APPENDIX A. PHOTOGRAPHS

Figure A-1. Circa 2003 photograph showing the east and south elevations of Building 3042, facing northwest.

Figure A-2. Current photograph showing the vestibule on the east elevation of Building 3042, facing west.

Figure A-3. Current photograph showing the shed-roof addition to the south elevation of Building 3042, facing northwest.

Figure A-4. Current photograph showing the west portion of the south elevation of Building 3042, facing north.

Figure A-5. Current photograph showing the west elevation of Building 3042, facing northeast.

Figure A-6. Current photograph showing the service entry on the west elevation of Building 3042, facing east.

Figure A-7. Circa 2003 photograph showing the north and east elevations of Building 3042, facing southwest.

Figure A-8. Current photograph showing the circa 1957 Change House addition to the north elevation of Building 3042, facing southwest.

Figure A-9. Current photograph showing the retaining wall enclosed well on the north elevation of Building 3042, providing access to the below-grade first floor, facing southwest.

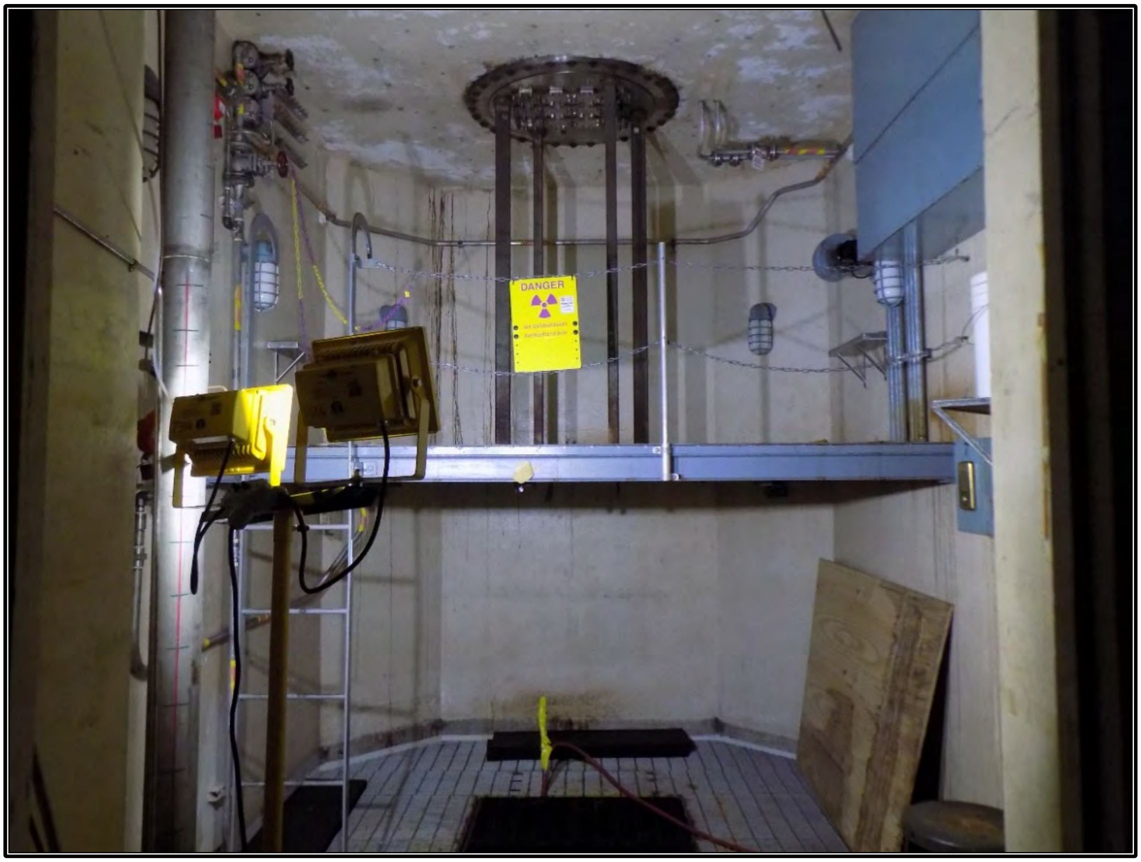


Figure A-10. Current photograph showing the ORR sub-pile room, or reactor pit, in the basement of Building 3042, facing west.

Figure A-11. Current photograph showing the ORR pipe corridor, or pipe chase, in the basement of Building 3042.

Figure A-12. Current photograph showing the east end of the ORR structure dominating the high bay of Building 3042 as seen from the second-level platform on the east wall, facing west.

Figure A-13. Current photograph showing the east end of the ORR structure dominating the high bay of Building 3042 as seen from the second floor south corridor, facing north.

Figure A-14. Current photograph showing the high bay dominated by the ORR structure, facing southwest. In the center background the hot cell area occupies the west end of the reactor structure.

Figure A-15. Current photograph showing the east portion of the high bay in Building 3042, including the second-level platform on the east wall, as seen from the third floor south corridor, facing northeast.

Figure A-16. Current photograph showing the east portion of the high bay in Building 3042, including the second-level platform on the east wall, as seen from the third floor north corridor, facing southeast.

Figure A-17. Current photograph showing the north portion of the high bay in Building 3042 as seen from the second-level service entry on the west elevation, facing east.

Figure A-18. Current photograph on the first floor of Building 3042 showing the containment cell, including the viewing window, located on the south side of the ORR structure, facing northwest.

Figure A-19. Current photograph on the first floor of Building 3042 showing the North Engineering Test Facility and equipment located on the north side of the ORR structure, facing southwest.

Figure A-20. Current photograph showing the Instrument Staff Shop area in the north wing of the first floor of Building 3042, including an air conditioning unit, facing southeast.

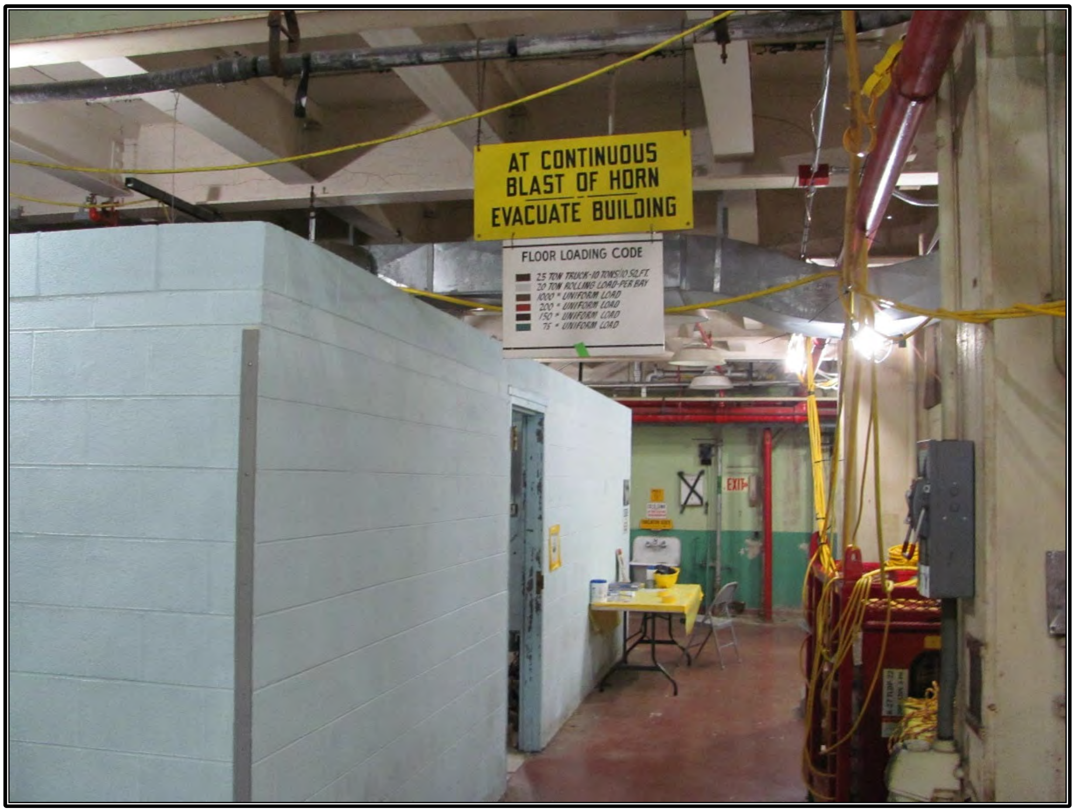


Figure A-21. Current photograph showing a portion of the first floor north corridor as well as the walls containing the Electrical Shop located on the north side of the ORR structure, facing west.

Figure A-22. Current photograph showing the Equipment Room, located on the first floor of the circa 1957 Change Room addition on the north elevation of Building 3042, facing west.

Figure A-23. Current photograph showing the stair access to the balcony of the ORR structure from the Truck Bay located on the second-level of Building 3042 at the west side of the ORR structure, facing east.

Figure A-24. Current photograph showing the elevator entry located in the southwest corner of Building 3042 at the second-level, facing south.

Figure A-25. Current photograph showing the second floor south corridor in the south wing of Building 3042, facing east.

Figure A-26. Current photograph showing Room 212 located on the south side of the ORR structure on the second floor of Building 3042, facing northwest.

Figure A-27. Current photograph showing an example of office space on the second floor of the south wing of Building 3042.

Figure A-28. Current photograph showing the Reactor Maintenance Plant and Equipment Division Office in the southeast corner of the south wing on the second floor of Building 3042, facing southeast.

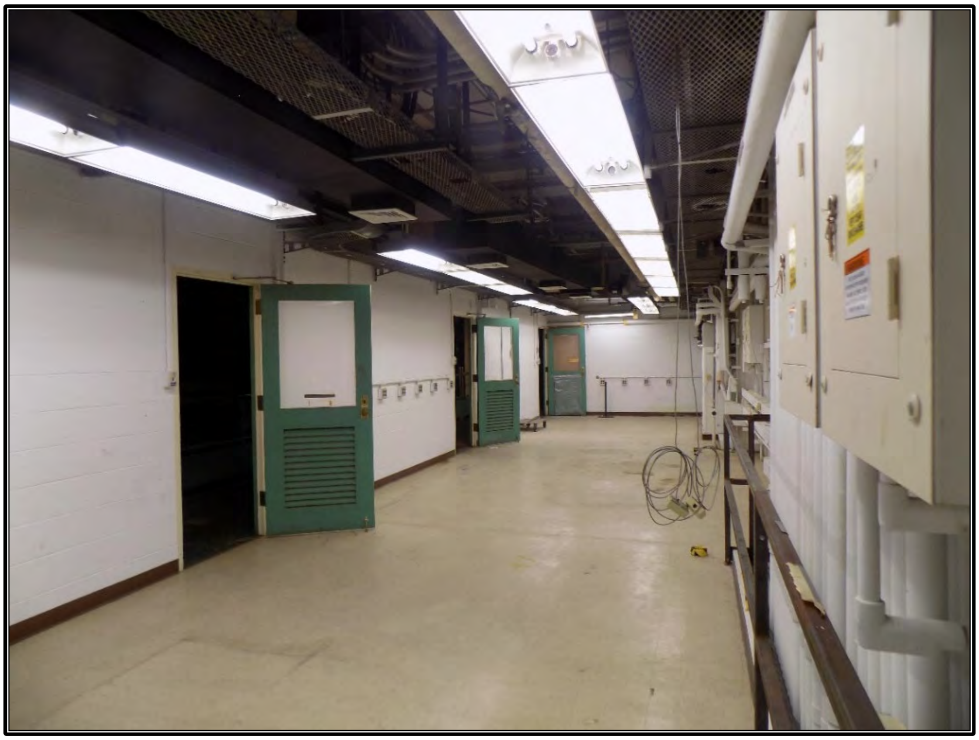


Figure A-29. Current photograph showing the Control Room for in-pile experiments located on the second floor of the north wing of Building 3042, facing west.

Figure A-30. Current photograph showing Room 308 on the third floor of the south wing of Building 3042, facing southwest.

Figure A-31. Current photograph showing the west end of the third floor north corridor in Building 3042, facing east.

Figure A-32. Current photograph showing the Control Room on the third floor of the north wing of Building 3042, facing northeast.

Figure A-33. Current photograph showing the viewing windows located in the third floor Control Room and a portion of the third floor north corridor in the north wing of Building 3042, facing west.

Figure A-34. Current photograph showing the hot cell area located on the west end of the ORR structure at the third-level of Building 3042, facing northwest.

Figure A-35. Archival photograph, circa 1956, showing the steel framing in progress during the construction of Building 3042, facing southwest (ORNL Photo 17223).

Figure A-36. Archival photograph, circa 1956, showing the south and east elevation of Building 3042 under construction, facing northwest (ORNL Photo 18608).

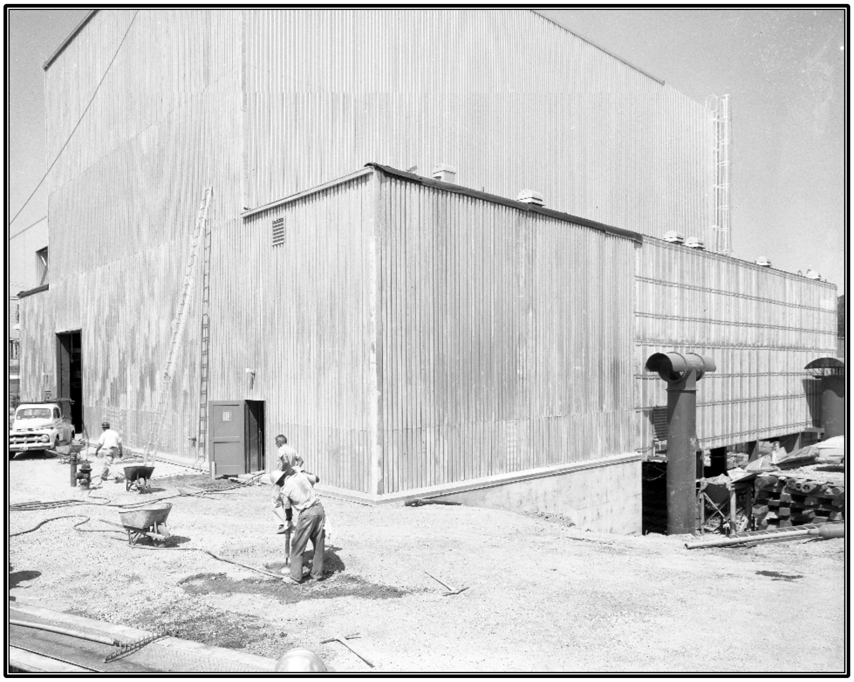


Figure A-37. Archival photograph, circa 1956, showing the west and south elevations of Building 3042 under construction, facing northeast (ORNL Photo 18606).

Figure A-38. Archival photograph showing the Change House addition to the north elevation of Building 3042 under construction, circa 1957 (ORNL Photo 42040).

Figure A-39. Archival photograph showing the Chang House addition to the north elevation of Building 3042 near completion, facing west, circa 1957 (ORNL Photo 42104).

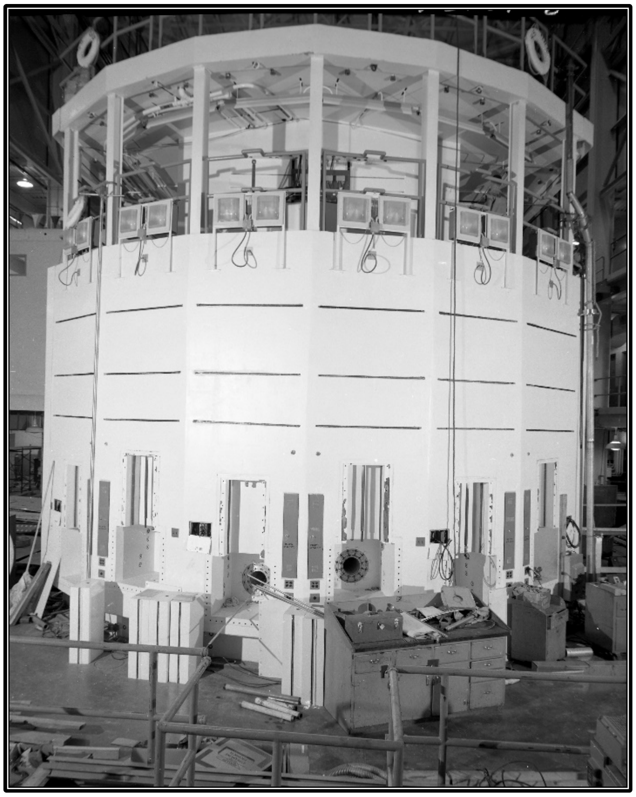


Figure A-40. Archival photograph showing the ORR structure in the high bay of Building 3042 nearing completion, facing west, circa 1957 (ORNL Photo 42186).

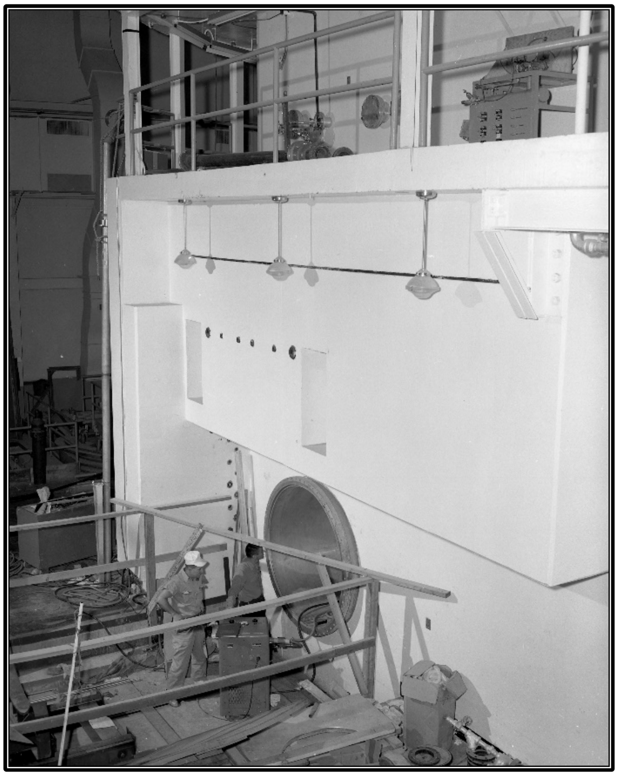


Figure A-41. Archival photograph showing one of the ORR Engineering Test Facilities nearing completion at Building 3042, circa 1957 (ORNL Photo 42190).

