴ The ceremony concluded with a benediction given by the Reverend Robert Peters, who was a pastor of the First Congregational Church.

The gathering then moved to the Plum Brook Country Club for luncheon festivities, where John F. Victory, NACA’s executive secretary, gave a presentation.⁹⁵ He was no less enthusiastic than the previous speakers had been. He stated that the development of the Plum Brook reactor would “presage a new era in aviation power.” He looked back at the increase in air speeds per year dating back to the Wright brothers’ first flight in 1903. In the years after their historic flight the aver-

⁹⁴ A. D. Baumhart’s remarks at the Plum Brook reactor groundbreaking, found in “Break Ground for Reactor Here,” *Sandusky Register Star-News* (26 September 1956).

⁹⁵ “Top Nuclear Research Officials to Describe New Lab in Erie Co.,” *Sandusky Register Star-News* (25 September 1956).

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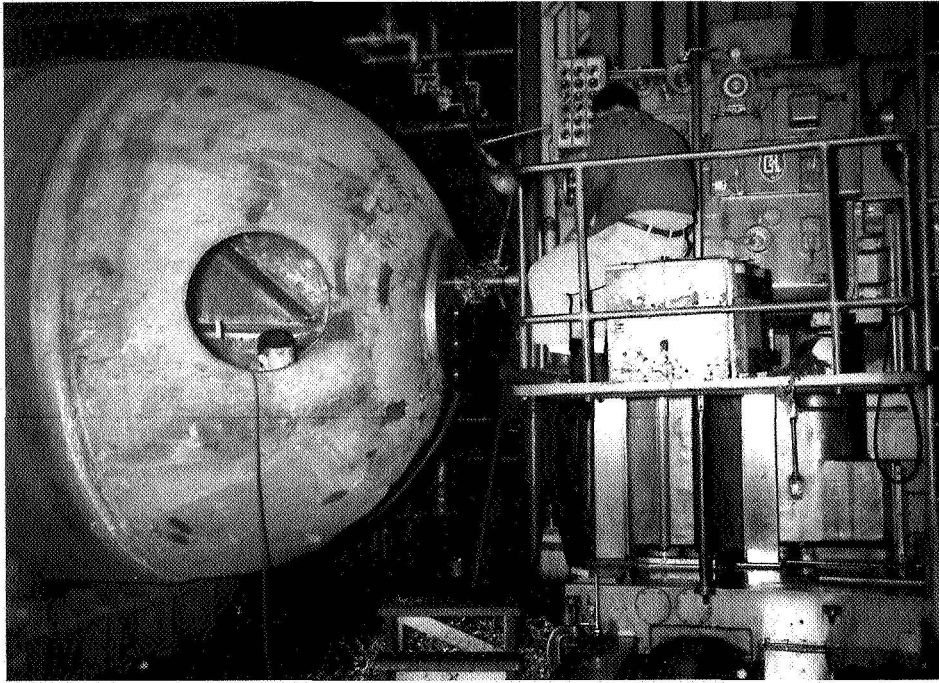
The reactor pressure tank being delivered to Plum Brook by railroad. (NASA C-2003-833)

age gain in air speed per year was only 12 miles per hour. Recently, he said, it had increased to a 165 miles per hour gain. But with nuclear power he imagined that future speeds could be dramatically improved and that 90-minute flights from San Francisco to New York would become commonplace. Victory concluded by praising the “progressive thinking community” that welcomed the reactor with open arms.⁹⁶

It took nearly five years for the reactor to be built. Construction involved the efforts of many Lewis engineers who designed the reactor and then monitored the building process. This was one of the defining characteristics of the NACA. Its culture was one that insisted on conducting projects in house or with government engineers as opposed to using contractors for all aspects of a job. Alan “Hap” Johnson recalled, “That didn’t mean we didn’t go out and hire an architect to do office

⁹⁶ John Victory, in “Ground-Breaking Marks Start of New Era in Aviation Power,” *Sandusky Register Star-News* (13 September 1956).

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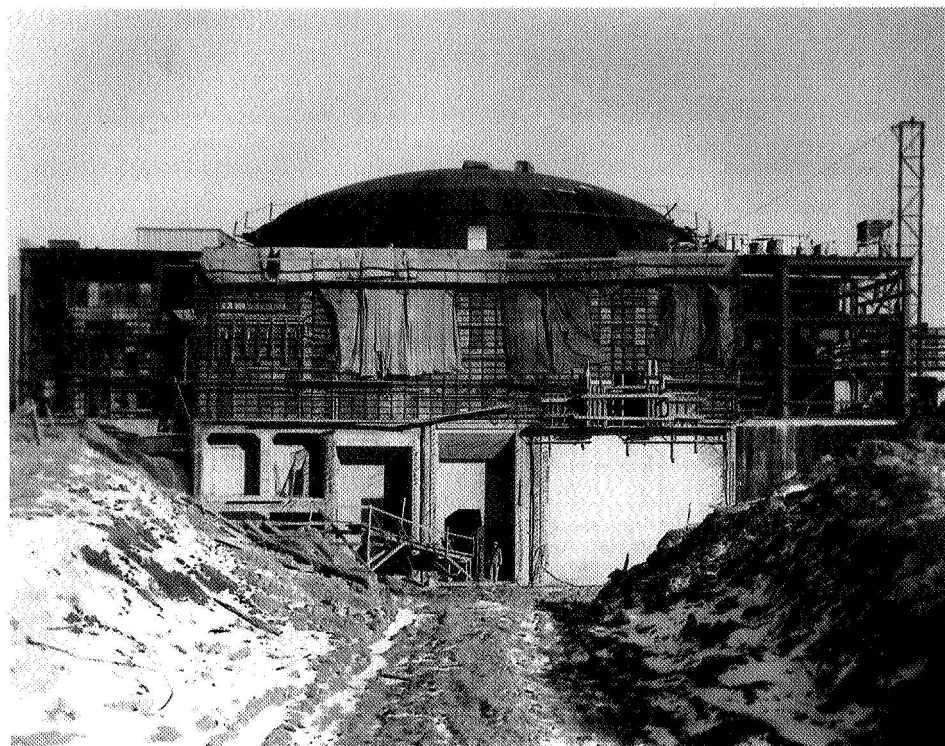
"Sputnick" on the reactor pressure tank. The misspelled name can be seen on the upper right portion of the tank. (NASA C-2003-835)

buildings or things like that, but the basic thinking was all done in house."⁹⁷ James R. Braig and Mabry V. Organ managed construction of the reactor. Braig was from the Lewis Contract and Construction Administration Office and worked primarily on the Plum Brook site to direct the workers. Organ was also from the Lewis Contract and Construction Administration Office. The rest of the Lewis design team frequently commuted the 50 miles to Plum Brook. They began their day early in the morning at Lewis, and then all boarded a bus to the reactor. Since this was before the interstate was completed, there were numerous small-town back roads that had to be traversed to get there. Many of the engineers passed the time by playing cards.⁹⁸ Lewis used construction companies as the major material suppliers. Kilroy Structural Steel Company of Cleveland, Ohio, provided all of the steel for the reactor buildings, and Hammond Iron Works of Warren, Pennsylvania, built the containment vessel.

⁹⁷ Interview with Alan "Hap" Johnson by Mark D. Bowles, 20 March 2002.

⁹⁸ Interview with John Acomb by Mark D. Bowles, 21 September 2002.

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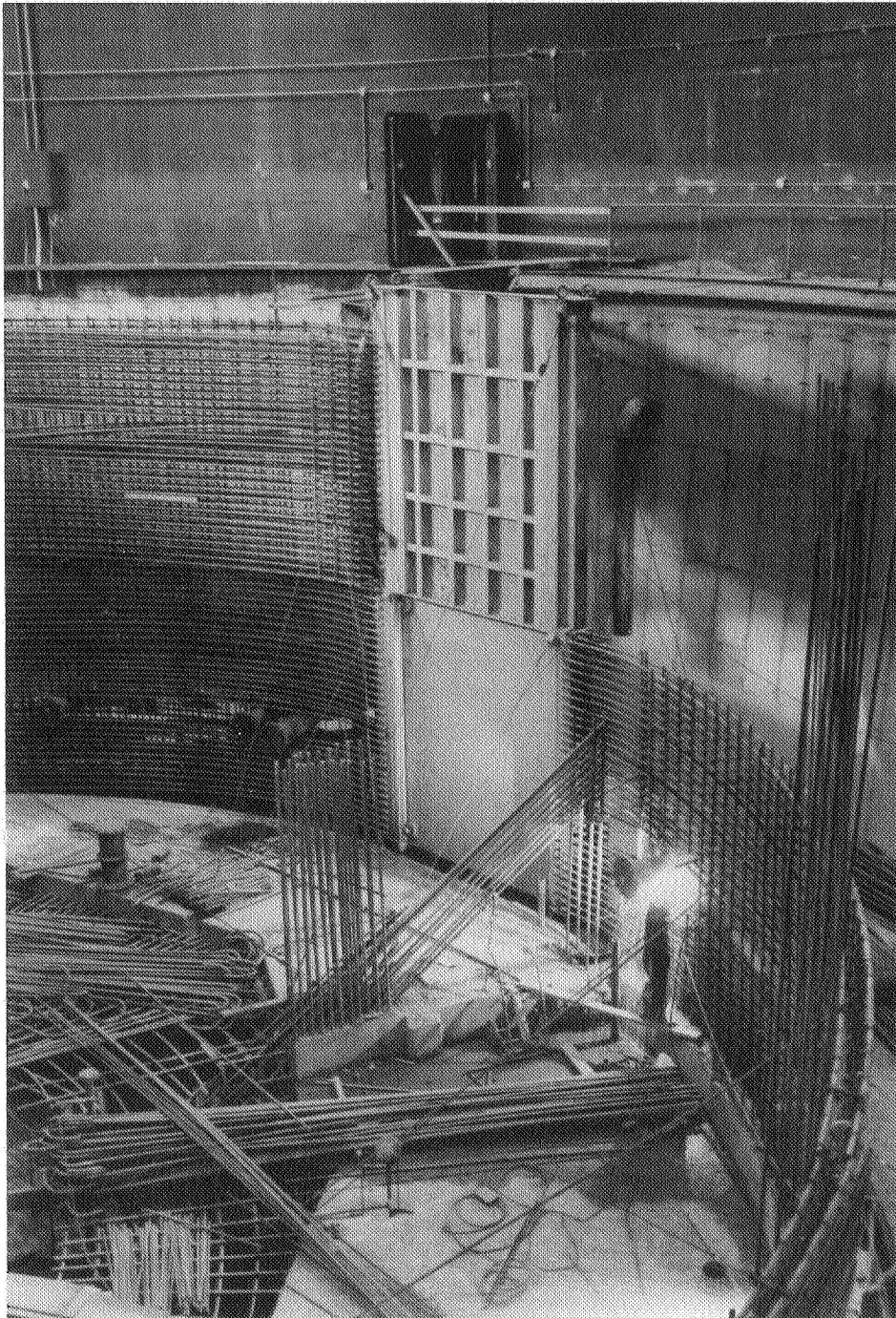


Side view of the construction of the containment vessel and main reactor area. (NASA 2005-1203)

The first step in the construction process was to demolish and decontaminate the Plum Brook Ordnance Work's Pentolite Area. It was on these 117 acres of land that Lewis engineers chose to build the reactor facility. Construction crews then excavated a hole in the ground for the pressure tank. The tank extended approximately 32 feet under ground, and its dimensions were 9 feet in diameter by 32 feet high. It 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. There were several pipes that jutted out from the tank. These "test holes" would later be used to transport experiments to the reactor core for radiation during its operating cycles. Because it bore a resemblance to the Soviet's first orbiting satellite, engineers scrawled the word "Sputnik" into the side of the pressure tank. This was perhaps a not so subtle reminder of the Cold War race to perfect a nuclear airplane.

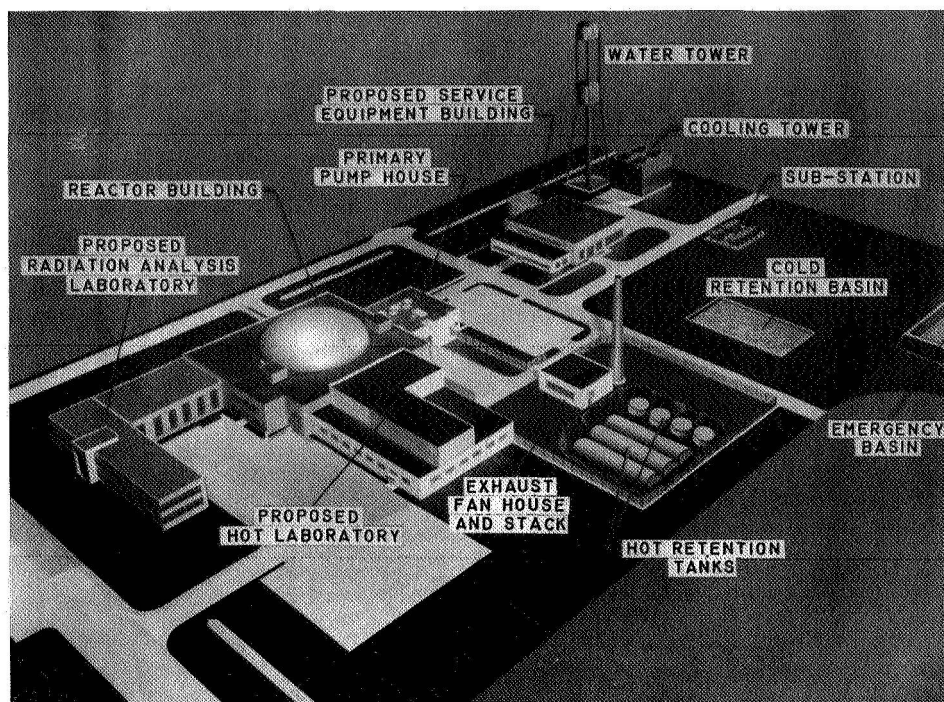
Starr Truscott, Plum Brook administrator, recalled that while the reactor building was being built there was no official photographer for the facility. Only he and one of the construction engineers had personal high-speed cameras of their own.

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Interior view of the construction of the containment vessel. (NASA 2005-2-1197)

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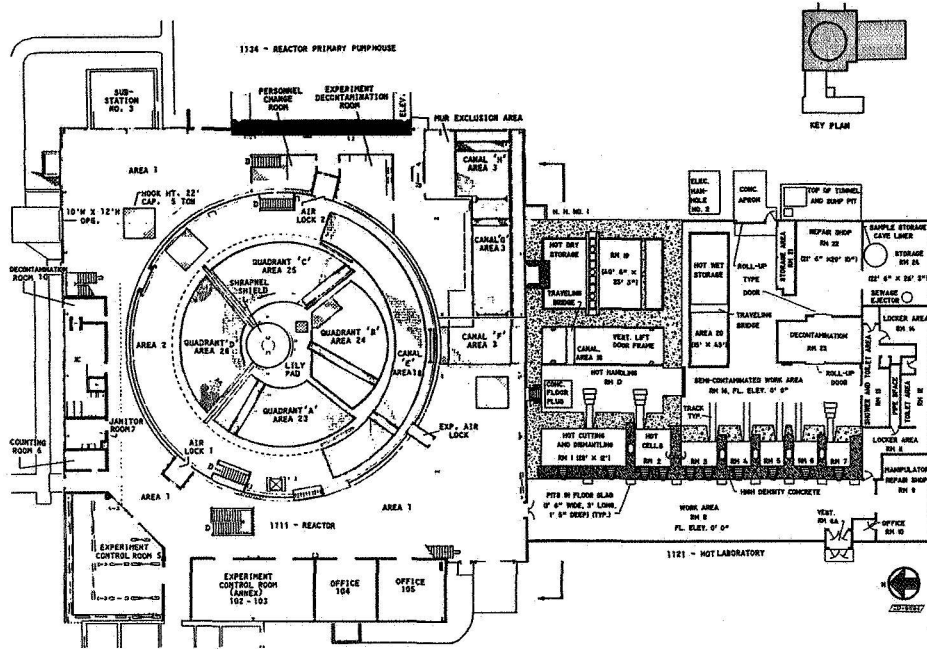
Artist's rendering of the proposed layout of the Plum Brook reactor, along with support buildings and laboratories (1957). (NASA C-2003-818)

The other construction engineers used Polaroid cameras to document progress, but these did not provide high-quality pictures. One day when the reactor core was nearing completion, one of the engineers suggested that it would be nice to actually get a picture of the reactor. The only way to do it was to lower someone down into the core—someone who knew how to take a good picture. Truscott volunteered. He said, “They put me on the end of a crane and dropped me down inside and then explained, from above, what they wanted me to take the pictures of.”⁹⁹

Many of the students who went through Plum Brook training school were assigned to the reactor to assist during construction. For example, Steven Borbash graduated with an engineering degree from Ohio University in 1958. That summer he applied to Lewis Research Center and became a student at the reactor training program. By 1959 he had completed the program and moved to the Plum Brook reactor. He recalled that he was handed a roll of blueprints, a hardhat, and tools and was told, “This is your project. This part of the reactor is installed but we don’t

⁹⁹ Interview with Starr Truscott by Virginia Dawson, 21 September 2002.

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First-level floor plan of the reactor building. (Plum Brook Archives)

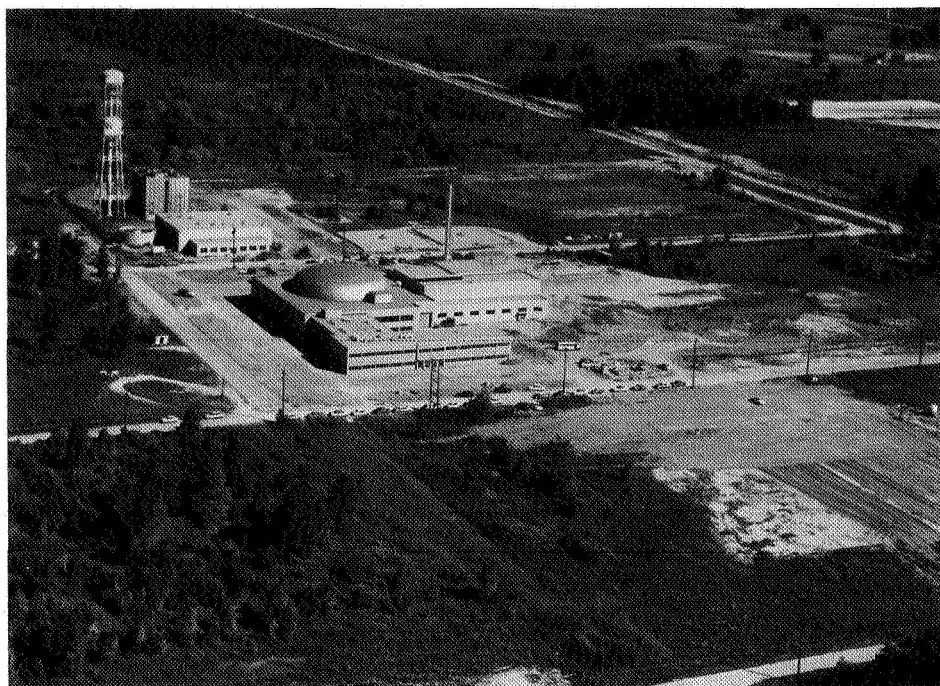
know if it works yet. We don't know if it works properly. Fix it. Test it.”¹⁰⁰ With students like Borbash taking his theoretical knowledge and applying it in practical situations at the Plum Brook reactor, the Lewis nuclear expertise played a direct role in helping to construct the facility and prepare it for operation. He later worked in the reactor operations section.

The steel containment building (55 feet above grade, 56 feet below grade, and 100 feet high) was the large domed structure that surrounded the reactor pressure tank, quadrants, and canals. It was designed to prevent any radioactivity from being released to the outside environment 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 MTR had no shield because small amounts of contamination could be released into the atmosphere without endangering the public, since it was in such a remote region.

The entire reactor building was roughly 30 feet high, 160 feet in length, and

¹⁰⁰ Interview with Steven Borbash by Mark D. Bowles, 15 February 2002.

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The Plum Brook reactor nearing completion. (NASA 2005-1201)

150 feet wide. It comprised four stories, two above ground and two below. Additional facilities included the reactor control room and offices on a mezzanine that extended along the north and west walls. A locker room and a shower were nearby for personnel who wanted to change their clothes. The final main area of the reactor building was the Mock-Up Reactor, which was a low-power reactor used to verify experiment properties before insertion into the larger reactor. This was a very important addition to the Plum Brook facility (its significance is discussed in the chapter on experimentation).

Adjacent to the reactor on the west side was the office and laboratory building. It contained an engineering management division, a chemistry laboratory, and a health safety office.¹⁰¹ To the south was the hot laboratory, a 40-foot by 70-foot area for the handling and study of radioactive materials. A canal extended from the quadrants to the back of the hot laboratory so that experiments could be transferred in underwater casks from the reactor for analysis in the laboratories. As an additional precaution the area had 72-inch-thick concrete walls. Engineers analyzed the experiments here with claw-like manipulator arms while they safely watched

¹⁰¹ Interview with William Stokes by Mark D. Bowles, 23 January 2002.

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behind thick windows. To the east was the primary pump house. This contained the pumps, heat exchangers, and ion exchangers that were used for the primary cooling water system. The primary loop carried water from the heat exchanger to the reactor and back. The heat exchanger itself was a shell type that ensured that the primary water (which could be radioactive) never made contact with the secondary water, which was returned to the cooling tower or escaped into the environment. A secondary loop sent water from the heat exchanger to the service equipment building. A final loop took water from the heat exchanger to the cooling tower. The cooling tower and two overhead tanks were in the northeast corner of the reactor site.

Between the cooling tower and the main reactor building was the service equipment building. Softening, filtering, and deionizing equipment was stored here. It also contained air compressors, electrical control equipment, and diesel generators to power the reactor if the electricity was cut off for some reason. The Ohio Edison Company maintained the electrical substation, southeast of the service equipment building.

East of the hot laboratory was the fan house. This contained all of the ventilating fans for the containment building. Over 13,000 cubic feet of air could be discharged per minute after it was filtered through the exhaust stack. Directly to the south of the fan house was the hot retention area, where the radioactive water from the facility was stored. It consisted of a one million-gallon "cold basin" where water could be kept for the canals or quadrants. In addition there were eight hot retention tanks with capacities of 64,000 gallons each, which could also hold radioactive water. Though very large, these basins paled in comparison to a 10 million-gallon earthen basin located in the southwest corner of the fenced-in area around the reactor facility. This provided emergency water storage. Also in this southwest corner area was the effluent control station. Surface water and wastewater were collected here in the culverts and ditches, and the flow rate could be controlled with a series of flumes.

Since weather was a potential danger to the operations at the facility, engineers dedicated two structures to predicting when any threatening storms might approach the area. The first was a weather station by the southwest corner of the hot laboratory. It consisted of a 150-foot collapsible tower, and it provided the reactor staff with detailed meteorological reports. The second weather structure was a 100-foot radar tower located west of the reactor building. This also provided advanced storm warning. Storms were considered one of the many potential hazards of operating a nuclear reactor.

However, a far greater threat than Mother Nature loomed on the horizon—political change. As the construction of the reactor progressed, the Plum Brook engineers were confident that they were building a valuable facility that would become an important, long-used, national asset for both NACA and the Aircraft Nuclear Pro-

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pulsion program. But by the time they had completed the reactor, neither NACA nor the Aircraft Nuclear Propulsion program would be in existence. Would Plum Brook share this fate?

The End of NACA and the Aircraft Nuclear Propulsion Program

In October 1957 the Soviet Union shocked the world by launching and orbiting Sputnik, the first manmade satellite. Its dim blinking in the nighttime sky as the spacecraft passed over the United States made the Cold War seem more real. It also created a heightened sense of urgency that America had to do everything in its power to keep up. Partly, this entailed a deepening of its commitment to protecting the space above the country. No longer could Americans ensure their safety by simply patrolling the skies. Military and scientific supremacy now meant voyaging into and controlling space. Significant change was on the horizon.

The Plum Brook reactor was a NACA project, and this institution was now in trouble. Though NACA was considered one of the top institutions in the world for aeronautical research, the most urgent research needs for the future appeared in space, not aviation. What most observers claimed the nation needed was a new agency that was a "NACA in space."¹⁰² But NACA as constituted was not equipped to achieve these higher goals. Some in Congress and the military believed that the agency was too conservative and unimaginative.¹⁰³ Throughout his presidency, Eisenhower had been reducing NACA budgets, and the organization as a whole was conservative and skeptical about venturing into space-related work.¹⁰⁴ Less than one year after Sputnik, NASA, the National Aeronautics and Space Administration, replaced NACA. NASA's new mission was to perform basic research and development for military and civil space exploration programs.¹⁰⁵

NACA employees knew that this was a significant change for Plum Brook because NASA, unlike NACA, was a political agency that was headed by a political appointee, who was nominated by the president of the United States and confirmed

¹⁰² "NACA in Space," *Washington Post* (29 January 1958): A18.

¹⁰³ Michael Gorn, "Who was Hugh Dryden and Why Should We Care?," eds. Virginia P. Dawson and Mark D. Bowles *Realizing the Dream of Flight* (Washington, DC: NASA SP-2005-4112, 2005), pp. 182-183.

¹⁰⁴ McDougall, *The Heavens and the Earth: A Political History of the Space Age*, p. 164.

¹⁰⁵ Ford Eastman, "NACA Wins Approval as Space Agency," *Aviation Week* (21 July 1958): 18; Robert Hotz, "NACA to Spearhead U.S. Space Drive," *Aviation Week* (7 April 1958): 28.

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by the Senate.¹⁰⁶ According to the *Los Angeles Times* this made the nation's efforts in space more political and gave "the President overriding power over the agency."¹⁰⁷ NASA, and the centers under its control like Lewis and Plum Brook, became much more vulnerable to the winds of political change. With the political winds soon changing from the Republican Eisenhower to the Democratic Kennedy administration, and an intensified focus from aeronautics to aerospace, would there be a future for the nuclear airplane?

Setbacks to the Aircraft Nuclear Propulsion program were mounting. In 1958 President Eisenhower informed Congress that there was no national urgency to the Aircraft Nuclear Propulsion program, and as a result he cut funding back to \$150 million per year. In 1960, Herbert York, the first director of research and engineering at the Pentagon, told a House Defense Appropriations Subcommittee that "a nuclear-powered bomber with suitable operational characteristics probably lies beyond 1970."¹⁰⁸ His testimony was noteworthy because previous estimates from 1959 had predicted that a nuclear airplane would be flying in three to five years.¹⁰⁹ In his memoirs, York argued that the haste with which the United States had launched the Aircraft Nuclear Propulsion program had played a large role in its demise. He wrote, "The political pressure to put a plane in flight as soon as possible eventually proved fatal to the program. The part of the program which was supposed to develop reactor materials had by no means reached the point where it could be certain of coming up with something suitable."¹¹⁰

Another nuclear airplane setback was the success of traditionally fueled airplanes. The advanced capabilities of chemical propulsion enabled them to begin performing at levels that were once thought to be achievable only by a nuclear airplane. Bombers were now able to fly to Moscow and back, and intercontinental ballistic missiles armed with small nuclear warheads could be launched from the United

¹⁰⁶ Interview with Hank Pfanner by Mark D. Bowles, 26 September 2002. Interview with Alan "Hap" Johnson by Mark D. Bowles, 20 March 2002; Interview with Starr Truscott by Virginia Dawson, 21 September 2002.

¹⁰⁷ "Conferees Agree on Space Agency," *Los Angeles Times* (16 July 1958): 6.

¹⁰⁸ Herbert York, quoted in Ford Eastman, "York Says Useful Nuclear Plane May Not Be Flown Before 1970s," *Aviation Week* (18 April 1960): 27.

¹⁰⁹ J. S. Butz, Jr., "Nuclear Plane Construction Feasible Now," *Aviation Week* (30 March 1959): 86.

¹¹⁰ Herbert York, *Race to Oblivion: A Participant's View of the Arms Race* (New York: Simon and Schuster, 1970), p. 63.

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States and accurately hit targets in the Soviet Union.¹¹¹ It also turned out that the reports stating that the Soviet Union was flying its own nuclear aircraft were untrue. Paul R. Josephson in his recent history of Soviet nuclear power wrote that far more is known about the American nuclear airplane program because most of the Soviet documents relating to it remain classified. But, he said, "There is no doubt that the Soviet's program paralleled the United States's, even if it was somewhat less extensive."¹¹² The United States never had a plane powered by a nuclear reactor, and neither did the Soviet Union.

Rumors of a Soviet nuclear airplane continued until 1959. Many of those responsible for promoting them were the officials from companies who were receiving nuclear airplane contracts. For example, the Nuclear Propulsion Division of the General Electric Company carried out most of the work for the nuclear airplane.¹¹³ Officials from this company were also some of the last to give up the Cold War technology race as a rationale for continuing the Aircraft Nuclear Propulsion program. In March 1959, John W. Darley, Jr., manager of the operational analysis section of the General Electric Nuclear Propulsion Division, sent a long letter to President Eisenhower, informing him about the urgency of the program and the Soviet threat. This report was later published in *Aviation Week* in its entirety.¹¹⁴ Leonard Harmon, a retired colonel from the United States Air Force who also worked in the General Electric nuclear division, reiterated Cold War dangers. He proclaimed, "There is every reason to believe the Russians are flying nuclear-powered aircraft."¹¹⁵ But the nuclear aircraft never materialized, and the Soviet nuclear airplane remained more significant as a propaganda tool (perhaps used more by the United States aviation industry than the Soviets themselves) than as a military weapon.

A further concern was the safety issues surrounding the atomic plane. In 1960 one report stated that the biological problems associated with the atomic planes were considered a "limiting factor in the development of a practical nuclear-powered aircraft."¹¹⁶ There was always a chance that a flying reactor would crash, and whereas ground-based reactors could be built in sparsely populated areas with mas-

¹¹¹ Interview with Dick Schuh by Mark D. Bowles, 25 September 2002.

¹¹² Josephson, *Red Atom*, p. 129.

¹¹³ "Nuclear Plane Contracts," *Aviation Week* (30 March 1959): 29.

¹¹⁴ "GE Official Details Nuclear Plane Need," *Aviation Week* (16 March 1959): 67-84; "GE Official Urges Nuclear Plane Acceleration, Cites Soviet Effort," *Aviation Week* (23 February 1959): 27.

¹¹⁵ Leonard Harmon quoted in, "Soviet Nuclear Bomber," *Aviation Week* (9 February 1959): 28.

¹¹⁶ Craig Lewis, "Nuclear Plane Radiation Hazards Defined," *Aviation Week* (25 January 1960): 113.

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sively thick and heavy shields, a nuclear airplane could crash anywhere. Gary Snyder, assistant chief of the Plum Brook project engineering office, recalled, “having [the possibility of] that plane crash was more than people could stand. Although I don’t know that with an absolute certainty, I would guess that that was very high on the list of reasons why the project never came to fruition.”¹¹⁷ While environmental contamination was one significant drawback, the inability to protect the crews from the radiation was the most significant safety concern that was not solved.¹¹⁸ It became clear in 1961 that the government was about to terminate the nuclear airplane program. But questions remained. What should it do with the infrastructure left over from the project? Nowhere was the answer to this question more eagerly awaited than at Plum Brook, where the reactor’s future was in jeopardy even before its first experiment began.

Overview and Timeline of the United States Aircraft Nuclear Propulsion Program¹¹⁹

1946	The Air Force begins funding the Nuclear Energy for the Propulsion of Aircraft (NEPA) program, which was designed to prove the feasibility of nuclear-powered aircraft flight. Fairchild Engine & Aircraft Company becomes the project manager at the AEC’s Oak Ridge laboratory. Consultants from aircraft engine manufacturers and universities participate.
1948	The AEC establishes the Lexington Project at the Massachusetts Institute of Technology with the same goal as the NEPA program. It recommends continuing the project.
1949	The Oak Ridge AEC laboratory establishes a nuclear aircraft propulsion research program. A technical advisory board reviews the NEPA program and recommends continuance.
1950	Although the Lexington Project and NEPA both concluded that nuclear-powered flight was possible, but concluded it would be difficult and expensive to achieve. Scientists predict that it would take 15 years and over \$1 billion to achieve its goals. The Air Force and the AEC phase out both of these programs and form the Aircraft Nuclear Propulsion (ANP) program. Its objectives are to develop the technology of reactor materials, shielding, power-plant, and aircraft design to the point where feasibility can be established. Because of a change in top management, Fairchild is relieved of its duties in the project.

¹¹⁷ Interview with Gary Snyder by Mark D. Bowles, 21 September 2002.

¹¹⁸ J. Newell Stannard, *Radioactivity and Health, A History* (Virginia: Battelle Memorial Institute, 1988), p. 1221.

¹¹⁹ Text adapted from “U.S. Nuclear Powered Aircraft Program,” *Aviation Week* (1 December 1958): 29; “Chronology of Nuclear Program Reorientations,” *Aviation Week* (19 December 1960): 56.

Overview and Timeline of the United States Aircraft Nuclear Propulsion Program

1951	The objectives of the ANP program expand to include the demonstration of nuclear-powered flight. Development begins on two types of engines. The first is assigned to General Electric to develop direct-cycle engines, and the second is assigned to Pratt & Whitney to develop an indirect-cycle engine.
1952	The decision is made to build an experimental nuclear engine suitable for flight testing in the Convair B-36. A flight date is predicted for 1956. A direct-cycle engine is chosen for this experiment, and General Electric creates a separate ANP division and begins working on the project six days a week.
1953	The Convair-GE experimental flight test program is canceled because of the demands of Defense Secretary Charles E. Wilson. The General Electric direct-cycle development work continued through Air Force Secretary Harold Talbot's diversion of unallocated funds to the project. The Pratt & Whitney work on the indirect-cycle engine is also terminated because of the engine's poor growth potential.
1954	The Air Force begins its WS-125A nuclear bomber program, which is a subsonic cruise bomber with supersonic dash capabilities. Pratt & Whitney and General Electric are the engine contractors, and Lockheed and Convair are the airframe contractors.
1955	Contractors are split into two engine-airframe teams for the WS-125A competition. Convair and GE are one team, and Pratt & Whitney and Lockheed are the other. The Navy also begins independent nuclear-powered seaplane studies.
1956	The Air Force cancels the WS-125A competition. NACA breaks ground on a nuclear test reactor at Plum Brook.
1957	In May, Pratt & Whitney completes its Connecticut Aircraft Nuclear Engineering Laboratory (CANEL) under an AEC contract. In August, the Air Force cancels Pratt & Whitney's work on the circulating fuel reactors. CANEL drastically cuts back its operations. AEC continues to support Pratt & Whitney on a very small scale.
1958	In March, President Eisenhower informs Congress that there is no urgency in the nuclear aircraft propulsion program. He rejects an effort to accelerate the program, but authorizes \$150 million per year to continue the program with no clear-cut goal. In June, the Air Force proposes another weapon system, the CAMEL nuclear aircraft, to provide continuous airborne alert, missile launching, and a low-level penetration capability.
1959	Convair wins the CAMEL airframe competition. Herbert York, director of defense research and engineering, rejects the subsonic CAMEL program because he believes that a militarily useful aircraft must be capable of sustained supersonic flight.
1960	The Air Force goes ahead with plans to build two Convair NX-2 subsonic experimental nuclear-powered aircraft. The first flight was estimated for 1965. General Electric and Pratt & Whitney engine projects continue.
1961	John F. Kennedy terminates the nuclear airplane program.

Going Critical with NERVA

On 21 March 1961, with the Plum Brook reactor nearly complete, community leaders, NASA, and AEC representatives held a massive press conference to celebrate its opening. More than 60 journalists and radio and television reporters met at the site to learn about its role in supporting the nuclear airplane. NASA provided data on the importance of the program, the value of Plum Brook, and the uniqueness of the facility. Over the next few days journalists reported the stories in newspaper articles praising the significant role this local facility was to play in an important national program. The *Chillicothe Gazette* wrote, "The Plum Brook research nuclear reactor, to be used in efforts to develop an atomic airplane, has received the Atomic Energy Commission's approval to go into operation."¹ Soon it appeared that this quiet community would be a part of the leading edge of nuclear research for airplanes.

However, just seven days after the open house, President John F. Kennedy officially terminated the nuclear airplane program. On 28 March 1961 Kennedy delivered a message to Congress on the defense budget, which was also informally known as the "kiss of death for the atomic plane." He said that despite the time and money (15 years and \$1 billion) that NACA and NASA sank into the project, "the possibility of achieving a militarily useful aircraft in the foreseeable future is still very remote." Kennedy planned to "terminate development effort" on the nuclear airplane immediately.² John Acomb, one of the Plum Brook engineers, recalled how astonished he was at the government's sudden cancellation of the program. He said, "They just cancelled the whole program. Bang. And it was gone."³

Two months later, in May 1961, Kennedy delivered his famous "Urgent National

¹ "Reactor for A-Plane Gets Okay," *Chillicothe Gazette* (8 March 1961).

² John F. Kennedy, "Special Message to the Congress on the Defense Budget, March 28, 1961," Record # 12508 "Selected Statements of President Kennedy on Defense Topics December 1957 – August 1, 1962," NASA HQ Archives.

³ Interview with John Acomb by Mark D. Bowles, 8 July 2002.

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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 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, before its rival superpower, the Soviet Union. What is often forgotten about this speech is that Kennedy also advanced an even more compelling dream. Though he had just canceled the nuclear airplane, he now called for increased funding to develop a nuclear rocket. He said, “This gives promise of someday 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.”⁴

Along with the nuclear airplanes, the United States had also been working on a nuclear space initiative since 1955, and this was the brave new world that Kennedy wanted to explore. Many high-ranking officials shared his optimism. Some believed nuclear propulsion to be the single best hope for space exploration. Hugh Dryden, NASA’s deputy administrator, asserted, “We are confident that the future of extensive manned exploration of the moon and planets rests on the mission capabilities afforded by nuclear propulsion systems.” Others thought that the value of nuclear propulsion went beyond scientific curiosity. Harold B. Finger, manager of NASA’s Space Nuclear Propulsion Office, said, “I believe [nuclear propulsion] is essential to . . . this country’s technological stature in the world.”⁵

If President Kennedy was the one to essentially kill the nuclear airplane program and Plum Brook’s planned contribution to it, he was also the one to grant the nuclear initiative a new life and Plum Brook a new mission. Like the nuclear airplane, the nuclear rocket also required extensive materials research in a radioactive environment to achieve flight readiness. NASA chose to answer this challenge by utilizing the two nearly completed reactors at Plum Brook—a test reactor and a research reactor. Just 20 days after Kennedy gave his Urgent National Needs speech, the Plum Brook test reactor went critical, and it became the second most powerful American test reactor facility. In a survey of all 48 research reactors licensed by the AEC in 1968, the National Academy of Sciences found that their combined power production was 45 megawatts.⁶ Plum Brook’s test reactor at 60 megawatts

⁴ John F. Kennedy, “Urgent National Needs,” 25 May 1961 (Washington, DC: Department of State, 1961).

⁵ Dryden and Finger quotes found in Ford Eastman, “Bold Action is Urged on Nuclear Rockets,” *Aviation Week* (6 March 1961): 29.

⁶ National Academy of Sciences, Subcommittee on Research Reactors Committee on Nuclear Science, National Research Council, “Survey of Research Reactors,” 1970, Box 252, Folder 2, Plum Brook Archives.

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was by itself significantly more powerful than all of these other reactors combined. Plum Brook represented one of the most powerful test reactors ever constructed, anywhere in the world. Scientists and politicians hoped that once they shifted Plum Brook's focus, it would play an important role in realizing the dream of a nuclear rocket. This chapter examines the nation's shifting focus on the nuclear rocket and describes the NASA engineers' efforts that took the Plum Brook facilities critical in order to conduct research in support of this program.

Genesis of the Nuclear Rocket Program

The idea of a nuclear rocket to propel craft into space first appeared in science fiction. In the early part of the twentieth century one story prophetically described a ship traveling through space, powered by the disintegration of uranium. However, it would be several decades before scientists brought these fictional speculations closer to reality. In 1938 German physicists Otto Hahn and Fritz Strassman at the Kaiser Wilhelm Institute for Chemistry designed a tabletop device that split a uranium atom. One year later Krafft Ehrlicke published a paper in Germany stating that a higher specific impulse could be obtained by heating hydrogen by fission rather than by chemical combustion.⁷

Research on nuclear propulsion did not begin in the United States until near the end of World War II. Beginning in 1944, several researchers at Los Alamos, North American Aviation, and Douglas Aircraft Company began to suggest the possibility of using the thrusting power from nuclear blasts as a method to propel rockets.⁸ These early discussions all pointed out the difficult problems that had to be solved, including the high heat-transfer rates and the high temperatures associated with a nuclear rocket. In 1947 a team of engineers and physicists at Johns Hopkins University's Applied Physics Laboratory concluded that liquid hydrogen would be the best propellant for a nuclear rocket. They argued that extensive materials research was required to build an efficient pile and construct a rocket that could withstand the radiation. This early enthusiasm for nuclear rocket technology ended with a report published by North American Aviation's Aerophysics Laboratory in 1947. It determined that no currently known material could withstand the 5700°F operating temperature of the reactor. According to Robert W. Brussard, "the field languished,

⁷ Keith Boyer, "Nuclear Rockets" AIAA Paper No. 67-981 (1967).

⁸ Robert W. Brussard, "Nuclear Rocketry—The First Bright Hopes," *Astronautics* (December 1962): 32–35.

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died, and was all but buried with full military honors by 1952.”⁹

Brussard had joined with Oak Ridge National Laboratory to work on the Aircraft Nuclear Propulsion program in the early 1950s, and he became one of the most important people involved in resurrecting the nuclear rocket program. Initially he was disappointed to find that not only was no one aggressively working on nuclear rockets, but there was “active antipathy and ridicule from many quarters for such an idea.”¹⁰ Brussard and others strove to open up the field of nuclear rockets and explore its potential. Eugene Wigner, the director of Oak Ridge, and John von Neumann, at Princeton University and the Institute for Advanced Study, became influential proponents. Because of their advocacy the Air Force began investigations with the assistance of Los Alamos, Livermore, and Oak Ridge laboratories. Soon the efforts to develop a nuclear rocket as an intercontinental ballistic missile evolved into a nuclear rocket for space exploration.

In November 1955 the Los Alamos Scientific Laboratory began work on a nuclear rocket propulsion program under the code name Rover.¹¹ Though not as urgent a program in the years before the Sputnik launch, it would soon become one of the important initiatives in the Cold War’s space race with the Soviet Union. One month after Sputnik the Lewis Flight Propulsion Laboratory in Cleveland held an important conference that “signaled Lewis’ transition to a position of leadership in space nuclear power and propulsion technology.”¹² At the conference Lewis engineers outlined key feasibility issues, areas that required technology advances, and reasons why nuclear propulsion was so important to the nation.¹³ After Congress established NASA in October 1958 the Rover program became a joint operation between NASA and the AEC, and Lewis maintained an important role.

One important advantage of the nuclear rocket over chemical rockets was its high “specific impulse.” Rockets operate by expelling gas out of a nozzle.¹⁴ Specific

⁹ Ibid., p. 33.

¹⁰ Ibid.

¹¹ “Nuclear Rocket Being Developed by a New Team at Los Alamos,” *New York Times* (10 September 1956), 1; Raemer E. Schreiber, “Los Alamos’ Project Rover,” *Nucleonics* 16, 7 (July 1958): 70–72.

¹² H. S. Bloomfield and R. J. Sovie, “Historical Perspectives: The Role of the NASA Lewis Research Center in the National Space Nuclear Power Programs,” presented at the Conference on Advanced Space Exploration and Initiative Technologies, September 4–6, 1991, NASA Technical Memorandum 105196.

¹³ Lewis Flight Propulsion Laboratory, “NACA 1957 Flight Propulsion Conference,” 22 November 1957, proceedings found in NASA TM X-67368 and TM X-61622.

¹⁴ James Dewar, *To the End of the Solar System: The Story of the Nuclear Rocket* (Lexington, KY: University of Kentucky Press, 2004), p. 252.

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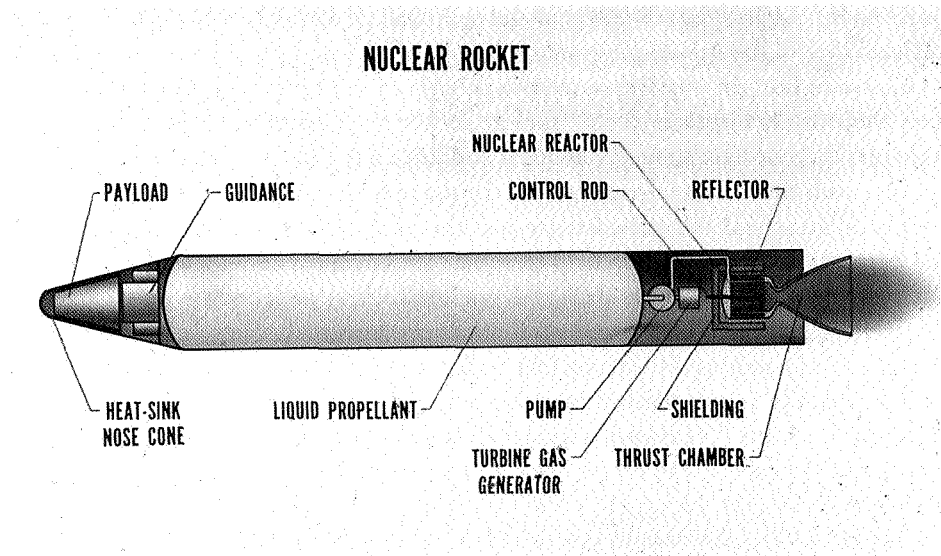


Diagram of a basic nuclear rocket. (NASA CS_18292)

impulse was an indicator of the efficiency of the rocket by measuring the distance in miles per gallon that was possible with a hydrogen fuel propellant. In theory, nuclear rockets produced propulsion by directing cold liquid hydrogen into a hot reactor.¹⁵ This caused the liquid hydrogen to expand into a high-pressure gas, resulting in a very high specific impulse. By exhausting the liquid hydrogen through a nozzle, engineers believed that between 50,000 and 70,000 pounds of engine thrust was possible.

To determine the specific impulse for any rocket, the thrust is divided by the propellant flow, and the higher the number, the more efficient the rocket. Some considered this the most important part of the nuclear rocket. The heated hydrogen was the best of all possible fuels because it had the lowest molecular weight. This low weight meant a higher velocity when it went through a nozzle jet.¹⁶ When the high degree of heat in the reactor combined with the low weight of the hydrogen fuel, the resulting specific impulse was twice that of conventional chemical rockets. This potential made the technical challenges associated with the construction of a nuclear rocket appear to be well worth the effort. However, though nuclear rockets had greater power, chemical rockets were far better understood and immediately

¹⁵ Paul G. Johnson, "Nuclear-Rocket Applications," *Astronautics* (December 1962): 22–27.

¹⁶ Interview with Frank Rom by Virginia Dawson, 27 September 2002.

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available for use in space. Because of the technical challenges, NASA did not use a nuclear stage in the Apollo program.¹⁷

In one important way the nuclear rocket promised to be an easier undertaking than the nuclear airplane. If the nuclear rocket expelled radioactivity into space, engineers did not have to worry about it contaminating Earth or the crew. This was not true with the nuclear airplane, since the plane was continually flying over highly populated areas and the radioactivity had the potential to penetrate the shielding and harm those on board.¹⁸ To help eliminate the concerns about a rocket malfunction during liftoff, engineers designed nuclear rockets to launch with traditional chemical propulsion systems, and then ignite the nuclear systems only when safely in space. Environmentally, the nuclear rocket appeared to be a much safer alternative. Technically, it promised to have the propulsive capability to enable astronauts to journey to Mars.¹⁹ However, some environmentalists remained concerned about what might happen if the rocket were to lose control prior to reaching orbit and crash into the Earth. Eventually these voices of protest would become louder, and the nuclear proponents would not be able to ignore them. But for the time being, the nation pressed forward with its plans for a nuclear rocket.

In 1959 NASA and the AEC placed KIWI-A, a test reactor named for a flightless bird, on a flatbed truck in Jackass Flats, Nevada. It became the first full-scale firing of a nuclear rocket.²⁰ KIWI-A was the first of three reactors that were ground tested, and KIWI-B included an additional five.²¹ These KIWI reactors helped to demonstrate the feasibility of a future nuclear rocket engine. The reactors could be quite dangerous. When fully operational, they could deliver a lethal radiation dose to a human standing 20 feet away in 0.1 second.²² Pleased with the success of the program and under pressure from Congress to spend more funds on it, the AEC allocated an additional \$11 million from other projects for the Rover.²³ Many

¹⁷ Interview with Harold Finger by Virginia Dawson, 4 April 2002.

¹⁸ Interview with Jim Blue by Mark D. Bowles, 11 February 2002; Interview with Jim Blue by Virginia Dawson, September 2002.

¹⁹ Interview with Frank Rom by Virginia Dawson, 27 September 2002.

²⁰ Ted Sell, "Atom Rocket Engine Test Successful," *Los Angeles Times* (21 June 1959): 1; "Pentagon Pushes Atom-Powered Rocket Engine," *Wall Street Journal* (17 February 1958): 4.

²¹ Raemer E. Schreiber, "Kiwi Tests Pave Way to Rover," *Nucleonics* 19, 4 (April 1961): 77-79.

²² J. Newell Stannard, *Radioactivity and Health, A History* (Virginia: Battelle Memorial Institute, 1988), p. 1234.

²³ "AEC Diverts Funds from Other Projects to Use More to Develop Nuclear Rocket," *Wall Street Journal* (9 March 1960): 5.

Going Critical with NERVA



SPRINGBOARD TO MARS AND VENUS

NERVA—Nuclear Engine for Rocket Vehicle Application. Now being developed as the nation's first nuclear powered rocket engine, NERVA will permit extensive space explorations, including delivery of extremely large payloads to the nearest planets. As part of the Rover nuclear rocket propulsion program, NERVA will be flight tested on an advanced SATURN booster in combination with a nuclear powered upper stage. ■ Development of the NERVA engine is the responsibility of REON (Rocket Engine Operations—Nuclear), an organization which manages and directs the development of nuclear rocket systems for the Aerojet-General® Corporation. Westinghouse Astro-Nuclear Laboratories shares the responsibility for the NERVA reactor under the team leadership of REON. The over-all Rover program is under the direction of the Space Nuclear Propulsion Office, a joint office of the Atomic Energy Commission and the National Aeronautics and Space Administration.



An advertisement for NERVA, the Nuclear Engine for Rocket Vehicle Application program. Aerojet General and Westinghouse were primary contractors to NASA-AEC Space Nuclear Propulsion Office. (Harry Finger Collection)

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believed that Rover would become the answer for successful future space exploration. A second nuclear space application also began during this period, SNAP (the Space Nuclear Auxiliary Program). Its goal was to develop a nuclear generator that provided electrical power for a spacecraft or satellite.²⁴

In 1960 NASA renamed Rover to NERVA (Nuclear Engine for Rocket Vehicle Application).²⁵ The Lewis Laboratory was going to play an important role in the NERVA program, with an assignment to help design and test an engine. Lewis engineers believed that the Plum Brook reactor, still under construction at that point, could be vital in this testing effort, even though it was designed to work primarily on the nuclear airplane. But a problem was developing at Plum Brook in the late 1950s. The nuclear airplane was losing support, and some members of Congress asked why it was spending funds on Plum Brook. They attacked NASA and the AEC and criticized them for failing to coordinate their efforts. Congressman Clarence Cannon, a Democrat from Missouri and Chairman of the House Appropriations Committee, argued that the AEC and NASA were duplicating efforts with respect to the creation of nuclear test reactors. In June 1960 the government suggested two courses of action. One was to close down the Plum Brook reactor before its construction was completed. The other was for the AEC and NASA to work together more efficiently.²⁶ The latter course was accepted, and in August 1960 the joint AEC-NASA Space Nuclear Propulsion Office (SNPO) was formed in Washington, DC, with Harold Finger, a former Lewis engineer, as manager. Finger's office coordinated the NERVA effort through the following locations (also see the Nuclear Rocket Program Organization 1962 chart on page 88):

- SNPO-C (the Cleveland extension) administered the NERVA contract with Aerojet-General Corporation and subcontractor Westinghouse.
- SNPO-N (the Nevada extension) was responsible for the Nuclear Rocket Development System (NRDS). It tested all hot-reactor, engine, and vehicle development.
- SNPO-A (the Albuquerque extension) was the liaison with the Operations Office of the AEC and the Los Alamos Scientific Laboratory.
- The Los Alamos Scientific Laboratory was the center of the nuclear rocket program with its materials information, criticality data, design techniques, test methods, and fabrication methods.

²⁴ Harold B. Finger, "The Case for Nuclear Energy," *Nucleonics* (April 1961): 58–63.

²⁵ Dewar, *To the End of the Solar System*; Dewar, "Project Rover: A Study of the Nuclear Rocket Development Program, 1953–1963," Ph.D. dissertation, Kansas State University, 1974; William R. Corliss, *Nuclear Propulsion for Space* (United States Atomic Energy Commission, 1967): 11–20.

²⁶ "Administration Reorganizing Nuclear Rocket Program," *Nucleonics* (June 1960): 23–24.

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Abe Silverstein, director of NASA's Lewis Research Center, addresses an audience about the benefits of nuclear propulsion. (NASA 1961_58357)

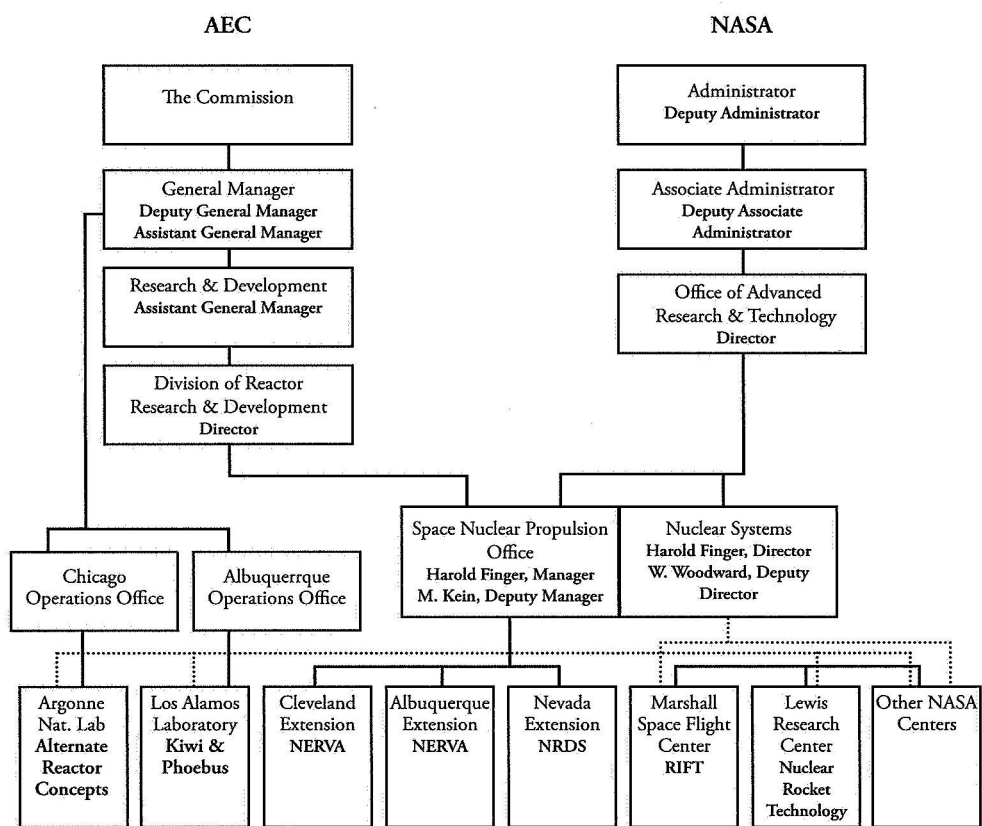
- Argonne National Laboratory was responsible for reviewing and evaluating nuclear rocket concepts that might differ from those developed at Los Alamos.

The Office of Nuclear Systems in NASA had responsibilities different from those of SNPO. Its functions included program review, the establishment of program objectives, budget preparation, technical decision review, and all contracting. The following locations assisted in this work:

- Marshall Space Flight Center was responsible for technical direction with its Nuclear Vehicles Project Office. It also managed the contractor work of Lockheed Missiles and Space Co.
- Lewis Research Center conducted a large part of NASA's program of advanced research and technology for nuclear-rocket propulsion. It also reported to SNPO for analysis, experimental, and research support.

In the fall of 1960 the NERVA project officially began. SNPO began taking bids from industry to build the NERVA engine and selected Aerojet-General Corporation in July 1961. It chose Westinghouse Electric Corporation's Astronuclear Laboratory to build the reactor itself, and it based the design on the KIWI test reac-

Nuclear Rocket Organization (1962)



* Dotted lines are Program Direction

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tors. Lockheed was then hired to develop a flight test vehicle for Aerojet-General's NERVA engine. In May 1962 Marshall Space Flight Center was given control of the RIFT (Reactor In Flight Test program) to design, develop, and fly a nuclear-powered upper stage for the Saturn V rocket.²⁷ Several other industrial organizations worked with Los Alamos, including American Car and Foundry, North American Aviation, Lockheed, Vitro, Aetron, Bechtel, and Air Products and Chemicals. Finger articulated three main management philosophies for the entire NERVA government industry team. The first was the use of public funds for research and development. Second was an "in-house" government effort, with the technical expertise of the government (NASA centers and AEC laboratories) to guide the program. Third was the use of industrial organizations for design, engineering, fabrication, and construction of the rockets.

In 1961 Harold Finger and Hugh Dryden testified before the House Space Committee that the United States was having "astounding successes" with the nuclear rocket and that they were "very encouraged."²⁸ Raymond L. Bisplinghoff, director of NASA's advanced research and technology programs, predicted that America's nuclear space development would have an "enormous influence on national prestige and strength," as well as open a gateway into deep space exploration.²⁹ By the mid-1960s NASA and the AEC had spent an accumulated \$584.5 million on NERVA and SNAP.³⁰

The nuclear rocket program was a large organization that was supported by a vast array of government and industrial participants. It is beyond the scope of this book to explore the details of this entire effort. Others have done this, most notably James Dewar in *To the End of the Solar System: The Story of the Nuclear Rocket* (2004). The purpose here is to examine the specific contributions of the Plum Brook facility. Plum Brook endured the transition from the nuclear airplane to the nuclear rocket and became an important part of the Cleveland-based Lewis Laboratory. Finger argued that Cleveland played a key role in the nuclear program. He said, "The advice of the Lewis Research Center [and Plum Brook] is sought to assist in the solution of many of the problems that arise in the on-going nuclear-rocket development effort." Cleveland was designated as the first of the three national extensions of the SNPO office because of the "substantial Lewis in-house programs in compo-

²⁷ Robert E. L. Adamson, "Nuclear Space Program," *Nucleonics* 19, 4 (April 1961): 54–57.

²⁸ Neal Stanford, "Nuclear Rocketry: New Horizons," *Christian Science Monitor* (6 March 1961): 3.

²⁹ Raymond L. Bisplinghoff, "Atoms in Space," *General Electric Forum* 3 (July/September 1964): 17.

³⁰ "Rover Fact Sheet," 27 January 1966, Record #13842. NASA HQ Historical Reference Collection.

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nent, subsystem, full-system, and mission-analysis work.”³¹

Before the Plum Brook reactors could begin supporting the NERVA program, it had to complete several key technological milestones. The first came in June 1961, when the reactor went critical for the first time and subsequently in April 1963 when it achieved full power. The second came during the summer of 1963, when the Mock-Up Reactor received its license from the AEC and then became operational in September. Plum Brook’s final major preparatory technological achievement was the completion of its hot laboratory in December 1963, where experiments could be analyzed after being irradiated in the reactor. The following three sections will discuss these three critical moments in Plum Brook’s evolution as a nuclear experimentation facility. They were the result of several years of intense work by a team of engineers working together to build a unique, sophisticated, and massive laboratory instrument that finally, it seemed, had a long-term mission and support from the government.

Going Critical

Criticality is a term that describes an event where the number of neutrons released by fission is equal to the number of neutrons that are absorbed (by the fuel and poisons) and escape the reactor core. A reactor is said to be “critical” or “reach criticality” when it can sustain a nuclear chain reaction when the reactor is operating. When Plum Brook first reached criticality in June 1961, it joined 120 other research and test reactors already in operation across the country.³² The only other more powerful non-power reactor in the United States at that 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 leading facility for performing experiments in support of the nation’s nuclear space program.

Reaching criticality for the first time was a momentous occasion. The engineers had been planning for and dreaming about this occasion for many years. Ruth Hasse was one of the executive secretaries at Plum Brook, and she recalled the excitement of the engineers as they prepared for the event. She compared them to eager children in anticipation of Christmas morning. She said, “Well, I won’t say they could hardly

³¹ Harold B. Finger, “Managing the Nuclear-Rocket Program,” *Astronautics* (December 1962): 18–21.

³² Harold W. Giesler, Harry J. Reilly, and William A. Poley, “Low-Power Tests of the Plum Brook Reactor,” February 1963, Box 252, Folder 14, Plum Brook Archives.

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wait, but they were gearing up toward that because this was why we were here.”³³ Criticality signaled the point at which the reactor would become ready to begin generating scientific data. Criticality was Plum Brook’s coming-out party.

In the months leading up to criticality all of the engineers worked long and hard hours. Joe Savino a process systems engineer recalled the experience as “fun and challenging,” but for eight months he went to work early in the morning and did not come home until midnight. This included a two-hour daily roundtrip commute from Lewis to Plum Brook and late-night work in the Lewis computing division analyzing the data. He said, “I was told the Congress was interested in getting that reactor started; that’s the reason I worked [so hard.] I enjoyed the experience tremendously. I felt I made a valuable contribution to reactor science.”³⁴ This was the type of commitment that it took to prepare a reactor to reach criticality for the first time and was why there was such great anticipation of the event.

Prior to criticality there were political issues that threatened to delay the start of Plum Brook’s experimentation. In April 1961 the *Washington Post* reported that there was a “smoldering jurisdictional dispute” between NASA and the AEC that could potentially hinder nuclear testing for space projects at Plum Brook.³⁵ The local congressman who represented the Plum Brook region, Charles A. Mosher, testified that the problem centered on a debate over which agency would actually be responsible for performing the work at the reactor. The answer was a compromise, with NASA retaining control of the facility and the AEC having close oversight of safety and operational issues.

But this resolution did not end the disagreements between the AEC and NASA. In April 1961 Congressman Mosher announced that once Plum Brook was operational the AEC would still not allow it to conduct nuclear rocket fuel experiments because the AEC had not licensed it. This was an issue that had been brewing for over an entire year, but Mosher made it public. The journal *Nucleonics* reported, “Mosher thus brought out in the open a sensitive situation which has existed since last summer.”³⁶ NASA director Keith Glennan and AEC chairman John A. McCone started the debate, and their successors, AEC leader Glenn T. Seaborg and NASA’s James Webb, continued the struggle.

One of the problems was that the AEC was burdened by all of the other reactors being built in the country at the time. The AEC had been involved at the beginning

³³ Interview with Ruth Hasse by Mark D. Bowles, 5 December 2002.

³⁴ Interview with Joe Savino by Mark D. Bowles, 21 September 2002.

³⁵ “Jurisdictional Dispute Hinders A-Research,” *Washington Post* (25 April 1961): A10.

³⁶ “Ohio Congressman Criticizes Restrictions on NASA,” *Nucleonics* (June 1961): 28.

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of Plum Brook to authorize construction with a permit, but Plum Brook later found it difficult to get its license application reviewed.³⁷ It fell to Abe Silverstein to use his unique persuasion skills to motivate the AEC into action. The first step was to actually get the AEC officials to visit Plum Brook to work out the final licensing issues. Once they arrived, Silverstein told AEC's Glenn Seaborg that his staff could not leave until they reached an agreement. Plum Brook engineer Jack Crooks recalled that Silverstein sat the AEC visitors in the Plum Brook conference room and said, "We'll close the doors and work out all the problems and get our license. So what do we need to do?"³⁸

Before granting the operating license the AEC had to ensure that Plum Brook passed specific qualifications in accordance with the Atomic Energy Act of 1954. Saul Levine, chief of the AEC's test and power reactor safety branch, verified that the reactor was built in conformity with its construction permit, ensured that NASA could operate the reactor without endangering public safety, and confirmed that NASA was technically capable of operating the reactor. Since NASA was a federal agency, it did not have to prove that it was financially qualified to possess the reactor, as was necessary for private institutions. The license also dictated that NASA keep the required records tracking shutdowns, safety violations, and radioactivity releases into the environment. The AEC required reporting of any unusual occurrences as well as ongoing updates.³⁹

Silverstein and Seaborg worked out the problems, and on 17 March 1961 Plum Brook received a provisional AEC seal of approval for its license. Approval for fueled experiments would come later when the AEC issued its permanent license. The AEC recognized that there were such significant differences between research and test reactors that they began to issue separate licenses for them. The AEC issued its permanent license (No. SNM46) to Plum Brook's test reactor on 31 December 1963 and designated it as TR-3. This signified that it was the third test reactor licensed in the United States.⁴⁰ This license granted Plum Brook authorization to use 500 grams of uranium enriched of the uranium-235 isotope, and the AEC announced that the reactor could be operated "without undue hazard to the health and safety of

³⁷ "Public Hearing Set on Atomic Permits," *New York Times* (6 September 1957): 41; "Permit is Issued for Building of Reactor for Research," *New York Times* (22 July 1958): 14.

³⁸ Interview with Jack Crooks by Mark D. Bowles, 22 January 2002.

³⁹ Saul Levine, "Facility License No. R-93," 1 August 1963, Folder 11, Box 10, Plum Brook Archives.

⁴⁰ Robert Lowenstein, "License No. TR-3," 14 March 1961, Folder 11, Box 10, Plum Brook Archives.

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Tom Fox (at the reactor controls) and Harold Geisler (standing at his right) take the Plum Brook reactor critical for the first time on the evening of 14 June 1961. (NASA C-1961-56899)

the public.”⁴¹ In 1971 it increased this allowance to 10,000 grams.⁴²

When the day finally arrived for the reactor’s initial criticality in 1961, many of the engineers gathered around the control room. Those not inside watched through the big plate-glass windows from the outside walkway. The control room was the command center of the reactor itself, and Plum Brook’s was one of the most complex and sophisticated in the nation. Don Rhodes, reactor operator supervisor, said theirs was the “first solid-state electronic control room in the country.” This meant that there were no vacuum tubes in any of the components. Since the technology was so new, it required additional time to set up and for the engineers to learn how

⁴¹ “Space Agency Reactor--A.E.C. Issues Limited License for Ohio Installation,” *New York Times* (17 March 1961): 10.

