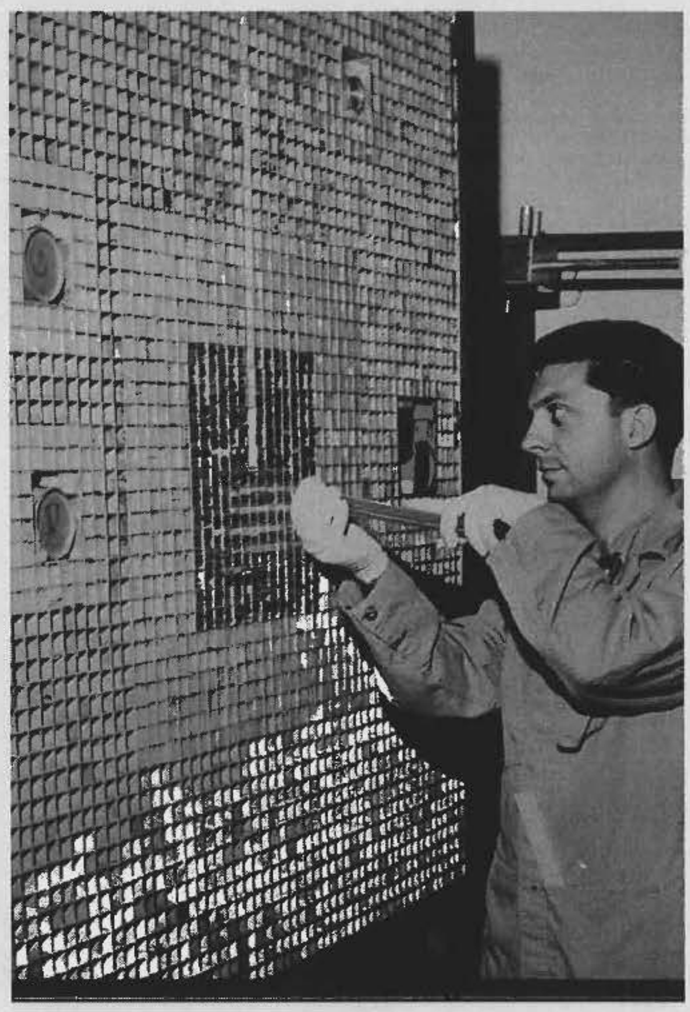
FUSRAP-13

Combustion Engineering, Inc.
Windsor, Connecticut

Critical Facilities Building No. 1
Critical Assembly Building No. 2



Prepared for:
Combustion Engineering, Inc.
2000 Day Hill Road
Windsor, CT 06095

Prepared by:
Historical Technologies
1230 Copper Hill Road
West Suffield, CT 06093

COMBUSTION ENGINEERING, INC. - BUILDINGS 1 AND 2

Location:	2000 Day Hill Road (formerly 1000 Prospect Hill Road) Windsor Hartford County Connecticut
UTM:	USGS Windsor Locks, Connecticut Quadrangle, 1:24000 UTM Coordinates: Zone18 - Easting 689575 - Northing 4639425
Date of Construction:	1956
Engineers:	Stone & Webster; Combustion Engineering, Inc.
Present Owner:	Combustion Engineering, Inc.
Present Use:	Demolished
Significance:	Building #1 housed the Flexible Critical Experiment, a research reactor that operated at a virtually zero power level. The reactor first achieved a self-sustaining nuclear chain reaction in July, 1956. Building #2 was the site of the Advanced Critical Experiment, a research reactor for complex developmental work. This reactor achieved a self-sustaining nuclear chain reaction in November of 1956. Finalized specific engineering and physics design of individual reactors were carried out in these facilities.
Project Information:	This documentation commenced in 2002 in compliance with a Letter of Agreement between ABB Prospects, Inc. and the Connecticut Historical Commission.
Historian:	Robert C. Stewart - Historical Technologies - West Suffield, Connecticut
Acknowledgement:	The author wishes to thank Elaine Hammick and John Conant of Combustion Engineering, Inc. for their efforts in obtaining historic materials and for their reviews of the final report. A taped interview with Richard Knapp, retired engineer, contributed useful insight into the working environment at the site.

Cover Photograph: Technician charging experimental reactor mock-up in building No. 1, circa 1956

CONTENTS

INTRODUCTION:

This report focuses on the nuclear activities of Combustion Engineering, and particularly on the significance of Buildings #1 and #2 at the company's Windsor facility. To appreciate the context of what was accomplished at Windsor, a review of the company's history and particularly the events that prepared it to be a major supplier of components for the nuclear power industry and submarine reactors is desirable. The development of technology for producing steam power produced expertise that was essential for producing reactor vessels and other nuclear components.

A Brief History of Combustion Engineering, Inc.

The oldest component of the company that ultimately became Combustion Engineering, Inc. was the Heine Boiler Company starting its operation in 1882.[1] However, while Heine's origin preceded that of other corporate components, it did not become a part of the company until other acquisitions had established a more linear genealogy. Consequently, the origins of Combustion Engineering, Incorporated are generally considered to be rooted in a company called the Locomotive Superheater Company, a Delaware corporation incorporated on October 25, 1912. The companies that formed Combustion Engineering and when they were acquired are shown in Figures 1a through 1e.

As with most business ventures, Combustion's success was based on fulfilling market needs. Combustion's predecessor developed a successful railroad engine superheater during a period of rapid growth in railroading. The theory of superheating steam to increase engine efficiency went back to the inventor of the steam engine, James Watt, and was an important contribution to efficiency in the Cornish pumping engine. Essentially, in a superheated steam engine the steam passed through a heat exchanger on its way to the cylinders. This raised the temperature of the steam, limited the amount of condensation on the cylinder walls and contributed to engine

---

1 C-E Experience. C. 1980 - Manuscript, p.1. Corporate Archives, Combustion Engineering , Windsor, Connecticut

efficiency. Unfortunately, the higher temperatures also reduced the life of the packing materials and vegetable oil lubricants available in the early 19th century. Improved materials and mineral oils developed in the 1850s made superheating practical and it became accepted after 1859, especially in Great Britain on stationary engines. [2]

Superheating was not utilized on locomotives; requirements dictated that speedy mobile engines run on high-pressure steam that was exhausted up the smokestack to increase draft. The design emphasis was on weight reduction. Frequent coaling stations and water tanks minimized the need for hauling heavy fuel and water supplies. The pre-eminent manual for locomotive design during the waning years of the 19th century was Modern Locomotive Construction, published in 1892. This comprehensive volume makes no mention of superheating.[3] Yet, if a lightweight superheater were available, railroads would be able to glean significantly more heat from fuel and produce more power at greater efficiency.

The Locomotive Superheater Company designed a superheater for steam locomotives that soon became standard for the industry. In 1913 the company set up a manufacturing plant in East Chicago, Indiana and by 1917 began to build superheaters for stationary boilers.[4]

Another company, Combustion Engineering Corporation, formed in 1914 with the merger of two fabricators of fuel burning equipment - the American Stoker Company and the Grieve Grate Company. By the early 1920s Combustion Engineering absorbed several companies involved with coal burning technology. The Locomotive Pulverized Fuel Company, the Coxe Traveling Grate Company, Coshocton Iron Company, and the Green Engineering Company formed the components that made up a major company involved in solid fuel combustion. By 1923 the

---

2 Louis C. Hunter. Steam Power (Charlottesville, Virginia: University Press of Virginia, 1985), 674.

3 J.G.A. Meyer. Modern Locomotive Construction (New York: John Wiley and Sons, 1892).

4 Maria Miranda, , ed., "The First Fifty Years," Combustion Engineering World, October/November, 1987, 4.

Raymond Brothers Impact Pulverizer Company joined Combustion and enabled the company to supply complete coal pulverizing systems. In the late 1920s Combustion bought the Heine Boiler Company and the manufacturing facilities of the Hedges-Walsh and Weidner Boiler Company in Chattanooga, Tennessee. These acquisitions positioned the company to supply completely integrated solid fuel combustion systems.

The stock market crash and dearth of investment capital caused by policies of the Federal Reserve Board brought the company into receivership on December 19, 1929. The Locomotive Superheater Company was still in excellent financial shape and proposed to reorganize Combustion Engineering and take it out of bankruptcy. On August 1, 1933 Combustion became a subsidiary of the Locomotive Superheater Company.[5] While the technology of solid fuel combustion was advanced during the 1930s with development of regenerative air pre-heaters and high-efficiency coal pulverizers, business during the Great Depression was stagnant. World War II pulled the company and the country out of the business doldrums. The company supplied about 5000 steam generator plants for the Liberty ships that formed a supply line to the various theaters of war. Combustion boiler systems powered about half of the boilers that the U.S. Maritime Commission required during the war.[6]

Most of the company's activities during World War II focused on production rather than research and development. A 1939 steam generator design using pumps to aid circulating water and steam through the boiler tubes evolved into the controlled circulation boiler that was sold to utilities starting in 1949. In 1946 research started on the feasibility of nuclear power generation. Because of its production technology in manufacturing large welded pressure vessels and the ongoing nuclear research, Combustion was positioned to become a major supplier of nuclear power plant components. The company's first nuclear contract was for design and fabrication of oil-fired

5 ibid., 4.

6 ibid., 6.

heaters for melting sodium for the heat transfer agent in an experimental reactor. It was positioned to be a major contractor in the nascent nuclear energy industry.

During this period the company was known as Combustion Engineering-Superheater, Inc. The Superheater Company was fully merged into Combustion on December 31, 1948. By 1953 the company took the name Combustion Engineering, Inc.[7]

Historical Perspective of Nuclear Science and Energy in the United States

Before detailing Combustion Engineering's activities and accomplishments in the nuclear energy industry, an understanding of the theory and experiments that led to the exploitation of this source of energy is useful. In 1905 Albert Einstein theorized that $E=MC^2$, energy equals mass multiplied by the speed of light squared. The radical concept that mass could be converted to energy, almost limitless energy, was one of the most significant scientific ideas of the 20th century. In the early years of the century it was pure theory, there was no practical way of extracting energy from mass. By 1933 the prospect of producing nuclear energy still looked dim; Sir Ernest Rutherford, perhaps the most noted physicist of the period flatly declared, "The energy produced by the breaking down of the atom is a very poor thing. Anyone who expects a source of power from the transformation of these atoms is talking moonshine." [8]

Still, a number of brilliant experimental scientists continued to discover the fundamental properties of atoms and built up a body of work that enabled engineers to develop practical techniques for extracting nuclear energy. By the fourth decade of the 20th century some of the particulate composition of atoms including electrons, neutrons and protons was understood. In Germany, Otto Hahn, Fritz Strassmann and Lise Meitner determined that the uranium nucleus could be split into two smaller nuclei by bombarding it with neutrons. The experimental results

7 ibid., 7

8 Edward Edelson. The Journalist's Guide to Nuclear Energy. Washington, DC: NEI, 1994, 1.

found barium in residue from an experiment in which they had bombarded uranium with neutrons from a radium-beryllium source. Results indicated that uranium atoms bombarded by neutrons split into two different elements, each approximately half the mass of the uranium. The phenomenon was named "fission." Meitner added the atomic masses of the residual elements and found that the total was less than the atomic mass of uranium. Some of the mass of the uranium had vanished. Meitner and O.R. Frisch theorized, consistent with Einstein's theory of relatively, that the mass that disappeared was converted to energy. Einstein's theory predicted that this energy release would be approximately 200,000,000 electron volts for each atom fissioned.[9]

The Hungarian physicist Leo Szilard theorized that a uranium nucleus undergoing fission expelled several additional neutrons from itself. These neutrons bombarded other nuclei that in turn released additional neutrons creating a self-sustaining "chain reaction." Possibly, if this reaction occurred quickly enough, an enormous amount of energy would be released explosively. Could the release of energy be controlled? Could this energy be utilized in a weapon? Much of the atomic work prior to World War II, influenced by the context of the coming global conflict, was directed at weapons research utilizing the destructive power of fission.[10]

Walter H. Zinn, who eventually went on to be a major contributor to Combustion Engineering's nuclear programs, and Leo Szilard began experiments to quantify the number of neutrons emitted by fissioning uranium on February 27, 1939.[11] Concurrently, Enrico Fermi, Herbert L. Anderson and H.B. Hanstein probed the same problem. The results of these investigations confirmed that uranium emitted additional neutrons that might sustain a chain reaction.[12]

---

9 "Years of Preliminary Research" 2003 http://www.atomarchive.com/history/fermi/firstpile_02.shmtl

10 ibid., Edelson

11 "Enrico Fermi" 2003 http://www.atomicarchive.com/reports/Form/firstpile_03.shmtl

12 ibid.

By 1939 the Italian, Enrico Fermi had produced encouraging results that indicated that a sustained, fission reaction could be achieved. During 1941 his team, working at Columbia University, were developing a slow-neutron chain reaction in uranium and graphite.[13] Part of the project involved obtaining materials of sufficient purity so as not to interfere with the reaction. Much of the commercially available graphite was contaminated with boron, a neutron absorber and reaction poison. During August and September preparations went forward to build a large graphite-uranium lattice. The volume of uranium and graphite moderator in such a reactor has to be sufficient enough to maintain neutron multiplication in spite of losses of neutrons from the surfaces and neutron absorption. The volume required to accomplish this was not known-except that it had to be large - in the order of hundreds of tons. Simply stacking graphite and uranium plaques together would be dangerous - an uncontrolled reaction might occur. Fermi ran a series of subcritical experiments with the objective of quantifying the amounts and spacing of the components and developing control and shutdown methods.[14]

Several configurations were evaluated. Graphite in the form of extruded bars and bricks were tried. Uranium oxide powder contained in evacuated cans of tinned iron sheet and later compressed in baseball sized spheres underwent evaluation. The final experiment before the laboratory was moved to the University of Chicago used cylinders of compressed uranium oxide three inches long by three inches in diameter and weighing four pounds. These were inserted into blind holes drilled in graphite blocks. Walter Zinn developed the pressing techniques and stainless steel dies for the cylinders.[15]

The Work of Walter H. Zinn - Major Contributor to Combustion's Nuclear Program

13 Rhodes, Richard. The Making of the Atomic Bomb. New York: Simon & Schuster, 1986, 394.

14 ibid., 395.

15 ibid., 401.

Walter H. Zinn was born in Kitchener, Ontario in 1907. His first degree, in mathematics, was obtained form Queen's University in Kingston, Ontario and he started out his professional career as an actuary in an insurance company. He was fascinated by laboratory experimentation and left insurance to study physics at Columbia University. Columbia University granted Zinn a Ph.D. in nuclear physics in 1934 and he joined the faculty at City College of New York and collaborated with Leo Szilard and Enrico Fermi on investigating nuclear chain reactions. He was a member of the team Enrico Fermi assembled to develop an atomic bomb under the Manhattan Project.[16] As a team member, Zinn supervised all phases of construction of the first atomic pile at the University of Chicago and actually started up the reactor by withdrawing the control rod that allowed the reactor to achieve the world's first self-sustaining nuclear reaction. In the sources used for this report, Zinn frequently appears as the team member who was responsible for coordinating much of the effort between the scientists and the firms that contracted to do the actual fabrication work. His contributions exhibit a unique blend of scientific, engineering, technical and managerial skills. On December 2, 1942, Zinn went on to design breeder reactors, and his boiling water reactor design served as a prototype for subsequent commercial reactors.

On July 1, 1946, Walter Zinn was appointed first director of the Argonne National laboratory. At the laboratory he oversaw and participated in a number of critical projects. Argonne National Laboratory was the new name for the Manhattan Engineering District's Metallurgical Laboratory. On October 31, 1946, The University of Chicago assumed operational control over Argonne and on January 1, 1947 jurisdiction and sponsorship passed to the Atomic Energy Commission (AEC) while the University of Chicago continued to operate the laboratory. This arrangement

---

16 "Chicago Pile One Scientists" 2003 http://www.atomicarchive.com/reports/Form/firstpile_03.shmtl The scientists and engineers present at the first self-sustaining nuclear reaction were: Harold M. Agnew, Samuel K. Allison, Herbert L. Anderson, Wayne Arnold, Hugh M. Barton, Thomas Brill, Robert F. Christy, Arthur M. Compton, Enrico Fermi, Richard J. Fox, Stewart Fox, Norman Hilberry, Harold Lichtenberger, Leona Woods Marshall, Robert G. Nobles, Warren Nyer, William Sturm, Leo Szilard, Albert Wattenberg, Marvin Wilkening, and Walter H. Zinn.

continued until 1975 when Argonne and the AEC were absorbed into the Department of Energy. At the end of 1947, Argonne received approval to develop a nuclear submarine power plant.

The same year also saw the design of a liquid-metal-cooled, fast neutron reactor, known as "Chicago Pile 4" or "Zinn's Infernal Pile." Officially it became known as EBR-1. By 1951 experiments and development work with EBR-1 resulted in it's being the first nuclear reactor to produce electric power. It was also the first reactor to demonstrate the breeding principle, producing more nuclear fuel than it consumed.

In 1948, Zinn proposed establishment of a national reactor proving ground which, when created in 1949, was named the National Reactor Testing Station. Located in Idaho, this facility along with several others came under the jurisdiction of the Department of Energy on October 1, 1977. It is currently designated the Idaho National Engineering and Environmental Laboratory (INEEL).[17]

At the end of 1948 Zinn established the Naval Reactor Division at Argonne Laboratories and by March of 1949, Zinn and his staff of scientists and engineers determined that a water-cooled reactor was key to a successful naval reactor. In 1956 Zinn left the Argonne lab directorship and, on August 30, 1956, formed General Nuclear Engineering Corporation, a Delaware Corporation based in Florida as a foreign[18] corporation. This company was bought out by Combustion Engineering and was the genesis of Combustion's commercial nuclear program. It operated as a wholly owned subsidiary and completed a merger with Combustion on September 4, 1964, finally filing a certificate of dissolution in Florida on July 27, 1971.[19] Much of Combustion

17 Idaho National Engineering and Environmental Laboratory: http://www.inel.gov/about/historical.shtml

18 As used in the terminology of American State Corporate Registrars, a "foreign" corporation is one incorporated in another state as well as in another country.

19 Documents #811260 - 818291. Florida Secretary of State: http://www.sinbiz.org/corpweb/inquiry/

Engineering's work in nuclear power development can be traced to the company's association with Walter Zinn. In 1959 Combustion Engineering bought Zinn's company, General Nuclear Engineering.[20] Zinn, who had incorporated a Florida-based consultancy to develop nuclear power technology, merged his company with Combustion Engineering's operations in Windsor, Connecticut. Zinn was named Combustion's Vice President/Research in addition to maintaining his nuclear oversight responsibilities. Zinn retired in 1970 and died on February 4, 2000 in Clearwater, Florida at the age of 93.[21]

Fundamentals of Nuclear Power

Basically a nuclear power plant works on the same principle as a power plant fueled by fossil fuel. The fission of uranium produces heat that boils water to produce steam; the steam is directed on to the blades of a turbine causing the turbine to rotate. The rotational force then turns a generator, producing electricity or is directly coupled to a propeller. Instead of coal, oil or gas, the source of heat comes from the energy released from the splitting of the nucleus of a uranium atom.

There are three major principal particles in an atom. Its central part, the nucleus, is made up of protons, particles having a positive charge, and neutrons, particles that are uncharged. Particles having a negative charge, called electrons, spin around the nucleus. The electrons are maintained in orbit around the nucleus by an electrical force. The positive charge of the protons attracts the negative charge of the electrons. A stronger force, the nuclear force, holds the protons and neutrons together. When a nucleus undergoes fission or splits, this nuclear force is released as heat energy.

---

20 Presentation - Combustion Engineering Today - at Security Analysts of San Francisco by Arthur J. Santry, Jr. (December 7, 1967). Archives, Combustion Engineering, Windsor, Connecticut.

21 Argonne National laboratory website: http://www.anl.gov/OPA/logos18-1/zinnobit.htm

When a neutron strikes and is absorbed by the nucleus of a Uranium-235 atom, fission occurs. That atom becomes unstable and it quickly splits into two or more smaller atoms called fission products. Heat is released in this reaction as well as radiation and two or three more neutrons. Other Uranium-235 atoms can absorb these neutrons, causing them to split. The fissioning becomes continuous producing a "chain" reaction.

For the neutron to cause fission, it must be slowed down so that the Uranium-235 atom can absorb it. A "moderator" causes the neutrons to slow down by absorbing some of their energy and reducing their speed. This process of slowing down the neutron is essential to the process. If the neutron is traveling excessively fast, the nuclear forces within the U-235 atom would be insufficient to capture it and it will pass by the nucleus.

In many nuclear power plants the water that is heated by the reactor is also used as the moderator. Additionally, other neutron absorbing materials must also control the fission process. These materials, for example, Boron or Cadmium, are integral elements of control rods that can be inserted or withdrawn from the reactor to regulate fission by absorbing neutrons.