Figure A-42. Archival photograph showing the Control Room on the third floor of the north wing in Building 3042, circa 1958 (ORNL Photo 43209).

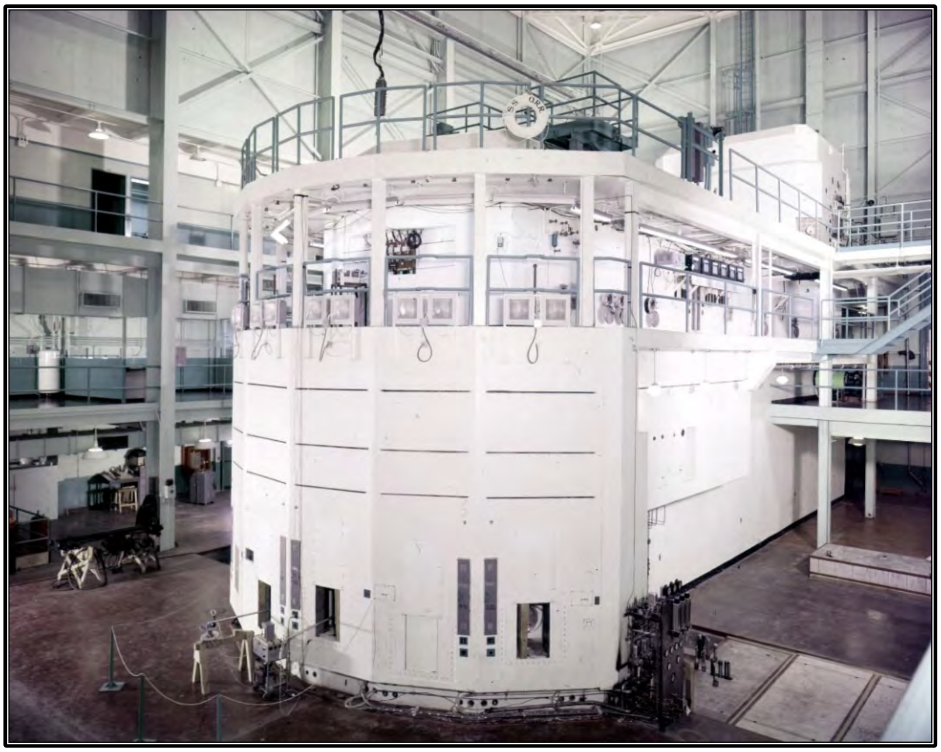


Figure A-43. Archival photograph showing the completed ORR structure in the high bay of Building 3042, facing southwest, circa 1958 (ORNL Photo 43965).

Figure A-44. Archival photograph showing future President Lyndon B. Johnson (third from left), Tennessee Senator Albert Gore Senior (second from right), and Tennessee Governor Buford Ellington (left) standing at the edge of the ORR pool in the high bay of Building 3042, circa 1958 (ORNL Photo 58-930).

Figure A-45. Archival photograph taken within the reactor structure showing personnel loading the ORR the day it went critical, March 21, 1958 (ORNL Photo 3208).

Figure A-46. Archival photograph showing Alvin Weinberg (third from left) standing on the top of the ORR structure in the high bay of Building 3042 with future President John F. Kennedy (second from left), future First Lady Jaqueline Kennedy (second from right), and Tennessee Senator Albert Gore Senior (third from right), circa February 1959 (ORNL Photo 04786).

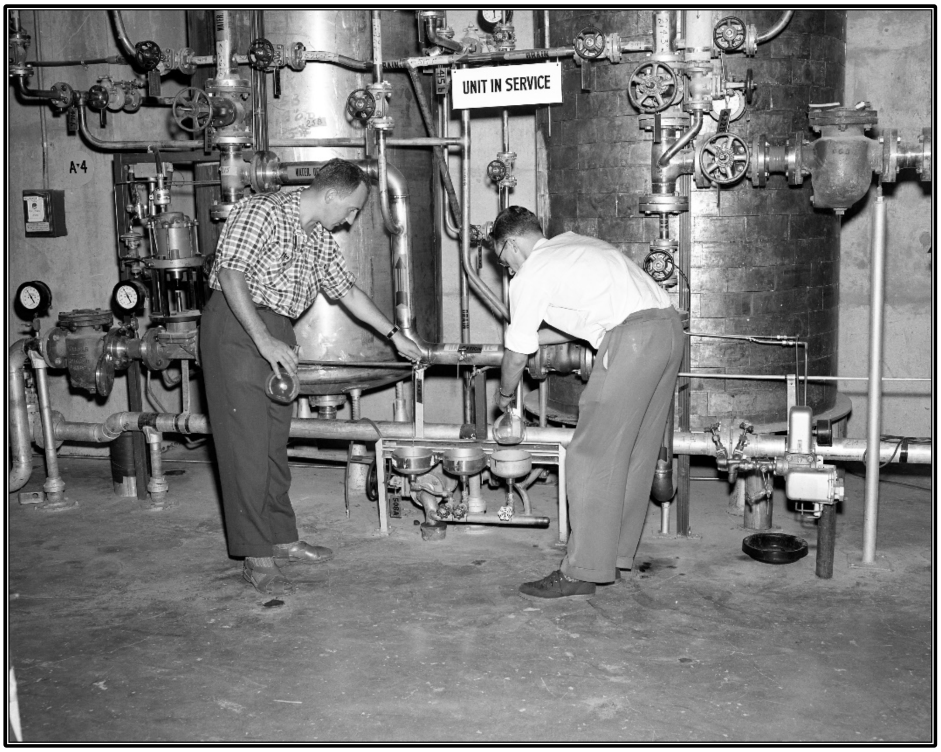


Figure A-47. Archival photograph showing employees working with the anion and cation exchangers located on the west wall in the basement of Building 3042, circa 1959 (ORNL Photo 47539).

Figure A-48. Archival photograph showing employees working on the reactor bridge at the west end of the ORR structure, facing southwest, circa 1959 (ORNL Photo 47543).

Figure A-49. Archival photograph showing the GCR-ORR Loop No. 1 control panel located in the Irradiation Engineering Room in the north wing of the basement in Building 3042, circa 1959 (ORNL Photo 48279).

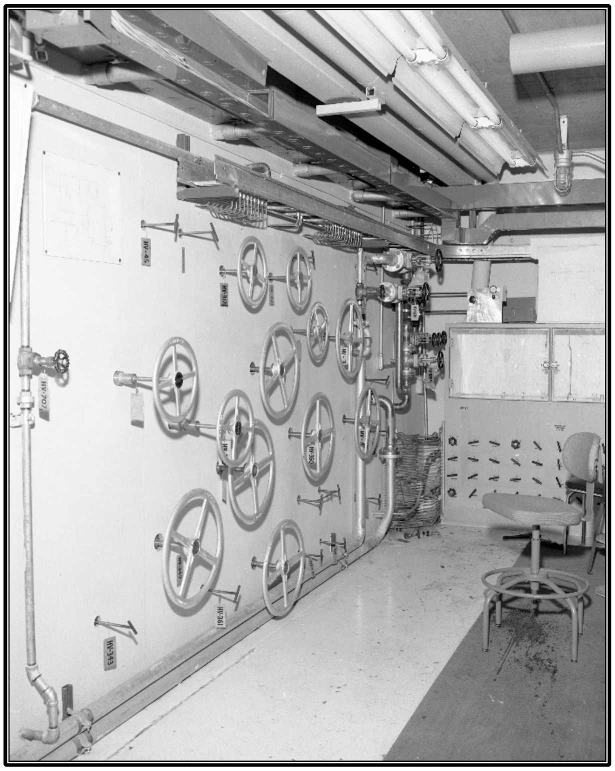


Figure A-50. Archival photograph showing the Pressurized Water Loop instrumentation located in the Irradiation Engineering Room in the north wing of the basement in Building 3042, circa 1959 (ORNL Photo 48273).

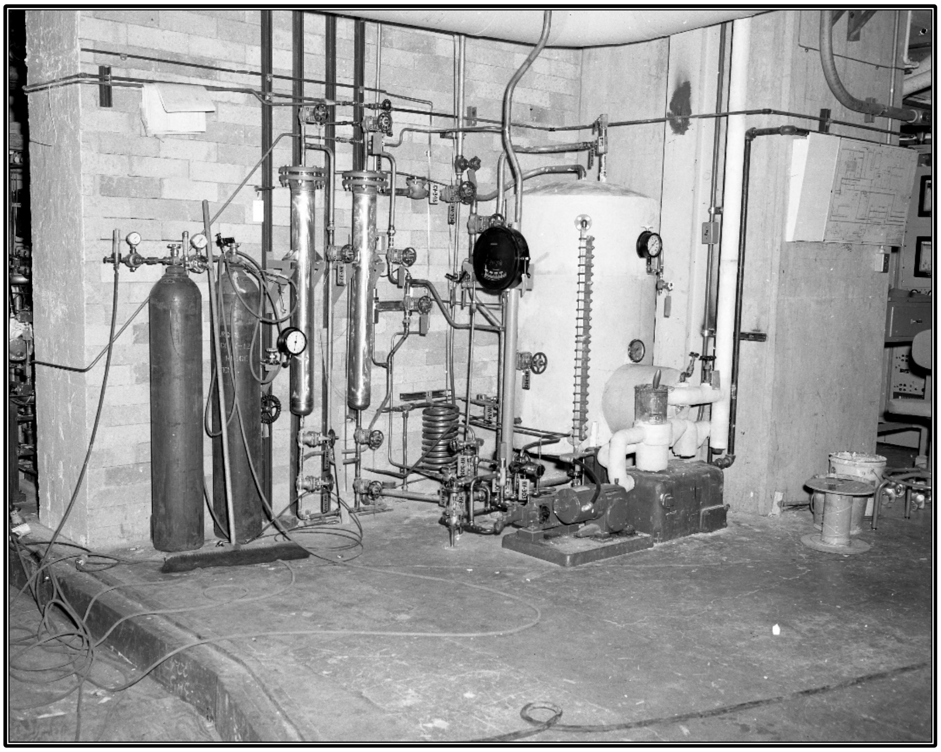


Figure A-51. Archival photograph showing Pressurized Water Loop equipment located adjacent to the ORR structure in the basement of Building 3042, circa 1959 (ORNL Photo 48278).

Figure A-52. Archival photograph showing employees working at an experimental facility located on the north side of the ORR structure at the first level, circa 1959 (ORNL Photo 47542).

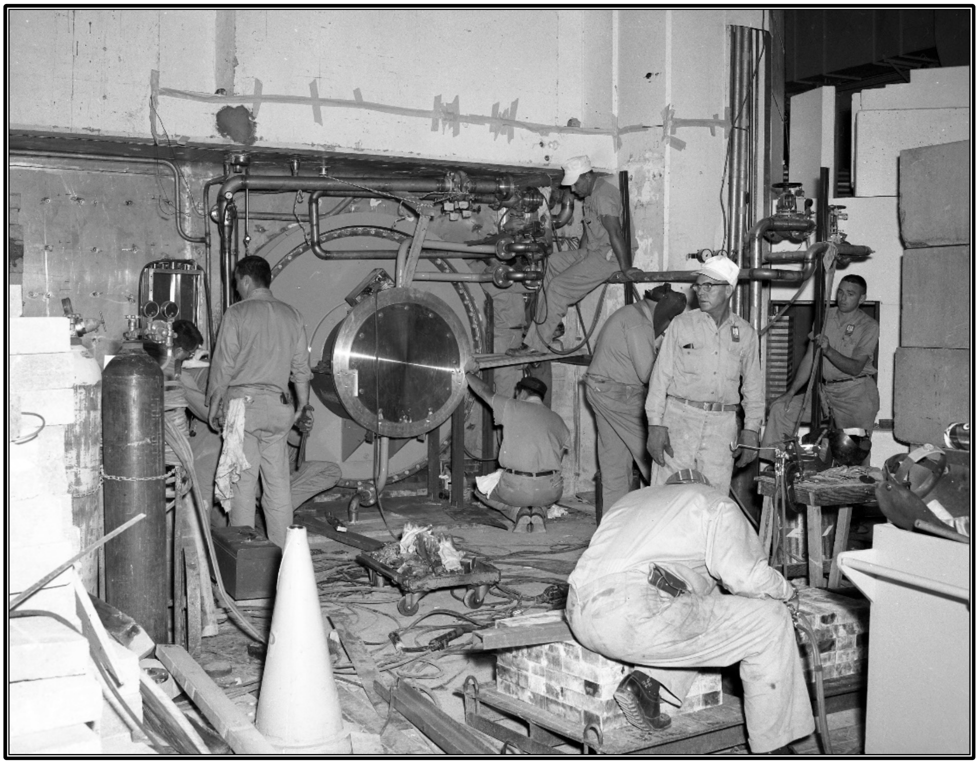


Figure A-53. Archival photograph showing the installation of the GCR-ORR Loop No. 2 at the South Engineering Test Facility at the ORR in Building 3042, circa 1960 (ORNL Photo 51474).

Figure A-54. Archival photograph showing the west and south elevations of Building 3042, facing northeast, circa 1960 (ORNL Photo 51411).

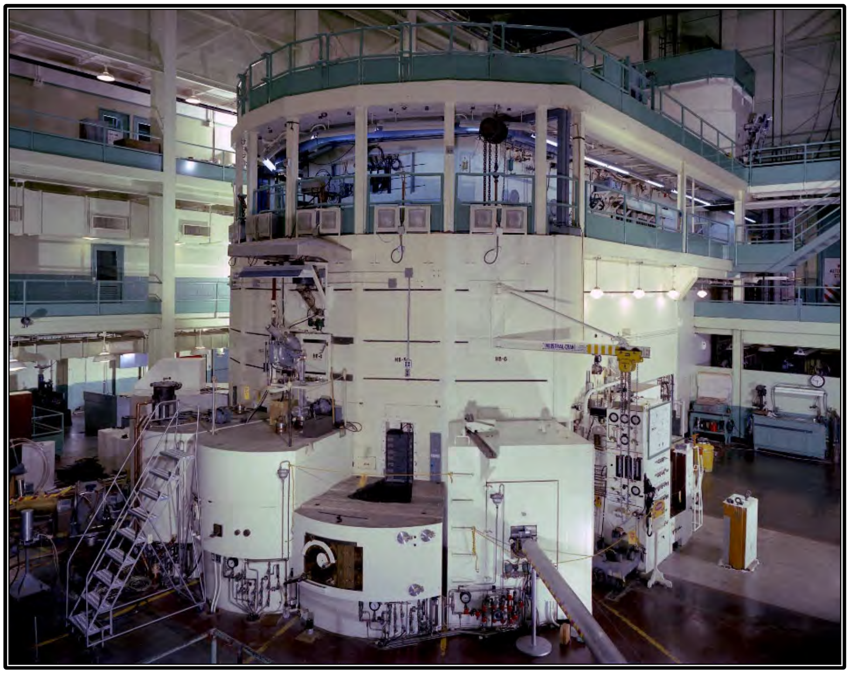


Figure A-55. Archival photograph showing the east end of the ORR structure in the high bay of Building 3042, facing southwest, with several experiments underway, circa 1960 (ORNL Photo 48863).

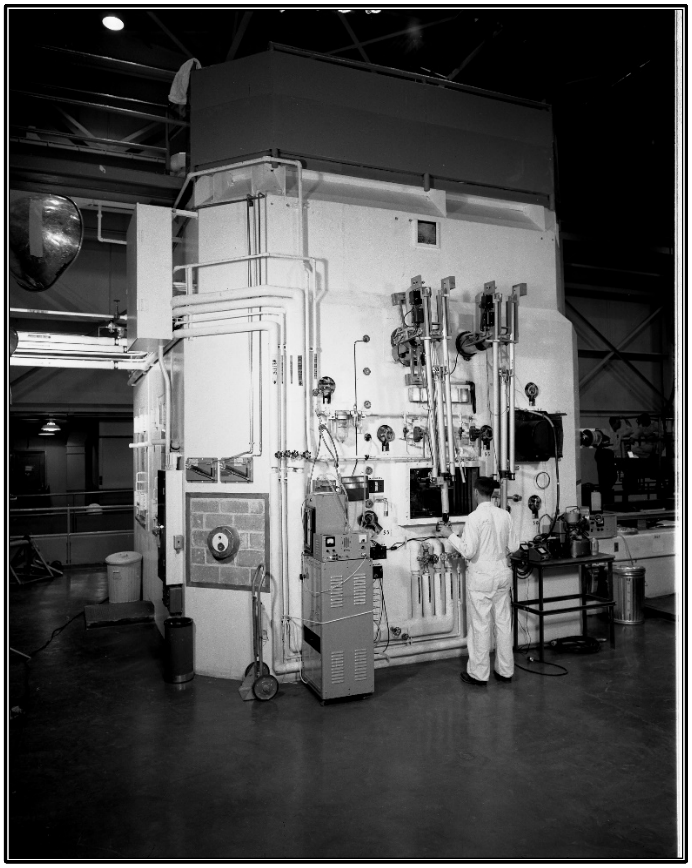


Figure A-56. Archival photograph showing an employee working at the hot cell area located on the west end of the ORR structure at the third-level of Building 3042, facing north, circa 1960 (ORNL Photo 48951).

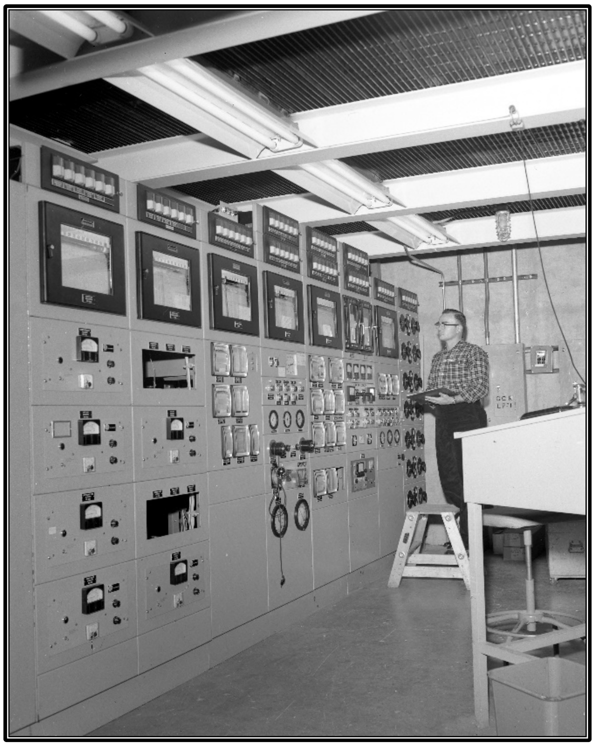


Figure A-57. Archival photograph showing a control panel for the GCR-ORR Loop No. 1 located in the Irradiation Engineering Room in the northeast corner of the basement of Building 3042, circa 1960 (ORNL Photo 52500).