⁴² U.S. Nuclear Regulatory Commission Inspection Summary of Plum Brook, March 1994, Box 10, Folder 19, Plum Brook Archives.

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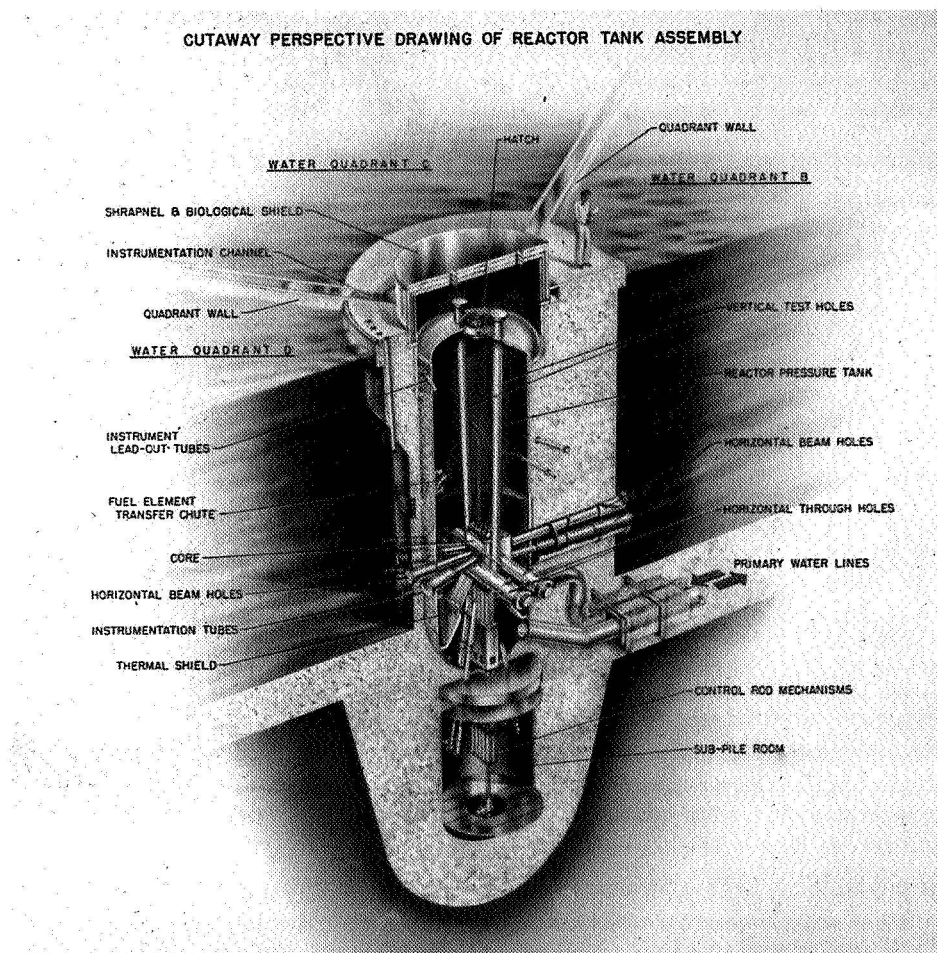


Diagram of the reactor tank assembly. (NASA CS_29736)

to operate the systems. Transistors enabled the electronics modules and the control room itself to be much smaller than would have been possible with vacuum tubes. Transistors had been on the market for only a few years when the Plum Brook control room was built, so few of the engineers had a great deal of experience with the new technology. Rhodes said, "NASA pushed the envelope on solid-state electronics. That alone was a learning curve right there."⁴³

The engineers around the control room all eagerly awaited the announcement that the reactor was finally critical. Most of them had put money in a pool betting

⁴³ Interview with Don Rhodes by Mark D. Bowles, 25 September 2002.

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on the time and day when the reactor would reach the critical moment, similar to common office pools anticipating the birth of a baby. Reactor operator Clyde Greer said, "It was breathtaking to see one instrument especially."⁴⁴ An ink line drawing on a chart recorder signified the power level of the reactor. Everyone knew that once it reached criticality it would begin to trace a straight line. Don Rhodes was the third person to take the reactor critical. To him the red line on the chart was a bit anticlimactic because the real action was inside the reactor and the chart pen simply was a representation of many other technological events all taking place at the same time.⁴⁵ Nevertheless, it was the only visual indication of success.

Approaching the first criticality, the chart held everyone's attention as it slowly drew a line at an upward angle. The engineers continued to put fuel into the reactor, slowly pulling the control rods out.⁴⁶ Once it was critical and the line was flat, Harold Giesler and Bill Fecych shouted, "We're critical," and everyone began clapping and cheering. 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."⁴⁷ Earl Boitel from the experimental equipment section recalled that it was "one of the most emotional moments that we've ever had."⁴⁸

The reactor itself was located below the pressure tank, which was surrounded by four quadrants that were 25 to 27 feet deep. Three of the quadrants (A, C, and D) were filled with water because it served as a radiation shield to protect those who were working nearby. Quadrant B was always dry and was constructed with extra concrete shielding, so the water was not necessary. The dry quadrant provided unique capabilities for handling experiment packages that could not be submerged in water.⁴⁹ Water canals extended throughout the reactor so that radioactive materials could be moved around the facility. A great deal of water was needed, with each quadrant holding 180,000 gallons and the canals requiring 220,000 gallons. The reactor needed one million gallons of water daily for cooling, shielding, and dilution of radiation. One of the early problems was quick disposal of the radioactive

⁴⁴ Interview with Clyde Greer by Mark D. Bowles, 5 February 2002.

⁴⁵ Interview with Don Rhodes by Mark D. Bowles, 25 September 2002.

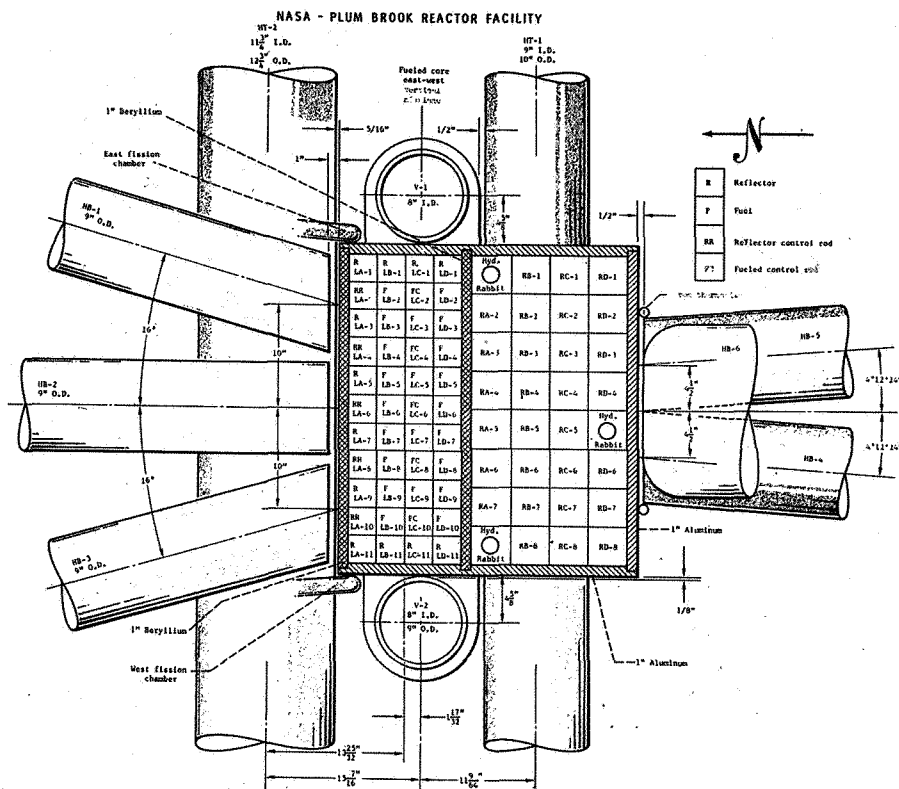
⁴⁶ Interview with Jim Greer by Mark D. Bowles, 26 September 2002.

⁴⁷ Interview with A. Bert Davis by Mark D. Bowles, 27 February 2002.

⁴⁸ Interview with Earl Boitel by Mark D. Bowles, 22 January 2002.

⁴⁹ Interview with Earl Boitel by Mark D. Bowles, 22 January 2002.

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This diagram shows the numerous experimental “facilities” in the Plum Brook reactor core. The left side was the fueled area containing cadmium and beryllium moveable regulating rods around the exterior, three shim safety rods, and twelve fixed reflector plugs. The unfueled right side of the core contained facilities for inserting up to 32 experiments. Three of these facilities (with circles) were hooked up to pneumatic rabbit tubes for easy insertion and removal of experiments. (NASA CS-46328)

water in the canals.⁵⁰ It was much easier to get the clean water into the facility. Plum Brook had two pumping stations to draw water from nearby Lake Erie. The main station was at Rye Beach, and the other was at Big Island.

The “lily pad” was located on top of the quadrants. Engineers gave it this name because with water in the quadrants the circular center resembled a floating lily pad. It was typically cluttered with experimental apparatus and large oval shrapnel shields, which weighed more than 20 tons each and were placed for safety purposes

⁵⁰ H. Brock Barkley, “Newsgram #1,” 24 May 1963, Box 45, Plum Brook Archives.

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over the pressure tank (9 feet in diameter by 31 feet high). Directly underneath the lily pad and in the center of the quadrants was the reactor itself. It was a materials-testing reactor that was cooled and moderated by light water. It had a beryllium reflector and a secondary water reflector. The fueled reactor was almost 25 inches high. The core was located beneath 21 feet of water and consisted of 93% enriched uranium, which was common at the time for research and test reactors.⁵¹ The uranium-fueled section (the center 3 by 9 array) surrounded by reflector material or experiments made up the 4 by 11 reactor core. The fueled core consisted of 22 stationary rods and 5 movable cadmium and fuel control rods. The fuel area was surrounded on three sides by reflector material. This included two movable cadmium and beryllium regulating rods, three similar shim safety rods, and 12 fixed reflector plugs for experiments. The fueled core housing had reflector plates on the right and left sides and aluminum end plates. To the left of the fueled section was a large 4 by 8 reflector section, which provided holes for the insertion of up to 32 experiments. The whole core structure sat on a stainless-steel rack in the stainless-steel-lined pressure tank. Three thermal shields were visible around the core. Two large vertical test holes ran next to the ends of the core. One large tube extended through the large reflector section, and another was next to the fueled section. Three smaller beam tubes were adjacent to the right side of the core, and three others were on the reflector side.

After the initial criticality the control room remained the heart of the reactor, but it rarely had such exciting moments. Robert Didelot, operations branch shift supervisor, said that being an operator in the control room was “99% boredom and 1% panic,”⁵² because when everything was operating as it should, there was often little work to do. Didelot said, “It was kind of a central location where people tended to stop in, say hello, talk, and ask how things were going. People would get a cup of coffee, walk through, stick their head in the door and chitchat, particularly on the back shifts. A lot of people passed though. Sometimes too many, especially when you got an alarm or panic struck.” The 1% panic time would often come when too much poison like xenon (a neutron absorber that results from fission product decay) built up in the reactor and the operators had a very limited amount of time to recover. The reactor operators would usually have less than 20 minutes to diagnose why an unplanned shutdown had occurred. The control rods could take up to 13 minutes to return or withdraw. If the operator did not recover in time, it would take 48 hours for the xenon to decay, and the experiments could be compromised. This

⁵¹ Interview with Jack Crooks by Mark D. Bowles, 22 January 2002.

⁵² Interview with Robert Didelot by Mark D. Bowles, 25 September 2002.

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is why reaction time during that 1% time of panic was so important.

Though the Plum Brook reactor went critical in 1961, it was not until over one year later that it operated at its full 60-megawatt power capacity. While this was an important date, it was not as memorable for the engineers as the first criticality. Davis said, “The day we went to full power does not register to me as a highlight . . . once you go critical that’s the first time you’ve had a sustained nuclear reaction in the core.”⁵³

While the power of the reactor was important, it was the neutron flux that was the main attribute that enabled advanced experimentation. While few people remember what a “neutron flux” is today, it entered the lexicon in the 1960s, associated with the nuclear arms race. In weapons terminology, a “neutron flux bomb” was a powerful new weapon that journalists described as a “new nightmare” that would “merely kill all living things within their range.”⁵⁴ But, in reactor terminology, the neutron flux was simply a measurement of the number of neutrons per second that a reactor could pass through a square centimeter of space. Plum Brook reactor engineer and radiochemistry section head, Robert DeFayette, said, “At the time Plum Brook was probably one of the biggest test reactors, because the test reactors didn’t get much bigger than that from the standpoint of power. We didn’t need it. What we were looking for was the neutron flux.”⁵⁵ Myrna Steele, from the nuclear experiments section, was the only woman physicist at Plum Brook. She 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.”⁵⁶

The Plum Brook reactor was capable of producing average neutron fluxes of “ 4.2×10^{14} neutrons/cm²-sec.” This meant that the reactor could transmit 420 trillion neutrons through a square centimeter of space every second, making it one of the most valuable experimental reactors in the world. In comparison with other reactors, Plum Brook’s neutron flux was the highest in the United States. Only the Engineering Test Reactor equaled the thermal flux in its core. These were followed by the General Electric test reactor at 230 trillion neutrons, the Materials Test Reactor at 200 trillion neutrons, the Oak Ridge Reactor at 130 trillion neutrons, and the Westinghouse reactor at 56 trillion neutrons.⁵⁷ Worldwide, only the Soviet

⁵³ Interview with A. Bert Davis by Mark D. Bowles, 27 February 2002.

⁵⁴ Joseph Alsop, “Neutron Flux and Other Items,” *Washington Post* (16 June 1961): A17.

⁵⁵ Interview with Robert DeFayette, 29 January 2002.

⁵⁶ Interview with Myrna Steele by Mark D. Bowles, 7 February 2002.

⁵⁷ Hugh Murray (nuclear experiments section), “Comparison of PBR Fast Flux with that Obtained in Other Reactors,” 25 June 1963, Box 252, Folder 4, Plum Brook Archives.

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SM-3 (5,000 trillion) and the Dounreay Fast Reactor in Britain (2,500 trillion) had a higher flux. Even though the Chalk River Laboratories reactor in Canada had a much higher power rating of 135 megawatts than Plum Brooks's 60 megawatts, it was only capable of a 400-trillion-neutron flux.

Reaching full power criticality was also significant because it also brought increased funding requirements. The budget changed significantly (increasing by nearly 50%) between the years 1962 and 1963, once Plum Brook was operating in full power mode. The following table compares the costs associated with running the various parts of the reactor, exclusive of any personnel salaries, insurance, or pensions:⁵⁸

Fiscal Year 1962 (Prior to Full Power Criticality)	Cost
Reactor	\$ 860,000.00
Mock-Up Reactor	\$ 57,000.00
Flux mapping equipment	\$ 30,000.00
Instrument calibration facility	\$ 60,000.00
Hot laboratory	\$ 400,000.00
Facility modifications	\$ 512,000.00
Miscellaneous	\$ 400,000.00
Total	\$ 2,319,000.00

Fiscal Year 1963 (After Full Power Criticality)	Cost
Reactor	\$ 1,137,000.00
New fuel contract	\$ 548,000.00
Igloo modification	\$ 26,000.00
Fuel element	\$ 105,000.00
Mock-Up Reactor modification	\$ 32,000.00
Modification for experiments	\$ 90,000.00
Facility modifications	\$ 279,000.00
Security control building	\$ 167,000.00
Service equipment building	\$ 88,000.00
Waste handling building	\$ 375,000.00
Experimental test & assembly building	\$ 515,000.00
Tracks for Ht-1 experiment	\$ 8,000.00
Miscellaneous construction	\$ 41,000.00
Total	\$ 3,411,000.00

⁵⁸ "Funding Required for Plum Brook," 12 October 1961, Box 1, Folder 12, Plum Brook Archives.

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On 15 August 1963 Plum Brook's main reactor completed its first experimental cycle. When the reactor was operational and engaged in active experimentation there was a plume of vapor over the reactor cooling tower. This plume became a symbol to all the reactor engineers that their systems were operating normally. But while reaching criticality was important, there were still other crucial reactor facilities that had to be completed before Plum Brook would achieve its full experimental capabilities. Perhaps none of these advances were more important than the design and construction of a second nuclear reactor.

The Mock-Up Reactor

Though the AEC stated that the Mock-Up Reactor "represents no new or novel features in the reactor design," Plum Brook significantly increased its experimental capability with its construction.⁵⁹ NASA designed the smaller research reactor to work in tandem with the larger 60-megawatt main reactor. The design work began in October 1960, construction started in December 1962, and the reactor was completed in July 1963.⁶⁰ Lockheed Nuclear Corporation designed and built the reactor for \$404,002 in accordance with specifications written primarily by Hap Johnson, who was the first project engineer of the Mock-Up Reactor (MUR).⁶¹ Once the MUR was finished, the AEC granted Plum Brook its license (No. SNM-0716) for the MUR and designated it as R-93.⁶² In August 1963 it reached its first criticality and became ready for operation.

The MUR 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 of the MUR occurred monthly for all of its electronic systems. The MUR made Plum Brook's main reactor a more efficient and more effective scientific tool. It achieved this by simulating the larger reactor's test environment, which helped engineers estimate the neutron

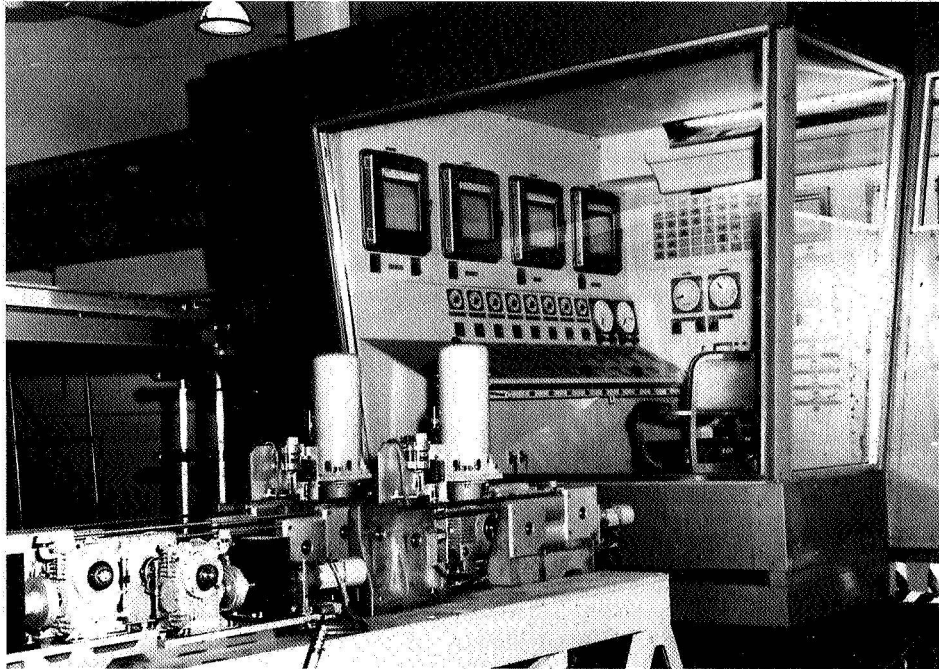
⁵⁹ Martin B. Biles, chief of the test and power reactor safety branch, division of licensing and regulation, "Hazards Analysis of the Mock-Up Reactor," Atomic Energy Commission, 14 June 1961, Box 251, Folder 37, Plum Brook Archives.

⁶⁰ Atomic Energy Commission, "Quarterly Report on Status of Reactor Construction," 2 July 1963, Box 1, Folder 5, Plum Brook Archives.

⁶¹ "Reactor Contract Let—Lockheed's Georgia Division to Build Nuclear Device," *New York Times* (23 December 1960): 38.

⁶² "License and Technical Specifications for the NASA Mock-Up Reactor," 29 July 1964, Folder 11, Box 10, Plum Brook Archives.

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The control room for the Mock-Up Reactor. (NASA PS63-0008)

flux. The main product of a test reactor was the neutrons and gamma rays from the nuclear fission. The neutron flux told the engineers how much radiation a material specimen received while in the reactor. Without the ability to predict or control the neutron flux, an accurate experimental environment could not be created or maintained.

A. Bert Davis began as the assistant project engineer and oversaw the construction of the MUR at Lockheed. He also was responsible for shipping and installing it at Plum Brook. Davis said, “[T]he purpose of the Mock-Up Reactor was to mock up these experiments as cheaply and simply as you could in order to determine what the [neutronic and other] effects would be of one experiment on another and what the effects would be of just the experiment itself.”⁶³ The AEC license enabled Plum Brook to use 1,000 grams of uranium enriched in the uranium-235 isotope.⁶⁴

The MUR was located in Canal H of the Plum Brook main reactor building,

⁶³ Interview with A. Bert Davis by Mark D. Bowles, 27 February 2002.

⁶⁴ U.S. Nuclear Regulatory Commission Inspection Summary of Plum Brook, March 1994, Box 10, Folder 19, Plum Brook Archives.

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which was just outside of the containment vessel and only 100 feet from the main reactor.⁶⁵ The two reactors were connected with each other through a system of canals. These assisted in transferring irradiated experiments or specimens between them. The MUR was a 100-kilowatt, swimming pool-type research reactor. The main core and the MUR reactor core were identical to each other in that they used the same design and configuration of fuel and control rod elements. However, the maximum power level of the MUR was limited to 100 kilowatts, so it did not require forced cooling water flow. The beam and test holes were also both in the same places, but engineers loaded specimens in the MUR holes through the surface of the pool.⁶⁶

The MUR first went critical at 9:30 p.m. on 10 September 1963, and the event was considered a “major milestone” for the facility.⁶⁷ Dick Robinson was the senior operator and supervisor, and Bill Poley operated the control panel. One month later the MUR began to be used as part of the experimental program. The MUR not only made the main reactor’s experiments more effective, but it was important because it saved both time and money for the experiment sponsors.⁶⁸ Its benefits included being able to make flux and reactivity measurements with the less expensive MUR without tying up the more expensive main reactor.

Operation of the MUR, like the main reactor, required a highly specialized team. The MUR supervisor was an AEC-licensed senior operator. The “scientist-in-charge” was the person responsible for each specific experiment. The AEC licensed all of the reactor operators, and they took orders from the senior operator. MUR facility personnel assisted the operators. They were unlicensed and were not permitted to run the reactor. There were also several reactor trainees, who were individuals learning how to become operators.

Not everyone was confident with the results obtained from the MUR. Dick Schuh, chief of the nuclear support branch, said that when running the experiments in the main reactor, the engineers still had to predict what the nuclear environment would be in a particular test hole. These holes were where the specimens were irradiated in or near the reactor. Although there were computer programs that could

⁶⁵ Stephen K. Breslauer, “Supplementary Testimony,” Atomic Energy Commission, Box 251, Folder 37, Plum Brook Archives.

⁶⁶ W. A. Poley and P.M. Finnegan, “Final Hazards Summary Mock-Up Reactor, NASA Plum Brook Facility,” September 1962, Folder 2, Box 15, Plum Brook Archives.

⁶⁷ Barkley, “Special Newsgram, Mock-Up Reactor,” 11 September 1963, Box 45, Plum Brook Archives.

⁶⁸ “Report of Reactor Operations for the NASA Plum Brook Mock-Up Reactor,” 20 November 1964, Box 40, Folder 2, Page 4, Plum Brook Archives.

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help make this determination, it was hoped that the MUR would solve this problem. Early on Schuh said, the MUR was “a simulation, albeit not too good. But, it was as good as we could make it with limited funds, of what the actual reactor was doing when it was operating at full power.”⁶⁹ Over time the engineers learned to make better use of the MUR by comparing it with their own predictions to make an “educated guess as to what’s really happening.” Accuracy was an essential goal for all of the work performed at the MUR. H. Brock Barkley said, “We have devoted considerable effort to make our nuclear flux measurements complete, detailed, and accurate.”⁷⁰ By the late 1960s the flux predictions from the MUR had a 95 percent confidence level.

The Rabbit in the Reactor

Myrna Steele was a physicist who worked at the Plum Brook Nuclear Experiments Section. Her job was to help set up experiments that were designed either by sponsors like Lockheed or Westinghouse, or internally by NASA itself. The experiments were usually focused on some type of material. Researchers needed to know how it would respond in a radioactive or cryogenic environment. Myrna and others conducted these experiments by sending the materials through various experimental beam facilities into the reactor and leaving them there for a predetermined period of time. Often this included placing the specimens in the small rabbit containers, which were then sent through the tubes and into the reactor core. Myrna recalled that once when her mother was staying with her at home, the telephone rang at about 3:00 a.m. and woke both of them both. Myrna answered and heard the voice on the other end say, “We need you to come to work.” There was a problem with one of the experiments, and Myrna quickly began getting dressed. When her mother asked from the next room where she was going, Myrna said that she had to go and see about a “rabbit test.” Her mother, understanding little of the reactor terminology, took this to mean something about the possible pregnancy of her unmarried daughter. She paced the house that day waiting for her return, only to find out that the “rabbit test” in question concerned basic research and not pregnancy.⁷¹

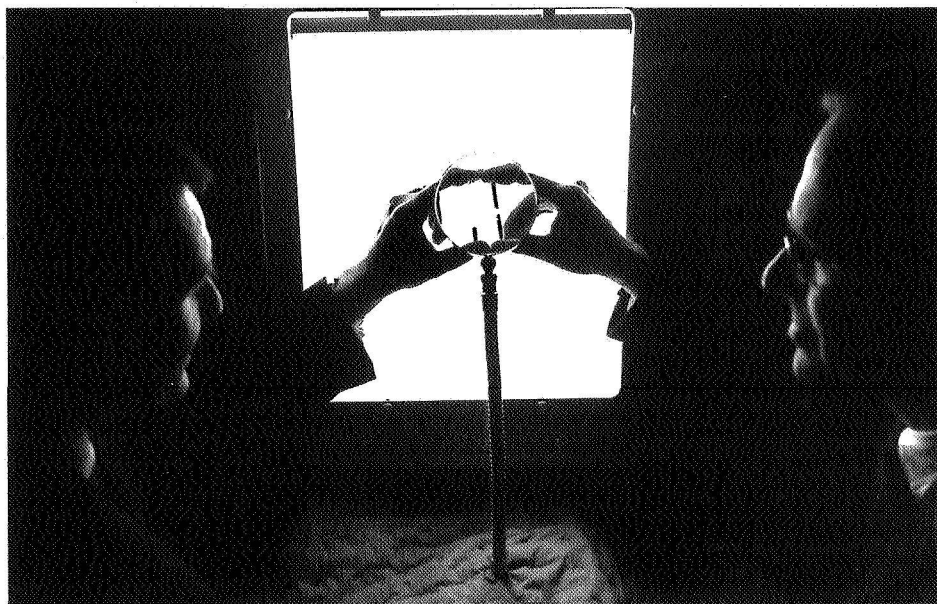
Rabbits were the name for the 3-inch-long (1.5-inch-diameter) aluminum cylinders that traveled through the test holes. They had a screw-top cap, and various

⁶⁹ Interview with Dick Schuh by Mark D. Bowles, 25 September 2002.

⁷⁰ H. Brock Barkley, “Significant Experiences of the NASA Plum Brook Reactor Facility,” 1968, NASA TM-X-52491.

⁷¹ Interview with Myrna Steele by Mark D. Bowles, 7 February 2002.

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Hap Johnson (left) and Brock Barkley (right) examine test specimens behind a magnifying glass. (NASA C-2004-741)

material specimens could be placed inside for testing purposes. Engineers used the term “rabbit” because of the fast transfer speeds, not because the cylindrical device looked anything like a rabbit itself. Once inside, the rabbits would travel along the tubes for irradiation. For the hydraulic tubes, water pressure was projected against the tubes and forced the rabbits to where they were supposed to go. They were then irradiated for a predetermined period of time, anywhere from 10 minutes to 10 days or longer. Then the water pressure was reversed, and the rabbits could then be brought back out.⁷²

The term “rabbit” was unique to the culture of research reactors.⁷³ After reactor operator Jim Greer left Plum Brook he went to work at a power reactor. He once began talking about the rabbits in the reactor and recalled getting very curious stares from the other engineers, who were imagining bunnies hopping around the reactor facility or, worse, being exposed to radiation. This also became a standard question every time one of the reactor engineers gave a public talk. Earl Boitel recalled that before he could explain someone would always ask, “What do you mean? Are you

⁷² Interview with Earl Boitel by Mark D. Bowles, 25 September 2002.

⁷³ Interview with Jim Greer by Mark D. Bowles, 26 September 2002.

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hurting the poor rabbits?”⁷⁴

One of the most important features of the Plum Brook test facilities was its accessibility. To run experiments, engineers were constantly moving materials near and even through the main reactor core. In contrast, a power reactor remained essentially isolated and immobile. The power reactor’s fuel was placed inside, and every so often it might be moved from one region to another because it burned more efficiently in the new location. Other than that, nothing moved near it. A research reactor was designed so it could be accessed, and this access was made possible by a series of experiment test holes.⁷⁵ The holes extended into or around the reactor fuel. Babcock & Wilcox developed the fuel elements for Plum Brook.⁷⁶

In total there were 43 test holes located around the core where experiments could be inserted. Multiple experiments could operate at the same time, and sometimes as many as 20 or 30 could be concurrently exposed to radiation.⁷⁷

Type	Name	Number	Size
Horizontal through hole	HT	2	9” inner diameter
Horizontal beam hole	HB	3	6” inner diameter
Vertical center hole	LC-6	1	3” square
Vertical hole	V	2	8” inner diameter
Thermal column	TC	1	41” outside diameter
Reflector hole	R	28	3” inner diameter
Hydraulic rabbit	RH	4	1.31” inner diameter
Pneumatic rabbit	RP	2	1.31” inner diameter

In total there were eight different types of test holes. There were two horizontal through holes (HT), which had an inner diameter of 9 inches and a wall thickness of .5 inches. They lay parallel to the core’s horizontal axis. HT-1 was located on the south side of the core, and HT-2 was to the north. The inner walls were actually aluminum tubes, and each end went into the pressure tank wall. Self-contained experiments could be inserted with underwater equipment in the quadrants directly

⁷⁴ Interview with Earl Boitel by Mark D. Bowles, 22 January 2002

⁷⁵ Interview with Jim Blue by Virginia Dawson, 26 September 2002.

⁷⁶ The uranium was encased in aluminum plates that were then assembled into the fuel element. They were nearly 3 feet long, and once they were assembled they were then inserted into the lattice in the reactor core. Interview with H. Brock Barkley by Mark D. Bowles, 21 September 2002.

⁷⁷ Interview with Don Rhodes by Mark D. Bowles, 25 September 2002.

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into the HT holes. These were considered the prime irradiation facility at Plum Brook.⁷⁸ The Plum Brook reactor also had horizontal beam holes, designated HB-1, HB-2, and HB-3. Each of these had an inner diameter of six inches, and they were located above HT-2 on the north side of the reactor. The most numerous types of test holes were the reflectors (R). There were 28 of these 3-inch-diameter holes, and they were located in the beryllium blocks above HT-1.⁷⁹

The largest of all of the test holes was the thermal column (TC). This 41-inch-diameter pipe was on the south side of the reactor along with HT-1. The thermal column was inside this pipe, and it ended one inch away from the primary reflector's beryllium blocks. It enabled experimenters to take a large number of fast neutrons (a neutron with kinetic energy greater than its surroundings when released during fission), moderate them, and then turn them into "thermal neutrons" (a neutron that, because of a collision with other particles, has reached an energy state equal to that of its surroundings). Because this hole was so large it could also be adapted to perform studies on shielding, and it could also irradiate large bodies, like pieces of electronic equipment.⁸⁰

Vertical test holes ran perpendicular to the HT pipes. There were two vertical test holes (V-1 and V-2) that had 8-inch inner diameters. The walls of these holes were also aluminum and extended from the top cover of the reactor tank down to the bottom of the core. There was also a vertical center hole (LC-6), which was made available for experimentation when the control rod at position LC-6 was removed from the reactor core. This was used for smaller in-pile tests, consisting of 3-inch-square unfueled experimental assemblies.

There were two pneumatic rabbit tubes (RP-1 and RP-2) that passed horizontally over the core and parallel to HT-2. This was much like the same pneumatic interoffice mail system once used in department stores or the one used in banks to transfer money to cars waiting at outside terminals. There were also four hydraulic rabbit tubes (RH-1, RH-2, RH-3, and RH-4), and these terminated at the beryllium blocks that surrounded HT-1. While real rabbits were never in the reactor, there was a story about some curious raccoons that had sneaked inside the reactor and began swimming in the canals. Jack Ross recalled, "Plum Brook is quite a wild-life center," and as soon as they saw the canals they jumped into the water and began swimming. Ross said, "I can remember a couple of fellows trying to be very creative

⁷⁸ Westinghouse Astronuclear Laboratory "Experiment Design Manual," WANL-TNR-173, August 1965.

⁷⁹ Interview with Jim Blue by Mark D. Bowles, 11 February 2002.

⁸⁰ A. B. Davis, B. Lubarsky, and T. M. Hallman, "Final Hazards Summary: NASA Plum Brook Facility" (December 1959), 11-12, 85, Box 252, Folder 8, Plum Brook Archives.

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on how they got those raccoons out of there.”⁸¹

The canals were a very important component of the facility. Once an experiment was taken out of the test holes, it was radioactive because of something called “neutron activation.” This occurred because after spending time in the reactor, the materials would trap the neutrons. According to Robert Defayette, at that point “It would be extremely hazardous and dangerous to bring it out of containment.”⁸² But for the engineers to actually analyze the experiments they had to manipulate and study the radioactive materials. This required not just a laboratory to examine the materials, but also a way to transport them there without endangering the engineers. Although some experiments were transported in lead casks above the water, most were moved in the canals. The canals were 25 feet deep, which was necessary for shielding purposes to protect the people standing nearby. At the bottom of the canals was a track on which a small electric vehicle could maneuver from the reactor core through the quadrants and canals. Not all of the experiments could fit on the vehicle. Those that would not fit had to be transported manually through the canals with poles, ropes, and other equipment to push them along. Earl Boitel said that in describing this journey, “sometimes people use the word *tortuous* because it took a long time.”⁸³ After they had been irradiated, these materials were sent to the “Hot Laboratory.” Once there, the experiments would be picked up by an overhead crane at the back of the laboratory and then moved into one of the cells for disassembly and data gathering. It was here that scientists could examine how the materials’ physical properties had changed after exposure to radiation.

The Hot Laboratory

In December 1963, three months after completion of the MUR, the Hot Laboratory, headed by Robert Oldrieve, became fully operational.⁸⁴ Facility design engineers at the Lewis Research Center (Samuel Kaufman, Abner Horwith, and Morton Krasner) conceived and designed the facility, and NASA constructed it for \$1.1 mil-

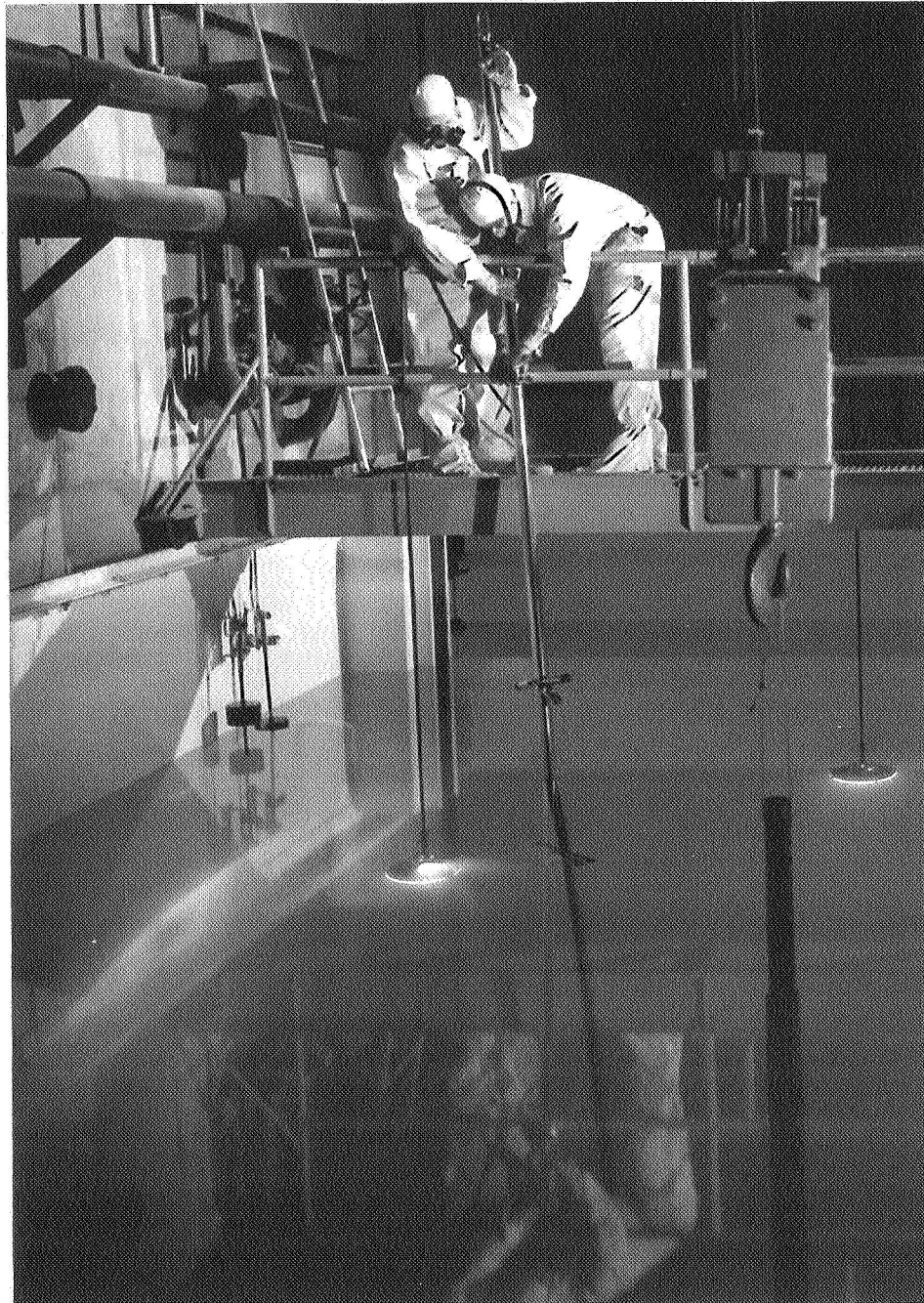
⁸¹ Interview with Jack Ross by Robert Arrighi, 27 September 2002.

⁸² view with Robert Defayette by Virginia Dawson, 21 September 2002.

⁸³ Interview with Earl Boitel by Mark D. Bowles, 25 September 2002.

⁸⁴ Oldrieve had earned an engineering degree from the University of Cincinnati in 1954 and then began working for NACA as a metals and materials engineer. NACA then sent him to the Oak Ridge laboratory to learn nuclear engineering, and in 1959 he was assigned to Plum Brook. He wrote a science fiction book based on his Plum Brook experiences. Robert Earle (pseudonym for Robert Oldrieve), *Hot Lab* (New York: Vantage Press, 1970).

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*Two technicians manipulate a shim safety control rod in a water canal in the hot laboratory (1961).
(NASA C-1961-55808)*

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ion.⁸⁵ Hot laboratories are a key element of test reactor facilities. They are shielded cells where engineers and technicians can safely analyze irradiated experiments. The walls of the Hot Cells ranged between 43 and 63 inches thick and contained various tools and equipment to inspect and dismantle the experiments. Once the experiments were disassembled, operators placed irradiated materials in small metal rabbits, which they sent through pneumatic tubes to other laboratory rooms in the facility.

Shielding was necessary because materials exposed to nuclear radiation become radioactive and emit gamma, beta, and alpha rays and therefore cannot be analyzed in a traditional laboratory setting. In the hot laboratories an elaborate system of radiation shields enabled investigators to study the radiation's effect on the physical properties of the materials, such as strength, brittleness, or elasticity. Operators peered through thick oil-filled plate-glass windows to observe their work. They interacted with the materials through the deft use of robotic "master-slave" manipulator arms, which were claw-like devices that enabled researchers to carry out chemical and physical tests without exposing anyone to the deadly radiation. Central Research Labs, Inc., of Red Wing, Minnesota, constructed Plum Brook's Model A and Model D manipulators. They were advertised as being "As obedient as your hand!" The "amazingly simple" operations duplicated natural hand motions, and the company promised that "An operator becomes perfectly adept with practically no training."⁸⁶ The Plum Brook Hot Laboratory also contained an office, manipulator repair shop, and a decontamination room that connected the "clean" operating area with the radioactive area behind the cells.⁸⁷

Hot laboratories attracted national attention when President Kennedy once tried his hand at a remote manipulator like the ones found at Plum Brook. Kennedy used a manipulator that disassembled radioactive parts from a nuclear rocket reactor. It 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."⁸⁸

While the best Kennedy could do was simply play with the reactors, the actual

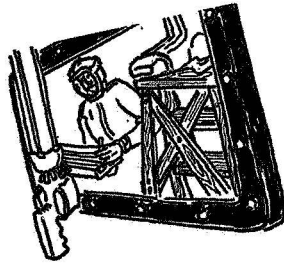
⁸⁵ Robert E. Oldrieve, "Plum Brook Reactor Hot Laboratory Facility," Box 252, Folder 12, Plum Brook Archives.

⁸⁶ Central Research Laboratories Inc. advertisement, in *Nucleonics* (June 1960): 45.

⁸⁷ Interview with Jack Ross by Robert Arrighi, 27 September 2002.

⁸⁸ Interview with Harold Finger by Virginia P. Dawson, 4 April 2002.

Science in Flux...



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Photo of Robert Oldrieve and pages from his book Hot Lab. (New York: Vantage Press, 1970. Photo of Oldrieve is NASA C-1961-58510.)

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President John F. Kennedy operates a hot lab manipulator at the Nuclear Rocket Development Station in Los Alamos. (Harry Finger Collection)

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operators developed a tremendous skill and dexterity in using them. The manipulators became, as the advertisements had promised, extensions of these operators' arms, hands, and fingers. The hand motion made by the operators at one end (including every twist, squeeze, and movement through space) translated to the tongs located on the other side of the thick windows in the hot cell.⁸⁹ While appearing as clumsy devices to the outsider, through much practice and skill the researchers could perform very delicate operations. Earl Boitel recalled, "We were completely amazed at those operators and technicians who could thread a needle with the manipulators. They said that anything your fingers could do, the manipulators could do. And I guess to the trained technician that was true. They were pushing the state of technology at that point in time."⁹⁰

This skill took a great deal of time and practice to perfect. William Stokes was a hot cell operator. He recalled that when he first tried to use the manipulators he fumbled around for quite some time. One of the problems was depth perception. Each window into the hot cell had a 52-inch oil-filled glass that protected the operator from radiation. While it served as a shield, it also distorted the operators' vision, creating an illusion, much the same way that a submersed stick looks broken under the surface of the water. Stokes would often demonstrate how to thread a needle with the manipulators at Plum Brook's public open houses. He would hold the needle in one manipulator grip and find the eye of the needle by using a monocular. He then used the other manipulator grip to pick up specially modified tweezers that could hold the thread. The manipulators had rubber "fingers," so that they could apply tension to something that fine. Stokes said, "After some practice, it was easy."⁹¹

This skill could occasionally be used in the real world. The nearby Cedar Point Amusement Park in Sandusky, Ohio, had numerous tests of skill and strength, like shooting basketballs, throwing a baseball at bowling pins, or smashing a hammer down. But the favored game by the families of the Plum Brook Hot Laboratory operators was the one with little hand-held grabbers that picked prizes out of a glass box. Robert Oldrieve's wife recalled that her husband never failed to win the best prizes.⁹²

The ability to do things like thread a needle was more than just play. It was a part of the operators' rigorous training program. This was such an important skill because most of their work in the hot cells dealt with very small objects. This could include anything from disassembling small motors to imbedding tiny metallographic

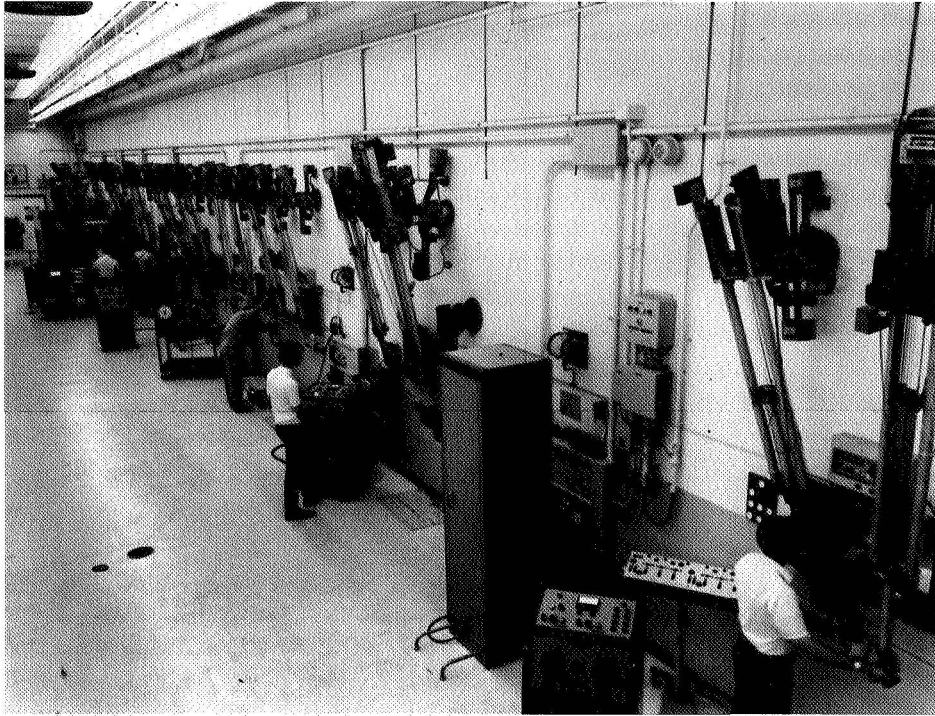
⁸⁹ Joel W. Chastain, ed., *U.S. Research Reactor Operation and Use* (Reading, MA: Addison-Wesley Publishing, 1958), p. 210.

⁹⁰ Interview with Earl Boitel by Mark D. Bowles, 25 September 2002.

⁹¹ Interview with Bill Stokes by Mark D. Bowles, 26 September 2002.

⁹² Interview with Rosalie Oldrieve by Mark D. Bowles, 26 September 2002.

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The safe work area in the hot laboratory. (NASA C-2003-839)

specimens into a plastic base for analysis under a microscope.⁹³ The microscope was especially tricky to design. Engineers custom-built a microscope into one of the cells so that the image reflected through several mirrors and into a camera that took photographs of the specimens at various magnifications.⁹⁴ Other devices included tensile testers, scales, micrometers, lathes, and cameras. Like the microscope, each of these tools required special adaptation for use by the manipulator arms. This often required the use of conventional tools, which also had to be modified. Stokes said, "We had to invent tools and make them fit onto the manipulator and mimic the same operation as your hand. We took conventional tools, like tweezers, cutters, pliers, screwdrivers, wrenches, and modified them with grips."⁹⁵ Finger grips were put on these tools and then slipped over the claws on the manipulator arms.

The 7 interconnected hot cells totaled 100,000 cubic feet of shielded research

⁹³ Interview with Jack Crooks by Mark D. Bowles, 25 September 2002.

⁹⁴ Interview with William Stokes by Mark D. Bowles, 23 January 2002.

⁹⁵ Interview with Bill Stokes by Mark D. Bowles, 26 September 2002.

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space, and each had its own function.⁹⁶ Cell 1 was for “Cutoff and Dismantling.” Technicians used its severing and milling capabilities for dismantling experiments when they entered the hot laboratory. It could also prepare metallographic specimens. Cell 2 was the “Machining” area, with its engine lathe. Operators modified a hardness tester with rubber grips. With the manipulators they could determine the hardness of the parts before machining. They collected all of the chips from the lathe and disposed of them as radioactive waste. Cell 3 was the “Physical Testing” area. This included a tensile testing machine to measure the compression and tear strength of materials. The engineers made comparisons of the material’s mechanical properties before and after it was placed in the reactor to determine the effects of radiation. A stereomicroscope was also located in this cell.

Cell 4 was for “Metallographic Preparation” of all of the specimens. “Metallographic” was a very important component of the Plum Brook research. It entailed the study of metals and their alloys through the use of microscopic or x-ray procedures. The resulting analyses provided the engineers with an indication of how well the materials would respond in a radioactive environment. Various machines could prepare these samples, including three vibratory polishing units, an ultrasonic cleaning unit, and an electropolisher and etching unit. Each of these had to be modified for operator use with the manipulator arms. Bakelite premolds facilitated specimen mounting, and a periscope enabled inspection of the specimens. Cell 5, called “Metallography,” was where the analysis actually took place. Equipment here included a metallograph, a microhardness tester, and a cathodic tester.

The final two cells were for compositional analysis. Cell 6, called “Chemical Analysis,” included a variety of testing equipment, including two remote-control burettes, a titrator, magnetic stirrers, electronic thermometers, and an analytical balance. All of the chemical dissolutions would be further analyzed in Plum Brook’s Chemistry and Radiochemistry Laboratories. Cell 7, called “Analytical Measurement,” was for x-ray diffraction and x-ray fluorescent analysis. A scintillation unit was eventually planned for inclusion in this cell but was never purchased.

Each cell had filtered air, water, special vents, an intercom, and floor drains for liquid waste effluent. There was also an intercell transportation system for the radioactive specimens. The carriers had a 3.125-inch inner diameter, were 9 inches long, and could transport 6 pounds of material at one time. Cell 3 was the central dispatch area for the pneumatic system that used the minimum amount of air to send the materials to Cells 4 through 7. It could also send a specimen to an outside area,

⁹⁶ Robert E. Oldrieve, “Plum Brook Reactor Hot Laboratory Facility,” Box 252, Folder 12, Plum Brook Archives.

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and special precautions were taken so that this could never happen by mistake.⁹⁷

With the Plum Brook infrastructure in place—a critical test reactor, test holes and rabbits, canals, the MUR, and the Hot Laboratory—the facility was prepared to begin what appeared to be a long-term experimental program. After approximately seven years of preparations and a change in priorities from a nuclear airplane to a nuclear rocket, the Plum Brook engineers were finally ready to begin conducting experiments.

⁹⁷ “Hot Cell Equipment,” Box 272, Folder 10, Plum Brook Archives.

Experimenting with the Reactor

Ernest Rutherford was singing “Onward Christian Soldiers” again, just like he did every time a new scientific discovery was within his grasp.¹ It was 1901, and he and his University of Montreal colleague, Frederick Soddy, were researching the mysterious world of radioactivity, a phenomenon that had been discovered only five years earlier. X-rays were enabling physicians to see inside their patients for the first time, but no one knew what these strange rays were. After intensive, ground-breaking research, Rutherford and Soddy realized that radiation was actually what happened when an atom was in the process of changing into an entirely different element. Soddy was the first to express his euphoria at the discovery. He said, “I was overwhelmed with something greater than joy—I cannot very well express it—a kind of exaltation.” The moment he knew what was happening he yelled to his partner, “Rutherford, this is transmutation!” A bit less impetuous, Rutherford tried to restrain Soddy, saying, “Don’t call it *transmutation*. They’ll have our heads off as alchemists.” But moments later Rutherford himself realized the significance of their experimental results and began celebrating in his own unique way, waltzing about his laboratory, heartily singing “Onward Christian Soldiers.”²

Rutherford’s moment of discovery in his laboratory is considered the starting point for developments that eventually led to the construction of atomic bombs and nuclear reactors and the conception of nuclear rockets.³ It is also emblematic of how the public typically imagines the way in which science progresses—the lone,

¹ Richard Rhodes, *The Making of the Atomic Bomb* (New York: Simon & Schuster, Inc., 1986), p. 46.

² Spencer R. Weart, *Nuclear Fear: A History of Images* (Cambridge: Harvard University Press, 1988), p. 6. Muriel Howarth, *Pioneer Research on the Atom: . . . The Life Story of Frederick Soddy* (London: New World, 1958), pp. 83–84; Thaddeus J. Trenn, *The Self-Splitting Atom: The History of the Rutherford-Soddy Collaboration* (London: Taylor & Francis, 1977); Alfred Romer, ed., *The Discovery of Radioactivity and Transmutation* (New York: Dover, 1964).

³ William Corliss, *Nuclear Propulsion for Space* (Washington, DC: U.S. Atomic Energy Commission, 1967), p. 10.

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iconic, white-coated genius shouting “eureka!” in the laboratory. The Rutherford story fits well with what most people expect to find when they inquire into the scientific past. However, rarely does science advance through these types of punctuated achievements and revolutionary discoveries. Instead, science grows through a much less glamorous, team-oriented, and slow process that typically remains invisible or hidden from public awareness. Sometimes science does not even “advance” at all, and experiments reveal little more than that a particular line of reasoning resulted in a dead end.

The scientists and engineers at Plum Brook were not establishing new world views on par with individuals like Rutherford. Instead, their basic engineering research employed a quiet incremental methodology that was necessary if NASA hoped to ever achieve dramatic success with a nuclear rocket. Newton is often quoted as saying, “If I have seen farther, it is by standing on the shoulders of giants.”⁴ More accurately in the history of science in the twentieth century, one might say that the scientific luminaries have seen farther and established revolutionary ideas because their work is based on the cumulative efforts of the numerous, nearly anonymous scientists and engineers who came before them. Though less accurate, “standing on the shoulders of giants” is a much more exciting notion.

Prior to Plum Brook, the nuclear field had already established several “giants.” The larger theories of radioactivity had already been established; Ernest Rutherford had seen to that. Nuclear test reactors had already gone critical in many different settings; Enrico Fermi and others had seen to that. Nuclear rocket engines were also being tested; facilities like Los Alamos were seeing to that. But despite the nationwide government and industry partnership to build a nuclear rocket (the Nuclear Engine for Rocket Vehicle Application program or NERVA), its development remained a highly complex undertaking. The United States needed less glamorous, yet highly advanced, research facilities like Plum Brook to conduct experiments in support of the nuclear rocket program.⁵

It was up to the scientists and engineers at Plum Brook to establish new facts and answer troubling practical questions related to the construction of a nuclear rocket. For example, which metals best maintained their properties in radioactive and cryogenic environments? How quickly would materials exposed to radiation (both from space and from the reactor itself) become weak and deteriorate? What types of materials endured these environments best? Which of these materials provided the

⁴ Robert K. Merton, *On the Shoulders of Giants* (Chicago: University of Chicago Press, 1993).

⁵ L. Kowarski, “Report on Research Reactors,” in *Nuclear Reactors for Research*, ed. Clifford K. Beck (Princeton, NJ: D. Van Nostrand Company, 1957), pp. 3–27. L. D. P. King, “What a Reactor Can Be Used For,” *Nucleonics* (April 1954): 11.

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greatest radiation shielding capabilities to ensure the safety of astronauts? Important questions also surrounded temperature. For example, what were 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 primary focus of the work at Plum Brook was for "hot and cold" materials research needed to answer basic nuclear science questions. Its purpose was to perform experiments on material specimens, components, and operating devices placed near the reactor to determine their tolerance to radiation, the nature and cause of any radiation induced change, and how to increase the radiation tolerance. The "hot" represented the radioactivity and high temperatures generated by the nuclear reactions, and the "cold" represented the cryogenic environments that materials in space (and from liquid hydrogen) would have to operate in. Together these contrasting experimental environments provided the unique qualities of the Plum Brook research. No other nuclear test reactor had the ability to test materials with such high-powered neutron radiation and simulate at the same time cryogenic conditions in space. But "hot and cold" has another connotation as well. It also implies a type of hit-or-miss approach that is fundamental to all normal science or basic research. The Plum Brook basic research was not simply blind empiricism. It was guided by a hypothesis requiring validation through experimental test results that explored what materials would best be suited for a nuclear rocket. But a trial-and-error, hot-or-cold approach was a component of the Plum Brook program. Sometimes the results were significant; at other times the data revealed dead ends. Nevertheless, the Plum Brook community was a representation of how scientists and engineers wend their way through numerous false starts to eventually uncover more promising lines of research.

Materials research was the small piece of investigation assigned to the Plum Brook facility to solve. It was small perhaps in the scheme of the discovery of radioactivity, establishing the first test reactor, or testing the first nuclear rocket. But it was essential basic engineering research if a nuclear rocket were to ever become a reality. This chapter explores a community dedicated to its pursuit of engineering research with its powerful reactor as its primary investigative tool. There were no "eureka!" moments that resulted in a fundamental change to the foundations of science, but there rarely are for the majority of researchers. What did emerge from Plum Brook was a large database of new engineering facts concerning radioactive and cryogenic environments and their effects on various types of materials and devices.

The examination of these Plum Brook researchers can help shed new light on how similar communities form, interact, work, play, and disband. There were moments when this community rejoiced at its technical accomplishments. It took a staggering amount of effort and ability to bring one of the most powerful test reactors in the world on line and to make it capable of generating meaningful scientific

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data. However, unlike Rutherford's famous singing in the halls of his laboratory, at Plum Brook few outside the gates noticed the moments of success.

In 1963 NASA engineers at Plum Brook began what they believed to be a long-term investigative program on materials to be used in rockets intended for space exploration. Already the program had undergone a massive change in government focus through the transition from the nuclear airplane to the nuclear rocket. Within 10 years the engineers would come to realize that the fate of the nuclear rocket would be much the same as that of its aeronautical counterpart. The nuclear rocket would never get off the ground and by the early 1970s would lose all political support. By this time the Plum Brook experimental program had achieved a number of productive years generating a data base of experimental facts about how a variety of materials responded to radiation. But when the engineers realized that the political support for nuclear rockets began to wane, they experimented with the reactor itself, looking for new ways to use it for a more environmentally conscious era. Emphasizing a technique called "neutron activation analysis," the engineers tried to find a new avenue for support, should NASA pull the plug on the nuclear rocket. The Plum Brook engineers postulated that their reactor would be important for improving life here on Earth by using it for experimentation sponsored by the U.S. Environmental Protection Agency. Although this was a viable new focus, and the Plum Brook engineers were making a case that their research was inherently valuable, they felt the political and economic tide shifting support away from their mission. This chapter explores the experimental program at Plum Brook, from its administration to execution, and the unique and unusual attempt to make the transition from rockets to environmental research.

Experiment Administration

With the main elements of the reactor up and running by 1963, the Plum Brook nuclear experimental program began operating at peak efficiency. Two years earlier, H. Brock Barkley had taken over as reactor chief from Patrick Donoughe, who returned to Lewis Research Center. Alan "Hap" Johnson became the head of Plum Brook Station.⁶ Admiral Rickover had sparked Barkley's first interest in the nuclear field. In 1949 Barkley had graduated from the Naval Academy, and in 1956 he was called into Rickover's office. He became one of the first four officers in the surface nuclear program. After 12 years as a naval officer, NASA recruited Barkley to head up the Plum Brook reactor facility. He surrounded himself with people who had also

⁶ Interview with H. Brock Barkley by Mark D. Bowles, 21 September 2002.

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Engineers conducting experiments from the reactor control room. (NASA 1970_00860)

come from the nuclear Navy program, and the reactor became known as “Barkley’s Navy.”⁷ For example, Bill Fecych had been a shift test engineer on the USS *Nautilus*, the first nuclear-powered submarine.⁸ These individuals applied their vast nuclear experience learned from the Navy to the experimental facilities at Plum Brook (See organization charts at the end of the chapter).

A key function of the reactor chief was to coordinate the activities of the reactor among the various organizations that sponsored research. There were many different types of individuals and organizations involved in performing an experiment at Plum Brook’s reactor. Some experiments were designed by NASA personnel, but the majority of them came from outside sponsors. These included the AEC, General Electric, Lockheed, Westinghouse, Sperry Engineering, Atomics International,

⁷ Interview with Dean Scheibly by Mark D. Bowles, 26 September 2002.

⁸ William Fecych Obituary, *Sandusky Register* (9 March 2004).

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and the Cleveland Clinic. Typically the sponsors first communicated with Lewis Research Center at its nuclear division, headed by Leroy V. Humble.⁹ Once this division granted its approval, the Lewis Policy Committee assigned a Request for Irradiation (RFI) number, and Plum Brook was contacted directly. Plum Brook then assigned a project engineer to work with the sponsor to get safety approvals and to ensure compatibility between the experiment and the reactor. During the early experimental cycles it could be two to three years from the time that the RFI was first assigned until the experiment began. As Plum Brook staff became more experienced, this process was streamlined.¹⁰

After the outside sponsor completed the design of the experiment it went to the safeguards committee for review. This committee was advisory to the chief of the reactor, and it consisted of the senior managers from Plum Brook, including chief of the engineering branch, chief of the operations branch, a health and safety officer, and the head of the reactor physics section. In addition, one committee member came from Lewis Research Center, and another was a consultant brought in from Oak Ridge for specialized problems. Other members came from MIT and the University of Virginia. The committee's job was to make a determination of whether the experiment would pose any undue safety hazards if it were put into the reactor.¹¹ Specifically the committee's job was to "determine that the experiment was safe, did not violate the reactor technical specifications, and posed no unreviewed safety questions."¹² This was an important legal and technical directive required by the AEC license. The committee members spent a great deal of time learning about each of the experiments before they even sat down together to discuss it. For example, Hap Johnson, former reactor chief, said, "In some cases it was almost volumes that you had to read first before you went to the meeting."¹³ They were a strict group that placed safety first and scientific research second. Earl Boitel recalled, "Many times it was difficult to get things through that committee, and rightfully so. I know sponsors would call me up and say, 'Earl can you give me some help?' I would give them some ideas. But you wouldn't want it any other way."¹⁴

⁹ Interview with Jack Crooks by Mark D. Bowles, 22 January 2002.

¹⁰ Interview with Earl Boitel by Mark D. Bowles, 22 January 2002; comments to author from H. Brock Barkley, 1 October 2004.

¹¹ Interview with Dick Schuh (a member of the safeguards committee) by Mark D. Bowles, 25 September 2002.

¹² Comments to author from H. Brock Barkley, 1 October 2004.

¹³ Interview with Alan "Hap" Johnson by Mark D. Bowles, 20 March 2002.

¹⁴ Interview with Earl Boitel by Mark D. Bowles, 22 January 2002.

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Once the safeguards committee approved the experiment the operations branch had the responsibility for configuring the reactor and setting up the test conditions to match the experimental design. Working with the sponsor, the Plum Brook team would determine the level of neutron and gamma radiation that was necessary for the experiment and the total dose that was required. Then the team calculated the position inside the reactor that would provide the best simulated environment for the experiment, in relationship to the actual environment to which the materials would be exposed. Finally, other factors had to be taken into account. For example, liquid hydrogen experiments required super-cold temperatures in the cryogenic facility, and thermionic diode experiments required temperatures up to 1800°C.¹⁵

The operations branch then coordinated six other sections, which were responsible for evaluating associated problems with the experiments and solving them. The reactor operations section managed the reactor and was responsible for the operation, control, and adjustment of the reactor during the experimental cycles. The process systems section monitored, maintained, and operated the water systems, drainage systems, air systems, the hot retention area, and the radioactive laundry. The electrical equipment section operated all of the commercial, diesel, and lighting systems. The mechanical equipment section maintained all of the reactor equipment, including the core, reflector, rabbit tubes, and regulating rods. The experimental equipment section was in charge of actually handling the experiment, including putting it into the reactor, taking it out, transferring it to the hot laboratory, and performing the data analysis. Finally, the hot laboratory analysis section managed all data analysis activities, including experiment disassembly and cut-up, and metallurgical and chemical studies. It also coordinated all of the decontamination of the radioactive equipment and packaged all of the radioactive wastes for shipment out of Plum Brook.¹⁶

An important part of Plum Brook's TR-3 operating license was to collaborate with the AEC to develop the first Test Reactor Technical Specifications. These specifications later became the guidelines for all future test reactors. The specifications were more stringent than those for power reactors (which operated under constant conditions) because test reactors were designed to operate with a high degree of flexibility under a variety of conditions. Plum Brook's first license did not provide an "envelope" for experiments, however. This envelope set operating limits for experiments, and so many of these first experiments required AEC approval of

¹⁵ Interview with H. Brock Barkley by Mark D. Bowles, 21 September 2002.

¹⁶ Interview with Len Homyak by Robert Arrighi, 27 September 2002; A. B. Davis, B. Lubarsky, and T.M. Hallman, "Final Hazards Summary: NASA Plum Brook Facility" (December 1959), pp. 63–165, Box 252, Folder 8, Plum Brook Archives.

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technical changes. This proved to be a very laborious process. By the mid-1960s Plum Brook was able to obtain approval from the AEC for an envelope for experiments in its Technical Specifications. For this, Plum Brook officials had to appear before the prestigious Advisory Committee on Reactor Safeguards, which advised the AEC on important safety questions. Once approval was obtained, Plum Brook was authorized to perform its own analysis of compliance. This provided considerable flexibility in types, operating conditions, and experimental equipment that could be installed and operated. This shortened the time sponsors had to wait for the approval of their experiments.¹⁷

Once the Plum Brook reactor was up and running, everyone believed that sponsors from around the country would begin seeking out the reactor to perform nuclear experimentation. William Fecych, chief of the reactor operations branch, predicted that "Large groups of diversified scientific personnel will vie for neutrons."¹⁸ But caution was necessary because each of these potential experiment sponsors would have to be "guided" through all of the technical requirements of the reactor itself. Fecych said that the best people for this job were those who were most experienced in the reactor operations—the Plum Brook engineers themselves. Furthermore, the sponsors were not always present during all of the irradiations.¹⁹ Sponsors wanted the results of their scientific experiments quickly and sometimes became frustrated over the numerous safety requirements and other procedures that slowed the turn-around times.