Combustion Engineering and Nuclear Power

The most significant single technological decision Combustion Engineering made after WWII was to enter the nuclear power field. In 1946 management authorized feasibility studies in nuclear power generation. Combustion Engineering became a major supplier of nuclear components as the result of this study and its experience in large welded pressure vessels.[22] The first contract was placed by General Electric for the design and fabrication of oil-fired sodium heaters for a sodium-cooled experimental reactor. In 1951 the U.S. Navy contracted with Combustion Engineering to produce a sodium-cooled reactor vessel and other components for

---

22 Presentation - Research and Development at Combustion Engineering, Inc. by Robert H. Pry, Vice President for Research and Development (June 1977). Archives, Combustion Engineering, Windsor, Connecticut.

the Seawolf, the world's second nuclear submarine. In 1953, President Eisenhower announced the "Atoms for Peace" plan to promote the spread of peacetime nuclear technology and Combustion's Nuclear Power Division was established.[23] This led to a number of firms competing for design, evaluation and construction projects for the Atomic Energy Commission. Combustion Engineering received the contract for the reactor vessel for the Shippingport Nuclear Power Plant, the world's first commercial-scale nuclear electric plant. The company contracted to design and build a reactor vessel for the first commercial sodium fast breeder reactor in 1955. This very complex unit was delivered to the Enrico Fermi nuclear power plant near Detroit in 1958.

In the early 1960s Walter Zinn of Argonne National Laboratories had built and operated the Experimental Boiling Water Reactor (EBWR) near Chicago. Sam Untermeyer, who was directly in charge of the EBWR design, left Argonne and received a position at General Electric. Untermeyer and Bruce Prentice designed the Dresden-1 reactor that GE sold to Commonwealth Edison for the Shippingport plant. GE contracted to build a nuclear power plant at $250 per kilowatt or absorb any costs beyond that. Dresden-1 became the first commercial nuclear power plant in the United States, beating out Westinghouse's Yankee Rowe plant by a few months.[24] Unconvinced as to which design was best, Untermeyer and GE developed a reactor that could run either as a boiling water reactor or as a pressurized water reactor (BWR or PWR). This was called a dual-cycle-boiling reactor.

Combustion Engineering entered the nuclear power field as a result of management decisions to continue serving its traditional market, the electric utility industry. Combustion had developed pressure vessel designs and manufacturing techniques for its boiler business. The company had

23 "C-E History." September 10, 1979 - R. Reimer - Manuscript. Corporate Archives, Combustion Engineering, Windsor, Connecticut, 16.

24 John W. Simpson. Nuclear Power from Underseas to Outer Space. (LaGrange Park, Illinois: American Nuclear Society, 1995), 161.

the ability to fabricate heavy pressure vessels and had developed advanced welding and machining techniques. Combustion had expertise in metallurgy and the capability for managing complex development projects. This background was instrumental in qualifying the company as a major contender in nuclear power plant development. As its technological expertise in the nuclear energy field increased, Combustion Engineering evolved into a major contractor for the U.S. Navy's nuclear reactor development program. In 1955 Combustion Engineering won a contract to build its first complete nuclear steam supply system to be installed in the submarine SSN Tullibee.[25] That same year the company bought its Windsor, Connecticut site, occupying it one year later. The facility location, site boundary lines and plan are shown in Figures 2, 3 and 4. Starting in 1960 the company increased its involvement in the nuclear power business. By 1967 Combustion's shops were at capacity fabricating heavy nuclear reactor components and the company was noted as the foremost supplier of commercial reactor vessels. They were also one of five U.S. suppliers of nuclear fuel.

Combustion delayed entry into the market for nuclear steam supply systems (NSSS) until 1965, when the market had developed sufficiently to warrant additional suppliers. They received the first order for a nuclear steam supply system early in 1966. [26]

Development of a Reactor for Submarines

In 1955 Combustion Engineering contracted with the U.S. Navy to build a prototype nuclear power system for an attack submarine. Completed in 1959, the S1C reactor system, with a rated power output of 33 megawatts, operated as an U.S. naval training facility until finally shut down

---

25 "C-E History." September 10, 1979 - R. Reimer - Manuscript. Corporate Archives, Combustion Engineering, Windsor, Connecticut, 17.

26 The contract was for an 821-Mw unit for the Palisades Plant of Consumers Power Company in Michigan. It was the first plant to be awarded to a contractor other than General Electric or Westinghouse.

on March 25, 1993.[27] A similar system was designed and built for installation in the U.S. Nuclear submarine Tullibee. (SSN 597). Tullibee was launched on April 27, 1960 and commissioned on November 9, 1960. She was designed as a nuclear-powered hunter-killer attack submarine. This was accentuated by her motto "Venator-Necator" (Hunter-Killer). The Tullibee was the first turbo-electric nuclear sub, a configuration that made her the quietest sub in the world when she was commissioned. However, the turbo-electric drive proved troublesome and the vessel had a reputation of being a "hangar queen." She was frequently designated as "Building 597" by the crew assigned to her.[28] Tullibee was the first submarine to have a large 15-foot spherical sonar array, the complex "AN/BQQ" integrated sonar system. To free space for it her torpedo tubes were placed amidships. The novel sonar design became the basis for all later U.S. SSN designs. The sub was highly automated to minimize crew size. The Tullibee was 272 feet, nine and one-half inches long, with a beam of 23 feet, four inches. She displaced 2,406 tons on the surface. Originally designed for a crew of 50-60 and 7 officers, the disasters and sinking of the subs Thresher/Scorpion forced crew requirements up to 100, making for a cramped accommodation. Her small size and propulsion system made the Tullibee the world's stealthiest undersea vessel. The Tullibee was decommissioned on June 25, 1988 and scrapped at the Bremerton, Washington naval shipyard in 1996.[29]

Nuclear Fuel - General Information

There are several isotopes of uranium atoms. All have 92 protons but differ in the number of neutrons in the nucleus. Naturally occurring uranium is >99% U-238 and <1% U-235. The numbers refer to the total number of protons and neutrons in the nucleus. U-235 nuclei can be fissioned relatively easily by absorbing a neutron. U-238 fissions much less readily. For a fission reaction to be sustainable, there must be a sufficient quantity of isotopes that can undergo

---

27 S1C Prototype Final Shutdown, Windsor, Connecticut: WSO, 1993.

28 Tom Clancy and John Gresham. Submarine. New York: Berkley Books, 1993, 336.

29 "Tullibee Nuclear Hunter Killer Attack Submarine" 2001. www.warships.com/ships.

fission present. The minimum amount of fissile material required to sustain a chain reaction is called a critical mass. The critical mass is influenced by several conditions and reactor design. A reactor must be loaded with an amount of fuel greater than the critical mass. Fission in a reactor loaded with exactly the critical mass would soon run out as the amount of fuel burned to below the critical mass. Reactors are loaded with fuel beyond the critical mass to allow continuous operation for many months without refueling.

Uranium fuel (U-238) for commercial power plants is enriched to contain about 3 to 5%, by weight of U-235 so that a chain reaction can be initiated and maintained. The enriched fuel contains sufficient fissile uranium to maintain a chain reaction. Yet it is not concentrated enough to allow a nuclear explosion. In most nuclear reactors, the uranium fuel is formed into small cylindrical ceramic pellets about one-half inch long by three-eighths inch in diameter. They have a melting point of 5180 degrees F. These pellets are placed in Zircalloy or stainless steel tubing that can resist temperatures of 2100 degrees F. Figure 5 shows the relationship of these components within the reactor vessel.

These tubes filled with uranium dioxide pellets are called fuel rods and are purged with inert helium gas, then sealed. The rods are bundled together with spacers and retaining clips. The bundled assembly must allow free passage of cooling water. As the bundle undergoes thermal expansion and contraction during reactor operation the critical spacing between elements must be maintained. A number of these assemblies are placed in the reactor to form the core. A patent drawing of a Reactor Fuel Assembly is shown in Figure 6.

As fission occurs it produces by-products such as Iodine-131, Krypton-85, Tritium, Strontium-90 and Cesium-137. These are considerably more radioactive than the original uranium dioxide. They emit radioactivity as soon as any fission takes place. The ceramic pellets of uranium dioxide retain the solid fission products while any gaseous products are retained within the metal tubular fuel rods. When the reactor is shut down and the chain reaction is stopped, the fission byproducts continue to produce heat. Consequently, coolant flow through the reactor must continue and depleted fuel rods removed from the reactor core and stored in a pool of water or other heat absorbent medium.

How a Submarine Reactor and Power System Operates

In a nuclear reactor, the heat is generated in the nuclear core, a thick walled pressure vessel containing the fuel rods. Pumps circulate coolant water through the core that is pressurized to prevent the water from boiling. This heated water flows through a heat exchanger, transferring its heat to water contained in a steam generator. The pressurized coolant water flows back into the core while the water on the secondary side of the steam generator boils. The steam formed flows to a turbine that drives the propeller shaft through a series of reduction gears. The rate at which the heat producing reaction occurs is controlled by inserting or withdrawing neutron absorbing rods into or out of the reactor. A simple schematic of a pressurized water reactor is shown in Figure 7. A more detailed schematic showing a submarine nuclear power system is shown in Figure 8.

The Role Assigned to Combustion Engineering-Site Specific Facilities

Windsor, Connecticut was the site of Combustion's Fuel Fabrication Plant. This facility fabricated the nuclear fuel elements for all of CE's Nuclear Steam Supply System requirements, including replacement fuel orders.[30] The site consists of 580 acres on the Farmington River approximately eight miles north of Hartford. Combustion Engineering's facility is in an industrial zone adjacent to areas devoted to commercial, agricultural and residential uses. Considerable sections of the northern and western portions of the property are wooded. The government owns a 10.6-acre portion, more or less centrally located on the site. This was the site known as "S1C" (Submarine 1-Combustion Engineering) and accommodated training facilities for U.S. Navy nuclear submarine operators.

30 "C-E Experience.," 7.

Building # 1

Combustion Engineering's work at the site began with the Atomic Energy Commission's (AEC) contracts directing research, development and manufacturing of nuclear fuel for the United States navy. These contracts also included construction, testing and operation of a naval test reactor, the S1C. Buildings 1, 2, 3, 5, 6 and 6A were built under these contracts for the development, design and fabrication of fuel element subassemblies for U.S. Navy Submarines. Building 1 was specifically built in 1956 to provide space for research and development of nuclear reactor experiments. The building served this purpose from 1956 to 1959. Contracts with the Atomic Energy Commission funded historic experiments including the Flexible Criticality Experiment (FCE) and the S1C. Building 1, known as the "Critical Facilities" Building was the site of the first criticality experiment. The purpose of these experiments was to determine, in the laboratory, the properties of materials used in nuclear reactors, then to use that work as a basis to confirm analytical methodology. Once those properties were determined accurately the materials could be used in subsequent reactors without additional materials investigations.

Building 1 encompassed approximately 4,400 ft^2. It was 100 feet long and 44 feet wide, a one story concrete structure covered with corrugated Transite siding.[31] The building housed three reinforced concrete vaults, a reactor control room, a reactor component assembly area and rooms used to support research and development activities.[32]

Building 1 had a so-called flexible critical experiment, which was a split-bed polyethylene moderated reactor. It was built in two horizontal beds with some heavy-duty springs, so that in the event of an emergency signal from the protective instrumentation, the two beds would spring apart to drop the reactor below criticality. In addition, there were control rods, located in the

31 Transite is a proprietary name for a dense, rigid board containing a high proportion of asbestos fibers bonded with portland cement. It is resistant to fire, flame and weathering. It was available in sheet and corrugated forms.

32 Combustion Engineering, Inc. Drawing No. PEM-1

fixed bed. The flexible critical experiment had the two split-bed feature, but the core of the reactor was essentially a model of the final configuration. The core in this mock-up of a submarine reactor was formed of polyethylene moderators and strips of zirconium. When the beds were moved apart, technicians could access the two faces and load fuel strips into the reactor.

These Building # 1 experiments were necessary for development of the S1C reactor. The concept was to mock up the core of a submarine reactor then use it to develop experimental benchmarks for the various calculational methodologies for demarcating final reactor design. Experiments were conducted for about a year with the reactor first achieving criticality in July of 1956.[33]

After completing experiments for the S1C program, the building was used as a laboratory for the Nuclear Super Heater Program (NUSU). This design featured can-shaped fuel elements, about three inches in diameter. This was an innovative design with the fuel formed as an annulus between an inner and outer cladding, tubes carrying steam ran through the center of the annulus. The steam would be superheated as it passed through the tube. The design reflected some of the early design thinking of Combustion Engineering when it was developing and manufacturing superheaters. While a prototype nuclear reactor was never built using this design, the critical experiments necessary were completed.[34] The plan of Building No. 1 is shown in Figure 9. Another set of criticality experiments developed data for a boiling water nuclear superheat reactor (BONUS). The design centered on a central core boiler with super-heating elements around it. The program was an extension of President Eisenhower's "Atoms for Peace" program. A prototype of this reactor was built in Rincon, Puerto Rico.

33 Richard Knapp. Interview by Robert C. Stewart, 6 March, 2003.

34 ibid.

Buildings # 2 and 2A

Building 2, the Critical Assembly Building, encompassed approximately 24,352 ft^2. The main portion., was a two-story, thirty-five foot high, flat roofed, steel-framed structure covered with corrugated Transite siding. Walls of the test cells at the North end of the building were made of reinforced concrete. The test cells extended below grade about twenty-five feet. The first floor of Section 2 housed the test cells, two control rooms adjacent to the test cells, a vault for storing radioactive materials, a machine shop, instrument shop, a shielded counting room where radioactivity and reactor output were monitored, a pre-assembly room and a men's locker room. Elevations of Building No. 2 are shown in Figure 10.

The second floor contained the upper portions of the test cells, air conditioning rooms, a storage room, men's and women's locker rooms, a lunch room, conference room, six offices and three undesignated areas. A section on the Northeast corner roof supported a tower that was not part of the original structure. It housed a crane for lifting components and rose 60 feet above the roofline over a portion of Test Cell #2. The Building No. 2 footprint was approximately square in shape and encompassed about 9457 ft^2 on each floor.[35]

Building 2A was a high bay area immediately North of Building 2, built in 1978 and connected to it by a fifteen-foot wide passageway. It was about eighty-one feet on the Northern side and sixty-two feet on the East and encompassed approximately 5078 ft^2. The building contained a square pit about 14 feet on a side and 8 feet deep in a flat concrete floor near its northern wall. It was framed in steel and sheathed in corrugated metal sheathing. The high bay had a ridge roof with a ridgeline running an East-West direction. Height of the building was approximately forty-five feet at the plate. It provided a large open area in which to assemble components.

---

35 Combustion Engineering, Inc. Drawing No. 9493-FA-3A

Building 2 was brought on stream for running experiments in 1957. The new facility was set up to conduct water-moderated experiments for the S1C program. Fuel bundles and operating conditions could be more accurately modeled in this facility. The floor plans and cell configurations of the building 2 group are shown in Figures 11, 12 and 13.

The fuel for the experimental reactor core in these early experiments was a plate-type configuration. The fuel bundles consisted of uranium "sandwiched" between, or clad with, zirconium plates. There were 21 or 22 plates in each fuel bundle with space between each plate. The zirconium formed the heat transfer surfaces as water flowed through the interstitial spaces between the plates. This fuel element configuration was used for several years in the S1C program.

Conclusion:

The buildings presented a functional and unassuming appearance. Aside from some features like the test cells, pits and special water-filled windows between the cells and control rooms, there is little to distinguish them from a number of industrial buildings built in the mid-twentieth century. Their significance lies in the experiments and research work that was performed there. The engineers, scientists and technicians of Combustion Engineering, Inc. developed much of the know-how needed to harness the atom and, with others, proved that Rutherford's comment about anyone expecting "a source of power from the transformation of these atoms is talking moonshine" was a seriously flawed prophesy. More importantly, the work on nuclear submarine propulsion and fuel was a very significant contribution to America's defense during the Cold War. The personnel who worked at this site made many important contributions to developing the technology needed to bring nuclear science to practical application.

BIBLIOGRAPHY AND SOURCES OF INFORMATION

Books

Clancy, Tom and Gresham, John. Submarine. New York: Berkley Books, 1993.

Edelson, E. The Journalist's Guide to Nuclear Energy. Washington, DC: Nuclear Energy Institute, 1994.

Hunter, Louis C. Steam Power. Charlottesville, Virginia: University Press of Virginia, 1985.

Meyer, J.G.A. Modern Locomotive Construction. New York: John Wiley and Sons, 1892.

Rhodes, Richard. The Making of the Atomic Bomb. New York: Simon & Schuster, 1986.

Simpson, John W. Nuclear Power from Underseas to Outer Space. LaGrange Park, Illinois: American Nuclear Society, 1995.

S1C Prototype Final Shutdown, Windsor, Connecticut: WSO, 1993.

Drawings and Plans

Combustion Engineering - Windsor, Connecticut
Building No. 1 - Key Plan
Drawing No. PEM-1: Dated 2-28-61

Combustion Engineering - Windsor, Connecticut
Building No. 2 Cell Details
No. PEM-210: Date 2-10-65

Stone & Webster Engineering - Combustion Engineering - Windsor, Connecticut
Plans and Sections - Critical Assembly Building Buildings 2, 2A & 2T Key Plan
No. PEM - 2: Date 2-24-56
Drawing No. 993-FA-3A

Combustion Engineering - Windsor, Connecticut
Critical Assembly Building
Drawing No. 9493-FA-4A: Date 2-23-1956

Interview

Richard Knapp. Taped interview by Robert C. Stewart. 6 March, 2003.

Magazines and Journals

Miranda Maria. ed., "The First Fifty Years." Combustion Engineering World, October/November, 1987, 4.

Schwartz, Frederick D,. "Time Machine-1978." American Heritage, November/December, 2003.

Manuscripts

"C-E Experience." C. 1980 - Manuscript. Corporate Archives, Combustion Engineering , Windsor, Connecticut

"C-E History." September 10, 1979 - R. Reimer - Manuscript. Corporate Archives, Combustion Engineering , Windsor, Connecticut

Patent

E. Frisch - Fuel Element Assembly for a Neutronic Reactor - U.S. Patent 3,287,231

Speeches

Presentation - Combustion Engineering Today - at Security Analysts of San Francisco by Arthur J. Santry, Jr. (December 7, 1967). Archives, Combustion Engineering, Windsor, Connecticut.