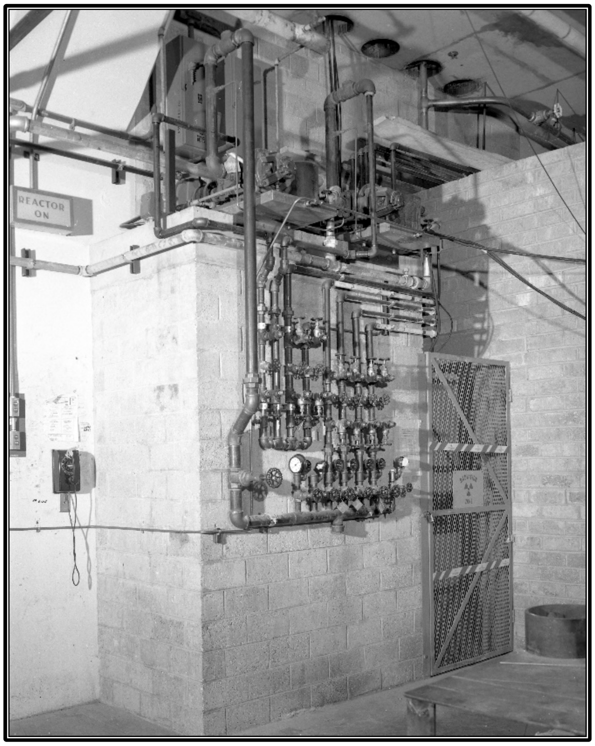


Figure A-58. Archival photograph showing control valves on a wall of the ORR substructure in the basement of Building 3042, circa 1960 (ORNL Photo 52496).

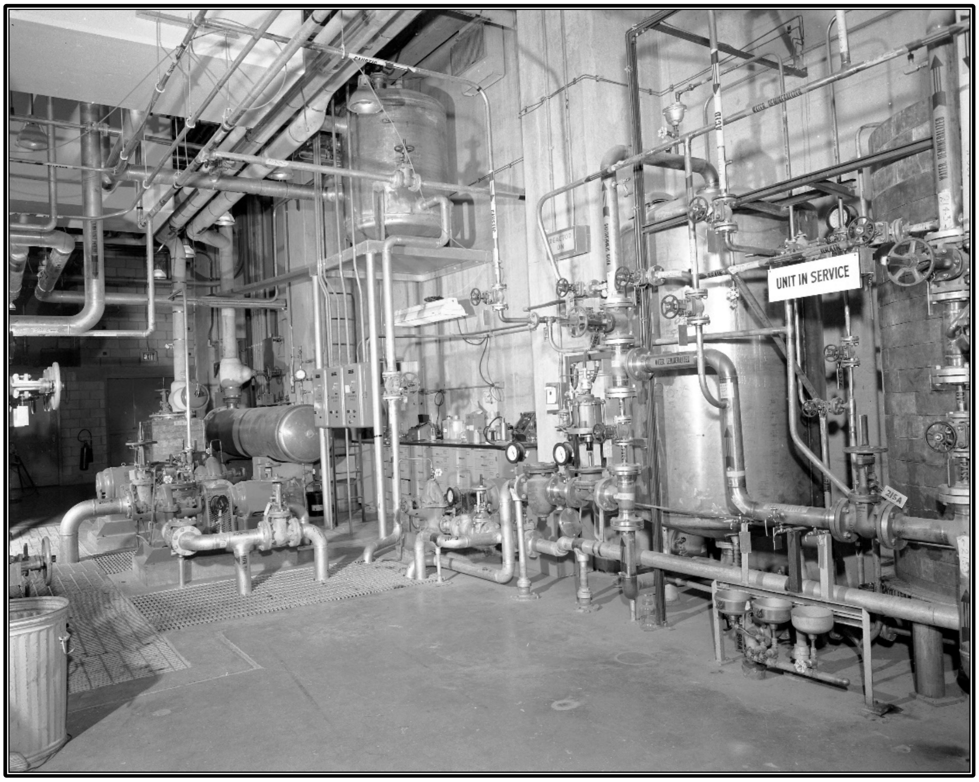


Figure A-59. Archival photograph showing the west portion of the basement in Building 3042, in between the ORR substructure and the west wall, facing southwest, circa 1960 (ORNL Photo 52498).

Figure A-60. Archival photograph of the Control Room on the third floor of the north wing in Building 3042, facing north, circa 1962 (ORNL Photo 59471).

Figure A-61. Archival photograph showing the ORR structure in the high bay of Building 3042, facing southwest, with several experiments underway, circa 1967 (ORNL Photo 86784).

Figure A-62. Archival photograph showing an employee setting up equipment on the south elevation of Building 3042, facing north, circa 1981 (ORNL Photo 2652-81).

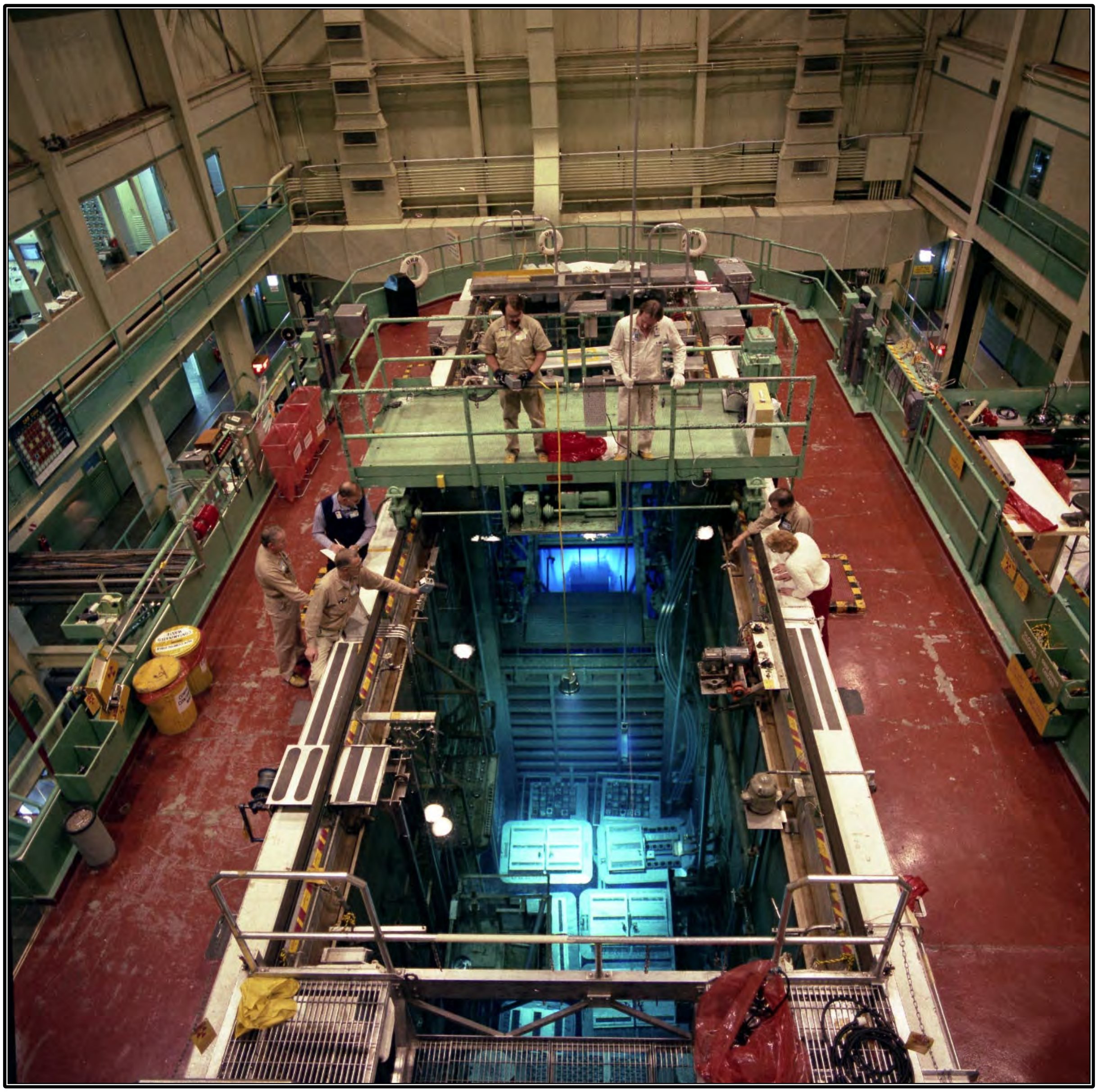


Figure A-63. Archival photograph showing employees working from the top of the ORR structure and pool, circa 1983 (ORNL Photo 08104-83).

APPENDIX B. ARCHITECTURAL DRAWINGS

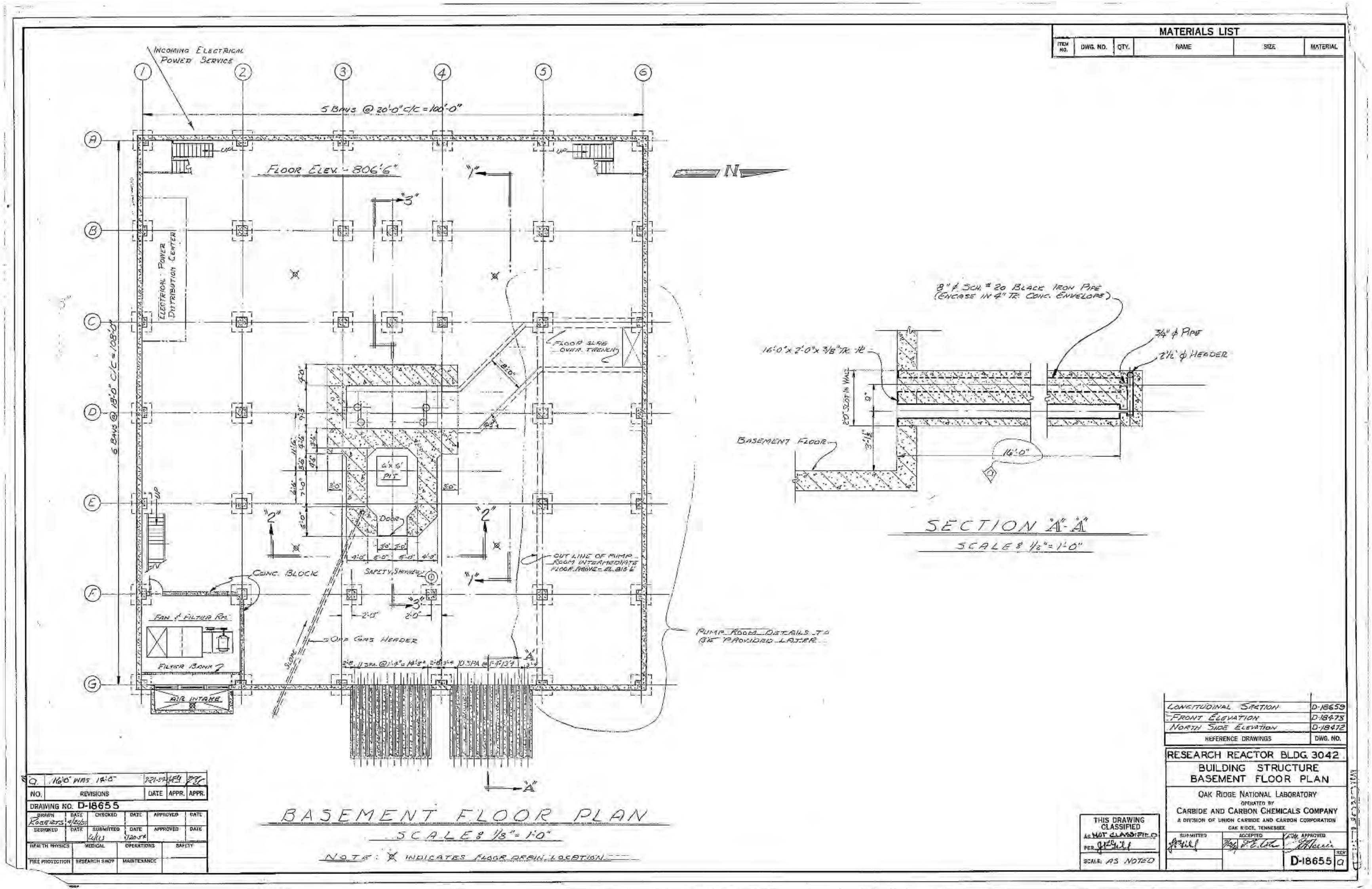


Figure B-1. Basement floor plan for Building 3042 (Oak Ridge National Laboratory, April 26, 1954).

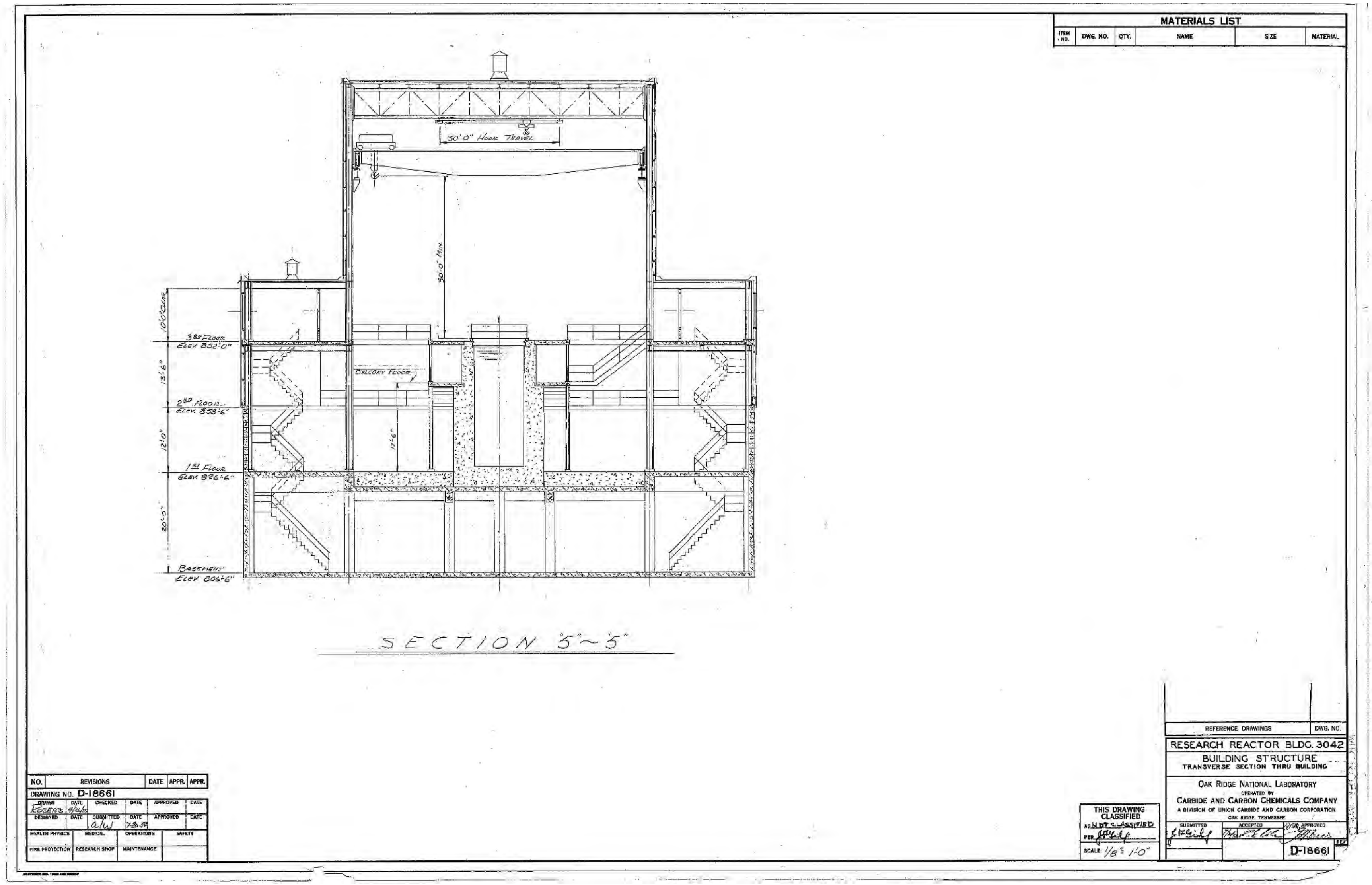


Figure B-2. Transverse section through Building 3042 and the Oak Ridge Research Reactor structure (Oak Ridge National Laboratory, April 26, 1954).