Because these goals of speed and safety were sometimes at odds, relations between the sponsors and the engineers at Plum Brook could become strained. A. Bert Davis, who at the time was project engineering chief, said that "A lot of the experiment sponsors didn't have, in our view, a proper appreciation of this reactor." The Plum Brook staff believed it was their job to become as informed as possible about the experiments themselves and to help the sponsors get valid data from the reactor. Davis said, "That made us a little unpopular" because the sponsors often did not want to convey confidential information to the Plum Brook staff. Despite the problems, Davis firmly held Plum Brook's "nose to the grindstone to try to get meaningful data out of the reactor."²⁰ The result, whether the sponsors liked it or not, was that the Plum Brook engineering team became instrumental in running the

¹⁷ Comments to Author from H. Brock Barkley, 1 October 2004.

¹⁸ William Fecych, "PBRF Experimental Program," 26 March 1964, Box 67, Plum Brook Archives.

¹⁹ Interview with H. Brock Barkley by Mark D. Bowles, 21 September 2002.

²⁰ Interview with A. Bert Davis by Mark D. Bowles, 27 February 2002.

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xperiments and intimately involved with the operation.²¹

The experiment sponsors also spent a great deal of time in the Plum Brook reactor overseeing the experiments. For example, Lockheed had over 20 people at Plum Brook, who were temporarily transferred from its Georgia facility. These engineers brought all of their own instruments with them, ran the experiments, and then returned home with their equipment and data. NASA provided the neutron beam, the neutron radiation, and the expertise of the reactor operators; the rest was up to the sponsor.²²

By the late 1960s the Plum Brook engineers' experience had developed to the point where they had a good intuitive sense about what would and would not work or obtaining valid test data. To assist the sponsors with developing better experiments and to reduce the Plum Brook review time, the reactor staff developed an Experiment Standards Guide, which provided sponsors all of the details needed to prepare experiments. The guide consisted of eight main sections that described various design standards for instruments, control systems, and mechanical devices. Other sections covered nuclear analysis, heat transfer, fluid flow, radiochemistry, activation analysis, materials selection, electrical design, and postirradiation testing. One of the most useful sections helped sponsors determine the experiment environment. H. Brock Barkley wrote, "It is a fact that most existing radiation effects data from different sources appear to show wide discrepancies and are frequently difficult to correlate. One of the major discrepancies is that the experiment environment is not adequately determined."²³ Plum Brook standardized a method to define and measure the temperature and neutron fluxes that they hoped would eliminate this discrepancy. With these standards in place, in conjunction with the nuclear administration around it, Plum Brook was finally ready to accept experiment sponsors (See Table 1 at the end of the chapter).

NERVA Experimentation

Basic research most typically involves a long series of experiments whose ultimate outcome is unknown. Homer E. Newell, head of the Office of Space Science and Applications, defined basic research as "the search for new knowledge for the sake of

²¹ Interview with Jim Blue by Virginia Dawson, 26 September 2002.

²² Interview with Don Young by Mark D. Bowles, 18 July 2002.

²³ H. Brock Barkley, "Significant Experiences of the NASA Plum Brook Reactor Facility," 1968, NASA Technical Memorandum TM X-52491, 15.

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new knowledge. [It] can be carried out only in that spirit.”²⁴ Newell always emphasized that there was a great difference between basic research and applied research and development. The goals of applied research are well defined, and its efforts are directed at achieving specific solutions, whereas the goals of basic research are open ended and investigative. But practical application could often be derived from earlier basic research. This had historically been the role that NACA played for government. Its contributions of basic knowledge and research for the aircraft industry stimulated innovation. Furthermore, it performed research that would have been too expensive for industry to explore on its own.²⁵ This was the model that NASA hoped to duplicate with the Plum Brook reactor—its main experimental mission was NERVA, and it performed basic engineering research into the effects of radiation on materials.

The Plum Brook reactor became an important tool for helping to gather the data necessary to construct a safe and efficient nuclear rocket and to design reactors to produce electrical power in space.²⁶ Scientists and engineers derived this data by developing an extensive experimental program. There were four basic types: nuclear rocket experiments, energy conversion experiments, basic radiation effects studies, and basic physics experiments. These experiments consisted of studying materials, components, and devices of various shapes and sizes to determine how their behavior changed while they were being irradiated.

The largest sponsors of these experiments were Lockheed, Westinghouse, and General Electric. Although these industrial organizations were carrying out the work, they were funded by government contracts. They used Plum Brook to investigate the relationship between cryogenic temperatures and radiation, research the best materials for the NERVA and Space Nuclear Auxiliary Power (SNAP) programs, and understand the behavior of thermionic diodes and fuel elements during and after irradiation (thermionics is the conversion of heat into electricity). In total the Plum Brook reactor staff managed 89 experiments (most involving multiple irradiation experiments) during its years of operation.

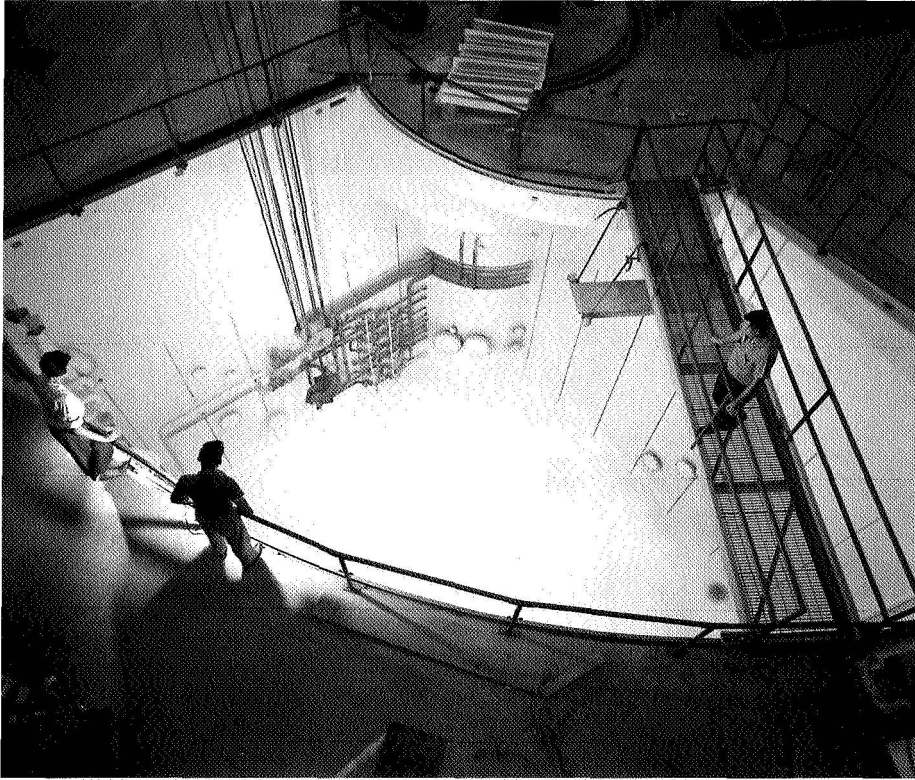
One of the main concerns affecting both the SNAP and NERVA programs was how the materials used to build the spacecraft would withstand the damaging effects of radiation. The answer to this question became the focus of the experimental program initiated at NASA’s Plum Brook Station. The chief of the reactor division H. Brock Barkley, said, “Although many experiments have been run in other facili-

²⁴ Homer E. Newell, “Scientists Explain U.S. Technical Lag,” *Aviation Week* (30 December 1957) 73.

²⁵ Dawson, *Engines and Innovation*, p. 79.

²⁶ Interview with Earl Boitel by Mark D. Bowles, 22 January 2002.

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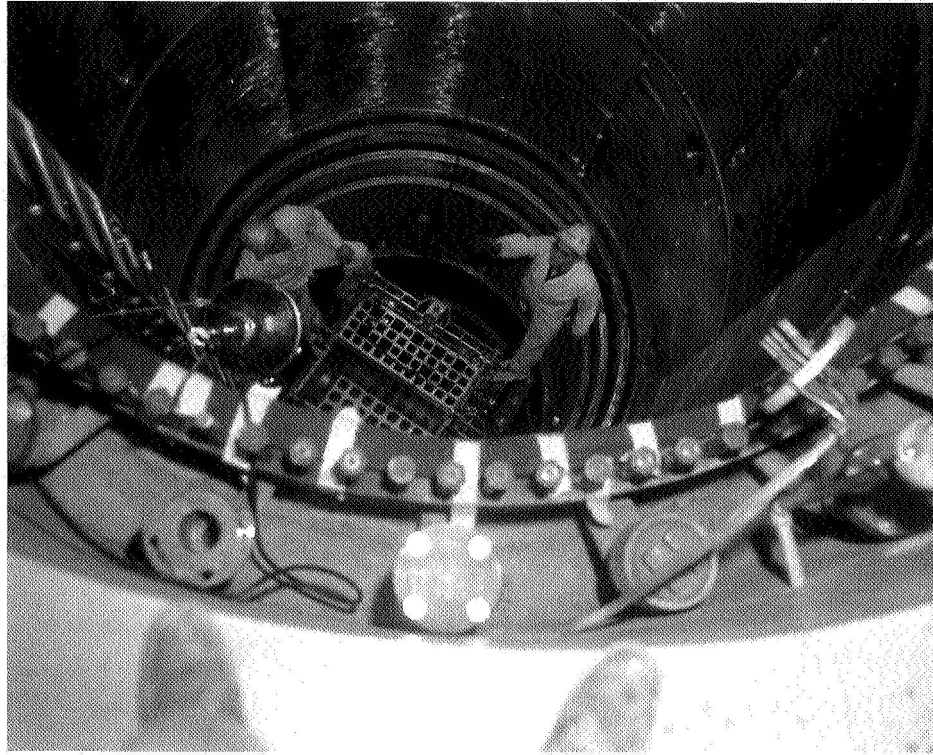
the reactor at night. Often during the late shifts, the operators would turn off the overhead lights and work by the glow of the indicators. (NASA 1959_51300)

es 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."²⁷

One feature that made the Plum Brook reactor unique and important for basic research was its cryogenic facility. Nuclear rockets not only had to be able to maintain structural integrity in a radioactive environment; they also needed to withstand the intense cold from the liquid hydrogen propellant and space itself. Plum Brook installed special refrigeration capabilities that enabled experimenters to both irradiate materials and subject them to cold at the same time. The first of these experiments

²⁷ H. Brock Barkley, "Newsgram #23," 24 June 1966, Box 45, Plum Brook Archives.

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Engineers working on the installation of the reactor core where experiments would be inserted. (NASA 1960_55018)

was the Lockheed Cryogenic Experiment (62-01).²⁸ The Lockheed experimenter knew that an engineering evaluation of the combined neutron-irradiation cryogenic effects on materials was a study that was of vital importance for advanced rocket design.²⁹ Both of these types of environments (intense cold and radiation) caused most alloys and metals to become brittle. However, although various researchers had examined the effects of cryogenic temperatures or irradiation on materials, Jack Ross, the health physics manager, said, “there had never been, up to this point, the ability to simultaneously determine the combined effects of both under common

²⁸ The first number indicated the year and then the sequence of approved experiments in that year. Thus the Lockheed experiment 62-01 meant that it was the first approved experiment in 1962.

²⁹ C. A. Schwanbeck, “Final Report: Effect of Nuclear Radiation on Materials at Cryogenic Temperatures,” August 1967, NASA CR-72332.

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conditions. That was one of the big . . . interests that NASA had here.”³⁰

Eugene Wigner, from Princeton University, was the first to propose that radiation weakened materials. In 1946 he called the “Wigner Effect” what happened when neutrons interacted with structural materials to knock atoms out of normal positions.³¹ He believed that this radiation damage would leave the materials weak and ineffective. However, he did not take into consideration the annealing effects. When atoms are moved from their original positions, they often relax back into place. Sometimes this changes the physical properties and some materials become harder, more brittle, etc. Temperature also affected the annealing process, and at lower temperatures some atoms would not relax the same way as they might at other temperatures. If all metals and alloys responded differently, then basic research was needed to measure and classify their reactions to cryogenic temperature and radiation so that the most suitable could be selected for a nuclear rocket. Developing a test facility to achieve this was an extremely difficult proposition. Jim Blue from the Lewis Research Center recalled, “This was quite a feat because of course the radiations from the reactor want to heat things up and here you’re trying to keep it cold. It was kind of like trying to cool something and heat it at the same time.”³² Engineers believed the entire setup was “kind of exotic.”³³

Plum Brook’s sponsors used the HB-2 experiment tube for cryogenic experiments to investigate the effects of low temperature and high radiation on various metals for potential use in space vehicles. The experimental apparatus consisted of a refrigeration system, a transfer system, and devices for measuring the resulting strain. There were four cryostats (or test loops) used to measure tensile-fatigue compression. Each cryostat was 6 inches in diameter and 9 feet long. One could be set up on the floor of Quadrant D, inserted into the core through the HB-2 beam port, and then transferred remotely to the hot cave on the outside of the quadrant to remove the specimen from the cryostat.³⁴ Tensile testers stretched a dumbbell-shaped specimen and measured its physical characteristics.³⁵

Plum Brook constructed a new \$1 million cryogenic facility for the NERVA

³⁰ Interview with Jack Ross by Robert Arrighi, 27 September 2002.

³¹ E. P. Wigner, *Journal of Applied Physics* 17 (1946): 857.

³² Interview with Jim Blue by Mark D. Bowles, 11 February 2002.

³³ Interview with Steven Borbash by Mark D. Bowles, 15 February 2002.

³⁴ Charles L. Younger and Fred A. Haley, “Effect of Nuclear Radiation at Cryogenic Temperatures on the Tensile Properties of Titanium and Titanium-Base Alloys,” September 1969, NASA TN D-42.

³⁵ Interview with Jack Crooks by Mark D. Bowles, 25 September 2002.

IRRADIATION AT CRYOGENIC TEMPERATURE - EQUIPMENT ARRANGEMENT

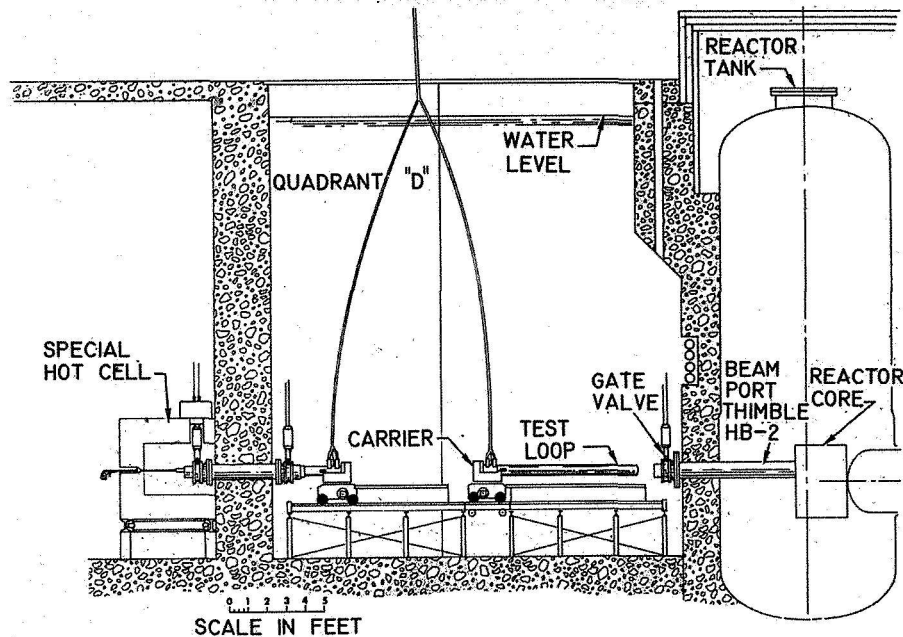


Diagram of the equipment used for cryogenic experiments. (NASA CS_19377)

Components Irradiation experiment (62-16); it was about 20 times larger than the one used in the Lockheed Cryogenic Experiment. It had a 20-kilowatt low-temperature helium refrigerator that could maintain a temperature between -409°F and -391°F . It could test larger instrumentation components such as accelerometer strain gages, and displacement transducers, as well as smaller components like control drum assemblies, dynamic bearings, and molybdenum instrumentation tubes. This further advanced Plum Brook's unique experimental facilities.³⁷

Westinghouse Astronuclear Laboratory designed experiments for the new cryogenic facility. Along with Lockheed, Westinghouse also played an important role in

³⁶ "Experiment 62-16, NERVA Components Irradiation," Westinghouse Astronuclear Laboratory Technical Report WANL-TNR-110, Barkley Private Collection.

³⁷ Barkley, "Newsgram #24," 19 July 1966, Box 45, Plum Brook Archives; Interview with Jim Blum by Mark D. Bowles, 11 February 2002.

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he NERVA program. The Westinghouse Astronuclear Laboratory was responsible for the nuclear reactor designed to go into the engine, and the Plum Brook facilities were essential for helping its scientists understand which materials were best suited for a radioactive environment. The goal of this experiment (62-16) was to develop a cryogenic in-pile loop where a variety of NERVA materials could be performance tested in a low-temperature and a highly radioactive environment.³⁸ The resulting data derived from these experiments would then help scientists and engineers in the NERVA program select materials for components that would best hold up under the harsh conditions of space and radiation.

One of the most difficult questions surrounding the Plum Brook experimental program was quantifying how important its data were to the scientific community. These experiments were all considered basic research, meaning that the reactor's primary mission was simply to better understand how materials responded to a radioactive environment. It was often difficult to objectively measure just how valuable and practical such research was in the short term. However, the information gained from the Plum Brook reactor occasionally resulted in significant findings with immediate results. For example, during the Westinghouse NERVA Experiment in 1964, the reactor irradiated pressure transducers (which converted mechanical energy into electrical energy) to be used for an upcoming full-scale reactor test in Nevada. During the early radiations the transducers failed, which was a complete surprise to the Westinghouse operators. This forced them to develop new transducers. Barkley said, "It's obvious how much more effective, economic, and important it was that the problems were detected in this reactor rather than waiting for the loss of the transducers to invalidate an extremely expensive and important full-scale NERVA reactor test."³⁹

Nevertheless, a controversy over the validity of the Plum Brook research developed. Not everyone believed that the data the reactor was returning were accurate. One engineer, speaking anonymously in a recent interview, said that measurements taken from the cryogenic experiments had no statistical relevance. He argued that while the cryogenic temperatures changed the physical properties of the materials, the radiation from the reactor itself had little if any measurable effect. This engineer stated that the same results would have been obtained if the materials were placed in cold storage alone without any reactor present. Barkley was aware of this contro-

³⁸ J. B. McGuffin, "Experiment Design Manual and Hazards Analysis, Plum Brook Reactor Facility," Westinghouse Astronuclear Laboratory, 1 July 1966, WANL-TNR-110; D. L. Burwell, "Nuclear Heating Measurement in the Plum Brook Reactor (RE-4)," Westinghouse Astronuclear Laboratory, November 1967, WANL-TME-1710.

³⁹ Barkley, "Newsgram #19," 7 May 1964, Box 45, Plum Brook Archives.

IN-PILE PUMPED LOOP EXPERIMENT LOCATION WITHIN THE PLUM BROOK REACTOR

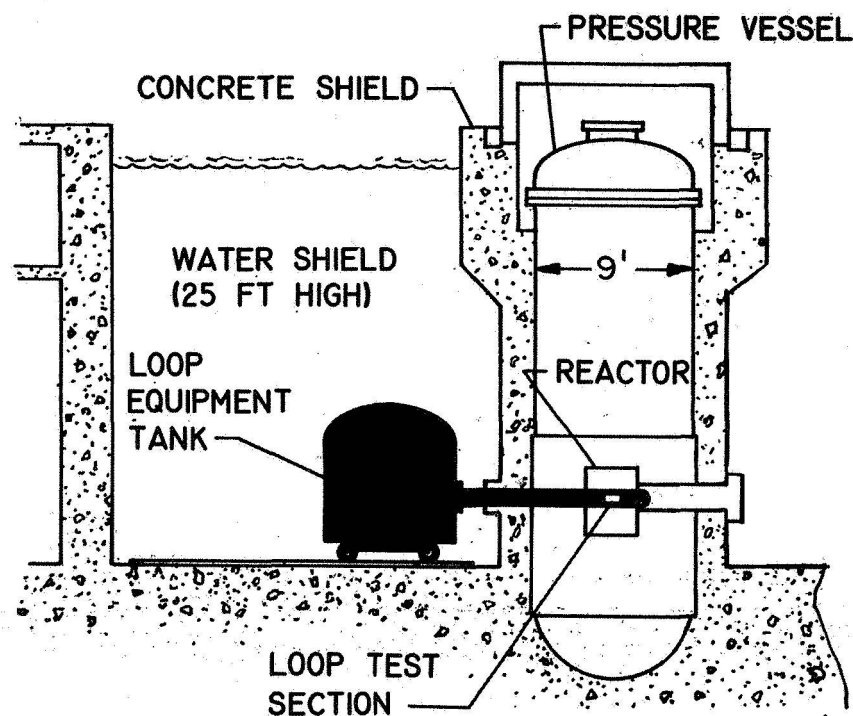


Diagram of an in-pile pumped loop experiment. (NASA CS_19857)

versy in the 1960s and agreed that during the early years of the reactor they were still struggling to determine how to best construct experiments to return significant data. By 1967 he felt confident enough to announce, "We now know how to obtain *valid* test data."⁴⁰ One year later, in a congratulatory report to his employees, Barkley said, "Plum Brook has the facilities and competence and is well on the road to becoming the standard for the industry in the field of radiation effects."⁴¹

Conclusions from a final Lockheed cryogenic study in 1967 supported Barkley's contention that the reactor was producing valid and significant data. This experi-

⁴⁰ Barkley, "Newsgram #27," 27 October 1967, Box 45, Plum Brook Archives.

⁴¹ Barkley, "Newsgram #28," 4 June 1968, Box 45, Plum Brook Archives.

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ment subjected various types of aluminum, titanium, and vanadium to the cryogenic and radioactive environments. It compared results of materials that were only subjected to cryogenic temperatures, materials that were only irradiated, materials that were irradiated while in cryogenic temperatures, and materials that were subjected to neither of these environments. C. A. Schwanbeck, project manager for Lockheed Nuclear Products, concluded, "The cryogenic irradiation facility described in this report is uniquely capable of producing valuable fundamental information on irradiation effects associated with changes in internal stress."⁴² One of the important findings was that A-286 stainless steel demonstrated no adverse cryogenic or irradiation effects.⁴³ Based on Plum Brook research, Lockheed believed this material was suitable for continued investigations of nuclear rocket structures.⁴⁴

Other important NERVA experiments followed, including the irradiation of control drum actuators (62-06). For the NERVA engine, experimenters changed the power level by varying the reactivity of the onboard nuclear reactor. One way to achieve this was with control drums. Changes in the power level were made by rotation of the control drums, which altered the size of the reflecting surface that was being exposed to the reactor core. Electropneumatic actuators actually rotated the drums. Since they were going to be exposed to radiation, vacuum, and cryogenic environments, experiments had to be performed to determine how they would withstand these conditions. Previously test facilities were able to determine the effectiveness of control drum actuators in only one of these environments. Plum Brook was able to test in all three. Lewis Research Center designed the experiment, and it was carried out in the Plum Brook reactor. After the proposed control drum actuator was irradiated for over 21 hours in the HT-2 facility, the actuator failed. Examinations in the Hot Lab revealed extensive radiation damage. This failure meant that future control drum actuators would have to be designed differently with materials that would be more resistant to a radioactive environment.⁴⁵

There were other more general problems associated with the NERVA program that Plum Brook investigated. S. S. Stein, manager of the Radiation Effects Program

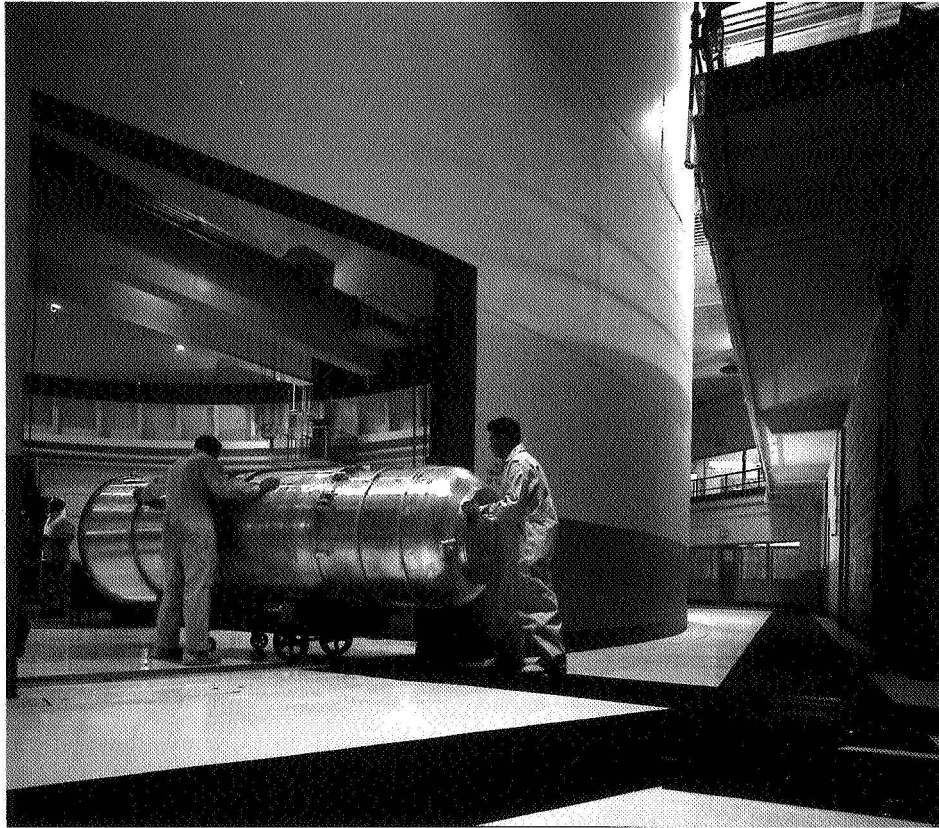
⁴² C. A. Schwanbeck, "Final Report: Effect of Nuclear Radiation on Materials at Cryogenic Temperatures," August 1967, NASA CR-72332.

⁴³ Lockheed Nuclear Products, "Effect of Nuclear Radiation on Materials at Cryogenic Temperatures," 1966, NASA CR-54881; C. A. Schwanbeck, "Effects of Interim Warming on Tensile Properties of a 286 Stainless Steel Irradiated at Cryogenic Temperatures," October 1968, NASA CR-72475.

⁴⁴ F. A. Haley and R. R. Wyer, "Irradiation System for Cryogenic Experiments in the Plum Brook Reactor," NASA Technical Memorandum TM X-52203, 1966.

⁴⁵ David J. Robinson, John T. Mayer, and Richard R. Wyer, "NERVA Control Drum Actuator Irradiation Test Program," NASA Technical Note TN D-5347, July 1969.

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*Technicians move a large "thimble" containing experiments for irradiation into the containment vessel.
(NASA C-1961-55811)*

at the Westinghouse Astronuclear Laboratory, wrote, "There is at present insufficient information on the performance of many items in the high radiation environment which is required in the NRX (NERVA Reactor Experiment) system."⁴⁶ To explore this problem, Plum Brook worked with Westinghouse on a three-year experiment (63-05). The engineers inserted a water-cooled capsule containing various materials into HT-1 from Quadrant C. These materials included instrumentation components (such as accelerometers), displacement transducers, strain gauges, and small

⁴⁶ S. S. Stein, "Experiment No. 63-05," Westinghouse Astronuclear Laboratory, May 1964, WANL-TNR-119.

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mechanical components (like the control drum actuators discussed previously).⁴⁷ Westinghouse Refractory Fuel Compounds (62-15) was the first fueled experiment of the reactor, run in August 1964. This meant that the materials could be irradiated at high temperatures and high powers for long periods of time. The ability to do fast fueled experiments was one of the major reasons that the Plum Brook Reactor was constructed. Lewis Research Center conducted a study (62-4) on the effects of radiation on solid lubricants. This was important because lubricants were exposed to a radioactive environment in space and had to maintain their properties for use in the nuclear rocket.⁴⁸

NASA performed other experiments for Westinghouse, one of which was to test fuel pins to determine how they would respond to a radioactive environment. Fuel pins were metal-clad containers that held fuel pellets. The heat that was generated by the fission process was then transferred to the pellets, which then passed through the metal containers and into the water. The heated water was the usable energy that the reactor generated. The fuel pins were very critical components for power reactors because if they failed, then dangerous radioactivity would be released into the main heat transport system. In the Plum Brook study the fuels were uranium dioxide (considered the “cornerstone of the power reactor industry”) and uranium carbide.⁴⁹ In mid-1963 Westinghouse and NASA began a program to test fuel pins for fast reactors in space applications. A fast reactor uses fast neutrons as opposed to the thermal neutrons that run in standard nuclear power plants. It was believed that this would be an ideal power reactor for the generation of electricity at a lunar base.⁵⁰ The Plum Brook engineers spent a tremendous amount of time in the Mock-Up Reactor trying to determine a better way to design and construct a fuel pin, but ultimately the experiments were not successful.⁵¹ M. G. Balfour from Westinghouse wrote that in experiment 62-15 the high incidence of uranium dioxide failure resulted in “re-evaluation and termination of the program.”⁵² Taken together these

⁴⁷ D. Newby and S. S. Stein, “Experiment No. 63-05R1,” Westinghouse Astronuclear Laboratory, August 1965, WANL-TNR-173.

⁴⁸ T. P. Jacobson, R. E. Kerkhoff, and H. H. Christenson, “A Capsule Design for Dynamic In-Pile Friction Experiments,” 1969, NASA Technical Memorandum TM X-52658.

⁴⁹ J. Belle, ed., *Uranium Dioxide: Properties and Nuclear Applications* (Washington, DC: Atomic Energy Commission), p. 1.

⁵⁰ Interview with Robert Defayette by Virginia Dawson, 21 September 2002.

⁵¹ Interview with Robert DeFayette by Mark D. Bowles, 29 January 2002.

⁵² M. G. Balfour, “Irradiation of Refractory Fuel Compounds, UO_2 and US, at High Specific Power to High Burnups,” NASA-CR-72515, undated.

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various NERVA experiments for Westinghouse and Lockheed contributed basic research to the nuclear rocket program. Some were successful, others not, but on the whole these experimental programs contributed significantly to the knowledge base needed for advancing NASA's nuclear programs.

Space Nuclear Auxiliary Power Experiments

NERVA was not the only nuclear space initiative researched at Plum Brook. Engineers also used the Plum Brook reactors to experiment with ways to design better circuits and other electrical equipment that could operate reliably and withstand the radioactive environment of a space reactor. NASA wanted to develop static nonmoving radioactive electrical generators that would be used in space. These were part of the Space Nuclear Auxiliary Power or SNAP program. SNAP was important because it had the distinction of being the only nuclear rocket initiative that actually became operational. There are still thermoelectric generators used in satellites, space probes, on the Moon, and in remote areas on Earth.⁵³ Plum Brook research helped to build these devices.

The main purpose of these SNAP generators from the beginning was to produce a very low level of electricity (35 to 50 kilowatts). President Eisenhower actually demonstrated a prototype on his desk in the White House that was used to power a light bulb. Scientists hoped that more advanced devices would convert nuclear power to electricity for longer non-human-piloted flights into the solar system (and potentially for future human trips to Mars).⁵⁴ This was needed because as craft ventured away from the sun, solar-powered cells would not be able to generate enough electricity for basic experimental and operational equipment on board to function. Furthermore, the sun could not provide enough energy for vehicles that would be in orbit for a long time or even for those going to the Moon. Therefore, a nuclear power generator appeared to be an excellent option because it had no moving parts, was an inexpensive source of fuel, and had a long lifespan. SNAP was also very dependable because the only scenario in which it might malfunction was if some-

⁵³ J. Newell Stannard, *Radioactivity and Health, A History* (Virginia: Battelle Memorial Institute, 1988), p. 654.

⁵⁴ A. W. Nice, "Information on Nuclear Space Power Systems, Volume III, SNAP-8 Mercury Rankine Power Conversion System," March 1970, Internal Memorandum, Glenn Research Center Archives.

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ing like meteorite dust hit it and disrupted the thermoelectric equipment.⁵⁵

NASA assigned the Plum Brook reactor key experiments in support of the SNAP program. One problem was that many of the electrical components were sensitive to radiation and were damaged after being exposed to this type of environment. One solution would have been to construct a shield around them, but this weight would reduce the speed and efficiency of the craft. A better solution was to develop components that were radiation tolerant. In particular, semiconductors were an important part of this system because of their low weight, low power consumption, and high reliability, but they were also the most radiation sensitive of all the electrical components. This was such a significant problem that some considered it to be the most important factor in determining the overall reliability of the electrical components, the lifetime of the system itself, and even possibly the feasibility of the entire SNAP program.⁵⁶

To help solve this problem, engineers at Plum Brook and Lewis Research Center designed a radiation-effects facility around the HB-6 beam hole as the location for a semiconductor-device radiation study program. This facility included a tank assembly within HB-6, a test package for mounting the specimens, biological shielding that included stacked blocks formed from paraffin-filled steel and aluminum shells, and a flux-measuring system.⁵⁷ In order for any of these studies to be significant, researchers had to know the neutron flux levels that the semiconductors were exposed to. These fluxes changed because of such factors as reactor operating conditions, the location of other in-core experiments, and the horizontal and vertical positions in the beam hole. After an extensive research project John M. Bozek and Michael P. Godlewski from Lewis were able to develop an empirical prediction equation that successfully predicted the flux.⁵⁸ Bozek later went on to develop another equation to predict the gamma exposure rate for the facility.⁵⁹ These studies helped to pave the way for other experimental research into specific semiconductors for the SNAP program.

⁵⁵ Interview with Jack Ross by Robert Arrighi, 27 September 2002.

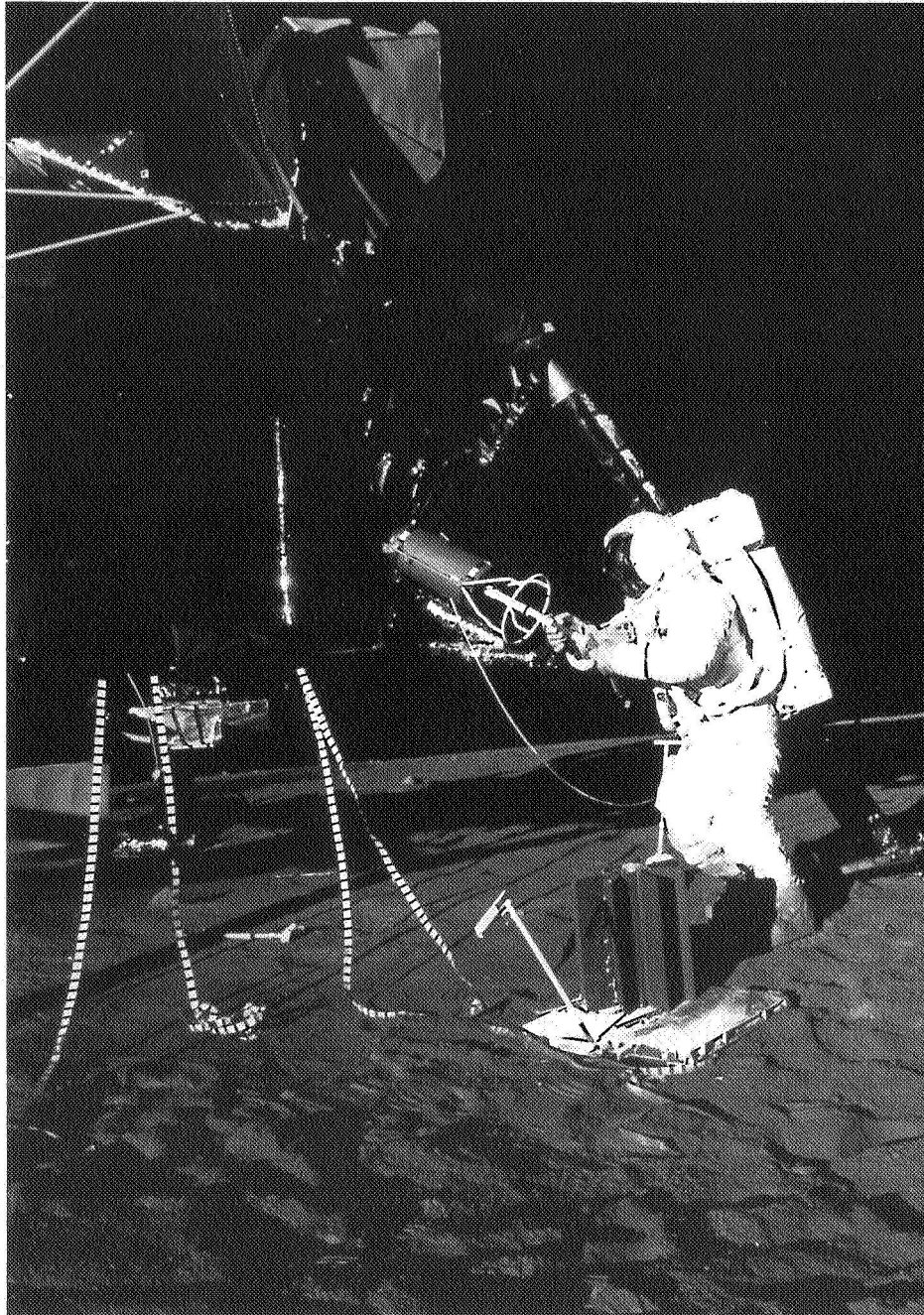
⁵⁶ Julian F. Been, "Effects of Nuclear Radiation on a High-Reliability Silicon Power Diode," NASA TN-4620, June 1968.

⁵⁷ "Experiment No. 63-09, Radiation Damage of Electrical Components," H. Brock Barkley Private Collection.

⁵⁸ John M. Bozek and Michael P. Godlewski, "Experimental Determination of Neutron Fluxes in Plum Brook Reactor HB-6 Facility with Use of Sulfur Pellets and Gold Foils," NASA Technical Memorandum TM X-1497, February 1968.

⁵⁹ John M. Bozek, "Experimental Determination of Gamma Exposure Rate in Plum Brook HB-6 Facility," NASA Technical Memorandum TM X-1490, February 1968.

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Astronaut Gordon Bean gets ready to insert the plutonium-238 heat source into the Space Nuclear Auxiliary Program 2 (SNAP-2) thermoelectric generator. This generator produced 73 watts of power for the Apollo lunar surface experiments (1969). (NASA AS12-46-6790)

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Engineers at Lewis Research Center used this radiation-effects facility to devise a variety of experiments to investigate the effects of reactor radiation on semiconductors. Nuclear Electric Sub-Systems and Component Irradiation (63-09) explored the reaction of electronic equipment to neutron and gamma radiation for the SNAP-3 program. Radiation damage occurred every time that radiation interacted with matter. What made this problem more difficult was that the damage to the materials occurred before any direct visual observations could be made. Experiment 63-09 helped to explore this phenomenon by electrically energizing components during irradiation and developing special test circuits to monitor their behavior and chart a graph comparing operation with radiation dosage received.⁶⁰

For example, Susan T. Weinstein tested 22-volt silicon voltage regulator (Zener) diodes by irradiating 25 of them in the HB-6 beam port and documented their specific failure points for further examination.⁶¹ Julian F. Been investigated silicon power diodes that were the first of a series of tests on silicon power devices for the SNAP-8 program. Its goal was to help design a more reliable nuclear power generator in space and to correlate changes in the devices' electrical parameters with basic radiation damage theory. After 480 hours of irradiation no major failures occurred. But radiation did cause the degradation of some of the electrical characteristics. Nevertheless, Been concluded that this diode could be reliably used in a nuclear electric power-generating system as long as the radiation levels did not exceed those levels simulated at Plum Brook.⁶²

For another promising concept for the SNAP program, scientists had to better understand the science of thermionics and how to integrate thermionic diodes with the fuel elements in a reactor. George Grover from Los Alamos initiated the investigations that showed the possibility of converting fission into heat electricity. This was a very attractive concept, but such an investigation required a new innovation in order to obtain valid data. The thermionic diode consisted of two closely spaced concentric cylinders around each thermionic reactor fuel element. For thermionic emission to be significant temperatures as high as 1,800°C were required, and the gap between the concentric cylinders had to be very small (~0.01 inch). Swelling of the thermionic reactor fuel with irradiation could eventually close this gap and short-circuit the diode. Because of this it was very difficult to accurately measure

⁶⁰ "Experiment No. 63-09 Radiation Damage of Electrical Components," Barkley Private Collection.

⁶¹ Suzanne T. Weinstein, "The Effects of Reactor Radiation on 22-Volt Silicon Voltage-Regulator Diodes," NASA Technical Note TN D-4923, November 1968.

⁶² Julian F. Been, "Effects of Nuclear Radiation on a High-Reliability Silicon Power Diode," NASA Technical Note TN-4620, June 1968.

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very high temperatures. This was eventually achieved through periodic measurement of gap closure by a neutron radiographic facility that could detect expansion changes as small as 0.001 inch.⁶³

At Plum Brook the first of its investigations into this area was the Thermionic Diode Experiment (63-03), which attempted to demonstrate the feasibility of converting fission heat into electricity. The experiment was placed in a vertical beam hole tube (VT-1). General Electric, through its Special Purpose Nuclear Systems Operation, sponsored a related experiment.⁶⁴ Funding for the project came from General Electric, along with support from NASA, the AEC, the Office of Nuclear Research (ONR), and the Advanced Research Projects Agency (ARPA). This experiment consisted of a long-term test of cylindrical diodes to be used in nuclear thermionic power systems. The performance of the diodes was monitored during irradiation in the Plum Brook Reactor and then was examined at the Vallecitos Atomic Laboratory or in the Plum Brook hot laboratory.⁶⁵ Throughout the 1960s Plum Brook continued to support experiments for sponsors like GE, Los Alamos, NASA, and others to help design and build effective components for SNAP generators.

Environmental Experiments

As Plum Brook engineers continued work on the nuclear rocket throughout the late 1960s, they began to become concerned over what might happen to their facility should the program lose political support and funding. This fear increased when it became clear that NASA had no future plan for the space program after the Apollo launches were over. While the Space Shuttle was the next big goal, funding for projects like nuclear rockets began to dry up. In response, the staff at the Plum Brook reactor began to actively redefine itself and look for additional areas of research where it could make a contribution. The new focus was a radical shift away from deep space and toward life on Earth as new experimentation emphasized the role that a test reactor could play in helping to improve the environment. This was something of an ironic role for a nuclear reactor to play, since those who protested nuclear power have done so primarily on the grounds of environmental endangerment. Now there was a chance for a nuclear reactor to actually find a way toward

⁶³ Comments to Author from H. Brock Barkley, 1 October 2004.

⁶⁴ "Experiment 63-03 Thermionic Diode Irradiation," Newsgrams, Box 45, Plum Brook Archives.

⁶⁵ "Experiment 64-01 Irradiation of Fuel/Clad Emitters," Newsgrams, Box 45, Plum Brook Archives.

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improving that environment.

One of the observations that Robert Oldrieve made in his science fiction novel based on his experiences at Plum Brook was that there were many strange objects placed inside the test reactor. He wrote, "It seems that everybody wants to irradiate everything they can lay their hands on in hopes of a scientific or commercial breakthrough."⁶⁶ While at Plum Brook it was easy to understand why materials that were potential components for nuclear rockets were the focus of experiments, it was more difficult to appreciate the importance of other investigations. For example, Plum Brook engineers also inserted Moon rocks, petroleum, coal, and corn into the reactor to determine the effects radiation had on their basic makeup. The reason for these types of experiments could not have taken the reactor farther away from its initial mission of testing rocket components. The new mission was environmental, and the sponsors included the Department of Agriculture and the Environmental Protection Agency. Although the results were again basic research, the experiments also proved the versatility of the Plum Brook reactor facility.

The new environmental focus for the reactor was an interesting maneuver to try to redefine it as a tool for the "green movement," rather than an enemy of it. The term "environmentalism" did not take its current meaning until 1970, and the first Earth Day celebration held that year, which drew 20 million people, represented the genesis of the modern environmental movement.⁶⁷ Though its meanings are many, it is essentially the crusade to save the Earth from perceived threats by humans and technology. One of these central concerns became the nuclear threat not only posed by warfare, but also by the radiological waste produced by reactors and the potential for a meltdown accident. The green movement began to specifically address concerns about nuclear reactors in the 1960s. The public initially voiced protests over the construction of the new power reactors in 1960, and by the early 1970s some scientists entered the movement. They argued that the AEC was too lenient on industry regulations and placed public safety second. Henry Kendall was a physicist who formed the Union of Concerned Scientists, which provided public data in support of the growing "antinuke" movement.⁶⁸

The environmental movement quickly attained political clout and widespread

⁶⁶ Robert Earle, *Hot Lab* (New York: Vantage Press, 1970), p. 18.

⁶⁷ Charles T. Rubin, *The Green Crusade: Rethinking the Roots of Environmentalism* (New York: The Free Press, 1994), p. 9; J. Brooks Flippen, *Nixon and the Environment* (Albuquerque: University of New Mexico Press, 2000), p. 1.

⁶⁸ Hal K. Rothman, *The Greening of a Nation? Environmentalism in the United States Since 1945* (Fort Worth: Harcourt Brace College Publishers, 1998), p. 144; Jerome Price, *The Antinuclear Movement*, rev. ed. (Boston: Twayne Publishers, 1990).

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public support, and in the late 1960s and early 1970s legislators signed new regulations into law.⁶⁹ In 1969 Congress passed the National Environmental Protection Act, which required all federal agencies to make official statements about any activities that might adversely affect the environment. Harsh penalties were imposed for not following the guidelines. For example, in 1971 the Space Nuclear Propulsion Office did not prepare a statement for one of its nuclear engine tests. An environmental group protested that the radioactive plume from the engine posed a significant threat to the health and safety of the surrounding community. While their lawsuit was pending the program encountered funding problems, layoffs, and its eventual cancellation.⁷⁰ The tide was turning against nuclear research. Thomas Raymond Wellock has argued that this “antinuclear movement halted nuclear construction by modifying the underlying values of state energy regulation.”⁷¹

The federal government responded to the new environmental awareness by establishing key regulatory agencies in the 1970s. These included the Environmental Protection Agency (1970), the Clean Air Act Amendments (1970), the Federal Environmental Pesticide Control Act (1972), the Safe Drinking Water Act (1974), and the Toxic Substances Control Act (1976). The AEC itself disbanded in 1975 and was transformed into the new Nuclear Regulatory Agency.⁷² But the nuclear protesters were most successful on a state and local level and assumed the authority to “prohibit nuclear plants, even encroaching on the federal government’s previously supreme domination over nuclear safety issues.”⁷³ The environmental movement was not directly responsible for Plum Brook’s demise. But the nation was moving away from support of nuclear projects, and this made it less likely that the government would allocate funds in its budget to support a controversial long-term reactor, especially if the NERVA project was ever canceled.

In the midst of this growing environmental awareness the engineers at Plum Brook sought to expand the experimental program at their facility. If the reactor

⁶⁹ Jacqueline Vaughn Switzer, *Green Backlash: The History and Politics of Environmental Opposition in the U.S.* (London: Lynne Rienner Publishers, 1997), p. 7.

⁷⁰ James Dewar, *To the End of the Solar System: The Story of the Nuclear Rocket* (Lexington, KY: University of Kentucky Press, 2004), p. 170.

⁷¹ Thomas Raymond Wellock, *Critical Masses: Opposition to Nuclear Power in California, 1958–1978* (Madison: University of Wisconsin Press, 1998), p. 4.

⁷² Glenn T. Seaborg with Benjamin S. Loeb, *The Atomic Energy Commission Under Nixon: Adjusting to Troubled Times* (New York: St. Martin’s Press, 1993), p. 232. Jacqueline Vaughn Switzer, *Green Backlash: The History and Politics of Environmental Opposition in the U.S.* (London: Lynne Rienner Publishers, 1997), p. 7.

⁷³ Wellock, *Critical Masses*, p. 6.

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could be used as a scientific tool to support the environmental movement, then, according to reactor chief H. Brock Barkley, it could “further its chances for survival.”⁷⁴ The scientific rationale for placing natural materials from the environment in the reactor was a procedure called “neutron activation analysis.” In this technique a material sample (for example, metals or corn) was bombarded with neutrons to make it radioactive. Once this occurred the gamma rays that the sample emitted were measured and the constituent trace elements could be accurately identified with a multichannel analyzer. Scientists were then able to determine the amounts of various elements present in the original sample. The idea for this was first conceived by Georg Hevesy and Hilde Levy in 1936 when they exposed rare-earth salts to a natural source of radiation.⁷⁵ It was not until the 1950s and 1960s that test reactors possessed neutron fluxes capable of enabling neutron activation analysis to play a significant analytical role in the laboratory. Gary Snyder, assistant chief of the project engineering office at Plum Brook, recalled that this technique gained widespread media attention as a very significant technique. He said, “The newspapers got involved and this was touted as the best thing since sliced bread.”⁷⁶ Today it remains one of the primary tools that the National Institute of Standards and Technology uses to certify concentrations of elements in standard reference materials.⁷⁷ The Nuclear Regulatory Commission (NRC) also currently identifies this process as “a very powerful tool.”⁷⁸

Plum Brook was not the only reactor equipped to perform neutron activation analysis in the early 1960s and 1970s. Three other commercial reactors, as well as government and university reactors, could also conduct these types of experiments. But the Plum Brook reactor was unique for several reasons. Because it was one of the most powerful test reactors in the world, it was able to identify approximately twice as many trace elements as any other facility. One Plum Brook engineer stated, “Identification of the source and existence of trace elements, which are potentially harmful to man, is the first step in cleaning up the environment and assuring that

⁷⁴ H. Brock Barkley, email to author, 28 April 2005.

⁷⁵ W. D. Ehmann and D. E. Vance, *Radiochemistry and Nuclear Methods of Analysis* (New York: Wiley, 1991).

⁷⁶ Interview with Gary Snyder by Mark D. Bowles, 21 September 2002.

⁷⁷ Michael D. Glascock and Hector Neff, “Neutron Activation Analysis and Provenance Research in Archaeology,” *Measurement Science and Technology* 14 (2003): 1516.

⁷⁸ “Fact Sheet on Research and Test Reactors,” U.S. Nuclear Regulatory Commission, found at, www.nrc.gov/reading-rm/doc-collections/fact-sheets/research-reactors.html. Accessed 11 May 2005.

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it remains clean.”⁷⁹ Plum Brook typically charged its sponsors \$150 per sample for each neutron activation analysis.

One of the first neutron activation analysis experiments at Plum Brook focused on Moon rocks and lunar soil (70-5). In the 1960s the University of Chicago had a contract with NASA to explore the properties of rocks and soil samples sent back with the Apollo astronauts. This was one of the experiments that Gary Snyder worked on at Plum Brook, and he was in close contact with the University of Chicago. After he irradiated the samples he sent the data back to the university, and he would often get an excited call from researchers, who said that they had or hadn’t found a particular element in the analysis. This work was important because it enabled the scientists to begin to theorize how the Moon had formed.⁸⁰

Plum Brook conducted experimental programs for other government agencies using neutron activation analysis. The Environmental Protection Agency (EPA) designed an experiment for the Plum Brook reactor to analyze coal, crude oil, and fly ash from coal-fired power plants by neutron activation analysis (70-8). The purpose of the experiment was to take pollution-producing materials and determine exactly what elements were released into the air from their use. A typical experiment included placing 50 to 100 milligrams of coal into a polyethylene vial. It was irradiated for five minutes, and then the gamma rays from the sample were analyzed after decay periods of 5 minutes, 30 minutes, and 24 hours. Another sample was placed in a synthetic quartz vial and irradiated for 12 hours, and then the gamma rays were analyzed after a 3-week decay period. Plum Brook engineers analyzed the data on IBM 360 computers and sent the information back to the EPA as parts per million for each of the trace elements in the sample. The results were that calcium, cerium, iron, aluminum, barium, potassium, manganese, sodium, rubidium, tin, titanium, thorium, uranium, vanadium, and zirconium were concentrated in the fly ash. For each ton of coal that was burned, data from the Plum Brook reactor showed that a potential hazard existed of emitting 0.3 curies of alpha activity from the 1 part per million of the uranium in the coal.⁸¹ Plum Brook irradiated over 1,000 samples per year in this program for the EPA.⁸² Taken together, the entire sum of neutron activation analysis at Plum Brook resulted in more experimental data than any other

⁷⁹ “Operation of Plum Brook Reactor at Reduced Power for Neutron Activation Analysis,” 19 March 1973, Box 106, Folder 15, Plum Brook archives.

⁸⁰ Interview with Gary Snyder by Mark D. Bowles, 21 September 2002.

⁸¹ Dean W. Sheibley, “Trace Element Analysis of Coal by Neutron Activation,” NASA report, NASA Technical Memorandum TM X-68208 (August 1973).

⁸² Dean Sheibley, email to author, 4 May 2005.

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irradiation study at the reactor for either the NERVA or SNAP programs.⁸³

Plum Brook also became involved in another environmental program—developing a way to determine the source of oil spills. Using neutron activation analysis, Plum Brook engineers began determining a trace element “fingerprint” of petroleum produced by different countries throughout the world. The hope was that if a database were to be established, then once an oil spill occurred, a sample of the spill could be sent to a test reactor facility like Plum Brook. Neutron activation analysis could be conducted on it, and the trace elements could then be matched up with the database to find out which country actually produced the oil and therefore might be responsible for the spill.⁸⁴ Plum Brook was also the only reactor that had accepted the challenge of irradiating gasoline. This was considered an important experimental project in the early 1970s.

Other types of neutron activation analysis at Plum Brook included jet fuel to determine trace element content in compliance with the Clean Air Act of 1970 (PL88-206). Corn and other grains were irradiated for the Department of Agriculture to determine trace element content. Dean W. Sheibley wrote, “This work is significant because it demonstrates that [instrumental neutron activation analysis] is a useful analytic tool for monitoring trace elements . . . related to environmental protection.”⁸⁵ It was also significant because it began proving that the work at the Plum Brook test reactor could extend beyond space applications to protect the environment.

The Value of the Experiments

What was the ultimate value of the experiments performed by Plum Brook? This is not an easy question to answer. Chapter 6 will address the premature termination of the nuclear rocket program. Due to its demise, much of the importance of the Plum Brook reactor went unrealized. Because of this, A. Bert Davis, former reactor chief, alluded in a recent interview to the difficulty of making an assessment of the value of the work performed at Plum Brook. In responding to a question about what the scientific community learned from these experiments he said, “Well, I don’t know that I can answer that too well. You know that we’d irradiate [the materials],

⁸³ Dean Sheibley, email to author, 5 May 2005.

⁸⁴ Interview with Robert DeFayette by Mark D. Bowles, 29 January 2002.

⁸⁵ Dean W. Sheibley, “Trace Elements by Instrumental Neutron Activation Analysis for Pollution Monitoring,” *Trace Elements in Fuel*, ed. Suresh P. Babu (Washington, American Chemical Society, 1975), p. 98–117.

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provide the data to the sponsor and the sponsor then would decide how the data was utilized.”⁸⁶ Plum Brook often represented the middle stage in scientific research. It was not responsible for designing the experiments, nor was its job to integrate its findings into the space program. This was the function of the sponsor. Plum Brook was the radioactive workhorse that permitted these investigations to take place.

Technical reports written by sponsors of experiments at Plum Brook indicate that the data acquired were useful. For Lockheed it was essential because it was the only facility where its scientists could expose materials to radioactive and cryogenic environments at the same time. C. A. Schwanbeck, a Lockheed project manager, credited his Plum Brook experiment with establishing “valuable fundamental information on radiation effects” for NERVA.⁸⁷ For Westinghouse the Plum Brook reactor helped its scientists to evaluate materials that would not be appropriate for fuel pins.⁸⁸ For NASA the reactor tested key electrical components for the SNAP-8 program to prove or disprove their viability.⁸⁹ For the EPA the reactor was able to provide neutron activation analyses that could identify significantly more trace elements than any other reactor.⁹⁰

Most of the former engineers at Plum Brook believed that the reactor’s experimental program had a broader significance. The data from the reactor were stored not only in the reports themselves but also in the people who generated them. Even after the reactor was shut down, the employees remained in the nuclear industry and went on to make significant contributions at other reactors. Don Rhodes, a Plum Brook reactor operator supervisor, said that Plum Brook had become a “training ground.”⁹¹ For example, the Army assigned people to the reactor to learn nuclear physics in a hands-on environment, and nuclear power plants sent representatives to watch Plum Brook go critical. Steven Borbash from the reactor operations section said that while he thought that the story of Plum Brook was important to tell, he saw its significance in the personal growth opportunities for the people who worked

⁸⁶ Interview with A. Bert Davis by Mark D. Bowles, 27 February 2002.

⁸⁷ C. A. Schwanbeck, “Final Report: Effect of Nuclear Radiation on Materials at Cryogenic Temperatures,” NASA CR-72332, August 1967.

⁸⁸ M. G. Balfour, “Irradiation of Refractory Fuel Compounds, UO_2 and US , at High Specific Power to High Burnups,” NASA-CR-72515, undated.

⁸⁹ Julian F. Been, “Effects of Nuclear Radiation on a High-Reliability Silicon Power Diode,” NASA Technical Note TN-4620, June 1968.

⁹⁰ “Operation of Plum Brook Reactor at Reduced Power for Neutron Activation Analysis,” 19 March 1973, Box 106, Folder 15, Plum Brook Archives.

⁹¹ Interview with Don Rhodes by Mark D. Bowles, 25 September 2002.

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there. He was proud to have worked there for the first decade of his technical career. He said that what should be remembered was that Plum Brook was a “a facility that was built and run properly by good people, and it provided a great growth opportunity for all of us youngsters that went there.”⁹²

Jack Crooks, assistant chief of the reactor operations branch, agreed that one of the main contributions of the reactor was primary knowledge and the development of a corps of nuclear experts. Every time a new reactor went critical it encountered many of the same problems that the Plum Brook scientists and engineers had faced when they built the reactor in the 1950s and took it critical in 1961. But Crooks also believed that the significance was in the technology as well. He said, “We were doing things that were new and exciting, pushing the state of the art . . . in the reactor area.”⁹³ As his colleague Earl Boitel, who worked in the experimental equipment section, said, “We were on the cutting edge of technology. We were doing things that had never been done before.”⁹⁴ What they left behind was a storehouse of basic research. Gary Snyder, assistant chief of the project engineering office, said that Plum Brook’s “legacy is the tremendous amount of information that was obtained from the experiments.”⁹⁵ H. Brock Barkley, former head of the reactor, recalled, “[We were] innovative and very much the state of the art.”⁹⁶

But Barkley cited one other area of significance for the facility. He stated that Plum Brook and its staff proved that test reactors were able to obtain data at a fraction of cost of full-scale prototypes. Plum Brook achieved its data at one-half the irradiation cost (this is the unit many test reactors use to apportion cost to experimenters) of other similar government and private reactors. It achieved this cost savings through innovative technical approaches, attention to experimental designs, and the development of specialized facilities. After leaving Plum Brook, Barkley managed four major test facilities at the National Reactor Testing Station in Idaho and used this comparison as the basis for his assessment of Plum Brook’s cost efficiency. Barkley also said that Plum Brook developed “design reviews” before this technique became standard in the industry. This “approach” to nuclear experimentation is as important as any technical data that it discovered.⁹⁷

⁹² Interview with Steven Borbash by Mark D. Bowles, 15 February 2002.

⁹³ Interview with Jack Crooks by Mark D. Bowles, 22 January 2002.

⁹⁴ Interview with Earl Boitel by Mark D. Bowles, 22 January 2002.

⁹⁵ Interview with Gary Snyder by Mark D. Bowles, 21 September 2002.

⁹⁶ Interview with H. Brock Barkley by Mark D. Bowles, 21 September 2002.

⁹⁷ Comments to author from H. Brock Barkley, 1 October 2004.

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In contrast to the comments from Boitel, Barkley, and Crooks, John Acomb saw the significance of the reactor differently. Acomb was the instrument development section head; he left Plum Brook to work for Los Alamos in the late 1960s. He said, “We weren’t pioneering. We were following other people’s guidelines.”⁹⁸ When he finally heard that the reactor was closing in 1973, his only surprise was that the end had not come sooner. He said, “I wasn’t surprised at all that it shut down, I was just surprised that it had lasted as long as it had.”

In part, Robert DeFayette, radiochemistry section head, agreed with Acomb. He said, “We did a lot of experiments at the reactor and I’ve asked myself at times, well what did this contribute to . . . science in the country?” His answer was, “Frankly, I’m not sure the work that we did contributed that much to the space program.”⁹⁹ In the years immediately following the closure of Plum Brook, NASA itself struggled to specifically define the importance of what went on there. For example, in 1976 NASA listed its accomplishments simply as a number of experiments on radiation effects at cryogenic temperatures. Although NASA could point to no specific accomplishment, it concluded only that the “work was an important element of the Agency’s ill-fated nuclear research program.”¹⁰⁰ In looking forward NASA said that there was “no foreseeable need for the reactor facility.”¹⁰¹

Nevertheless, DeFayette regarded Plum Brook as an example of what the United States was capable of when it combined educated people with financial backing and a defined goal. The Apollo program and the Manhattan Project were two of the most famous examples of this type of endeavor and, on a smaller scale, Plum Brook was also born of the same national interest. DeFayette said that NASA’s efforts with the reactor demonstrated that the “country can put its mind to do something, get together a group of people, and they can get it done.”¹⁰² The converse, however, was also true. When the country loses its desire to accomplish these goals, the facilities and the people who built and operated them are no longer needed. This loss of political support then is often the prevailing factor determining the success, failure, or inconclusiveness of the science itself.

The question of the significance of its experiments still remains. The results of its experiments were not associated with any groundbreaking ideas or technical

⁹⁸ Interviews with John Acomb by Mark D. Bowles, 13 February 2002, 8 July 2002, 21 September 2002.

⁹⁹ Interview with Robert DeFayette by Virginia Dawson, 21 September 2002.

¹⁰⁰ “Plum Brook Station Retention Plan,” 1976, Box 106, Folder 11, Plum Brook Archives.

¹⁰¹ Ibid.

¹⁰² Interview with Robert DeFayette by Mark D. Bowles, 29 January 2002.

Experimenting with the Reactor

developments. Plum Brook achieved very little with regard to establishing specific solutions for the space program that are in use today. But this is primarily because the government terminated the nuclear rocket program. Therefore it is unfair to judge it by the number of applications it developed. It was difficult to quantify the significance or the accomplishments of a program that ended before it was able to reach completion. Harold Finger concluded, "Fundamentally Plum Brook really did work in a very broad science area and established a significant science base in radiation effects that would relate to flight systems broadly."¹⁰³ This was the legacy of the experiments that Plum Brook performed. Plum Brook helped to establish a unique data base on the effects of radioactive and cryogenic environments on materials to be used for nuclear rockets and space reactors for electrical power. Though not responsible for groundbreaking new theory or well-remembered "eureka!" moments, its history is representative of the way in which our modern scientific enterprise functions. Had the nuclear rocket program remained a national priority, Plum Brook would have played an essential role in its success.

There was one other area that contributed to Plum Brook's legacy today. For John Acomb the significance of Plum Brook was its exemplary safety record, which could serve as a model for future reactors. He said, "I think that the safety record was impeccable . . . [It] speaks well of the people that were involved in that program and the care and detail of the safety of that facility and the surrounding community."¹⁰⁴ It is this legacy of safety that we turn to in the next chapter.

¹⁰³ Interview with Harold Finger by Virginia Dawson, 4 April 2002.

¹⁰⁴ Interviews with John Acomb by Mark D. Bowles, 13 February 2002, 8 July 2002, 21 September 2002.

Table 1. Reactor Experiments

Note: Data from this table were compiled from the 152 reactor cycle reports located in the NASA Plum Brook Station's Library. The cycle column does not only refer to when the experiments were in the reactor, it also indicates when preparatory work began in setting up the equipment. Footnotes to technical reports on these experiments not described in the main text also appear here.

Exp. #	Cycles	Name	Description
62-01	3, 5-84	Lockheed Cryogenic Experiment	Determined the effects of radiation on metals at cryogenic temperatures. This took place in HB-2 and Quadrant D.
62-02	36-52, 54-63, 75	In-Pile Helium Cooled Loop	Aided in evaluating loop performance under gamma heating on the in-pile experiments. A great deal of effort went into preparing equipment for this type of experimentation.
62-03	3-11, 30, 31, 33-45, 58-61, 64, 75-79, 83-88, 92-94, 96-100, 102-103	Neutron Scattering & Diffraction Experiment	Provided a collimated beam of gamma and neutron radiation for use by experimenters.
62-04	76, 78-152	Irradiation of Solid Film Lubricants	The experimental data for this test were programmed on the EDLAS computer.
62-05	19, 21-31, 33-91, 93-111	Neutron Diffraction	Utilized a collimated beam of thermal neutrons emerging from HB-4 to conduct experiments in basic physics, and more specifically in neutron diffraction studies. This was initially sponsored by Kent State University. For example, during one cycle 52 data point runs were made with a barium chlorate monohydrate crystal. During another, in cycle 80, 93 data points were made with a calcium bromate monohydrate crystal.

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Exp. #	Cycles	Name	Description
62-05R1		Interim NERVA Irradiation	Modifications to the previous experiment were made to improve the reliability of the system.
62-06	30, 45-49, 55-75	General Electric NERVA Actuator	After a great deal of setup time, in November 1967, drum actuator type AG-20 was irradiated for 65 minutes at 60 megawatts of power.
62-07	3, 5-8, 12-15, 19-24, 30	Mallory and Tungsten Irradiation	Determined the radiation effects on material properties and corrosion resistance of Mallory 1000 and pure tungsten.
62-07R1	76-78	Radiation Effects on Material Properties of Tungsten	A capsule that contained 30 tungsten tensile test specimens was irradiated.
62-09	3	PB Space Propulsion Facility Activation Measurement	Determined the optimum material composition for walls at Plum Brook's Space Propulsion Facility. Rabbits were irradiated with samples of unclad and cadmium clad 304 stainless steel and unclad and cadmium clad 5083 aluminum.
62-12	19, 21, 23-45, 49, 51-53, 55, 62, 63, 65, 70-72, 76, 79, 91, 96-100, 102-104, 108, 109, 111, 118, 146	Fueled Material Specimens Irradiation	Evaluated the fuel and fission product retention qualities of tungsten-uranium dioxide dispersions, which are fission heated to anticipate rocket fuel element operating temperatures. Capsules from this experiment were sent to the Battelle Memorial Institute and the Westinghouse Electric Corporation for postirradiation examination.
62-12R1	73-75, 77, 78, 81, 82, 85-93 95-152	Fueled Material Specimen Irradiation	A series of tests determined the extent of uranium dioxide relocation and densification in small fuel pins operating at high clad surface temperatures. During cycle 88 engineers irradiated a stainless-steel shell-type capsule, containing a sealed fuel pin. The purpose of this experiment was to provide a capsule required for checkout of the Plum Brook hot cell fracturing device and to determine the extent of pressure buildup in the sealed fuel pin.