Websites

Argonne National laboratory website: http://www.anl.gov/OPA/logos18-1/zinnobit.html

Federation of American Scientists website: http://www.fas.org/man/dod-101/sys/ship/eng/reactor.html

"Enrico Fermi" 2003 http://www.atomicarchive.com/reports/Form/firstpile_03.shmtl

Idaho National Engineering and Environmental Laboratory web site: http://www.inel.gov/about/historical.shtml

Documents #811260 and 818291. Florida Secretary of State website: http://www.sinbiz.org/corpweb/inquiry/cormenu.html

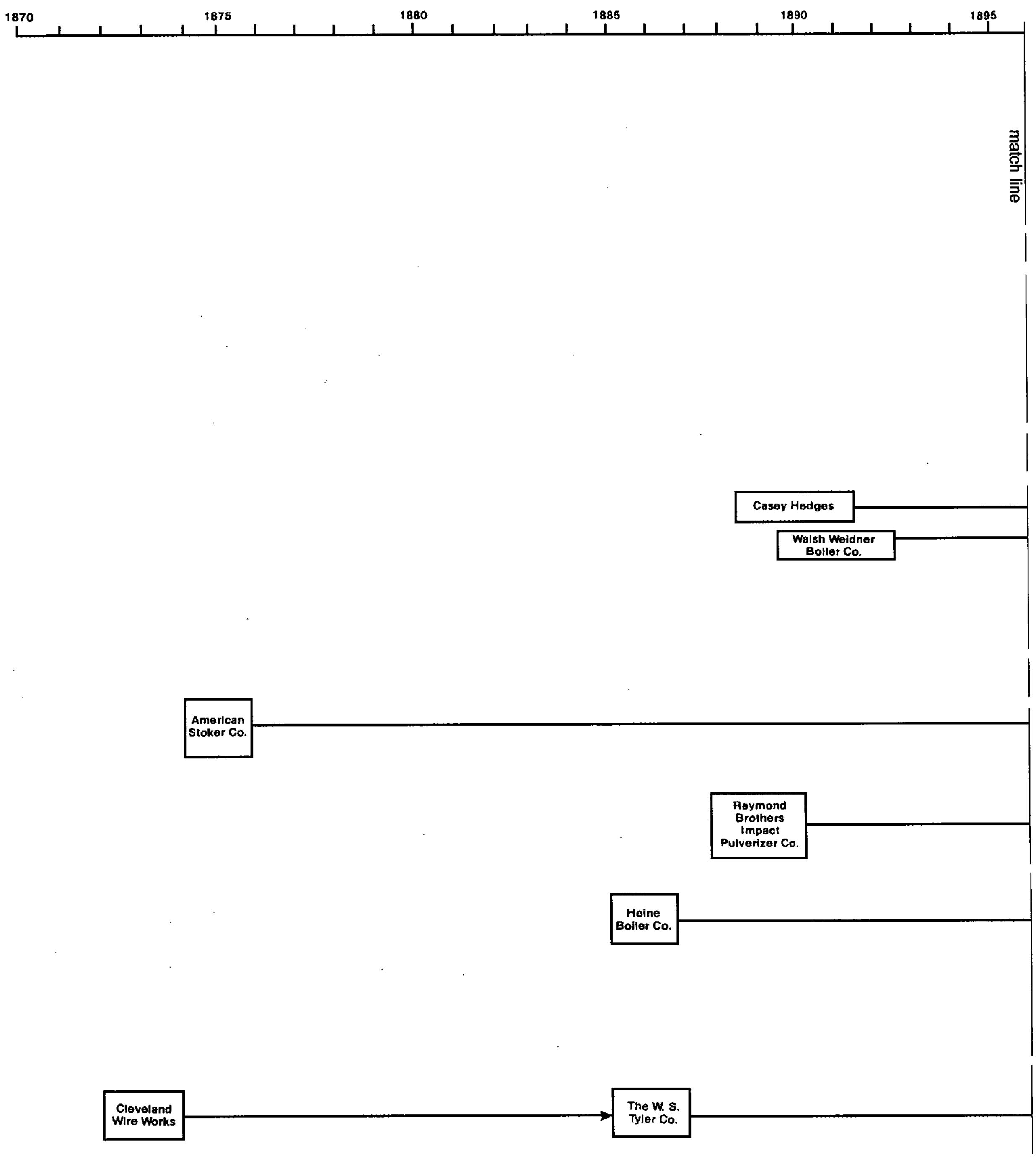


Figure 1a - Genealogy of Combustion Engineering, Inc. - Section 1

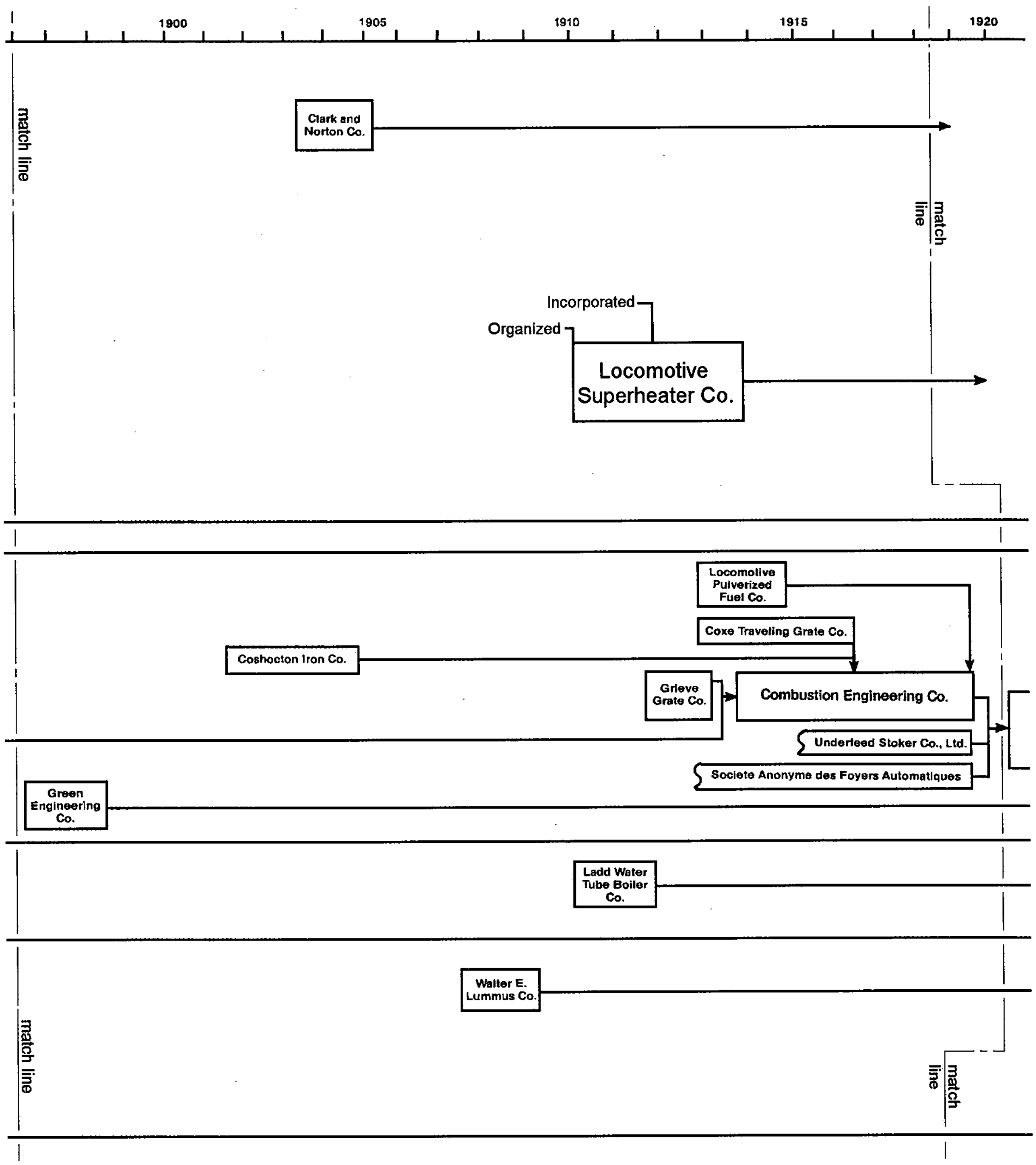


Figure 1b - Genealogy of Combustion Engineering, Inc. - Section 2

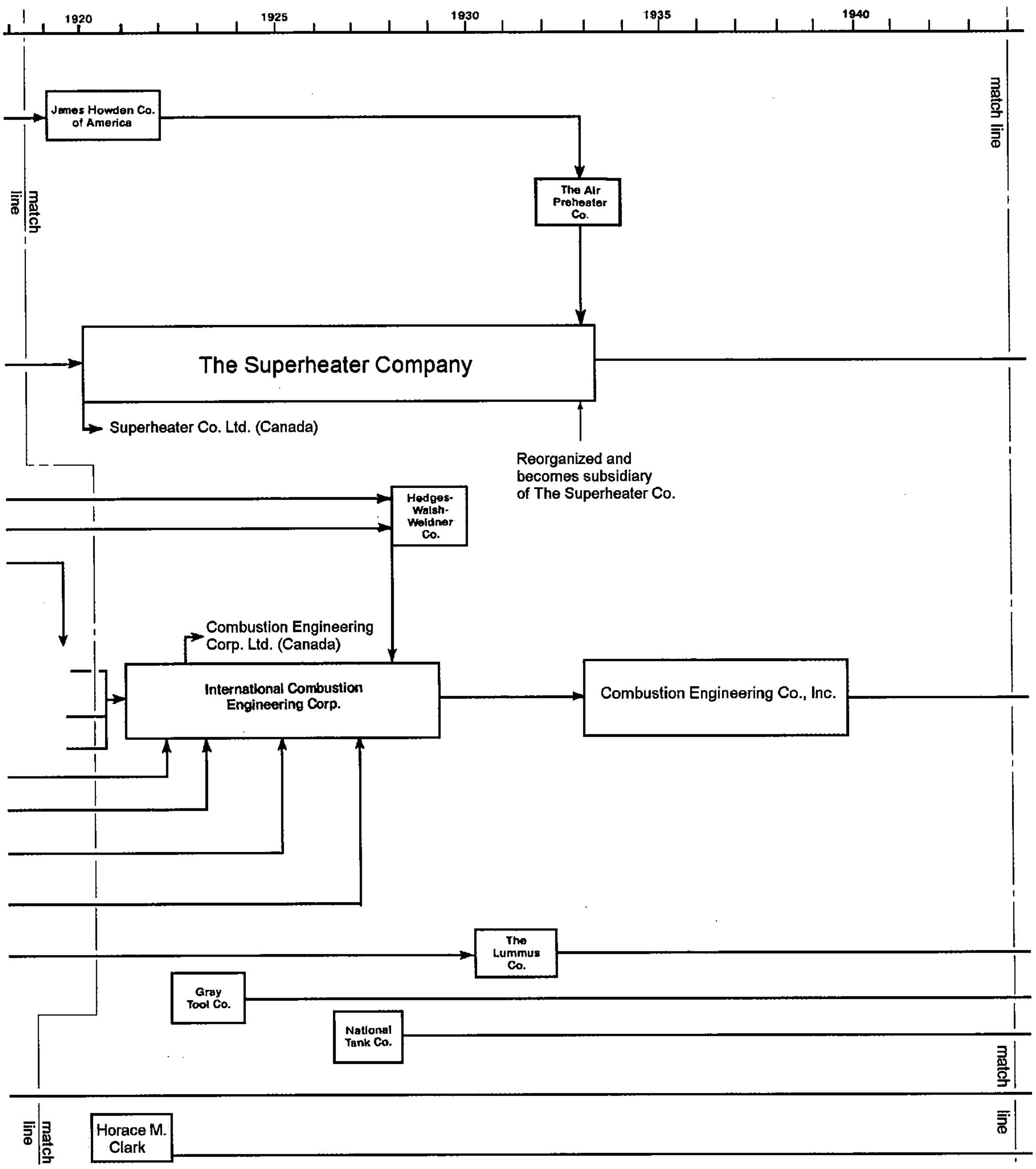


Figure 1c - Genealogy of Combustion Engineering, Inc. - Section 3

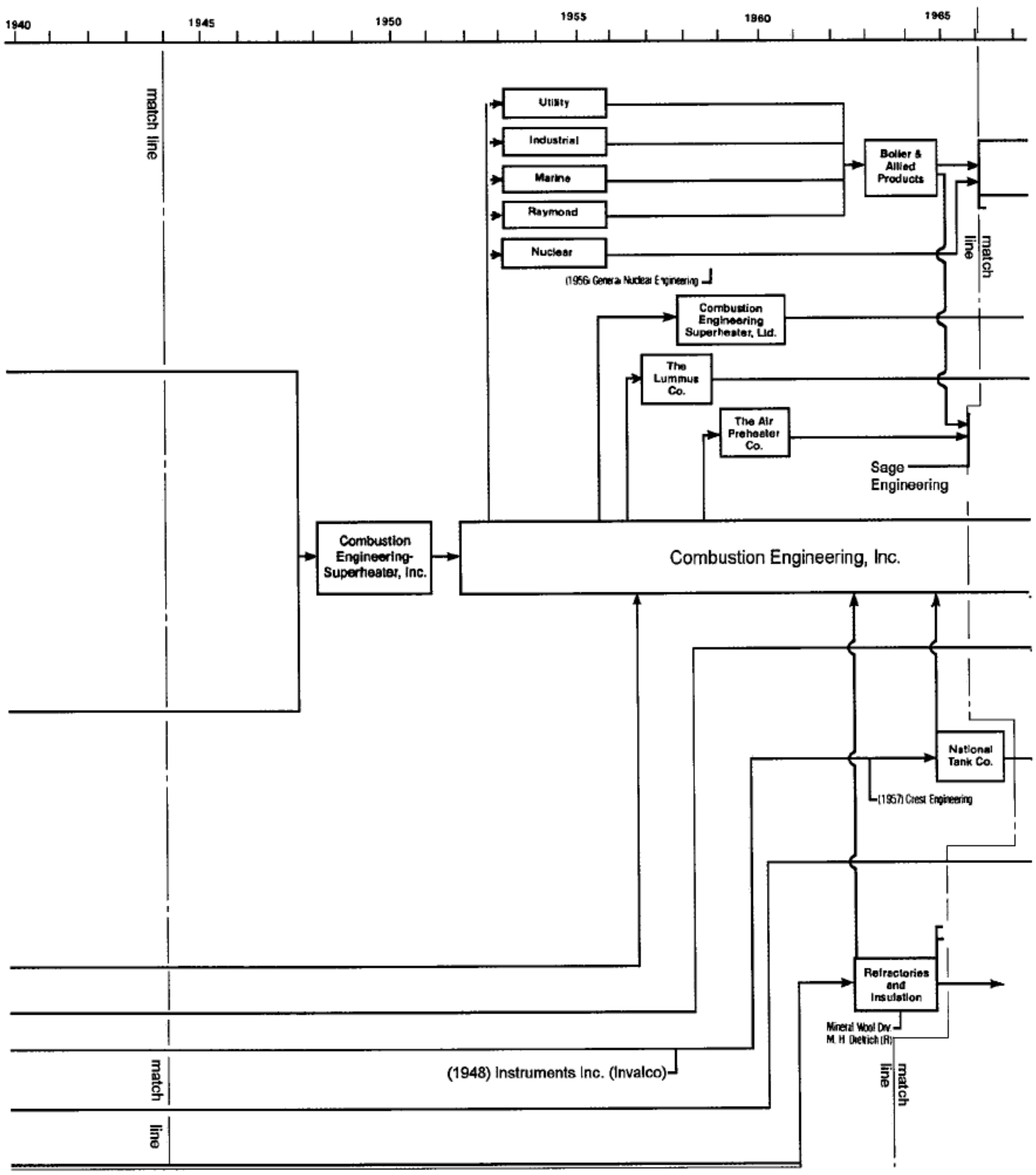


Figure 1d - Genealogy of Combustion Engineering, Inc. - Section 4

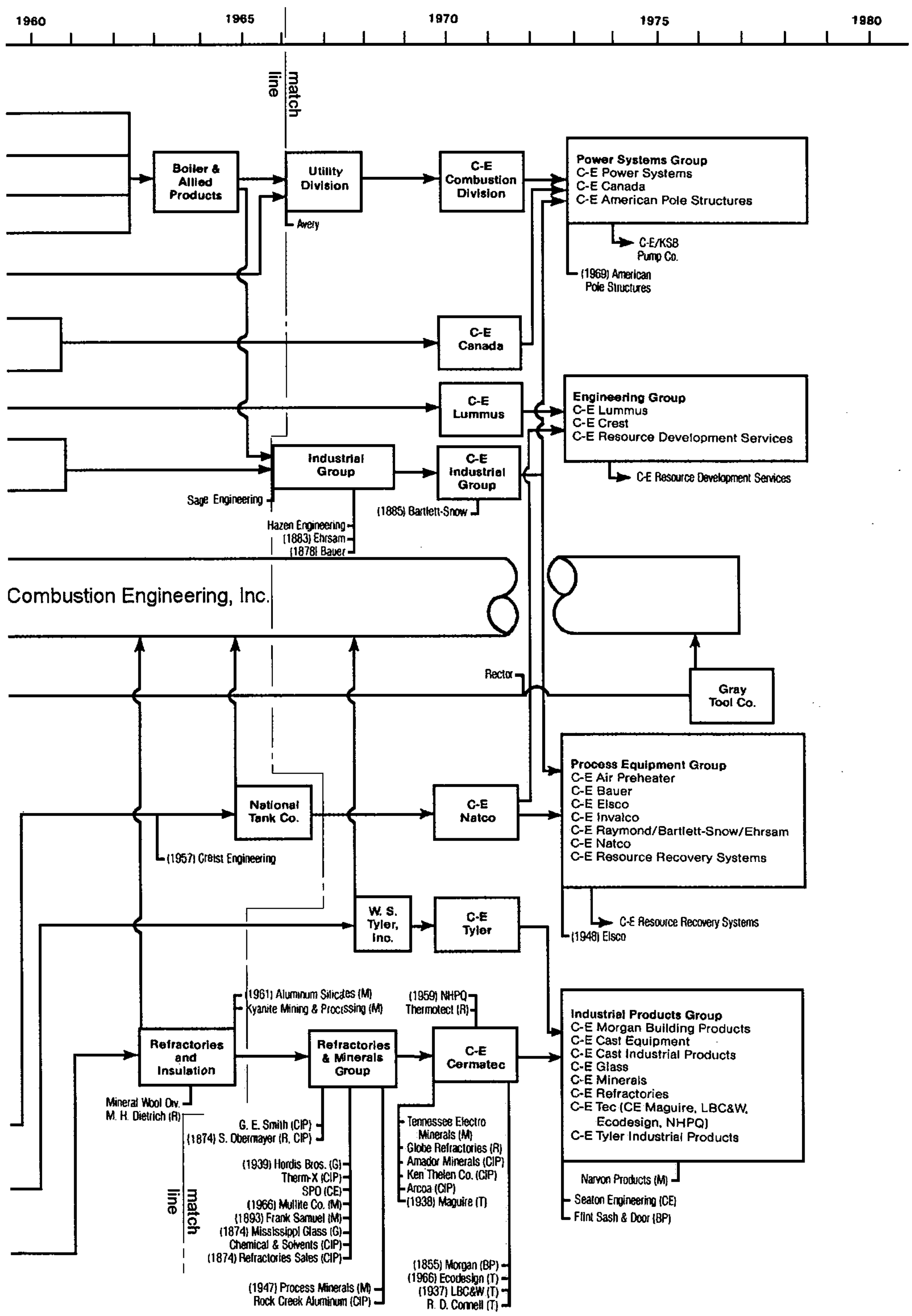


Figure 1e - Combustion Engineering, Inc. Section 5

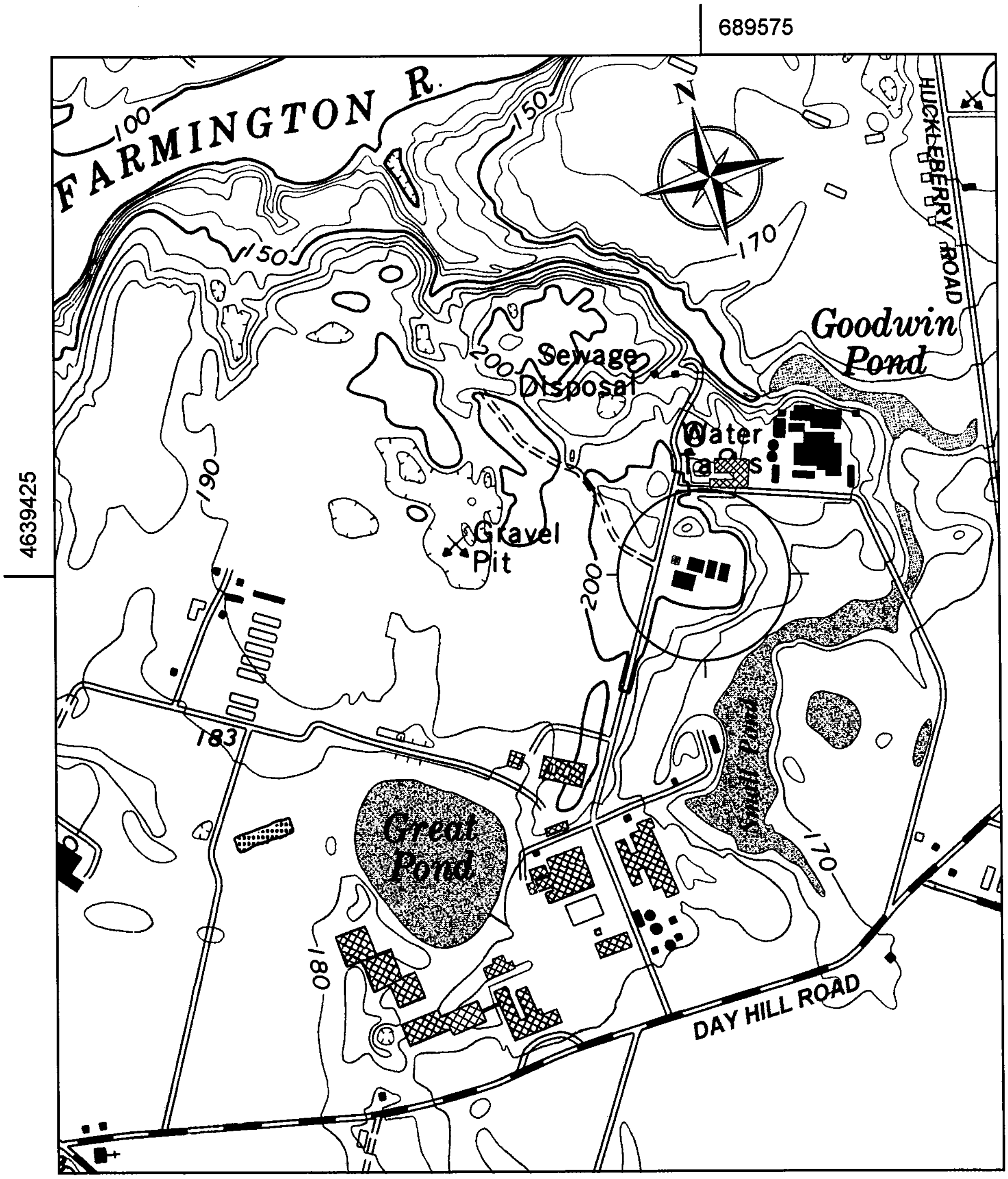


Figure 2 - Location Map - Combustion Engineering, Inc.
USGS Quadrangle - Windsor Locks, Connecticut - 1:12,000