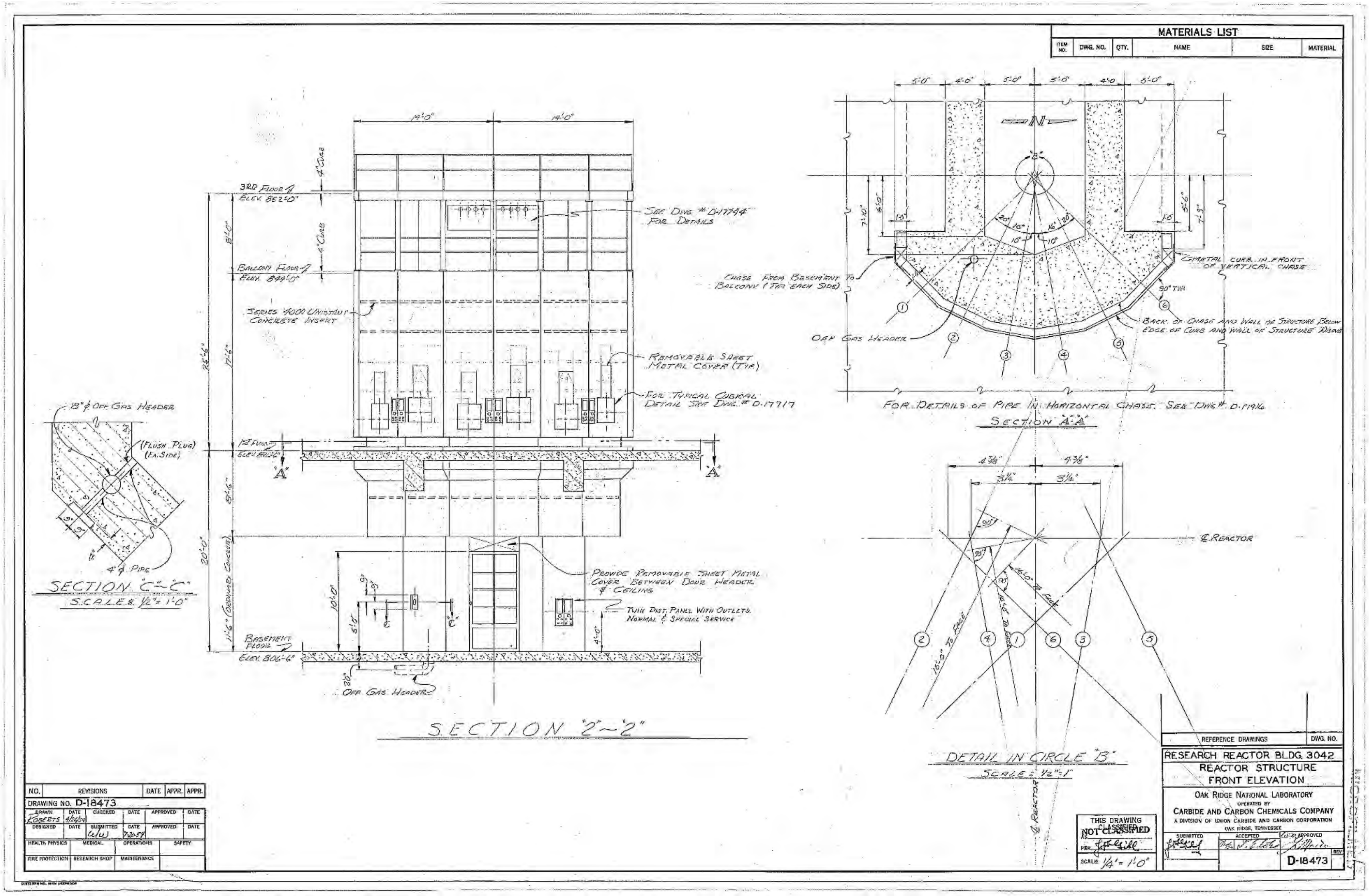


Figure B-3. Front elevation of the Oak Ridge Research Reactor structure in Building 3042 (Oak Ridge National Laboratory, April 26, 1954).

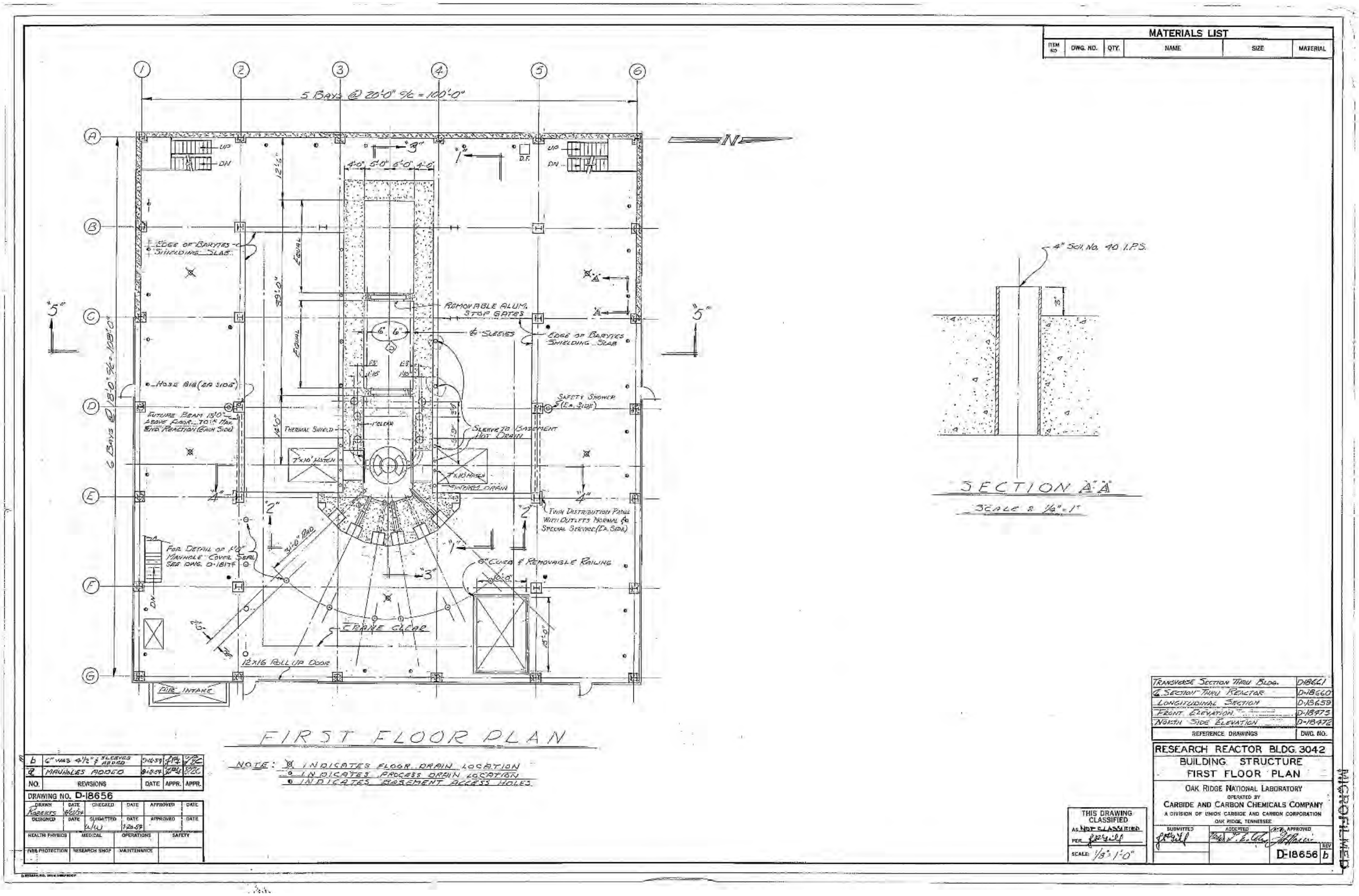


Figure B-4. First floor plan for Building 3042, including sections (Oak Ridge National Laboratory, April 27, 1954).

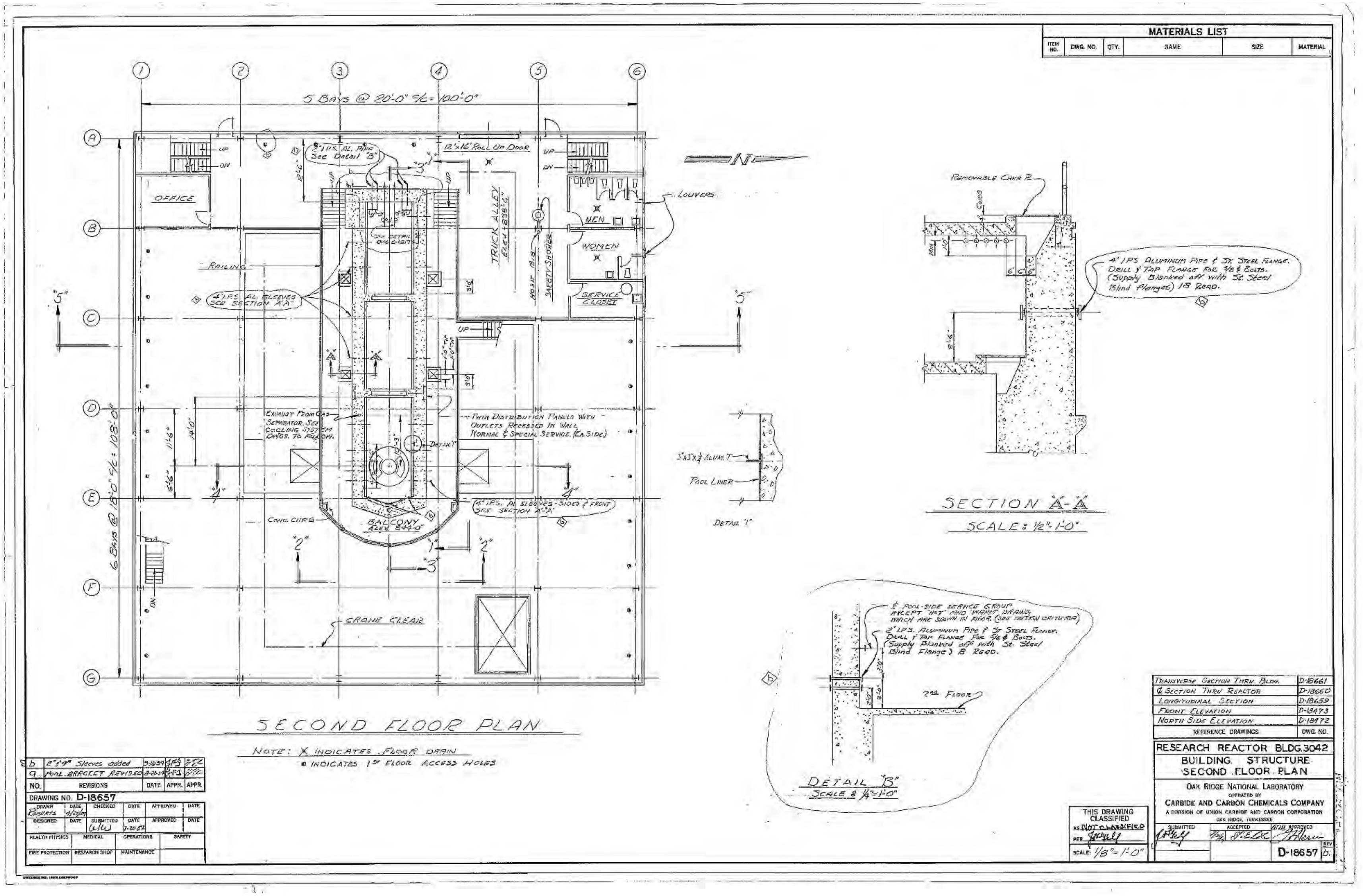


Figure B-5. Second floor plan for Building 3042, including section (Oak Ridge National Laboratory, April 27, 1954).

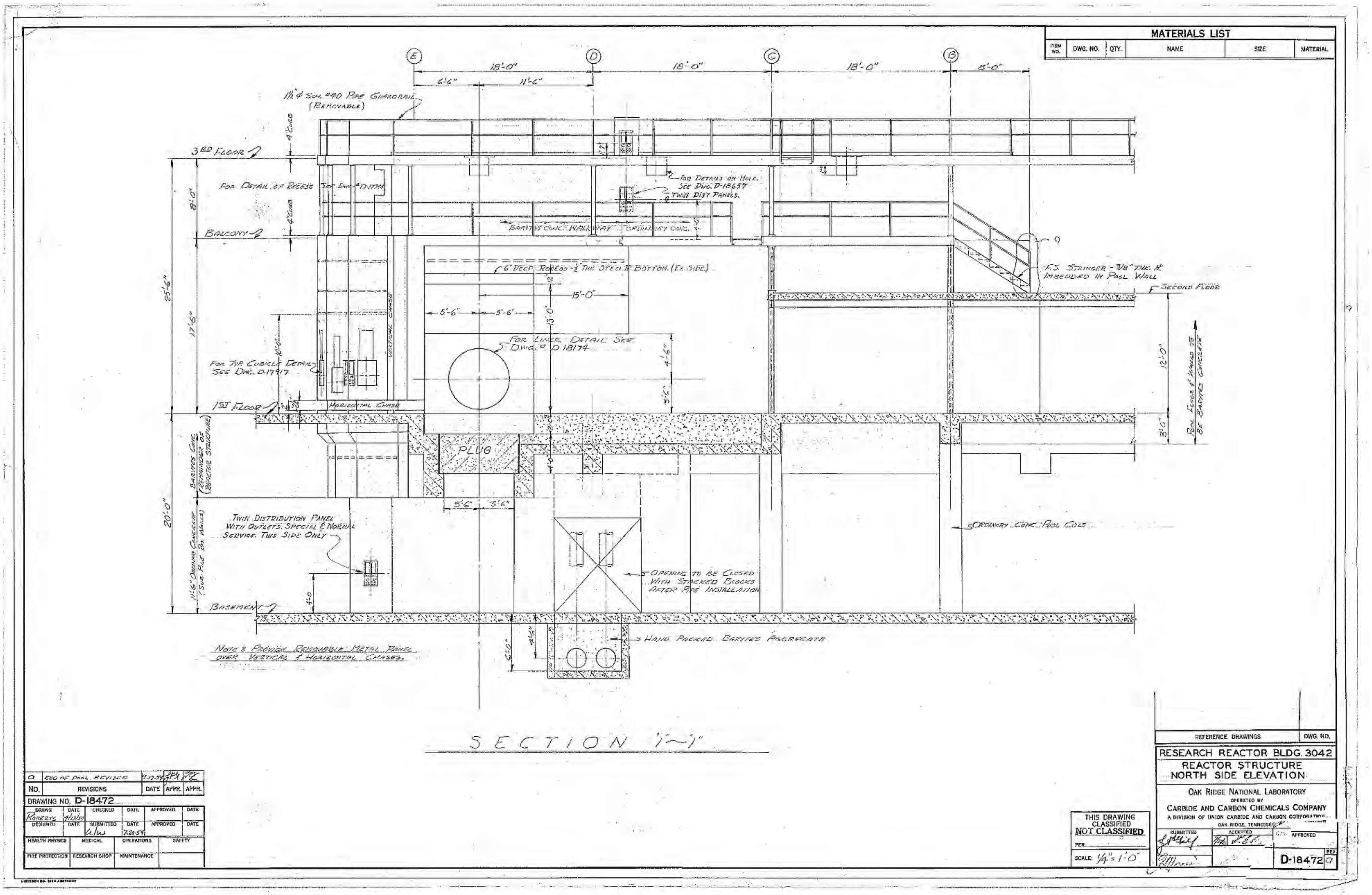


Figure B-6. North elevation of the Oak Ridge Research Reactor structure in Building 3042 (Oak Ridge National Laboratory, April 27, 1954).

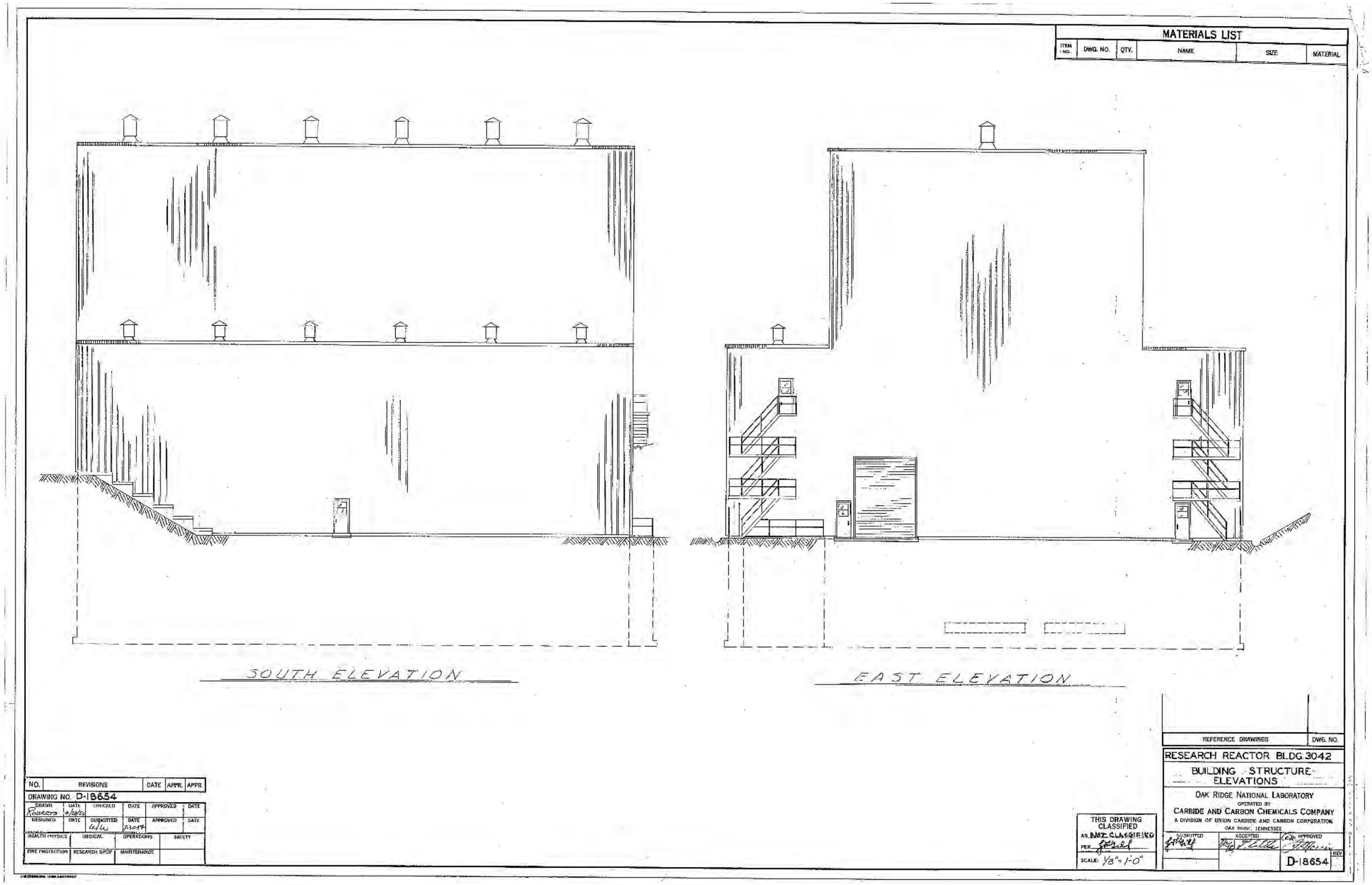


Figure B-7. South and east elevations of Building 3042 (Oak Ridge National Laboratory, April 28, 1954).