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Exp. #	Cycles	Name	Description
62-13	102-103, 105	Unnamed	Unknown
62-13R1	42-45	Thermionic Materials Irradiation	Irradiation studies of thermionic materials. ¹⁰⁵
62-13R2	80-116, 118, 119, 124-126	Thermionic Materials Irradiation	Two capsules containing uranium carbide fuel were irradiated to determine suitability for use in a high-temperature reactor. ¹⁰⁶
62-14	3-105, 107-152	Irradiation of PBRF Materials	Investigated the long-term effects of critical materials used in the construction of the reactor. For example, in cycle 4, 60 carbon steel specimens that were identical to the material that the reactor pressure tank was constructed from were irradiated.
62-15	20-73, 97	Fuel Refractory Compounds Irradiation	Studied the effects of irradiation of refractory fuel components at high specific power to high burnups. This was the first fueled experiment. It was sponsored by Westinghouse.
62-16	64, 65, 76	NERVA Components Irradiation	This included shielding materials tests.
63-01	11-28	Measurements of Materials for SPF Walls	Tested the radiation effects on the full-scale thickness of the Space Propulsion Facility chamber walls. This included aluminum plate and foils and non-borated concrete block. ¹⁰⁷
63-02	25-27, 30	Thermal Conductivity of Refractory Fuel Compounds	Continuously measured the in-pile thermal conductivity of high-density UO ₂ fuel at temperatures up to 2,200°C. ¹⁰⁸

¹⁰⁵ Gulf General Atomic, "Studies of Thermionic Materials for Space Power Applications," 1969, NASA CR-72517.

¹⁰⁶ John R. Smith and Gary L. Snyder, "Irradiation of Uranium-Carbide Fuel Forms," 1969, NASA Technical Memorandum TM X-52696.

¹⁰⁷ John J. Smithrick and Ira T. Myers, "Effects of Cable and Circuit Parameters on the Precision Calibration of a Charge Amplifier," 1967, NASA Technical Note TN D-4300; Smithrick and Myers, "The Energy Required to Produce an Electron-Hole Pair in Silicon by Tritons," 1966, NASA Technical Note TN D-3694.

¹⁰⁸ M.G. Balfour, J.A. Christensen, and H.M. Ferrari, "In-Pile Measurement of UO₂ Thermal Conductivity," 1966, NASA CR-54740.

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Exp. #	Cycles	Name	Description
63-03R2	82-87, 95-98, 100-112, 119-122, 126-128, 130-134, 137, 139	Thermionic Diode Irradiation	The diode was irradiated at defined temperatures to see how it would react. During cycle 83 the diode would not generate current.
63-03	28-38, 58, 60, 76, 93, 94, 100, 115, 116, 122	Martin Thermionic Diode Irradiation	Demonstrated the reliable performance of a state-of-the-art thermionic diode in a nuclear reactor.
63-04	76, 78-84, 88, 93, 95-98	Thermionic Reactor Fuel Form and Insulator Irradiation	Thermocouple readings were measured as the experiment capsules were subjected to helium and argon at various power levels in the reactor. Polaroid photos were then sometimes taken of the disassembled capsules.
63-05	4-8, 14, 16, 17, 20, 22, 28, 29, 55, 58, 60	Westinghouse Interim NERVA Experiment	Provided information on materials selection for components used for the NERVA reactor designed by the Westinghouse Astronuclear Laboratory.
63-05R1	30-48, 58	NERVA Transducer Irradiation Program	Sponsored by Westinghouse, this modified the previous 63-05 experiment was the addition of a charging table. Other modifications included an HT-1 isolation valve, a capsule seal assembly, a seal pump, controls for the table drive, a pump a valve motor, and new piping.
63-07	3-6	Rabbit Test of Mallory Material to Establish Source of Tungsten in Coolant	Investigated the tungsten 187 buildup in the primary cooling water system during the reactor's full power operation.
63-08	14, 15	Sperry Experiment: Irradiation of Digital Computer Components	Evaluated the radiation temperature resistance of materials used in digital computer switching circuits.

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Exp. #	Cycles	Name	Description
63-09	8, 24-75, 122	Nuclear Electric Sub-Systems and Component Irradiation	Investigated the effects of neutron and gamma radiation on the input and output parameters of nuclear-electric components and subsystems. The experiment was for the SNAP-8 program. In cycle 32 a sheet metal "roof" was constructed over the instrumentation rack to prevent damage from water drippage.
63-09R1	76-79, 81-88, 92-96, 99-105, 107-129	Nuclear Electric Subsystems & Components	Testing included a foil plate and holder with thermocouples attached. Argon-41 buildup and biological shielding effectiveness were conducted.
63-10	23-30	Alumina Insulators Irradiation	Examined the effects of radiation on the electrical resistivity of high-purity alumina insulators.
63-11	10, 11	Unnamed	Investigated radiation effects on tungsten metal. Most important, it examined the elastic recoil mechanism of tungsten and tungsten effective resonance integral measurements.
63-11R1	31	Unnamed	Two rabbits with tungsten specimens and flux-measuring foils were irradiated for 60 seconds. They were then packaged in the hot lab and sent to the experiment sponsor.
63-12	46-56, 58	Radioisotope Electrical Generator	Unknown
63-12HL	45, 57-61, 88, 93-96, 98-103, 105	Radioisotope Electrical Generator	Tested and evaluated the concept of direct conversion of the kinetic energy of radioisotope decay into electrical power.
64-01	58	Irradiation of Fuel/Clad Emitters	Experiment performed on thermionic diodes for General Electric sponsor, Vallecitos Nuclear Center, in California. ¹⁰⁹
64-01R1	38-58	Fuel/Clad Emitter Irradiation	Modifications made to improve previous experiment

¹⁰⁹ General Electric Company, "Development Program on Long Term Testing of Cylindrical Thermionic Diodes and the Irradiation of Fuel and Insulators," 1968, NASA CR-72580.

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Exp. #	Cycles	Name	Description
64-02	12-14, 30-34, 36	Copper Irradiation	Produced the Cu-64 isotope by exposing a high purity copper foil to a thermal neutron flux. The Cu-64 can be used as a positron source to investigate the behavior of positronium in liquid gases.
64-03	12, 20	Unnamed	Produced a radioactive source (sodium-24) of such magnitude that it can be used to evaluate the decontamination efficiency of the newly built evaporator located at the PBRF waste-handling building.
64-04	22, 24-26, 28-43, 50, 51, 65	Concrete Materials Trace Element Control	Determined by neutron activation of concrete samples whether or not the sample batch was satisfactory for the construction of the Space Propulsion Facility biological shield.
64-06	89-92, 95, 97, 98, 100-105, 107-112, 117-119	Radiation Damage Experiments in Ion Complexer and Exchanger Systems	This purpose of this experiment was to procure basic data necessary to determine the feasibility of a concept for control of a water-moderated nuclear reactor. ¹¹⁰
65-01	40	Production of Uniform Line Source	Thirty-eight target specimens were loaded into two rabbits. Deionized water was added to each of the rabbits, which were then welded shut. The rabbits were then irradiated for just over 61 hours and then inspected. The rabbits ruptured. A modified vent enabled the rabbits to remain sealed, and the experiment was continued for a full 80-hour irradiation.
65-02	41, 42, 44	NaCl Crystals	Three NaCl crystals were placed in polyethylene containers and loaded into three rabbits. They were then irradiated.

¹¹⁰ J. L. Power, "In-Pile Gamma Dosimetry Measurements with Oxalic Acid," 1969, NASA Technical Memorandum TM X-52678.

Exp. #	Cycles	Name	Description
66-01	44, 54, 59-62	Irradiation of Various Insulating Materials	Two Al_2O_3 crystals were irradiated for 574.4 MWD in a rabbit. A silicon carbide crystal was also irradiated at 60 megawatts for 24 hours and then sent to Lewis Research Center for analysis.
66-03	76, 77, 80-82, 84, 85	Irradiation of Bulk UO_2 Fuel/Clad Bodies	These experiments included lengthy irradiations. For example, during cycle 80, a capsule was operated at the desired temperature for 241 hours.
66-03-01	78, 79, 83, 86-94	Irradiation of Bulk UO_2 Fuel/Clad Bodies	Unknown
66-03-2	95-98, 100-119, 121, 123	Irradiation of Bulk UO_2 Fuel/Clad Bodies	In cycle 105 the capsule was inserted into reactor tank in 1-inch increments to obtain the designed operating temperature. The capsule was then withdrawn completely in one motion, letting the temperature stabilize. This was done 50 times as quickly as possible to study the effects of thermal cycling on the fuel and thermocouples.
66-05	47, 76	Neutron Irradiation of Ammonium Bromide	A 5-milligram sample of ammonium bromide (NH_4Br) was irradiated for 30 minutes at 60 megawatts and then was sent to Lewis Research Center for analysis.
66-06	92-105, 107-152	Fission Gas Retention Studies	In Cycle 106 the irradiation lasted 330 hours or 93% of the total time available for that cycle. The fuel pin was operated at three temperature levels. Fission gas release data were also collected with the online detection instrumentation. The capsule contents were UO_2 .
66-07	59-66	Charpy Impact Specimen Irradiation	Irradiation of high-strength aluminum specimens.
66-08	73-75, 80, 81, 84, 86-88	Irradiation of a Rare Gas-Filled Thermionic Diode	This experiment was installed in the experiment 62-16 (NERVA irradiation) water-cooled capsule.

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Exp. #	Cycles	Name	Description
67-01	58-61, 63-65, 81	Irradiation of Glassy Silicates	Six irradiations were initially performed in the rabbit facility, and the specimens were then sent to the Case Western Reserve University for analysis.
67-04	87-105, 107-123	Radiolysis of Water	The objective of this experiment was to investigate the pressure buildup and composition of gases resulting from the radiolysis of water in sealed aluminum containers. ¹¹¹
67-05	71-82	Micrometeorite Irradiation	This experiment consisted of three powder containers that held two major crystalline silicates of meteorites (Olivine and Enstatite) and six flux monitors.
67-06	76-78, 80-88, 92, 93, 113	Nuclear Reactor Materials Evaluation	This included testing like an experiment in cycle 93. This included seven wear test specimens for metallurgical examination. Also, 18 fatigue and 6 tensile specimens were placed in Hot Cell #1 to await reloading into future capsules for irradiation. Corrosion tests were also started on 21 specimens in 200°F deionized water. The fatigue testing equipment was built by Material Testing Systems (MTS).
67-06-71	94	Nuclear Materials Evaluation Program	Unknown
67-06-81	94-96, 98, 103, 105, 115-140	Fatigue and Tensile Properties of Irradiated Materials	Unknown
67-06-91	99-105, 107-112, 120-127, 129-142	Irradiation of NERVA Materials	Materials included Waspaloy, Inconel, and General Dynamics test specimens.

¹¹¹ Dean W. Sheibly, "Design of a Lead-Type Capsule System to Investigate the Radiolysis of Water," 1969, NASA Technical Memorandum TM X-52663.

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Exp. #	Cycles	Name	Description
67-07	76, 77, 79, 81, 82, 91, 94-112, 114-139, 142-150	Irradiation of Gas-Cooled Fuel Pins for Compact Reactors	This experiment arrived at the reactor from Oak Ridge on 21 May 1968. One test (cycle 103) attempted to measure the diffusion rate of gaseous fission products in a static system. ¹¹²
68-01	76, 79-82, 84, 86, 87, 89, 104, 107-109	Irradiation of Plastic Containers	Over 25 samples of plastic were irradiated for various lengths of time and then were analyzed in the hot lab. This was increased to 50 samples in cycle 81. In Cycle 104, 15 plastic vials—which contained with lead, aluminum, or air samples—were irradiated and then analyzed at the radiochemistry laboratory.
68-03	105, 128-139	Nuclear Thermionic Ceramic Insulators	Unknown
68-04	89-91, 94, 95	Radioactive Tracer Production for Tektite Research	Unknown
68-05	92, 94, 100-102, 105-142	Irradiation of High-Temperature Thermocouples	The temperature of the irradiation was 1,600°C. ¹¹³
68-06	93-101, 103-105	Hot Laboratory Examination of Irradiated Tri-Layer Specimens	Sponsored by Oak Ridge. The high-temperature vacuum furnace was placed in cell #1. It raised the temperature of the experiment to 2,200°C with a vacuum. In cycle 105 metallographic specimens were photographed at 250× and 500× magnification
69-01-1	107-152	Nuclear Experiment Power Reactor Technology Fuel Capsule Irradiations I	Fuel pins received from the experiment sponsor were irradiated. In Cycle 107 samples of stainless steel were irradiated to determine the variation of cobalt content.

¹¹² G. E. McDonald, H. A. Putre, M. C. Swanson, P. M. Finnegan, and L. Homyak, "Compact 30KW Circulating Helium Capsule for Fuel Element Tests in NASA Plum Brook Reactor," 1969, NASA Technical Memorandum TM X-52676.

¹¹³ James D. Heckleman, "A Retractable-Replaceable Thermocouple for In-Pile Experiments," 1969, NASA Technical Memorandum X-52654.

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Exp. #	Cycles	Name	Description
69-01-2	111-113, 115-152	Nuclear Experiment Power Reactor Technology Fuel Capsule Irradiations II	Unknown
69-01-3	139-152	Space Power Reactor Technology	Unknown
69-02	108, 109, 111, 128, 133, 144	Unknown	Unknown
69-03	98-100	Irradiation of Apollo Glycol-Water Solutions	Vials containing glycol-water were irradiated for 4 hours (cycle 98) and then analyzed in the radiochemistry laboratory.
70-01	106, 107, 109, 112, 115, 116, 118, 123, 126, 128- 131, 133, 135, 136, 139, 140, 143-145, 147-152	Irradiation of Lunar Soil	Several vials that contained 1.2 grams of lunar soil (Cycle 106) were irradiated in the rabbit facility for 6 days. The rabbit was then sent to the hot laboratory, where the vials were removed, packaged, and shipped to the experiment sponsor. In Cycle 107, 0.6 gram of lunar soil, 1 gram of Columbia River basalt, and 1 gram of ordinary chondrites were irradiated for 6 days, and the samples were then sent back to the sponsor.
70-02	118-122, 124-137, 142, 143	Vapor Transport Fuel Pin Experiment	Unknown
70-03	111, 112	Irradiation of Pyrolytic Graphite	Unknown
70-04	112, 113, 115-119	Irradiation of Grain Boundary Impurities	In Cycle 115, 5 pairs of grain specimens were irradiated in the rabbit facility for 94 hours and then unloaded in the hot laboratory and sent back to the experiment sponsor.
70-05	111, 118, 120, 126, 130-134, 137	Irradiation of Lunar Soil, Meteorites, Terrestrial Rocks, and Standards	Unknown

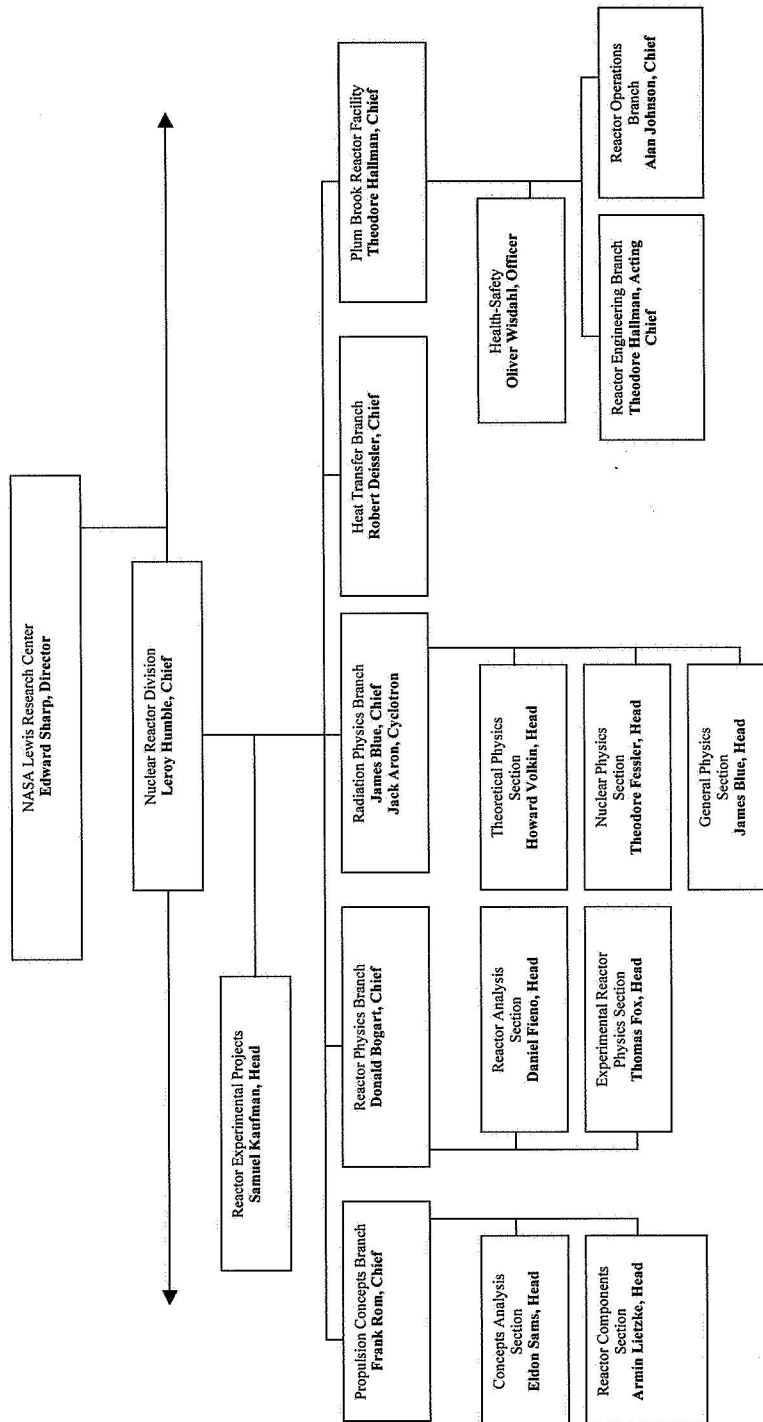
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Exp. #	Cycles	Name	Description
70-06	127, 132-152	Thermionic Reactor Fuel Form Irradiation	Unknown
70-07	117, 118	Irradiation of Meteorite Crystals	Unknown
70-08	117, 119, 120, 122, 123, 125, 126, 128-152	Irradiation of Particulate Materials from Cuyahoga County Air Samples	Unknown
70-09	117, 118, 120, 121, 123, 126, 129, 130, 133, 134, 136, 139-142, 147, 151	Irradiation of Extraterrestrial Material	Unknown
70-11	125, 138-144, 146-151	Loss of Coolant Experiment	Unknown
70-12	118-146, 148	Irradiation of NERVA Materials at Cryogenic Temperatures	During Cycle 119, 25 specimens of aluminum were loaded into the cryogenic capsule and irradiated at a temperature below 77 Kelvin.
71-02	142, 143, 145, 150- 152	Unknown	Unknown
71-03	124-129, 131, 133-138, 140, 151	Determination of Mercury & Selenium in Air Particulate	Unknown

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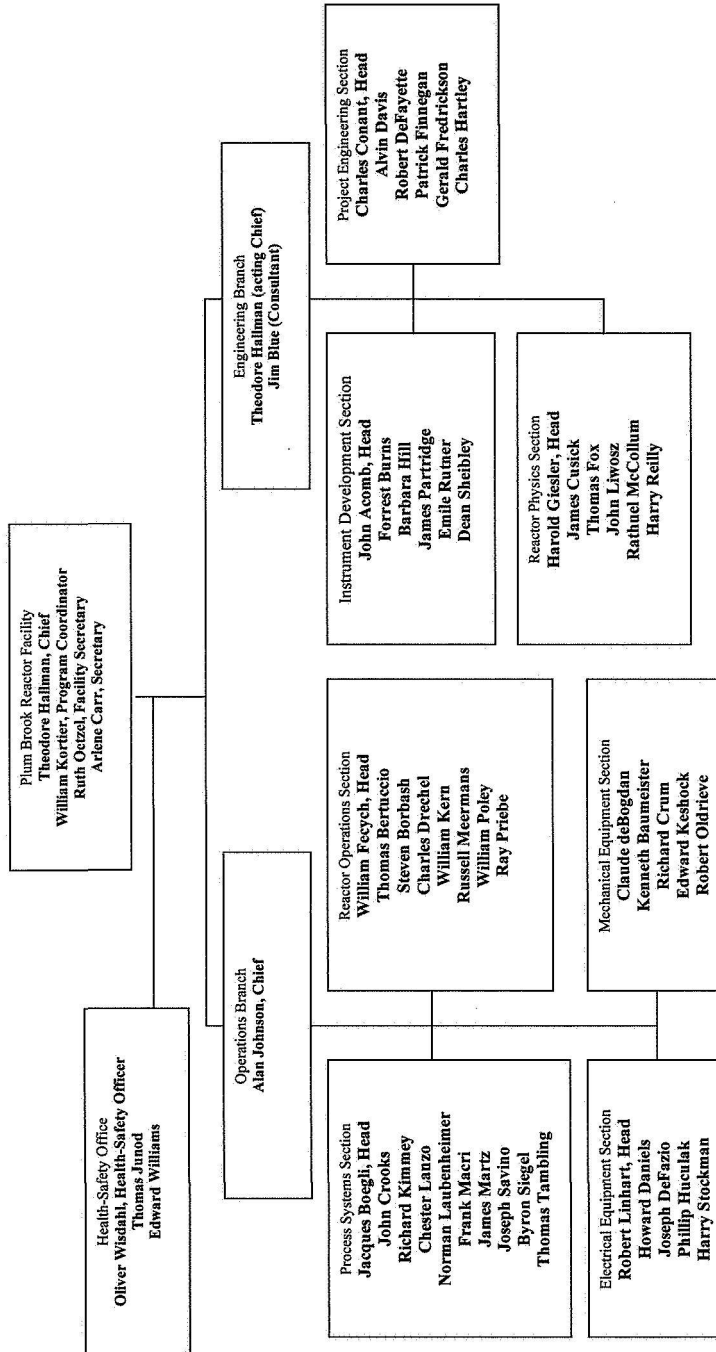
Exp. #	Cycles	Name	Description
71-03R1	139, 141-147, 149, 150, 152	Determination of Hazardous Trace Elements in Samples & Fuels	Unknown
71-05	128, 132, 133, 136, 139	Radioisotope F-18 Production	Unknown
71-07	135, 136, 140-144	Radiation of Reentry Heat Shield Material	Unknown
71-08	133, 134	Irradiation of Pure Silicon	Unknown
71-09	137-139	Irradiation of Corn	Unknown
72-01	143, 150-152		Unknown
72-02	140	Irradiation of Thin Silver Films	Unknown
72-03	149-152	Nuclear Power Reactor Technology IV	Unknown
72-04		Unknown	Unknown
IT-A-1		Neutron Radiographic Facility	This was located underwater in quadrant A. It used a voided tube to direct a neutron beam through a specially designed 15-foot-long collimator. The collimated beam of thermal neutrons that emerged provided a 3-inch by 3-inch area suitable for radiography. For example, in cycle 89 tests included evaluation of different types of x-ray film provided by Eastman Kodak and Agfa-Gevaert. It was also used to irradiate fuel pins.

Lewis Research Center Nuclear Reactor Division (1960)

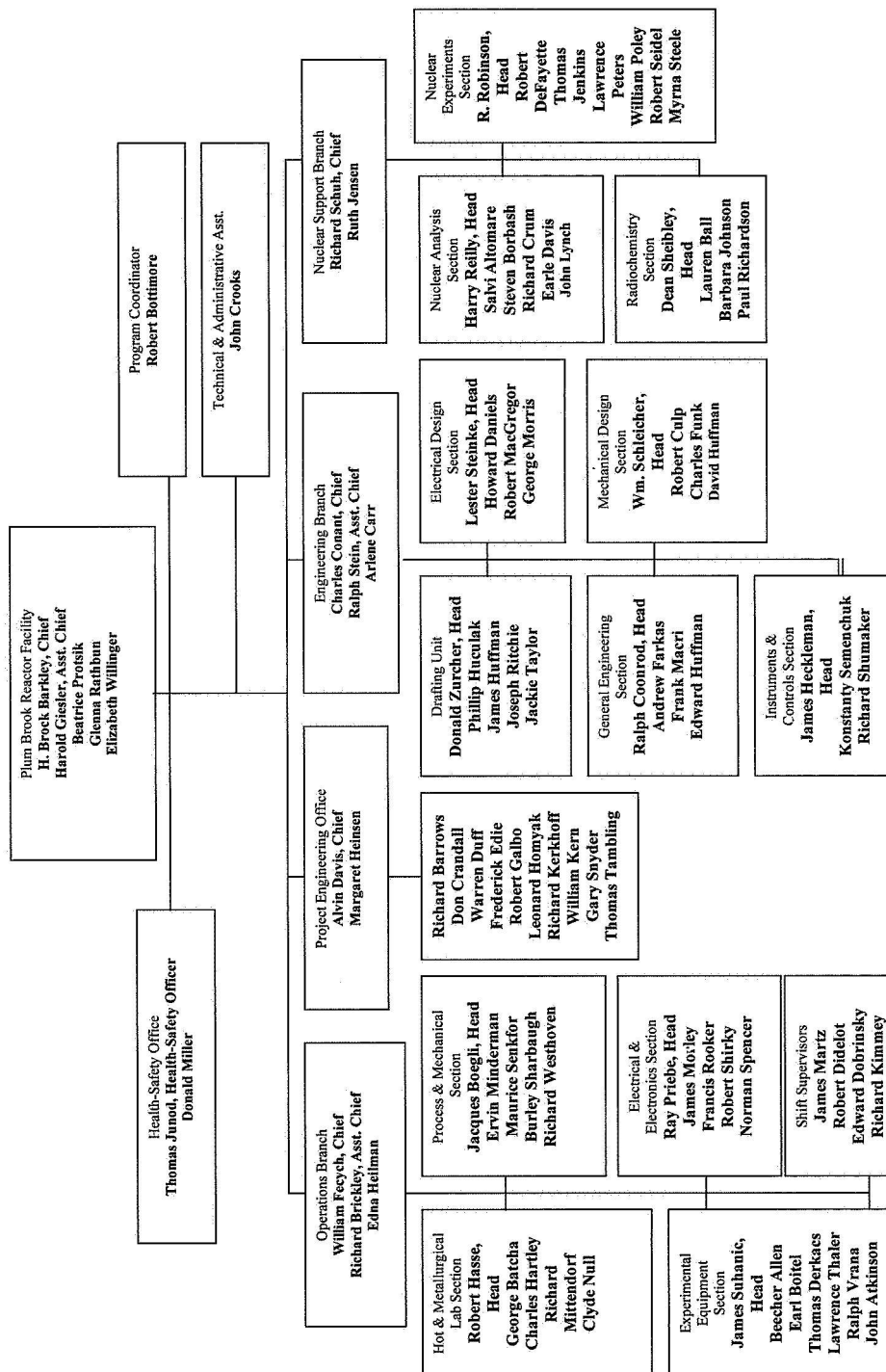


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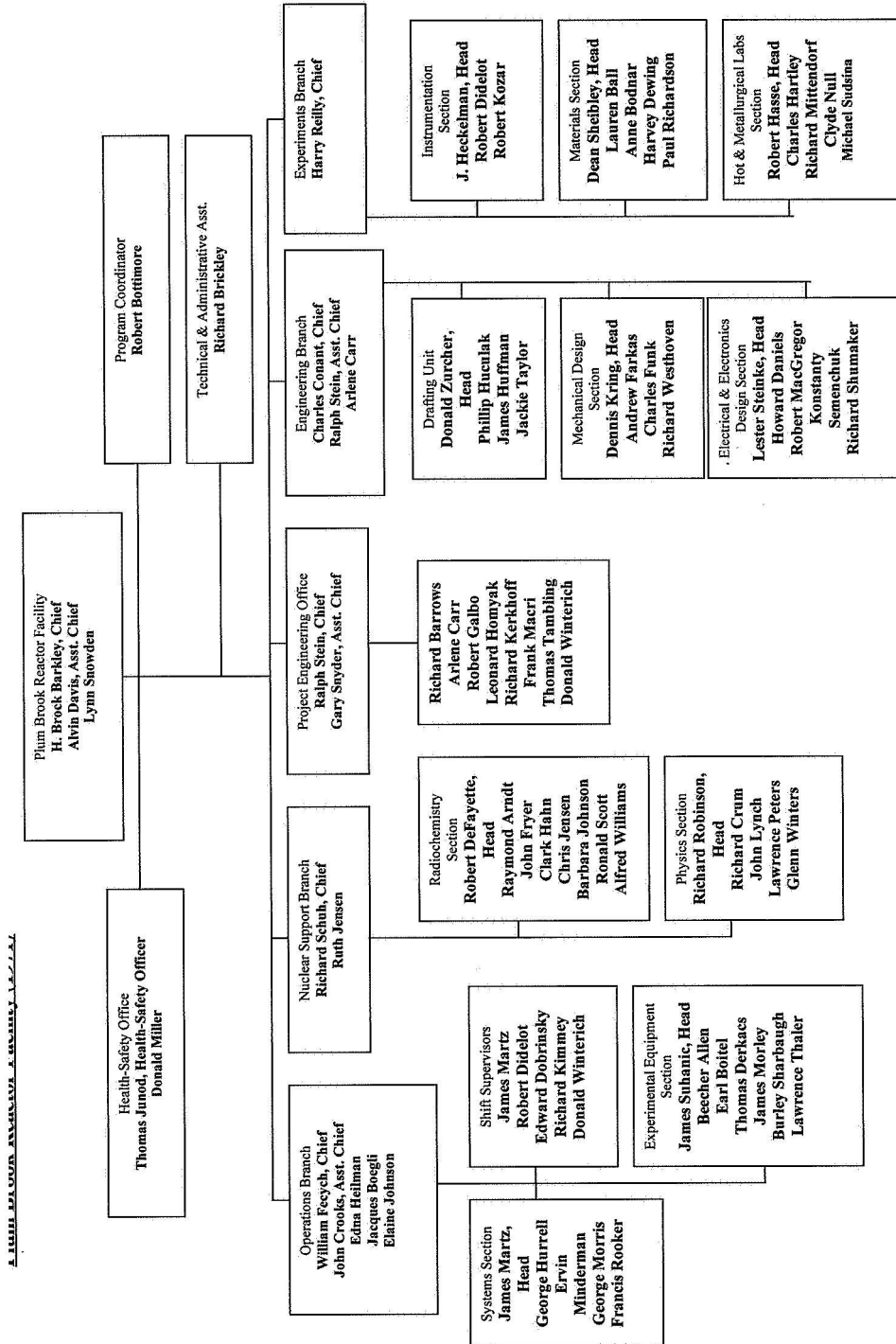
Plum Brook Reactor Facility (1952)



Plum Brook Reactor Facility (1966)



Experimenting with the Reactor



Living with Radiation

Myrna Steele, a physicist in the Plum Brook nuclear experiments section, was one of many employees who worked long hours to help to prepare the reactor for its initial criticality. She recalled the difficult schedule of days, nights, and weekends and remembered one evening in particular when she needed to get away for a short break. She decided to make an appointment at a beauty parlor and called a local salon to schedule a 7:00 p.m. appointment. When she arrived and sat down in the chair, she asked the beautician to wash and cut her hair as quickly as possible because she was on her dinner break and did not want to be late returning to work. The woman washing her hair seemed surprised that Myrna was working so late at night and asked her what she did for a living. Myrna told her that she was an employee at the NASA Plum Brook test reactor. The beautician immediately stopped soaping her hair and asked, "You mean that place where they make radioactivity?" Myrna said that she had never heard it put quite that way before, but that yes, the reactor generated radioactivity for experimental purposes. The woman seemed more perplexed and exclaimed, "You mean you actually work at the reactor?" When Myrna said yes, the woman disappeared, leaving her hair wet and full of soap. Several minutes passed before the owner of the salon appeared and asked Myrna if she could finish her hair. When Myrna asked what happened to the other girl, the owner said, she was "afraid you'll radioactivate her."¹

These concerns about radioactivity were not isolated to Plum Brook but by the 1970s were part of the nuclear fabric in the United States. In 1973 (the year that the Plum Brook reactor shut down) E. F. Schumacher wrote that radiation was the "most serious agent of pollution in the environment and the greatest threat to man's survival on earth."² Twenty years later these fears had not lessened, and in the 1990s sociologist Kai T. Erikson wrote that radiation "clearly has a special place in the

¹ Interview with Myrna Steele by Mark D. Bowles, 7 February 2002.

² E.F. Schumacher, *Small Is Beautiful: Economics as if People Mattered* (New York: HarperCollins, 1989), p. 143.

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human sense of terror.”³ This fear has been heightened by a legacy of misinformation the government has conveyed to the public about radioactive hazards and a policy of secrecy. Michael D’Antonio argued that the human toll of over four decades of nuclear pollution and deceit has yet to be measured or truly understood.⁴

NASA was well aware of the concerns about operating a reactor at Plum Brook, only three miles away from Sandusky, Ohio. The AEC’s Reactor Safeguards Committee was responsible for reviewing all site selections for reactors prior to granting an operating license. At only its second meeting, held in 1957, it expressed doubt that Plum Brook was a safe location for a reactor because of the proximity of a sizable population. Nevertheless, it reluctantly endorsed the site despite its concerns.⁵ The fact that NACA (NASA’s predecessor) selected the site in 1955 and the AEC voiced its safety concerns two years later revealed one of the inherent problems about radioactivity—there was no clear, objective measurement or set of guidelines that established what was safe and what was unsafe in this new world of nuclear construction.

This inability of scientists, regulators, and public health officials to come to an agreement about the risks of low-level radiation further contributed to the public’s growing uncertainty and fear. J. Samuel Walker argued that because the scientific evidence of a “permissible dose” remained inconclusive, the resulting debate “generated confusion, uncertainty, and fear among members of the public who had no reliable way to evaluate the competing positions.”⁶ Even at Plum Brook scientists debated the meaning of radiation safety. Despite the assurances of the health physicists at Plum Brook that the reactor posed no threat to the community, a radiologist from the University of Pennsylvania disagreed. Ernest J. Sternglass argued that mortality rates rose with increased proximity to the Plum Brook reactor. His claims made front-page headlines in the local *Sandusky Register*.⁷ Although other scientists rejected his arguments, within this context it is understandable that a resident living outside the fences might be deathly afraid of washing the hair of a scientist from Plum Brook.

³ Kai T. Erikson, “Radiation’s Lingering Dread,” *Bulletin of the Atomic Scientists* 47 (March 1991): 34–39.

⁴ Michael D’Antonio, *Atomic Harvest: Hanford and the Lethal Toll of America’s Nuclear Arsenal* (New York: Crown Publishers, 1993), p. 3.

⁵ George T. Mazuzan and J. Samuel Walker, *Controlling the Atom: The Beginnings of Nuclear Regulation, 1946–1962* (Berkeley: University of California Press, 1985), p. 221.

⁶ J. Samuel Walker, *Permissible Dose: A History of Radiation Protection in the Twentieth Century* (Berkeley: University of California Press, 2000), p. 2.

⁷ Tim Sowecke, “Radiation-Death Claim Repeated,” *Sandusky Register* (26 July 1973): 1.

Living with Radiation

In many cases scientists do not realize the intense social and cultural impact their work has on the public. This is often the case with those engaged in research involving radioactivity. While scientists and engineers who work in reactors understand better than anyone the potentials and perils of fission and radiation, they often fail to appreciate the growing pervasiveness of nuclear fear. The fear originated early in the twentieth century with concerns about transmutation and the mysterious powers of atomic rays. The fear was intensified during the bomb shelter craze during the Cold War in the 1950s, when the public was frequently told that nuclear war might be imminent. It entered a new phase with antinuclear protests in the 1960s and 1970s, and today the United States remains more skeptical and concerned than ever about the use of nuclear power. The author of the history of Los Alamos National Laboratory wrote, "Even understanding the science behind radiation does not necessarily erase the profound fear that it inspires. . . . As much as the average citizen struggles to comprehend the mind-set of scientists, the technical culture often fails to understand the deeply entrenched fears and concerns of the general public."⁸

To the credit of those who worked at NASA, a great deal of effort was devoted to informing the public about reactor safety and explaining the details of its declassified experiments. Through tours, lectures, and a constant emphasis on safety, the reactor staff worked hard to ensure positive community relations. Over time the surrounding community slowly learned to accept the fact that they lived next to a mysterious region that was performing secret radioactive work for the government. However, some of the reactor neighbors would never come to terms with the perceived dangers of living close to a place that produced radioactivity. Some hairdressers would always be afraid to touch the heads of people who worked at Plum Brook for fear that they would "radioactivate" them. Some farmers would remain convinced that the reactor would make their chickens produce square eggs. For some nuclear fear would never disappear.

The technical culture at Plum Brook established close collegial bonds as they worked together and spread good news about nuclear research. This was not unusual for a group working in government secrecy, closed off for the most part from the wider world. One could find these close bonds at places like Los Alamos too during World War II.⁹ Within the reactor gates at Plum Brook a strong community formed, where men and women worked long hours, shared the difficulties of shift work, made safety a primary concern, and often spent their time outside work together as well. As a result, two communities developed, the wider public commu-

⁸ Jo Ann Shroyer, *Secret Mesa: Inside Los Alamos National Laboratory* (New York: John Wiley & Sons, Inc., 1998), p. 14.

⁹ Richard Rhodes, *The Making of the Atomic Bomb* (New York: Simon & Schuster, 1986), p. 567.

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nity outside and the technical community inside the reactor. No matter how much outreach and information was disseminated about the nuclear reactor, few outsiders could appreciate the culture that thrived behind the fences. This chapter describes the relationship between these two communities and the common bond that united them—living with radiation.

Radioactive Monsters and Utopias

Radiation entered the public consciousness as soon as x-rays were discovered and Ernst Rutherford and Frederick Soddy began to apply scientific understanding to the phenomenon. Typically the work of theoretical physicists does not capture widespread attention. But when the public learned about the discovery of radiation, the promise of harnessing the power bound in the atomic nucleus spawned dreams of brave new worlds where radiation would cure diseases and create wondrous utopian atomic-powered cities. Many tempered this optimism by recognizing the darker side of the power whereby evil scientists might overtake the world, creating radioactive monsters or weapons that ravaged cities. While science fiction was often the vehicle for debating these contrasting positions, they were based on enough real science to make these once absurd notions appear plausible. Even though no scientist had artificially split an atom before 1938, already these fears and hopes had swept through popular culture.¹⁰

Shortly after the discovery of radiation and the transmutation of atoms many people believed that it would usher in a new golden age. Frederick Soddy, Ernst Rutherford's colleague, himself did much to fuel this idea. In 1908 he published a popular book called *The Interpretation of Radium* in which he expressed the utopian possibilities for the future. He wrote, "A race which could transmute matter would have little need to earn its bread by the sweat of its brow. . . . Such a race could transform a desert continent, thaw the frozen poles, and make the whole world one shining Garden of Eden."¹¹

Journalists quickly picked up on these ideas and wrote countless stories about the remarkable prospects. With more and more people interested in these subjects, popular science writers emerged to transmit the latest scientific advances to an eager public. Waldemar Kaempffert became the leading science journalist in the nation as the scientific editor of the *New York Times*. He often wrote about the marvels

¹⁰ Spencer R. Weart, *Nuclear Fear: A History* (Cambridge: Harvard University Press, 1988). Weart calls the period from 1902 to 1938 the "years of fantasy" concerning nuclear radiation.

¹¹ Frederick Soddy, *The Interpretation of Radium*, 3rd ed. (London: Murray, 1912), p. 251.

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of atomic power, which included such fantasies as trips to the moon, a small glass of uranium propelling ships across the Atlantic, buildings with gold-plated roofs, and meals that were precooked. Further speculating on Soddy's utopia, Kaempffert envisioned atomic power creating "thousands of small towns with plenty of garden space, low rents, breathing space . . . health, and a finer outlook on life."¹²

Throughout the early part of the twentieth century some believed radiation to be an elixir. Many scientists who carried a radium substance in their pockets found that it burned their skin. Physicians then began using it to treat skin cancers and tumors. Soddy speculated in the *British Medical Journal* in 1903 that breathing radioactive gas would be an effective treatment against tuberculosis.¹³ Newspapers reported wild claims that radiation was giving sight to the blind and preventing the onset of old age. The image of the radioactive rays being linked to an invisible life force that could significantly raise standards of living became prevalent in society.¹⁴ But there was a dual nature to these rays. Tales soon began to be told about radiation being transformed from healing rays to rays of death as weapons of mass destruction.¹⁵

The scientists often were themselves responsible for this imagery. For example, when Soddy first exclaimed, "This is *transmutation*," Rutherford immediately warned him not to use that word to describe their experimental findings because of the association with alchemy. Alchemy was a secret, pseudoscientific practice that existed for 2,000 years and was most notably linked with the dream of turning lead into gold. It appeared as if the elemental change associated with the twentieth-century discovery of radioactivity might represent the emergence of modern alchemy. Rutherford later welcomed the association with this mystical practice by publishing a book in 1937 called *The Newer Alchemy*.¹⁶ But the symbol of alchemy and transmutation had a darker side as well. The process of change was a violent one, both spiritually and physically, as the transmuted object was passed through a destructive fire to bring it into its new state. Nuclear fear was born.

In 1904 Rutherford casually joked with a newspaper reporter about the potential of a scientist to destroy the world. The reporter wrote, "Professor Rutherford has

¹² Waldemar Kaempffert, *Science Today and Tomorrow* (New York: Viking, 1945).

¹³ Frederick Soddy, *British Medical Journal* 2 (25 July 1903): 197–199, as cited in Weart, *Nuclear Fear*, p. 37.

¹⁴ George T. Mazuzan and J. Samuel Walker, *Controlling the Atom: The Beginnings of Nuclear Regulation, 1946–1962* (Berkeley: University of California Press, 1985), p. 2.

¹⁵ Weart, *Nuclear Fear*, p. 43.

¹⁶ Ernest Rutherford, *The Newer Alchemy* (Cambridge: Cambridge University Press, 1937).

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playfully suggested . . . the disquieting idea that, could a proper detonator be discovered, an explosive wave of atomic disintegration might be started through all matter which would transmute the whole mass of the globe into helium or similar gasses."¹⁷ This idea of the mad and dangerous scientist hearkened back to the sixteenth-century literary figure Dr. Faust and the selling of his soul to acquire awesome demonic powers. Misguided science was a central theme of Mary Shelly's *Frankenstein*; readers tend to forget that the title of the book was the name of the scientist, not the monster. This is a telling indication of the sometimes blurred distinction between the symbolic image of scientists and monsters. The image is a familiar one to children as well. For example, in the *Batman* comic book, Professor Radium was a brilliant nuclear physicist who mistakenly transformed himself into an evil monster and used radiation as a weapon against humanity.¹⁸

Soon there was real evidence to prove that radiation was extremely harmful to the human body. Though physicians realized that radium was a treatment against cancer, excessive exposure proved deadly. In the 1920s radium was used on watch dials because the luminous paint would glow in the dark. The radium was painted on watches by "radium girls" who over time became very sick from their radiation exposure.¹⁹ These sicknesses included anemia, weakening of bones such that arms or legs might snap under normal pressure, and a host of different cancers. In 1932 there was one well-publicized case of a wealthy man named Eben M. Byers who died of radium poisoning from drinking tremendous amounts of a radioactive elixir called Radithor.²⁰ As more and more chemists, physicians, and physicists who worked with radium on a daily basis fell ill, they made a connection between the substance and the onset of cancer.²¹ The beginnings of radiation toxicology began in the 1930s.

By the 1950s and early 1960s Hollywood added its own perspective on medical concerns about radiation exposure and further shaped the public's consciousness with images of nuclear power and radioactivity. Some films perpetuated the theme of radioactive monsters with movies like *Them!*, which showed giant ants mutat-

¹⁷ W. C. D. Whetham, "Matter and Electricity," *Quarterly Review* 397 (January 1904): 126.

¹⁸ George Perry and Alan Aldridge, *The Penguin Book of Comics* (Harmondsworth, England: Penguin, 1967), p. 61.

¹⁹ Claudia Clark, *Radium Girls: Women and Industrial Health Reform, 1910–1935* (Chapel Hill and London: The University of North Carolina Press, 1997), p. 1.

²⁰ Lawrence Badash, *Radioactivity in America: Growth and Decay of a Science* (Baltimore: Johns Hopkins University Press, 1979), pp. 10–12.

²¹ J. Newell Stannard, *Radioactivity and Health, A History* (Virginia: Battelle Memorial Institute 1988), p. 25.

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ing as the result of atomic bomb tests. Other films depicted similar mutations like *The Beast from 20,000 Fathoms* (arctic radioactive monsters), *Godzilla* (prehistoric radioactive monsters), and *The Deadly Mantis* (flying radioactive monsters). When filmmakers ran out of real creatures to corrupt with radiation, they invented new ones, as in *X the Unknown* (radioactive sludge seeking isotopes) or *The Thing* (a radioactive vegetable-like creature). Another popular cinematic genre depicted what the world might be like after a nuclear holocaust. Many showed the earth plunged into savagery because of radioactive wastes, as in *Captive Women*, *World Without End*, and *The Time Machine*. The most popular of these were the six *Planet of the Apes* films, with the memorable image of the Statue of Liberty left decaying in its postnuclear waste.²²

Statements from President John F. Kennedy in 1961 reminding everyone that “Every inhabitant of this planet must contemplate the day when this planet may no longer be habitable” served to heighten these fears and the desire for personal fallout shelters.²³ In July Kennedy gave a speech stating that families should do all that they could to protect themselves against the possibility of a nuclear attack. He also warned them to take precautions for the subsequent lingering effects of radiation. Soon thereafter, news magazines began running advertisements depicting frontier-like heroes living in their own bomb shelters. *Life* magazine suggested drinking hot tea to help combat radiation sickness. Coca-Cola depicted a girl in a bomb shelter, laughing and holding a bottle of refreshing soda in her hand.²⁴

NASA was also busy making specific plans should there be a nuclear strike. One of these plans consisted of a scenario in which a nuclear attack on the United States would make working conditions in Cleveland impossible for its Lewis Research Center employees. The plan was to designate Plum Brook as an “emergency command center” in case of an enemy attack near the Cleveland area.²⁵ It called for the Plum Brook munitions bunkers from its ordnance days to be turned into homes for high-ranking Lewis officials and their families. Ironically, if this had happened, Plum Brook would have become an oasis to protect those inside the bunkers against the radiation poisoning that would potentially kill millions in the wake of a nuclear

²² Alan M. Winkler, *Life Under a Cloud: American Anxiety About the Atom* (New York: Oxford University Press, 1993), pp. 96–99. Spencer R. Weart, *Nuclear Fear: A History of Images* (Cambridge: Harvard University Press, 1988), pp. 191–195.

²³ Weart, *Nuclear Fear*, p. 215. See also Weart’s discussion on film, radioactive monsters, and nuclear holocaust, pp. 191–194, 220.

²⁴ *Time* 78 (20 October 1961): 25; *Life* 51 (15 September 1961): 95–108.

²⁵ Alan D. Johnson (Director Plum Brook Station) Memorandum for the Record, 8 November 1961, Plum Brook Archives, unprocessed material.

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disaster. The plan also recommended what to do if an unexpected attack occurred that prevented people from getting to a fallout shelter. NASA told employees to “seek immediate shelter under a desk” and cover exposed body parts for protection against radiation.²⁶ But this worst-case scenario was not what was foremost in the minds of most residents living near the reactor on a daily basis. Ever since construction on the reactor had begun they were concerned not so much with a catastrophic nuclear disaster, but the potential of slow, invisible, low-level radiation. As J. Samuel Walker argued, throughout the century there was a transformation of public attitudes and scientific beliefs since radiation was first discovered. This transformation “reflected the gradual recognition and then growing fear of the hazards of radiation and the protracted scientific debate over the risks of low-level exposure.”²⁷

The Hazards Report

There are three key nuclear terms that are often used to describe the hazards associated with reactors.²⁸ *Radiation* in this connotation includes the alpha particles, beta particles, gamma rays, x-rays, neutrons, and high-speed electrons and protons that produce ions. The atom emits radiation because of an instability caused by an excess of energy or mass in its nucleus. *Contamination* is the unwanted radioactive material that can be deposited on surfaces, mixed into materials, or ingested by biological organisms.²⁹ A *dose* is the amount of radiation energy absorbed by a unit of mass. Doses are measured in rads, and for a person a radiation dose is measured in a unit called a rem.³⁰ Although it was true that the city of Sandusky, the Chamber of Commerce, and the local congressional representative actively campaigned for the reactor to be built at Plum Brook, citizens still had reservations about a nuclear

²⁶ Charles A. Herrmann (Lewis Emergency Coordinator), “. . . What to Do in the Event of a Civil Defense Emergency,” 25 July 1961, Box 1, Folder 10, Plum Brook Archives.

²⁷ Walker, *Permissible Dose*, pp. 2, 19.

²⁸ John L. Minns and Michael T. Masnik, “Staff Responses to Frequently Asked Questions Concerning Decommissioning of Nuclear Power Reactors,” Nuclear Regulatory Commission, June 2000, Box 8, Folder 6, Plum Brook Archives.

²⁹ Harry C. Harrison (Plum Brook health physicist), “Radiation and Contamination,” Box 1 Folder 10, Plum Brook Archives.

³⁰ A rad is a unit of measure for an absorbed dose of radiation where 1 rad equals 100 erg (centimeter-gram-second unit) absorbed per gram of material. One rad is also about equal to one rem. A rem is a unit of measure for the dose of ionizing radiation that has a biological effect similar to that of one roentgen of x-rays. Michele Stenehjem Gerber, *On the Home Front: The Cold War Legacy of the Hanford Nuclear Site*, 2nd ed. (Lincoln: University of Nebraska Press, 2002), pp. 349, 351.

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reactor in their backyard. They were concerned about these new terms like *radiation*, *contamination*, and *doses* that had entered their lexicon, and they debated their meanings and the potential effects on the local population. Soon after the groundbreaking ceremonies in the mid-1950s, a group of Sandusky residents visited the Lewis Laboratory to ask some very pertinent questions about their safety.

The first question came from a resident who wondered what would be done if a problem occurred and especially, "How do you stop the production of radioactivity?"³¹ The Plum Brook reactor engineers responded with the assurance that control was always maintained and that all that had to be done to shut off the reactor was to "release the control rods so that they fall by gravity into the reactor core." The engineer stated that the time required to do this was less than one second. The Sandusky public was well-informed about the radiation debate, and a second question came from someone who was still skeptical. He said that he had read an AEC report of an incident where dropping a control rod did not actually shut down the reactor as planned. The engineer dismissed this question by stating that this was a different type of reactor and that reactors similar to Plum Brook's had never had a problem with the control rod drop.

Concerns about contamination were another important area that the residents wanted to address. The next question was about the issue of contaminated water and where it went when it was no longer of use. The engineer stated that the radioactive water was stored in underground tanks where it was allowed to naturally decay. To assist this process, dematerializers were used to remove radioactivity from the water. By combining these two processes, after a period of six months the level of radiation was reduced to a level in which it was safe to dump the waters into the Plum Brook River. Other concerns about radioactive water were raised. One person asked if there was a problem with surface water becoming contaminated and draining into Lake Erie. The engineer said that this was nearly impossible, but just in case the engineers had constructed a dike around the reactor to control runoff surface water.

The final questions dealt with the problems of personal contact with radioactivity. One person asked what the symptoms of radiation exposure were and if there was a cure for it. The engineer could not answer this directly. He said, "This is an involved question that is receiving constant attention by world-renowned specialists in medical radiology and biology. The literature pertaining to this subject is very extensive and cannot be summarized adequately in a brief statement." All that he could say with any confidence was that "excessive" radiation was harmful and there

³¹ Community Safety Transcript, unprocessed Plum Brook records, Glenn Research Center Archives.

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was no cure for it. There was no objective measure that determined an excessive exposure.

One of the reasons why the public's concern could not easily be extinguished was that scientists and the government could not be certain of health risks even at the "tolerance dose" or a "maximum permissible dose." In 1946 the government, through the Atomic Energy Act, gave the Atomic Energy Commission the responsibility to protect the public from radiation hazards. That same year the government also established the National Committee on Radiation Protection (NCRP) to develop a policy of radiation safety. It quickly reduced the permissible dose level by 50% of what it had been previously and defined it as a whole-body limit of 0.3 roentgen over a 6-day work week. The NCRP published this finding in 1954, two years before construction on the Plum Brook reactor began. While it stated that permissible doses were those that should not cause harm to a body over the course of a lifetime, it also claimed that there was a possibility of harmful results occurring from low-level exposure below the permissible level. In 1958 the AEC restricted its exposure guidelines to one-third the previously allowed level.³² Ten years later the NCRP proposed another change to its regulatory policy, stating that radiation release should be "as low as practicable." The AEC was not convinced that this was adequate and raised questions over all existing regulations. The controversies were not only within the government. Scientists were at odds over the risks of and the health threat represented by nuclear fallout.³³

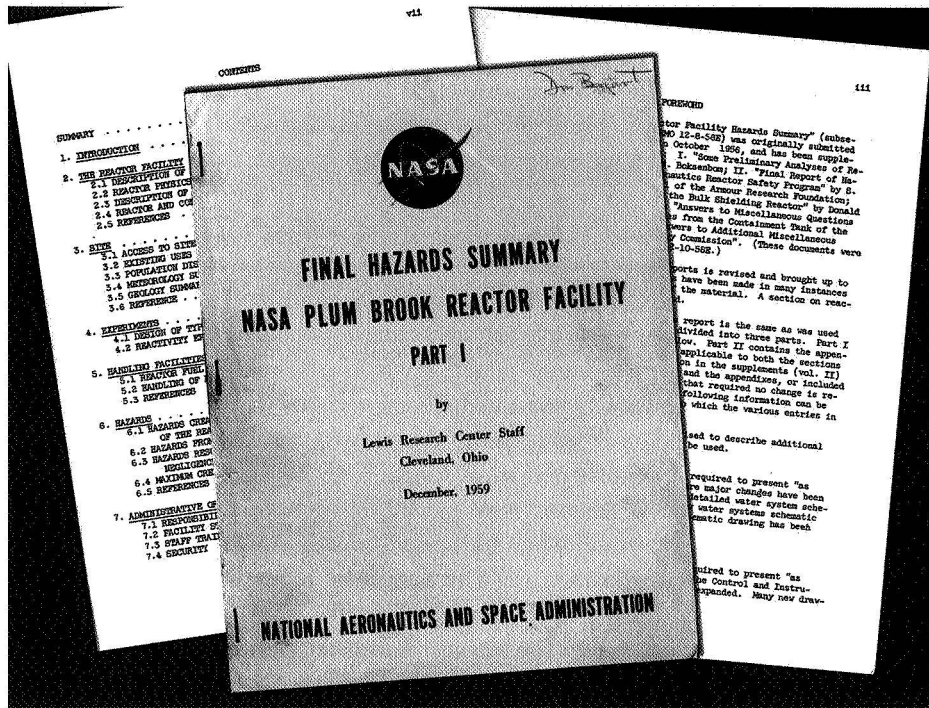
To address potential dangers associated with a nuclear reactor, before construction was completed, engineers at Plum Brook had to complete a detailed hazards report. The purpose of this report was to provide information to the AEC concerning the design of the reactor facility, the characteristics of the site, hazards of operation at Plum Brook, and general operating and emergency procedures. Without this document the AEC would not license the reactor. Plum Brook submitted the initial report to the AEC in 1956 just as construction was under way. Over the course of the next few years the document was amended and expanded, and the "Final Hazards Summary" appeared in 1959, two years before the reactor went critical.

The main disadvantage of the Plum Brook location was the proximity and density of the surrounding population. The nearest residents lived just 3,200 feet from the reactor itself, and there were an estimated 300 people residing within one mile. The total population within a 6-mile radius was 38,450. Furthermore, the area was home to a growing number of businesses. Though the areas to the west, south, and

³² Len Ackland, *Making a Real Killing: Rocky Flats and the Nuclear West* (Albuquerque: University of New Mexico Press, 1999), p. 132.

³³ Walker, *Permissible Dose*, pp. 11, 32.

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Cover of the "Final Hazards Summary" document and two internal pages. (NASA Plum Brook Archives, Box 267, Org 6200A, Folder 1)

east were still primarily farming communities, to the north was the suburban and manufacturing center of Sandusky. According to 1954 estimates, within a 6-mile radius of the reactor there were 28 companies that employed more than 50 people each for a total of 9,376 employees. The largest were the General Motors ball and roller bearings division (2,671 employees 3.4 miles away) and Ford Motor Company's auto parts division (2,000 employees 3.5 miles away). Another 731 people were employed in smaller companies in the area.³⁴ This was a thriving community, and it was estimated that the growth would continue because of the recent completion of the St. Lawrence Seaway, increased Great Lakes shipping, and the resulting spike in commerce and manufacturing activities in the port cities.

There were six primary types of hazards that could potentially endanger those in the vicinity of the reactor. One type included a variety of potential component

³⁴ A. B. Davis, B. Lubarsky, and T. M. Hallman, "Final Hazards Summary: NASA Plum Brook Facility," (December 1959), 81-82, Box 252, Folder 8, Plum Brook Archives.

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malfunctions, including pump or pipe failures, startup accidents, or broken fuel element plates. Emergency procedures were defined by the hazards report, which explained how to recover from these problems. For example, standby pumps were available to restore coolant flows to normal conditions should others fail.

Experiments presented a second potential hazard. In general, however, the standard operating procedure was to not even consider putting an experiment into the reactor until all of the engineers had a deep understanding of the reactor facility. Until this occurred only the smallest and safest experiments would be conducted. Even when more dangerous experiments were considered, some could still be rejected if they had the potential to cause an accident that resulted in levels of radiation that the reactor control systems would be unable to safely contain. However, despite these safeguards, dangers remained. As the hazards report indicated, "If the experiments are to yield data of value to the nuclear propulsion program, they must be operated at high temperature and stress levels."³⁵ To help ensure that these risks were minimized, radiation detectors were placed throughout the experiments that could report to the safety system when to "scram" or shut down the reactor.

"Acts of God" were a third hazard. The Sandusky region averaged 32 days of thunderstorms per year, mostly in the summer months. Lightning had the potential to disrupt electrical power to the reactor. If this happened, the reactor would immediately shut itself down, and a diesel generator would supply the power to pump 1,000 gallons of water per minute through the primary shutdown cooling water system to disperse the reactor afterheat. The reactor was built to withstand the damage that could be caused by a tornado; however, the violent winds could potentially destroy outlying buildings. But this would not cause any radiation release. Floods and earthquakes were not considered problematic. The Plum Brook site was 65 feet above Lake Erie, and it gently sloped down toward the lake. And no earthquake with an epicenter in Sandusky had ever been recorded, so no seismograph-operated shut-down circuit was installed in the facility.

A fourth hazard was sabotage. A bomb dropped directly on the facility could pierce the containment vessel and explode in one of the quadrants. The result would be a core meltdown in about 10 seconds, releasing a "considerable amount of fission products."³⁶ Sabotage was another threat, though it was thought to be very difficult for an intruder to sneak into the facility. Any saboteur would have to break through the fence surrounding the entire Plum Brook facility, and guards watched it at all times. Additional security was in place at the reactor itself. The hazard:

³⁵ Davis et al., "Final Hazards Summary: NASA Plum Brook Facility," 130.

³⁶ Davis et al., "Final Hazards Summary: NASA Plum Brook Facility," 144.

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report predicted that a more likely scenario was sabotage by a “demented or subversive employee.” Still it would be difficult even for an employee to cause significant damage. The only way for the reactor to be destroyed was to remove the control rods from the core and keep them withdrawn. The only person capable of performing such a task would be a reactor operator with great knowledge of the wiring of the reactor who was also able to break into several locked cabinets without being detected.

A fifth hazard was negligence. This was a significant concern because, throughout the history of atomic energy, careless mistakes had been one of the largest causes of minor nonthreatening accidents. However, the potential for a serious accident due to negligence was always present. The only way to prevent negligence was to actively promote safety consciousness. It was especially important to continue to emphasize safety even when no accidents had occurred because that was when employees could become lax in their safety awareness.

A final hazard was known as a “maximum credible accident.” This most serious problem would occur if the control system were unable to stop a large-step increase in reactor power, thereby melting the reactor fuel cladding, resulting in a large release of radioactive gasses. The result would be an unstoppable rise in reactor power and temperature until the reactor core was destroyed. Runaway destruction of the Plum Brook reactor would likely entail melting of the fuel plates, rupture of the pressure tank, and scattering of the radioactive material. The Plum Brook engineers stated, “It is an event which could create a considerable hazard both for the operating personnel and the general populace.”³⁷ “Considerable hazard” was defined in the following way. For such an accident, anyone located just outside the containment tank would not survive. Other people working in the area would have to evacuate immediately or also face radiation exposure. The dose rate at the Plum Brook fences would also be high, and the entire area would have to be quarantined for about 100 days before it became safe again.

Though the hazards associated with the Plum Brook reactor appeared serious, they represented a minor threat compared with those of a power reactor. One Plum Brook engineer said, “Plum Brook wasn’t very powerful. In those days it seemed it was, but it was a little candle flicker compared to today’s reactors.”³⁸ But the reactor team had to consider every conceivable danger, even those that at the time were, according to Hap Johnson, “vanishingly small,” like a direct hit from an airplane.³⁹

³⁷ Davis et al., “Final Hazards Summary: NASA Plum Brook Facility,” 147.

³⁸ Interview with John Acomb by Mark D. Bowles, 8 July 2002.

³⁹ Interview with Alan “Hap” Johnson by Mark D. Bowles, 20 March 2002.

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Nevertheless, the engineers had to prove that the reactor could keep running safely despite these threats. Plum Brook's head reactor officials, like Johnson, discussed preparations for all of these contingency scenarios in public hearings. AEC scientists reviewed the documentation, listened to the testimony, and determined whether a facility deserved their seal of approval. Ultimately, the hazards report was a successful document. Its chief editor, A. Bert Davis, sent it to the AEC, and eventually Plum Brook acquired its license.⁴⁰

The Mock-Up Reactor also had its own hazards report, but since it operated under less power (100 kilowatts), the potential risk was much less than that of the main reactor (60 megawatts). According to the AEC, any accident would necessitate the evacuation of part of the main reactor building. Martin B. Biles, chief of the test and power safety branch of the AEC division of licensing and regulation stated, "It is our opinion that there is no significant hazard off-site."⁴¹

Despite the official license and the assurances of the AEC, some local residents would never be convinced that the Plum Brook reactor was safe. Though this low-level radiation was of greatest concern to the population surrounding Plum Brook, it also became a national issue. J. Samuel Walker wrote that by 1963 (the year that Plum Brook was first at full power) nationwide radiation fears had reached their highest levels. He said, "As low-level radiation moved from the rarified realms of scientific and medical discourse to a featured subject in newspaper reports, magazine stories, and political campaigns, it became for the first time a matter of sustained public concern."⁴² At Plum Brook rational fears were always present, but for a minority the mysteries of radiation and the secrecy behind the fence became a source of imaginative tales throughout the reactor's life.

Controlling Mother Nature and Other Apocryphal Stories

If popular culture and Cold War politics generated at the very least a low level of nuclear anxiety for all Americans, for those who lived close to nuclear facilities these fears were magnified. For example, at the Brookhaven National Laboratory, which housed research and test reactors, the local community expressed many concerns. Even though the press praised the laboratory for its safety consciousness, citizens expressed numerous worries. Some airline pilots who flew near the reactors ques-

⁴⁰ Interview with A. Bert Davis by Mark D. Bowles, 27 February 2002.

⁴¹ Martin B. Biles, "Hazards Analysis of the Mock-Up Reactor," Atomic Energy Commission, 14 June 1961, Box 251, Folder 37, Plum Brook Archives.

⁴² Walker, *Permissible Dose*, p. 19.

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The fence surrounding Plum Brook. (NASA C-2003-850)

tioned whether the radiation would make them sterile. One woman wrote officials to ask if there was a chance that the radiation would make her pregnant. A man accused the Brookhaven scientists of tampering with weather patterns. Many of the neighbors complained that gases emanating from the laboratory were making them sick. Ironically, all of these concerns were expressed in 1947, before Brookhaven even possessed any radioactive materials on site.⁴³

Brookhaven was not an isolated example. Many similar stories reappeared two decades later at Plum Brook. The reactor had gone critical just one month before John Kennedy's speech about protecting one's family from radiation. Not only did the Sandusky community have to worry about international Cold War politics; they were also concerned about the reactor in their backyard. One of the main types of stories came from people who believed that scientists at the Plum Brook reactor were changing the weather. Since many of the local residents were farmers, this was a serious concern. A few believed that when the reactor went critical their chickens might suddenly start laying square eggs.⁴⁴ Some farmers complained that a drought or a hard rainstorm was the result of the scientists tinkering with radiation in the

⁴³ Weart, *Nuclear Fear*, p. 178.

⁴⁴ Interview with Alan "Hap" Johnson by Mark D. Bowles, 20 March 2002.

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reactor.⁴⁵ Charlie Nichols was a farmer whose crops were located to the east of the reactor. He was convinced that when rainstorms came, the rain clouds split over the reactor. One cloud traveled north, the other traveled south, and then both missed his fields altogether, leaving his crops dry.⁴⁶ He had actually retained a lawyer and began legal proceedings against NASA. Myrna Steele assisted with the defense in preparation for the legal hearing, but since NASA was not spewing radiation into the air, and it could not control Mother Nature, the case was thrown out.⁴⁷

When Plum Brook employees visited other reactor sites they often heard similar stories. H. Brock Barkley recalled one trip to the Materials Test Reactor at Idaho Falls. He visited a flower nursery about 50 miles from the reactor, and the proprietor told him, "The temperature sure has been lots hotter here since those reactors have been operating."⁴⁸ Earl Boitel would often go out into the community and give talks about the reactor and dispel some of these notions. He said that the community "would hear the loud noises and the bangs and they would see the plume of steam coming from the various facilities and I would try to assure them that none of these things would be detrimental to their health and safety."⁴⁹

Some of the fears stemmed not just from the radiation, but from the assumption that the Plum Brook facility might become a military target. Rosalie Oldrieve, an English teacher and wife of Robert Oldrieve, the hot laboratory manager, recalled that "The news media scared the kids."⁵⁰ They were worried about reports claiming that Fidel Castro might launch missiles at all nuclear facilities, including Plum Brook. Oldrieve said, "The kids suddenly were afraid, and they'd never even thought about it before." They approached the teachers to ask them more about the threat. Oldrieve had a unique perspective, since her husband worked at the facility, and she reassured them all that the installation was safe, even if attacked.