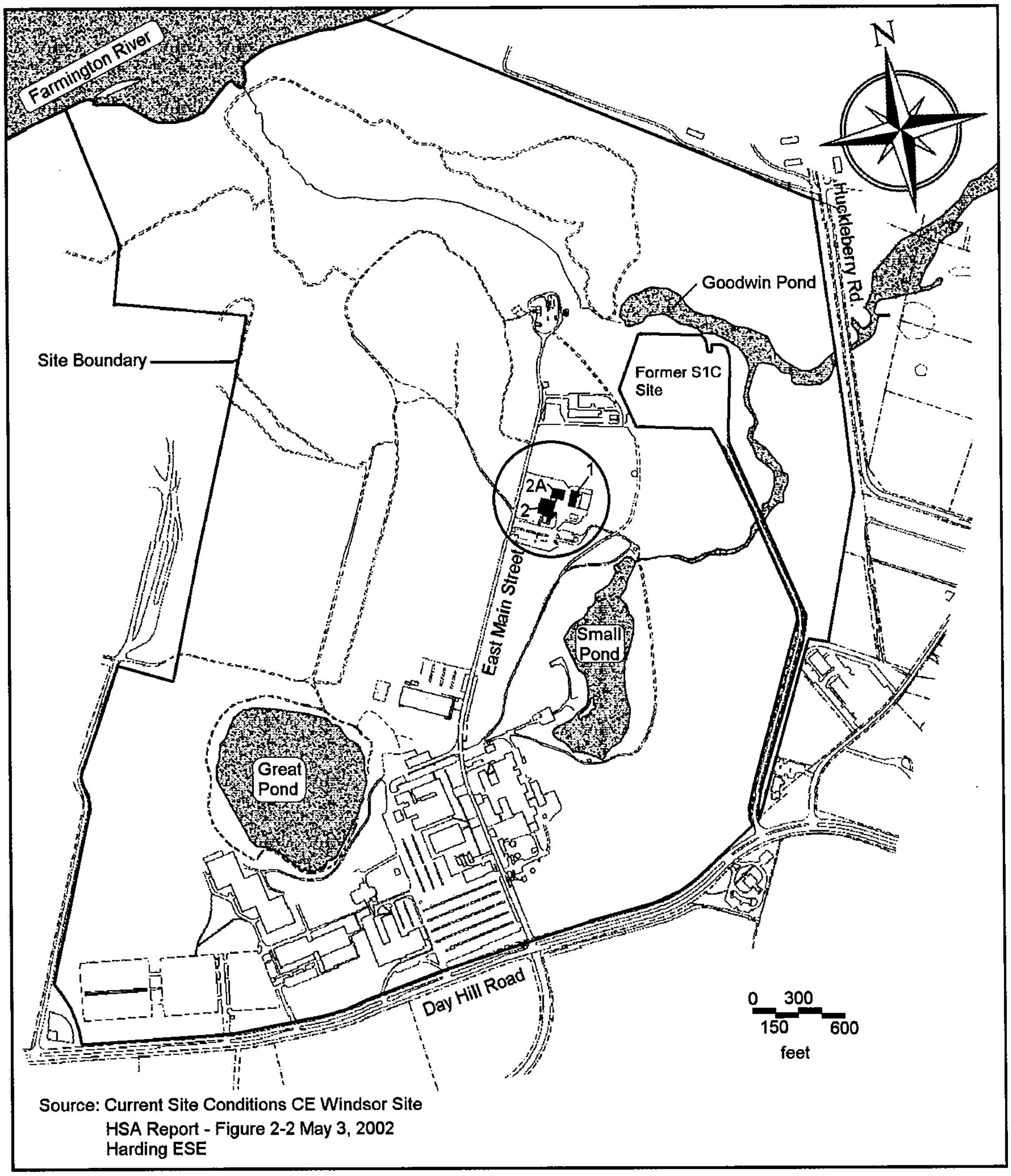


Figure 3 - Combustion Engineering - Windsor, Connecticut - Site Property Lines

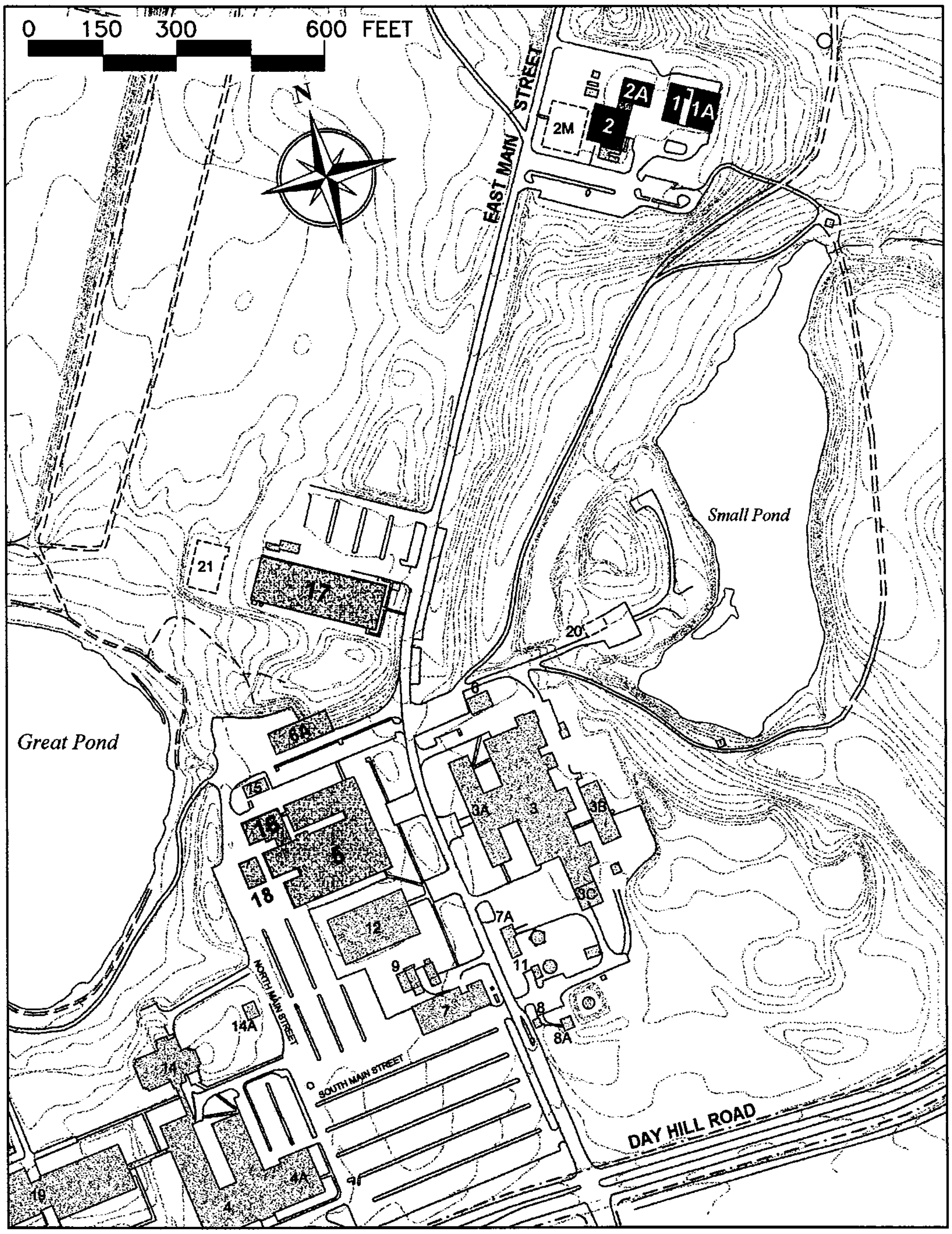


Figure 4 - Site Plan of Combustion Engineering Facility - Windsor, Connecticut
Showing Location of Buildings 1 and 2

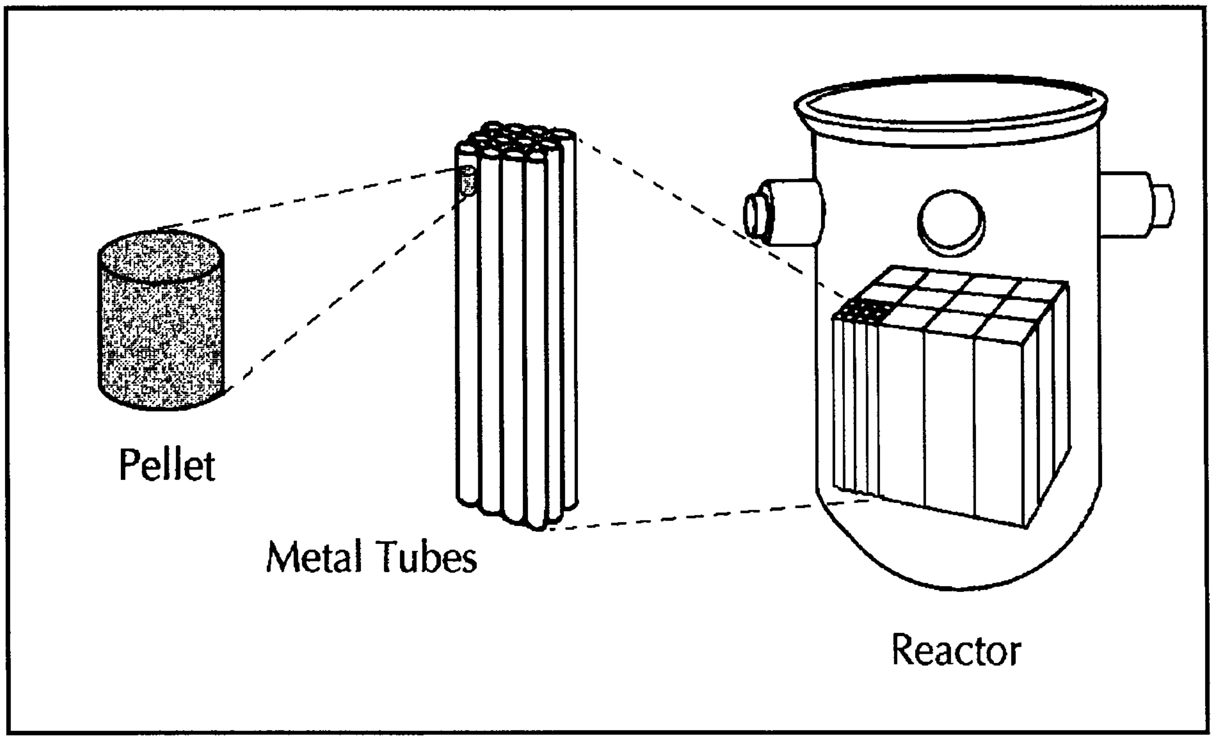


Figure 5 - Fuel Pellets and their physical relationship to zirconium tube encasements and the reactor fuel assembly.

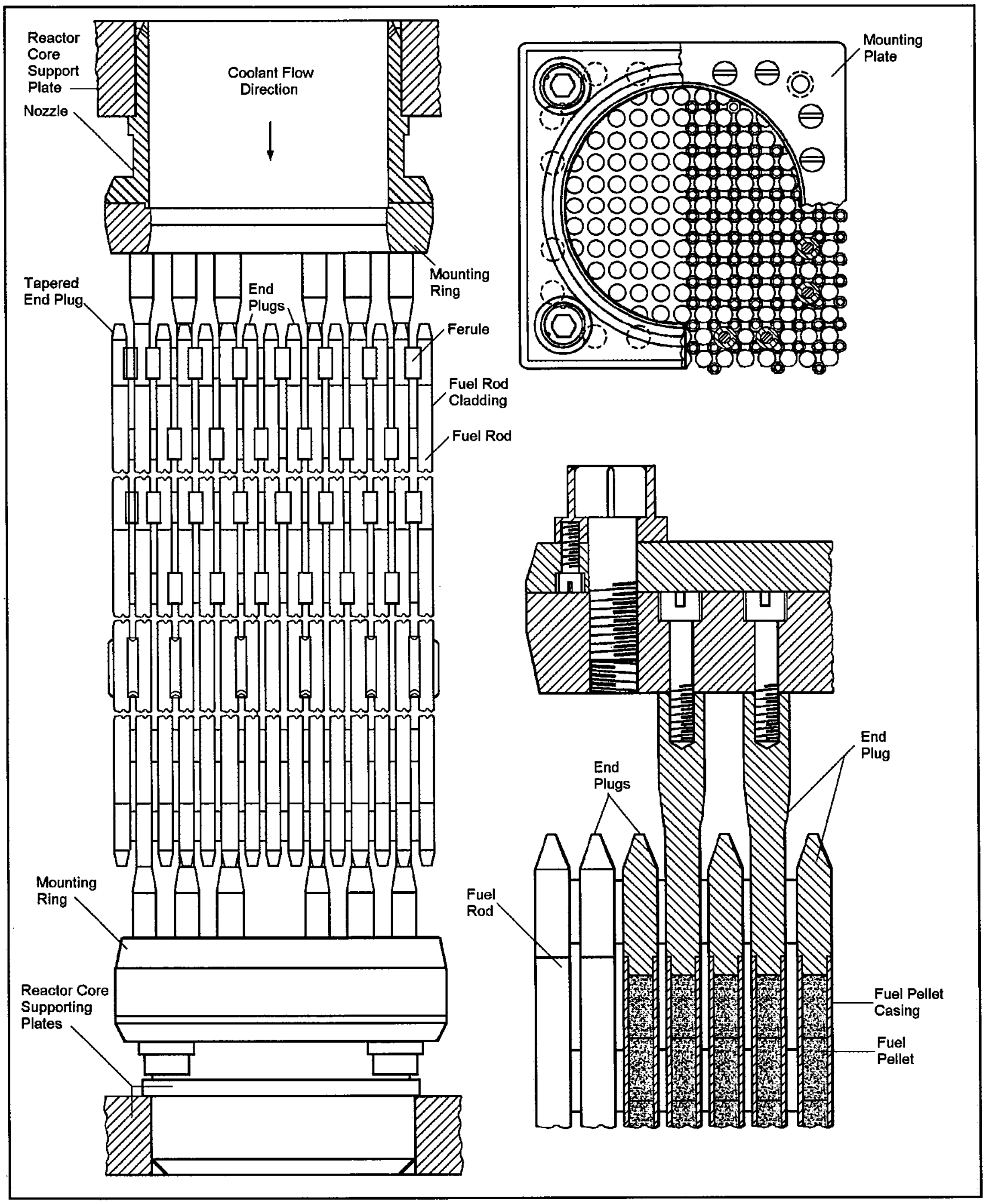


Figure 6 - Drawing of a Reactor Fuel Assembly based on Patent #3,287.231 by E. Frisch

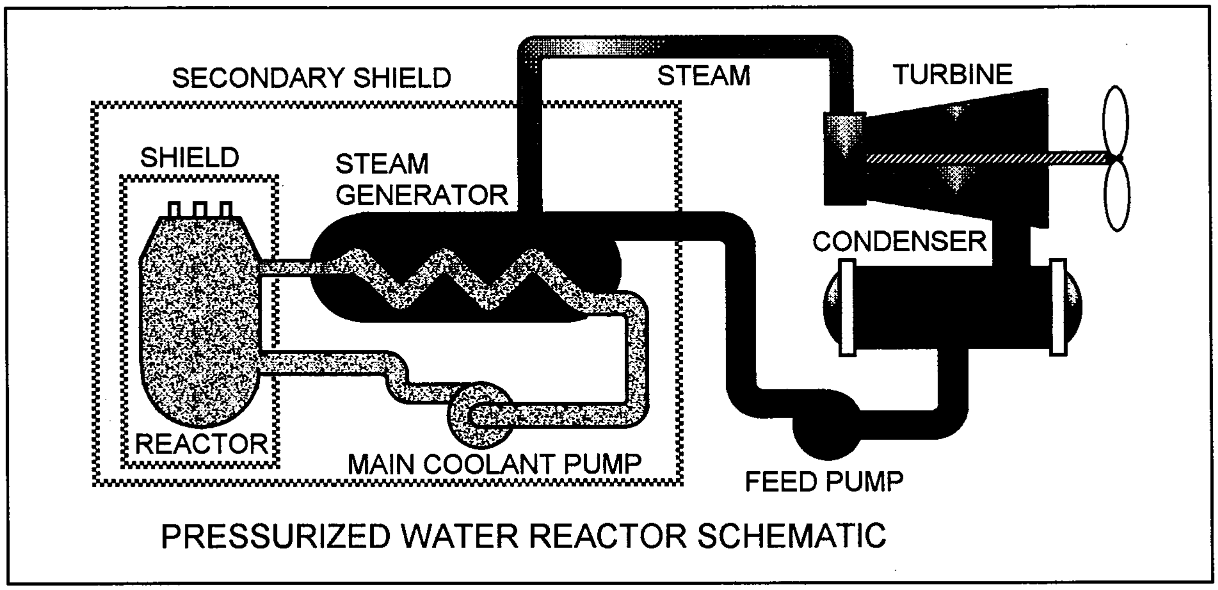


Figure 7 - A simplified schematic of a pressurized water nuclear reactor system.

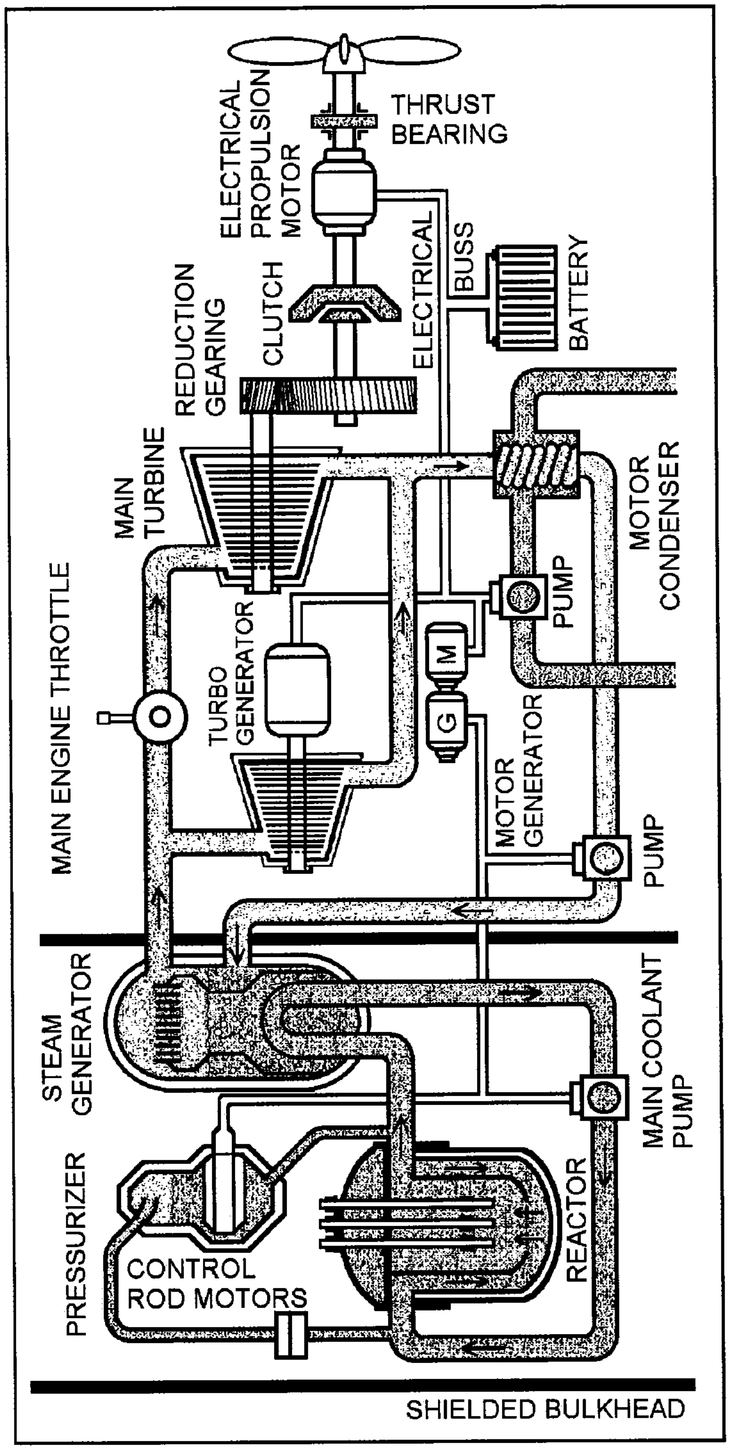


Figure 8 - Detailed schematic diagram of a pressurized water reactor for a submarine.