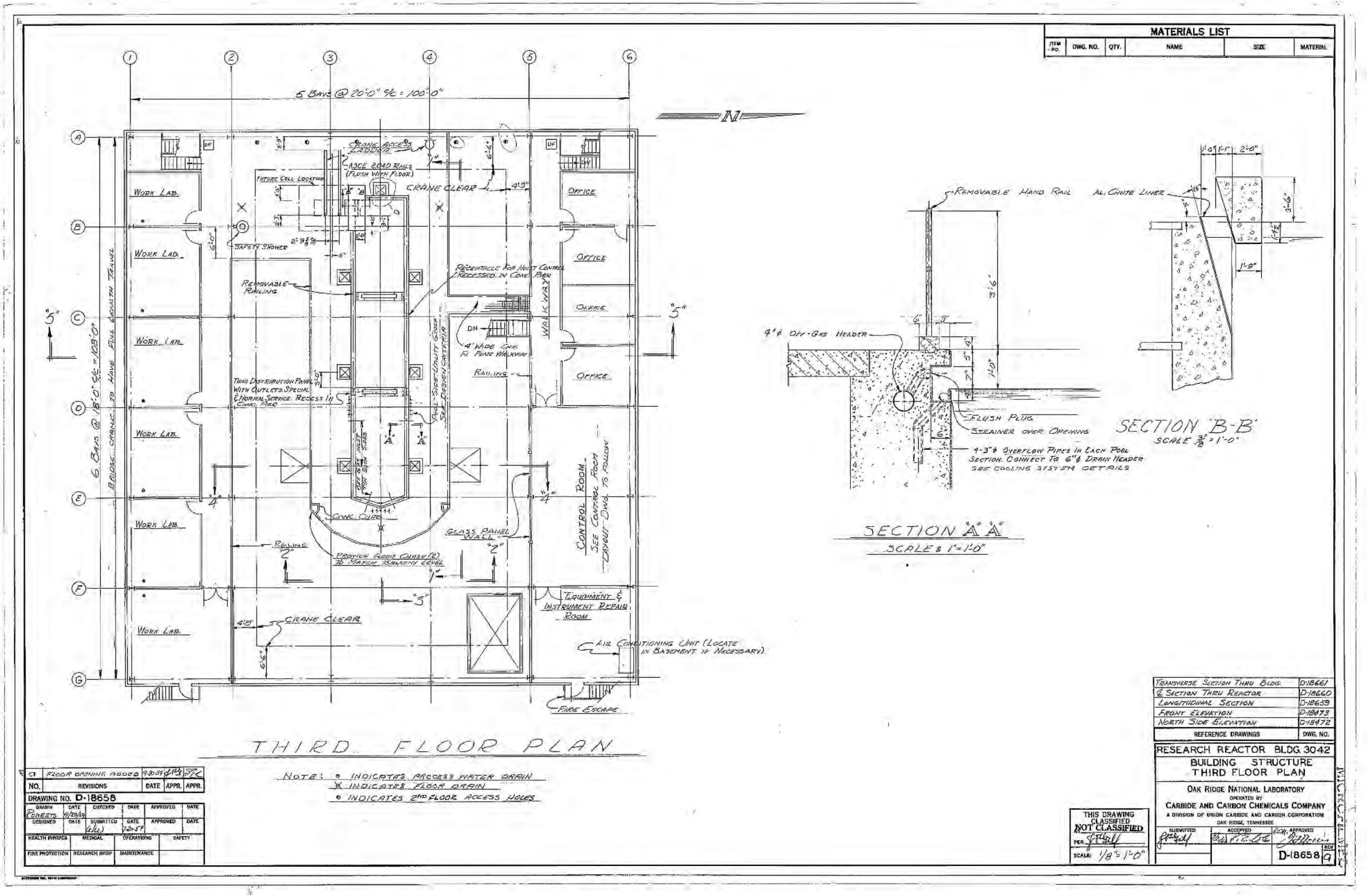


Figure B-8. Third floor plan for Building 3042 (Oak Ridge National Laboratory, April 28, 1954).

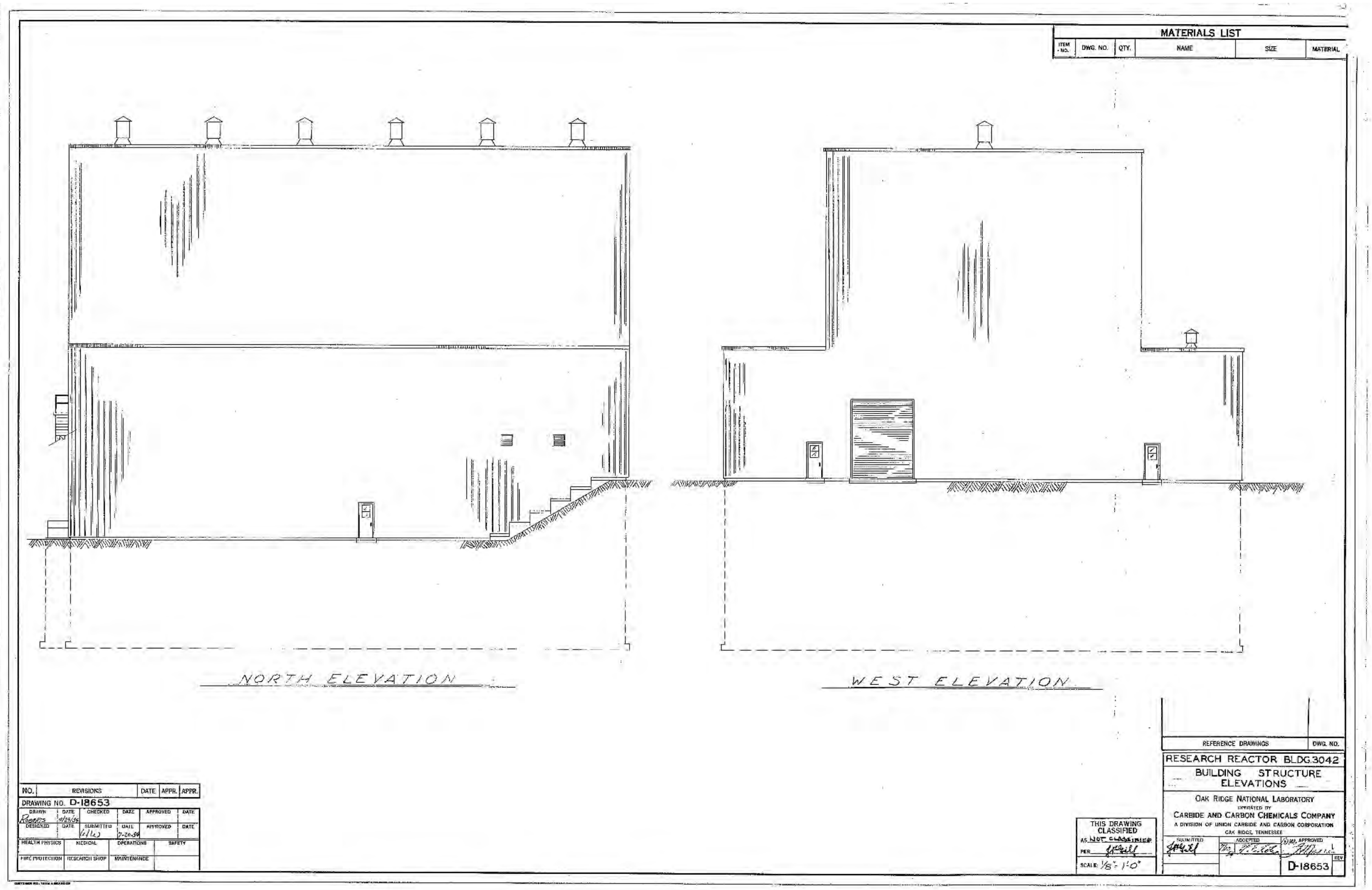


Figure B-9. North and west elevations of Building 3042 (Oak Ridge National Laboratory, April 29, 1954).

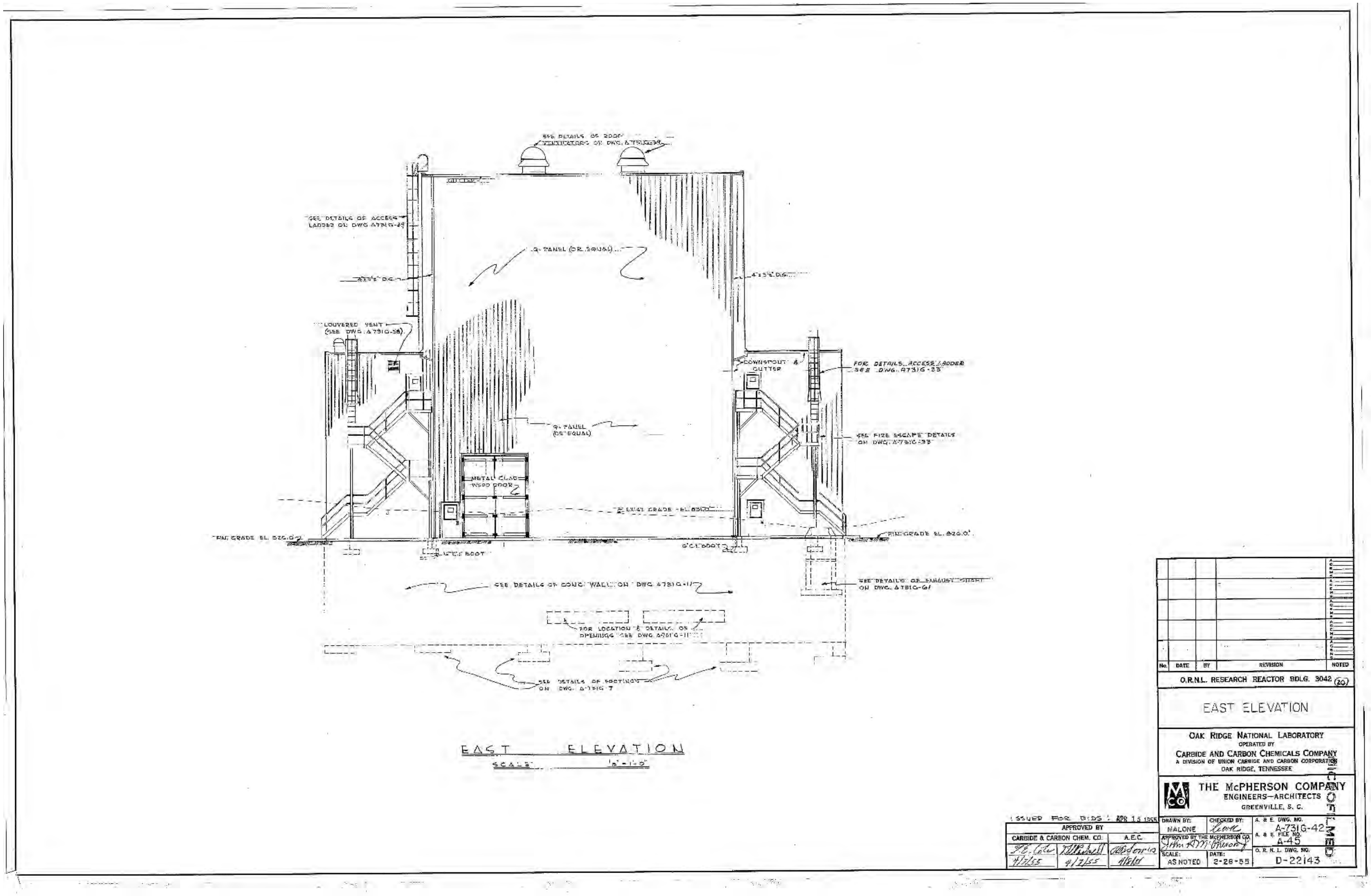


Figure B-10. East elevation of Building 3042 (The McPherson Company, February 28, 1955).

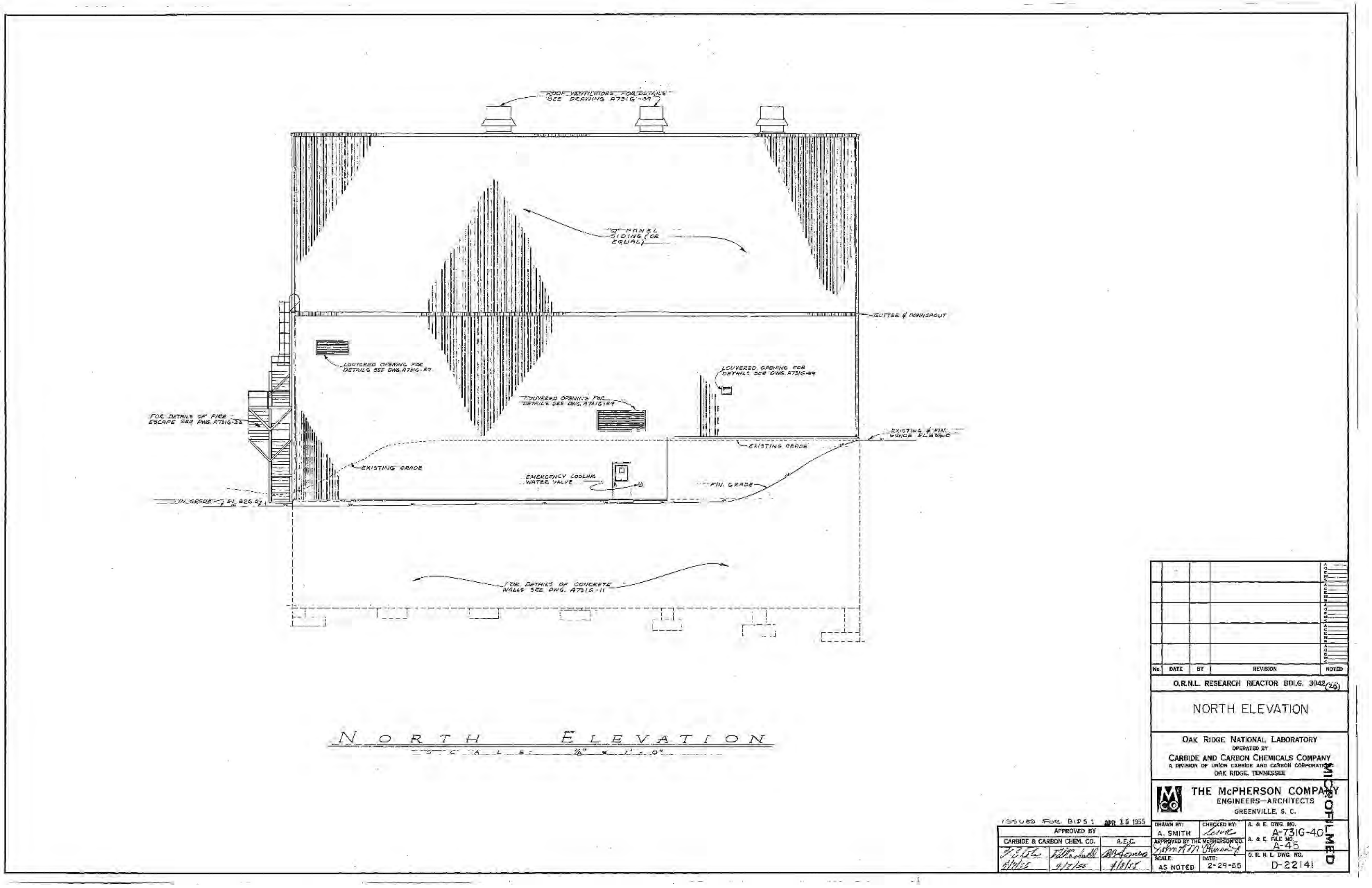


Figure B-11. North elevation of Building 3042 (The McPherson Company, February 28, 1955).

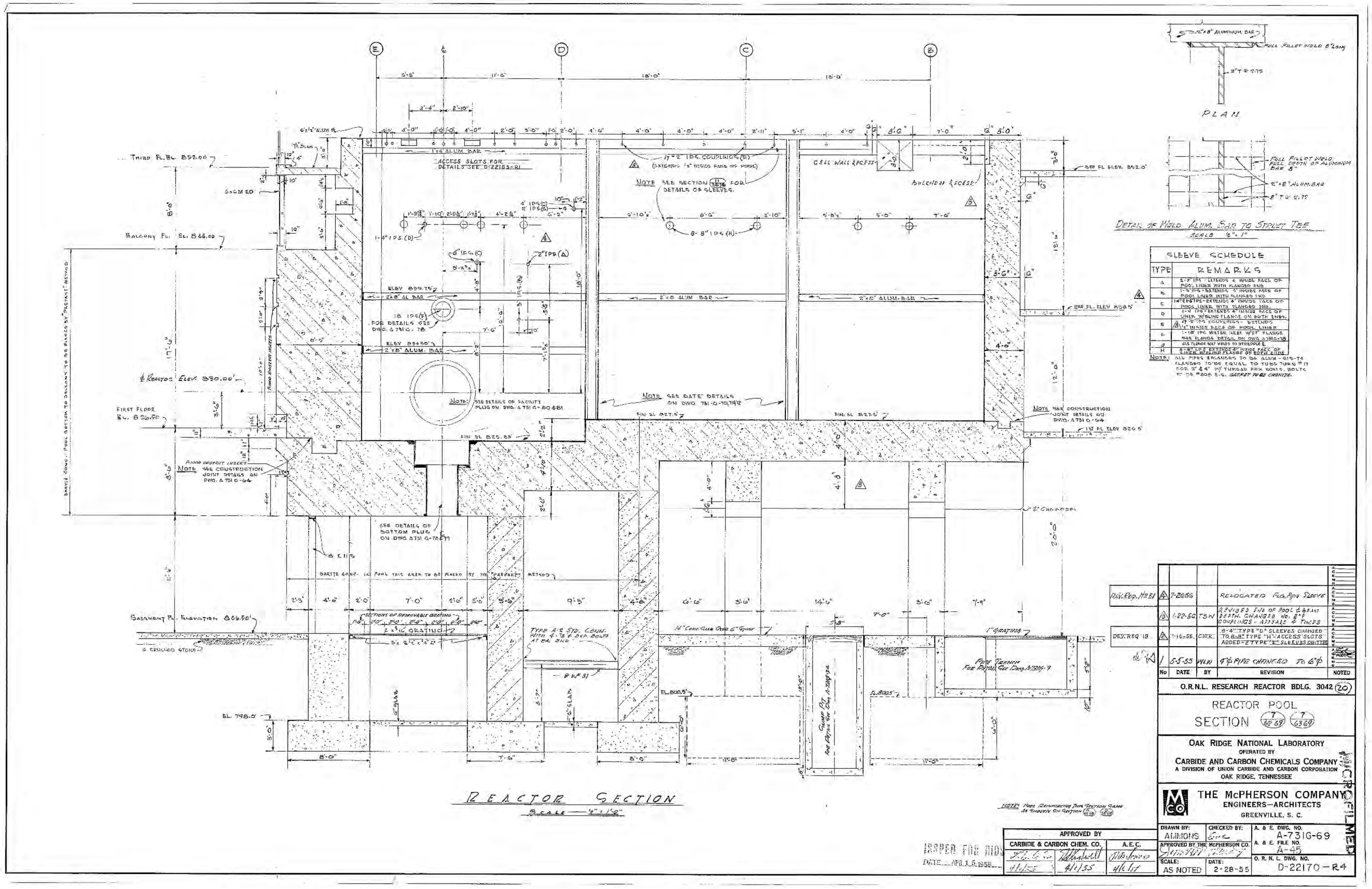


Figure B-12. Oak Ridge Research Reactor pool vertical section (The McPherson Company, February 28, 1955).