The nuclear drills run by the schools also served to frighten the students while preparing them for the worst. Janet Bohne recalled the "duck and cover" drills that she was required to participate in as a student.⁵¹ Unlike some other schools where this was due to the potential of nuclear attack, in Sandusky these were "nuclear reactor drills." In case of a maximum credible nuclear accident, the students would get

⁴⁵ Interview with Jack Ross by Robert Arrighi, 27 September 2002.

⁴⁶ Interview with Don Young by Mark D. Bowles, 27 September 2002.

⁴⁷ Interview with Myrna Steele by Mark D. Bowles, 7 February 2002.

⁴⁸ Interview with H. Brock Barkley by Mark D. Bowles, 21 September 2002.

⁴⁹ Interview with Earl Boitel by Mark D. Bowles, 25 September 2002.

⁵⁰ Interview with Rosalie Oldrieve by Mark D. Bowles, 26 September 2002.

⁵¹ Interview with Jan Bohne by Mark D. Bowles, 26 September 2002.

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under their desks and tuck into little balls in order to have the least amount of skin exposed to radiation. One local resident recalled that when she was a high school student, "Plum Brook seemed very mysterious."⁵²

The Plum Brook employees sometimes used general concern about radiation for a little good-natured fun. Jack Ross recalled two men who came to Plum Brook looking for jobs as laundry operators and decontamination technicians. Ross hired them and on their first day gave them a walking tour of the facility. Both had expressed some fear of working with radiation, but most everyone explained how safe Plum Brook was. During the walk-through, they met an older man who was in the early stages of Parkinson's disease and whose body sometimes shook. The two new men became a little concerned when they saw him and asked what was wrong. As a practical joke, one of the Plum Brook employees said, "Oh, there's nothing wrong with him. He's only 29, but he's been working here a long time." At lunch time the men left to go eat and never came back. Jack Ross said that he worked for a month trying to track them down to give them their paychecks for their four hours of work.

Everyone at Plum Brook learned a lesson from that story. Ross said, "It pointed out to us that . . . you don't know what kind of fears people have. You shouldn't add to those fears, you should address them." This was a conclusion that Plum Brook administrators came to soon after this unfortunate incident. Ross said, "It seemed a little humorous at the time, but it was sad because those two young fellows could have had a lot of training. They could have had a whole new career door open to them but for a comment that another employee made."⁵³ It was a testament to Plum Brook's commitment to the community that this mistake never happened again. In fact, Plum Brook instituted a concerned effort to inform the community about its work and dispel any misconceptions about working and living with radiation. In an attempt to achieve this, Plum Brook became a unique showplace and hands-on working museum for thousands of visitors.

A Showplace for the Space Program

Public relations were very important, and most reactor operators considered it a "vital part of our job."⁵⁴ Plum Brook formed a speaker's bureau to organize talks about the reactor at local schools and to civic organizations. Those who volunteered

⁵² "Anne Hinton: Community Workgroup Member Profile," *Decommissioning News* (July 2005): 3.

⁵³ Interview with Jack Ross by Robert Arrighi, 27 September 2002.

⁵⁴ Barkley, "Newsgram #1," 24 May 1963, Box 45, Plum Brook Archives.

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for this duty were able to get all of the films and models that NASA produced and used them as demonstration pieces. Not only did they talk about Plum Brook; they also showed the latest Saturn rocket models and launch movies.⁵⁵ But as Robert DeFayette, who was on the speaker's bureau, said, despite all of the positive feedback and enthusiasm, "That's not to say there was no controversy."⁵⁶ There were skeptics in the community, and no matter how much public information was released, they remained convinced that the engineers working behind the Plum Brook fences were conducting dangerous and mysterious experiments. One NASA policy that may have contributed to this early skepticism was its strict visitor policy prior to the time when the reactor went critical in 1961. While Patrick Donoughe, chief of the reactor, allowed limited tours, he stated that "the visitor must not be an area resident." He defined area residents as anyone who lived within a four-hour drive of the reactor.⁵⁷

After the reactor went critical, NASA relaxed this policy and did all it could to defuse concern, skepticism, and fear. Frequent public tours were given to demonstrate how safe the reactor was for the surrounding community and to let people know that public funds were being properly utilized. For most visitors the favorite part of the tour was getting to actually use the master-slave manipulator arms. Earl Boitel of the experimental equipment section volunteered to be one of the tour guides. He said, "People looked at this as space-age technology and perhaps maybe science fiction."⁵⁸ Letting visitors actually operate some of the equipment with the manipulator arms helped to make the facility much more real and comprehensible. After the hot laboratory the guests were then taken to the reactor building, where they entered the containment vessel through the airlock doors. The tour guides would point out the reactor tank, shrapnel shields, and the water in the canals and quadrants.

Another tour highlight was opening the reactor hatch so that people could walk out onto the lily pad and look down into the reactor core itself. What they saw there often amazed them—a light-blue glow emanating from the spent fuel.⁵⁹ During criticality the reactor core emitted a blue glow, known as Cherenkov radiation. The visitors always asked for an explanation of the blue light, and this was one of the

⁵⁵ Newsgram #11, 9 September 1963, Box 45, Plum Brook Archives.

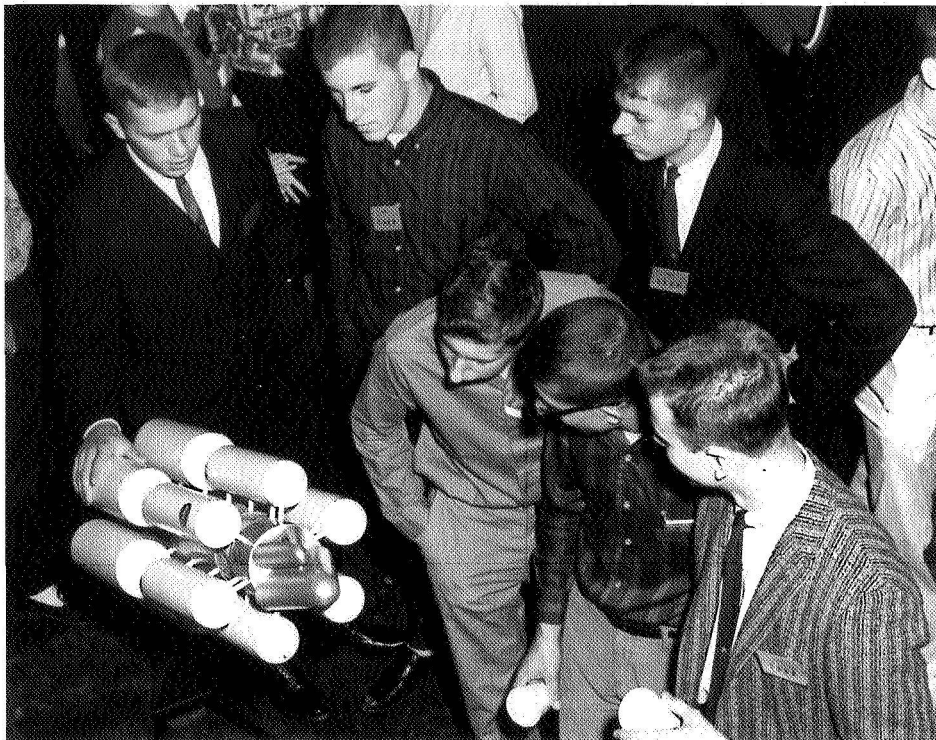
⁵⁶ Interview with Robert DeFayette by Mark D. Bowles, 29 January 2002.

⁵⁷ Patrick L. Donoughe, "Visitors to Plum Brook Reactor Facility," 21 August 1961, Box 1, Folder 10, Plum Brook Archives.

⁵⁸ Interview with Earl Boitel by Mark D. Bowles, 25 September 2002.

⁵⁹ Interview with Jack Crooks by Mark D. Bowles, 25 September 2002.

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A reactor tour by local high school students. Here they are examining a model of a nuclear rocket. (NASA P62-1740)

most exciting parts of the tour. The Cherenkov effect was 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. The experiments themselves were described in very general terms to the Plum Brook visitors to ensure that no classified secrets were given away. Finally, the tours would go through the offices and end at the reactor control room. Boitel recalled, "most people were just amazed at the myriad of instruments that were used in the reactor. This was the first time they had ever seen anything as complicated and with as much instruments."⁶⁰

General open houses were also held for the public. Tours were of tremendous interest to the community, and during one in October 1963 over 1,600 people vis-

⁶⁰ Interview with Earl Boitel by Mark D. Bowles, 25 September 2002

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ited. In total the reactor had over 10,000 visitors during its lifetime. Because of the frequent influx of guests one engineer recalled that the Plum Brook reactor was “a showplace in the early days of the space program.”⁶¹ A great deal of time was spent not only on preparing presentations for visitors, but also making the reactor facility itself more attractive and aesthetically pleasing. One major effort was making the water in the quadrants and canals look cleaner. John Bonn achieved this by suggesting that what might be good for home swimming pools might also be good for the reactor. He installed swimming pool skimmers in the reactor recirculation system, and this became the best method available for cleaning the water.⁶²

Every fall NASA opened its doors, and not just to the Plum Brook reactor, but to the entire station. All of the local schools in the area were invited to come, and for two weeks, every afternoon, a different group of high school students was given a tour.⁶³ These tours were more orchestrated, and the reactor became a living museum. The presentation began with a taped introduction in the auditorium, and at each location someone gave a demonstration about a specific aspect of the reactor. When it was time to move on, a bell rang, and the students walked to the next area of interest. H. Brock Barkley, the reactor chief, believed that the time spent on these tours was well worth it. He wrote, “We realize that much time is involved in work and preparation for these tours. . . . However, I know of no more fertile or productive endeavor than showing young high school students some of the interesting facets of the engineering profession.” In conveying the importance of these tours to reactor employees he said, “If your work encouraged just a few to study harder, to become more curious about or interested in engineering, or to go into the engineering profession, the time was extremely worthwhile.”⁶⁴

For families with small children that toured the reactor, special precautions were put in place. Memos were sent out to all employees giving tours with children to remind the parents to hold their hands in some of the more dangerous areas. For example, the canals posed a potential threat, and some radioactive areas were also off limits. Only one member of each family was given a radiation monitoring badge, so the families were encouraged to stay together not only for safety reasons, but also to ensure that everyone was exposed to the same level of radiation.⁶⁵

Plum Brook gave special tours to distinguished visitors, including NASA

⁶¹ Interview with Jack Crooks by Mark D. Bowles, 25 September 2002.

⁶² Newsgram #14, 30 October 1963, Box 45, Plum Brook Archives.

⁶³ Interview with Don Rhodes by Mark D. Bowles, 25 September 2002.

⁶⁴ Newsgram #13, 9 October 1963, Box 45, Plum Brook Archives.

⁶⁵ Newsgram #13, 9 October 1963, Box 45, Plum Brook Archives.

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administrators like T. Keith Glennan, James Webb, and Tom Paine. Other officials included Raymond Bisplinghoff (director of NASA's Office of Advanced Research and Technology), Harold Finger (manager of SNPO), Glenn Seaborg (chairman of the Atomic Energy Commission), the editors of *Nucleonics* magazine, officials from the Japanese Atomic Energy Commission, and professors from local universities considering use of the reactor for their own experiments. Abe Silverstein, director of Lewis Research Center, made frequent appearances, usually with guests. Politicians also visited, including congressmen and senators. Astronauts were often at Lewis Research Center working on the gimbal rig, and many of them—including Scott Carpenter, Gus Grissom, and John Glenn—took time to tour the reactor. In 1963 an aircraft landing strip was built in the southern portion of Plum Brook so that visits by important guests could be handled more efficiently.

Those who visited the open houses and went on these tours were very appreciative of the rare opportunity to see inside a working nuclear reactor and interact with the people and some of the machinery. After one tour by 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."⁶⁶

Coping with Stress

While the tours took reactor employees away from their jobs, they often served as a needed respite. With the constant attention to safety and the demanding experimental schedule, employees at the reactor continually faced stressful situations. Earl Boitel said, "There was no question that it was very stressful."⁶⁷ Plum Brook engineers, under pressure to return meaningful data from the reactor, at all times had to remain vigilant about safety—their own as well as that of the surrounding community. This was not a typical eight-hour-a-day job. The reactor operated 24 hours a day, 7 days a week, and as a result employees were required to work around the clock on shifts. Myrna Steele recalled that these late-nights were where she learned to drink what she called "back-shift coffee."⁶⁸ The shift teams operated together as a unit, and they became a tight-knit group, much like a family. Every seven days the

⁶⁶ Barkley, "Newsgram #3," 7 June 1963, Box 45, Plum Brook Archives.

⁶⁷ Interview with Earl Boitel by Mark D. Bowles, 25 September 2002.

⁶⁸ Interview with Myrna Steele by Mark D. Bowles, 7 February 2002.

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NASA Administrator James Webb and Lewis Director Abe Silverstein (center, with glasses) look into the reactor tank while visiting Plum Brook. (NASA C-1961-58735)

shifts rotated to a different time slot. The first shift was from midnight to eight in the morning, the second was from eight in the morning until four in the afternoon, and the final shift was from four in the afternoon until midnight. The midnight shift was especially difficult for employees who had families. Robert Didelot said, "It was kind of rough," especially trying to keep the children quiet in the summer-time in the afternoon when he was trying to sleep.⁶⁹ Every week the units would take a different shift so that no one would be stuck with the most difficult hours for any extended period of time.⁷⁰

The Plum Brook employees found ways to cope with the stresses of the job by creating numerous social outlets. Boitel said, "I think that what many of us found is that we needed some way to relieve that stress."⁷¹ He had worked his way through

⁶⁹ Interview with Robert Didelot by Mark D. Bowles, 22 January 2002.

⁷⁰ Interview with Robert Didelot by Mark D. Bowles, 25 September 2002.

⁷¹ Interview with Earl Boitel by Mark D. Bowles, 25 September 2002.

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school by playing music, and when he heard that there were others at NASA who were also musically inclined, they decided to form a band. They called themselves the Mach IVs, and NASA hired them to play at various social functions throughout the year. Jim Greer was the bandleader, and he converted one of the reactor office laboratories into a practice space where they worked on their set lists.⁷² For more organized activities the PACER group was formed, an acronym for the Plum Brook Activities Committee for Entertainment and Recreation. It often hired the Mach IVs to play at Halloween and New Year's dances. The PACER group also worked together to build the recreational grounds at Plum Brook, which included a baseball field and a small structure for entertaining. Softball games were organized after work in the summer, and the families would come out for a picnic. Abe Silverstein, director of Lewis Research Center, frequently attended these gatherings.⁷³ Children often fished in the stream, and there was a playground for them.⁷⁴ Plum Brook also hosted egg hunts for children on Easter Sunday.

Educational games were also encouraged for workers to pass the time, particularly on the late-night shifts, when the reactor was operating normally. H. Brock Barkley called one game "Can you stump your buddy?"⁷⁵ Employees played it by trying to come up with operational questions that would help co-workers prepare for any problems that might occur. For example, questions might include: What would you do if that light went out? What would you do if that alarm sounded? What would you do if that gauge suddenly read full scale? Barkley believed that this game helped everyone learn more about the reactor and enabled them to respond more quickly when emergencies arose.

One other way to reduce stress was to play practical jokes. Unfortunately, the person who bore the brunt of many of these pranks was Myrna Steele, one of only five women who worked with the male-dominated reactor. She was an unusual employee at Plum Brook for several reasons. First, she was a trained physicist among a group that consisted mostly of engineers and technicians. She graduated with degrees in both physics and mathematics from the University of Kentucky. Her father, an engineer, disapproved of her academic pursuits because he believed that the only thing that a physicist could do was teach. To prove him wrong, Myrna stopped working on an advanced degree, moved to Sandusky, and began working at Plum Brook while the reactor was being constructed. Though she eventually

⁷² Interview with Jim Greer by Mark D. Bowles, 26 September 2002.

⁷³ Newsgram #10, 15 August 1963, Box 45, Plum Brook Archives.

⁷⁴ Interview with Robert Defayette by Virginia Dawson, 21 September 2002.

⁷⁵ Newsgram #12, 25 September 1963, Box 45, Plum Brook Archives.

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The band formed by reactor employees. Earl Boitel is on drums and Jim Greer is on his left. Courtesy of Earl Boitel.

became an important and respected colleague, she initially had to confront the same prejudice about her background that she had encountered from her father. She said that all of the Plum Brook engineers thought of physicists as “damned useless egg-heads,” and Myrna worked hard to dispel this belief.⁷⁶ But an even more difficult hurdle for her to overcome was the fact that she was a woman working in a male-dominated culture.

Myrna said that when she first began working at Plum Brook, the other engineers “picked on me. I blushed on command, which they thoroughly enjoyed.” The men played many pranks on her. For example, there was only one unisex changing room where workers could put on the protective gear to go into the reactor. Sometimes she would return to the changing room after working a 12-hour shift and find her shoes over 100 feet in the air, dangling from the polar crane. She said, “The guys would know whether I had on slacks or whether I had on a dress. If I had on slacks, it never happened.”⁷⁷ Eventually one of the men would crawl up the crane

⁷⁶ Interview with Myrna Steele by Mark D. Bowles, 7 February 2002.

⁷⁷ Interview with Myrna Steele by Mark D. Bowles, 7 February 2002.

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April 1972 Easter egg hunt at Plum Brook. (NASA C-2003-846)

and retrieve her shoes for her. But as the months went on she said that she blushed less often and began to turn some of the practical jokes back on her co-workers. To teach a lesson to some of the more notorious pranksters, she baked chocolate-chip brownies with Ex-Lax pills in them.

Not only did Myrna overcome these jokes, she became a well-liked colleague at the reactor. For example, one of the rules at Plum Brook was that no one was allowed to drink alcohol at night if they were working in the reactor the next day. The evenings before holidays or when there was an extra day off during a shift provided opportunities for imbibing at the local lounge. Since Myrna's house was the closest of anyone's to the reactor, she always extended an open invitation to any of her friends who needed a place to sleep. She said, "I just left the doors open a lot of the time and some nights the guys that had just gotten off shift had stopped at two or three of the bars and I would come in and find them sleeping on the sofa or sleeping on the floor."

Though Myrna stopped bearing the brunt of jokes because of her gender, the engineers chided her about being a physicist. And the men still did not like Myrna to actually pick up a wrench and work on the machines herself. The belief that her mechanical capabilities were somehow substandard was something that she never overcame at Plum Brook. However, when she left the reactor to work at Oak Ridge



About 250 former reactor retirees gather at Plum Brook for a reunion in September 2002. (NASA C-2002-01879)

in 1966, she was pleased to find that there “they didn’t tell me that reactors weren’t built for women.” Oak Ridge employed many women physicists who had been there since the Manhattan Engineering District days. For the most part the spirit of camaraderie, friendship, and family pervaded the working conditions at Plum Brook. Stress and difficult and tense working conditions often serve as a binding mechanism between people. Everyone who worked there went through the same trials as everyone else, and as a result close bonds formed that lasted a lifetime. These friendships still continue today as former employees meet on a regular basis at a local restaurant less than a mile from the Plum Brook gates.

Reactor Safety and Risk

Public tours and presentations helped to lessen the community’s anxiety over living near a reactor, but the most important factor in reducing fears was the emphasis on safety by the reactor employees. Project Engineer Len Homyak recalled, “We were drilled on safety. We were taught safety. We practiced safety. It was the foremost thing in our minds when we were doing anything.”⁷⁸ This attention to operat-

⁷⁸ Interview with Len Homyak by Robert Arrighi, 27 September 2002.

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ing a reactor with the least amount of risk to the surrounding community was the central factor in establishing it as a good neighbor. Earl Boitel, a member of the speaker's bureau, said, "I used to tell people that safety was so prominent here that it was more difficult to keep the reactor operating than not."⁷⁹

Safety was not only important for the community, but it was also essential for the workers at Plum Brook who coexisted with the reactor every day. Plum Brook engineers drew upon the safety experience of others who operated test facilities for nuclear experiments. The Oak Ridge National Laboratory was one important model. In one internal document used at Plum Brook, Oak Ridge's C. D. Cagle discussed the dangers and risk present at the early low-flux test reactors. He said that there were personnel overexposures due to open beam holes, materials that became more radioactive than engineers expected, and a general failure to safely shield workers and provide handling tools. He said that there were also building evacuations because of radioactive gases, contaminations from ruptured capsules, and spills of liquids and dusts that were radioactive. Cagle said that with the low-flux test reactors these dangers did not pose a significant health risk. But these problems served as a warning for those who built higher flux test reactors like Plum Brook. He said that "the advent of the high-flux reactors, which could magnify the degree of hazard by a factor of ten to a hundred or more, made it apparent that better guarantees of safety were needed."⁸⁰

It was the responsibility of the health physics officers to ensure the safety of the Plum Brook employees. While the engineers reviewed each experiment to determine if it would produce relevant data, health physicists conducted simultaneous reviews to ensure that the experiment was safe. "Health physics" was a vital part of the reactor's operation. Manhattan Project scientists created this job classification during World War II as another term for "radiation protection."⁸¹ The job of the health physicist was to study basic knowledge about radiation's effect on health and develop new monitoring devices and shielding techniques.⁸² Elevating health to the status of a science was an important factor in helping to ensure the safety of all those who worked and lived near a radioactive environment. Tom Junod, a radiation safety officer at Plum Brook, defined health physics as "the protection of the workers and the public from the damaging effects of ionizing radiation, which could

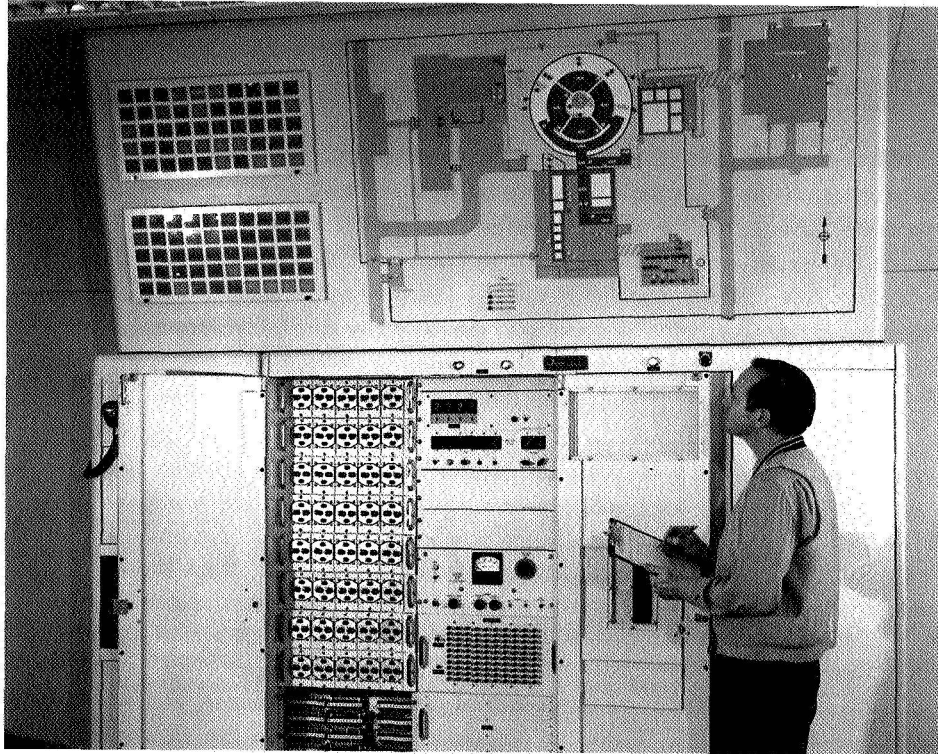
⁷⁹ Interview with Earl Boitel by Mark D. Bowles, 25 September 2002.

⁸⁰ C. D. Cagle, "Considerations Involved in the Safety Review of Experiments to be Operated in Nuclear Reactors," undated, ORNL-TM-745, Box 252, Folder 6, Plum Brook Archives.

⁸¹ Ackland, *Making a Real Killing*, p. 102.

⁸² Michele Stenehjem Gerber, *On the Home Front: The Cold War Legacy of the Hanford Nuclear Site*, 2nd ed. (Lincoln: University of Nebraska Press, 2002), p. 29.

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Tom Junod, the Health and Safety Officer, looks at radiation sensing monitoring equipment. The color of the lights indicated the presence or absence of radiation. (NASA 1961_55636)

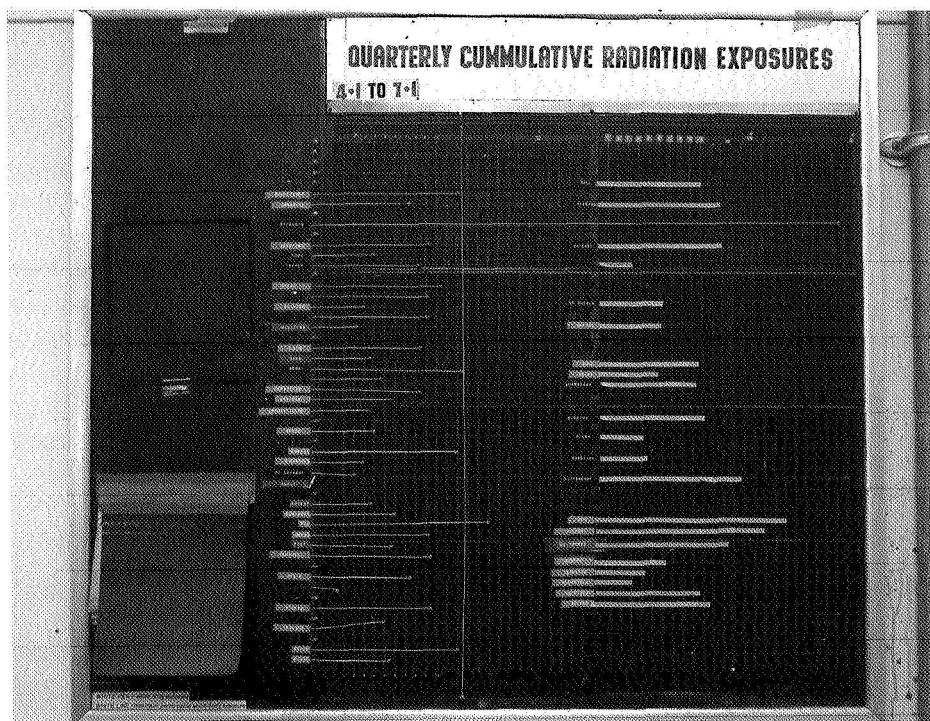
be emitted from a reactor facility, from a hot lab, or from a radiochemistry lab.”⁸³

Jack Ross was the health physics manager at the reactor. He worked for Teledyne Isotopes, the company that Plum Brook contracted with to perform all of its safety monitoring. After leaving the Marine Corps in 1954 he went to work at Westinghouse as a health physics technician and worked there for eight years. At that point Plum Brook contacted him and invited him to manage the health physics section in the reactor. He remained associated with Plum Brook for the next 29 years. His responsibilities included health physics as well as trace environmental analysis, bioassay decontamination, waste packaging, and electronics monitoring and surveillance.⁸⁴ The final important responsibility for Ross and the other health physicists

⁸³ Interview with Tom Junod by Mark D. Bowles, 25 September 2002.

⁸⁴ Interview with Jack Ross by Robert Arrighi, 27 September 2002.

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Health physicists updated this chart from daily pocket ionization dosimeters and other monitoring instruments to ensure that no employee received more than the permissible radiation exposure dose. (NASA 2001-01153)

was to authorize all work permits and review them to ensure that all safety procedures were followed.⁸⁵ If an area became contaminated, a health physicist would place a special “Danger Tag” near the area and cordon it off.⁸⁶

Safety and operability reviews consisted of a detailed check of each experiment and a survey of a variety of different factors that could jeopardize either the success of the test or the safety of the reactor employees. These reviews consisted of several items, like the following list compiled by C. D. Cagle: complete equipment layout; compatibility of materials and environments; strength of the structures and the piping components; reliability of the instruments; provisions for the containment of wastes; critical dimensions of the experiments and the beam holes; fabrication,

⁸⁵ Interview with Tom Junod by Mark D. Bowles, 25 September 2002.

⁸⁶ Newsgram #3, 7 June 1963, Box 45, Plum Brook Archives.

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installation, operations, removal, and disposal procedures; the proper handling of radioactive tools; the security of supplies of electrical power, water, and gases; and all waste disposal.⁸⁷

The health physics technicians and the lab analysts performed the routine radiation surveys both internally at Plum Brook and throughout the surrounding community. These surveys looked for unusually high concentrations of contamination (radioactive particles that combined with each other like dust or dirt). Airborne contamination measuring stations were located at Plum Brook, at the Sandusky post office, and at Lake Erie. They were left out for a week at a time and then collected and analyzed.⁸⁸ Water analyses were performed at various locations in Lake Erie, as well as in streams that were part of the local connecting tributaries. Technicians would also go into some of the local farmers' fields in the summer to determine if any of the crops were contaminated. Internal Plum Brook monitoring included air and sewage tests. Technicians would routinely take sample wipes of laboratory instruments to determine the amount of radiation on them. They would also monitor the laundry operations to ensure that the contaminated clothes were clean and that the water was disposed of safely. Water drains were painted throughout Plum Brook in two different colors, magenta for radioactive water and green for clean water. Magenta was always the color used to designate a dangerous contamination area. Rope with magenta and yellow strands was used to barricade radiation control areas.

To ensure that Plum Brook followed its safety procedures to minimize radiation risk, the AEC performed frequent inspections. These included both planned and surprise visits.⁸⁹ These inspections included reviews of all operating logs, safeguard minutes, and an examination of corrective actions taken as a result of problems. The AEC inspectors also examined all of the health safety records from the employee and would sometimes ship samples back to the AEC Idaho Operations Laboratory for analysis of the concentration of specific isotopes.⁹⁰

Lee Early was a laboratory technician who performed these radiological sur

⁸⁷ C.D. Cagle, "Considerations Involved in the Safety Review of Experiments to be Operated in Nuclear Reactors," undated, ORNL-TM-745, Box 252, Folder 6, Plum Brook Archives.

⁸⁸ Interview with Don Young by Mark D. Bowles, 18 July 2002.

⁸⁹ Letter from Assistant Chief Reactor Division to Reactor Division Files, "Visit of AEC, Division of Compliance Inspector, E.O. Smith," 17 May 1965, Box 255, Folder 6, Plum Brook Archives.

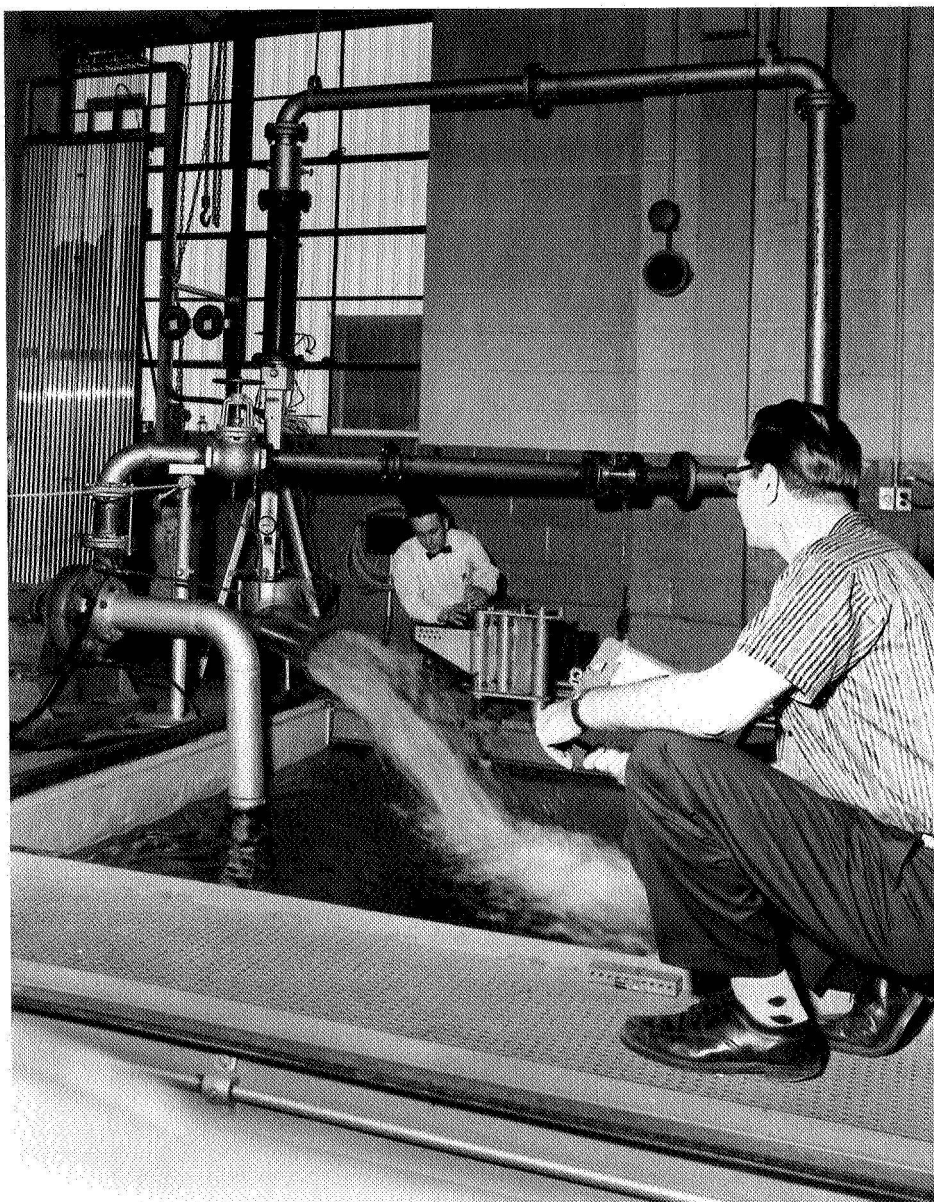
⁹⁰ Memorandum for record from chief of the Plum Brook reactor division regarding the surprise inspection by AEC compliance inspectors Eldon Brunner and Karl Seyfrit, 30 August 1971, Box 255, Folder 8, Plum Brook Archives.

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A health physics technician uses a handheld "curie pie" radiation detector to check equipment for contamination. (NASA C-2003-840)

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Monitoring radioactive content of the water. (NASA 2005-1207)

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veys for a period of eight years at Plum Brook.⁹¹ He said that in all of his years of performing these surveys he never found any radiation levels out of the ordinary outside of the Plum Brook fences. However, he said that he could always tell when a nuclear test bomb was occurring anywhere in the world because his fallout pots that collected rainwater registered higher levels of radioactivity after one of these tests. This was the case before 1963 and the limitations imposed by the Test Ban Treaty. Inside the fence he would periodically find elevated radioactivity levels in his monitoring equipment, but when he reported the findings the engineers typically said that they had expected his reading to increase because of a specific experiment they were conducting.

All the employees wore personal “dosimeters,” which were small tube-like devices that measured radiation exposure. Other personal monitoring devices included film badges, pocket chambers, and neutron spectrum badges.⁹² Urinalysis tests checked for any internal abnormalities, and each worker also stepped into a whole-body radiation counter that could detect any trace amounts of contamination anywhere in the body. At the end of the day health physics officers took a dosimeter and badge reading for each employee and carefully recorded it in on a large chart. Health safety officers provided an assortment of protective clothing for those who worked in contaminated areas or with radioactive materials. These included coveralls, topcoats, undergarments, shoe covers, disposable gloves, head covers, filter masks, etc. The outer garments all carried the radioactive symbol on the back. The most important rule was never to wear these outer garments anywhere other than the in radioactive areas. This especially included the lunch room, library, or offices. Health physicist Dayne H. Brown said, “The mere presence of the ‘radioactive’ symbol in such places can result in criticism and confusion.”⁹³

The AEC defined the limits of the doses that all workers could receive, and the chart provided a quick visual reference for where each employee was in relation to his limit. Over time, if a worker was exposed to more than the maximum amount of radiation, then his or her duties would be restricted to areas away from the reactor core or any irradiated materials. For highly radioactive jobs a timekeeper would be in place to help ensure that no one was overexposed too quickly. Employees were also reminded that if they had any preexisting cuts or abrasions in their skin,

⁹¹ Interview with Lee Early by Mark D. Bowles, 12 August 2002.

⁹² Harry C. Harrison (Plum Brook health physicist), “Proper Use of Personal Monitoring Devices,” December 1963, Box 1, Folder 10, Plum Brook Archives.

⁹³ Dayne H. Brown and Floyd B. Garrett, “Use of NASA Supplied Clothing for Radioactive Contamination Control,” 18 September 1964, Box 1, Folder 10, Plum Brook Archives.

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Monitoring the health of an employee. (NASA 2005-1205)

they had to notify the health physics personnel so that they could ensure the injury would not permit the entry of contamination into the body.

Not all of the wastes could be processed at Plum Brook, and some had to be shipped off site. The procedure was to put low-level radioactive materials into 50 gallon drums, then seal them and label the contents. Then they were stored in the fan house until enough materials were accumulated to fill a truck. Materials with higher levels of radiation were placed in lead-lined casks. The primary destination for all of the materials was a radioactive waste dump in Morehead, Kentucky.

Water was an essential tool for the health physicist. It served not only as a shield to protect workers from radiation; it was also used to decontaminate a person if he or she came into contact with radioactive material. This could happen if people came out of a potentially contaminated region and did not remove their clothes properly, thereby tracking contamination into a clean area. The health physicist monitored these areas, and anyone who became contaminated was ordered into the showers, where the water would literally rinse off the radiation. A health physicist would then monitor the skin to ensure that there was no damage. For more localized areas of contamination, another very low-tech device was used to remove it—tape. Frequently, common household masking tape was used to literally pull the contamination off of whatever surface it was on, including the body.

Dean Sheibley, a radiochemistry section head, became contaminated severe

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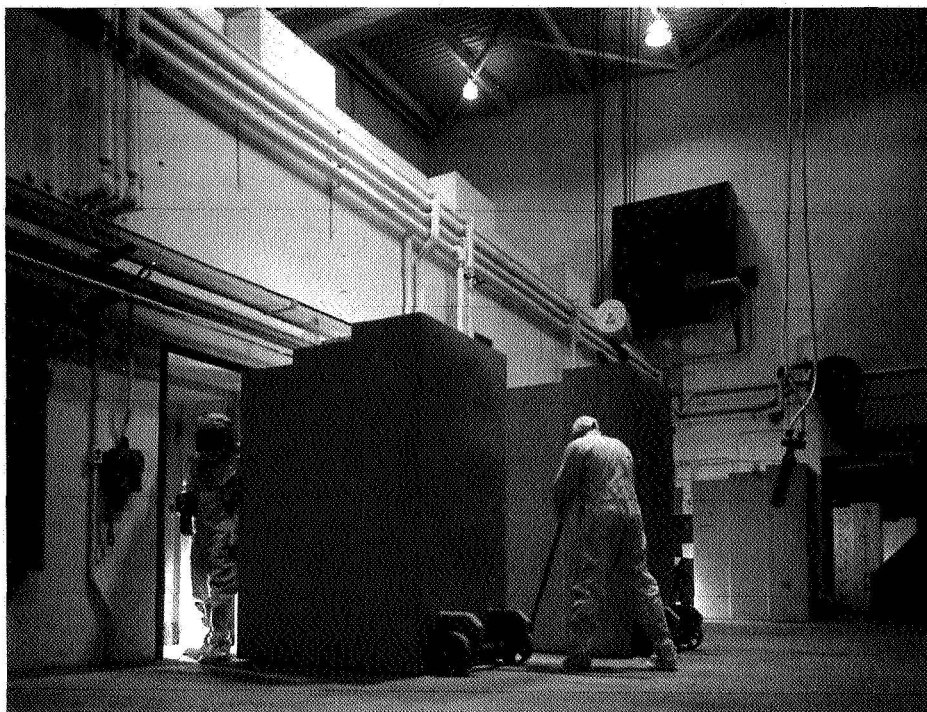


Moving containers of radioactive waste. (NASA 2005-1204)

times in the reactor where he worked. Every precaution was taken for employees going into radioactive areas. They would put on protective clothing over their regular clothes—shoe covers, coveralls, several layers of rubber gloves, caps, and breathing apparatus (if necessary). Nevertheless, sometimes contaminated water would seep through the coveralls or contaminated dust would touch extremities. Sheibley said that if a health physics person discovered that he was contaminated, he would begin the decontamination procedure. This included scrubbing with water under the showers to remove the contamination from exposed skin. Regular clothes also had to be left at the Plum Brook hot laundry facilities for cleaning. This would take over 24 hours, and Sheibley returned home that evening in noncontaminated Plum Brook coveralls. The next day he would return to work and have his old decontaminated clothes waiting for him.⁹⁴ The Plum Brook employees learned to live alongside and protect themselves from contamination and radiation.

⁹⁴ Interview with Dean Sheibley by Mark D. Bowles, 26 September 2002.

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A technician emerges from the rear of the hot laboratory in full protective clothing. Another technician wheels open the massive 63-inch-thick concrete door plug. (NASA CS-22203)

A health and safety officer wrote a report on every accident that occurred at Plum Brook, from employee contamination to other types of problems. Each report described the accident, listed the most probable cause and detailed the corrective action taken and the future action recommended. For example, one report highlighted a serious safety problem when John R. Baughman fell backward from the lifepad platform onto the reactor tank dome. The issue was that the walkway on the lifepad was narrow and had no hand railing for support. To prevent this problem from recurring, NASA installed a new railing.⁹⁵ These accident reports described serious problems, but safety officers also wrote them for the most minor of cases. In 1971 William Belsterli was walking outside the cooling tower on an inspection tour, and as he stepped off the sidewalk "his foot landed in a small grass covered hole in the

⁹⁵ Memo from Head of Reactor and Systems Operations Unit to Chief of the Reactor Division, 1 March 1973, Box 255, Folder 1, Plum Brook Archives.

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ground, causing his right ankle to turn slightly and he fell.”⁹⁶ The most probable cause here was identified as sunken ground due to recent rainfall, and the corrective action was to fill it with dirt. This level of detail indicates the attention that even the most minor safety hazard received.

Though the reactor maintained a very good safety record, shutdowns or “scrams” (an acronym meaning Safety Control Rod Ax Man) 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 21 unscheduled shutdowns.⁹⁷ These were most often due to operator errors, defective equipment, safety or control system malfunctions, and loss of electrical power. Forced evacuations of the containment area were not common, but when they did occur they usually resulted from the presence of high levels of airborne radiation. Flooding within the containment area caused at least one evacuation. The majority of medical emergencies were common eye, hand, and bruise injuries. Individual reactor employee radiation exposure was monitored daily, and health physics managers used this information to keep track of monthly and annual radiation exposure. This radiation safety program helped prevent employees from receiving exposures higher than established safe limits. In total, 20 percent of all of the workers at the reactor were part of the health physics team.⁹⁸

However, on occasion accidents happened. In October 1963 there was an “incident which had the potential of causing the most severe hazard of improper operation conducted to date.”⁹⁹ The problem was an improper valve lineup, and the result was an inadvertent draining of the water in quadrant C. To make matters worse, it had spent radioactive fuel in its bottom. Fortunately the operator whose task it was to watch the water level was alert and caught the error after only three feet of water had drained. Mistakes like these were inevitable, and they became important learning tools for what to avoid and how to become better operators in the future.

Another incident occurred one evening during the second shift on 20 May 1964, when three workers were removing control rod drive assemblies from the subpile room. Because of a simple mistake they were suddenly “drenched with primary

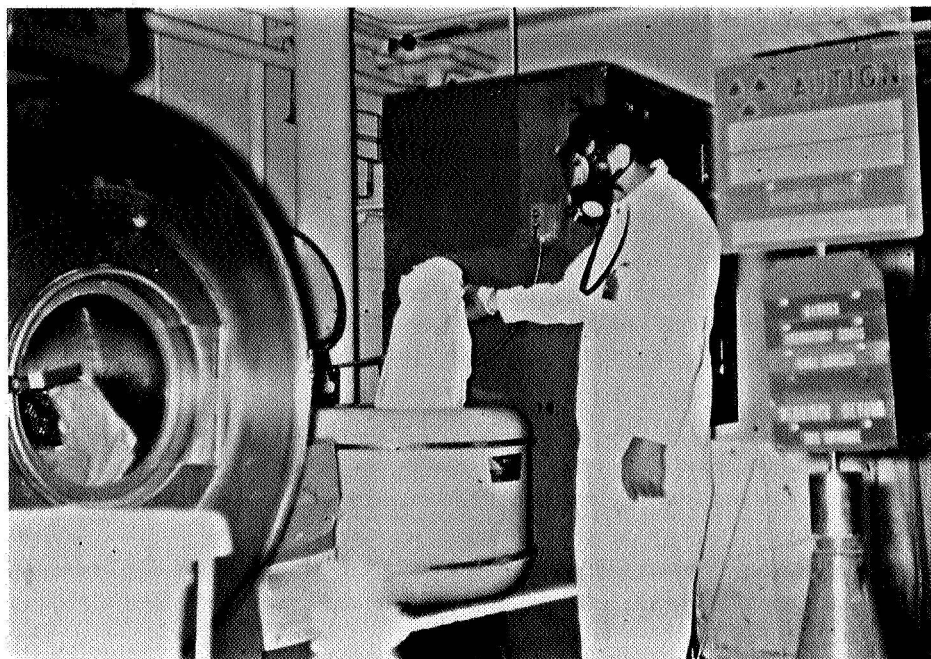
⁹⁶ Letter from John Braeunig (radiological monitoring unit) to Charles H. Rau (reactor services ranch), 13 July 1972, Box 255, Folder 1, Plum Brook Archives.

⁹⁷ “Report of Reactor Operations for the NASA Plum Brook Reactor,” 12 May 1965, Box 40, File 1, p. 7.

⁹⁸ PBRF Records, Cabinet 12: Medical & Bioassay Records.

⁹⁹ Newsgram #14, 30 October 1963, Box 45, Plum Brook Archives.

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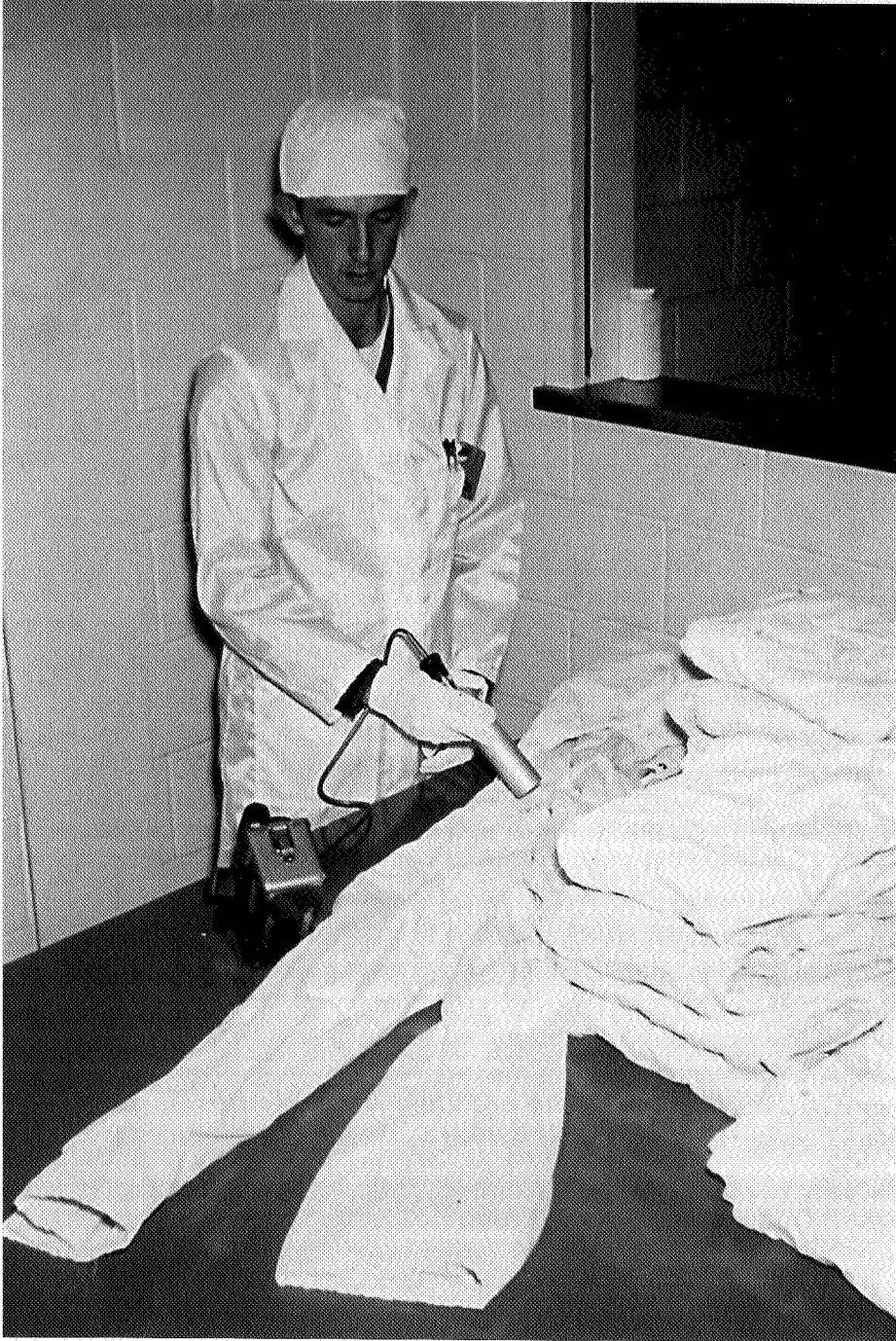
A Plum Brook technician wearing protective clothing and a mask washes contaminated clothing. (NASA C-2003-841)

water contaminating themselves and their protective clothing.”¹⁰⁰ 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 reactor employees firmly believed in the importance of the experimental program at Plum Brook.

Simple accidents could occur as well, and everyone had to be constantly aware that the slightest misstep could cause a serious problem. One concern was people inadvertently dropping items into the reactor quadrants. No one was allowed to carry loose items with them when they walked around the tanks. This included tools, items in pockets, instruments, hats, etc. But this rule was sometimes difficult to remember. In one instance a technician dropped a calibration tool from a radiation instrument into the tank. Although this did no real damage, it was possible for small objects like this to compromise an experiment and cause the loss of a great deal

¹⁰⁰ Lawrence A. Thaler, “Report of Reactor Operations, Cycle 19,” 14 May 1964 to 27 June 1964 J. Ross and T. L. Junod, “Health Safety,” 7, Plum Brook Library.

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health physicist examining clothing for traces of radiation. (NASA 2005-1206)

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of operating time.¹⁰¹ The most famous story about recovering an item was when a Lucite box, supposed to float on top of the water, suddenly sank to the bottom. This occurred before the reactor went critical and there was not a great deal of radiation. While others were debating how to get it out, Tom Tambling, one of the engineers, decided that he could get it himself. He quickly took off his clothes, jumped in the water, and dove down 20 feet to retrieve the box. Joe Savino later recalled this was “not exactly an approved safety procedure.”¹⁰² Stories like this demonstrate the level of personal commitment to ensuring that the reactor would be a success.

Accidents also occurred in the control room. One day Jim Greer, an operator, was cleaning the control panel when he inadvertently pressed the Poison Injection System start button. This was a safety system that contained explosive valves and a pressurized tank filled with gadolinium nitrate solution, a neutron absorber (called a “neutron poison”). This system was designed to shut down the reactor by injecting the gadolinium nitrate solution into the primary cooling water, which circulates through the reactor core, to absorb neutrons so that a chain reaction would not occur. Greer quickly realized his mistake and announced on the intercom, “The reactor has scrammed, the reactor has scrammed.” Everyone reacted as they had been trained to do in numerous emergency drills. It took several days to clean the gadolinium nitrate out of the water system. When it was finally removed the reactor started up again safely. The day after the incident Greer wrote up an “unusual occurrence report,” and he later said, “All I could do was hang my head in shame for a few days and then everybody patted me on the back and said, ‘Jim, it could happen to anybody.’”¹⁰³ Later a plastic cover was installed over the poison injection system start button to prevent any further accidental actuation. Plum Brook employees always tried to learn from their mistakes. This error actually presented an opportunity to prove that the quantity of gadolinium nitrate needed to shut down the system was correct.

Was the community satisfied with the Plum Brook safety record? The extensive outreach effort consisting of speaking engagements and the frequent tours and open houses did have a very positive effect on the community. However, it was impossible to convince everyone that the reactor was safe. Jim Blue said, “I think one has to recognize when you’re doing a nuclear program that you’re not going to satisfy the general public or perhaps even the media, at least some of the media, that you’ve got a safe program. It doesn’t matter what you do, they’re going to treat it as a hazardous

¹⁰¹ Newsgram #15, 20 November 1963, Box 45, Plum Brook Archives.

¹⁰² Interview with Joe Savino by Mark Bowles, 21 September 2002.

¹⁰³ Interview with Jim Greer by Mark D. Bowles, 5 February 2002.

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ing. The public is very easily alarmed by things that are played up in the media as hazardous.”¹⁰⁴

Radiation Deaths at Plum Brook?

One significant media scare at Plum Brook came from Ernest J. Sternglass, the director of radiological physics at the University of Pittsburgh’s School of Medicine. In 1973, the same year that the Plum Brook reactor began shutting down, Sternglass studied radioactive emissions from the reactor and came to some startling conclusions. He used data provided by the Ohio Bureau of Vital Statistics and claimed that in the Sandusky region (where the reactor was located), mortality rates, cancer deaths, and premature births were all higher than in other nearby cities. He argued that heart-disease deaths had increased by 23% in Sandusky from 1958 to 1970, whereas the state as a whole had experienced only a one percent increase. Likewise, infant mortality had decreased by 27% in the state and had increased by 3% in Sandusky during this same period of time. These alarming statistics appeared in front page headlines in the *Sandusky Register*. Sternglass said, “It is clear that only the pattern of radioactivity wastes diffusing from a nuclear reactor fits all the measurement and mortality statistics at Plum Brook.”¹⁰⁵

NASA did not immediately have a response to Sternglass’s attack. Immediately after the announcement Alan “Hap” Johnson, director of Plum Brook, told reporters that he would not comment. He furthermore dismissed the Sternglass findings, stating: “I’m a busy man and I have a busy schedule, and I can’t take the time to read the entire Sternglass statement and all the supporting material he claims to base his findings upon.”¹⁰⁶ Johnson said that the issue was out of his hands and that it was up to the AEC to decide the matter and the threat level posed by Plum Brook.

Sternglass believed that the AEC, which was so closely aligned with the reactor industry, was unable to police itself. He claimed that the AEC was hiding the truth about these emissions. Related stories in the *Sandusky Register* told of the AEC hiding key facts about radiation dangers. In one article it reported that the “AEC as part of an ‘atomic establishment’ which uses secrecy and confusion to stifle

¹⁰⁴ Interview with Jim Blue by Virginia Dawson, September 2002.

¹⁰⁵ Ernest J. Sternglass, in Tim Sowecke, “Radiation-Death Claim Repeated,” *Sandusky Register* (6 July 1973): 1.

¹⁰⁶ “Johnson Mum on Charges,” *Sandusky Register* (27 July 1973): 1.

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protest and subvert the public's right to know."¹⁰⁷ Michael D'Antonio has recently supported this contention that the government had hidden portions of our nuclear past in his book *Atomic Harvest*. He has written that it will be impossible to measure "the shattered faith of thousands of loyal citizens who were deceived and betrayed by their government."¹⁰⁸

Sternglass's published statements widely criticized the safety record of numerous nuclear facilities. But his statistics were also attacked by the scientific community. B. Kim Mortensen, chief of the epidemiology and toxicology bureau, criticized Sternglass's mortality claims about the Perry Nuclear Power Plant in Ohio. Mortensen said, "The rise is artificial. He created the rise. If you look at what he did he picked points, whether intentional or not, that made them go in the direction he wanted."¹⁰⁹ James Wynd, director of the Radiological Monitoring Division at the Ohio health department, also disagreed with Sternglass's conclusions. But he and the state Environmental Protection Agency claimed that the radiation discharge into the air and water around Plum Brook was the "highest recorded in Ohio."¹¹⁰ Despite these levels the EPA said that these were "within AEC limits."¹¹¹ It was in this area of a perceived safe amount of radiation that Sternglass had his greatest support. George Wald, a Nobel laureate in physiology and medicine from Harvard wrote that in general Sternglass made a strong case and that the most important point was that there was no "permissible level" of radiation exposure. Wald stated "There is no threshold: a little, however little, causes some increased risk, and more causes more risk."¹¹²

NASA was never able to prove the Sternglass theory incorrect. Soon after he published his findings, the *Sandusky Register* reported that NASA was "unable to disprove claims by a noted radiologist that Plum Brook is causing an increase in the mortality rate in the Sandusky area."¹¹³ The reason for this inability was, according

¹⁰⁷ "Charge of AEC Part of 'Atomic Establishment,'" *Sandusky Register* (14 August 1973): 1.

¹⁰⁸ Michael D'Antonio, *Atomic Harvest: Hanford and the Lethal Toll of America's Nuclear Arsenal* (New York: Crown Publishers, 1993), p. 3.

¹⁰⁹ B. Kim Mortensen, *Cleveland Plain Dealer* (7 October 1993), as found at www.nei.org. Accessed 13 May 2005.

¹¹⁰ "Radiation Within Limits: AEC," *Sandusky Register* (6 August 1973): 1.

¹¹¹ "Plum Brook Radiation Levels Brought Into A-Plant Hearing," *Sandusky Register* (25 July 1973): 1, 6.

¹¹² George Wald, introduction to Ernest J. Sternglass, *Secret Fallout: Low-Level Radiation from Hiroshima to Three Mile Island* (New York: McGraw-Hill, 1981).

¹¹³ Cess Niceswanger, "Radiation Within Limits: AEC," *Sandusky Register* (6 August 1973): 1.

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g to Plum Brook health physicist Tom Junod, that the NASA equipment was not sensitive enough” to determine whether area residents were receiving too much radiation. Nevertheless, it was his belief that this level of radiation had a negligible effect on the human body. He said that someone who works at a reactor is allowed dosage of 5,000 milliroentgens per year. Someone from the public is allowed 500 milliroentgens per year, but the average person receives 170 milliroentgens per year from background sources of radiation. In comparison, Junod said that Plum Brook solely sent a maximum of 240 milliroentgens into the air around the Sandusky region. The Plum Brook equipment could not measure below 20 milliroentgens per month, and so this is how he calculated the 12-month, 240-milliroentgen average. His permissible dose was therefore within AEC recommendations for radioactivity release, yet these levels were unacceptable for researchers like Sternglass, who argued that this was the primary factor driving up mortality rates.

Today there remains no definitive conclusion about Sternglass’s research or his warnings about low-level radiation risk. J. Newell Stannard, who has written a definitive history on the subject of radioactivity and health, believed that Sternglass’s research raised important questions that have yet to be answered. Stannard said, “No one can prove conclusively that [Stannard] is wrong, only that much more information would be needed to prove that he is right.”¹¹⁴ There was, and still is, no objective way to know what absolute risk level is posed by low-level radiation. Scientists disagree, and the public is left uncertain about what is and is not safe. One example of this debate at Plum Brook was a controversy surrounding NASA’s attempts to establish a new “safety zone.”

The Community Protests the “Safety” Zone

In the late 1960s NASA made plans to establish a new “safety zone” around Plum Brook.¹¹⁵ This was 3,000 acres of land designed to buffer the local community from any hazardous activity that might take place behind its fences. NASA officials argued that it had a responsibility to protect the community from any potential escape of nuclear radiation.¹¹⁶ They believed the buffer zone would increase the safety of the local population if one of the existing containment vessels ruptured. This could occur either because of an accident in the reactor, or because of the other

¹¹⁴ J. Newell Stannard, *Radioactivity and Health, A History* (Virginia: Battelle Memorial Institute, 1988), p. 1024.

¹¹⁵ “Safety Zone Eyes in Plum Brook Bid,” *Plain Dealer* (14 February 1967).

¹¹⁶ “NASA Reveals Lines—Land Owners Ask Questions,” *Sandusky Register* (14 February 1967).

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rocket tests using liquid hydrogen fuels at Plum Brook. The problem was that the land was already owned by over 50 residents who used the fertile soil for crop production. NASA budgeted \$2.1 million for the purchase, giving the farmers \$70 per acre. Some of these farming families remembered the traumatic experience of having the government take their land by eminent domain during World War I. Now it was their turn to experience something similar to what their parents had 30 years previously.¹¹⁷

This was the same property that the government had actually sold back to the farmers nearly two decades earlier, as surplus from the ordnance works days. But there was a clause in the deeds that the farmers signed stating that the government had a right to buy back the land within 20 years. This period was about to expire and NASA was ready to exercise its claim.¹¹⁸ On 21 August 1967 Congress authorized the acquisition of 57 tracks of land. NASA knew that it also had a strong claim on the land, but it also knew, as one politician stated, of the callous way that the government had acted toward these families during World War II. Local Congressman Charles Mosher wrote to one landowner, "NASA is very conscious of the fact that years ago . . . the government evidently acted in a very arbitrary and obnoxious manner."¹¹⁹ NASA hoped it could achieve its expansion goals while also treating the farmers as well as possible.

NASA not only wanted the land as a safety zone, but it also thought that it would be important for the future growth of Plum Brook. Deputy Director of Lewis Research Center Eugene J. Manganiello said, "We would be subject to criticism if we found ourselves hemmed in."¹²⁰ Officials were convinced that the nation's commitment to space exploration and nuclear rockets would only increase in the future. In an era of well-funded NASA budgets, expansion sometimes took precedence over need. Hap Johnson, Plum Brook's director, stated in 1967 that though safety and expansion were the primary reasons behind the land acquisition, the "exact needs were not known." Nor did he believe that they would be known, because, he said "It [is] a little difficult to try and guess into the future."¹²¹

¹¹⁷ "U.S. Plum Brook Addition Fought," *Plain Dealer* (2 February 1967).

¹¹⁸ "NASA, Owners To Meet—Protest Brings Government Response," *Sandusky Register* (February 1967).

¹¹⁹ Charles Mosher to Mrs. Richard J. Fries, 3 May 1967, Box 88, Folder 19, Plum Brook Archives.

¹²⁰ "Safety Zone Eyes in Plum Brook Bid," *Plain Dealer* (14 February 1967).

¹²¹ Alan Johnson quoted in, "NASA Plans Expansion of Plum Brook Station," *Sandusky Register* (26 January 1967).

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The debate over a safety zone provided a forum for the community to raise safety concerns about Plum Brook. It was likely these safety concerns had existed below the surface for many years, and the sudden emphasis by NASA on the need for an additional buffer zone brought them to light. Residents held secret meetings and pooled their resources to do their best to protest the decision, but as one resident said, “You can’t fight the government.”¹²² So they tried to get the government on its side by enlisting Eighth District Representative Jackson E. Betts to launch a congressional inquiry into the land purchase. He attacked NASA’s safety rationale, stating, “A buffer strip is designed to protect somebody from something. [Residents] want to know, ‘protect who from what?’”¹²³

Betts called for NASA to open its “curtain of secrecy” and truly explain what activities it was pursuing that necessitated such a large “safety zone.” He contacted NASA’s highest ranking officials to try to make his case. In 1968 he wrote a letter to Thomas Paine, NASA’s acting administrator. He told him that after meeting with the local community they were concerned about why a buffer was needed and how Plum Brook’s research would “endanger adjacent property and buildings.”¹²⁴ If there was real danger, then the community was also concerned because the proposed buffer extended only along the east and south sides of Plum Brook, but not the north. Just north of the facility was a residential region, and Betts pressed the issue of why safety seemed not to be a concern there.

NASA never answered these questions to the satisfaction of the community. So in 1969 Congressman Betts coordinated a way for the landowners to make their case to NASA in Washington, DC. Betts, along with Robert Hermes (Oxford Township trustee), Fred Deering (Erie county commissioner), William Dwelle (Perkins Township trustee), and Floren James (county agriculture agent), met with NASA top officials. They made the case that the “danger factor” should be removed from Plum Brook.¹²⁵ Furthermore, if NASA could not eliminate the hazards, then the residents wanted to at least be informed exactly what the risks were. Hermes said, “We want

¹²² “A United Front Against NASA? Secret Meeting Probes Prices,” *Sandusky Register* (20 November 1968). “Where Am I Going to Go?” *Sandusky Register* (10 January 1968).

¹²³ Ron L. Coffman, “Betts Tell Landowners He’ll Probe NASA Land Deal,” *Sandusky Register* (21 November 1968).

¹²⁴ Jackson Betts to Thomas O. Paine, 5 December 1968, Box 88, Folder 20, Plum Brook Archives.

¹²⁵ “Landowners Join Betts to Ask Removal of NASA Danger Factor,” *Sandusky Register* (3 April 1969).

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to know what we must be protected from.”¹²⁶ Betts argued that facilities like this should be in remote places in Nevada, not in the middle of a populated area in Ohio. He made the case that instead of a buffer, Plum Brook should change its focus away from hazardous experiments that endangered the population.¹²⁷

Congress held a hearing to discuss the issues involved in the creation of this zone. William Woodward, the director of the Plum Brook Space Power Facility, stated that he was not concerned about the reactor “doing damage to people,” especially if a larger safety zone was established. He said that any release of contaminated materials was well below the established “safe limits” in terms of “parts per million” of hazardous materials released beyond the Plum Brook fences. Congressman Kenneth William Hechler of West Virginia immediately took offense at Woodward’s statement. He said, “I become suspicious . . . whenever anybody talks about parts per million in the atmosphere.” He said that industry in the past has made the same claims that pollution was “not a threat to health,” when in fact the Public Health Service argued differently. Hechler said, in considering the safety risks at Plum Brook, “I wonder whether this really is something that is a potentially serious threat to the health of the people of the [Sandusky] area.”¹²⁸

NASA responded that there was simply increased danger if the buffer zone was not there. The buffer had previously existed in the form of farmland. The act of buying back the land ensured that it would always remain vacant. James London, NASA’s deputy director of research and technology, said, “Our work at Plum Brook can be dangerous if not properly handled—and shielded.”¹²⁹ The buffer zone presented a level of additional safety should any of the already built containment vessels fail. NASA claimed that it had already invested \$100 million in the various Plum Brook facilities, and it was not going to reduce the scope of its research to be less dangerous in the future when a long-term fix like the buffer zone could solve this problem.