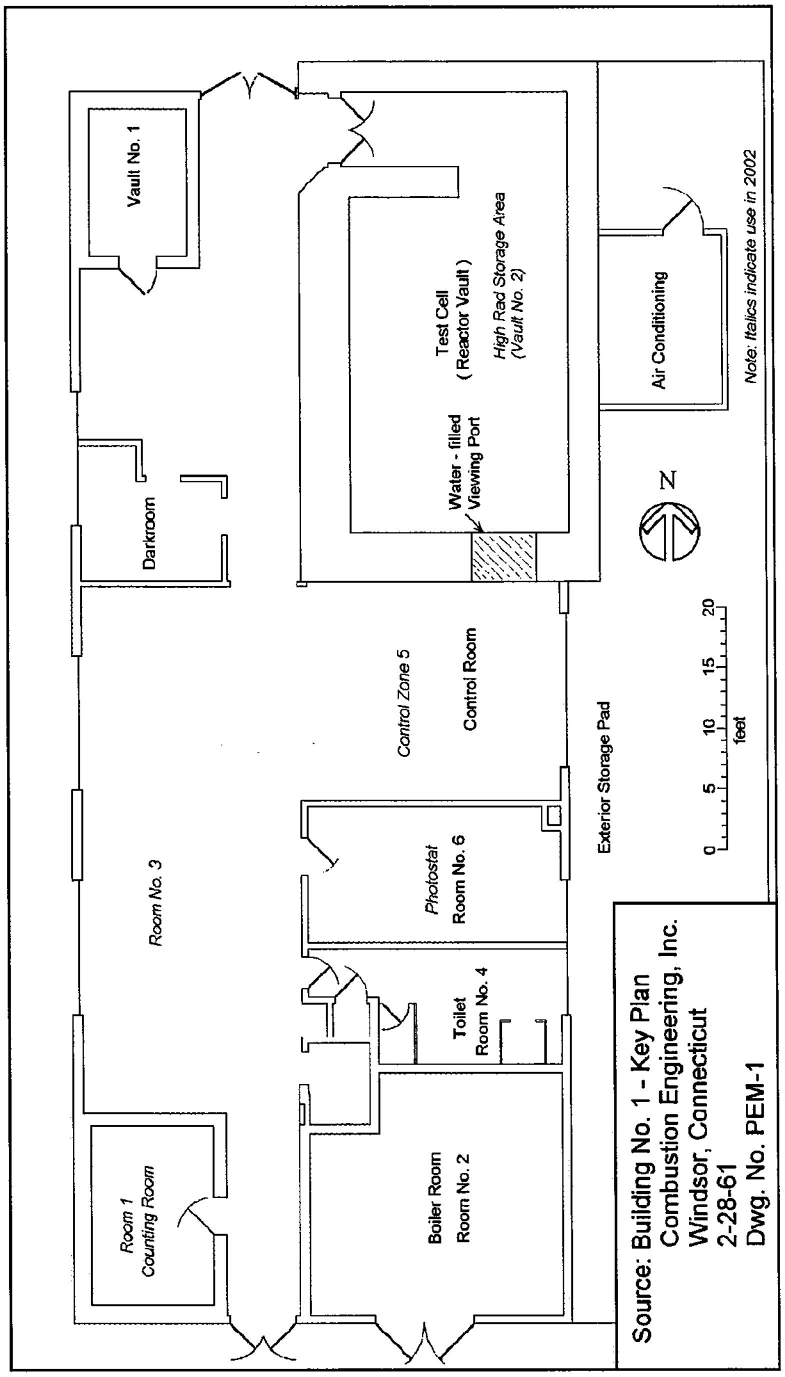


Figure 9 - Floor Plan of Building No. 1 - Critical Facilities Building

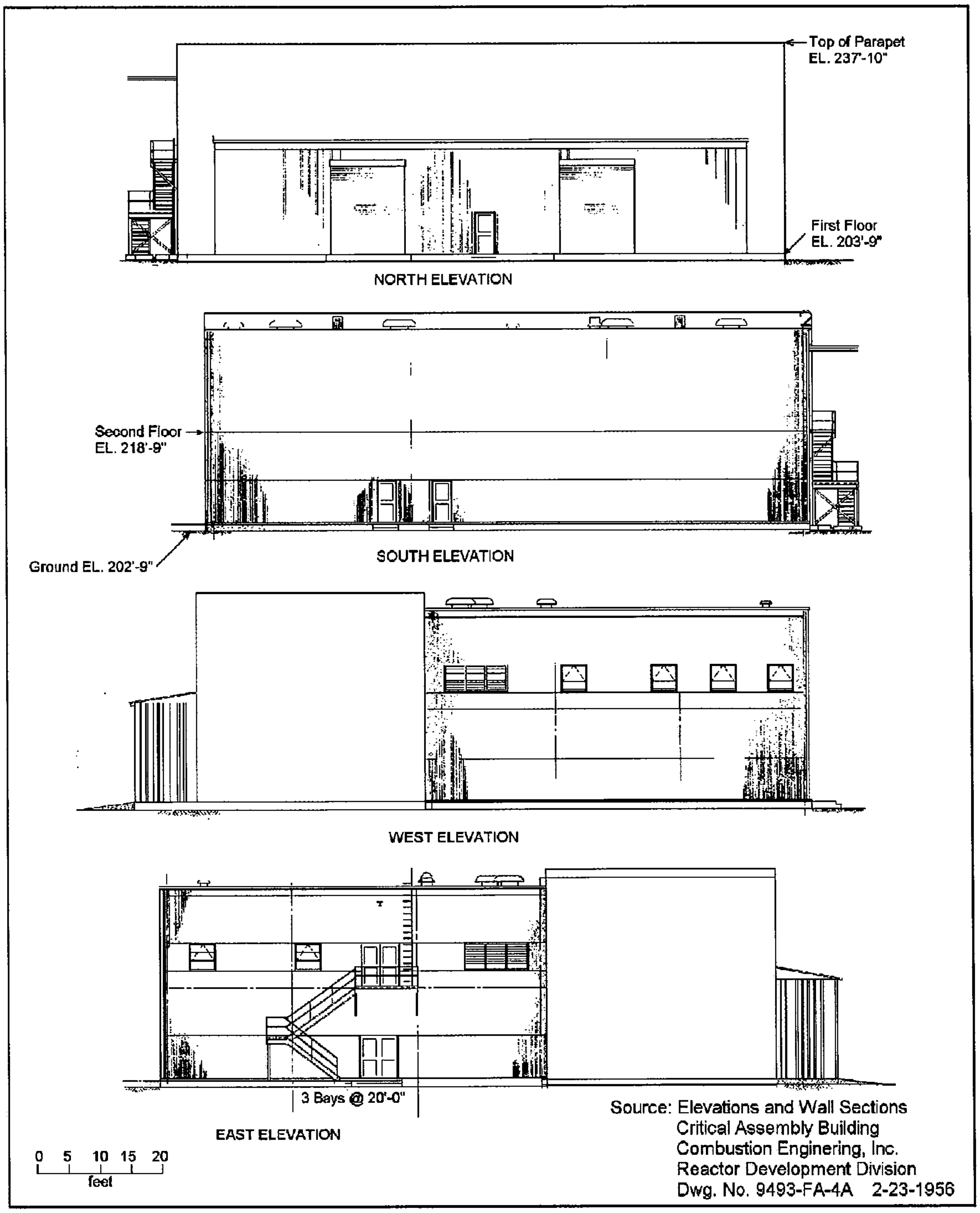


Figure 10 - Critical Assembly Facility - elevations

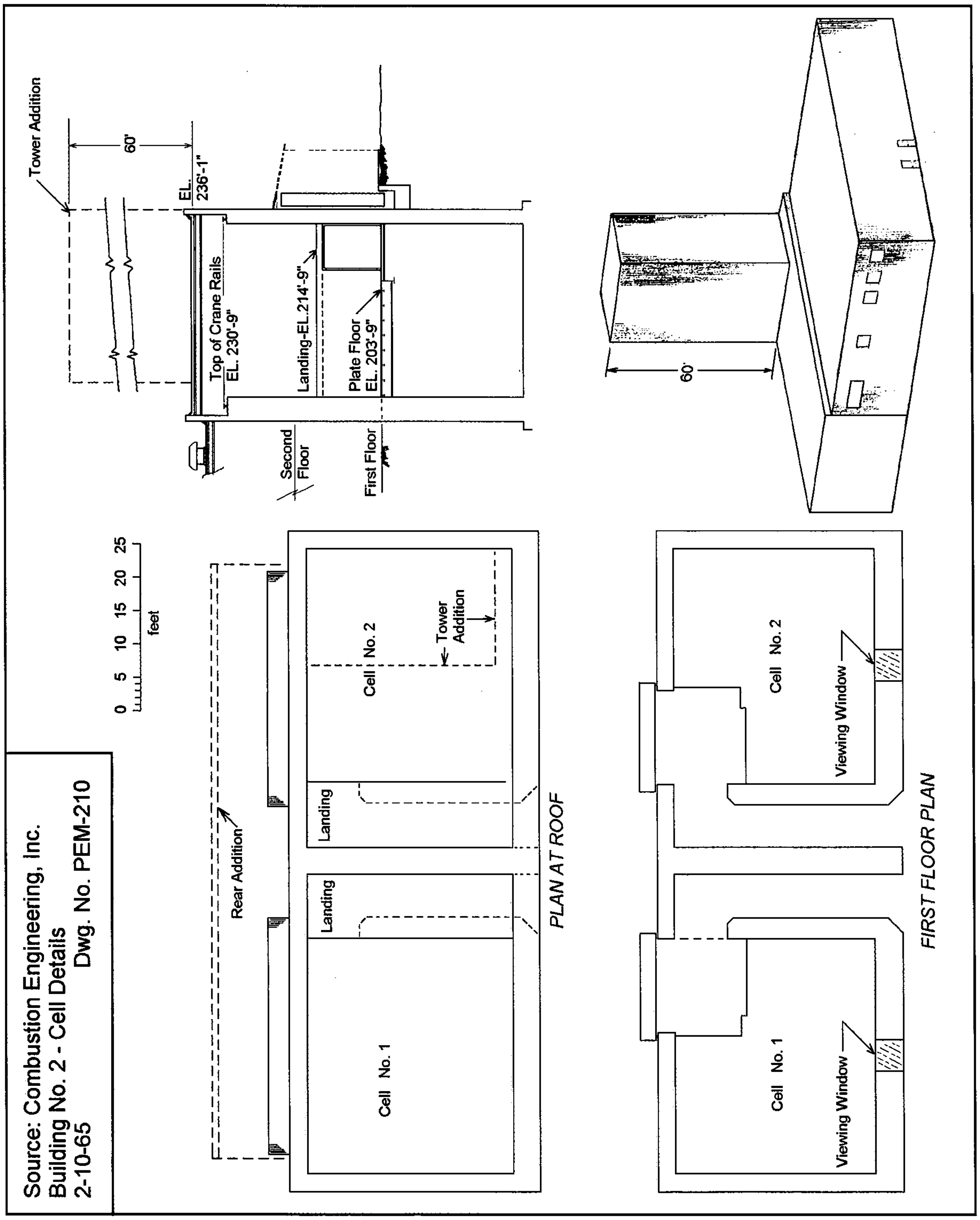


Figure 11 - Sketches of Cells and Perspective View

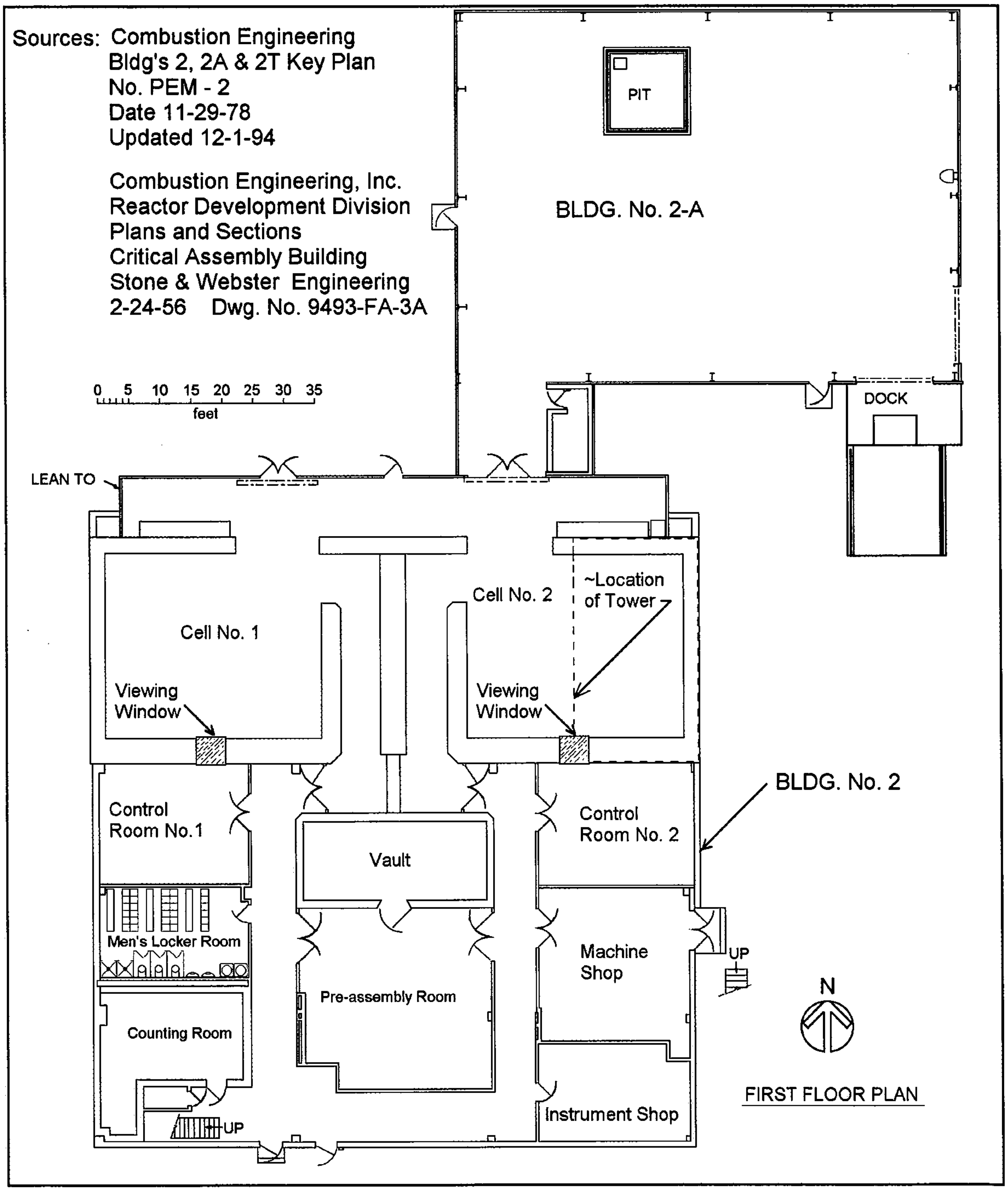


Figure 12 - Building No. 2, 2A Plan

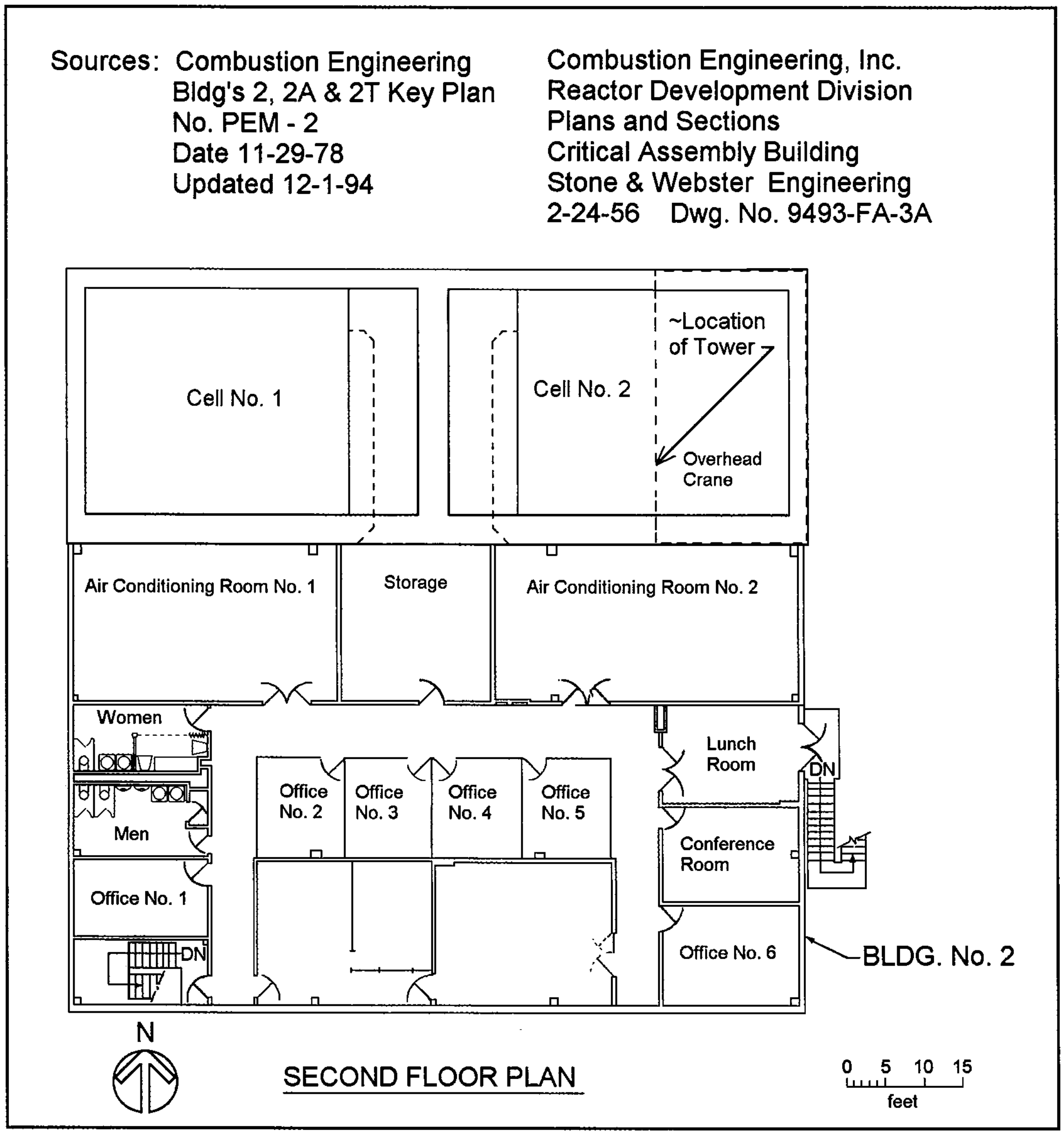


Figure 13 - Building No. 2 - Second Floor Plan

Photographs 1-23 were taken by Robert C. Stewart August-September, 2002
Photographs 24-25 were provided by Combustion Engineering