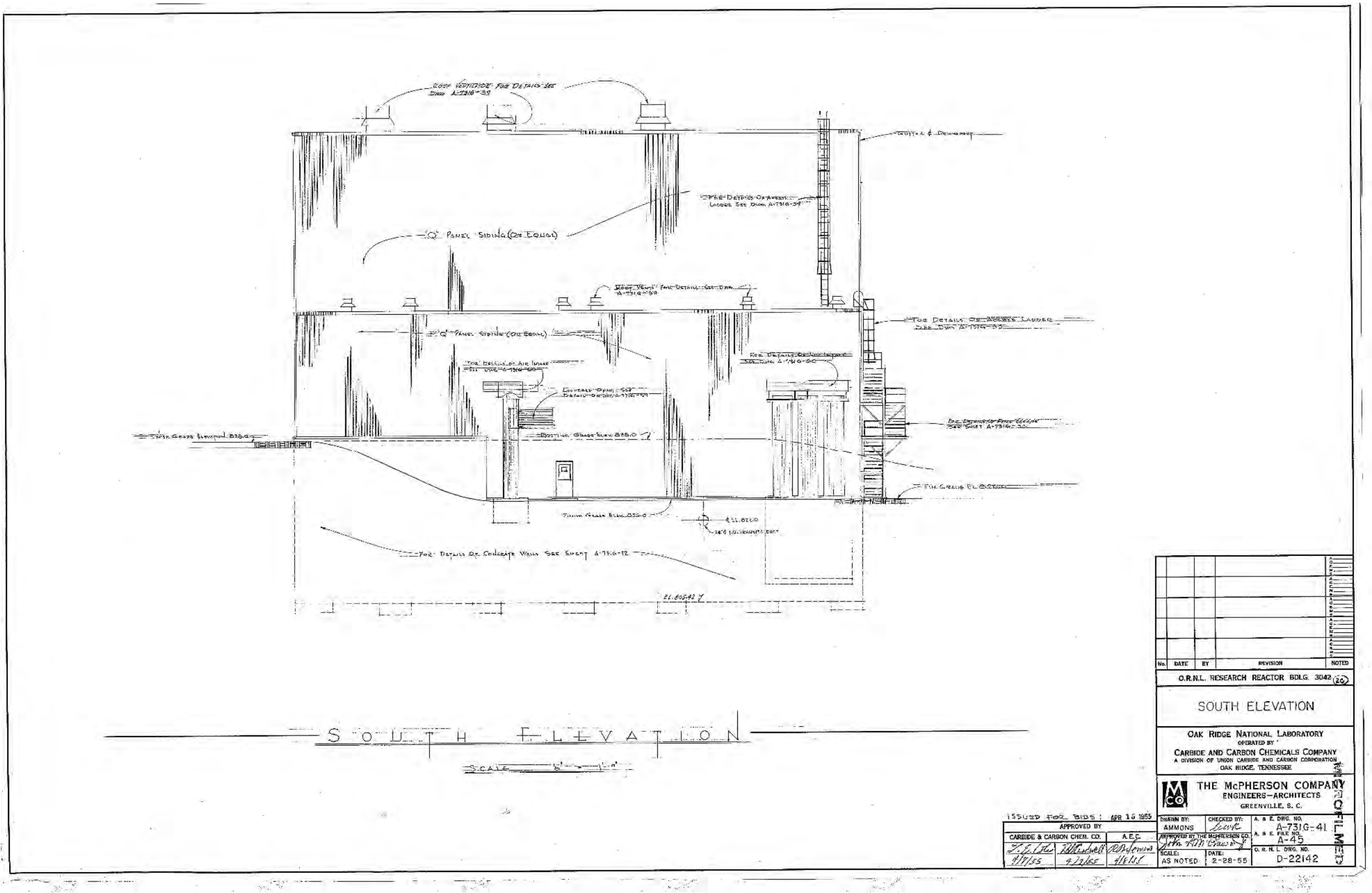


Figure B-13. South elevation of Building 3042 (The McPherson Company, February 28, 1955).

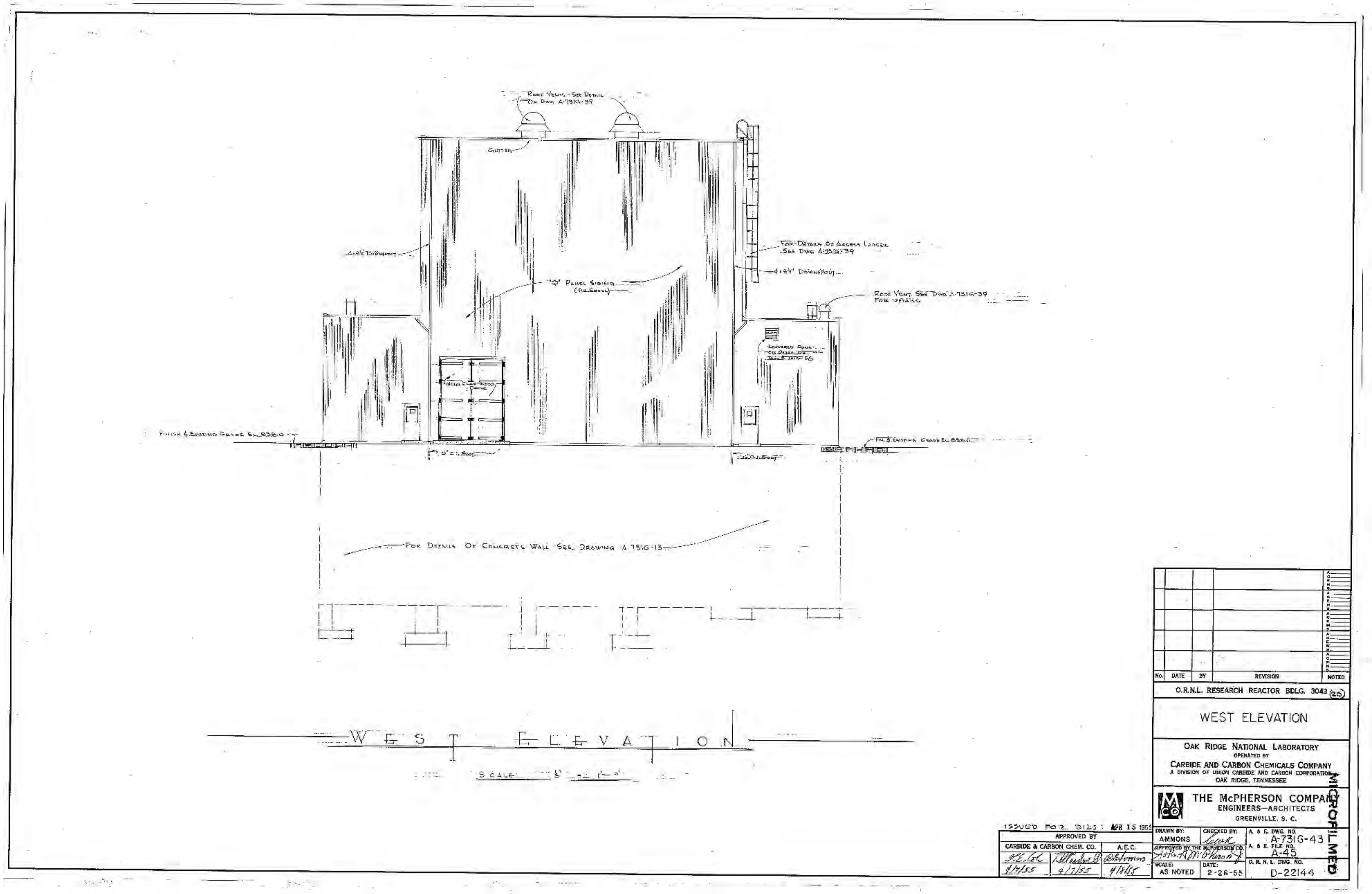


Figure B-14. West elevation of Building 3042 (The McPherson Company, February 28, 1955).

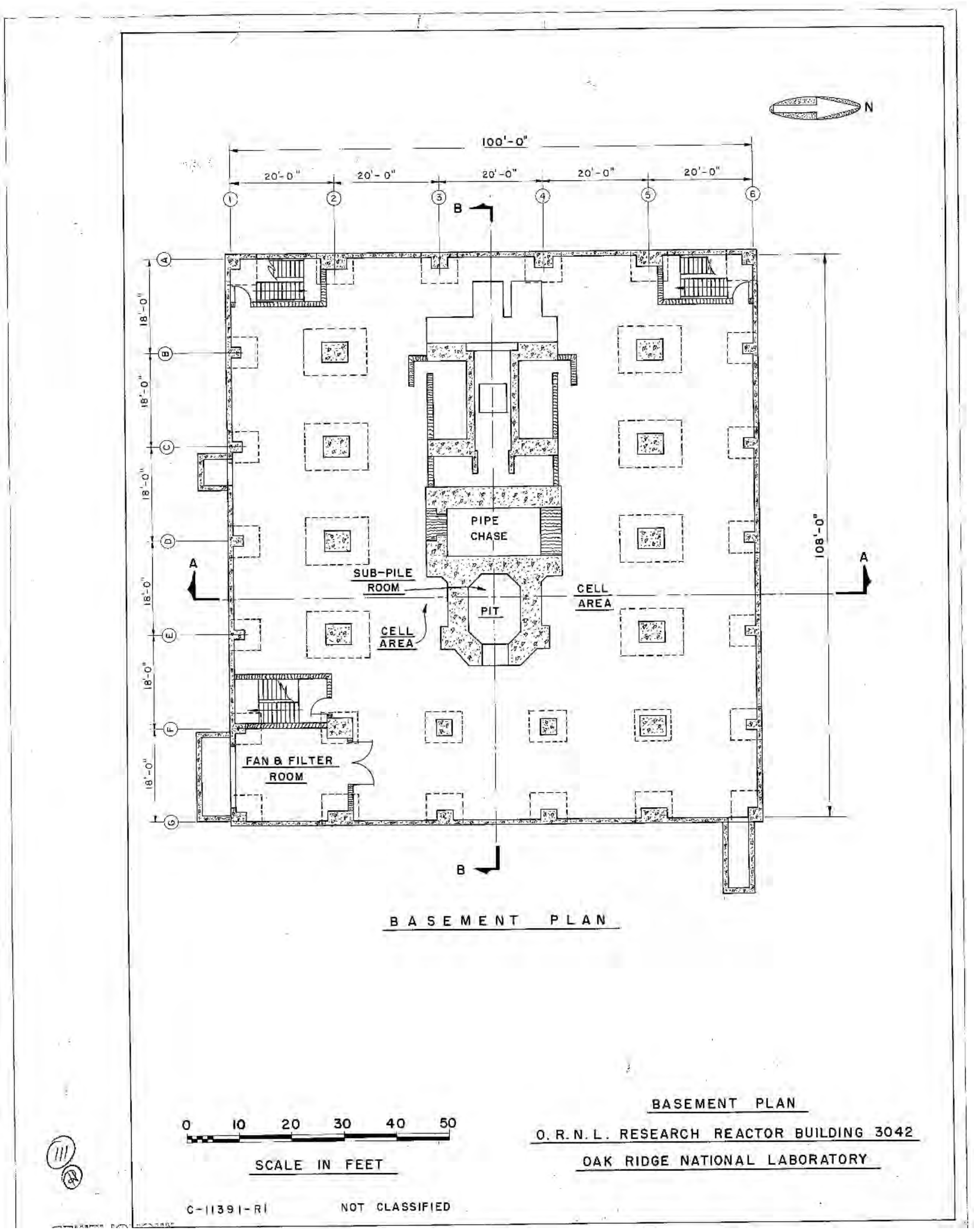


Figure B-15. Basement plan for Building 3042 (Oak Ridge National Laboratory, n.d.).

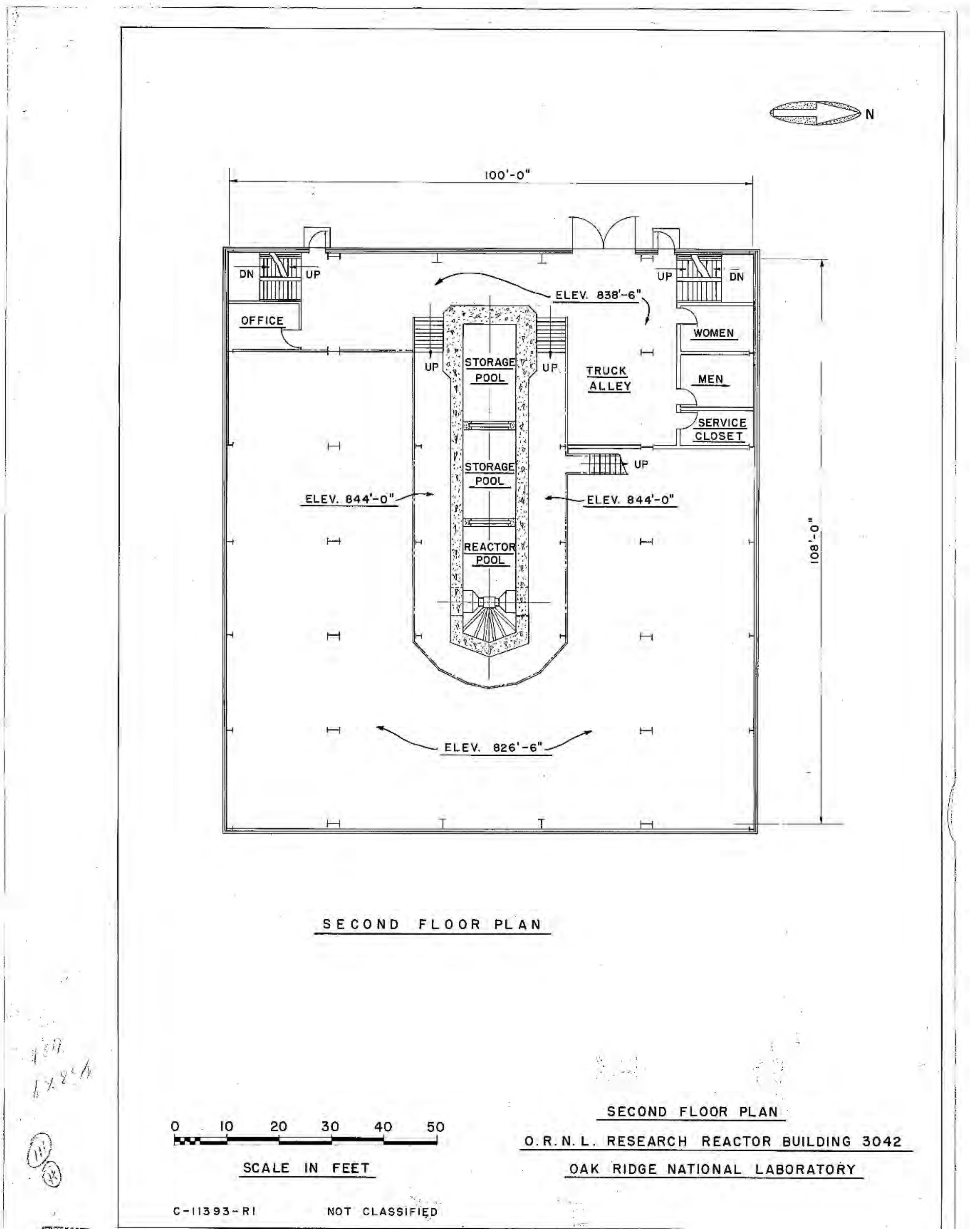


Figure B-16. Second floor plan for Building 3042 (Oak Ridge National Laboratory, n.d.).

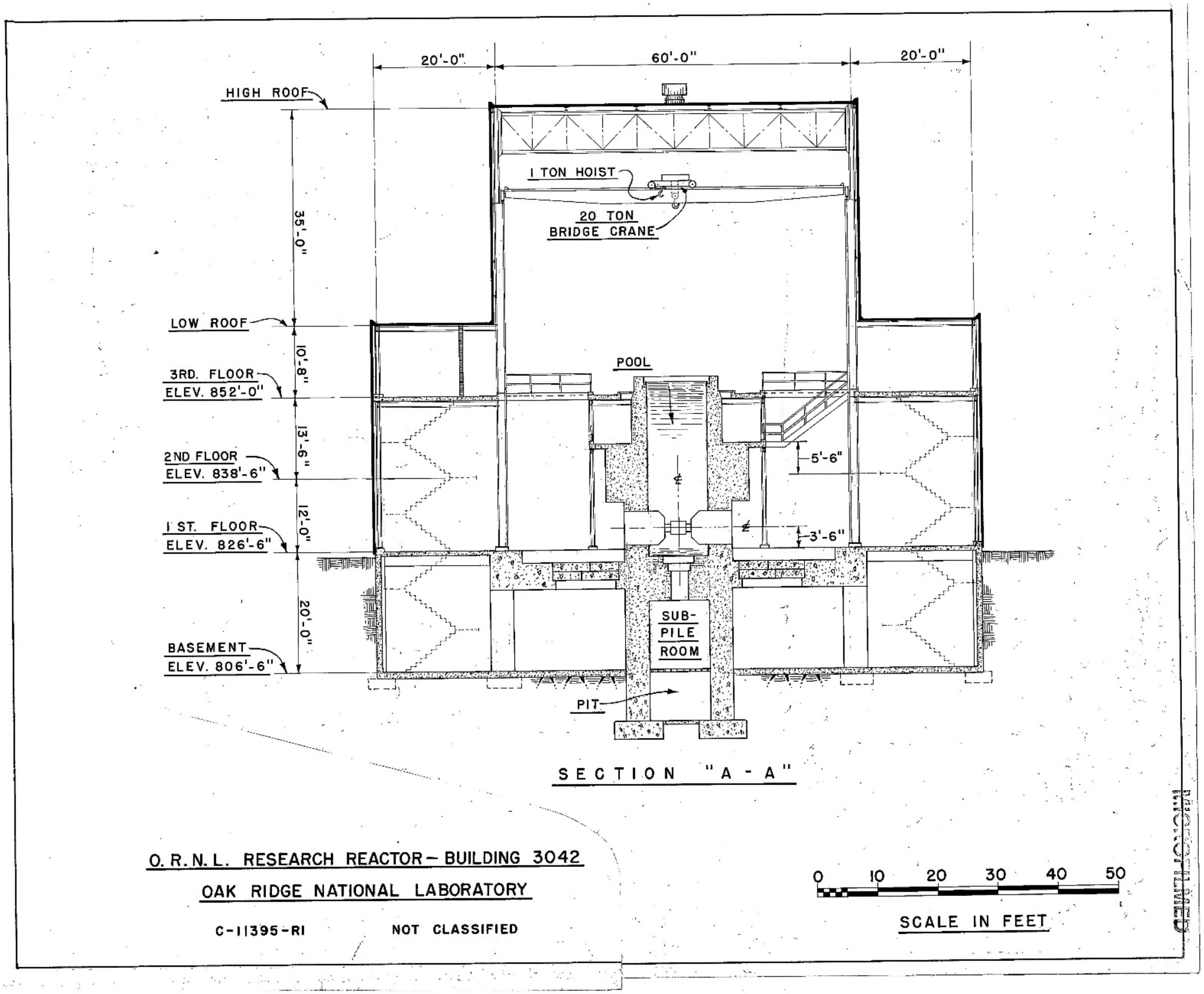


Figure B-17. East to west vertical section of Building 3042 including the Oak Ridge Research Reactor structure (Oak Ridge National Laboratory, n.d.).