Some local residents did not believe that “safety” or the community’s well-being was reason enough for the expansion. To some the danger of Plum Brook had always been there, and the buffer zone would do little to protect the community. Joyce

¹²⁶ Ron L. Coffman, “Landowners to Talk to NASA in Washington,” *Sandusky Register* (10 February 1969).

¹²⁷ Ron L. Coffman, “‘Buffer’ Compromise Leaves Owners Doubtful,” *Sandusky Register* (14 March 1969).

¹²⁸ “Statement of William Woodward, 1969 NASA Authorization,” page 577, Box 88, Folder 9 Plum Brook Archives.

¹²⁹ James London, quoted in Ron L. Coffman, “Betts: Can NASA Move Plum Brook Testing Hazards?” *Sandusky Register* (27 February 1969).

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Buoy, a resident and guidance counselor from the local Vermillion high school, also questioned what she called the “danger element” in one town meeting. She said, “It just doesn’t make sense. You mean an explosion is not going to affect [other] residents? You mean smells from the plant are going to stop in the middle of Patton Tract Road [the outer edge of the proposed safety zone]?”¹³⁰ Arthur Feger, a 70-year-old barber, had built a home on this land that he planned to retire in. He told one community group that he would not be as upset if NASA really needed the property for growth or safety. But he was firmly convinced, “I don’t think they need all that for a buffer zone.”¹³¹

Fred Deering, senior Erie County commissioner, took his concerns to Abe Silverstein, head of Lewis Research Center in Cleveland. But Deering did not meet with the sympathetic ear that he was hoping for. After the meeting Deering said, “[Silverstein] was abrupt and unfriendly. We walked into his office door and he started insulting us, saying we were just a bunch of publicity seekers.”¹³² The Erie county commissioners eventually passed a resolution condemning the federal purchase plan and argued that if Plum Brook contained “something dangerous . . . [it shouldn’t even] be in this populated area anyway.”¹³³ The Perkins Chamber of Commerce and the Sandusky Chamber of Commerce also officially denounced the NASA plan, arguing that the land should remain in private hands.¹³⁴

But NASA officials tried to sell the community on the idea that not only did the buffer zone make the community safer, Plum Brook was also a great stimulus to the local economy. Manganiello told local residents that a stronger, bigger Plum Brook was good for the community in terms of salaries and taxes. He said, “In the long run you’re making a long-range investment which will return big dividends.”¹³⁵ But some were concerned that NASA budgets would not be able to support an aggressive expansion policy and that this long-range investment would never pay off. An editorial in the *Sandusky Register* stated, “Government budgets are becoming such

¹³⁰ Joyce Buoy, quoted in, “NASA Will Take ‘Buffer’ Acreage,” *Sandusky Register* (10 January 1968).

¹³¹ “Where Am I Going to Go?” *Sandusky Register* (10 January 1968).

¹³² Ron L. Coffman, “Silverstein ‘Insulted Us’—Negotiators,” *Sandusky Register* (17 June 1969).

¹³³ “Erie Snubs NASA Land Acquisition,” *Sandusky Register* (20 February 1969).

¹³⁴ “Perkins Chamber Opposes NASA,” *Sandusky Register* (17 April 1969).

¹³⁵ Eugene Manganiello quoted in, “NASA Will Take ‘Buffer’ Acreage,” *Sandusky Register* (10 January 1968).

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that vastly increased funds for NASA just won't be continuing as in the past."¹³⁶ When some residents brought up concerns that Vietnam and other social pressures would divert government funds away from NASA growth, congressional and NASA officials quickly silenced these rumors.¹³⁷ Local Congressman Charles Mosher was emphatic about one point. He said, "You can get rid of any notions that [Plum Brook] is going to close up. . . . I'd like to kill that rumor right now."¹³⁸

Mosher's prediction was dead wrong. Plum Brook's days were numbered after Apollo 17 returned to Earth, carrying the last of the astronauts to visit the Moon. Their return signified a new era at NASA that emphasized reusability and confined human involvement in space to orbiting Earth. There was no longer budgetary support for nuclear rockets, and the philosophical and financial landscape was tilting away from Plum Brook. In March 1970 the government took title to the property around Plum Brook for its safety zone, still espousing its argument that despite the sacrifice of a few families, it was good for the local community to invest in an important technological capability for the nation.¹³⁹ Less than three years later, in January 1973, the workers at Plum Brook's reactor received the unexpected news that their work was about to end. The government had decided that it no longer needed a nuclear rocket, and the entire Plum Brook facility was about to close down.

¹³⁶ "NASA: A Middle Ground," *Sandusky Register* (20 June 1969).

¹³⁷ "Plum Brook Financial 'Pinch' Likely," *Lorain Journal* (4 May 1967).

¹³⁸ Charles Mosher quoted in, "NASA Will Take 'Buffer' Acreage," *Sandusky Register* (10 January 1968); "Statement by Congressman Charles A. Mosher on Plum Brook Land Acquisition," 8 January 1968, Box 88, Folder 18, Plum Brook Archives.

¹³⁹ Land Acquisition Office to Director of Plum Brook Station regarding "Acquired Property," 25 March 1970, Box 88, Folder 34, Plum Brook Archives.

Halting Nuclear Momentum

On 14 December 1972 two men awoke on the surface of the Moon to the music of Richard Strauss's "Thus Spake Zarathustra." This was to be the last day that any human would spend on the lunar surface in the twentieth century. NASA had chosen this music for Apollo 17 astronauts Eugene Cernan and Harrison Schmitt's wake-up call because of its association with Stanley Kubrick's movie *2001: A Space Odyssey*, which had premiered four years earlier.¹ The underlying themes of Strauss's symphony and Kubrick's film seemed most appropriate for the superhuman effort required for these men to land, walk, play, and perform scientific research on the Moon. At the Frankfurt premiere of the symphony in 1896, Strauss said, "I wished to convey by means of music an idea of the development of the human race from its origin, through the various phases of its development, religious and scientific, up to Nietzsche's idea of the superman."² Kubrick likewise used this music not only for its ominous opening tones, but also because of the idea of human progress, from the Earth and into space. For these same reasons NASA selected it for the final ceremonial wake-up call to its astronauts.

But Nietzsche's philosophical tale of Zarathustra, the superman, did not conclude with his unending ascension of the ladder of progress. Ironically, his quest for knowledge ended in retreat. At the beginning of the story Zarathustra went into the mountains seeking wisdom, but after ten years his quest became too much for him, and he decided to leave the mountain and return home. He said, "Zarathustra is again going to be a man." Though NASA did not intend it, the Strauss symphony in homage to Nietzsche's superman was much more a symbol than a simple allusion to a popular science fiction movie. Like Zarathustra, the "supermen" astronauts were

¹ "Apollo 17 Lunar Surface Journal," transcript by Eric M. Jones, found at www.hq.nasa.gov/alsj/a17/a17.launch.html.

² Richard Strauss, quote from the premiere of *Also Sprach Zarathustra*, Op. 30 (1896), James L. Christian, *Philosophy: An Introduction to the Art of Wondering* (California: Thomson Wadsworth, 2006), p. 14.

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also about to come down from their mountain. Five days after awakening on the Moon for the last time, on 19 December, the Apollo 17 mission splashed down in the Pacific Ocean. Its return signified the end of Apollo and a new vision for NASA that included massive budget cuts, program closures, and a new philosophy of space exploration. Trips to the Moon were no longer a national priority, and much of the infrastructure used to support space exploration died with it.

Historian Thomas Hughes's theory of large technical systems can be used to understand the sudden termination and loss of momentum for technological projects. In his work "systems" comprised numerous interacting components that were both technical and nontechnical. Technical components were the physical artifacts used to design the system, whereas the nontechnical components included political, economic, social, and institutional factors.³ The various organizations involved in creating and maintaining a system made up the system's culture. A key part of Hughes's theory was that as any system grows, it acquires momentum through the symbiotic relationship between the technical and nontechnical components. Momentum increases as engineers solve critical technical problems and as the political culture continues to support the endeavor. But momentum does not always move forward. A technological *catastrophe*, a *conversion* in society's belief system, or a changing cultural *contingency* (political, environmental, economic, etc.) could all result in the loss of momentum and potential project termination.⁴

After Apollo 17 the government and NASA adopted a new vision of spaceflight that immediately ended the momentum they had generated since Kennedy declared it a national goal of vital political and technical significance. In the wake of this changing vision the Apollo program came to an inglorious conclusion. Astronaut Cernan said, "Apollo was over and NASA's golden age of exploration was fast fading into glimmering memory."⁵ Humans abandoned the spaceflight missions beyond low-Earth orbit, and the infrastructure that had been built up to achieve these endeavors came to a crashing halt. One casualty of this change was the Plum Brook reactor. NASA's new vision consisted of shuttling humans back and forth into orbit, and facilities like the reactor no longer had a future use. Nuclear propulsion itself had no place in the new Space Shuttle era. The Plum Brook reactor was designed in an era that had political, scientific, and public support for nuclear initiatives in

³ Thomas Hughes, *Networks of Power: Electrification in Western Society, 1880–1930* (Baltimore MD: Johns Hopkins University Press, 1983), p. 6.

⁴ Hughes, *American Genesis: A Century of Technological Innovation and Enthusiasm* (London England: Penguin Books, 1989), p. 462.

⁵ Eugene Cernan and Don Davis, *The Last Man on the Moon* (New York: St. Martin's Press, 1999) p. 342.

Halting Nuclear Momentum



Apollo 17 Crew Eugene Cernan, Ronald Evans, and Harrison Schmitt at the Lewis Research Center with Bruce Lundin. (NASA C-1973-00774)

space. Although scientific support for the experiments at Plum Brook continued, the political and public commitment changed. Plum Brook had been subject to such an unpredictable political climate before when Kennedy suddenly shifted the program's focus from a nuclear airplane to a nuclear rocket. But this time the change would not be in a new direction for research. This time the momentum shift would bring Plum Brook's demise.

Seventeen days after the Apollo 17 splashdown, NASA officials called a sudden meeting at the Plum Brook auditorium, and the head of Lewis Research Center, Bruce Lundin, made the surprise announcement that all of Plum Brook was to shut down immediately. NASA could no longer support its long-term research programs. These became limited by budgetary constraints in favor of projects that promised short-term results. The first project to suspend operations was to be the nuclear reactor, and suddenly on 5 January 1973, the nuclear momentum ended.

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The Dark Days at NASA

By the early 1970s Plum Brook Station had become a vibrant research community, boasting several world-class and unique testing facilities. Soon after the reactor was constructed and went critical in 1961, NASA began building other test and research facilities at Plum Brook (see Appendix D for descriptions of these facilities). These included:

- Space Power Facility (SPF)
- Spacecraft Propulsion Research Facility (B-2)
- Rocket Dynamics and Control Facility (B-3)
- Cryogenic Propellant Tank Site (K-Site)
- Controls and Turbine Test Site
- Dynamics Research Test Center (E Site)
- Liquid Hydrogen Pump Site
- Control and Instrument Building
- Hypersonic Tunnel Facility
- Rocket Engine Dynamics Facility
- High Energy Rocket Engine Research Facility
- Fluorine Pump Site

These other sites were primarily concerned with research and testing chemical and nuclear rocket applications and liquid hydrogen fuel. Robert Kozar, former director of Plum Brook, stated that the experimental research and testing sites at the station helped to establish the “legacy of hydrogen” and contributed to groundbreaking nuclear and space simulation experimentation.⁶ By 1969 all of the Plum Brook facilities were completed, and together they were valued at \$114 million. Its installations included testing facilities for rocket engines, launch vehicle systems, engine components, high-energy propellants, and full-scale spacecraft (chemical and nuclear).⁷ Over 630 civil servants and 132 support service contractors worked at Plum Brook during its peak years.⁸

⁶ Interview with Robert Kozar by Virginia Dawson and Mark D. Bowles, 30 March 2000.

⁷ “Lewis Research Center, 30th Anniversary,” unprocessed Plum Brook Archives.

⁸ “Plum Brook Station Review,” 30 December 1976, NASA-Glenn Research Center, unprocessed archives.

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As Plum Brook was reaching its maturity, NASA entered some of its most difficult years. Richard Nixon had just taken over the White House, and he inherited from Lyndon Johnson massive budgetary commitments to the Vietnam War, social reforms of the Great Society, and the civilian space program.⁹ By late 1972, despite proclamations that “peace is at hand,” Nixon ordered a massive attack (the infamous “Christmas Bombings”) on Hanoi on 18 December, just a day before the last Apollo astronauts returned to Earth.¹⁰ With the war apparently escalating the federal budget had to be substantially reduced. The space program was the first to be scaled back because, according to historian Joan Hoff, it was the smallest program that Nixon had inherited. Furthermore, it became the “easiest to target for cuts by the new economy-minded administration because it had the least broad public constituency.”¹¹ Space was no longer the special place that had captured the hearts and minds of the public during the early Apollo voyages and subsequent ticker-tape parades for the returning astronauts. Nor was there any longer an added political incentive of a space race with a rival superpower. America had won the race, and political support and funding turned elsewhere.

Over \$200 million in budgetary cuts by the Nixon administration resulted in a troubling new period for NASA.¹² The government slashed or eliminated much of the infrastructure that supported deep-space exploration. As Walter McDougall explained, “By the time of the last Apollo flights even men on the moon were boring.”¹³ In early 1973 *Newsweek* questioned whether the administration was downgrading all scientific activity.¹⁴ Specific targets in these cutbacks were long-range scientific initiatives and basic and applied research.

However, the government did make new space commitments during this period when the Moon missions were successfully completed. NASA was at a crossroads. Faced with tightening budgets, its leaders decided that seemingly more economical

⁹ Jonathan Aitken, *Nixon: A Life* (Washington, DC: Regnery Publishing, 1993).

¹⁰ Stephen R. Ambrose, *Nixon: Volume III, Ruin and Recovery* (New York: Simon & Schuster, 1987), pp. 38–59.

¹¹ Joan Hoff, “The Presidency, Congress, and the Deceleration of the U.S. Space Program in the 1970s,” *Spaceflight and the Myth of Presidential Leadership*, ed. Roger Launius and Howard E. McCurdy (Urbana and Chicago: University of Illinois Press, 1997), p. 92.

¹² Harold M. Schmeck, Jr., “NASA Cuts Programs to Save \$200-Million in Current Budget,” *New York Times* (6 January 1973): 11.

¹³ Walter A. McDougall, *The Heavens and the Earth: A Political History of the Space Age* (New York: Basic Books, Inc., 1985), p. 422.

¹⁴ “Is Science Being Downgraded?” *Newsweek* (12 February 1973): 66–67.

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ferrying systems and reusability were the most important goals to strive for in the future. In November 1971 NASA administrator James C. Fletcher listed three key reasons for making a reusable space shuttle the focus of the post-Apollo program. First, the shuttle was the only new program that was both meaningful and cost effective. Second, the shuttle would significantly reduce the complexity of future space operations. Finally, the shuttle could perform useful functions, such as helping to build a space station.¹⁵ Two months later, after a meeting with Fletcher and his deputy, George Low, President Richard Nixon officially announced the plan to dramatically change the American initiative in space.¹⁶ He called the centerpiece of the new system a space vehicle that could “shuttle repeatedly from earth to orbit and back.”¹⁷ The Space Shuttle was born, and with it the dream to revolutionize space travel by making the voyage routine and the craft reusable.¹⁸

The idea of reusability was also related to a new societal emphasis on conservation and recycling. For the Apollo missions the spacecraft was used only once, and only a small pod returned to Earth with the astronauts inside. Comparing spaceflight to oceanic voyages, some observers suggested the absurd analogy of building an elaborate vessel like the *Queen Elizabeth II*, only to destroy it after it crossed the Atlantic one time.¹⁹ In an era of environmental consciousness, Apollo looked expensive and wasteful. For the Space Shuttle, the majority of the craft could be used again and again.

Environmentalists were also protesting the use of nuclear power. Concern about the health and vitality of Earth increased throughout the 1960s, and nuclear weapons, power, and research were some of the central contributing causes of alarm. Thomas Raymond Wellock described the importance of these values and the rise of the antinuclear movement. He said, “New social values as much as any other factor

¹⁵ James C. Fletcher, “The Space Shuttle,” 22 November 1971, *Exploring the Unknown*, Vol. I, pp. 555–558.

¹⁶ Henry C. Dethloff, “The Space Shuttle’s First Flight: STS-1,” *From Engineering Science to Big Science: The NACA and NASA Collier Trophy Winners*, ed. Pamela E. Mack (Washington, DC: Government Printing Office, 1998), p. 286.

¹⁷ White House Press Secretary, “The White House, Statement by the President,” 5 January 1972, Richard M. Nixon Presidential Files, NASA Historical Reference Collection, NASA Headquarters, Washington, DC, in Roger D. Launius, “Nixon Approves the Space Shuttle,” in *NASA: A History of the U.S. Civil Space Program* (Malabar, FL: Krieger Publishing, 1994), p. 232.

¹⁸ For a bibliography on the history of the Space Shuttle, see Roger D. Launius and Aaron K. Gillette, *Toward a History of the Space Shuttle: An Annotated Bibliography*, Studies in Aerospace History, 1 (December 1992).

¹⁹ Isaac Asimov, “Coming of Age,” foreword to Jerry Grey, *Enterprise* (New York: William Morrow, 1979), pp. 7–9.

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brought the antinuclear movement to life.”²⁰ Nonmaterialists espoused new values which included a mission to protect and preserve the environment. This conversion to a new value system by individual activists influenced state governments, eroded the authority of scientists and the federal government, and ended the broad support for the nuclear movement. Jim Blue, radiation physics branch chief at Lewis Research Center, said that antinuclear activity was a great concern for all those who worked within the NASA nuclear program because everyone knew that they were ‘going to face a lot of resistance from the public.”²¹ Historian Spencer R. Weart wrote that by the early 1970s “environmentalism [gave] a solid base for the opposition to reactors.”²²

Because of these new political and environmental realities and space recommitments, the early 1970s became a very difficult period for all of NASA and in particular the Lewis Research Center and Plum Brook, its satellite station. With the space program changing and antinuclear sentiment turning the tide against reactors, the space and nuclear programs at Lewis and Plum Brook were in serious jeopardy. In 1971 the laboratory cut 700 civil service employees. In 1972, 400 additional people were terminated from space nuclear power and propulsion systems. In space research, 318 people lost their jobs, and 100 other employees chose early retirement. As historian Virginia Dawson wrote in her history of the laboratory, “Nothing in Bruce Lundin’s background prepared him to preside over the most difficult period in the history of Lewis Research Center.”²³

Bruce Lundin was born in 1919 and graduated from the University of California in 1942 with a degree in mechanical engineering.²⁴ One year later he joined the Lewis Laboratory and worked during World War II to improve aircraft engine performance. In 1946 he became chief of the jet propulsion research section and conducted some of the first research on turbojet engines. In 1957, when Lewis was still in the NACA organization, he established himself as a bold and aggressive visionary for the agency. In a December 1957 memo to Abe Silverstein he argued that research was essential for national survival. He said, “In our technological age,

²⁰ Thomas Raymond Wellock, *Critical Mass: Opposition to Nuclear Power in California, 1968–1978* (Madison: The University of Wisconsin Press, 1998), p. 8.

²¹ Interview with Jim Blue by Virginia Dawson, September 2002.

²² Spencer R. Weart, *Nuclear Fear: A History* (Cambridge: Harvard University Press, 1988), pp. 325–326.

²³ Virginia Dawson, *Engines and Innovation* (Washington, DC: NASA SP-4306, 1991), p. 201.

²⁴ “Bruce T. Lundin,” biographical file (Washington, DC: NASA Historical Reference Collection, NASA History Division, NASA Headquarters).

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it will be the country that advances in science that will have the greatest impact on the emotions and intelligence of men..."²⁵

Silverstein supported these ideas in a meeting of laboratory directors to discuss the future of the NACA. Lundin's memo, transformed by Silverstein into the "Lewis Laboratory Opinion of a Future Policy," contributed to the formulation of NACA's plan for the new agency. It was later called the "Dryden Plan."²⁶ In it Lewis was given the mission for research on launch vehicles, including nuclear propulsion. In 1958 Lundin became the assistant director at Lewis and led the center's efforts in space propulsion and power generation. In 1969 he became the director of Lewis and held that position until 1977.

While Lewis, like the rest of NASA, suffered from the Nixon budget cuts, it was also hurt because it was unable to secure a significant role in the Space Shuttle development project. Ironically, many of the Lewis-based programs in the 1960s helped to establish the technological feasibility of the Shuttle's main engine. Furthermore the Shuttle used liquid hydrogen for propulsion. This was a fuel that remained dangerous, yet by this time it was considered to have been "tamed" through the Lewis-led experiences with the Centaur upper-stage rocket.²⁷ The reasons behind Lewis' initial exclusion from the Shuttle project are still a matter of debate. But one of the contributing factors was Lundin himself, who allegedly opposed the development of the Shuttle because of technical problems that he saw with it. As a result, Lundin's relationship with NASA headquarters became strained. Lundin became more and more bitter each time he was forced by headquarters to cut jobs. And he often blamed the Shuttle decision by NASA for forcing him to eliminate his programs and people. Almost 15 years to the day after Lundin wrote his influential memo to Silverstein advocating nuclear propulsion, headquarters gave him the order to suspend operations on NASA's nuclear program—the Plum Brook reactor.

Going to the Reactor Funeral

In the wake of Nixon's reduced budget demands new NASA administrator James C. Fletcher and his deputy, George Low, were faced with the task of restructuring

²⁵ Bruce Lundin to Abe Silverstein, 9 December 1957, NARA Records, 221/115.1-71, in Dawson *Engines and Innovation*, p. 170.

²⁶ Dawson, *Engines and Innovation*, p. 160.

²⁷ Virginia Dawson and Mark D. Bowles, *Taming Liquid Hydrogen* (Washington, DC: NASA Special Publication-4230, 2004).

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NASA's goals.²⁸ In 1971 the *New York Times* characterized this period as a "low point in that agency's fortunes," due to budget cuts, serious moral issue, and a lack of public support.²⁹ Fletcher had an uphill battle ahead of him as he tried to reshape and revitalize NASA. One way to do this was to concentrate on programs like the Shuttle and stop work on nuclear initiatives. Nuclear rockets for deep-space exploration required a long-term commitment, and NASA was fighting for survival in the present. In September 1972 Fletcher wrote in his private notes, "Why not end nuclear propulsion now?"³⁰ Low confided in others that NASA should focus on chemical rockets and a liquid hydrogen tug to fit inside the Space Shuttle. Fletcher and Low told only a few insiders of their plan to end NASA's nuclear initiative. This 'secret execution' would not be made public until January 5 and the secret was well kept.

One month later, in October 1972, Plum Brook reactor chief H. Brock Barkley held a division meeting and complimented everyone on the job they were doing. He told them that NASA was pleased with the on-line efficiencies of the reactor, and as a vote of confidence NASA purchased an additional 24 months of fuel elements to keep the reactor research going.³¹ It looked as if the Plum Brook future was secure; however, there were a few people who sensed that something unpleasant was about to happen. Barkley realized during the summer of 1972 that NASA was going to have difficulty finding the funds to support the space nuclear power program after the Apollo missions were over. He said, "Like many things in this country, we started with great expectations and then we lost interest after a period of time."³² But with two years of new fuel purchased he never imagined that the end would come so quickly. Unaware of the pending announcement, Barkley left Plum Brook for a job in the nuclear power industry in December 1972.

On 26 December, the day after Christmas, Lundin received a memo from NASA headquarters that revealed to him for the first time the secret plan to end the nuclear rocket program. The surviving handwritten memo is unsigned, but it is likely to have been from either Fletcher or Low. The subject heading was "Termination of Space Nuclear Power and Propulsion Programs," and it listed a series of programs

²⁸ "NASA Chief Named," *Washington Post* (28 February 1971): 2.

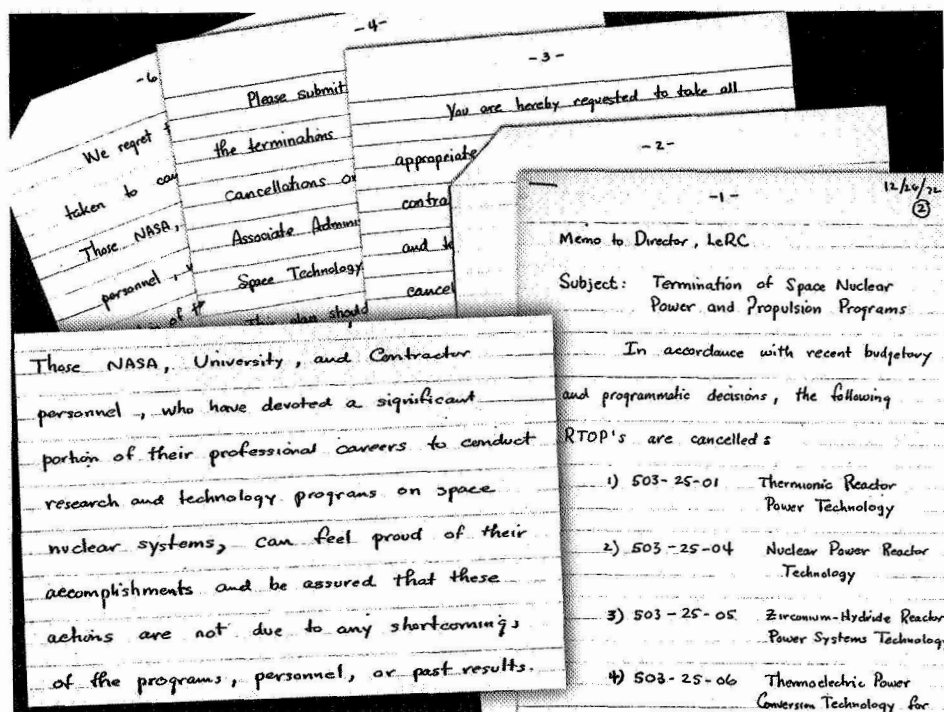
²⁹ "NASA Under Dr. Fletcher," *New York Times* (21 May 1971): 38.

³⁰ Fletcher handwritten notes, nuclear rocket meeting, 15 September 1972, in James Dewar, *To the End of the Solar System: The Story of the Nuclear Rocket* (Lexington, KY: University of Kentucky Press, 2004), p. 201.

³¹ Interview with Dean Sheibley by Mark D. Bowles, 26 September 2002.

³² Interview with H. Brock Barkley by Mark D. Bowles, 21 September 2002.

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Memo to Bruce Lundin from NASA Headquarters to terminate Space Nuclear Power and Propulsion programs. (NASA-Glenn Archives)

that were to be cut immediately because of “budgetary and programmatic decisions.” These included thermionic reactor power technology, nuclear power reactor technology, zirconium hydride reactor power systems technology, thermoelectric power conversion technology for reactor heat sources, energy conversion and transport research, and advanced nuclear propulsion research. The memo gave Lundin the following order: “You are hereby requested to take all appropriate actions and to notify affected contractors to terminate all research and technology activities . . . as soon as possible after January 5, 1973.”³³

Lundin decided not to share this memo with anyone until after the holiday season. He took his first action on 2 January 1973 and invited A. Bert Davis to Lewis Research Center for a private meeting. Davis had been Barkley’s assistant, and he believed that the reason Lundin wanted to talk to him was to promote him to chief of the reactor facility. Instead, Lundin told him that in a few days he would be

³³ Memo to Bruce Lundin, 26 December 1972, Glenn Research Center unprocessed archives.

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calling a meeting with all the employees at Plum Brook to tell them that the entire station was going to be shut down. Davis was stunned. But Lundin also told him that in fact he was to become the reactor chief, and that he was to be in charge of mothballing the reactor and putting it in a standby condition. Davis recalled, "It was deflating." Especially difficult was the fact that Lundin forbade Davis to tell anyone about the closing until he made the announcement. Davis said, "He didn't exactly say I would get fired but the implication was there. I knew something that nobody else knew. I felt very disloyal."³⁴

On 5 January 1973 the terminations began. The AEC announced staff cutbacks and a \$12 million reduction in nuclear space propulsion work in Nevada and New Mexico.³⁵ NERVA was also simultaneously canceled, and neither the Space Nuclear Propulsion Office nor anyone at Los Alamos was prepared for the announcement, because they had believed NASA had made a budgetary commitment to their programs. Historian James Dewar wrote, "NASA broke its word and betrayed its trust, despicable sins in Washington."³⁶ *Newsweek* reported one White House official as saying, "There is blood all over the carpet. Everything's under the knife. Everybody's mad."³⁷ At the exact same moment that NERVA was terminated, coordinated to the hour, the Plum Brook staff gathered in their auditorium. They assembled believing they would hear congratulatory praise by Lewis center director Bruce Lundin. Earl Boitel of the reactor's experimental equipment section sat in the audience and, when he saw Bruce Lundin walking down the center aisle to the podium, he looked at the expression on his face. From that expression, Boitel recalled, "We all knew this was not good news."³⁸

Lundin took the podium and did not immediately tell his audience the worst of his news. He began his presentation instead by discussing national issues.³⁹ He told them about President Nixon's plans to cut the federal budget and impose no new taxes on the American people. The president also wanted to reduce the federal bureaucracy but at the same time keep a strong defense department to continue the costly war in Vietnam. Though at that time Nixon had not made clear what federal

³⁴ Interview with A. Bert Davis by Mark D. Bowles, 27 February 2002.

³⁵ "NASA and AEC Begin Staff Cutbacks," *Washington Post* (6 January 1973): A3.

³⁶ James Dewar, *To the End of the Solar System: The Story of the Nuclear Rocket* (Lexington, KY: University of Kentucky Press, 2004), pp. 202–203.

³⁷ "The Big Budget Battle," *Newsweek* (15 January 1973): 55.

³⁸ Interview with Earl Boitel by Mark D. Bowles, 25 September 2002

³⁹ The material and quotes from this section comes from the audiotape of Bruce Lundin's shutdown speech, 5 January 1973, Glenn Research Center archives.

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programs he was going to cut, Lundin speculated in his speech that many of Lyndon Johnson's Great Society programs would be eliminated.

Lundin then turned from the national political issues to the NASA agency as a whole. He told his increasingly anxious audience that NASA administrator James Fletcher believed that he had an agreement with the Nixon administration about a "level budget concept" that would keep NASA funding intact at about \$3 billion per year. That agreement was now gone, though several projects retained their funding. These projects included the Space Shuttle, docking with the Russians in orbit, the Viking Mars landers, and Skylab. The Titan-Centaur shroud development was to continue, and Lundin called it the "most important piece of development and testing" that the Lewis center was engaged in. Other programs were to be cut, including Pioneer, the HEAO large astronomical observation satellite, and some other planned communication satellites.

At this point Lundin changed the focus of his talk to Lewis Research Center. He then dropped his first bombshell. Lundin said that in order to fit within the new budgetary requirements, the center was going to suspend all research, or anything that "cannot be expected to have a needed or useful application . . . within this decade." Short-range projects with operational dates of less than five years were given priority. This meant that all nuclear power and nuclear propulsion work at Lewis was to be terminated. It was at this point that the Plum Brook audience knew that their own jobs were now in jeopardy. After a brief pause Lundin confirmed their worst fears. He said, "This means, of course, that the reactor here at Plum Brook will be closed down during the remainder of this current fiscal year." Furthermore, he said that though the reactor would be closed first, the remainder of Plum Brook would be shut down in 1974. A murmur of stunned disbelief echoed through the audience.

Lundin tried to lighten the mood by saying that he hoped that these closures would not be permanent. All of the facilities were to be placed in a standby or "mothball" condition, and they were not to be abandoned or sold off as surplus. He reassured them that many of the facilities and the people involved in running them would be offered their jobs back when the space program needed them again. But for the short term a reduction in force, or RIF, was unavoidable. He said that by 30 June 1973, 400 people had to be let go. Half of these people were to come from Lewis and the other half from Plum Brook.

Lundin then stepped back for a moment from the official announcement and took time to offer what he called his own "philosophical views" on why this happened. It is uncertain whether or not this part of the speech was scripted in advance; he seemed to speak extemporaneously and very candidly about his criticisms of NASA policy. In his opinion the Space Shuttle and those who supported it were the reason for Plum Brook's impending closure. Lundin had never been a supporter of

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Bill Fecych shutting down the reactor for the final time on 5 January 1973 as Dale McCutcheon, Dan Gerdner, George Gowan, and others look on. (NASA C-2003-847)

the Shuttle, and he took this opportunity to place the blame for these cuts on the shoulders of those who supported a Shuttle-dominated vision of NASA's future. Plum Brook was created to support a space program that had as its goal exploration in space through the use of nuclear rockets. The goal of the Shuttle was to remain in low Earth orbit. Plum Brook's facilities would be of little use in this endeavor, and as a result it became expendable. Lundin said, "I can understand this and can therefore accept the rationale for this decision. It's one I don't agree with. I don't think that it's exactly right to do it just this way, but I can understand it and accept it and that's what all of us have to do now."

In conclusion, Lundin admitted that he told everyone all that he knew and even confessed that he shared probably a bit more of his feelings than he should have. Before he left the stage he addressed the emotions that he was certain his audience was trying to come to terms with. He said, "What happened to me a week or few days ago is the same thing that's happening to you now. You suffer a shock that you can't quite believe it, a feeling of pain and anguish, of course, and you lick your

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wounds for a day or two. Then you decide that's not very constructive so where do we go from here?" The answer was for the reactor employees to return to work and shut it down before the day was over.

A few hours after Bruce Lundin's announcement most of the reactor employees gathered together in the control room and watched Don Rhodes and Bill Fecych shut the reactor down for the last time. They were in the middle of a 14-day experimental cycle, but suddenly neither the data nor the experiments mattered any longer. There were 35 active research experiments ongoing, and another 7 university grant studies under way.⁴⁰ Robert Didelot retrieved his Polaroid camera, and as soon as the control rods were locked for the last time he took a picture of all the employees huddled together. The next day major newspapers across the country carried the dire news about NASA significantly reducing its budget and the shutdown of the Plum Brook reactor.⁴¹ Though eventually 600 civil servant jobs were cut from Lewis Research Center and Plum Brook, these employees had to devote their attention not only to looking for new jobs, but to the huge task of mothballing a nuclear reactor.

The response from the employees at the reactor was immediate and intense. Recent interviews conducted with some of the men who were in the audience for the Lundin shutdown speech demonstrate that little of the pain of that day has lessened with time. Robert DeFayette recalled, "It just came down like a ton of bricks."⁴² Jim Greer said, "The speech was dismal for me."⁴³ Len Homyak called it a "Sad, sad situation. There were a lot of sad eyes."⁴⁴ Dean Sheibley said it was a "shock. . . . There were a lot of stunned people that day."⁴⁵ William Stokes lamented, "It was almost like going to the reactor funeral."⁴⁶ Earl Boitel said, "It was a very traumatic experience . . . a lot of tears in people's eyes."⁴⁷ Loren Ball returned to the

⁴⁰ Edward A. Richley (Chief, Office of Operations Analysis and Planning), "Summary Status Report: Phase Out of Nuclear Program," 19 January 1973, Box 105, Folder 10, Plum Brook Archives.

⁴¹ Harold M. Schmeck, Jr., "NASA Cuts Programs to Save \$200-Million in Current Budget," *New York Times* (6 January 1973): 11; "NASA Spending Cut \$200 Million for Fiscal 1973," *Wall Street Journal* (8 January 1973): 8.

⁴² Interview with Robert DeFayette by Mark D. Bowles, 29 January 2002.

⁴³ Interview with Jim Greer by Mark D. Bowles, 26 September 2002.

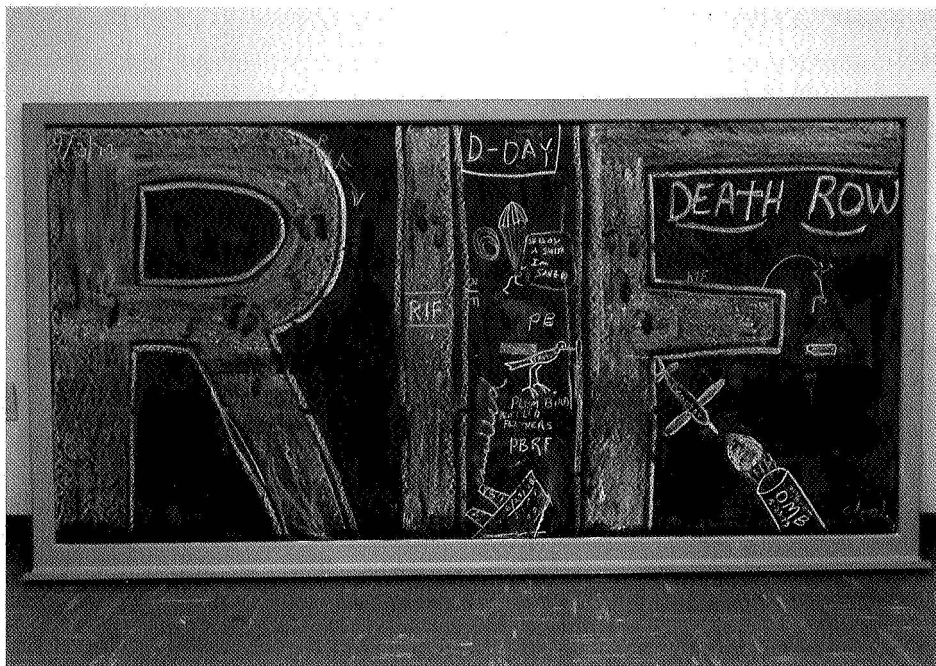
⁴⁴ Interview with Len Homyak by Robert Arrighi, 27 September 2002.

⁴⁵ Interview with Dean Sheibley by Mark D. Bowles, 26 September 2002.

⁴⁶ Interview with William Stokes by Mark D. Bowles, 23 January 2002.

⁴⁷ Interview with Earl Boitel by Mark D. Bowles, 22 January 2002.

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Employees expressed their dissatisfaction with drawings like this on blackboards. This one remained untouched for over 25 years. (NASA C-2001-01166)

reactor office complex and drew a picture on a blackboard of a sinking ship with the name SS *Plum Brook* and the letters R.I.P. above it.⁴⁸ Bill Fecych isolated himself in an office and wrote a poem in memory of the reactor, left it on a table, and walked away. Robert Didelot found the note and to this day recalled one of the lines: "Old reactors never die, they just decay away."⁴⁹

Pursuing Environmental Uses

While the various shutdown procedures continued, some looked optimistically toward the future. They hoped that they could preserve the reactor in the short term and reactivate it at a future date when research could again be funded. Don Young said that while everyone was looking for new jobs, many considered them to be only

⁴⁸ Interview with Dean Sheibley by Mark D. Bowles, 26 September 2002.

⁴⁹ Interview with Robert Didelot by Mark D. Bowles, 25 September 2002.

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temporary, and when the reactor was opened again they would return and begin working on new experiments.⁵⁰ Specifically, the employees held out hope that the reactor would be an essential tool when (or if) the nation revived the human Mars mission. But the most likely chances for its survival rested with its work to support environmental research, which it had been pursuing for several years.

Republican Congressman Charles A. Mosher headed an effort to find future uses for the facility in the early months after the termination announcement, from February through April 1973. Mosher had been a representative of the Sandusky community since 1960 and served as the ranking minority member of the Science and Astronautics Committee of the U.S. House of Representatives. He knew that Plum Brook was vitally important to his constituents and the nation.⁵¹ He wrote letters to NASA leaders James C. Fletcher (NASA administrator), George M. Low (NASA deputy administrator), and Bruce Lundin (director of NASA's Lewis Research Center) to discuss an idea of using the reactor specifically for environmental analyses with its neutron activation.⁵² Mosher said that focusing Plum Brook specifically on this type of research would enable it to operate at a power (less than ten megawatts) and within a budget lower than was needed to perform space-related experiments.

The previous chapter discussed the details of neutron activation analysis, the process by which engineers bombarded samples with neutrons to identify their trace elements for air pollution, water pollution, and other environmental studies.⁵³ Hap Johnson, Plum Brook's director, said that for Plum Brook to successfully market itself for this type of research, it had to compete against other reactors with this capability (i.e., Oak Ridge National Laboratory and Battelle Memorial Institute). In Johnson's opinion the neutron activation analysis at Plum Brook was "far superior to work being done by others."⁵⁴ Johnson worked closely with Mosher, who became NASA's political voice advocating its survival.

George Low seemed intrigued by the idea. He called the Plum Brook reactor a "valuable national asset" and strove to convince the Environmental Protection

⁵⁰ Interview with Don Young by Mark D. Bowles, 27 September 2002.

⁵¹ Harry J. Lorber, "Mosher Says He Won't Run Again," *Sandusky Register* (12 December 1975).

⁵² Charles A. Mosher to George M. Low, 6 February 1973, Box 106, Folder 15, Plum Brook Archives.

⁵³ Michael Woods, "Outside Use of Plum Brook Facility NASA Alternative to Standby Status," *Toledo Blade* (29 April 1973).

⁵⁴ Memo from Hap Johnson, Operation of Plum Brook Reactor at Reduced Power for Neutron Activation Analysis, 23 February 1973, Box 105, Folder 2, Plum Brook Archives.

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Agency (EPA) to “use the reactor for a different purpose than it was originally designed.”⁵⁵ Low had his associates contact the director of Plum Brook to ask questions, such as the cost of using the reactor’s environmental projects, should a sponsor not immediately become available.⁵⁶ He wrote back to Mosher to tell him that James Fletcher planned to discuss the situation with the head of the EPA. The EPA had already been sponsoring experiments at Plum Brook, and Low said that Fletcher was going to suggest that the “EPA might want to take over the operation of the reactor.”⁵⁷

Bruce Lundin was also sympathetic to the effort to keep Plum Brook alive. To assist in this fight, he appointed John V. Dugan to the full-time job of finding future uses for the facility. Lundin told him to “focus his immediate attention on the Reactor Facility” because it was scheduled to enter standby condition on 30 June.⁵⁸ Dugan quickly began contacting government officials and nuclear researchers in the university community. He hoped that he would find support at the EPA or from another sponsor that could commit to enough funded research to keep its doors open.

Mosher continued his efforts by soliciting help from Guy Stever, the director of the National Science Foundation. He explained to Stever, who was also Nixon’s new science advisor, the importance of Plum Brook, calling it a “major national scientific resource” that housed unique research facilities that were duplicated nowhere else in the world. He also argued that it was a “horrible waste” to close Plum Brook, not only because of its scientific significance, but also because the government had invested approximately \$120 million to create the facility. Mosher hoped Stever would become an important ally in helping to solve what he called the “Plum Brook problem.”⁵⁹

Coordinating with Mosher’s political effort to save Plum Brook was an effort by reactor engineers. Dean Sheibley, Plum Brook’s radiochemistry section head, and others tried to find sponsors to fund the continuation of its important envi-

⁵⁵ George M. Low’s testimony before the House Subcommittee on Manned Space Flight, 6 March 1973, Box 106, Folder 15, Plum Brook Archives.

⁵⁶ Alan D. Johnson to Kurt Strauss, in answer to George Low’s questions, 19 April 1973, Box 105, Folder 10, Plum Brook Archives.

⁵⁷ George M. Low to Charles A. Mosher, 19 March 1973, Box 106, Folder 15, Plum Brook Archives.

⁵⁸ Bruce Lundin to Roy P. Jackson (associate administrator for office of aeronautics and space technology), 11 May 1973, Box 106, Folder 15, Plum Brook Archives.

⁵⁹ Charles A. Mosher to Guy Stever, 21 March 1973, Box 106, Folder 15, Plum Brook Archives.

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ronmental studies. They developed a comprehensive plan to determine how many neutron activation radiations Plum Brook would have to perform each year to pay for its operating costs. They began with an annual operating budget of what they estimated to be \$520,500. This included 26 employees, contractor services, a health physics program, radioactive fuel, etc. Since Plum Brook performed neutron activation analyses at \$150 per sample, they calculated they would need to perform 3,470 tests per year to break even. Through a preliminary "market survey" they contacted some previous and potential sponsors to find out what level of commitment they could give to Plum Brook for this type of testing. They discovered that the EPA could commit to 375 tests per year (\$56,000), and Lewis Research Center's Environmental Research Office wanted 600 tests per year (at a reduced rate of \$100 per sample for a total of \$60,000). Plum Brook considered these "firm customers." A list of potential customers included the Ohio Criminal Bureau of Investigation, John Carroll University, the Air Force Institute of Technology, and Cleveland State University. These customers would result in an approximate income of \$155,000 per year, for a total of \$271,000 when matched with the firm sponsors. These funds were enough to cover over half of Plum Brook's yearly operating costs and were the result of a very limited marketing effort. With a concerted marketing campaign the Plum Brook engineers felt confident that their environmental initiative would be a success.⁶⁰

In April 1973 a symposium of over 80 scientists, educators, Ohio politicians, and economists was held to explore other future uses of the station.⁶¹ Bruce Lundin sent out personal invitations, hoping to attract an influential audience interested in the survival of the reactor.⁶² The local press called it the best-educated group ever assembled at Plum Brook, with more than half holding doctorates in fields such as nuclear physics, chemistry, chemical engineering, and electrical engineering. Attendees came from universities, NASA, the Atomic Energy Commission, the National Science Foundation, the Department of Defense, Argonne National Laboratory, and the EPA.⁶³

Proposals presented at the symposium included an industrial park and a 17-

⁶⁰ "Operation of Plum Brook Reactor at Reduced Power for Neutron Activation Analysis," 19 March 1973. Box 106, Folder 15, Plum Brook Archives.

⁶¹ "Symposium Explores Future Plum Brook Station Usage," *News Herald* (26 April 1973).

⁶² Bruce Lundin, Future Use Symposium invitation, 10 April 1973, Box 105, Folder 1, Plum Brook Archives.

⁶³ "Preliminary Attendee List for the Symposium on Possible Uses of the Plum Brook Station," Box 105, Folder 1, Plum Brook Archives.

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university consortium and research center. Another plan was to convert the reactor into a power facility, but both the AEC and NASA said that was impossible. A third proposal called for using the reactor at a lower power (six megawatts) for continued neutron activation analysis testing for the EPA. This would incur only about one-tenth the cost (\$.5 million per year) to operate the facility.⁶⁴ James Blue of the NASA Lewis Research Center's cyclotron facility proposed a final use of the reactor. At the time Blue was working with the Cleveland Clinic, treating cancer patients with neutrons from the cyclotron. With a 10-year grant from the National Cancer Institute he helped treat over 4,000 patients at Lewis. He suggested converting Quadrant B at Plum Brook into a medical facility where epithermal neutrons could be used to treat patients who had brain tumors, referred to as glioblastomas.⁶⁵

Any decision for future use had to be made before the reactor was finally shut down in June 1973, but none of the proposals met with success. Universities could not come up with a nongovernment use that was cost effective. Though all of the scientists who toured the facility were in awe of the impressive array of instruments, they knew that it was too big for any of them to actually take over. After the symposium ended one scientist addressed the media as he was preparing to leave in his car. He said, "It's like offering a science fiction fan the opportunity to participate in a space flight. . . . Here's all that equipment. I'd like to have access to some of it—all of it. But I don't know how I'd be able to put it to good use."⁶⁶

Fletcher had no luck in trying to talk the EPA into supporting Plum Brook. Lundin said that no individual user or joint cooperative effort seemed feasible, even after the work by the symposium to stimulate interest.⁶⁷ Sheibley recalled that his efforts failed because of "the political pressures of NASA competing with other for-profit facilities."⁶⁸ Despite the best efforts of local politicians, NASA leaders, and Plum Brook's engineers, the reactor received no second lease on life. Fletcher explained that the reason Plum Brook could not be saved was because it did not fit into the government's new budgetary policy of supporting initiatives with short-term scientific returns. He agreed that even though the Plum Brook reactor had assembled a "first rate team," it was necessary to suspend its experimental program because of this new short-term "philosophy." Fletcher said, "We decided that pro-

⁶⁴ "NASA and Plum Brook Footage, 1961–1973," John Carroll University Media Archives.

⁶⁵ Interview with Jim Blue, conducted by Mark Bowles, 11 February 2002.

⁶⁶ John Hammack, "Plum Brook's Future: Private Use or Disuse? Everyone's Interested, But..." *Sandusky Register*, undated, Box 105, Folder 1, Plum Brook Archives.

⁶⁷ Bruce Lundin to Roy P. Jackson, 11 May 1973, Box 106, Folder 15, Plum Brook Archives.

⁶⁸ Dean Sheibley, email to author, 4 May 2005.

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grams that were pretty far out in the future [late 1980s] . . . were the ones we had to defer.”⁶⁹

To Mosher this problem was bigger than just Plum Brook itself. He felt that it was representative of the nation’s inability to provide long-term commitment and support to scientific endeavors. Mosher argued to any other politician that would listen to him that “this ‘go and stop’ policy for major institutions such as Plum Brook is terribly costly and wasteful.”⁷⁰ He said that there were many important uses for Plum Brook, but none of these would be realized because of economic reasons.⁷¹ Mosher considered this to be a “among the major mistakes we make in government.” He believed that without a strong commitment from government, large-scale science would be doomed to failure. He said, “Persistence is imperative to the productive search for new knowledge.”⁷² If Plum Brook failed in its mission, it was because it did not have the persistent support from the government that created it. When Plum Brook did not find outside sponsorship, it became clear that its closure was going to be permanent, and the outplacement activities took on greater significance.

Reactor Operators for Hire

Outside the door leading into NASA’s outplacement center for displaced reactor employees, a local TV news crew interviewed one of the engineers who was about to go inside. The first question was about the reaction among the employees. The reactor engineer said, “From what I have been able to see, there is a lot of bitterness.” While he could understand the reasons for the budgetary cutbacks, he identified what he believed was one crucial mistake that the Nixon administration was making. He said, “There is a mistake in cutting back the research that produces new technologies for our country . . . this is the only thing that we have to sell to the rest of the world. If we do not continue to produce new technologies, what are we going

⁶⁹ James C. Fletcher’s testimony for the House Subcommittee on Manned Space Flight, 6 March 1973, Box 106, Folder 15, Plum Brook Archives.

⁷⁰ Charles A. Mosher to Norman P. Phillips (president Sandusky Area Chamber of Commerce), 22 March 1973, Box 106, Folder 15, Plum Brook Archives.

⁷¹ “Plum Brook Facility Loses 50 More Jobs,” *Sandusky Register* (26 November 1974).

⁷² Charles A. Mosher to Donald J. Pease, 3 February 1978, Box 106, Folder 15, Plum Brook Archives.

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Plum Brook to close

Nuclear propulsion, power projects to phase out

Director Bruce T. Lundin, announced to employees of the Center on January 5 that the necessity to reduce Federal expenditures during the current fiscal year and beyond has forced a significant reduction in many of NASA's current and planned programs. These reductions affect the expenditure level for the remainder of this fiscal year and planning for fiscal year 1974. In general long range research and technology efforts not expected to be needed for some time in the future will be reduced or terminated. Priority will

be given to more urgently needed (near-term) work.

The impact on Lewis will be the termination of essentially all of the current nuclear propulsion and power programs by the end of this fiscal year. Major facilities not to be utilized in NASA's restructured program will be phased out and placed in standby condition. At the Plum Brook Station, the Reactor Facility will be placed in standby condition by the end of this fiscal year and the remainder of the Station will be closed by the end of Fiscal Year 1974.

The closedown of Plum Brook and program terminations at the Lewis Cleveland site will result in the separation of many employees over the next 18 months.

Officials expect a reduction of about 600 Civil Service positions at Cleveland and Plum Brook. About half of these jobs will be eliminated by the end of this fiscal year, the others during FY 1974. This reduction is in addition to the earlier planned reduction of 90 that must be made by the end of FY 1973.

NASA explains cutbacks

NASA has made a number of program reductions to adjust its activities in space and aeronautics to a lower spending level. These reductions are necessary as part of all the actions required to reduce total government spending to the \$250 billion target set by the President for the Fiscal Year 1973.

Every effort has been made to continue the essential elements for a balanced and productive space and aeronautics program within tight fiscal constraints. This includes retention of the Skylab experimental space station, the space shuttle, the Apollo-Soyuz test project, Viking, the Mariner Jupiter-Saturn mission, and many applications and aeronautics projects. NASA will proceed with development of a new front fan for reducing the engine noise generated by jet

aircraft.

The actions announced are being taken in the context of NASA's planning for FY 1974. Details of the revised programs and spending plans for FY 1973 and FY 1974 will be submitted to the Congress later this month. Announced actions were taken in advance of that time in order to save the maximum amount of money in this fiscal year.

The following is a list of major actions being taken by NASA:

In manned space flight, the manpower buildup on the space shuttle will be slowed down, with some resulting delay in the shuttle's first orbital flight. In space science, work on the high energy astronomy observatory (HEAO) project is being suspended for the time being. In space applications, NASA will phase out of its work on communi-

cations satellites. In research and technology, work on nuclear propulsion will be discontinued and work on nuclear power will be sharply curtailed. The Plum Brook Station will be closed. In aeronautics, an experimental quiet propulsive lift short takeoff and landing (QUESTOL) research aircraft will be cancelled. However, quiet propulsive lift technology will continue to be developed.

Here are some of the reasons for making these specific reductions:

The space shuttle is the key to the U.S. future in space, and its development will proceed. However, at the overall slowed pace of the U.S. space program, shuttle development will also be slowed somewhat so that it will not require an inordinate share of available resources.

HEAO is designed to explore the unknown through

Five plans

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NASA Lewis News articles explaining the end of the nuclear propulsion programs and employee cutbacks. (Lewis News, Vol. 10, No. 1)

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to produce ten years from now?”⁷³ He believed the nation was losing its commitment to science and its technological future. With that, the former reactor employee turned from the cameras and began to look for a new job.

Bruce Lundin made a promise to everyone during his shutdown announcement. He said, “We’re going to be completely dedicated to finding every one of you that wants a job, a good job someplace.” He said that he would begin this process by contacting NASA administrator Thomas Paine, Harry Finger, and other friends of his at nuclear agencies to tell them that there was a large group of individuals with nuclear experience that were looking for employment. To assist this process, NASA established an outplacement service in Cleveland. Lundin felt confident enough to say that “There will be interest in a lot of places of making use of your skills and experience.”⁷⁴ Six days after the shutdown speech he sent out a memo to employees, letting them know that he already had several interested organizations asking him about the people out of work.⁷⁵ But not everyone would find employment. Lundin said that while these were “some of the very best people in their fields in the country,” the harsh reality was that “we simply do not have the positions available” for all of them.⁷⁶

Finding jobs for nuclear engineers was especially difficult in the early 1970s because Plum Brook was not the only nuclear facility that was in the process of shutting down. Many other reactors and nuclear programs were also forced to close nationwide. The NERVA program had been terminated the same day as the Plum Brook reactor. The Space Nuclear Propulsion Office would close in June 1973. The Brookhaven Graphite Research Reactor closed in 1969, the Materials Test Reactor in 1970, and a Los Alamos reactor shut down in 1974. Fears swept throughout NASA that other high-profile programs would be cut.⁷⁷ The AEC’s influence was also in decline. After a 1971 Supreme Court ruling regarding the AEC’s licensing procedures, the commission was forced to streamline its organization and operations. Critics claimed that it was improper for the agency to regulate the very same reactors that it managed. The AEC, which was founded in August 1946, officially suspended operations in October 1974 when President Ford signed the Energy

⁷³ Interview of unknown former reactor employee, “NASA and Plum Brook Footage, 1961–1973,” video clip from John Carroll University Media Archives.

⁷⁴ Bruce Lundin shutdown speech, 5 January 1973, Glenn Research Center Archives.

⁷⁵ Bruce Lundin to employees, 11 January 1973, Box 105, Folder 10, Plum Brook Archives.

⁷⁶ Bruce Lundin quoted in “NASA Creates Office to Aid Lost Workers,” *The Cleveland Press* (19 January 1973), C2, Box 105, Folder 10, Plum Brook Archives.

⁷⁷ “Life on a Far-Off Moon?” *Time* (22 January 1973): 76.

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Reorganization Act. The Act placed the AEC's research and development functions under the Energy Research Development Administration and its licensing functions under the newly formed Nuclear Regulatory Commission.

Each month the journal *Nuclear News* published a list of reactor jobs available in the industry. It also published a list of unemployed nuclear professionals who were seeking employment. The journal was about to become flooded with resumes. On 30 June 1973 (the last day before NASA terminated the Plum Brook employees) 2,720 individuals from other nuclear institutions throughout the United States also lost their jobs. These included 700 at Oak Ridge National Laboratory, 700 at Sandia Laboratory, 275 at Lawrence Livermore Laboratory, 250 at Argonne National Laboratory, 225 at Brookhaven National Laboratory, 210 at Lawrence Berkeley Laboratory, 140 at the Stanford Linear Accelerator Center, 120 at Atomics International, and 100 at Hanford Engineering Development Laboratory.⁷⁸ This was the reality of the job market that Plum Brook employees faced as they began looking for future employment in a nuclear industry that was being cut back virtually everywhere.

The hunt for a new job was different for each employee. Some sent out a few resumes, while others contacted over 100 organizations looking for employment.⁷⁹ The NASA Outplacement Service Center assisted with the transition.⁸⁰ It provided special training sessions to teach employees the most effective ways to write resumes and give them tips for how to present themselves at interviews. NASA modeled one event after a college job fair and brought in various nuclear industry representatives to interview large groups of people to determine if any of them might be candidates for a job at their organization.

Starr Truscott, Plum Brook administrator, became a central point of contact between the former reactor employees and other nuclear facilities. Although NASA liked to say that all of the former employees found work, this was not the case. Truscott said, "There was a story that went out for a while, which was . . . not true, that everybody found a position. There were people here that did not find a position. It tears people and it tears families apart; it's just a terrible thing. Terrible thing."⁸¹ Some had more financial incentive than others to find new work. Robert Defayette had just bought a new farm in Milan and had still not sold his old home in Sandusky. When he first learned the reactor was closing, he had a wife and five

⁷⁸ "Staff Reductions," *Nuclear News* (March 1973): 18.

⁷⁹ Interview with Earl Boitel by Mark D. Bowles, 25 September 2002.

⁸⁰ Edward A. Richley (Chief, Office of Operations Analysis and Planning), "Summary Status Report: Phase Out of Nuclear Program," 19 January 1973, Box 105, Folder 10, Plum Brook Archives.

⁸¹ Interview with Starr Truscott by Virginia P. Dawson and Jim Polaczynski, 22 August 2001.

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children; he had two mortgages, and it would be only six months before he would no longer have a paycheck.⁸² Some who could not find work in the nuclear industry eventually gave up. For example, one of the reactor engineers took over as manager of a small grocery store in Huron, Ohio.⁸³

Of the 200 or so Plum Brook reactor employees, the vast majority left NASA. About 20 were sent to Lewis Research Center. Some found jobs with organizations like the Atomic Energy Commission (which then became the Nuclear Regulatory Commission) or Los Alamos. Most believed that the effort NASA invested in relocating them was commendable. Jim Greer found work at the nearby Davis-Bessie Nuclear Power Plant. He said that NASA “helped me tremendously get my position. NASA just didn’t shut the key off and say bye, bye boys. They tried to take care of us. Very much so.”⁸⁴

Suspending Momentum by Mothballing

Halting nuclear momentum is not an easy process. Resisting the modern tendency to simply tear down buildings when they are no longer needed, the nuclear reactor stands as an anomaly. Reactors cannot simply be abandoned. They require careful preservation to ensure that none of their still radioactive components contaminate the water supply or escape into the surrounding air. Once the nuclear momentum began, NASA soon discovered the significant investment required to bring it to a complete stop. The only way to destroy a reactor is through a costly and difficult decommissioning process. NASA delayed this process for 25 years by instead opting for a “possess but do not operate” strategy. This meant “mothballing” the reactor or sealing it up in such a way that it could one day be put to use again. NASA called this a “standby condition,” which it defined as “that condition from which any major facility of the station may be returned to full capacity operation with a reasonable effort and in a reasonable time without a major expenditure of resources for repair or rehabilitation.”⁸⁵

Though this plan gave some reactor employees hope that the reactor would once again need their services, others roundly criticized the decision. Alan “Hap” John-

⁸² Interview with Robert Defayette by Virginia Dawson, 21 September 2002.

⁸³ Interview with Starr Truscott by Virginia Dawson, 21 September 2002.

⁸⁴ Interview with Jim Greer by Mark D. Bowles, 26 September 2002.

⁸⁵ Letter from Roy P. Jackson (Associate Administrator for Aeronautics and Space Technology) to Bruce Lundin and George Low, 5 February 1973, Box 105, Folder 10, Plum Brook Archives.

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on, former Plum Brook reactor manager, said that “The idea of somebody mothballing a reactor is stupid.”⁸⁶ Once a reactor was shut down its life was essentially over. The goal to begin operating an old reactor would have been nearly impossible to achieve because it would have to pass increasingly stringent nuclear regulations. By that point it would have been more cost effective and safer to just build a new reactor.

Nevertheless, the mothball and standby orders remained in place. A. Bert Davis took over as reactor chief and was responsible for negotiating the new standby license with the AEC. NASA told Davis to leave the reactor in a condition in which it was capable of being restarted, despite the fact that most everyone involved knew it never would be returned to operation. Davis was responsible for informing the AEC director that “NASA management has decided to place the Plum Brook Reactor in a standby condition.”⁸⁷ This counterintuitive demand was something that Davis strongly objected to. Like Johnson, he was aware of the near impossibility of starting up a reactor again. Davis also knew no reactor had ever been mothballed before. He said, “It was the first time I knew of when somebody was really taking an operating test reactor and putting it into a standby condition.”⁸⁸ While a potential restart contributed to the care taken during the initial shutdown, it was not the only reason the engineers took precautions. Earl Boitel said that he was concerned first and foremost with the legacy of the reactor. If things were not shut down properly and if the environment or community were endangered, then that legacy would be forever tarnished.⁸⁹

Everyone knew much work had to be done and that emotions had to be put aside. The reactor staff was given six months to shut down their facility. This would include removing the fuel, eliminating the waste, configuring all of the equipment to sit idle, writing procedures to monitor the reactor, and planning for routine inspections of the facility. This was a very tight schedule, and the employees knew that they would have to work as diligently to shut down the reactor as they had in preparing to take it critical for the first time. They also battled a morale issue. When they were taking the reactor critical in 1961 there was the added excitement that they were building a new and powerful scientific instrument. Now that same energy had to be directed toward a much less inspiring goal—closing the reactor. Further-

⁸⁶ Interview with Alan “Hap” Johnson by Mark D. Bowles, 20 March 2002.

⁸⁷ Bert Davis to John F. O’Leary (director AEC), 22 January 1973, Box 10, Folder 18, Plum Brook Archives.

⁸⁸ Interview with A. Bert Davis by Mark D. Bowles, 27 February 2002.

⁸⁹ Interview with Earl Boitel by Mark D. Bowles, 22 January 2002.

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more, this all had to take place while the employees were looking for new jobs.

Reactor officials held extensive meetings to establish all of the necessary procedures required to mothball the reactor. Then they set up additional procedures to define how to maintain the facility in this condition and make certain that no radioactive contamination would leak out into the community. Teams were set up to accomplish these tasks.⁹⁰ The basic facility and shutdown team was responsible for closing down the entire reactor system. The hot laboratory team cleaned out all of the cells and secured all of the manipulator arms. A fuel team oversaw shipping of the new and used fuel off site to the Savannah River reprocessing plant.⁹¹ A mock-up team was assigned to close down the research reactor. An experiment team ensured that the experiments were mothballed. A data team was responsible for sending remaining experimental results to sponsors. Finally, a safeguards team helped to guarantee that all of the proper health and safety precautions were taken for the employees engaged in the clean-up activities, as well as the surrounding community.

For six months the staff worked to mothball the reactor. They not only fought against the deadline to finish their work; their numbers were constantly dwindling as people found new jobs. But the work continued. Power lines and other wires were cut. Offices were closed. The library was shut down. The water fountains, bathrooms, and washrooms were all drained. The hot laboratories were used to process and dispose of the highly contaminated waste. Most all of the pipes had to be severed, flanged, and sealed.⁹² This was difficult and dirty work that often involved direct contact with radiation. Many of the reactor engineers and technicians had already received their maximum allowable radiation exposure doses, and so they were not eligible to do much of the decontamination work. Volunteers were taken from the office staff who had not been exposed to radiation previously, and they worked to clean out the hot laboratories.⁹³

There was also a large amount of equipment that could be recycled. Robert Defayette thought that it should be donated to the local Firelands Community College. So Defayette called the head of the chemistry department and invited him to drive his pickup truck out to the reactor. He was “like a kid in a candy shop,” moving from one lab to the next, identifying equipment that he could take for

⁹⁰ Interview with Robert Didelot by Mark D. Bowles, 25 September 2002.

⁹¹ “Standby Procedure Completion Report,” Box 10, Folder 6, Plum Brook Archives.

⁹² Interview with William Stokes by Mark D. Bowles, 23 January 2002.

⁹³ Interview with Don Young by Mark D. Bowles, 18 July 2002.

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ree.⁹⁴ He loaded up his truck several times. Though Defayette never had authorization to donate the equipment, he thought that since the government had spent taxpayer money on it, the materials should go to an educational organization. However, much of the equipment could not be salvaged, and it remained locked inside the reactor. The official order was still to possess the building but not operate it. Even though everyone believed the facility would never become operational again, all of the basic technological systems were left in place.

Despite the uncertainty about the future, there were still moments of levity. Don Young recalled one day when he was in his hip boots with double protective clothing and an air respirator, mucking through the radioactive sludge at the bottom of one of the hot retention tanks. He was trying to squeegee the sludge into one of the pumps when he looked up to the top of the tank and saw his health safety supervisor leaning over the railing. All of a sudden a large wad of money fell out of his shirt pocket and landed in the middle of the radioactive waste. Young walked over to the money, picked it up, and climbed up the ladder to give it to him. Of course it was highly contaminated by that time, and as Young recalled, his boss “spent the rest of the day *laundering* his money.”⁹⁵ To clean the contamination off of it, he washed it with soap and water and a decontamination solution.

During spring 1973 the reactor area was fenced off and locked, and emergency telephone, water, and electrical systems were retained. A. Bert Davis remained in close contact with the AEC to ensure that the process was performed safely.⁹⁶ The nuclear fuel and wastes were removed, and the still-radioactive equipment was placed into the hot laboratories, containment vessel, and canals. The rest of the facility was decontaminated and became subject to licensing. The “possess but do not operate” license required annual renewals, quarterly radiological testing, and regular inspections of alarms and security tools. It also required a manned communication center, an administrative staff, and the continuation of regular records and reports—enough to keep a skeleton crew at work.