1. VIEW NORTHWEST OF BUILDING No. 1 - CRITICAL FACILITIES BUILDING

2. VIEW NORTHEAST OF BUILDING No. 1 - CRITICAL FACILITIES BUILDING

3. BUILDING No. 1 - VIEW SOUTH INSIDE TEST CELL -(REACTOR VAULT) NOTE WATER FILLED VIEWING PORT AT CENTER LEFT.

4. BUILDING No. 1 - VIEW NORTH FROM CONTROL ROOM INTO TEST CELL THROUGH WATER FILLED VIEWING PORT AT CENTER RIGHT.

5. VIEW NORTHEAST OF BUILDING 1A - STORAGE FACILITY

6. VIEW NORTHEAST OF BUILDING No. 2 - CRITICAL ASSEMBLY BUILDING

7. VIEW NORTH-NORTHWEST OF BUILDING No. 2-CRITICAL ASSEMBLY BUILDING

8. VIEW EAST OF BUILDING No. 2-CRITICAL ASSEMBLY BUILDING

9. VIEW NORTHWEST OF BUILDING No. 2 - CRITICAL ASSEMBLY BUILDING

10. VIEW EAST OF BUILDING No. 2-CRITICAL ASSEMBLY BUILDING

11. VIEW NORTHWEST OF BUILDING No. 2A - HIGH BAY OF BUILDING No. 2-CRITICAL ASSEMBLY BUILDING.

12. VIEW SOUTHWEST OF BUILDING No. 2A-CRITICAL ASSEMBLY BUILDING

13. VIEW EAST INSIDE HIGH BAY OF BUILDING 2A OF BUILDING No. 2-CRITICAL ASSEMBLY BUILDING

14. VIEW SOUTHWEST INSIDE HIGH BAY - BUILDING No. 2A-CRITICAL ASSEMBLY BUILDING.

15. VIEW NORTHWEST INSIDE HIGH BAY OF BUILDING No. 2A-CRITICAL ASSEMBLY BUILDING

16. VIEW INSIDE HIGH BAY AREA-OF BUILDING No. 2A-CRITICAL ASSEMBLY BUILDING

17. VIEW OF PIT ON NORTH SIDE OF HIGH BAY AREA -BUILDING No. 2A.

18. VIEW EAST WITHIN TEST CELL No. 2 - BUILDING No. 2 -CRITICAL ASSEMBLY BUILDING.

19. OBSERVATION PORT (WATER FILLED) IN TEST CELL No.2.

20. VIEW EAST INTO TEST CELL No. 2 PIT - BUILDING No. 2 -CRITICAL ASSEMBLY BUILDING.

21. VIEW UP INTO TOWER OVER TEST CELL No. 2 - BUILDING No. 2 -CRITICAL ASSEMBLY BUILDING. NOTE JIB CRANE AT TOP LEFT.

22. VIEW EAST INSIDE TEST CELL No. 2 - PIT AREA BUILDING No. 2 -CRITICAL ASSEMBLY BUILDING.

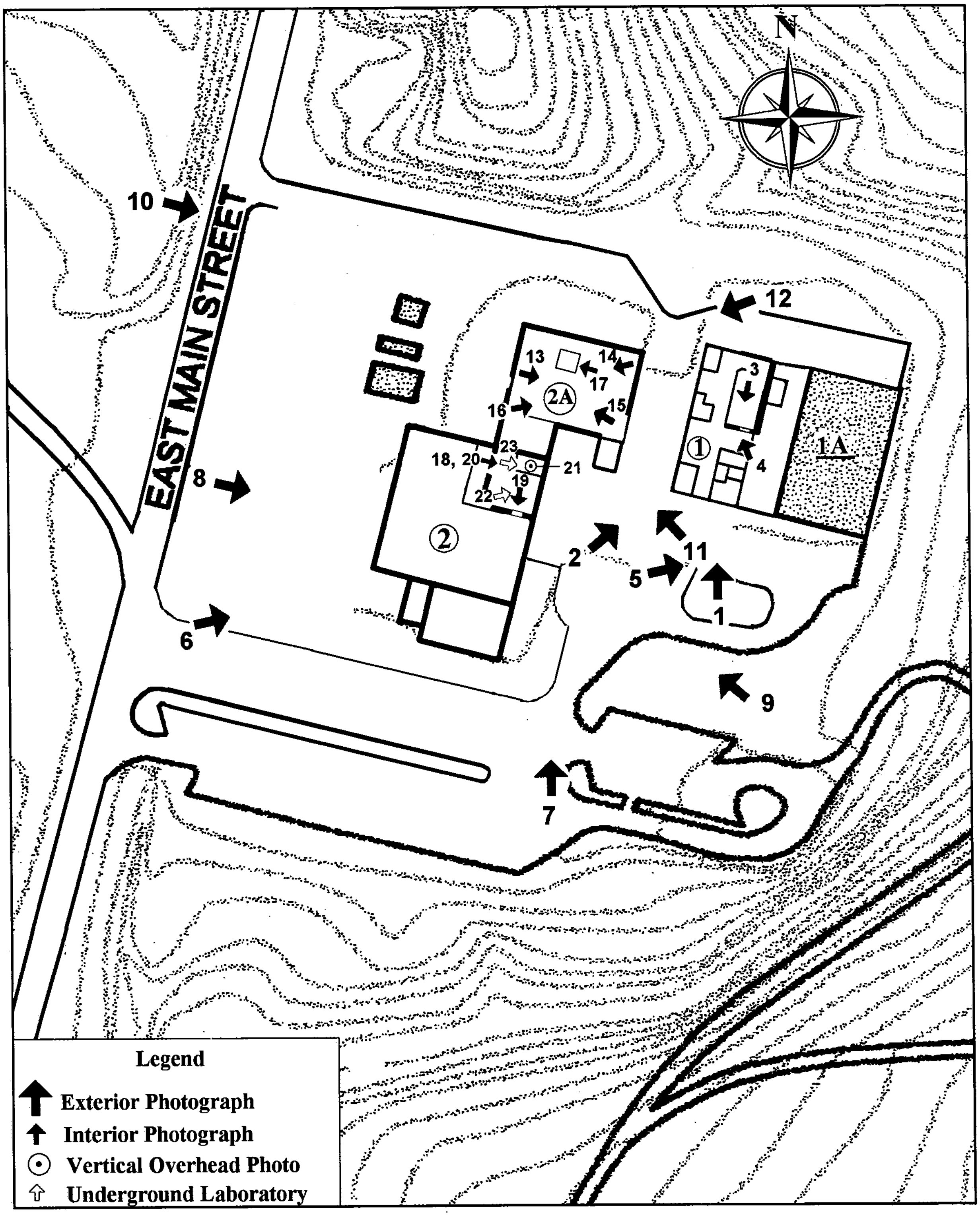
23. VIEW EAST WITHIN TEST CELL No. 2 - PIT AREA BUILDING No. 2 -CRITICAL ASSEMBLY BUILDING.

24. HISTORICAL AERIAL PHOTO TAKEN DURING CONSTRUCTION OF BUILDING No. 2 - CRITICAL ASSEMBLY BUILDING IN 1956. BUILDING No. 1, CRITICAL FACILITY IS AT LOWER RIGHT. DATED JUNE 8, 1956.

25. UNKNOWN TECHNICIAN CHARGING EXPERIMENTAL REACTOR MOCK-UP IN BUILDING No 1.C 1956.

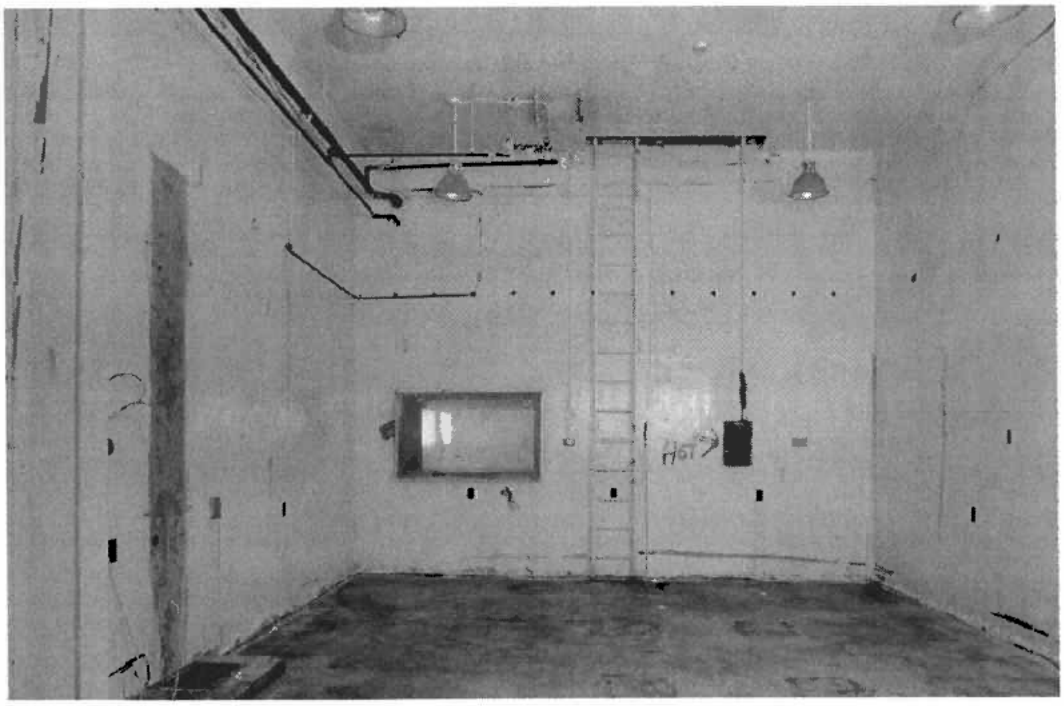
26. HISTORIC SHUTDOWN-WALTER ZINN (STANDING) PRESSES A BUTTON TO SHUT DOWN CHICAGO PILE 3 RESEARCH REACTOR AT ARGONNE NATIONAL LABORATORY.

Combustion Engineering
Buildings 1 and 2
Windsor, Connecticut
Key to Photographs
(Page 43)

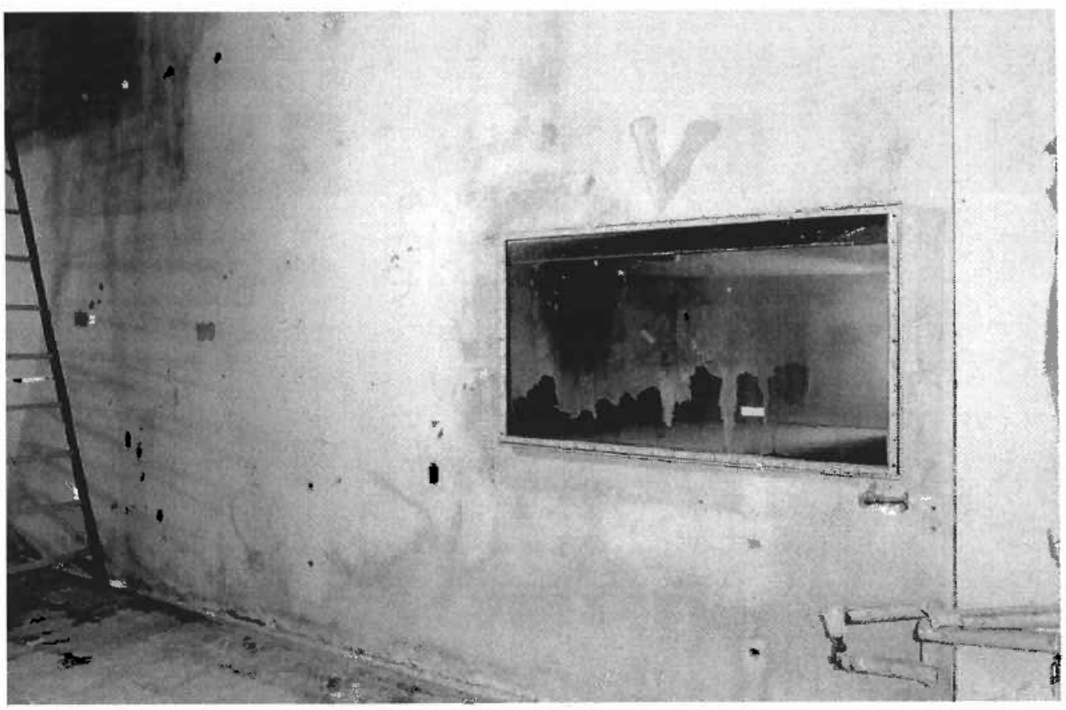


1. VIEW NORTHWEST OF BUILDING No. 1 - CRITICAL FACILITIES BUILDING

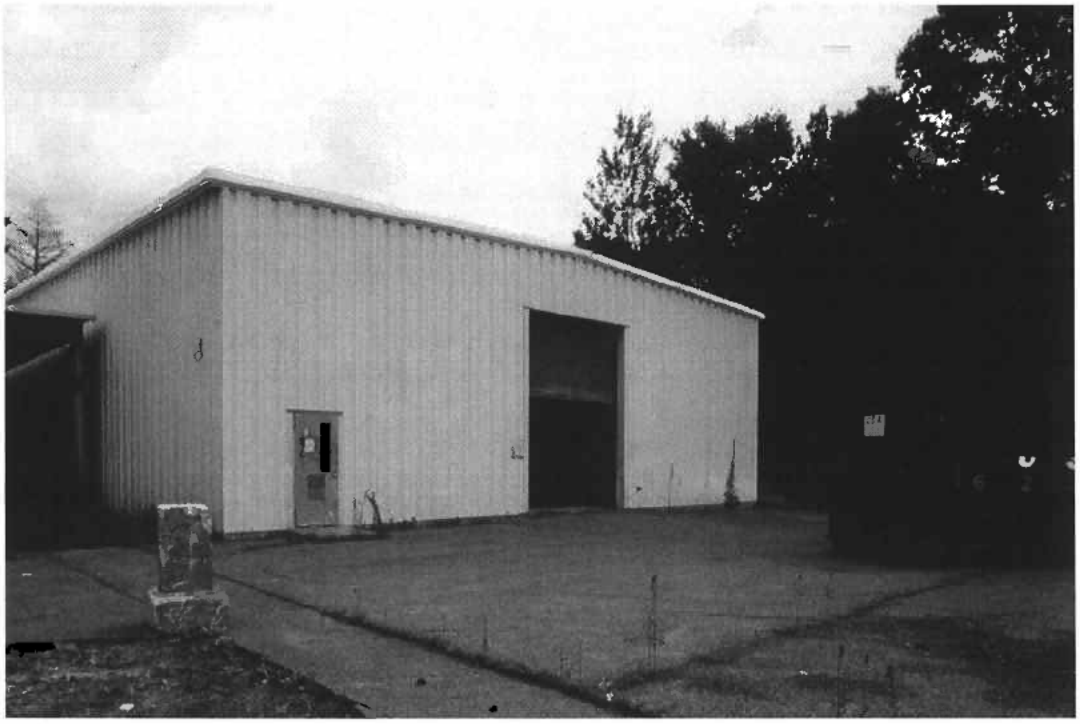
2. VIEW NORTHEAST OF BUILDING No. 1 - CRITICAL FACILITIES BUILDING



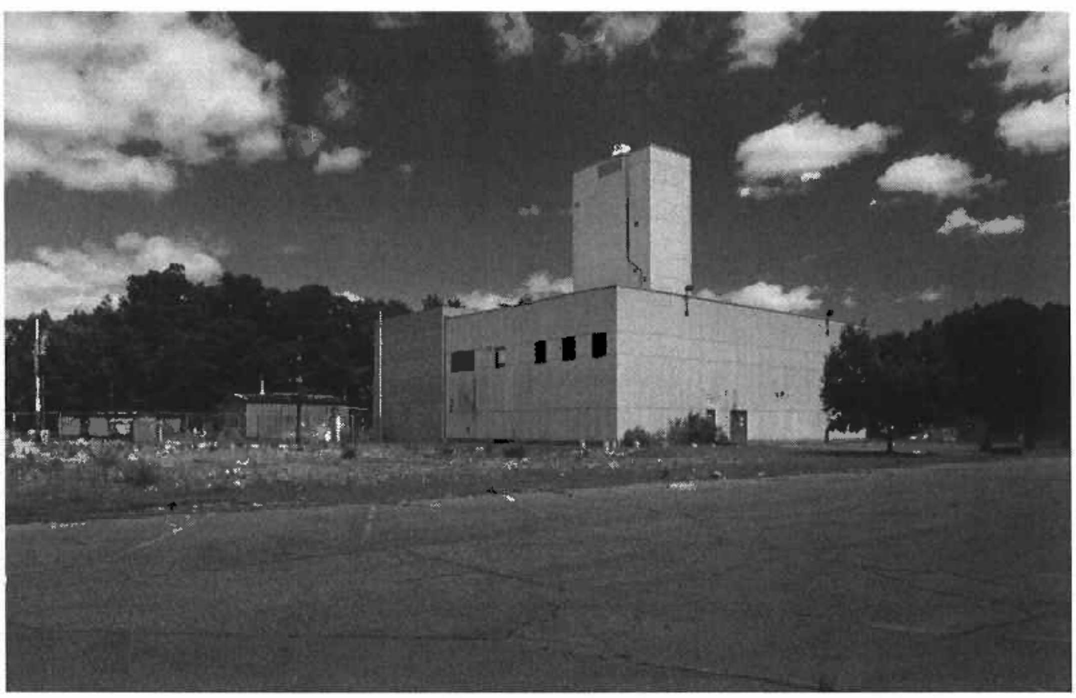
3. BUILDING No. 1 - VIEW SOUTH INSIDE TEST CELL -(REACTOR VAULT) NOTE WATER FILLED VIEWING PORT AT CENTER LEFT.



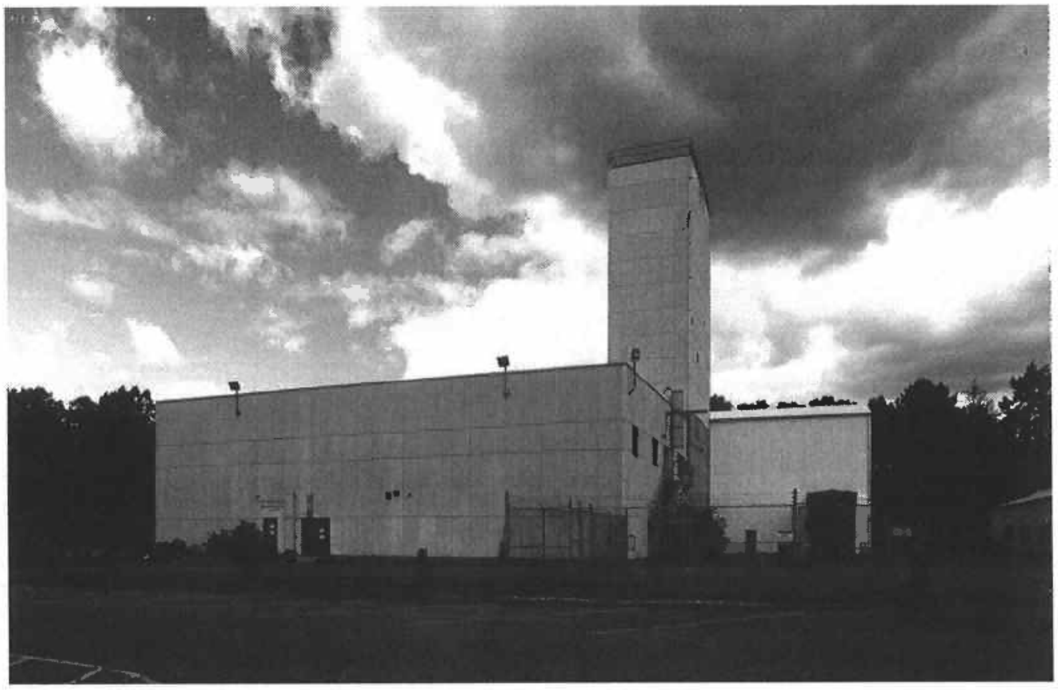
4. BUILDING No. 1 - VIEW NORTH FROM CONTROL ROOM INTO TEST CELL THROUGH WATER FILLED VIEWING PORT AT CENTER RIGHT.