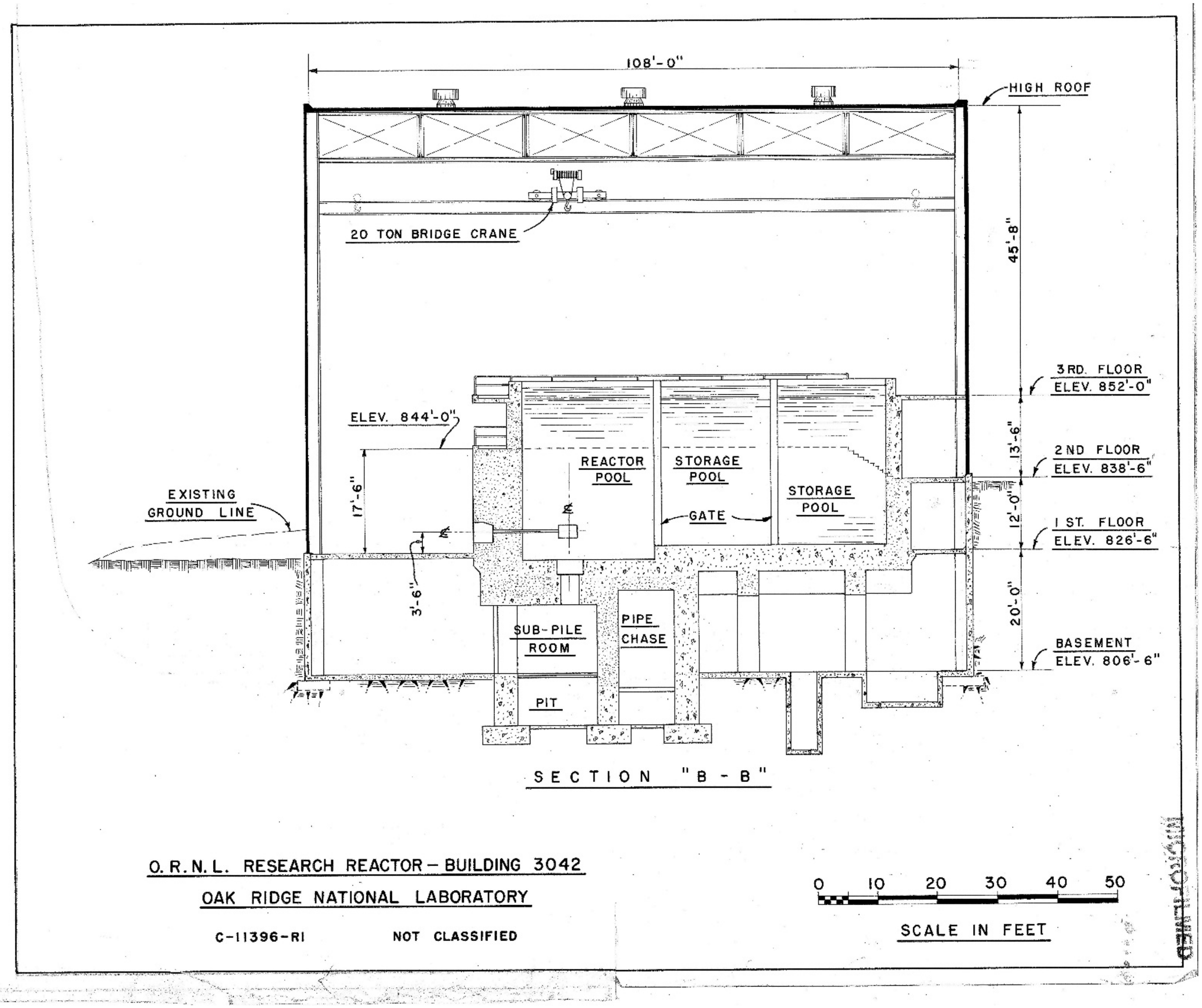


Figure B-18. North to south vertical section of Building 3042 including the Oak Ridge Research Reactor structure (Oak Ridge National Laboratory, n.d.).

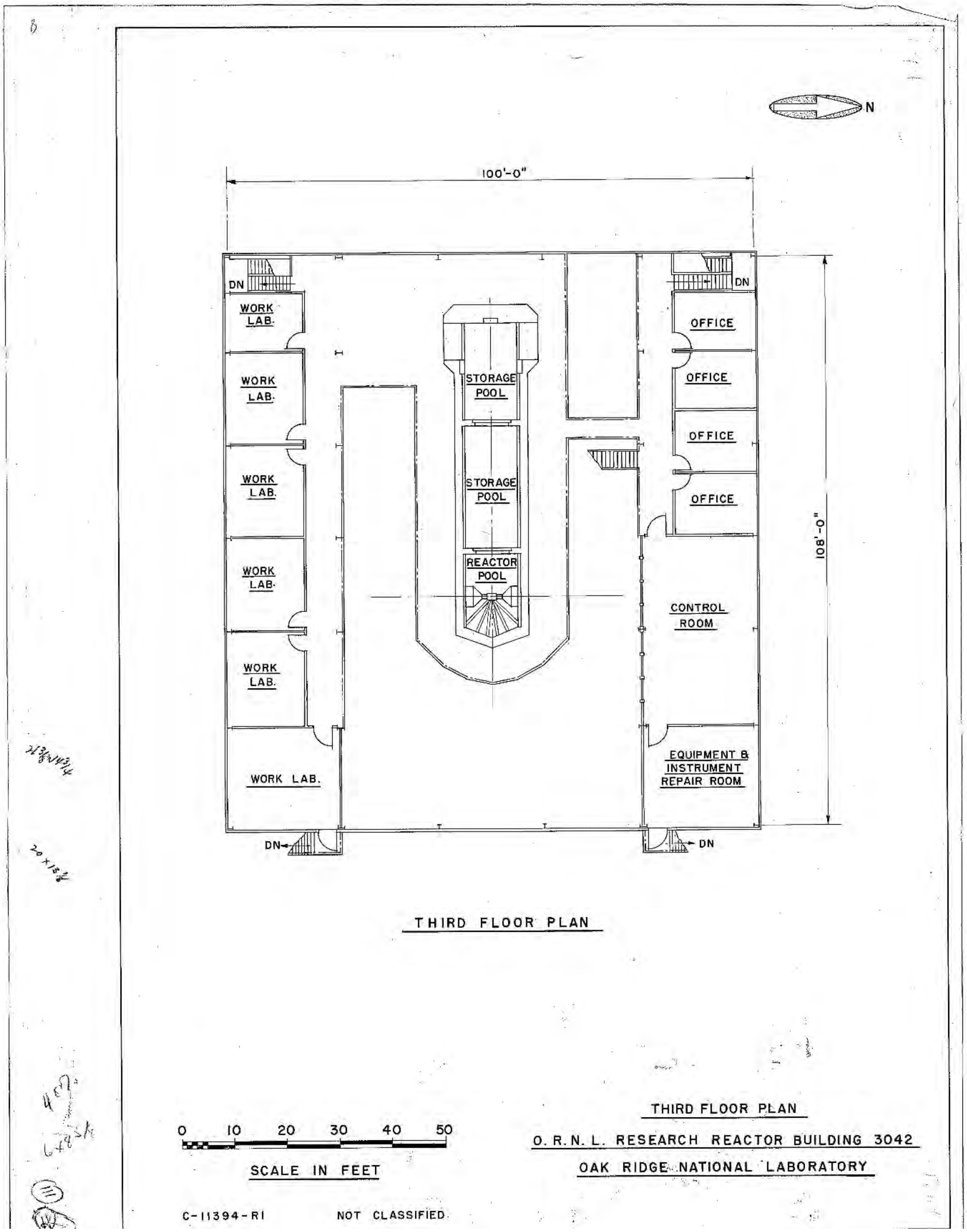


Figure B-19. Third floor plan for Building 3042 (Oak Ridge National Laboratory, n.d.).

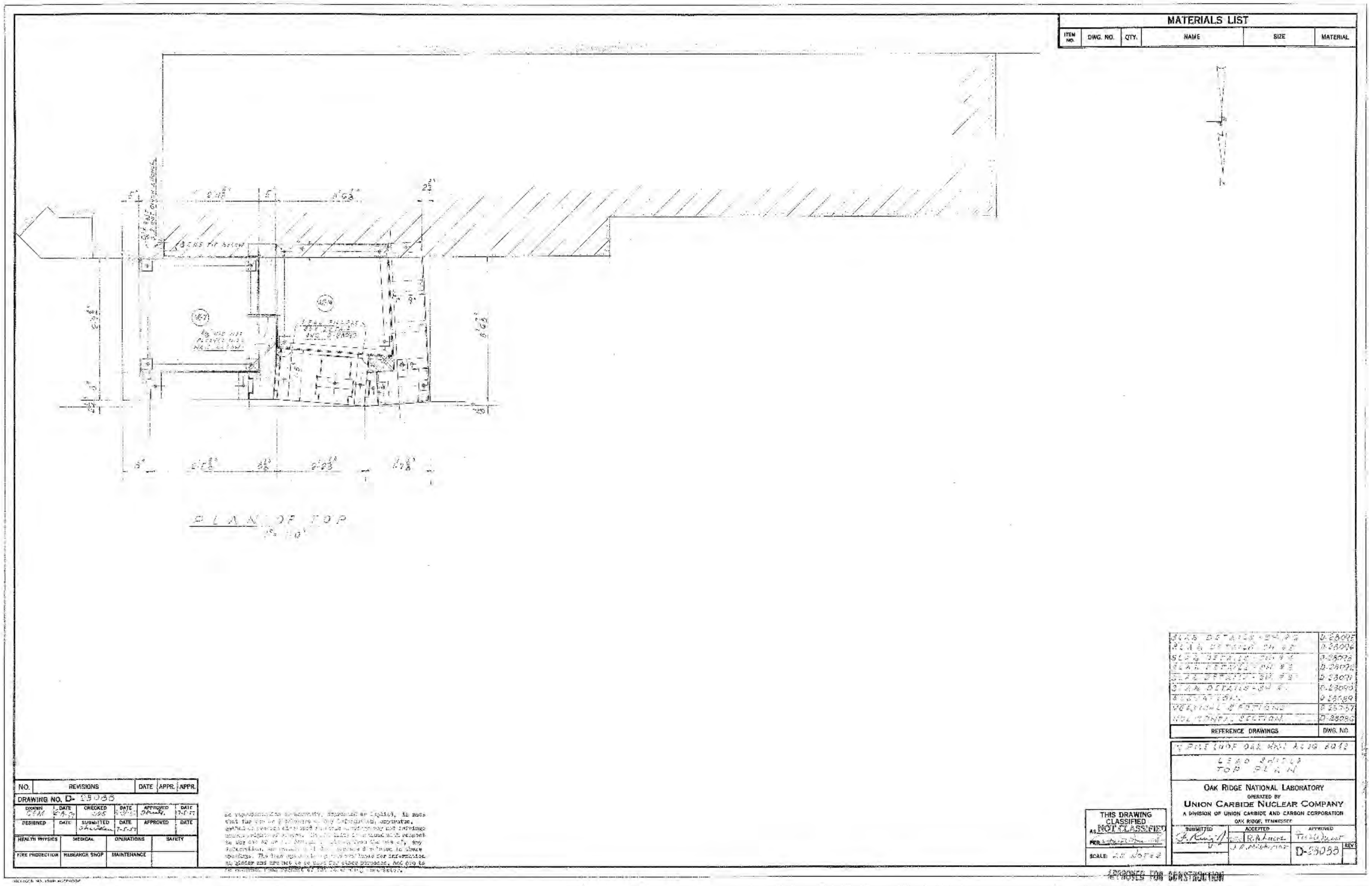


Figure B-20. Lead shied top plan for the in-pile loop at the Oak Ridge Research Reactor experimental facility HN-1 in Building 3042 (Oak Ridge National Laboratory, February 8, 1957).

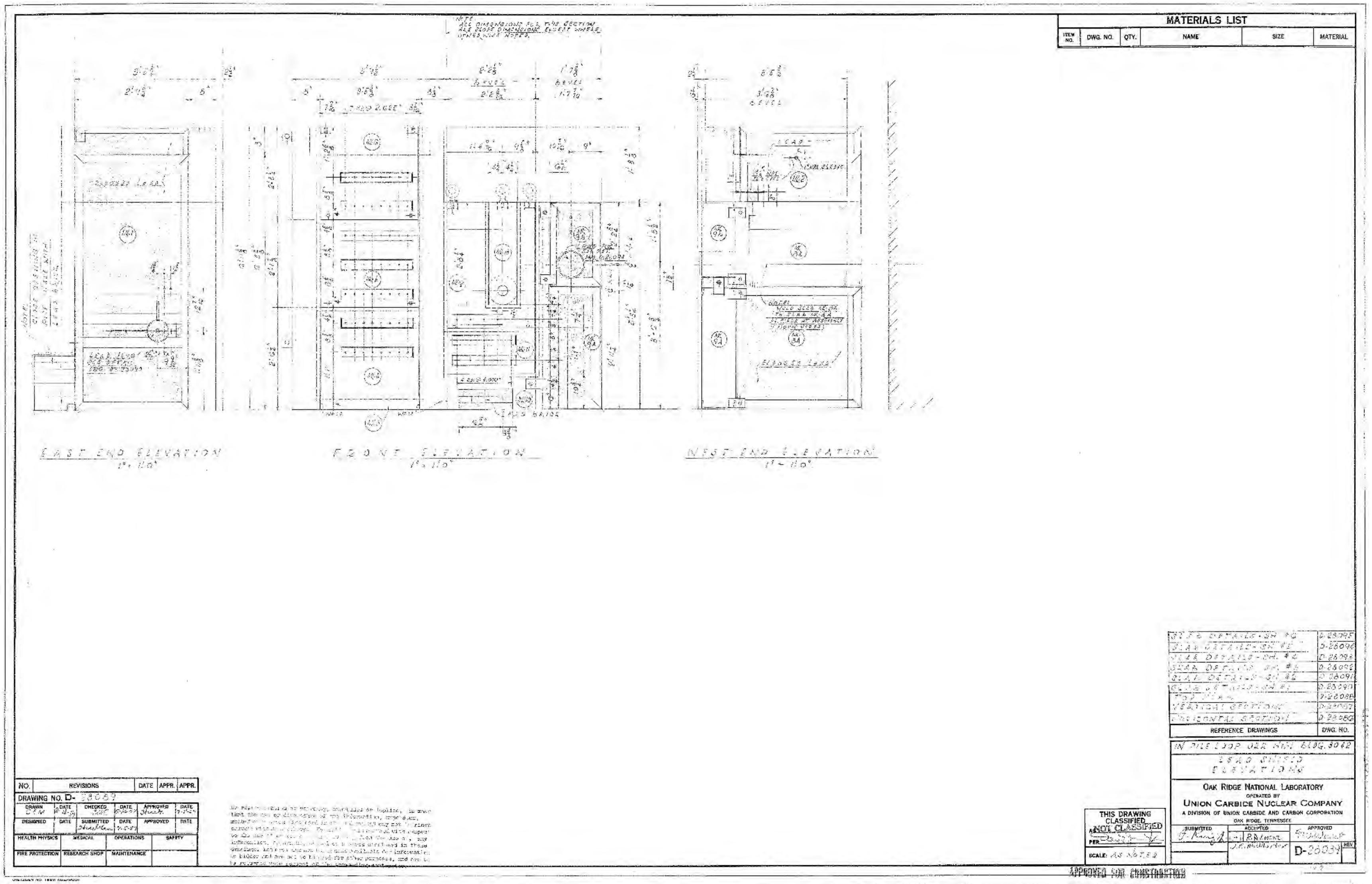


Figure B-21. Lead shield elevations for the in-pile loop at the Oak Ridge Research Reactor experimental facility HN-1 in Building 3042 (Oak Ridge National Laboratory, February 13, 1957).