In June, right before the mothballing was completed, Plum Brook set up a reactor standby office staffed by two people.⁹⁷ Robert Didelot took over as first reactor manager, and Tom Junod oversaw all of the safety requirements. Teledyne won a contract to ensure that the reactor was preserved safely. It prepared surveys and

⁹⁴ Interview with Robert Defayette by Virginia Dawson, 21 September 2002.

⁹⁵ Interview with Don Young by Mark D. Bowles, 18 July 2002.

⁹⁶ Bert Davis to A. Burger (AEC), 11 May 1973, summary of teleconference, Box 10, Folder 18, Plum Brook Archives.

⁹⁷ Interview with Robert Didelot by Mark D. Bowles, 22 January 2002.

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NASA and the Energy Research Development Administration installed this large 100-kilowatt wind turbine for alternative energy research at Plum Brook (28 September 1976). (NASA C-1976-3906)

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reports for the NRC after a certain time period had elapsed or after a particularly damaging storm to determine if any radioactive waste was getting into the local water supply. Water and air samples were taken regularly, as Don Young recalled, to make sure we did not have any “radioactive contamination creeping out any place.”⁹⁸

Health physicists established contamination and radiation standards and defined four radiation zones at the facility. This included the magenta zone (direct radiation levels of 100 mrad/hr), the magenta-yellow zone (direct radiation levels of 2.5 to 100 mrad/hr), the white zone (less than 0.5 to 2.5 mrad/hr), and unrestricted zones (less than 0.05 mrad/hr). The white zone was for areas inside the Plum Brook fence, and unrestricted zones were for radiation outside the fence.⁹⁹

Routine maintenance was performed for the next 25 years to ensure that the buildings would not crumble. The temperature inside was kept above 45°F with an old boiler system in the winter to ensure that the drains would not freeze up. This cold temperature also helped to preserve all of the equipment that still remained inside. The reactor standby office was responsible for the maintenance on the boiler and the sump pumps. An alarm system was installed in the building and hooked up to the Plum Brook communication center so that it could be monitored around the clock to prevent trespassers from entering.

The AEC, and later the NRC, assisted NASA in setting up administrative controls. This included procedures to maintain the “safe storage” condition, internal audits, the hiring of a radiation safety officer, and the establishment of an executive safety board and a Plum Brook safety committee. A reactor manager ensured that the safe storage of the mothballed reactor remained as risk free as possible. A Plum Brook management office was to authorize all plant security, inspection, health physics, and maintenance functions. Annual reports were to be filed with the NRC, as were communications about any “reportable occurrence” that deviated from the norm. The NRC required a telephone call, telegraph, mailgram, or facsimile transmission no later than 24 hours after any unplanned occurrence at the reactor. NASA kept detailed records on the reactor, including radiological surveys and equipment maintenance records, and the NRC retained the authority to call for special reports from time to time.¹⁰⁰

Plum Brook itself became a desolate place. Ironically, though the reactor lost

⁹⁸ Interview with Don Young by Mark D. Bowles, 27 September 2002.

⁹⁹ “Plum Brook Reactor Facility End Condition Statement: Contamination and Radiation Standards,” Folder 6, Box 10, Plum Brook Archives.

¹⁰⁰ “NASA Amendment to Facility License, 26 July 1985, Box 10, Folder 12, Plum Brook Archives.

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out on the opportunity to engage in environmental research, a new environmental project began at Plum Brook. Because of the energy crisis the government began to take a close look at alternative forms of energy. Though Plum Brook lost out on its bid for a \$35 million federal solar research institute from the Energy Research and Development Administration, the government did select it as a site for windmill research.¹⁰¹ The National Science Foundation provided \$200,000 for construction at Plum Brook of a 100-kilowatt windmill, with 2 massive 62-foot propeller blades on a 125-foot tower. This became the second largest windmill ever constructed in the United States, and its total cost was \$1.2 million.¹⁰² Joe Savino, who had worked at the Plum Brook reactor in the process systems section, headed the team to build the windmill. He predicted that based on its success, the country would soon see “hundreds of thousands of windmills generating electricity across the U.S.”¹⁰³ He believed that this commitment would be a lasting national priority because the windmill could reduce national dependence upon coal and oil. Two additional windmills were planned for Plum Brook. According to a *New York Times* article, the engineers who worked on it constantly operated under the shadow of budget cuts and the potential for termination of the program.¹⁰⁴ Their concerns were justified. When the energy crisis of the 1970s ended, so too did the government commitment to alternative forms of energy, like the Plum Brook windmill experiments.

So how would NASA finally halt the nuclear momentum it had begun decades earlier? Mothballing reactors and preserving them in a “possess but do not operate mode” merely delayed the inevitable. NASA finally decided to allocate the funds for the decommissioning project in 1998, and began the final steps, after a quarter-century delay, to actually bring its nuclear momentum to a halt.

¹⁰¹ “Ohio to Seek Solar Institute: NASA’s Plum Brook Facility Could be Considered as Site,” *Sandusky Register* (10 December 1975); Harry J. Lorber, “Plum Brook Being Considered as Site,” *Sandusky Register* (11 December 1975); “Plum Brook Prime Site for Research Institute,” *Sandusky Register* (11 December 1975).

¹⁰² “Plum Brook Station Research Facilities,” 10 January 1986, Box 106, Folder 1, Plum Brook Archives.

¹⁰³ David Brand, “It’s an Ill Wind, Etc.; Energy Crisis May be Good for Windmills,” *Wall Street Journal* (11 January 1974): 1.

¹⁰⁴ William Diem, “NASA Has Trouble with its Big Windmill,” *New York Times* (27 June 1976): 89.

Restoring the Garden

In 1844 Nathaniel Hawthorne wrote an essay titled “Sleepy Hollow” while sitting in the Concord, Massachusetts, woods. As he observed the early morning light he described an idyllic, almost utopian scene. With his elegant prose Hawthorne described the glimmering sunshine breaking through forest shadows, the natural sounds of the birds and rustling leaves, and even the blending of manmade noises like the tinkle of a cow bell and farmers with their scythes. Then, in an instant, something intruded upon Hawthorne’s Eden-like morning. He wrote, “But, hark! there is the whistle of the locomotive—the long shriek, harsh, above all other harshness, for the space of a mile cannot mollify it into harmony.” The industrial machine was in the garden—disharmonious—and contradicting the symbiotic agrarian existence between man the farmer and Mother Nature. The locomotive’s whistle cut through that stillness, just as the railroad’s track cut through the farmers’ land, symbolizing the coming of industrialization to the American pasture.¹

In the United States the tension between industrialism and agrarianism was most dramatically played out during World War II. As described in the first chapter of this book, in the early 1940s the government took land from farmers to support the needs of the coming war. Prior to World War II, some referred to the Plum Brook farming region as “one of the garden spots of America.”² Generations of farmers had cultivated their farms into a symbiotic relationship with the natural world surrounding them. Yet, much like the train in Hawthorne’s story, the government’s industrial machine invaded this Plum Brook garden and transformed these pastures—most believed, forever. During World War II the Army subjected the land to numerous environmental hazards associated with explosives production. A decade later, with much of this waste still contaminating the Earth, the government rede-

¹ Leo Marx, *The Machine in the Garden: Technology and the Pastoral Ideal in America* (Oxford: Oxford University Press, 1964), p. 5.

² Congressman Weichel, quoted in “Colorful Ceremony Marks Presentation of Honors to Plum Brook Employees,” *Sandusky Star Journal* (1 May 1943).

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veloped the area as a site for Plum Brook Station, which included the construction of a nuclear test reactor. After over a decade of reactor operation it sat for the next quarter-century in quiet standby. The mothballed reactor was costly and completely nonproductive, and it remained a potential environmental threat. When would NASA come to terms with its environmental responsibility? And, once it did, would it be able to restore the land to its agrarian heritage, in effect taking the industrial machine out of the garden?

According to some observers, the agency had a long way to go to rectify its own environmental record. In 1991 one of its most well-known advocates spoke out against its past transgressions. John Glenn, former astronaut and United States senator from Ohio, said that the “world’s best space program,” has been responsible for “serious pollution problems” on Earth.³ He targeted several NASA sites as contributing to the problem, including Lewis Research Center (now Glenn Research Center) and Plum Brook Station. At Lewis he said that the “lack of management attention . . . caused costly environmental damage.” This included mercury contamination, 42 underground leaking storage tanks at Plum Brook, and soil and groundwater damaged by the storage of batteries, drums, and PCB transformers in a landfill. NASA slowly learned its lesson. Throughout the 1990s it became more conscious of its environmental shortcomings and began allocating funds to correct these problems. One such concern was the two nuclear reactors sitting idle at Plum Brook.

Since 1973 NASA had flirted with the idea of “decommissioning” or tearing down this facility several times. In 1977 the government asked Teledyne to recommend a future course of action regarding the reactor.⁴ One option was to keep it in a standby condition and try to reopen it at a later date. Another option was to keep it mothballed until the money was available to properly decommission it. A final, preferred plan was to completely decommission it and remove all traces of radiation from the site. Though this was the favored option, NASA considered the \$1,200,000 expense too much to incorporate into its budget.⁵ NASA decided to maintain the reactor in standby mode. But this was only postponing the inevitable. The reactor would have to be decommissioned at some point, and the costs of keeping the facility mothballed were rising dramatically. In 1979 yearly maintenance alone was \$230,000. Meanwhile, a new 1979 analysis estimated that decommissioning the

³ John Glenn, quoted in Keith C. Epstein, *The Plain Dealer* (15 May 1991).

⁴ Interview with Jack Ross by Robert Arrighi, 27 September 2002.

⁵ John E. Ross (Teledyne Isotopes) to R. Koch, 3 September 1976, Box 106, Folder 3, Plum Brook Archives.

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reactor facility would require 6 years and \$14,744,000. Again, NASA declined to decommission it.⁶ In 1984 the government revisited these decommissioning plans. A seven-member Teledyne team and former reactor employees explored the problem. After 18 months of sampling, monitoring, analyzing the site, reviewing the drawings, and measuring the amount of radiation, the team completed its calculations down to the actual number of truckloads required to haul away all of the material. One year later they estimated the cost at \$35 million.⁷ Once again NASA declined to decommission, believing the costs were too prohibitive.

By the late 1990s it cost the government \$1.4 million per year for its environmental monitoring and round-the-clock security just to keep the reactor in its mothballed status.⁸ With dismantling costs increasing at an average of 6% per year, and radioactive waste disposal costs increasing by 27% per year, NASA decided that it finally had to do something about this growing problem. In 1998 the agency established a plan that would require a decade of work to safely dispose of Plum Brook's radioactive remains. It had cost \$15 million to build the reactor, and it was going to cost the government an estimated \$150 to \$160 million to tear it down.⁹ This was roughly the cost of a small unmanned NASA space mission (the Mars Climate Observer had cost \$125 million), or 1% of NASA's annual \$13.7 billion budget.¹⁰ Eventually, the cost of decommissioning Plum Brook will be far more than what the government spent to construct and operate it. The efforts to mothball and decommission the site will last more than three times longer than the period in which the government actually used the reactor for active scientific research.¹¹

⁶ "Decommissioning Plan for the Plum Brook Reactor Facility," Revision 1, March 2001, NASA Decommissioning Archives; "Dismantling Plan Plum Brook Reactor Dismantling," NASA Lewis Research Center, Cleveland, Ohio Docket No. 50-30, 18 February 1980.

⁷ Interview with Hank Pfanner by Mark D. Bowles, 26 September 2002; Interview with Jack Ross by Robert Arrighi, 27 September 2002.

⁸ Ulysses Torassa, "Delay by NASA Inflates Cost of Dismantling Idle Reactors," *The Plain Dealer* (28 February 1998): 1A.

⁹ Keith Peacock, email to author, 26 April 2004; Karen Schaefer, transcript of "NASA Plum Brook – Part 2," aired 8 October 2002, found at <http://www.wcpn.org/news/2002/10%2D12/1008plum%2Dbrook%2D2.html>.

¹⁰ John Mangels, "NASA to Dismantle Two Ohio Reactor Devices at Plum Brook," *The Plain Dealer* (30 October 1999): 11B.

¹¹ While these figures seem high, the cost of cleanup for the Plum Brook reactor is dwarfed by the legacy of the nuclear arms race. Analyst estimates of the costs of safely decontaminating nuclear bomb sites have varied from \$200 billion to nearly \$1 trillion. But there is a similarity between the smaller environmental issues of dealing with Plum Brook's nuclear radioactive legacy and the larger problem that the United States continues to address. Stewart Udall, secretary of the interior from 1960 to 1968,

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Other institutions that decommissioned research and testing reactors did not wait so long. In the 1970s the Ames Laboratory operated a 5-megawatt research reactor that was owned by the Department of Energy (DOE). After 12 years of research the DOE no longer had a use for it and debated whether to mothball or decommission it. Unlike NASA, Ames officials decided to deal with the problem immediately by safely decommissioning the reactor at a cost of \$4.3 million. The Ames researchers called this decision one of the most important lessons they had learned from the project. They said, "The decision to proceed with decommissioning immediately after shutdown seems to have been correct." The speed of their decision was important because it enabled them to rely on the talents of workers who were employed at the reactor and knew best how to decommission it without having to hire expensive contractors. In 1983 the Ames officials concluded, "If the work had been postponed, the total cost would have been considerably greater."¹² NASA continually chose the path of postponement.

Decommissioning was not only a costly process; it was also an environmentally delicate one. As the Nuclear Regulatory Commission stated in 1978, "The environmental impacts of decommission may be high. Special attention will be needed to minimize these impacts."¹³ NASA had a very difficult task in front of it, but its goal was nothing short of attempting to turn back the environmental clock in a region that still suffered not only from a contaminated reactor but also from pollution left over from the ordnance days of World War II. NASA sought a return of Plum Brook's agrarian state by making the health of the land itself the criterion for decommissioning success. Bill Wessell, the director of safety and assurance technologies, claimed that NASA wanted to be a "good steward" and that the job would not be completed until Plum Brook was the "same as any other land in Northwest Ohio."¹⁴ One member of the Decommissioning Community Workgroup stated, "NASA's

said "the cleanup will cost more than the weapons themselves and will last for decades." Likewise, the cost of decommissioning Plum Brook will be far more than what the government spent to construct and operate it. Stewart Udall, foreword to Michael D'Antonio, *Atomic Harvest: Hanford and the Lethal Toll of America's Nuclear Arsenal* (New York: Crown Publishers, 1993), p. xi.

¹² B. W. Link and R. L. Miller, "Evaluation of Nuclear Facility Decommissioning Projects: Summary Report Ames Laboratory Research Reactor," May 1983, Box 271, Folder 1, Plum Brook Archives.

¹³ Nuclear Regulatory Commission, "Plan for Reevaluation of NRC Policy on Decommissioning of Nuclear Facilities," April 1978, Box 271, Folder 4, Plum Brook Archives.

¹⁴ Bill Wessel, Minutes of First Meeting, Plum Brook Reactor Decommissioning," 3 November 1999, NASA Decommissioning Archives. The decommissioning archives can be found online at www.grc.nasa.gov/www/pbrf. A Community Information Bank has also been established at the Bowling Green State University's Firelands Library. Hereafter these sites are referred to as the NASA Decommissioning Archives.

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The reactor as it appeared in 2003 before the major decommissioning demolition began. (NASA C2003_00870)

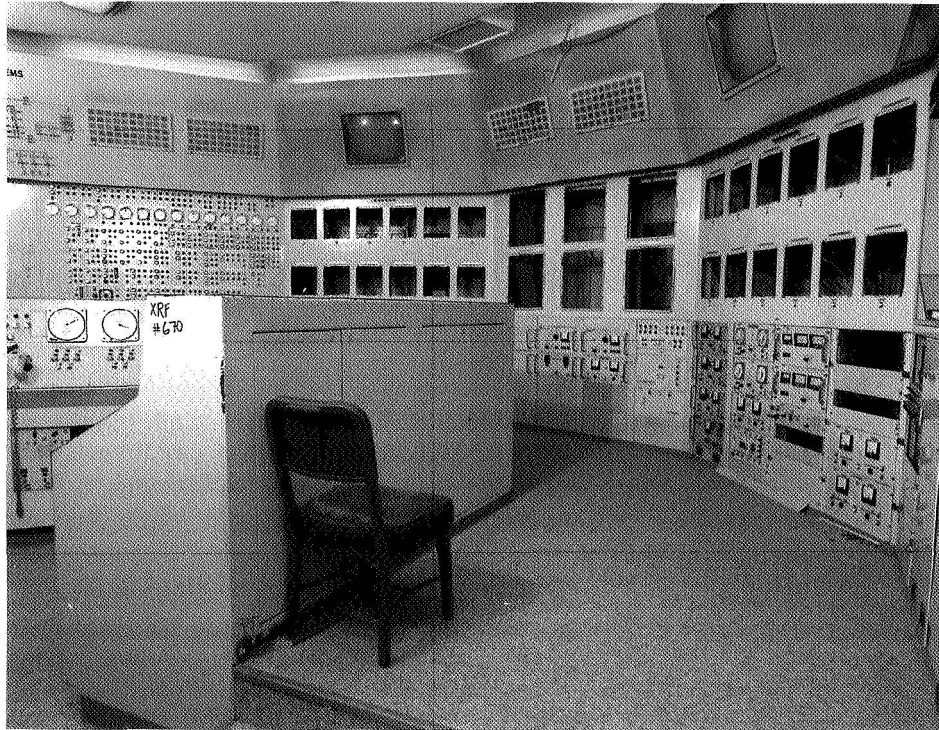
approach is to make it as though someone . . . in the future, could farm. You could plant tomatoes in the soil underneath what is now the reactor, eat the tomatoes and have no more radiation than you would if you would have planted your tomatoes in any other Perkins Township garden.”¹⁵ NASA called its plans the “resident farmer scenario” as the farmer and the garden became the measure of success for its decommissioning process. In terms that Nathaniel Hawthorne might approve of, NASA’s goal was to return the “lap of bounteous nature” and “mollify it into harmony” once again by removing the reactor from the garden.

The Decommissioning Plan

The impetus for NASA’s decommissioning plan came from the Nuclear Regulatory Commission (NRC) in 1998. In evaluating the Plum Brook reactors, it found that the radiation still at the site, particularly the cobalt 60, had decayed dramatically. This would make disposal easier now than it would have been in the past. But

¹⁵ Interview with John Blakeman by Virginia Dawson, 26 September 2002.

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The control room in 2001 with holes in the walls showing where instrumentation had been “cannibalized” for use elsewhere. (NASA C-2001-01221)

most important, the costs of maintaining the facility continued to increase each year. Since the NRC knew that it would never again be used as a research facility, it denied its “possess but do not operate” license, and as a result NASA had to develop a decommissioning plan. This was also necessary for safety reasons because eventually the walls would cave in and there would then be a danger of spreading the existing radioactivity.¹⁶ The decommissioning effort that had been deferred for 25 years was finally going to become a reality. NASA approved the funds to dismantle the facility, with a projected completion date of 2007. In December 1999 NASA submitted a decommissioning plan to the NRC.¹⁷ This plan included the main reac-

¹⁶ “Minutes of Community Workgroup Meeting #2, Plum Brook Reactor Decommissioning,” 7 December 1999, NASA Decommissioning Archives.

¹⁷ Cabinet 12-E: Decommissioning Team Management Policies, unprocessed records at NASA’s Plum Brook Station.

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tor (license TR-3) and the Mock-Up Reactor (license R-93).¹⁸

The NRC regulates and oversees the decommissioning process until the point at which it actually terminates the reactor license. The central mission of the NRC is to protect the public and the environment, safeguard the nuclear materials through long-term storage, and maintain the interests of national security.¹⁹ The government established the current decommissioning regulations on 21 July 1997, when the NRC published the Radiological Criteria for License Termination. This rule and its associated regulations replaced similar guidelines written in 1988 and spelled out all of the main criteria that a reactor licensee had to satisfy before the license itself could be terminated. The effort to decommission a reactor also has to comply with EPA standards and satisfy its regulations, such as the Clean Water Act, Clean Air Act, and the National Pollutant Discharge Elimination System. As of May 2005 the NRC was responsible for the regulation of 36 operating research and test reactors. Since 1958 the NRC and its predecessor organization, the AEC, had decommissioned 73 research and test reactors. The NRC is now in the process of decommissioning 13 additional facilities. These include:

- CBS Corporation, Waltz Mill, Pennsylvania
- General Atomics, San Diego, California (two reactors)
- Georgia Institute of Technology, Atlanta, Georgia
- Iowa State University, Ames, Iowa
- Manhattan College, Riverdale, New York
- NASA's Plum Brook Station, Sandusky, Ohio (two reactors)
- Sexton Nuclear Experimental Corporation, Sexton, Pennsylvania (one power reactor)
- University of Illinois, Urbana, Illinois
- University of Washington, Seattle, Washington
- University of Virginia, Charlottesville, Virginia (two reactors)²⁰

¹⁸ Donald J. Campbell to U.S. Nuclear Regulatory Commission, 20 December 1999, NASA Decommissioning Archives.

¹⁹ John L. Minns and Michael T. Masnik, "Staff Responses to Frequently Asked Questions Concerning Decommissioning of Nuclear Power Reactors," Nuclear Regulatory Commission, June 2000, Box 8, Folder 6, Plum Brook Archives.

²⁰ "Fact Sheet on Research and Test Reactors," U.S. Nuclear Regulatory Commission, found at www.nrc.gov/reading-rm/doc-collections/fact-sheets/research-reactors.html. Accessed 11 May 2005.

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The Plum Brook decommissioning plan detailed an extensive process through which, piece by piece, the entire building would be dismantled. Engineers planned to transform the 117-acre site into a barren field, with an assurance to environmentalists that the ground would be safe enough for a family to actually live on, grow crops on, drink water from, and raise livestock on. Great care would be taken to decontaminate everything that came into contact with radiation before it was transported to landfills in Utah and South Carolina. Keith Peacock, senior project engineer, said, "It's not just going in with a wrecking ball, it's a little more surgical in nature."²¹ The plan included the following activities:²²

- Removing asbestos and lead paint
- Removing reactor internals and tank
- Removing radioactive material in the hot dry storage area
- Removing all equipment and components in the buildings
- Removing contaminated portions of concrete from the shielding and buildings
- Removing all piping in the buildings and embedded in the concrete
- Removing all contaminated soil and backfilling the holes
- Demolishing all above-grade decontaminated buildings
- Backfilling the below-grade portions of the buildings

The cornerstone of the plan was a federal partnership between NASA, the U.S. Army Corps of Engineers (USACE), and Argonne National Laboratories (a section of the U.S. Department of Energy). USACE was an important partner because it had extensive experience in managing large clean-up and construction projects. It also served as an important link to expertise in the private sector. USACE hired Montgomery Watson Harza, from Pasadena, California, as the prime contractor for the project. Duke Engineering Services, from Charlotte, North Carolina, and MOTA Corporation, from Columbia, South Carolina, were also chosen as subcontractors to assist with the engineering challenges.²³

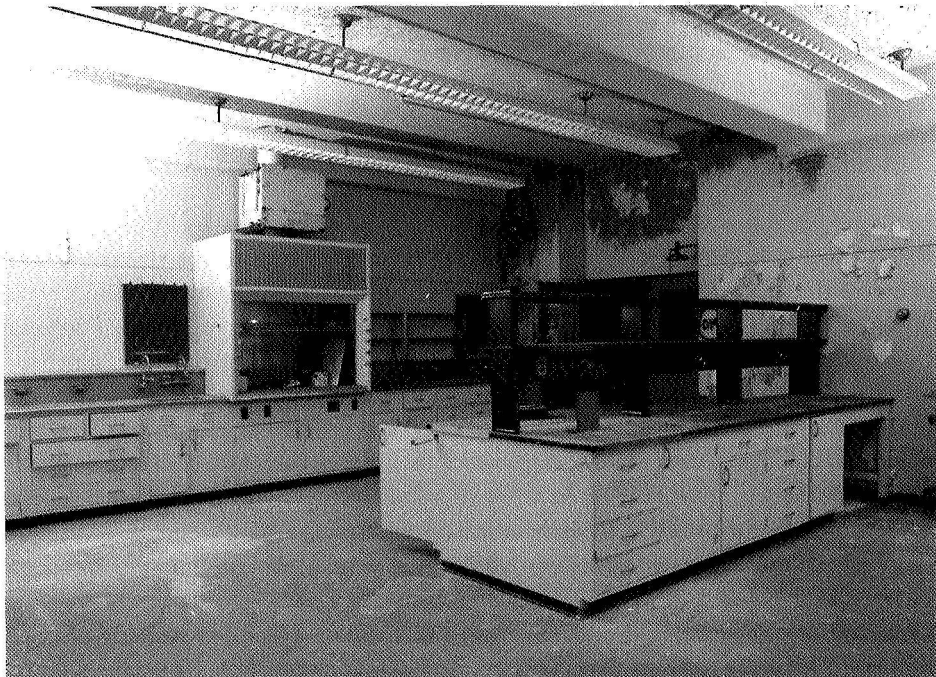
Despite the importance of the team, NASA was the organization that was ulti-

²¹ Keith Peacock, quoted in John C. Kuehner, "NASA Reactors Take Final Voyage," *The Plain Dealer* (27 June 2002): B10.

²² "Decommissioning Plan for the Plum Brook Reactor Facility," Revision 1, March 2001, NASA Decommissioning Archives.

²³ Sally Herrington, "U.S. Nuclear Regulatory Commission Approves NASA Decommissioning Plan," 1 April 2002, NASA Decommissioning Archives.

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A former chemistry lab after 40 years of disuse. (NASA C-2001-1173)

mately responsible for the decommissioning process. Tim Polich left the NRC to become NASA's decommissioning manager in 1999. He and his team became responsible for overseeing the entire process, which is sometimes conceptualized as "construction in reverse." Unlike conventional building from the ground up, Polich and his team literally proceed from the roof to the ground. This includes removing and safely disposing of all radioactive materials, decontaminating and demolishing all of the buildings at the site, and finally backfilling the entire area with clean fill dirt. On 21 March 2002 the NRC officially approved the decommissioning plan. NASA-Glenn Research Center director Donald J. Campbell said that the NRC approval of NASA's approach "reflects confidence in the capabilities and experience of our project team The pre-decommissioning activities to date were just the beginning; now the real work begins."²⁴

One other important part of the decommissioning plan was to preserve any remaining materials that might have historical significance. Kevin Coleman from

²⁴ Donald Campbell, in "U.S. Nuclear Regulatory Commission Approves NASA Decommissioning Plan," 1 April 2002, NASA Decommissioning Archives.

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NASA-Glenn coordinated this work, but by the time the decommissioning started there were few artifacts that met the criteria for preservation. The NASA Procedures and Guidelines as defined in *Identification and Disposition of NASA Artifacts* state that the organization is to preserve all artifacts that are “unique objects that document the history of the science and technology of aeronautics and astronautics.” Although the Plum Brook reactor was the state of the art for its time, over the years the technology that it housed was of little lasting significance. In 2001 a historic preservation firm reported that its principal recommendation was to save a scale model of the reactor facility that had been on display at the Plum Brook cafeteria. Other small items like the “reactor on” sign could also be preserved by the National Air and Space Museum.²⁵ The only large artifacts thought worthy of preservation were portions of the control room that had not already been cannibalized.

The plan for actually taking the reactor apart was called “segmentation,” and this process was broken down into seven phases. Its goal was to reduce radioactive materials to smaller segments for ease in safe packaging, transport, and disposal. The first phase (Phase 0) consisted of equipment setup and testing. Cranes were installed and tested for safety, and their operators were certified and trained. The old electrical system was removed and safety lighting was installed. A new ventilation system was put in place to provide workers with clean air. Tools and supplies were distributed throughout the reactor and stored where they would most likely be needed. Waste contracts with disposal companies were signed, and the permits were finalized. The Mock-Up Reactor was itself used for training exercises to help the workers better understand the segmentation process.²⁶

The decommissioning team called in former Plum Brook reactor engineers to assist with delicate operations like segmentation. This was considered the “most critical part of the Decommissioning Project.”²⁷ Dean Sheibley (safety committee chairperson), Jack Crooks (process systems section), and Jack Ross (health physics manager) assembled six former employees to meet with the decommissioning team. The discussions surrounded a procedure for conducting a nitrogen purge test that would help determine the tritium release from irradiated beryllium plates. They also examined the items contained in the hot dry storage and the hot cells, which included used experimental apparatus. Sheibley said that the decommissioning team was a “good group of people with excellent decommissioning experience.

²⁵ Patrick W. O'Bannon, “Artifact Identification and Assessment: Plum Brook Reactor Facility, Sandusky, Ohio,” 16 April 2001, NASA Decommissioning Archives.

²⁶ “Equipment Set Up & Testing,” NASA Decommissioning Archives. “Mock-Up Reactor Put to Work One Final Time,” *Decommissioning News* (July 2003): 3.

²⁷ “Project Update,” *Decommissioning News* (October 2003): 1, NASA Decommissioning Archives.

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What we've done is expedited their knowledge to the particulars of the Plum Brook Reactor Facility."²⁸

The next three phases (1, 1A, and 2) consisted of removing the horizontal beam tubes and the beryllium plates because these contained some of the highest amounts of radioactivity at the reactor. The horizontal beam tubes were where the experiments were placed when the reactor was operating. To reduce exposure, workers removed these tubes remotely while watching their progress through video terminals. First the tube was moved into quadrant D. Then an automatic band saw cut through the tube. A crane lifted the tube 25 feet into a shielded liner, and a stainless-steel plug was bolted into the hole that was left in the wall of the reactor. The beryllium plates were also heavily contaminated. They were initially used during operations to reflect neutrons back toward the reactor core. To remove these plates, workers again used video monitors to see inside the reactor, while they stood above the shrapnel shields. They then used remote tools to unbolt the plate from the core and a crane to lift the plates out and into a steel box that was shipped to the Barnwell Disposal Facility.²⁹

The final three phases (3, 4, and 5) will consist of the removal of the major elements of the reactor and the tank. Phase 3 will remove the reactor internals below the core region, leaving an empty reactor tank when completed. Phase 4 will dismantle and remove the vessel walls. This will be a process that some describe as similar to peeling an orange from the inside out, or in this case peeling away the concrete and metals that once made the reactor strong. Many of the disposal casks from this operation will go to Envirocare of Utah. Phase 5 will consist of clean-up and demobilization. This will complete a major decommissioning milestone and will have resulted in the removal of the most significant source of remaining radiation.³⁰

As of early 2004 the decommissioning team was in the midst of removing the reactor internals, which was part of Phase 3.³¹ Once segmentation is complete the team will dismantle the hot laboratories and demolish the remaining buildings. Though the team originally planned to finish all decommissioning work by 2007, the project will now likely continue beyond that deadline. Estimates are that when it is completed, 132,000 cubic feet of dry, low-level radioactive waste will have been

²⁸ "Decommissioning Team Goes to the Source: NASA Retirees 'Back on the Job,'" *Decommissioning News* (April 2003), 4, NASA Decommissioning Archives.

²⁹ "Reactor Internals Removal," NASA Decommissioning Archives.

³⁰ "The Reactor Vessel," NASA Decommissioning Archives.

³¹ "NASA Completes Productive Year of Decommissioning" (January 2004), 1, NASA Decommissioning Archives.

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One of the most dramatic moments of the decommissioning process was the demolition of the water tower. (NASA C-2004-744)

removed, along with 230,000 cubic feet of nonradioactive, solid industrial waste.

Despite all of the decommissioning team's efforts to keep local people informed about their work, the community has remained skeptical and concerned about what was often regarded as "mysterious" work beyond the NASA fences. Outreach efforts have been specifically designed to solve that mystery and let many of the residents see for the first time what existed behind the gates that had remained hidden from the community for so long.

Solving the Mystery Behind the Fence

NASA believed that building an open relationship with the local community was a main priority in the effort to decontaminate and demolish the reactor. Perkins Fire Chief Richard Ennis said that most of the community viewed Plum Brook as the "other side of the fence."³² It was an isolated place, hidden behind gates, fences, guards, and open land that spawned stories about "mysterious" loud noises, lights,

³² "Minutes of First Meeting," Plum Brook Reactor Decommissioning Community Workgroup, Firelands College, 3 November 1999, NASA Decommissioning Archives.

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and unexplained activities.³³ A community member said that everyone knew that UFOs had landed behind those fences. One of those stories appeared in a book on UFOs in 2001. *UFOs Are Here!* recounted the story of Reinhardt N. Ausmus from Sandusky, Ohio. At 6:45 p.m. on 30 January 1967, he and his wife observed a strange object hovering over Plum Brook. Ausmus, who was an aviator, claimed to have always been skeptical of this phenomenon, but witnessed this unexplained object for over four minutes.³⁴

Officials at Plum Brook were well aware of these stories. In 1998 Robert Kozar, the director of the facility, commented to a reporter that there was a great deal of curiosity about what lay inside its fences. He said, "We get a lot of people who think we're doing something secret, that we must be housing a flying saucer in here and that's why we won't let people in."³⁵ Another reporter likened it to an "X Files-like setting of high-tech buildings."³⁶ Though NASA restricted public access to Plum Brook once it was shut down in 1973, it approached decommissioning differently. Officials sought to not only erase the rumors of paranormal phenomena, but also to try to educate the public about the difficult process of removing radiation from the land.

Open communication between the engineers and the community was considered essential for project success. NASA set up community workgroups, established a repository of information at a local college, and let residents tour the facility and ask questions about any safety concerns that they had. Tim Polich, NASA's Decommissioning Project Manager, said that "our responsibility is to be a good neighbor." With safety as NASA's main priority, he wanted to establish an information "conduit with the public."³⁷

Nuclear fear had not lessened over time. Reactors continue to operate in the cultural shadows cast by Three Mile Island and Chernobyl. There is still intense debate among scientists over the ambiguities of radiation effects. According to J. Samuel Walker, reports published through the 1990s resulted in no definite conclusions.

³³ Minutes of Community Workgroup Meeting #2, Plum Brook Reactor Decommissioning," 7 December 1999, NASA Decommissioning Archives.

³⁴ Brad Steiger and Sherry Hansen Steiger, *UFOs Are Here!: Unmasking the Greatest Conspiracy of Our Time* (Citadel, 2001), p. 78.

³⁵ Robert Kozar, quoted in Ulysses Torassa, "10,9,8,7 . . . Little-Known Ohio NASA Facility Tests New Rockets, Jet Engines," *The Plain Dealer* (19 April 1998): 1J.

³⁶ John Mangels, "NASA Testing Facilities Count Rivals Among Customers," *Newhouse News Service* (27 July 1999): 1.

³⁷ Tim Polich, Minutes of First Meeting, Plum Brook Reactor Decommissioning," 3 November 1999, NASA Decommissioning Archives.

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The debate was not just about power reactors, but also about the threat of low-level radiation. Walker said that these reports “provided a confusing and sometimes contradictory variety of assessments of the risks of exposure to low-level radiation.”³⁸ This kept public fears of radiation at a high level and made these concerns a more pressing issue than any other environmental or industrial health threat.

When the local community first learned that the Plum Brook reactor was finally going to be torn down, there was a great deal of concern among the residents. One joke about the process was: “How do you tear down a nuclear reactor?” The answer was: “Very carefully.”³⁹ But humor aside, the community took this process very seriously. John Blakeman had been a resident of the area for over 30 years as a high school science teacher.⁴⁰ When he first heard that NASA was going to decommission he said, “I am reasonably familiar with the problems of radiation and remnant radiation and so forth. So yes, I had concerns, as did everyone.”⁴¹ He volunteered to become a member of the Decommissioning Community Workgroup, established by NASA and made up of concerned citizens who regularly met with decommissioning officials to discuss every aspect of the process.

The workgroup had a hard task ahead of it because of the years of secrecy surrounding the Plum Brook region.⁴² Though there had been public tours when the reactor was in operation, these stopped in the early 1970s, and few citizens had been allowed inside for nearly 30 years. Janet Bohne, a local environmentalist, had lived close to the reactor for nearly 50 years. She said, “There were many people that had concerns about what was going on out here behind the fence. No one could ever get in and you knew there was a nuclear reactor out here and everything was very . . . secretive.”⁴³ One community member constantly complained of loud unexplained noises and believed that the security guards at the gate were less than forthcoming when asked for an explanation. Another commented that there was a belief by some

³⁸ J. Samuel Walker, *Permissible Dose: A History of Radiation Protection in the Twentieth Century* (Berkeley: University of California Press, 2000), p. 129.

³⁹ Bruce Lieberman and Paul Horn, “Mission Possible,” Decommissioning the San Onofre Nuclear Generating Station, at <http://www.celsoc.org/ftp/sanonofrenucleargs.pdf>.

⁴⁰ “Meet John Blakeman,” *Decommissioning News* (October 2001), 3, NASA Decommissioning Archives.

⁴¹ Interview with John Blakeman by Virginia Dawson, 26 September 2002.

⁴² “Minutes of Community Workgroup Meeting #2, Plum Brook Reactor Decommissioning,” 7 December 1999, NASA Decommissioning Archives.

⁴³ Interview with Jan Bohne by Mark D. Bowles, 26 September 2002; “Community Workgroup Profile: Janet and Mark Bohne,” *Decommissioning News* (January 2002), 3, NASA Decommissioning Archives.

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that the reactor could affect weather patterns in the area.⁴⁴ Some believed that UFOs were landing behind the fences, similar to rumors told about communities like Roswell, New Mexico. Ethel Roldan predicted that there would be new questions, speculations, and concerns once the community began to see the trucks carrying radioactive waste out of Plum Brook and onto the highways.⁴⁵

The first meeting of the Plum Brook community workgroup was held at Firelands College (Bowling Green State University) on 3 November 1999. A group of eight community members attended, along with representatives from NASA, the Nuclear Regulatory Commission, and Argonne National Laboratories.⁴⁶ Topics of conversation included the communication process, the dissemination of information, and the steps involved in the decommissioning. Questions from the community representatives included the amount of radiation that would potentially be stirred up and travel into the community—the answer was “nearly none.” Other questions focused on background radiation, how the waste would be transported off the facility, and the extent to which the workers were being protected from radiation.⁴⁷ The first few meetings were held at Firelands College, and others were held at churches because of their centrality to the community. For example, one African American member said that virtually no one in her community knew about the decommissioning. As a result the workgroup team planned on a future gathering at a Sandusky African American church.⁴⁸

By the second meeting, held 1 month later, an audience of 20 members from the public attended. Some of them expressed concerns about the decommissioning process. One person said that he thought it would be better to simply leave the reactor

⁴⁴ “Minutes of Community Workgroup Meeting #3, Plum Brook Reactor Decommissioning,” 15 February 2000, NASA Decommissioning Archives.

⁴⁵ “Minutes of Community Workgroup Meeting #7, Plum Brook Reactor Decommissioning,” 24 April 2001, NASA Decommissioning Archives; “Community Workgroup Profile: Ethel Roldan,” *Decommissioning News*, (October 2002), 3, NASA Decommissioning Archives.

⁴⁶ Workgroup members at this first meeting included John Blakeman, Janet Bohne, Mark Bohne, Fred Deering, Richard Ennis, Jonathan Granville, Robert Speers, and Bill Walker. Other representatives included Tim Polich, Decommissioning Project Manager; Bill Wessel, Director of Safety and Assurance Technologies; Sally Harrington, Public Affairs Specialist; Marvin Mendonca from the Nuclear Regulatory Commission; Bob Hysong, a health physicist from Argonne National Laboratories; Susan Santos and Michael Morgan from Focus Group; and Keith Peacock and Larry Schroder from NASA.

⁴⁷ “Minutes of First Meeting, Plum Brook Reactor Decommissioning,” 3 November 1999, NASA Decommissioning Archives.

⁴⁸ “Minutes of Community Workgroup Meeting #3, Plum Brook Reactor Decommissioning,” 15 February 2000, NASA Decommissioning Archives.

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alone. He also said that his house was only 300 yards from the reactor and that no one on his street had been alerted to any of the decommissioning events. This was an important concern since a distribution error caused only one side of his street to be informed about the first decommissioning meeting, and NASA apologized for the "inadvertent oversight."

NASA established a Multifaceted Community Relations Plan, which created a communication link between the decommissioning team and local residents who were not a part of the workgroup. The plan included educational initiatives to teach the public about decommissioning activities and extensive outreach efforts with people from the surrounding area to ensure that they understood what was happening behind the secured Plum Brook fences. NASA assured the community that any family living in the area would receive no more than a dose of 25 millirems of radiation because of their proximity to the reactor. Ohio residents on average receive about 360 millirems per year from all sources, and the government has set a limit that no worker is allowed to receive more than 5000 millirems on the job during any year. Those who work at the site every day will likely receive only about one-fifth that amount.

In determining what an acceptable level of radiation risk is, the NRC currently uses findings from the International Commission on Radiation Protection (ICRP) and the National Council on Radiation Protection and Measurements (NCRP). These organizations accept that 100 millirems per year is an acceptable level of risk for an average person to receive who is not undergoing medical treatments. But these two organizations wanted to set the permissible dose level at 25 millirems per year as the value for residual radiation at a site undergoing license termination (which is the limit set for Plum Brook). Despite these established levels, uncertainty remained. In June 2000 the NRC admitted, "Both organizations have acknowledged the difficulty in setting acceptable levels of risk for the public."⁴⁹ The EPA has a radiation dose limit of 15 millirems per year, and in areas requiring radiation clean-up the NRC abandoned the use of a set number in favor of its ALARA standard (As Low As Reasonably Achievable).

Further complicating the discussion on permissible dose levels is the fact that the doses themselves have to be estimated. This responsibility falls to the entity that licensed the reactor in the first place. The estimation is made, according to the NRC, by "using assumptions about the amount of radioactive materials that will be released to the proximity of the public to the source of radiation."⁵⁰ The doses

⁴⁹ John L. Minns and Michael T. Masnik, "Staff Responses to Frequently Asked Questions Concerning Decommissioning of Nuclear Power Reactors," Nuclear Regulatory Commission, June 2000, Box 8, Folder 6, Plum Brook Archives.

⁵⁰ Ibid.

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are then calculated through a rigorous set of NRC-approved formulas, models, and parameter values. It is the NRC's responsibility to then evaluate this estimation and recalculate if it feels it was done improperly.

These technical debates over risk aside, the bottom line for the community was safety and risk to their health. Would their children be safe playing outside? Could radiation contaminate their drinking water? Might their descendents have a higher rate of cancer? These were the types of questions that NASA endeavored to answer by conveying its commitment to safety to the public. Officials explained to local residents that throughout the decommissioning process, safety issues were made a primary focus to protect the workers, the surrounding community, and the environment. Tim Polich said, "NASA is committed to the safest method of decommissioning these reactors."⁵¹ This was more than rhetoric; it was a part of the decommissioning work culture. Every worker and visitor to the reactor was given extensive training and had to pass a test to prove awareness of radiation safety issues. Everyone who went inside the reactor carried a personal dosimeter, which indicated any unplanned exposure to radiation. Furthermore, upon leaving the reactor everyone had to pass through full-body radiation monitors to detect any trace amounts of contamination.

Several intense focus group sessions indicated that the tremendous effort that was put into community outreach was working well. These sessions took place at a local hotel, with participants grouped by how close they lived to the reactor, including residents from Sandusky, Huron, Milan, Berlin, and Oxford Township. The resulting focus-group analysis revealed that the public trusted NASA to do a good job with the decommissioning and ensure the safety of the community. In particular, the focus group considered the Community Workgroup a "trusted independent source" that was essential in ensuring that NASA's interests remained in line with the good of the community.⁵² Mark Bohne, a local resident and member of the workgroup, confessed that although some people still think of Plum Brook as the mysterious place with the ten-foot fence around it, he felt confident that they were "pulling that veil aside."⁵³ What the community saw in the efforts taking place at Plum Brook comforted them. But environmental concerns still cast a shadow over the region.

⁵¹ Tim Polich, Decommissioning Video—Narration, at http://www.grc.gov/WWW/pbrf/video_script.htm.

⁵² Minutes of Community Workgroup Meeting #13, Plum Brook Reactor Decommissioning, 16 October 2002, NASA Decommissioning Archives.

⁵³ Interview with Mark Bohne by Mark D. Bowles, 26 September 2002.

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Plum Brook Runs Red

The most recent environmental scare at Plum Brook emerged when local news media in 2005 began reporting the possibility of radiological contamination in the area. In October the Toledo *Blade* published an article entitled “Radioactivity Found in Lake Erie Tributary.” It stated that NASA revealed that a one-mile portion of the Plum Brook creek had soil with isotopes of radioactive Cesium 137 that were slightly above background levels.⁵⁴ This radioactivity was most likely due to the Plum Brook reactors that were in operation between 1962 and 1973. Despite these elevated readings, NASA and the NRC were convinced that “the levels we found do not represent a health risk.”⁵⁵ But these findings did require further inquiry to determine if additional cleanup efforts were needed.

NASA is not the only agency carrying out environmental restoration efforts at Plum Brook. The United States Army Corps of Engineers is also involved in cleaning up areas that are still contaminated from the days of the ordnance works. The history of environmental concern in the area dates back to when the ordnance works was operational in World War II. The Army conducted the first environmental survey in October 1942, investigating complaints of pollution of Plum Brook and Sandusky Bay. In March 1945 another investigation documented “heavy fish killing” in the bay, where the water was turning red-brown because of the wastes that came from the ordnance works. Even after the war ended and no additional explosives were being manufactured, pollution continued because of TNT-contaminated surface waters flowing into Sandusky Bay.⁵⁶

Although these were isolated reports, the Army conducted another major survey of Plum Brook’s condition after the war for the commanding officer of the Ravenna Arsenal, which was responsible for the land. In 1955 E. R. Sanders, Jr., manager of product engineering, performed this survey and wrote, “From our first inspections as to conditions at Plum Brook Ordnance Works it was realized that T.N.T. areas at this location represented what we considered a hazardous condition.”⁵⁷ There had

⁵⁴ Tom Henry, “Radioactivity Found in Lake Erie Tributary,” *Toledo Blade* (19 October 2005).

⁵⁵ Richard Payerchin, “Officials: Radiation in Sediment not Threat to Health,” *The Morning Journal* (19 October 2005).

⁵⁶ “Historical Pollution Reports,” as found in, Dames & Moore, “Draft Records Review Report,” U.S. Army Corps of Engineers Huntington District, Administrative Record for Plum Brook Ordnance Works, Volume 1.05, Firelands College Library.

⁵⁷ E. R. Sanders Jr. to Commanding Officer Ravella Arsenal, 23 August 1955, U.S. Army Corps of Engineers Huntington District, Administrative Record for Plum Brook Ordnance Works, Volume 1.06, Firelands College Library.

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*One of the contaminated reservoirs left over from the Plum Brook Ordnance Works days.
(NASA 2005-1200)*

been questions of lead releases by the Army Corps of Engineers, and several of the streams ran red. The recommendation was to decontaminate the land completely and then lease it back to the community, possibly for the resumption of farming activities.

However, this decontamination never occurred. One year after Sanders's assessment the Army gave 500 acres of land (formerly the Pentolite Area of the Plum Brook Ordnance Works) for use to construct the reactor. Three years later, in January 1958, the Army transferred an additional 3,180 acres to NASA and in 1961 gave up the remaining ordnance lands.⁵⁸ There were minimal efforts to clean up this land over the next two decades. John E. Ross of Teledyne Isotopes stated in 1977 that Plum Brook had several areas that still had neutralized chemical wastes. He said, "These wastes were generated in the early 1940s and essentially have been 'in place' since 1945–1946 when explosive manufacturing ended at this location."⁵⁹ The most

⁵⁸ Colonel Michael H. Fellows, "Defense Environmental Restoration Program for Formerly Used Defense Sites," U.S. Army Corps of Engineers Huntington District, Administrative Record for Plum Brook Ordnance Works, Volume 1.08, Firelands College Library.

⁵⁹ John E. Ross, Memorandum for the Record, 28 June 1977, U.S. Army Corps of Engineers Huntington District, Administrative Record for Plum Brook Ordnance Works, Volume 1.06, Firelands College Library.

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significant concern was the “red water” problem, which everyone familiar with the area knew about.

During World War II the United States Army established two red water retention basins. The West Area Red Water Ponds held 120,000 cubic yards of waste water, and the Pentolite Road Red Water Ponds contained an additional 182,000 cubic yards of waste. In total these basins covered eight acres of land, and when it was filled too high it overflowed into Pipe Creek, which ran through the western part of Plum Brook. Red water seepage occasionally was carried through surface drainage into the Plum Brook stream itself, ironically making its “plum” name more literally true than ever before. Hank Pfanner grew up around the Plum Brook region and later spent his career working there as a controls engineer and the reactor manager. He recalled that Pipe Creek, which ran through the back of his father’s lot in the western part of Plum Brook, was a favorite place for him and his cousins to play. The only problem was that they emerged from the water with red legs from the contaminant that still remained.⁶⁰

Over the years NASA did make an attempt to understand why the water was red and what chemicals caused its coloration. None of these inquiries ever found that the waters were hazardous.⁶¹ Most concluded that it was the result of one or more of the chemicals that were used to produce explosives. These included nitric acid, sulfuric acid, ammonia, soda ash, sulfur, sodium sulfite, acetone, and toluene. The red water was more of an aesthetic than an environmental problem. It did not appear to be toxic to aquatic life since minnows and other creatures inhabited the red ponds. Vegetation grew all around the red water areas, and ducks, geese, and blue herons were frequently seen feeding there. Furthermore, raccoons, groundhogs, and deer often drank the red water.

There were other environmental concerns besides the red waters. There was 4,680 feet cubic feet of asbestos stored in deteriorating cardboard boxes, many of which were split open. These were located in several of the storage igloos originally built during the war to house explosive powder. In 1980 NASA began to look into disposing of this waste in a safe and efficient manner. There were three waste oil retention tanks (1,200 gallons, 500 gallons, and 1,000 gallons) that held oils and solvents associated with Plum Brook operations. These were buried underground, and when they became 75% full, a service contractor pumped out the materials in accordance with Ohio EPA regulations. There were also 1,000 gallons of waste elec-

⁶⁰ Interview with Hank Pfanner by Mark D. Bowles, 26 September 2002.

⁶¹ R. J. Koch, “USEPA Inquiry Regarding the Storage or Disposal of Wastes at the Plum Brook Station,” 10 June 1980, U.S. Army Corps of Engineers Huntington District, Administrative Record for Plum Brook Ordnance Works, Volume 1.06, Firelands College Library.

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trical insulating oils that contained PCBs, stored in a separate building. Every 24 hours this facility was checked for any potential leakage. In 1973, 8,000 cubic yards of lime sludge was taken from the reactor settling basins and disposed of on Plum Brook grounds. The sludge was a by-product of treatment of process cooling water from the reactor, though it was nonradioactive. None of this sludge had leaked into the surrounding streams. Since that time all similar materials were disposed of in authorized landfills.⁶²

Residual deposits of TNT were also present at Plum Brook. There were many underground wooden drain lines or flumes that had carried liquid and solid wastes to basins. In total there was over 8 miles of underground pipe: 20,825 feet of 4-inch pipe; 2,050 feet of 5-inch pipe; 11,250 feet of 6-inch pipe; and 8,875 feet of 10-inch pipe.⁶³ Over time these lines became contaminated with TNT and often became completely plugged. Once the flumes became plugged they were not cleaned, but instead were bypassed with new lines. To complicate the restoration effort, these bypass lines were not documented on any drawings, and thus a search effort that required underground digging was necessary to first find them. Once found, these underground lines were removed and burned. Also excavations were made 20 feet to either side of the lines to ensure that all of the bypasses were found. However, NASA continued to periodically encounter these lines, and when it did they were also removed and burned.⁶⁴

In March 1980 John N. Wuthenow from the U.S. Army Corps of Engineers visited Plum Brook to determine if the Army had any responsibility to help to clean up the site because of the contamination from the ordnance works. He determined that the Army still had responsibilities to the land. Shortly thereafter work began and continues to this day. The U.S. Army Corps of Engineers Huntington District is responsible for environmental restoration at Department of Defense sites. The Huntington District works in conjunction with NASA, the Ohio EPA, and the Restoration Advisory Board, which is made up of a group of concerned local citizens. Funding for this environmental activity comes from the Defense Environmental

⁶² R. J. Koch, "USEPA Inquiry Regarding the Storage or Disposal of Wastes at the Plum Brook Station," 10 June 1980, U.S. Army Corps of Engineers Huntington District, Administrative Record for Plum Brook Ordnance Works, Volume 1.06, Firelands College Library.

⁶³ "Site Management Plan," 30 September 1995, U.S. Army Corps of Engineers Huntington District, Administrative Record for Plum Brook Ordnance Works, Volume 1.05, Firelands College Library.

⁶⁴ R. J. Koch, "USEPA Inquiry Regarding the Storage or Disposal of Wastes at the Plum Brook Station," 10 June 1980, U.S. Army Corps of Engineers Huntington District, Administrative Record for Plum Brook Ordnance Works, Volume 1.06, Firelands College Library.

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Restoration Program for Formally Used Defense Sites.⁶⁵

Mark Bohne is a co-chair of the Plum Brook Restoration Advisory Board.⁶⁶ He said that since the 1940s there have been numerous efforts to clean up and decontaminate Plum Brook, but they have been “a little bit horrendous by today’s standards.”⁶⁷ With higher environmental standards in place, the U.S. Army Corps of Engineers is now “getting down to the nitty gritty of whatever is left, determining where [contamination remains] through scientific method.” Bohne said that the Plum Brook clean-up was not unique and that there were hundreds of other restoration advisory boards in existence throughout the United States performing similar functions. The goal for the Restoration Advisory Board, according to his wife and co-chair, Janet, is to guarantee that no contamination remains at Plum Brook when they are done.⁶⁸ But in spite of all of this contamination, not only from the ordnance works but also from the reactor, would it be possible for the garden-like aspects of the land to reassert themselves? How could decades of waste be washed away and the fertile garden once again emerge?

The Return of the Garden

The relationship between the technological and environmental aspects of the Plum Brook region has been one of the defining features of its history. The Plum Brook reactor became a “reactor in the garden,” a phrase quite literally true, with allusions to a classic work in the history of technology. Leo Marx wrote *The Machine in the Garden* in 1964 to discuss the inherent tension between technology and the pastoral ideal in our American past.⁶⁹ The example of Nathaniel Hawthorne in

⁶⁵ Plum Brook Ordnance Works Restoration Advisory Board Homepage, found at <http://www.lrh.usace.Army.mil/pm/pbow/>.

⁶⁶ “Community Relations Plan,” 17 August 2000, U.S. Army Corps of Engineers Huntington District, Administrative Record for Plum Brook Ordnance Works, Volume 8.06, Firelands College Library.

⁶⁷ Interview with Mark Bohne by Mark D. Bowles, 26 September 2002.

⁶⁸ Interview with Jan Bohne by Mark D. Bowles, 26 September 2002.

⁶⁹ Leo Marx, *The Machine in the Garden: Technology and the Pastoral Ideal in America* (Oxford: Oxford University Press, 1964). Other writers have brought this phrasing to other types of historical inquiry. See Ken Goldberg, *The Robot in the Garden: Telerobotics and Telepistemology in the Age of the Internet* (Cambridge: MIT Press, 2000); Colin Tudge, *The Engineer in the Garden: Genes and Genetic from the Idea of Heredity to the Creation of Life* (New York: Hill and Wang, 1995); Michael Ian Luger, *Technology in the Garden: Research Parks and Regional Economic Development* (Chapel Hill: University of North Carolina Press, 1991).

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Sleepy Hollow at the start of this chapter was one of Marx's examples that he used to illustrate this idea. Specifically, he asked what meanings were attached to the transition of a land from an agricultural to industrial production.⁷⁰ Paul R. Josephson associated Marx's idea with Soviet nuclear technology in a chapter that he titled "The Reactor in the Garden." He described a river flowing through a nature preserve that the community used for fishing and swimming and engineers used for cooling water for several nuclear reactors. Josephson said this was a reactor in the garden in the "sense of showing complete agreement between nature and human designs for huge machines..."⁷¹ However, Marx's thesis was not that there was "complete agreement" between technology and nature; in fact, he argued just the opposite. To Marx the machine was a contradiction of the ideal of a garden. Machines encroached upon and changed the land in fundamental ways, never becoming a part of it, yet transforming the environment by making it adapt to the technology.

This tension has always been a part of Plum Brook's history. It began when agricultural farming gave way to military/industrial production in World War II. It continued and intensified when what was industrial was again transformed to nuclear in the 1960s. And yet Plum Brook today is attempting a reversal that Marx did not envision—a return to nature. Can machines be removed from land they once transformed, and can people help to restore the environment to its original garden-like state? When the reactor was in operation the engineers often asked if they were permitted to pick apples off the numerous apple trees that grew around the facility, left over from the farmers' apple orchards. In 1963 H. Brock Barkley, reactor chief, gave this warning: because of the "significant amounts of toxic materials used in this work, nothing growing on the [Plum Brook] Station should be picked or removed."⁷²

The stated goal of those who are now tearing down the reactor is a level of success that is measured in environmental terms. Some 40 years after Barkley's warning, Tim Polich, the reactor decommissioning project manager said, "The ultimate goal of the decommissioning project is to return the land back to what's called, a resident farmer scenario. That is where somebody could come in to where the reac-

⁷⁰ This transition violated what Mark Fiege has called the "garden myth." Although it is an ancient story, Americans have modified and adapted it since the time its first colonists transformed the untamed wilderness into productive farms. This defined an important part of the new nation's character as agrarianism "became central to the American identity." The loss of this agrarian identity came with the industrial incursion. Mark Fiege, *Irrigated Eden: The Making of an Agricultural Landscape in the American West* (Seattle and London: University of Washington Press, 1999), p. 171.

⁷¹ Paul R. Josephson, *Red Atom: Russia's Nuclear Power Program from Stalin to Today* (New York: W. W. Freeman and Company, 2000), p. 6.

⁷² H. Brock Barkley, "Newsgram #1," 24 May 1963, Box 45, Plum Brook Archives.

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tor was at, build a home, raise crops, raise animals that they would eat, and still not get more than natural background radiation.”⁷³ This goal is supported by the NRC which has stated that when it terminates a reactor license there are no restriction on land usage. It stated that possible uses included restoring the natural habitat or even farming.⁷⁴

But could nature return to these lands? Strangely, the distinctions between the natural and the unnatural could become blurred at places like nuclear reactors. The Hanford Engineer Works had its start producing plutonium during World War II and required a large open space around it to serve as a buffer region. Richard White wrote that this space became an area where animal life thrived and prospered. He said that the lands around it became a “wildlife oasis” that included “eagles, black-crowned night herons, prairie falcons, long-billed curlews, a profusion of overwintering waterfowl, coyotes, deer and other species all . . . in the shadows of the reactors and processing plants.”⁷⁵ As the sand drifts filled the doorways where thousands of people once passed, a former worker at the facility “thought nature had returned.”⁷⁶

Today Plum Brook’s 6,400 acres of land demonstrate an incredible ecological variety and vitality. This includes 521 plant, 125 breeding bird, 21 amphibian/reptile, 16 fish, 53 butterfly, 450 moth, and 8 bat species. Several of these are protected by the Endangered Species Act, which maintains that federal agencies cannot jeopardize the existence of any threatened species. Plum Brook has 20 plant, 8 bird, 3 amphibian/reptile, and 1 moth protected species. Eleven populations of Least St. John’s Wort grow at Plum Brook, which are the largest concentrations of the plant in Ohio. The Sedge wren uses the area as one of the most important breeding grounds for its species. Recently a bald eagle pair built a nest at the facility, and onlookers anticipate the appearance of baby eagles. The deer population inside the fence is often in excess of 2,000. Controlled hunts are occasionally scheduled to keep the number of deer in proportion with a sustainable habitat.

The vitality of these Plum Brook lands was ironically attributed in part to the Indians first brought fire to the lands and used the technique to clear overgrown brush and attract deer by increasing the vegetation. The area became known as the

⁷³ Interview with Tim Polich by Virginia Dawson, 27 September 2002.

⁷⁴ John L. Minns and Michael T. Masnik, “Staff Responses to Frequently Asked Questions Concerning Decommissioning of Nuclear Power Reactors,” Nuclear Regulatory Commission, June 2000, Box 8, Folder 6, Plum Brook Archives.

⁷⁵ Richard White, *The Organic Machine* (New York: Hill and Wang, 1995), p. 84.

⁷⁶ Ibid.

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natural field at Plum Brook Station. NASA Glenn Environmental Office. (NASA C-2001-01214)

Fire Lands” when relatives of Connecticut citizens who lost their homes when the British set fire to them during the Revolutionary War first settled it. After World War II ordnance workers used fire as a primary technique to destroy buildings the government could no longer use. When the reactor was placed in standby condition, fire remained a part of the land. The caretakers who preserved the reactor took note that the once beautiful prairie land surrounding Plum Brook was being taken over by ugly brush. One of the engineers recalled that farmers burned brush to get rid of it, and so they set some controlled fires and watched them spread. This began the “burning of Plum Brook,” a biannual ritual that continues to this day and has been credited with restoring the natural ecological landscape and saving the rare prairie plants. The natural prairie land that emerged from this fiery cleansing always made for an intriguing juxtaposition between advanced technology and environmental preserve.

The Plum Brook forests and plains are also unique. The Central Meadows Area is significant because Ohio has no native prairie locations like it. Though the presence of humans has restricted its natural growth, through proper cultivation it has great potential to be restored to its original conditions. The West Area native forests are also important. According to Mike Blotzer, chief of the Environmental Management Office at Glenn Research Center, “[It] may be one of the most significant remnant forest areas in the Ohio Lake Plain. It is unique as a remarkable representa-

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tion of Ohio forest conditions at the time of the early settlement in the early 19th century.”⁷⁷ Keith Peacock, senior project engineer for the Plum Brook decommissioning, said, “The 500-acres around here [is] called one of the finest stands of hardwood wetlands in northern Ohio. I personally would like to see this land become part of the Erie County Metroparks system.”⁷⁸

A main difference between Plum Brook and Hanford is the level of environmental contamination. Though officials at Hanford pioneered the science of environmental monitoring by measuring contamination levels, the site was responsible for dumping billions of gallons of radioactive and chemical wastes, as well as billions of cubic meters of gases, into the Columbia River and into the ground and air of the surrounding region. According to Michele Stenehjem, a renaissance is now in progress at Hanford to clean up the lands, restore the environment, and involve the public in the process.⁷⁹ The scope of radioactive production at Plum Brook never approached the levels at Hanford. Today the Plum Brook decommissioning is considered NASA’s largest environmental project, not only because of the importance of safely disposing of radioactive remains but also because the surrounding area is a unique natural preserve. Every week air samples are taken, and water samples from the area are collected every month for analysis at an off-site laboratory.

The land the government forcibly acquired through eminent domain in 1949 for use as an ordnance works and later became the home of NASA’s most powerful nuclear test reactor will once again be restored to its natural condition. From the natural frontier to the nuclear frontier and back again, the Plum Brook lands have demonstrated the resiliency of nature and its adaptability to modern development. But what must not be forgotten is that without the emphasis on safety and environmental preservation by NASA’s scientists and engineers, the dangers of nuclear research would have forever contaminated an important piece of our American heritage.

The garden has not yet entirely returned to Plum Brook. The decommissioning process will not be completed for several years, and the clean-up from the ordnance works is an ongoing effort. But the goal still remains to restore the land and expel the previous two industrial machines from the garden. Whether anyone will ever want to farm this land is uncertain. But what is important is that NASA and its partners

⁷⁷ Mike Blotzer, “Protected Species Management at Glenn Research Center,” Office of Safety and Assurance Technologies Forum, 10 June 2002.

⁷⁸ Keith Peacock, transcript to “NASA Plum Brook – Part 2,” aired 8 October 2002, found at <http://www.wcpn.org/news2002/10%2D12/1008plum%2Dbrook%2D2.html>.

⁷⁹ Michele Stenehjem Gerber, *On the Home Front: The Cold War Legacy of the Hanford Nuclear Site*, 2nd ed. (Lincoln: University of Nebraska Press, 2002), pp. 2–10.

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Federal agencies and contractors associated with the clean-up are finally addressing significant environmental problem. The effort to restore the garden is a debt that JASA is now paying back for its brief tenure in nuclear experimentation.

Conclusion—Disappearing in the Night

In April 2005 Rick Weiss, a science writer for the *Washington Post*, published an article describing what he called the “incredible shrinking curiosity” in the United States. He argued that American science has “lost sight of the value of non-applied, curiosity-driven research—the open-ended sort of exploration that doesn’t know exactly where its going but so often leads to big payoffs.” Instead of patient, long-term support, quick deliverables have become the goal for the new research agenda. Weiss cited numerous examples. The Pentagon’s DARPA project has begun to shift initiatives away from basic research to goal-oriented endeavors. The Department of Energy is pulling funds from a Fermilab project to explore high-energy physics. The National Science Foundation has experienced significant recent cuts and now requires funding recipients to describe how and when their research will provide dividends. Weiss concluded, “We are losing . . . one of the oldest traditions in science: to simply observe, almost monk-like, with an open mind and without a plan.”¹

Weiss’s argument describes our present scientific climate but is also reminiscent of past criticisms of government-supported science. When the Plum Brook reactor was being shut down in 1973, Congressman Charles Mosher fought hard to keep it alive. His main argument was that the withdrawal of the government’s support of science was short sighted. Mosher testified in government hearings that he did not understand the policy of constructing not only a costly, but also a unique experimental facility like Plum Brook, and then suddenly pulling the plug on it and suspending its operations. It was not as if the government believed that it would never again return to its work on nuclear propulsion. The best estimates in the early 1970s were that the government would resume this work in the 1980s. But by that point the infrastructure then in place would be useless and the nation would have to start again from the beginning. Mosher criticized NASA administrator James C. Fletcher’s Congressional testimony, saying: “Now you are going through the very painful

¹ Rick Weiss, “Our Incredible Shrinking Curiosity,” *Washington Post* (10 April 2005): B01.