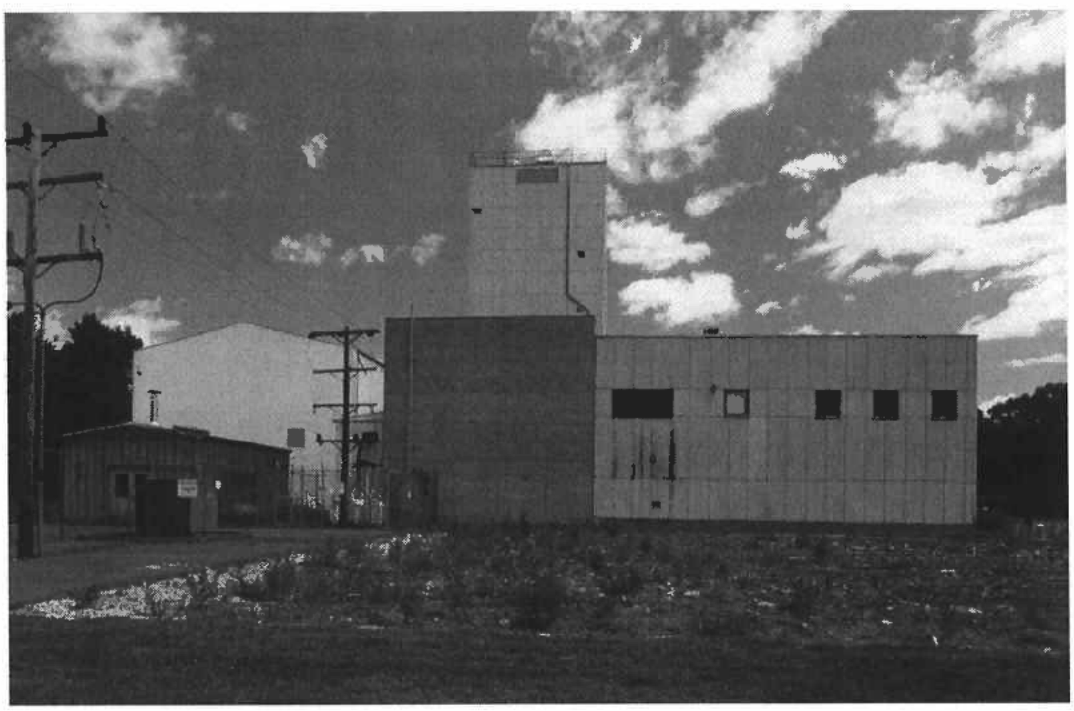
5. VIEW NORTHEAST OF BUILDING 1A - STORAGE FACILITY



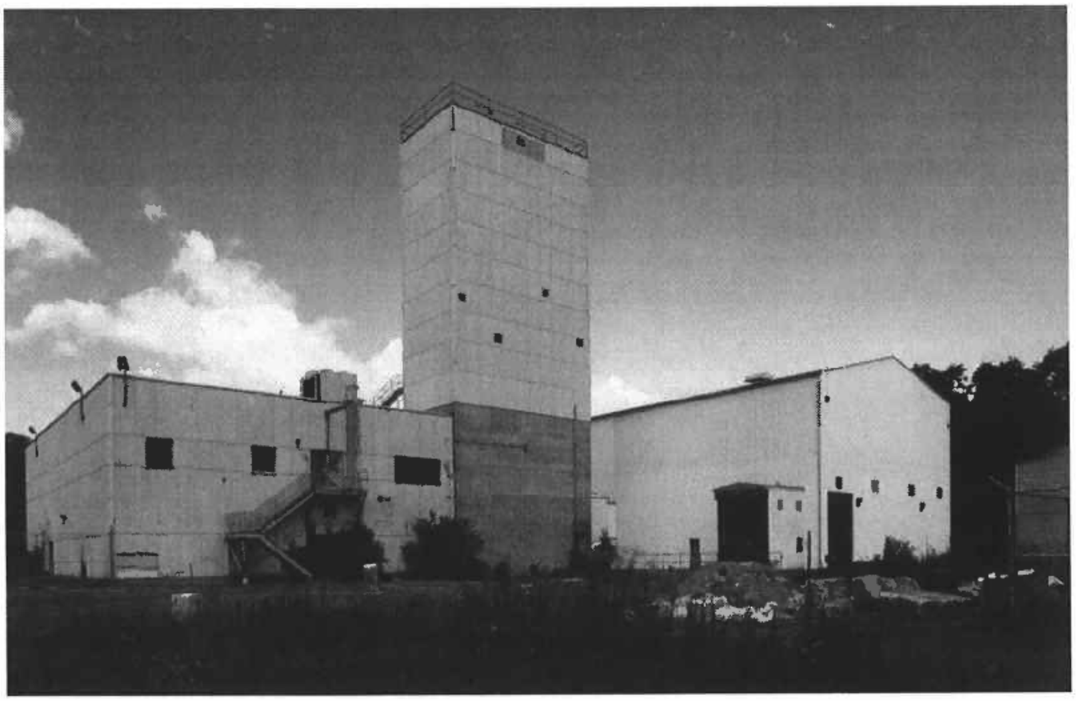
6. VIEW NORTHEAST OF BUILDING No. 2 - CRITICAL ASSEMBLY BUILDING



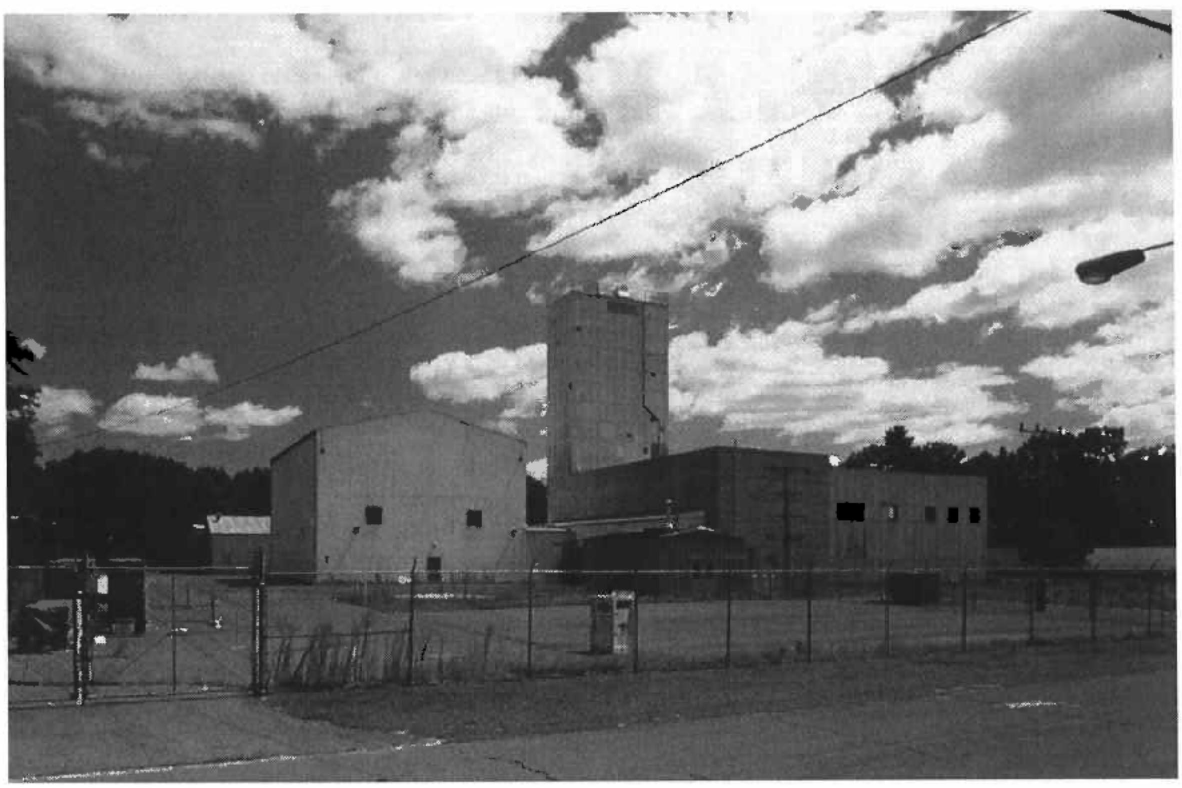
7. VIEW NORTH-NORTHWEST OF BUILDING No. 2-CRITICAL ASSEMBLY BUILDING



8. VIEW EAST OF BUILDING No. 2-CRITICAL ASSEMBLY BUILDING

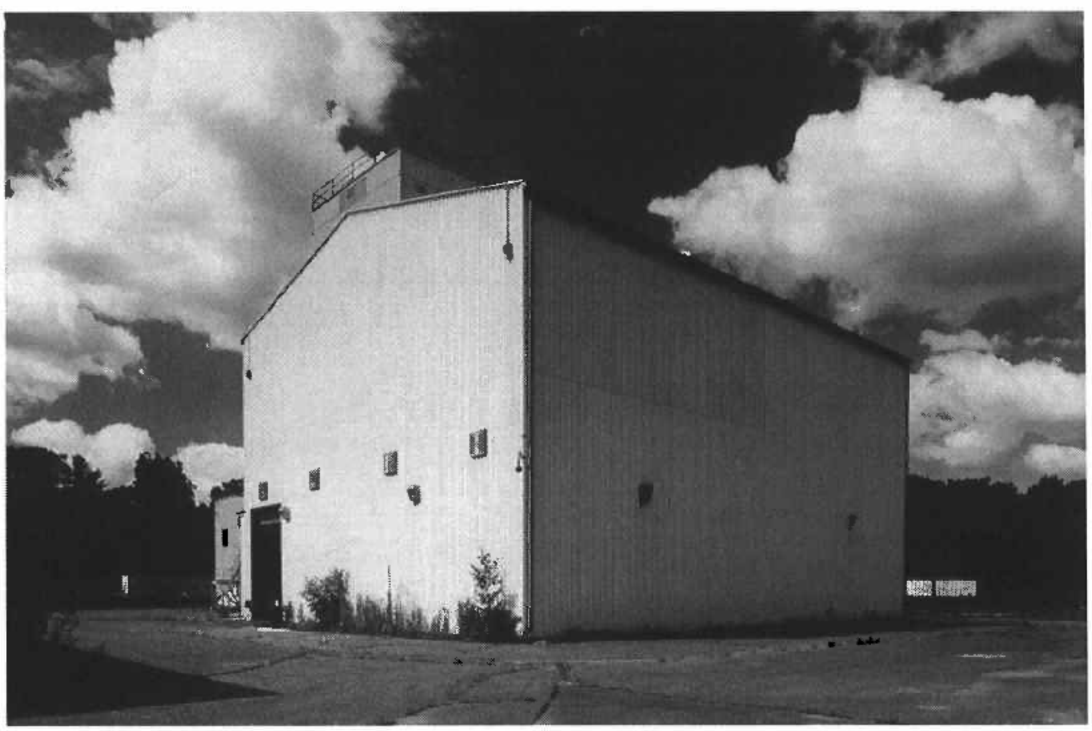


9. VIEW NORTHWEST OF BUILDING No. 2 - CRITICAL ASSEMBLY BUILDING

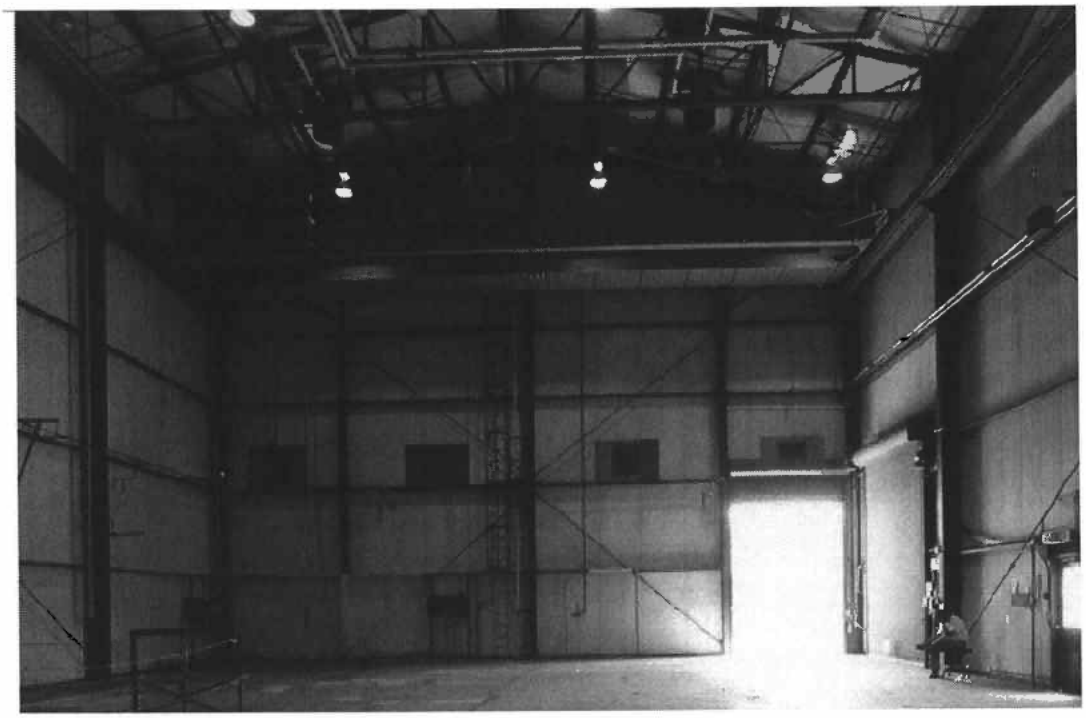


10. VIEW EAST OF BUILDING No. 2-CRITICAL ASSEMBLY BUILDING

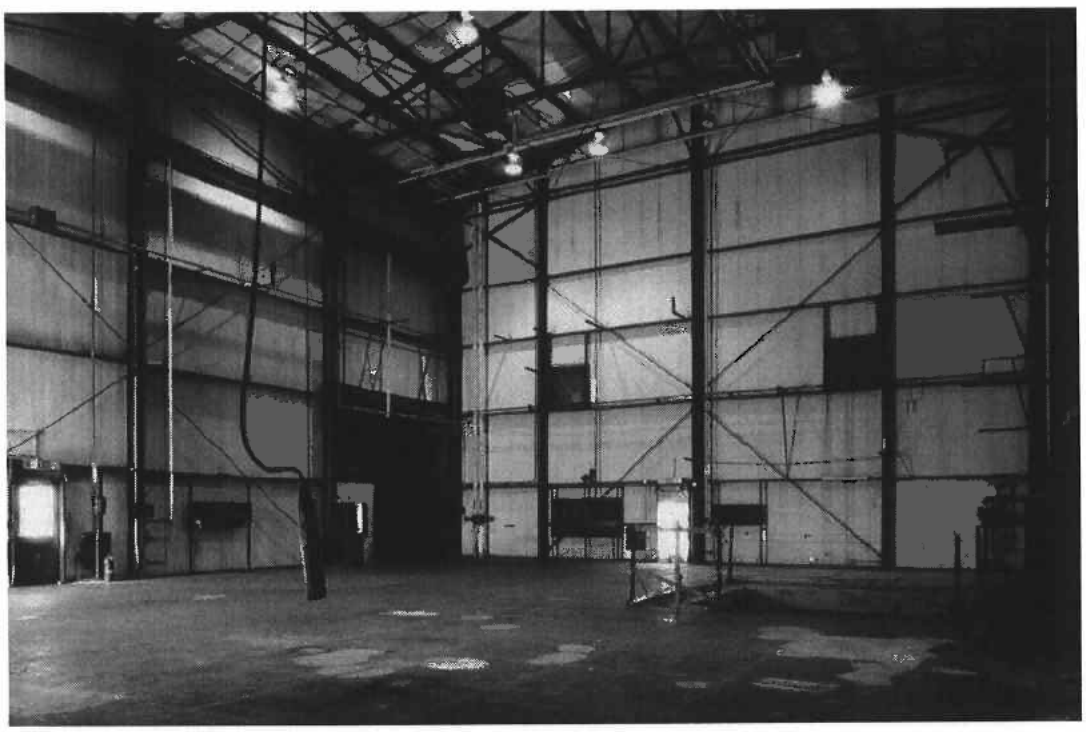
11. VIEW NORTHWEST OF BUILDING No. 2A - HIGH BAY OF BUILDING No. 2-CRITICAL ASSEMBLY BUILDING.



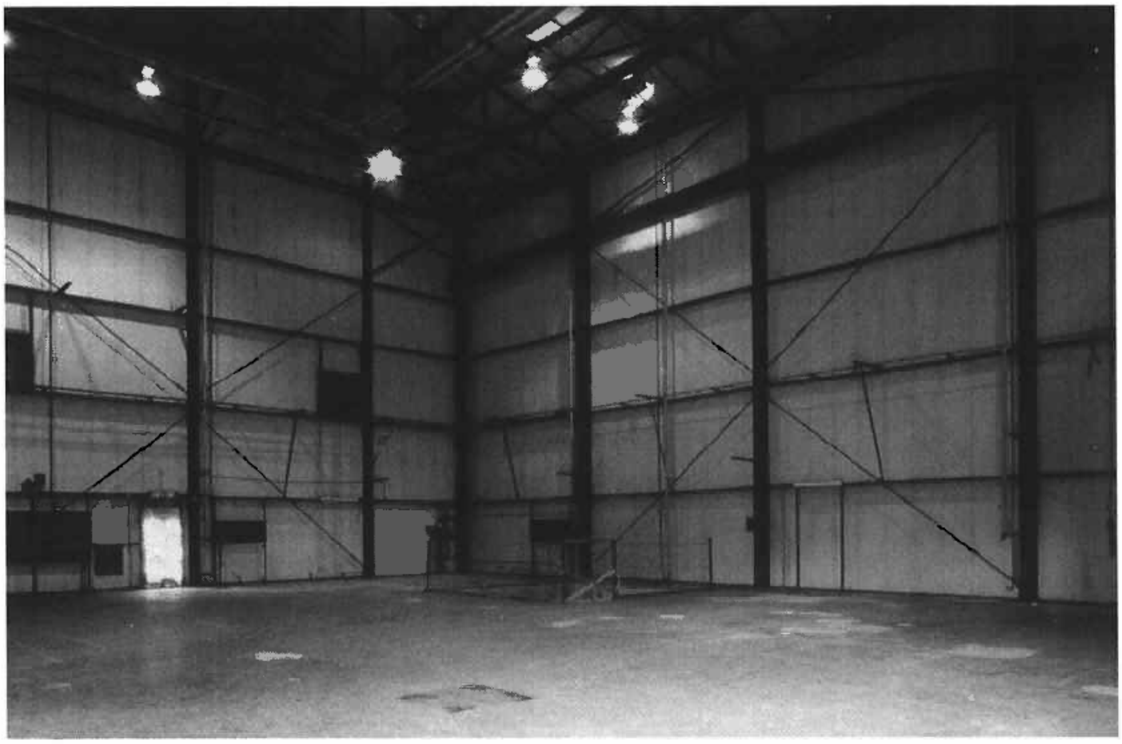
12. VIEW SOUTHWEST OF BUILDING No. 2A-CRITICAL ASSEMBLY BUILDING



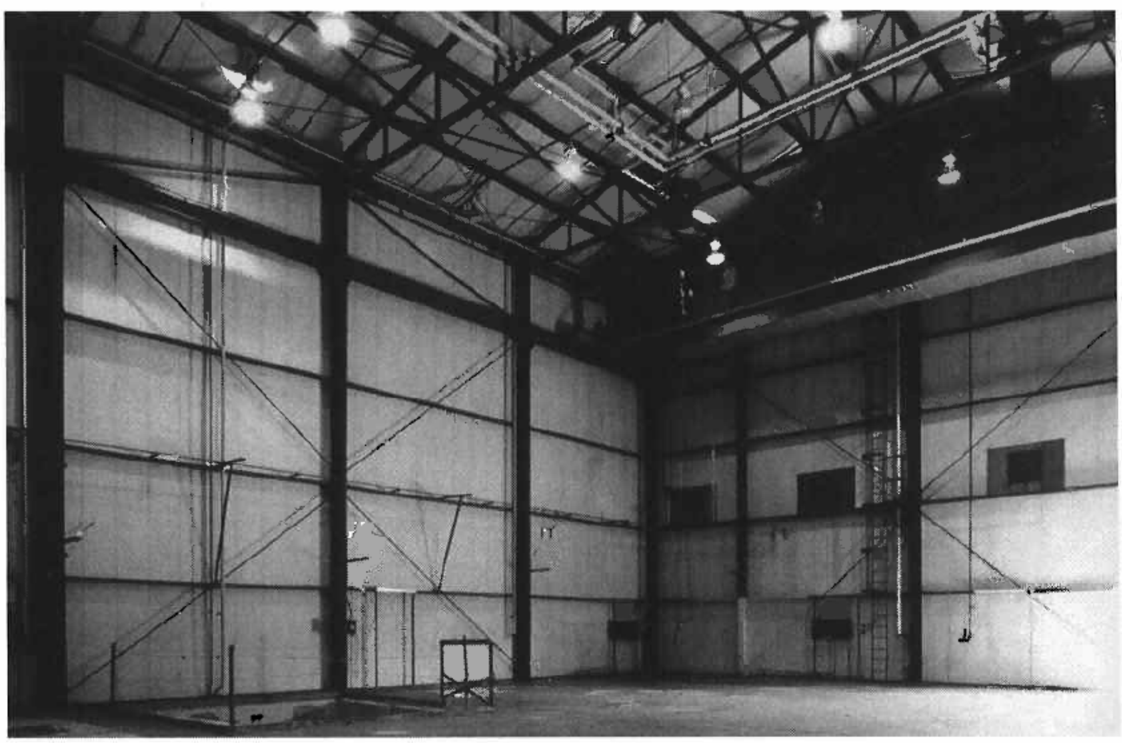
13. VIEW EAST INSIDE HIGH BAY OF BUILDING 2A OF BUILDING No. 2-CRITICAL ASSEMBLY BUILDING



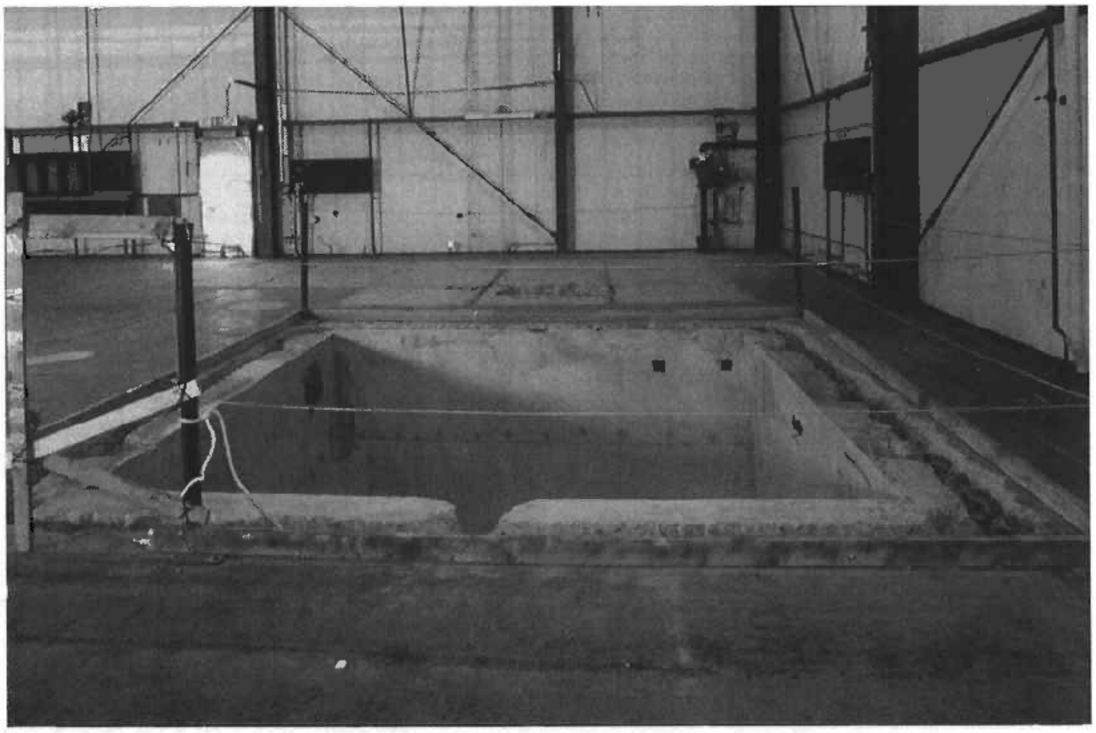
14. VIEW SOUTHWEST INSIDE HIGH BAY - BUILDING No. 2A-CRITICAL ASSEMBLY BUILDING.



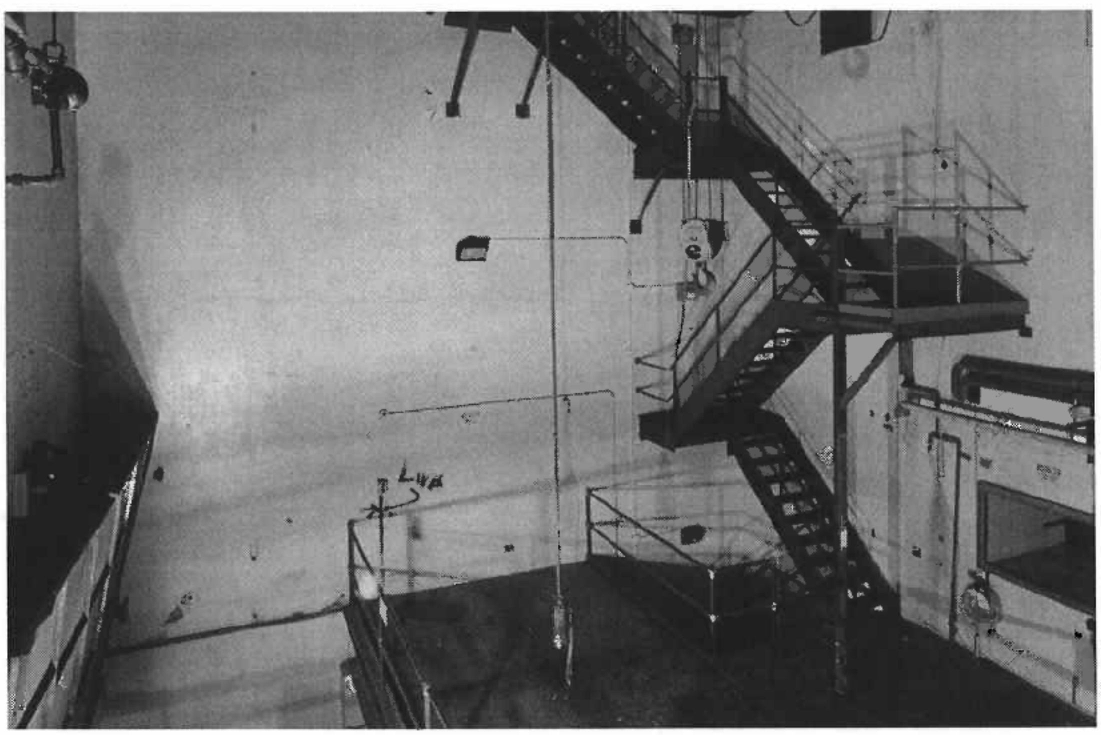
15. VIEW NORTHWEST INSIDE HIGH BAY OF BUILDING No. 2A-CRITICAL ASSEMBLY BUILDING



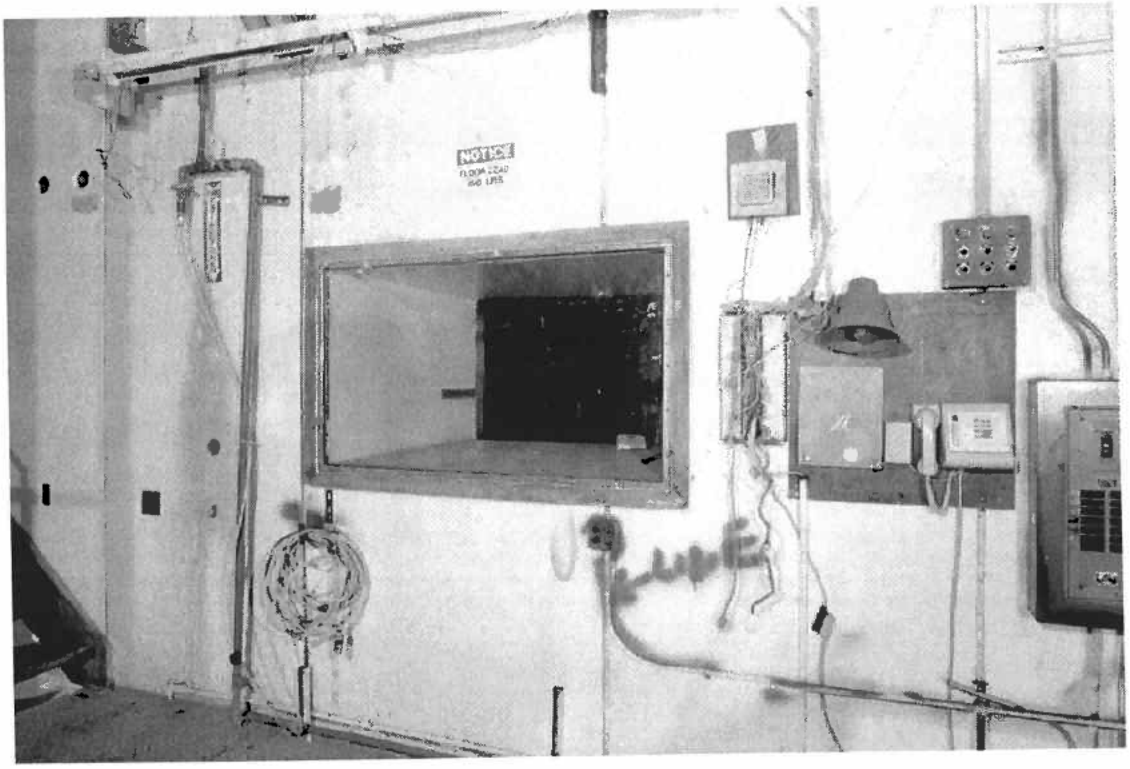
16. VIEW INSIDE HIGH BAY AREA-OF BUILDING No. 2A-CRITICAL ASSEMBLY BUILDING



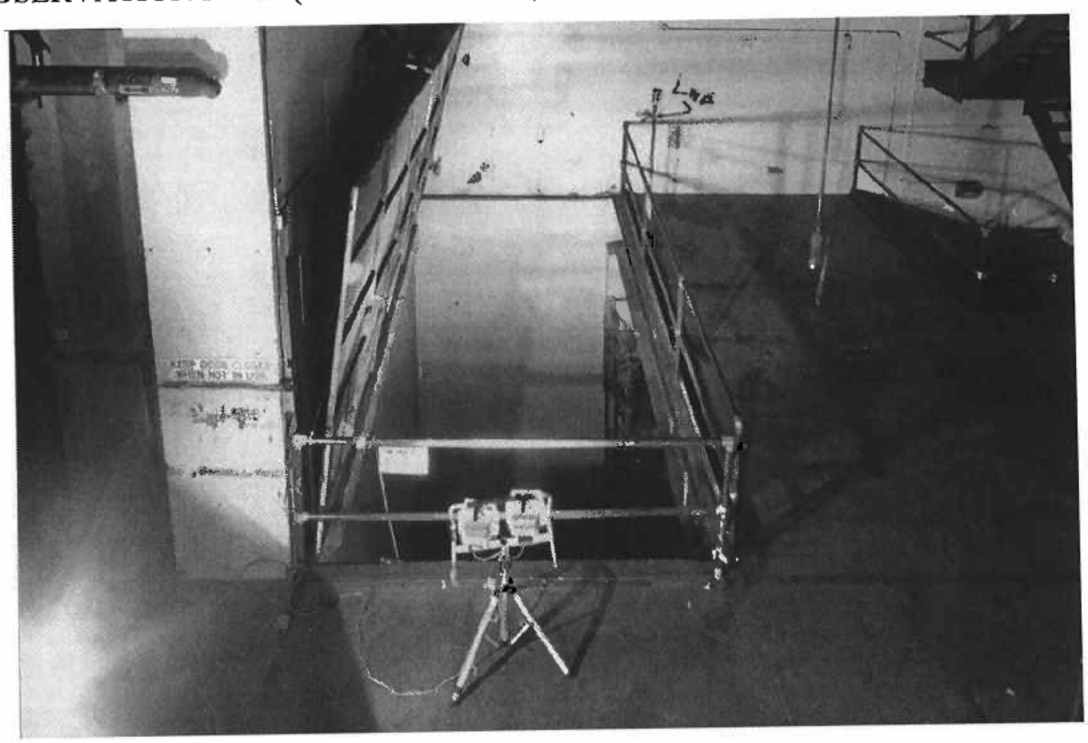
17. VIEW OF PIT ON NORTH SIDE OF HIGH BAY AREA -BUILDING No. 2A



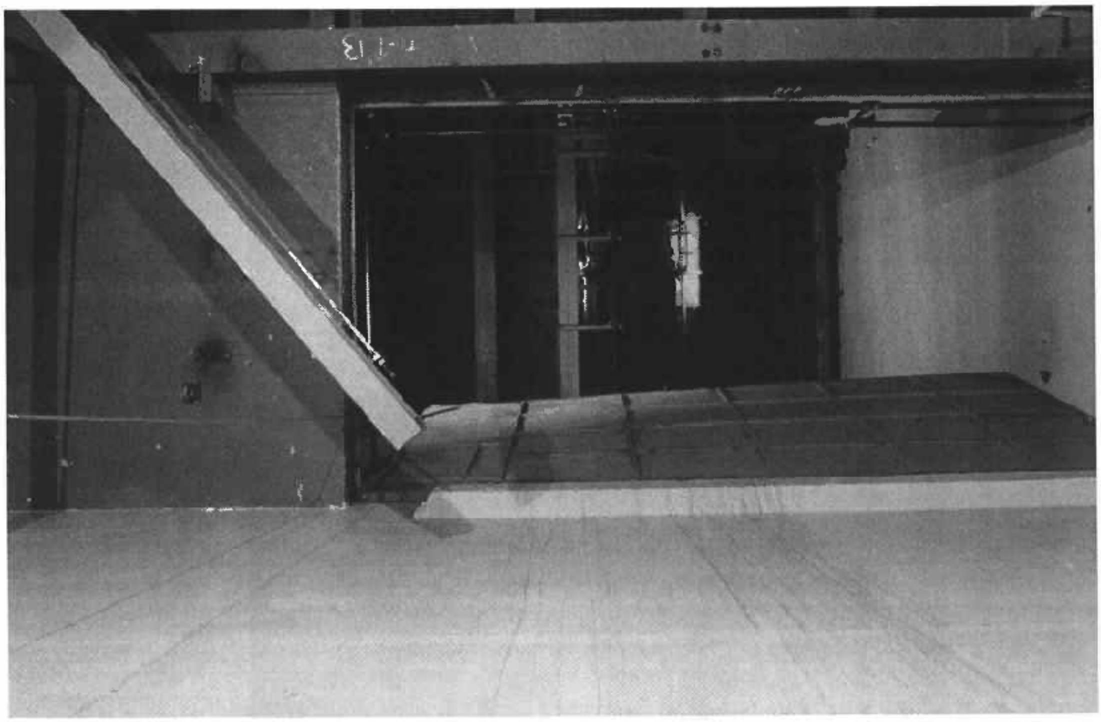
18. VIEW EAST WITHIN TEST CELL No. 2 - BUILDING No. 2 -CRITICAL ASSEMBLY BUILDING.



19. OBSERVATION PORT (WATER FILLED) IN TEST CELL No.2.



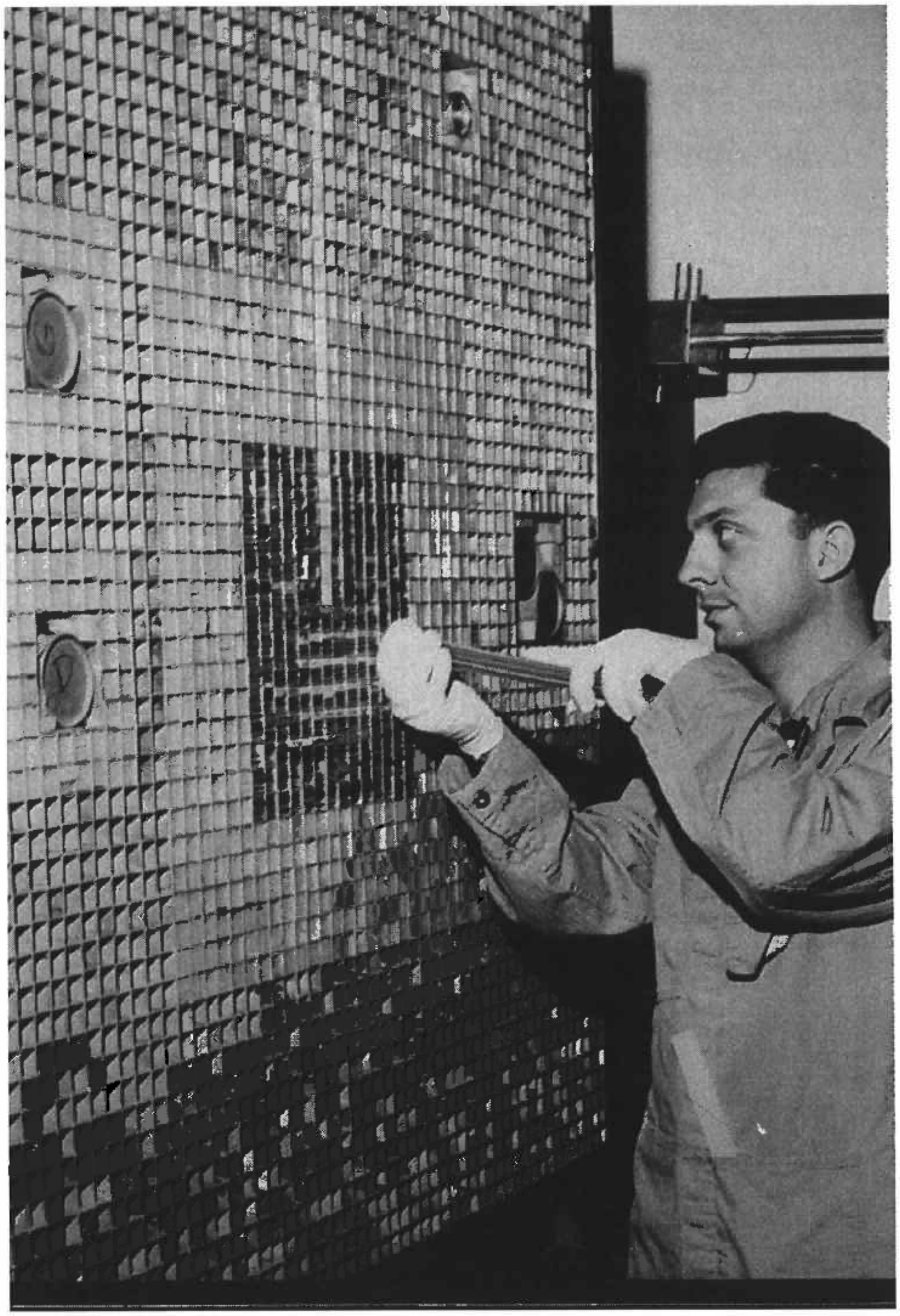
20. VIEW EAST INTO TEST CELL No. 2 PIT - BUILDING No. 2 -CRITICAL ASSEMBLY BUILDING.



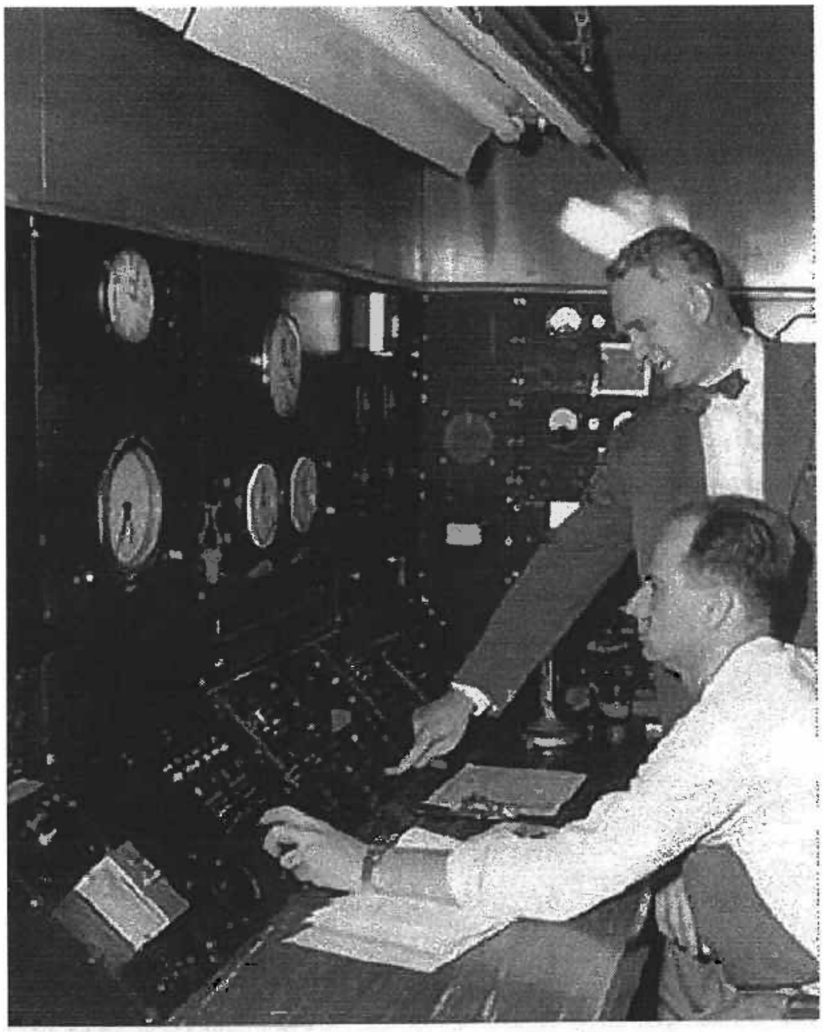
21. VIEW UP INTO TOWER OVER TEST CELL No. 2 - BUILDING No. 2 -CRITICAL ASSEMBLY BUILDING. NOTE JIB CRANE AT TOP LEFT.

22. VIEW EAST INSIDE TEST CELL No. 2 - PIT AREA BUILDING No. 2 - CRITICAL ASSEMBLY BUILDING.

24. HISTORICAL AERIAL PHOTO TAKEN DURING CONSTRUCTION OF BUILDING No. 2 -CRITICAL ASSEMBLY BUILDING IN 1956. BUILDING No. 1, CRITICAL FACILITY IS AT LOWER RIGHT. DATED JUNE 8, 1956.



25. UNKNOWN TECHNICIAN CHARGING EXPERIMENTAL REACTOR MOCK-UP IN BUILDING No 1 - C. 1956.



26. HISTORIC SHUTDOWN-WALTER ZINN (STANDING) PRESSES A BUTTON TO SHUT DOWN CHICAGO PILE 3 RESEARCH REACTOR AT ARGONNE NATIONAL LABORATORY.