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process of dismantling all of this, and yet we all know, as you say in your testimony that you do expect to get back to this type of work sometime in the eighties.”²

Alan “Hap” Johnson believed that the uncertainty of federal finances represented the most important lesson to be learned from examining the history of Plum Brook. Johnson had become director of Plum Brook in 1961 after having helped construct the reactor. In June 1974 he retired at age 55, along with 60 other colleagues from Lewis Research Center and Plum Brook, completing a 30-year career at NACA and NASA.³ Looking back over his tenure at Plum Brook he said that one of the main lessons from the experience was that “finances as supported by Congress are ephemeral.” Without a long-term commitment to any basic research program, it can easily “disappear in the night.”⁴ For future projects in basic research to succeed there had to be greater assurance that government funds would not quickly shift with changing political desires. Some people are today taking this issue seriously. Buzz Aldrin has recently put forth his own plan for devising a system for routine voyages to Mars and back. Aldrin believes that his plan’s “long-term economic advantages make it less susceptible to cancellation by congressional or presidential whim.”⁵ It is now imperative that those who plan long-term missions look for ways to counteract the ephemeral financing and changing political support.

Ironically, a future project that might benefit from this lesson is the new nuclear rocket. In the midst of the planning and preparation for the Plum Brook decommissioning there was a renewed national interest in nuclear rockets as the primary propulsion system for sending humans to Mars. The president of the United States, the NASA administrator, Congress, and space enthusiasts all began looking once again at the nuclear potential for taking humans into outer space. In February 2000 journalist Peter N. Spotts described what he called the “gleam in an engineer’s eye.” It centered on the effort to reach the edges of our solar system with robotic craft and sending humans to Mars. A nuclear rocket was the vehicle that propelled both of these endeavors. After launch of this fictitious craft by conventional solid or liquid hydrogen rockets, the engineers on the Earth would verify that it was successfully in orbit. At that point they would then press a button activating a small trash can-size nuclear reactor that would power the rocket to its destination. Spotts said, “The

² George M. Low’s testimony for the House Subcommittee on Manned Space Flight, 6 Mar 1973, Box 106, Folder 15, Plum Brook Archives.

³ “More Than 60 Staffers Choose Retirement—Many Helped Make Lab What it is Today,” *Lexington News* (28 June 1974).

⁴ Interview with Alan “Hap” Johnson by Mark D. Bowles, 20 March 2002.

⁵ Buzz Aldrin with David Noland, “Roadmap to Mars,” *Popular Mechanics* (December 2005): 6.

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reactor represents NASA's technological declaration of independence from gravity as a tool for propelling interplanetary spacecraft."⁶ This new nuclear rocket was a continuation of the dream that Plum Brook engineers worked toward in the 1960s. If successful, it would enable heavier and more sophisticated experimental equipment to reach the outer planets and maybe even transport humans to Mars.

This gleam in the engineers' eyes grew brighter after comments made in support of nuclear propulsion by NASA's leadership. Sean O'Keefe, NASA's former administrator, had been revisiting the advantages and disadvantages of designing and constructing nuclear rockets for space exploration for several years. O'Keefe outlined NASA's new nuclear vision for the future in April 2002. He said, "Conventional rockets and fuel simply aren't practical as we reach further out into the cosmos. That's why we are launching an initiative to explore the use of nuclear propulsion."⁷ He said that deep-space travel today is almost out of the question for humans because we have no fast ways to get there. In comparison, our astronauts could today only travel slightly faster than John Glenn did in America's maiden orbital voyage in Friendship 7 over 40 years ago. O'Keefe said, "The nuclear propulsion initiative is the next logical step to overcome this technology limitation. It's a mature technology, and its application to space travel has great potential." This technology, as O'Keefe pointed out, had been used to power nuclear ships in the Navy since 1955, traveling over 120 million miles without any accidents.

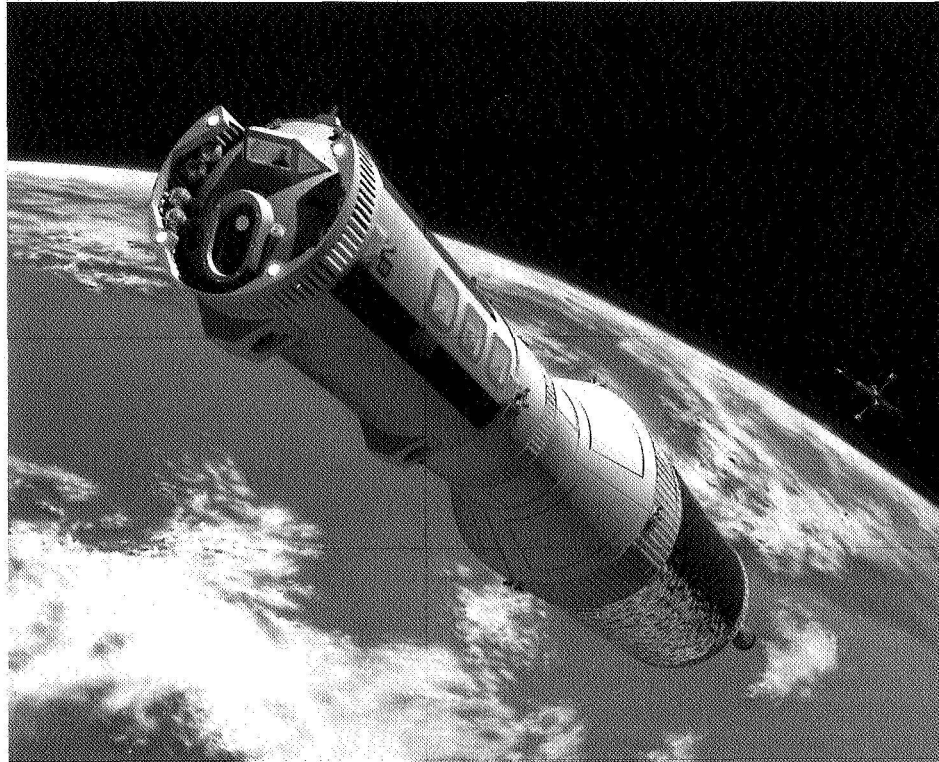
Technological development is often shaped by the prevailing political winds. Though Kennedy's dream of a nuclear rocket went unrealized in the 1960s, it has now become one of NASA's most pressing goals for the future. In 1989 President George H. W. Bush tried in vain to establish support for a nuclear rocket.⁸ While he was unable to generate congressional backing, his son, President George W. Bush, has been able to advance these ideas further. On 14 January 2004 Bush addressed his new plans for U.S. space policy to a NASA audience. He said, "Today we set a new course for America's space program. We will give NASA a new focus and vision for future exploration. We will build new ships to carry man forward into the universe, to gain a new foothold on the moon and to prepare new journeys to the

⁶ Peter N. Spotts, "NASA Eyes Nuclear Rockets to Reach Deep Space," *Christian Science Monitor* (28 February 2002).

⁷ Sean O'Keefe, "Pioneering the Future," Maxwell School of Citizenship & Public Affairs, Syracuse University, 12 April 2002, found at ftp://ftp.hq.nasa.gov/pub/pao/okeefe/2002/pioneering_the_future.pdf.

⁸ Peter Pae, "NASA Sets its Sights on Nuclear Rocket to Mars," *Los Angeles Times* (17 January 2003): A1.

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Rendering of a nuclear rocket capable of reaching the Moon in 24 hours. Drawn by Pat Rawlings (NASA) and Bill Gleason (SAIC). (NASA S99-04186)

worlds beyond our own.”⁹ Though he did not specifically mention nuclear rocket ships, he did emphasize the need for “new power generation” for new space vehicles. And though Bush’s refusal to use the word “nuclear” in any context related to the space program can be seen as continued wavering political support, others have filled in the gaps in his rhetoric.

Less than two weeks after Bush’s January 2004 speech the major news magazines published detailed stories about the new vision for NASA. *Time* ran a cover story titled “Mission to Mars,” with an artist’s rendering of an astronaut in a red space suit planting an American flag on the surface of Mars. *U.S. News & World Report* published an article entitled “Shoot the Moon,” in which it discussed how these new goals would be achieved. In evaluating Bush’s plan Charles W. Petit said, “The

⁹ “President Bush Delivers Remarks on U.S. Space Policy, 14 January 2004, speech reprinted in *NASA Facts* newsletter, NASA Decommissioning Archives.

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goals were bold [and] the details sketchy . . . Now engineers can start sweating.”¹⁰ The nuclear rocket became an important component of that vision because it would increase the speed of a Mars trip, thereby reducing astronauts’ exposure to cosmic radiation. Petit concluded that this was an important feature of the nuclear rocket, as long as “fears of the rockets’ own radiation don’t put the kibosh on them.”

The result of NASA’s new attention to nuclear rockets has been the inclusion of Project Prometheus in President Bush’s fiscal 2004 budget. This project included plans for the first nuclear-electric space mission, named the Jupiter Icy Moons Orbiter. The task of this orbiter will be to study Jupiter’s moons that might have subsurface oceans and explore them for possible signs of life. Not only will the scientific return be significant, but the voyage will also be used to test the capabilities of this type of spacecraft and enable engineers to improve upon it for the future. In comparison, Voyager, Galileo, and Cassini combined had less than 5,000 watts of onboard power. The Jupiter mission with a nuclear reactor would have 250,000 watts of power. The cost of this program is a proposed \$279 million and \$3 billion over five years.¹¹

In 2005, current NASA administrator Michael Griffin conducted a town hall meeting at Glenn (formally Lewis) Research Center. He discussed the Vision for Space Exploration and the central role that nuclear rockets would play. He said, “I believe nuclear thermal propulsion is the most intelligent way to go to Mars. And development of these systems has been a historical core competency at Glenn.”¹² Since Plum Brook’s shutdown, few other reactors continued the study of the effects of radiation on materials in space. Many of the materials that might be used for this new nuclear initiative were originally tested in the Plum Brook reactor decades ago. Plum Brook’s basic research into the effects of radiation on materials may serve as an important starting point for the rejuvenated nuclear program. Though the reactor is now quiet, its archived data can potentially be resurrected and put to use as America begins a renewed quest to explore the final frontier with nuclear rockets.

Many people who worked at Plum Brook in the 1960s are excited about the prospect that their terminated work will be taken up again. Len Homyak said, “A future trip to Mars would be very practical and I think the work that we had done

¹⁰ Charles W. Petit, “Getting There From Here,” as found in Thomas K. Grose, “Shoot the Moon,” *J.S. News & World Report* (26 January 2004): 50.

¹¹ President George W. Bush’s Fiscal 2004 proposal, found at <http://www.whitehouse.gov/news/sbudget/budget-fy2004/nasa.html>.

¹² “Administrator Michael Griffin Visits Glenn Research Center, 17 May 2005, <http://www.nasa.gov/centers/glenn/about/griffin-may05.html>.

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up until 1973 [would be] very instrumental in being able to complete that trip.”¹³ Jack Crooks also believed that the Plum Brook experimental results would prove useful. He argued, “Although, it’s dated, much of the basic physics data doesn’t change . . . physics is physics and it will stay that way.”¹⁴ While many of the former employees held out hope that nuclear rockets would one day fly, others were not as certain. Jim Blue said, “I am still skeptical.”¹⁵ He believed that national support for this type of project was still not strong enough to ensure that once begun the nuclear rocket would progress from research to development to flight.

Withstanding criticism requires long-term political commitment that does not waver in the face of vocal protests. One CNN science reporter said, “Taking a politically risky position, the Bush plan would push the development of nuclear power and propulsion for future missions into space.” The reporter said that this would give a much-needed boost to deep-space projects that did not have a vehicle powerful enough to achieve mission success within a feasible time span, especially for trips to Mars. But, the reporter concluded, “it could also set off storms of protests from activists who called into question the safety of past nuclear probes, citing the risks of accidental crashes should something go wrong at launch.”¹⁶ What might help further secure this political commitment are new reports out of Russia of a nuclear rocket (the RD-0410) developed at the Khimavtomatika design bureau. Anatoliy Kuzin, deputy director general of the Khrunichev State Space Science and Production Centre, stated that this rocket “has already undergone Earth-based trials.”¹⁷ Furthermore, China now has its sights set on landing humans on the Moon. Will such international developments be used as an impetus for U.S. technological development? Time will tell.

The future of the new nuclear rocket is yet to be written. Whether it will be terminated by a lack of political commitment, implode because of protests by nuclear activists, fail for technical reasons, or succeed in taking the first humans to Mars remains to be seen. In December 2004 Michael Behar wrote an article in *Wired* magazine about the five best ways to get to Mars, one of which was nuclear propulsion. Behar stated that though the nuclear option was technologically an excel-

¹³ Interview with Len Homyak by Robert Arrighi, 27 September 2002.

¹⁴ Interview with Jack Crooks by Mark D. Bowles, 25 September 2002.

¹⁵ Interview with Jim Blue by Mark D. Bowles, 11 February 2002.

¹⁶ Richard Stenger, “NASA Budget Cuts Human Flight, Pushes Nukes,” (5 February 2002), at <http://www.cnn.com/2002/TECH/space/02/04/nasa.budget/index.html>.

¹⁷ Anatoliy Kuzin, quoted in “Russian Design Bureau Considers Interplanetary Space Flights, *BBC Monitoring Former Soviet Union* (2 March 2005): 1.

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lent choice, he believed its biggest drawback was “Mostly political.”¹⁸ He thought that environmental concerns about contamination on Earth and political instability could easily halt any future nuclear momentum.

Science will struggle to succeed in a state of political flux, where researchers have to constantly look for short-term answers for fundamental research questions. The future pursuit of nuclear propulsion will not thrive in this type of environment, nor will the quest for any other long-term scientific program. The risks of changing political visions of space are too great. Plum Brook can play a role in future research by serving as a warning beacon from the past. The lesson of Plum Brook is that politically motivated, long-term, basic scientific research that does not have an immediate short-term payoff can be doomed to failure. This message of the Plum Brook reactor could likely survive as one of its greatest legacies.

¹⁸ Michael Behar, “5 Ways to Get to Mars,” *Wired* (December 2004).

Appendices

A. A History of Atomic and Nuclear Experimentation

The idea that all matter is made up of the discrete particles called atoms is one of the major discoveries in the history of science. However, the early history of the atom began in philosophy, not science. It started as an idea by Greek philosophers in the fifth century BCE and was inferred from logic and speculation, not observation. Leucippus of Miletus (435 BCE) and Democritus of Abdera (c. 410 BCE) developed the most well known of the first atomic theories.¹ They argued that atom-like substances existed in solids as interlocking hook-and-eye particles, in liquids as smooth and slippery particles, and in gases as widely dispersed, moving particles. In 50 BCE Lucretius wrote a long poem called *De Rerum Natura* (On the Nature of Things) describing these small atoms. He wrote, “for from our senses far, the nature of these primal atoms lies.”² It is important to remember that these Greeks were not establishing modern atomic theory, even though they theorized about the existence of “atoms.” Ironically, the term *atom* itself comes from the Greek *atomon*, meaning “indivisible.” Although modern scientists kept the term, they came to realize that an entire subatomic universe exists. Far from being indivisible, atoms themselves can be split in the fission process that makes nuclear reactors possible.

The philosophers who conceived these early atomic ideas met with resistance from their contemporaries, who argued that their theories were merely unobservable speculation. Few agreed with the seemingly counterintuitive notion that solids, liquids, and gases were made up of discontinuous particles. Plato (365 BCE) found the suggestion that the soul was made up of atoms repulsive, but did postulate

¹ G. E. R. Lloyd, *Early Greek Science: Thales to Aristotle* (New York: W. W. Norton & Company, 1970), p. 45.

² Lucretius, “On the Nature of Things,” in A. E. E. McKenzie, *The Major Achievements of Science* (Ames: Iowa State University Press, 1973), p. 436; Marshall Clagett, *Greek Science in Antiquity* (Salem: The Ayer Company, 1955), pp. 129–133.

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his own form of “geometrical atomism” made up of the five geometrical solids.³ His student Aristotle (384–322 BCE) argued against the atomic world, claiming that all substances were made up of earth, air, fire, and water. Galen (b. 129 AD), the influential physician and philosopher, believed that atoms were too much like unimportant bricks to make up complex, growing organisms.

The Greek achievements in natural philosophy resulted in one of the most dramatic periods of intellectual discovery in human history. Yet Greek science stagnated and died out in the West when the ability to read the Greek language was lost after the collapse of the Roman Empire. However, their philosophy was kept alive from roughly the seventh to the twelfth centuries by the efforts of Islamic intellectuals who maintained their ability to read the Greek language.⁴ These Islamic scholars did more than passively translate and preserve Greek thought; they also contributed their own ideas, and during this period they revised the atomic theories of antiquity. In the tenth century the “atomist” school of thought prospered in Islam, yet it became more theological than scientific. Sunni theology, which arose during this period, had the idea of “conceptual atomism” at its core.⁵ The Islamic alchemist Rhazes (865–925) also adopted a form of atomism that was similar to that proposed by Democritus. His irreducible elements included Creator, Soul, Matter, Time, and Space.

New variants of atomism were not revived in the West until the Middle Ages though most medieval philosophers believed in the continuity of material substances. Notable exceptions included Nicholas of Autrecourt (1298–1369), who attacked Aristotelian physics and replaced it with a new form of Greek atomism. He argued that all types of motion and change were the result of moving invisible and indivisible atoms.⁶ It was also during this period that for the first time the indivisibility of atoms was brought into question. William of Ockham (d. circa 1349) proposed a new theory called “minima” or “minima naturalia,” meaning the smallest natural parts. This was in some ways an attempt to revive atomism since both theories held that matter was made up of particles. The key difference was that the Greek

³ David C. Lindberg, *The Beginnings of Western Science: The European Scientific Tradition in Philosophical, Religious, and Institutional Context, 600 B.C. to A.D. 1450* (Chicago: University of Chicago Press, 1992), p. 40.

⁴ David C. Lindberg, “The Transmission of Greek and Arabic Learning to the West,” *Science in the Middle Ages*, ed. Lindberg (Chicago: University of Chicago Press, 1978), pp. 52–90.

⁵ Seyyed Hossein Nasr, *Science and Civilization in Islam* (New York: Barnes & Noble Books 1992), pp. 34, 35, 46, 268, 306.

⁶ Edward Grant, *Physical Science in the Middle Ages* (Cambridge: Cambridge University Press 1977), p. 32.

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atomists believed in indivisibility, whereas the proponents of minima believed that their particles were divisible. Interestingly, they also thought that the divided particle lost its identity when split and became an entirely new substance.⁷

It was not until the seventeenth century that atomism came to the forefront of contemporary scientific belief. During this time the “Scientific Revolution,” spurred by the work of Galileo Galilei (1564–1642), Johannes Kepler (1571–1630), René Descartes (1596–1650), and Isaac Newton (1642–1727), transformed the way that the universe was understood. One of the dominant themes of this era was the mechanical philosophy of nature. Historian Richard Westfall wrote, “Drawing its inspiration from the atomists of the ancient world, the new conception of nature set about explaining the mechanical reality that must lie behind every phenomenon.”⁸ This led to the prevalence of the “corpuscular” philosophy, the belief that the fabric of the universe itself was made up of minute particles of matter.⁹ Pierre Gassendi (1592–1655) argued that atomic theory was an important way to understand the mechanical universe. He was fascinated by the early Greeks and attempted to disassociate their ideas from a godless view of the universe. Robert Boyle (1627–1691) proposed his famous law, stating that the pressure of a gas is inversely proportional to its volume, and began accumulating the scientific data necessary for a new atomic theory. In describing Boyle’s law mathematically, Isaac Newton (1642–1727) attempted to prove that the gases were made up of mutually repulsive particles, where the forces between them were inversely proportional to their distances apart.

John Dalton (1766–1844), who published primarily during the Enlightenment, was responsible for the beginnings of modern atomic theory.¹⁰ His ideas were a continuation of Newton’s work on repulsive particles in a gas. Dalton thought that because of the laws of gravitation these particles should attract each other. So he postulated that each particle was an atom surrounded in a globe of heat. At the time, heat was considered to be a repulsive fluid called caloric, and he believed that this explained why the particles did not attract each other. In 1803 Dalton expanded

⁷ E. J. Dijksterhuis, *The Mechanization of the World Picture*, trans. C. Dikshoorn (Oxford: Clarendon Press, 1961), pp. 205–209; Norma E. Emerton, *The Scientific Reinterpretation of Form* (Ithaca, NY: Cornell University Press, 1984), pp. 85–93.

⁸ Richard S. Westfall, *The Construction of Modern Science: Mechanisms and Mechanics* (Cambridge University Press, 1977), p. 120.

⁹ Herbert Butterfield, *The Origins of Modern Science, 1300–1800*, rev. ed. (New York: Free Press, 1957), p. 132.

¹⁰ Thomas L. Hankins, *Science and the Enlightenment* (Cambridge: Cambridge University Press, 1985), pp. 110–112.

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upon this theory of gases and argued that atoms of different elements had different sizes and weights. To prove this, he analyzed water and found that one part of hydrogen combined with eight parts of oxygen. Therefore he argued that oxygen was eight times as heavy as the element of hydrogen. From this conjecture he began constructing the first table of elemental weights, with hydrogen having a value of one.

Where Dalton failed was in determining how many atoms of each element combined to form a molecule. His weight of oxygen was wrong by half because he believed that one oxygen atom combined with one hydrogen atom in the mixture, not two. It was not until 1860 that Stanislao Cannizzaro (1826–1910), using a 50-year-old hypothesis by Amedeo Avogadro (1776–1856), discovered the true atomic weight of the various elements, and the number of atoms that combined together in molecules. Through the efforts of these men the 2,000-year-old quest to prove that there was an atomic reality that existed beyond the human senses came to a close. But when the atomic nature of reality was discovered, Pandora's box was opened, revealing new questions about the universe that existed inside the atom itself and the mysterious rays that sometimes emanated from them.

With the efforts of Dalton, Avogadro, and Cannizzaro, modern atomic theory was born, but in one way it was still linked to its Greek ancestors—the atom remained an indivisible particle. In the 1890s atoms were still symbolized by billiard balls, irreducible elements that were the basic building blocks of nature. At the time there were fewer than four hundred physicists worldwide, and only a subset of these were concerned with atoms. But new discoveries soon resulted in a revolution in the field. A series of dramatic experiments revealed a subatomic universe filled with mysterious activity. Historian Daniel Kevles wrote: “At the opening of the twentieth century, physics was suddenly alive with new and revolutionary questions.”¹¹ One set of important questions revolved around the discovery of radiation.

This breakthrough occurred at the end of the nineteenth century in Germany, France, and England. In Germany in 1895 Wilhelm Conrad Röntgen (1845–1923) reported that under the proper conditions an electrical discharge could produce an invisible radiation that he called x-rays.¹² In France in 1896 Henri Becquerel (1852–1908) found that the element uranium could also darken a photographic plate with its radioactive waves. In 1898 Marie Curie (1867–1934) and her husband Pierre

¹¹ Daniel J. Kevles, *The Physicists: The History of a Scientific Community in Modern America* (Cambridge: Harvard University Press, 1987), p. 76.

¹² Otto Glasser, *Wilhelm Conrad Roentgen and the Early History of Roentgen Rays* (Springfield, IL: Charles C. Thomas, 1934), p. 45.

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(1859–1906) discovered two new elements that, like uranium, also emitted radiation. They named the first polonium, after their native country, Poland, and the other they called radium. They were also the first to refer to these general emissions as “radioactivity.”

These observations were groundbreaking, and they resulted in a host of new questions about the nature of radioactivity itself. The first answers came from Ernest Rutherford (1871–1937), a New Zealander who began his work with J. J. Thomson (1856–1940) in 1894 at Trinity College, Cambridge. Thomson’s own experiments eventually led him to find the existence of the electron, and Rutherford identified two different types of rays in uranium radiation. In 1898 he called these alpha and beta rays. After this accomplishment he left England to accept a new position at McGill University in Montreal.

While other researchers determined that the beta ray was actually Thomson’s electrons moving at speeds almost that of light, Rutherford began exploring what the alpha rays were (ten years later he would discover that the alpha rays were positively charged helium nuclei). This led him to develop, with Frederick Soddy (1877–1956), a general theory of radioactivity. Beginning work together in 1900, they postulated that all radioactive atoms were able to transform themselves into new elements by expelling alpha or beta particles. These new elements could be further broken down into other new elements. The radioactive energy came from the atom itself as it changed or, as they described it, “decayed.” For example, radium was actually decayed uranium.

Further questions remained, such as when and why would a radioactive atom expel a particle for the transformation? Nothing they tried in the laboratory would influence the decay process, such as heat or cold, nor did the age of the atom matter. Atoms seemed to decay at the same rate if they were 1,000 years old or just newly formed. As a result, Rutherford and Soddy fell back on statistics to estimate the behavior of groups of atoms, and they devised decay rates for various types of radioactive atoms. For example, they found that for any quantity of radium, half would decay into radon after 1,600 years. Thus radium had a “half-life” of 1,600 years. Although they could predict nothing about a single atom, their discovery of the half-life for atomic groups was remarkable. In 1908 Rutherford and Soddy won a Nobel Prize for their “investigations in regard to the decay of elements and . . . the chemistry of radioactive substances.” Today, very little about this basic theory of radiation has changed.

Rutherford then returned to Manchester, England, where he further defined the structure of the atom in 1909. By bombarding atoms with his alpha particles, he was able to determine that there was a solid mass inside the atom. In 1911 he called this mass the “nucleus.” The modern atomic model emerged from his work, and, astonishingly, it appeared to mirror the way that planets revolve around a sun. The

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negatively charged electrons revolved around the positively charged nucleus, which contained nearly all the mass of the atom in its protons (and, as they believed at the time, electrons). This was Rutherford's model of the atom, called the solar-system model.

While Rutherford and Soddy were working on radiation, a German physicist named Max Planck (1858–1947) began quietly developing his revolutionary quantum theory in 1900. Of this work Paul Davies wrote that it is “remarkable that the greatest scientific revolution of all time has gone largely unnoticed by the general public [since] its implications [are] so shattering as to be almost beyond belief—even to the scientific revolutionaries themselves.”¹³ Planck studied enclosed oscillating electrons and their corresponding radiation, which he realized occurred in discrete bursts, or packets of energy. He found that the value of this energy was $h\nu$, where ν was the frequency of the exchanged energy, and h was an unchanging number that he called Planck's constant.¹⁴ Planck's “theory of radiation” held that all electromagnetic radiation, including light itself, consists of noncontinuous packets of energy.

Using these revolutionary ideas in 1912, Niels Bohr (1885–1962), a young physicist who was working in Rutherford's own laboratory in Manchester, developed a new model of the atom. Though he began his investigations using the Rutherford solar-system model, by using Planck's quantum theory he devised a new way to understand the revolution of electrons around the nucleus and the emission of radiation. He argued that electrons were able to “spontaneously” jump from one orbit to another, and when they moved to a lower orbit the atom emitted a quantum of light, and when it moved to a higher orbit it absorbed a quantum of light, later called a “photon.”

Another troubling question was the possibility that a third subatomic particle might exist. In 1920 Rutherford argued that there was another particle inside the atom that shared space with the protons.¹⁵ He postulated that this was a negatively charged particle with a mass that was roughly equal to that of a proton, and he called it the “neutron.” Experimental confirmation of this hypothesis was complicated because scientific equipment of the time could only measure particles that had a positive or negative charge. For the next 15 years scientists looked for ways to

¹³ Paul Davies, *Other Worlds: A Portrait of Nature in Rebellion: Space, Superspace and the Quantum Universe* (New York: Simon and Schuster, 1980), pp. 9, 11.

¹⁴ I. Bernard Cohen, *Revolution in Science* (Cambridge: The Belknap Press of Harvard University Press, 1985), p. 420.

¹⁵ James Chadwick, “The Neutron and its Properties,” Nobel Lecture, 12 December 1935, found at <http://www.nobel.se/physics/laureates/1935/chadwick-lecture.pdf>.

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detect Rutherford's mysterious neutral particle. The road to success began in 1928 when two Germans, Walter Bothe (1891–1957) and his student Herbert Becker, developed an experiment in which they used alpha particles to bombard beryllium. The result was that the beryllium emitted a penetrating, neutral radiation that was able to pierce 200 millimeters inside lead. Bothe found this “radiation of beryllium” to have remarkable properties. Not only could it penetrate lead, it could also pass through a several-centimeter brass plate without losing any significant amount of velocity. Furthermore, when the radiation hit other atoms, it caused them to disintegrate, much like an explosion.

Four years later Marie Curie's daughter, Irene Joliot-Curie (1897–1956), and her husband, Frederic Joliot-Curie (1900–1958), attempted to further analyze the radiation to discover what it was. They began by speculating that the radiation was similar to electromagnetic waves, called gamma radiation, and was thus photons. But they found something very unusual in that the radiation was able to eject a stream of protons from paraffin containing hydrogen. This was a curious finding because photons have no mass.

When Rutherford heard about Curie's result, he simply said, “I do not believe it.” The protons were being ejected with velocities that would be impossible for the energy stored within the radiation to cause. Could this be the mysterious neutral particle that he predicted back in 1920? Since 1919 Rutherford had been the head of the prestigious Cavendish Laboratory in Cambridge. James Chadwick (1891–1974) was Rutherford's assistant, and he too found “grave difficulties” with the Curies' explanation.¹⁶ He decided to replicate their experiment in a new type of detector apparatus. He selected additional targets for the beryllium radiation, including hydrogen, helium, and nitrogen atoms, and measured the atoms after the collision. Like Rutherford, he was surprised by the speed of the recoil. He predicted that the recoil should have been about 1.3 millimeters, but the experiment showed the recoil to be 3 millimeters. Chadwick then concluded that the beryllium radiation was not gamma radiation at all. In a letter to the British scientific journal *Nature* he wrote, “These results, and others I have obtained in the course of the work, are very difficult to explain.” But he did have a solution. He concluded, “The difficulties disappear, however, if it be assumed that the radiation consists of particles of mass 1 and charge 0, or neutrons.”¹⁷

The discovery of the neutron is now considered one of the most significant of

¹⁶ James Chadwick, “The Existence of a Neutron,” *Proceedings of the Royal Society of London, AA* 136 (10 May 1932): 639.

¹⁷ James Chadwick, “Possible existence of a Neutron,” *Nature* (27 February 1932): 312.

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the twentieth century. After adapting the laws of conservation of momentum and energy to his findings, he was able to determine that the neutron had the mass of 1.0067 that of a proton. For this work Chadwick won the Nobel Prize for physics in 1935. Ironically, even though Irene and Frederic Joliot-Curie were incorrect about the nature of the beryllium radiation, that same year they won the Nobel Prize for chemistry, in recognition of their synthesis of new radioactive elements. In awarding Chadwick this honor the chairman of the Nobel committee said, "If the qualities of the neutron are made use of, this will certainly in the immediate future give us a new and deeper knowledge of matter and its transformations."¹⁸

Just months after Chadwick's discovery, Leo Szilard (1898–1964) was one of the first to envision a new use for neutrons. He conceptualized the possibility of releasing atomic energy through a chain reaction that began with the bombardment of neutrons. He further speculated that a devastating bomb could be made from this principle. One year later he fled Nazi persecution in Berlin and immigrated to Britain, where in 1934 he applied for and received a patent on an atomic bomb. In 1937 he moved to the United States, where he took a central place in the development of the atomic bomb during World War II. Through Szilard's work an important transformation had taken place. Theoretical subatomic physics was ready for practical applications. The nucleus of an atom held a tremendous energy reserve, which would be released if the atom could be split.

Atomic politics became serious the day that German physicists Otto Hahn (1879–1968) and Fritz Strassman (1902–1980) at the Kaiser Wilhelm Institute for Chemistry designed a tabletop device that split a uranium atom. This "startling discovery" in 1938 led many physicists worldwide to begin exploring the implications of this phenomenon, one of which was a nuclear bomb.¹⁹ When the uranium atom split, not only were large amounts of energy created, but neutrons were also released. Scientists like Szilard speculated that if the conditions were set up and controlled correctly, a chain reaction could occur with the expelled neutrons from the first split atom causing other nearby uranium atoms to do the same. This process could perpetuate itself and, if left unchecked, would unleash a terribly destructive power.

This discovery occurred on the eve of World War II, when the German military began pressing across much of Europe. Many elite German scientists fled to the United States to escape the horrors of Nazi anti-Semitism. These émigré physicists

¹⁸ H. Pleijel, "Presentation Speech for the Nobel Prize in Physics 1935," found at <http://www.nobel.se/physics/laureates/1935/press.html>.

¹⁹ Kevles, *The Physicists*, p. 324.

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included Enrico Fermi (1901–1954) and Eugene Wigner (1902–1995). Szilard personally knew both Hahn and Strassman and believed that the German military might begin looking for ways to turn their work into a devastating weapon. At Columbia University Fermi and Wigner researched uranium fission and thought that they could create a chain reaction by using a pile of uranium and graphite blocks, but they lacked both substances to test their hypothesis. In June 1940 President Roosevelt formed the National Defense Research Committee (NDRC), with MIT engineer Vannevar Bush (1890–1974) as its leader. Bush was a strong proponent of the NACA style of organization with its civilian leaders at the head, and he decided to model the new Office of Scientific Research and Development (OSRD) after it. Research on the potential for a nuclear chain reaction proceeded under the OSRD's Section on Uranium. Several universities pursued this work, including Columbia, Princeton, Chicago, and California.

The pace of nuclear experimentation intensified after 7 December 1941, when the Japanese attack on Pearl Harbor thrust the United States into World War II. Bush and the American scientific elite refocused and coordinated a massive nuclear research effort. The United States established the Manhattan Project in 1942, which, according to historian Thomas Hughes, “was unprecedented in its concentrated expenditure of human resources for the manufacture of a single product—atomic bombs.”²⁰ The project began with scientific research at the University of Chicago in a place called the Metallurgical Laboratory, which was a code name to disguise the nuclear research that was being carried out. Arthur Compton (1892–1962), a 1927 Nobel Prize winner in physics, organized the laboratory and was supported by the efforts of Fermi, Wigner, and Szilard. The president of the university looked for a place on campus where their research could take place. He decided to suspend the university's football games and designate the west stands at Stagg Field as the site for the secret nuclear research.²¹

There beneath the football field in the squash court, Compton and his team built the world's first atomic pile and the world's first research reactor, named Chicago Pile 1 (CP-1). It consisted of 45,000 graphite bricks with 19,000 holes drilled into them. Uranium oxide pellets were then inserted into the holes. The eventual pile was 20 feet high, 6 feet wide, and 25 feet deep. The total cost, including the 6 tons of uranium metal, 50 tons of uranium oxide, and 400 tons of graphite, was

²⁰ Thomas P. Hughes, *American Genesis: A Century of Invention and Technological Enthusiasm, 1870–1970* (New York: Penguin Books, 1989), p. 385.

²¹ For an excellent overview of the Metallurgical Laboratory, see Jack M. Holl, *Argonne National Laboratory, 1946–96* (Urbana and Chicago: University of Chicago Press, 1997), pp. 1–46.

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\$2.7 million. The team had to invent its own control systems for the pile, and 14 men were designated as “the circuit group” to manage it. They used cadmium rods to regulate the neutron production, and an automatic safety control was put in place, whereby if radiation levels increased too much, the rods would be dropped into the pile. A manual system was also in place. The control rods were suspended by ropes, and people stood at several places with axes in hand. If the pile accelerated too quickly, they would literally cut the rope and the control rods would fall, killing the pile. This was called the SCRAM line, which was an acronym for Safety Control Rod Ax Man. This feature was later found in every nuclear reactor’s control panel as a large red SCRAM button. Other inventive names came from A. A. Milne’s book *Winnie the Pooh*. At the time Fermi was improving his English skills by reading this children’s series, and the scientists used the character names in the book, like “Roo,” for their instruments.

By April 1942 over 150 people were working on the project when health concerns about radioactivity became a problem. A hematologist at the university took blood from those who were working closely with the dangerous materials, but little was known about the dangers of uranium and plutonium. Wigner made the suggestion to his colleagues not to build any houses anywhere close to the pile. That summer a separate health division was created to protect the researchers at the Metallurgical Laboratory. This was important because the lab continued to grow in size. By November over 400 people worked there, and the organization was structured much like a university, with specialists grouped together around common interests and goals. Fermi was in charge of the various research groups, and Wigner managed 15 theoreticians.

On 2 December 1942, CP-1 was tested. Before an audience of 42 scientists Fermi slowly ordered the control rods pulled from the pile. It successfully operated at one-half-watt power for less than five minutes. Wigner celebrated by opening a bottle of Chianti and passing it around to those watching the momentous occasion. Despite the success, no one at the time knew if it was the first controlled chain reaction or not. The Germans might have beaten them to it. But after the war was over it became clear that on that cold December day, the squash court was home to the world’s first nuclear research reactor.

Experimentation at research and test reactors in the 1950s became the next stage in the lineage of investigators into the atomic world. With the technology of reactor design understood, significant questions about the nature of radioactivity remained to be solved. How did other materials respond to a radioactive environment? This basic research required experimentation at large test facilities like those at Plum Brook.

B. The Fission Process and How a Test Reactor Works

This book is written for general educated reader and assumes no prior knowledge of nuclear physics or engineering. But to understand the history of the Plum Brook reactor it is necessary to have some basic understanding of the atomic and subatomic world, nuclear fission, and the design and operation of nuclear reactors. This appendix is a primer on how nuclear reactors work and the ways they are designed. The description is general and unrelated to any specific research reactor. The two following sections overview the basics of reactor physics (how it works) and reactor engineering (how it is built).

Everything that we can see or touch is made up of matter, which consists of the basic building blocks of life called *atoms*. The atoms exist in 92 natural variations called *elements*. The most common elements that make up living organisms are hydrogen, carbon, nitrogen, and oxygen. What differentiates hydrogen atoms from oxygen atoms is the structure inside them. Within each atom is a central core called the *nucleus*. The nucleus is made up of positively charged *protons* and neutral *neutrons*, which make up almost the entire mass of the atom. For example, if an atom were the size of a 150-pound person, the protons and neutrons would weigh 149 pounds and 15 ounces. The remaining one ounce of mass would consist of the *electrons*. These are negatively charged particles, which orbit the nucleus. The numbers of protons and electrons are identical in each atom.

The number of protons is constant for each element, and this represents the *atomic number*. For example, hydrogen always has one proton in the nucleus with one electron in orbit, while uranium has 92 protons in the nucleus and another 92 electrons in orbit. But the number of neutrons is not constant for a given element. *Isotopes* are similar elements that have different numbers of neutrons in the nucleus. Oxygen, with an atomic number 8, can exist with neutrons numbering 8, 9, or 10. The *atomic mass* represents the total number of protons and neutrons in the nucleus. This is the number commonly referred to when isotopes of a given element are being identified. For example, for the isotope uranium-238, the 238 is the atomic mass, representing 92 protons and 146 neutrons.

The majority of atoms are *stable*, meaning that the atomic nucleus will remain intact and not change over time. Though ancient alchemists looked for centuries to find magical methods to transmute lead into gold, these elements are stable and cannot be transformed. But not all atoms are stable. A select few are *unstable* and actually have the ability to change themselves into other elements by a process called *radiation*. When this change occurs, the radiation is emitted from the atom through four possible types of particles. *Alpha* radiation is identical to a helium atom, with two protons and two neutrons. *Beta* radiation is very small charged particles and takes the form of negatively charged electrons or positively charged particles called

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positrons. Gamma radiation is much like radio waves or light and is emitted in *photon* packets. The final type of emission is *neutron* radiation, in which a neutron leaves the atom at very high speed.

When radiation is emitted, the unstable atom is said to *decay*. New elements are formed in this very slow decay process. The *half-life* is the term used to designate how long it will take for a mass of unstable atoms to take its new form. This is the time required for one-half of the original mass of atoms to decay. The half-life of uranium-238 is four and a half billion years. But natural decay is not the only way for atoms to change form. Atoms were once thought to be indivisible, but scientists discovered that they could be artificially split or *fissioned*. Neutron radiation is very important in this process, because this is how nuclear fission begins. Once this division occurs, the nucleus releases a large amount of *kinetic energy*, which is the source of the power unleashed in atomic bombs and nuclear reactors.

All nuclear reactors generate energy through the fission process. Nuclear fission occurs when a neutron collides with a nucleus of an atom, such as the uranium-235 isotope. The result is that the original nucleus splits into two smaller atoms called *fission fragments* or *products*. Uranium-235 will split into barium and krypton. This split releases the tremendous energy contained within the original nucleus and causes additional neutrons to be expelled. It is this release of neutrons that makes a self-sustaining nuclear reaction possible. Approximately two and a half neutrons are released when uranium-235 is split. If these neutrons can in turn collide with another uranium-235 nucleus, then the entire process will begin again: a split, a release of energy, the formation of two new nuclei, and the release of additional neutrons. If sustained with a *critical mass* of uranium, this process is called a *chain reaction* and is located within a nuclear *pile*.²²

The energy release in a sustained chain reaction is enormous. One pound of fissioned uranium-235 is equal to the same amount of energy available in three million pounds of coal. However, this often-quoted ratio is misleading because there are several problems that greatly diminish the efficiency of this process. The first problem in sustaining a chain reaction is the speed of the expelled neutrons. At 20,000 kilometers/second the *fast neutrons* travel so quickly that their speed decreases their chances of colliding with another uranium nucleus and perpetuating the chain reaction. Slower moving neutrons have a far better chance of colliding with other

²² The following books and articles provide a basic overview of nuclear reactors. John G. Collier and Geoffrey F. Hewitt, *Introduction to Nuclear Power* (Washington: Hemisphere Publishing Corporation, 1987), pp. 13–47. L. A. Ohlinger, “Engineering Aspects of Nuclear Reactors,” *Nucleonics* (December 1949): 38–49. C. D. Gregg King, *Nuclear Power Systems: An Introductory Text* (New York: The Macmillan Company, 1964). Bernard L. Cohen, *Before It’s Too Late: A Scientist’s Case for Nuclear Energy* (New York: Plenum Press, 1983).

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uranium atoms. The probability of collision is 1,000 times greater if the speed of the neutrons is reduced from 20,000 to 2 kilometers/second. This speed is nearly identical to the motion of the atoms themselves, which is due to thermal motions. Neutrons that travel at this speed are called *thermal neutrons*. Some nuclear reactors are designed to use these fast neutrons (called *fast reactors*), but most are designed to use the artificially slowed neutrons (called *thermal reactors*).

But the problem was how to reduce the speed of the neutrons artificially. The answer was to bounce the neutrons off of smaller atoms. For example, imagine a marble represents a neutron. If you roll the marble at a large rubber object 50 times its size, the marble will bounce off it and lose very little of its speed. However, if you roll the marble into another marble that is the same size or smaller, a significant portion of its kinetic energy will transfer into the stationary marble and the original marble will lose speed. This is the same principle by which fast neutrons can be converted into thermal neutrons. After roughly 20 successive collisions with a light hydrogen atom the fast neutron is slowed to a rate that promotes fission. This entire process is called *moderation*, and the light material, hydrogen in this case, is called the *moderator*. The moderator itself can be a solid, such as graphite, or a liquid, such as water.

A second problem is what happens to the extra neutrons that are produced. Every time a uranium-235 atom splits, an average of two and a half neutrons are expelled, and since only one neutron is absorbed every time another uranium-235 atom splits, the remaining one and a half neutrons have to go somewhere. In an atomic bomb, where the goal is to produce progressively more and more energy, these excess neutrons are simply used to generate another split. This is called a *supercritical system*. But when the fission process needs to be controlled for energy production or research purposes, the reactor needs to be managed, whereby only one expelled neutron causes another atom to split. The other neutrons must be absorbed.

If this system becomes unbalanced, with either too few or too many neutrons causing fission, then it will either die out or accelerate to dangerous proportions. The way that this process can be manipulated is through the use of *control rods*. These are usually made of boron or cadmium and are important regulators because these elements absorb the extra neutrons. Lowering or raising the rods into or out of the core controls the neutron absorption rate. The deeper they are, the more neutrons are absorbed and the reaction is slowed. The further they are pulled out, the more reactions take place. The technical term used to define the neutron absorption and production rate is called the *multiplication factor k* . When k equals one, then one neutron is absorbed for every one produced. This is the ideal state to sustain a chain reaction and is called a *critical system*. When k is less than one, then the chain reaction will eventually die out over time. This is called a *subcritical system*. When k

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is greater than one the chain reaction will increase its fission rate over time. This is the supercritical system that is generated in atomic bombs.

A third problem is that not all isotopes of uranium are fissionable. Uranium itself was first discovered in 1789 by German chemist Martin Klaproth, who named the element in honor of the planet Uranus. Uranium is a heavy, hard, and silvery metallic element, which is number 92 on the periodic table, and is the 48th most common element found in natural crustal rock. One of the main areas for uranium mining is the Colorado Plateau, which extends over 50,000 square miles over Colorado, Utah, Arizona, and New Mexico.²³ In the 1950s its rate of uranium production was second only to that of the Belgian Congo. *Natural uranium* is the designation given to uranium that contains 99.3% of the isotope uranium-238 and 0.7% of the isotope uranium-235.

The problem for nuclear reactors is with these proportions. Uranium-235 is a *fissionable isotope*, whereas uranium-238 is an isotope that is not easily split or *nonfissionable*. As a result, in any one kilogram of natural uranium the fissionable material is only equal to about the energy from twenty tons of coal, a significant reduction in the amount of possible energy production. There is one solution which increases the energy potential by roughly 100 times. The uranium-238 isotopes usually absorb neutrons, unless they are moving extremely fast, and do not result in a split of the nucleus. But when a uranium-238 isotope absorbs one of these neutrons, it is changed into a new element—plutonium-239. This isotope is also fissionable, meaning that it can absorb neutrons and split to produce further energy production. This is an important part of the energy production process because in a thermal reactor, about 30% of all the generated energy actually comes from the fission of plutonium.

Another other way to increase the fissionable material from natural uranium is to artificially enrich it. The process of enrichment increases the amount of uranium-235 and decreases the amount of uranium-238. In the United States this is done through the gaseous diffusion method which, in a crude analogy, is similar to sifting for gold in streams of water. The process begins by heating uranium hexafluoride (UF_6) from a solid into a gas. The gas is then sent through a series of compressors and converters, which have barriers with small holes in them. This is the sifter. Since uranium-235 has slightly less a mass than uranium-238, it passes through the barrier more easily. Two streams of gases eventually emerge, and the one with the higher concentration of uranium-235 is called *enriched uranium*, and the stream with less uranium-235 is called *depleted uranium*. The entire process increases the proportion of uranium-235 from 0.7% to over 20%.

²³ "How Uranium is Mined," *Nucleonics* (April 1952): 38.

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Reactors can use either natural uranium or enriched uranium as their fuel. Natural uranium reactors are very large and expensive and require graphite or heavy water as the moderator. Enriched uranium reactors are much more common in the United States. One of the main reasons that the American nuclear energy program chose enriched uranium over natural uranium was that the operation cost was lower.²⁴

The following is an example of this entire fission process in a thermal reactor using enriched uranium, where the ideal state is to have 100 fissions produce another 100 fissions (see Figure 1). Each time this takes place (Step A), 259 neutrons are produced (Step B). Fifty-nine of these are lost by leakage or absorption into the reactor structure itself (Step C). The 200 neutrons that are left will then interact with the uranium fuel. Since only a small fraction of this fuel is the fissile uranium-235, this isotope absorbs 78 neutrons (Step D). Not every absorption results in a split, and only 63 fissions occur (Step E).²⁵ At the same time the nonfissile uranium-238 isotope absorbs 63 neutrons (Step F) and produces just five fissions (Step G), because, as stated earlier, this isotope can only be split with neutrons traveling at a very high rate of speed. However, in this process of absorption another element is produced—plutonium-239 (Step H). This is very important because it is a fissile isotope and absorbs 59 neutrons (Step I). The product of this absorption is 32 plutonium fissions (Step J).²⁶ The final result of these three fissions (32 plutonium + 63 U²³⁵ + 5 U²³⁸) equals another 100 fissions (Step K), and the chain reaction begins all over again. This entire process, taking place in a *nuclear pile*, results in intense fields of radiation, which are generated by test reactors for research and experimental purposes.

C. How a Test Reactor is Designed

The nuclear pile itself, where the fission process takes place, has a fairly simple design. Piles can be built in any size or shape and can be as small as an apple or as large as a house. Their shape also can be any geometric solid (sphere, cube, etc.), as long as its height, width, and depth are of relatively the same proportion. Despite the variety of sizes and shapes, there are only two main classifications of piles. The first type of pile considers the energy that is generated a waste product. This is how *research and test reactors* operate, since their primary function is to create neutrons

²⁴ Chauncey Starr, "The Case for Enriched Uranium," *Nucleonics* (August 1958): 86.

²⁵ Fifteen of the neutrons produce nonfissile uranium-236.

²⁶ The neutrons that are absorbed form higher plutonium isotopes, including plutonium-240, plutonium-241, etc.

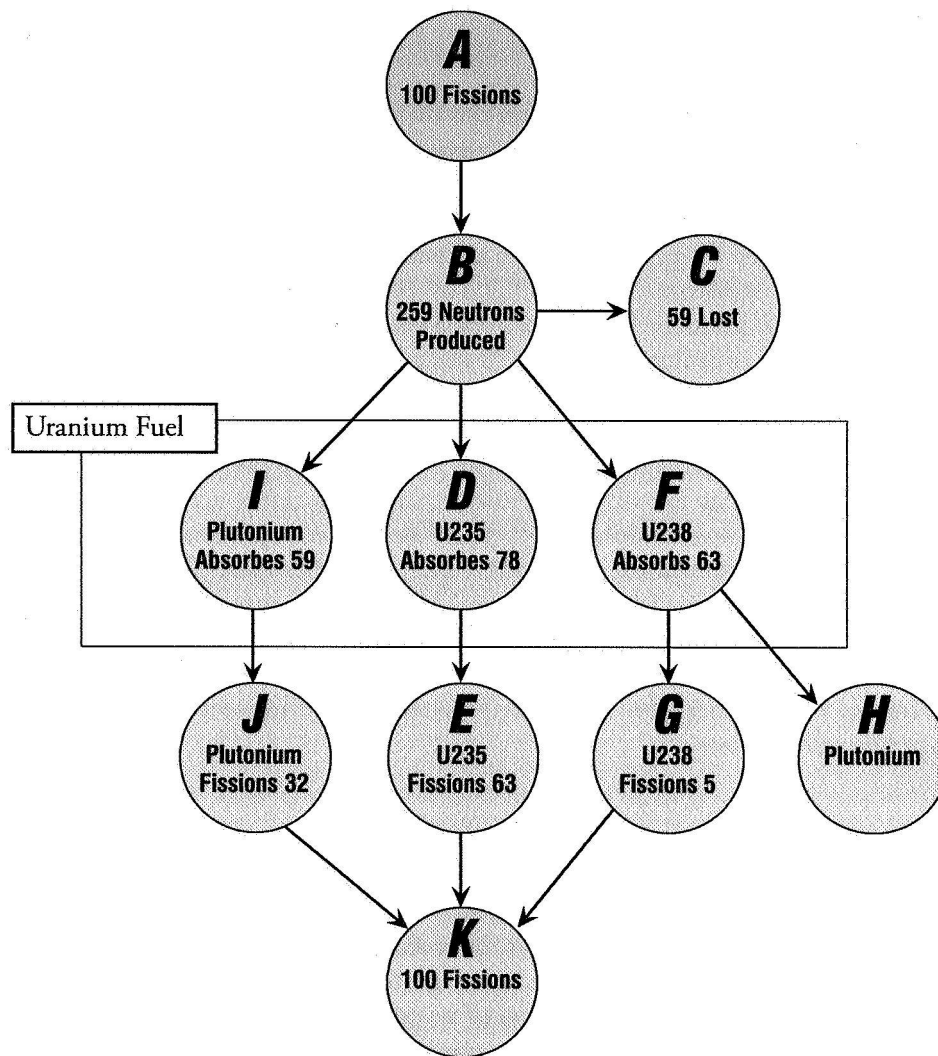


Figure 1: Diagram of the atomic stages of the fission

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for research. The term *neutron flux* describes the number of neutrons that cross a particular area (a square centimeter) over a given time. It essentially refers to the density of neutrons and is an extremely important measure of the efficiency of a test reactor.

The second type of pile converts the energy produced into usable forms. This is the purpose of *power reactors*. For energy-producing nuclear reactors the pile generates heat, which can easily be converted to other usable forms of energy, such as electricity. This process is accomplished by passing water in the primary loop through the core, which heats the water. The water then proceeds to a heat exchanger or boiler, where the water is converted into steam. The steam is then passed through a turbine, which drives a generator and produces electricity. When the steam leaves the turbine, it goes to a condenser and is returned as water back to the feed pumps. It is in this way that nuclear reactors generate electricity. The nuclear reactor is simply an extremely efficient steam generator, and it is this process that is the basis for all energy-producing reactors.

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. The fuel can be a variety of isotopes, as mentioned previously, including uranium-235, uranium-238, or plutonium. The fuel can also take the form of a number of shapes since all of the fuels are metallic and can be worked like any other metal. These shapes include tubes, balls, sheets, long rods, or short slugs. They can also be powdered or alloyed with other metals.

A *reflector* surrounds the core, which is a thin blanket of material. Its function is to prevent neutrons from leaving the pile by keeping them close to the core. The reflector can save some of these neutrons, but some do escape and leak out of the pile. Unlike in other forms of energy production, waste products (the fission fragments) from the reactor process remain inside the fuel itself. This can be a problem because the waste is usually considered a *poison*, since it robs the chain reaction of needed neutrons. Furthermore, the waste products are also highly radioactive, resulting in long-term radioactive contamination.

Shielding is used to contain the radiation around the reactor core. This is usually made up of steel, water, and concrete. These all are able to effectively block gamma, beta, and neutron radiation that results from the chain reaction. One problem with the shielding is that it gets very hot because of the radiation and requires cooling. To reduce the heat, a *coolant* mechanism is used, normally water, to carry away the heat. The shielding is important most of all for protecting people from the dangerous effects of radiation.

There are several ways that all of these design pieces are brought together to make a nuclear reactor. Within the category of research and test reactors there are several subclassifications. *Experimental reactors* and *critical-assembly facilities* are used

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mainly to test design concepts for future (often power) reactors. Although they are essentially for research, they are not built primarily as radiation sources for scientific experimentation. Generally the research reactor is designed simply to produce neutrons for scientific research.

In the 1950s there were four main types of research reactor designs. These included the large graphite pile, the water boiler, the tank type, and the open pool. The *graphite pile* reactors were first used in Fermi's early Chicago Pile-type experiments. They required several tons of graphite, had roughly a 25-foot cubed core, and used natural uranium as the fuel. Although the costs were high, the advantage of this type of reactor was that it had a large amount of space for scientific experiments. *Heavy-water*-moderated reactors also used natural uranium and were smaller than the graphite reactor, but more expensive because of the cost of the heavy water itself. These were soon joined by other design options. *Water boilers* were small reactors that used a *light-water* solution of uranyl sulfate or uranyl nitrate. The main advantage of this type was that it had a low cost and had a small critical mass. The problem was that it produced highly radioactive and corrosive liquids and it was capable of only a moderate power level (30 to 50 kilowatts). The *tank-type* reactor overcame the low power of the water boiler. It used heavy water as the moderator and coolant, which provided a five to ten times greater neutron flux. A similar type was the *open pool* reactor. Essentially in this design the fuel was suspended in a pool of light water, where the water became the coolant, moderator, and shield. The main advantages of this type of design were that it had a low operating cost, the fission products remained in the fuel, and it was extremely flexible for a variety of research purposes. Its main problem was that it had a larger critical mass.²⁷

One of the main concerns in the design of any type of research reactor was how to get the experiments near the core to be exposed to radiation. There were two main types of experimental access to the core. The first was by the use of *beam tubes*. These were horizontal or vertical openings that went through the shield and reflector into the core. The neutron streams could then be sent through the tubes in beams to strike objects outside the core, or experiments could be placed in the tubes themselves. A typical reactor had between 3 and 16 beam tubes that were under a foot in diameter each. A second approach was the *rabbit tube*. These were small tubes inside which materials could be placed and then shot hydraulically or pneumatically through small beam tubes toward the core, where they were irradiated for a specified length of time.²⁸

²⁷ William M. Breazeale, "Research Reactors: Selection and Operation," *Nucleonics* (November 1956): 77.

²⁸ Marvin Fox, "Use of a Reactor for Research," *Nucleonics* (June 1953): 46–48.

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Despite the ability to direct radiation through the use of beam holes, there were some results of the radiation that could not be controlled. For example, the radiation was harmful to the reactor equipment itself because of a phenomenon called *radiation damage*. This phenomenon was discovered in 1946 by Eugene Wigner and was known as the Wigner Effect.²⁹ What made this problem more difficult was that the damage occurred to the materials before any direct observations could be made. Radiation damage occurred every time that radiation interacted with matter.³⁰ The interaction caused several things to happen, including the displacement of atoms from their equilibrium positions, the creation of temporary high-temperature regions, the introduction of impurities due to decay, and the breaking of chemical bonds and the formation of free radicals.

D. Other Research Facilities at Plum Brook

The Plum Brook Reactor was only one of the various test facilities at Plum Brook Station. All of its main testing facilities were completed in the 1960s for a total cost of \$120,886,712.³¹ The Spacecraft Propulsion Research Facility (B-2) was one of its most unique and important facilities. Completed in 1968 at a cost of \$14,633,348, it was capable of testing space vehicles, especially upper stage rockets like the Centaur, in a simulated space environment. The large vacuum test chamber could accommodate vehicles as large as 22 feet in diameter and 50 feet in length. The facility stood 74 feet high, and it extended 176 feet below ground.³² It could simulate the cold temperatures of space and heat from the sun that a spacecraft encountered while orbiting 100 miles above Earth. These temperature conditions were possible while the engines were firing, which replicated the actual operating conditions in space. The liquid nitrogen-cooled walls could reach temperatures of -320°F found in space, and quartz-lamp thermal simulators mimicked the heat of the sun. Its program accomplishments included test firing of the improved Centaur, secret Air Force rocket plume studies, and federal records recovery (drying out 40

²⁹ E. P. Wigner, *Journal of Applied Physics* 17 (1946): 857.

³⁰ F. Steitz, *Discussions Faraday Society* 5 (1949): 271.

³¹ "Plum Brook Station Research Facilities," 10 January 1986, Box 106, Folder 1, Plum Brook Archives.

³² Interview with Robert Kozar by Virginia Dawson and Mark D. Bowles, 20 March 2000.

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truckloads of vital federal records that were nearly destroyed in a flood).³³

The Cryogenic Propellant Tank Site (K-Site) was converted in 1965 from an unused steam power plant building that was left over from the Plum Brook Ordnance Works days. At a cost of \$438,195 the renovations included removing all of the power plant equipment and replacing it with a 25-foot-diameter spherical tank with an access door that had a 20-foot diameter.³⁴ The tank was a test chamber for liquid hydrogen rocket fuel tanks. This was important because deep-space endeavors required high-energy cryogenic fuel that had to be stored at very low temperatures, -425°F. This facility became essential for testing insulation systems and for determining pressurizing gas requirements. During a test a 10,000-pound hydraulic actuator shook the rocket tank fuels, which provided essential experimental data.³⁵

The Controls and Turbine Test Site was originally developed to test research turbines. These turbines were used to power rocket propellant pumps for chemical and nuclear engines. Later this facility was used for developing and testing control systems for other Plum Brook test sites. It provided the electrical, pneumatic, and hydraulic power these sites required. Another feature of this facility was a very small space simulation chamber. It could test system components in a high vacuum and at very low temperatures, to -300°F.

The Rocket Dynamics and Control Facility (B-3) was the tallest building at Plum Brook at 200 feet. It was used for altitude tests for large rocket engines destined for interplanetary travel. For example, it tested the structural integrity of the Centaur-Viking spacecraft and its protective shroud. In front of the facility was a 200,000-gallon liquid hydrogen tank. It also played a part in NERVA experiments with turbo-pump tests and feed systems work.

The 144-foot-tall Dynamics Research Test Center (E Site), also called the “shake tower,” was the second tallest building at Plum Brook. It was equipped with electromagnetic shake devices that could simulate the various forces encountered by spacecraft both during launch and while in flight. This site played an essential role in testing the Atlas-Centaur rocket and providing the data necessary to ensure that the rocket would survive the forces of its own launch. Before the first controlled landing on the Moon in the Surveyor program, this facility tested an entire Centaur rocket, mated with an Atlas, along with a test model of the Surveyor spacecraft.

The Liquid Hydrogen Pump Site was used to test a variety of designs for liquid

³³ “Simulators Expand Space Role,” *Lewis News* (10 October 1969), Glenn Research Center Archives.

³⁴ “Plum Brook Station Research Facilities,” 10 January 1986, Box 106, Folder 1, Plum Brook Archives.

³⁵ “Plum Brook Station Tour Brochure,” unprocessed Plum Brook Archives.

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hydrogen research pumps. These pumps could be tested at various speeds of up to 60,000 revolutions per minute. The data were then used to help design liquid hydrogen pumps for both chemical and nuclear rockets. The liquid hydrogen itself was shipped to the research pump in 34,400-gallon railroad dewars.³⁶ The Hydraulics Lab recorded data on cryogenic and other liquids as they passed through various test setups. The cryogenic liquids were low-temperature fluids such as liquid hydrogen and liquid nitrogen. The experiments yielded new information about fluid flow conditions. Other tests used an experimental water-to-liquid-hydrogen heat exchanger.

The Control and Instrument Building was a reinforced concrete structure that housed the control equipment and data-recording instruments for five Plum Brook test sites. Over 13,500 electrical lines, looking like a gigantic spider's web, entered the building. This was an important site because, due to the danger posed by many of the Plum Brook tests, no one was actually permitted on the grounds of the testing facility itself. Engineers retreated to this control building to remotely monitor by closed-circuit television and then operate the experiments. A second Control and Instrument Building was required for the Hypersonic Tunnel Facility, the Rocket Engine Dynamics Facility, and the High Energy Rocket Engine Research Facility.

The Hypersonic Tunnel Facility was completed in 1966 at a cost of \$6,088,179.³⁷ It was capable of creating air velocities and temperatures that simulated flight speeds of seven times the speed of sound at an altitude of 120,000 feet. The 10-foot-diameter and 40-foot-high heat exchanger could heat 128 pounds of nitrogen gas per second to 4,000°F. The test chamber itself was 25 feet in diameter and 21 feet high. Its primary research area was the Hypersonic Ramjet Program based out of Langley. This facility enabled engine firings tested at Mach 5, 6, and 7. The High Energy Rocket Engine Research Facility (B-1) was constructed to test propellant systems at altitude conditions. It was capable of various types of research, including turbo-pump tests, examination of fluid instabilities in the engine flow passages, and equipment performance evaluations. It was used to evaluate the Centaur rocket and the NERVA rocket.

The Turbo Pump Site (C-Site) supported research on liquid hydrogen turbo-pumps and pump inducers. One of the main investigations was an exploration into the development of a pump that could efficiently operate in boiling hydrogen. The pump inducer was submerged in a 2,500-gallon stainless-steel, vacuum-jacketed,

³⁶ "Plum Brook Station," The Charles E. Frohman Collection, Rutherford B. Hayes Presidential Center Archives.

³⁷ "Plum Brook Station Research Facilities," 10 January 1986, Box 106, Folder 1, Plum Brook Archives.

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liquid hydrogen tank.

The Fluorine Pump Site tested liquid fluorine pumps that were capable of speeds of up to 20,000 revolutions per minute and flow rates of 50 pounds per second. Fluorine was the most active oxidizer and was very important for developing efficient chemical rockets. This was the first high-pressure fluorine pump facility in the United States.³⁸ The Oxidizer Hydraulics Lab enabled further research on high-performance oxidizers like oxygen and fluorine. Since both could violently react with other materials, the oxidizer system components had to be tested before the engines were actually constructed. This lab consisted of a 38-foot-diameter containment vessel that housed a research test loop where materials could be evaluated while they were being exposed to liquid fluorine or liquid oxygen at 1,200 pounds per square inch, at temperatures as low as -300°F .

Of all of the testing sites at Plum Brook the Space Power Facility (SPF) attained the widest international acclaim and use because it was the largest controlled-environment test chamber in the world (100 feet in diameter and 122 feet tall, a high-vacuum volume of 800,000 cubic feet).³⁹ The SPF was completed in 1968 and was the most expensive facility at Plum Brook, constructed for \$30,601,890.⁴⁰ It was also the only large vacuum chamber in the United States that was capable of testing nuclear reactors. It was surrounded by a 6- to 7-foot concrete shell that enabled a 15-megawatt nuclear reactor to operate safely.⁴¹ However, this capability was never utilized, and only non-nuclear tests were ever conducted within the massive structure. Inside the chamber, spacecraft and their subsystems could be evaluated in a simulated space environment. Giant 50-foot by 50-foot doors permitted large rockets to be wheeled inside. It was the last of the Plum Brook facilities to be built when it was finished in 1969. Its key accomplishments included a Skylab shroud test, a Shuttle base heating experiment, and a Titan-Centaur shroud and liquid oxygen test. One additional site, the Engineering Building, housed the main administrative activities at Plum Brook. It also included a cafeteria, classrooms, a library, and an assembly area.

³⁸ "The 1973 Plum Brook Station Nature Tour," The Charles E. Frohman Collection, Rutherford B. Hayes Presidential Center Archives.

³⁹ "Capabilities and Facilities of the Plum Brook Station," NASA-Glenn Research Center unprocessed records.

⁴⁰ "Plum Brook Station Research Facilities," 10 January 1986, Box 106, Folder 1, Plum Brook Archives.

⁴¹ "Simulators Expand Space Role," *Lewis News* (10 October 1969), Glenn Research Center Archives.

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3. Interviews Conducted for this Book

Name Position at Plum Brook

John Acomb, Instrument Development Section, Head
H. Brock Barkley, Plum Brook Reactor Facility, Chief
Eric Bertrand, Operations Supervisor for Decommissioning, Mota Corp.
John Blakeman, Plum Brook Restoration Advisory Board, member
Jim Blue, Radiations Physics Branch, Chief
Donald Bogart, Reactor Physics Branch, Chief
Jan Bohne, Plum Brook Restoration Advisory Board, member
Mark Bohne, Plum Brook Restoration Advisory Board, member
Steven Borbash, Reactor Operations Section
Earl Boitel, Experimental Equipment Section
Jack Crooks, Process Systems Section
A. Bert Davis, Plum Brook Reactor Facility, Chief
Robert DeFayette, Radiochemistry Section, Head
Robert Didelot, Operations Branch, Shift Supervisor
Lee Early, Laboratory Analysis
Harold Finger, Space Nuclear Propulsion Office, Manager
Tom Fox, Experimental Reactor Physics Section, Head
Harry Gerard, Field Supervisor, Mota Corporation
Jim Greer, Control Room, Operator
Ruth Hasse, Facility Secretary for Plum Brook Reactor
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