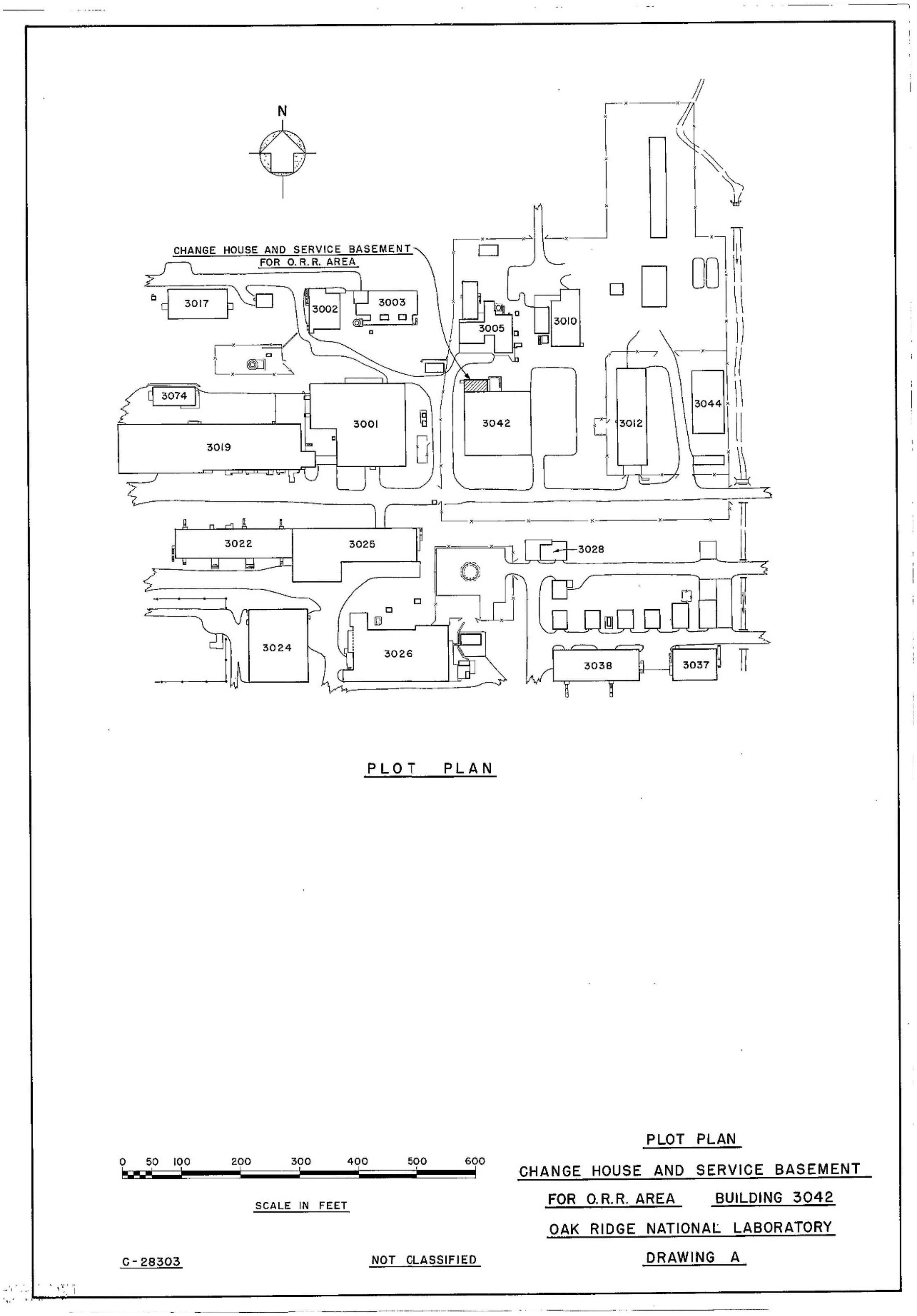


Figure B-22. Plot plan pertaining to the construction of the circa 1957 Change House and Service Basement on the north elevation of Building 3042 (Oak Ridge National Laboratory, n.d.).

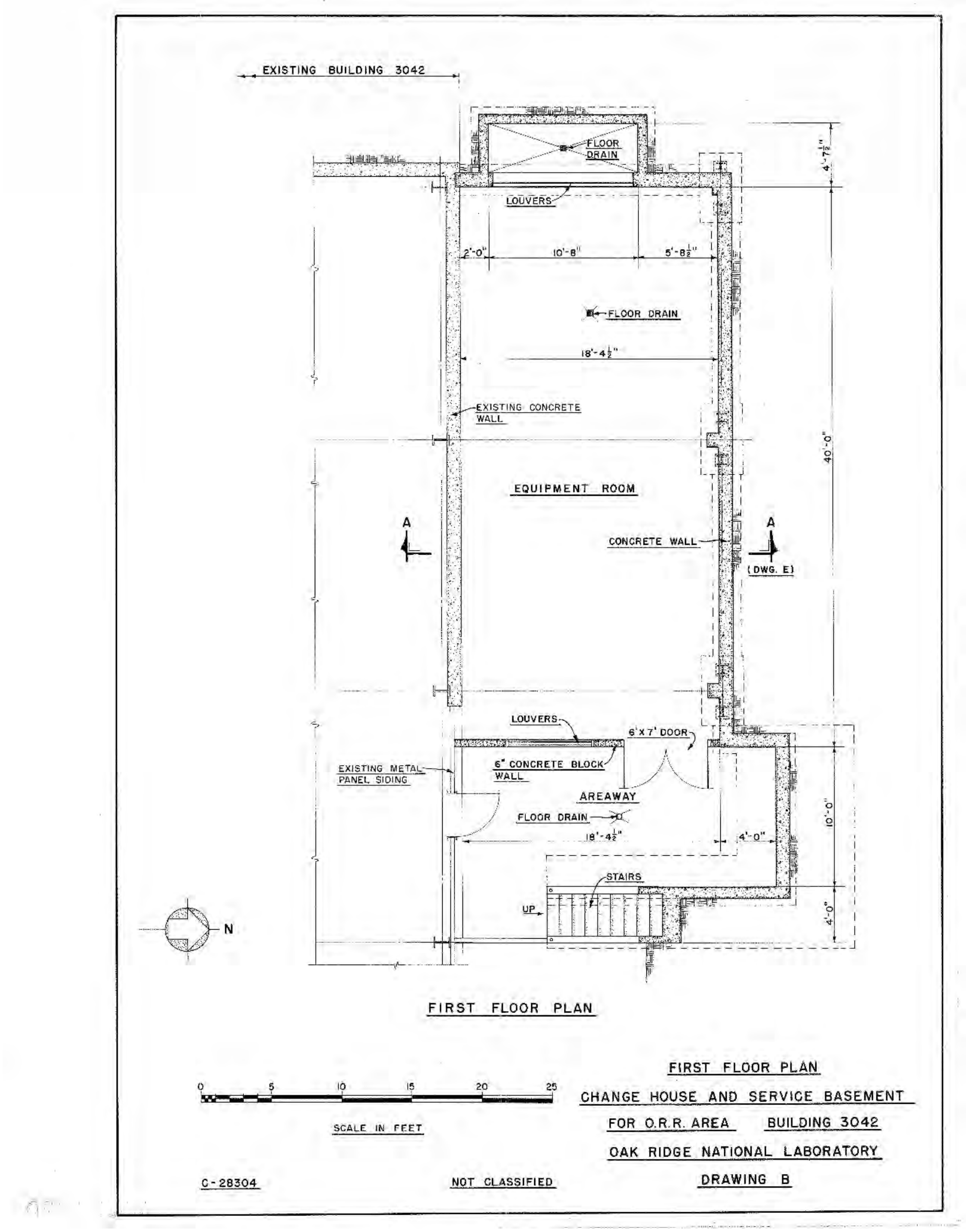


Figure B-23. First floor plan for the circa 1957 Change House and Service Basement addition to the north elevation of Building 3042 (Oak Ridge National Laboratory, n.d.).

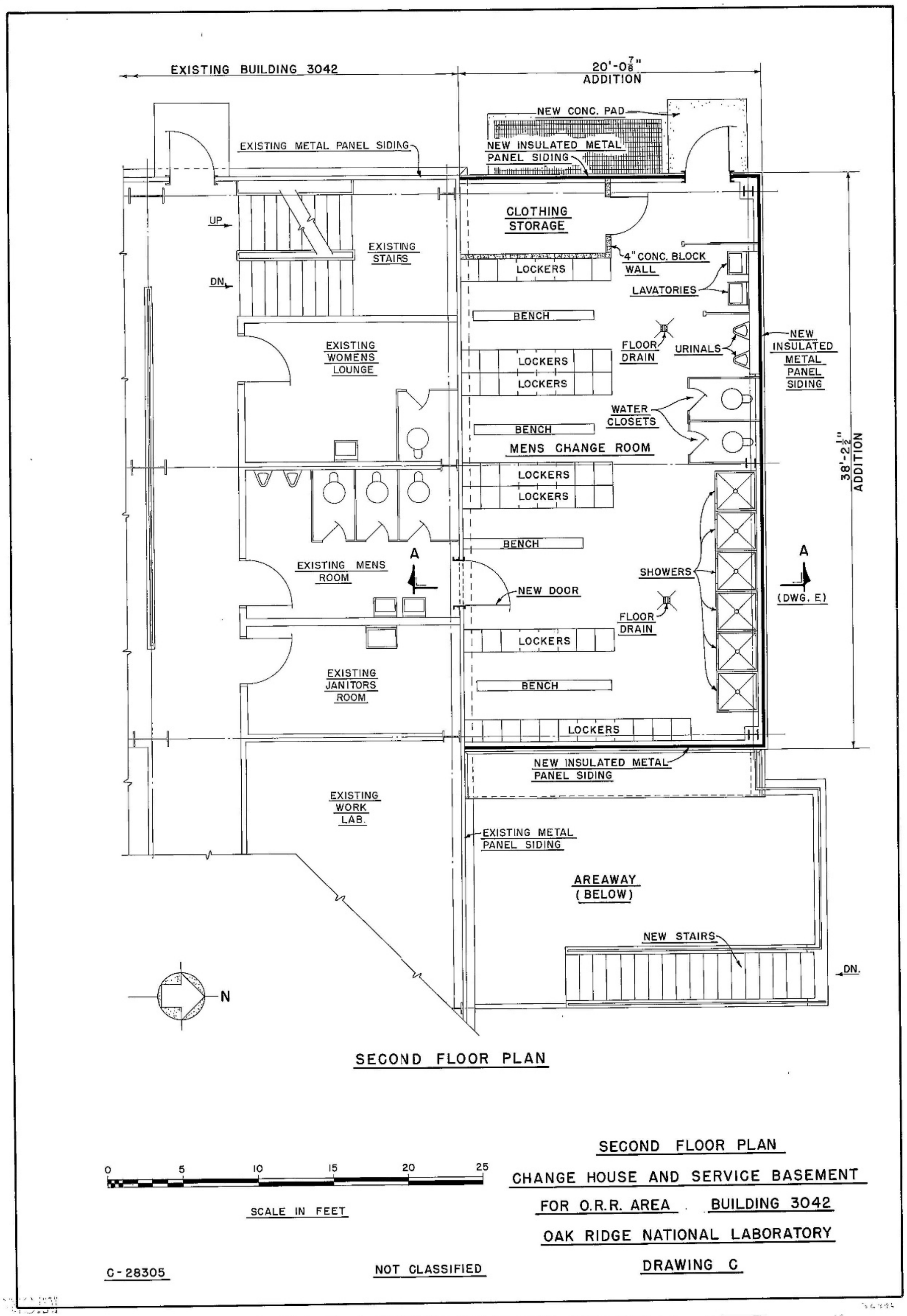


Figure B-24. Second floor plan for the circa 1957 Change House and Service Basement addition to the north elevation of Building 3042 (Oak Ridge National Laboratory, n.d.).

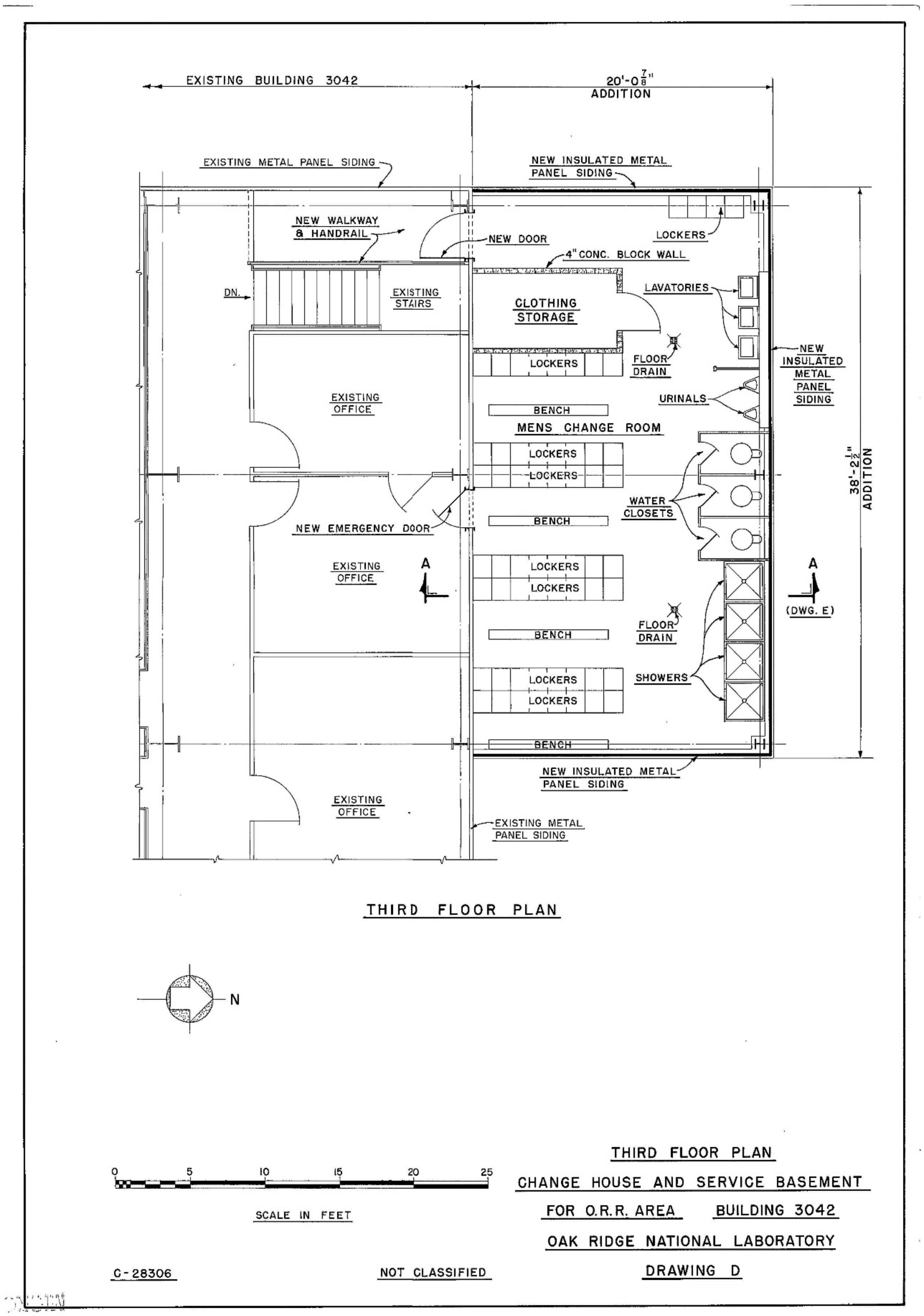


Figure B-25. Third floor plan for the circa 1957 Change House and Service Basement addition to the north elevation of Building 3042 (Oak Ridge National Laboratory, n.d.).

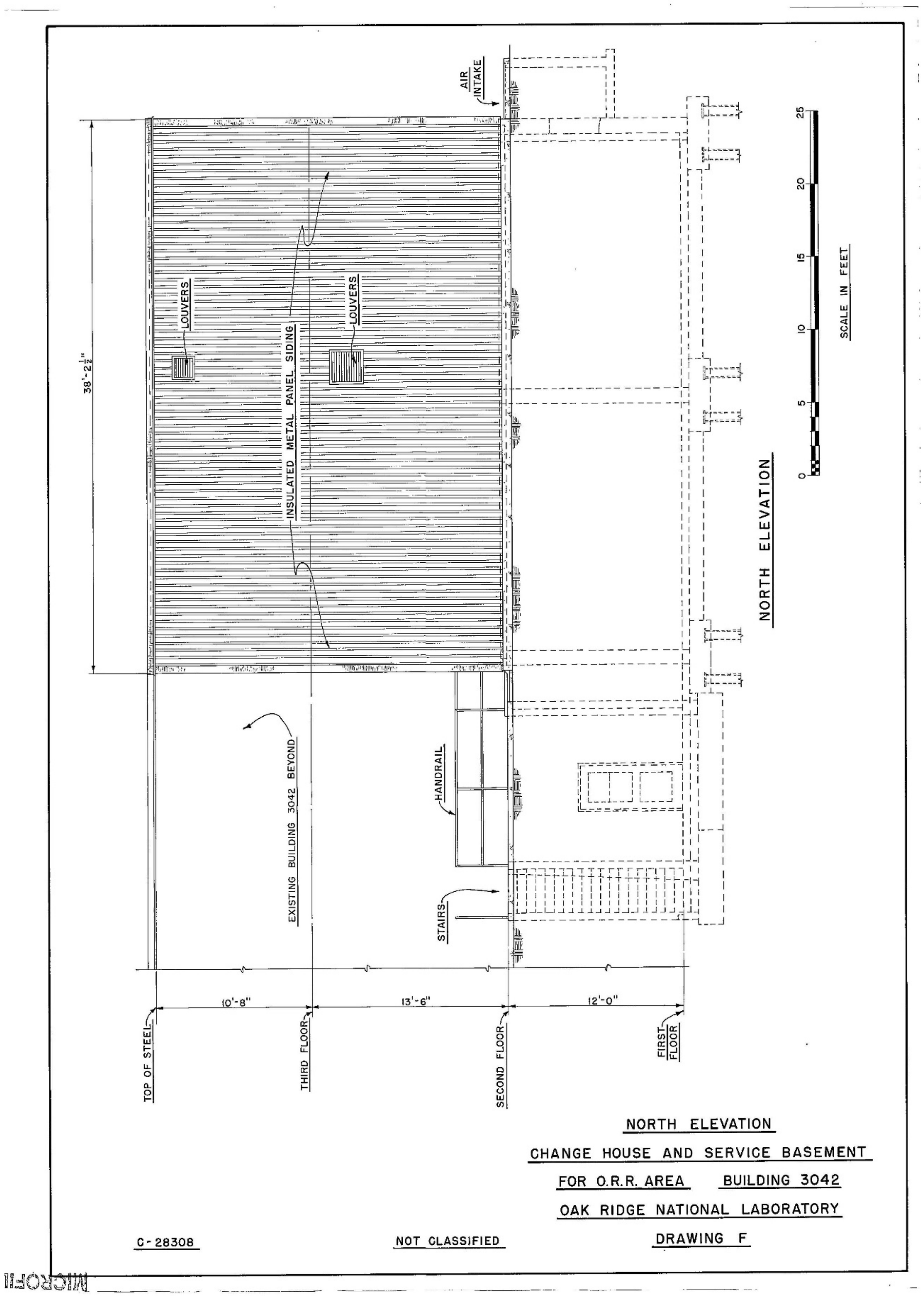


Figure B-26. North elevation of the circa 1957 Change House and Service Basement addition to the north elevation of Building 3042 (Oak Ridge National Laboratory, n.d.).

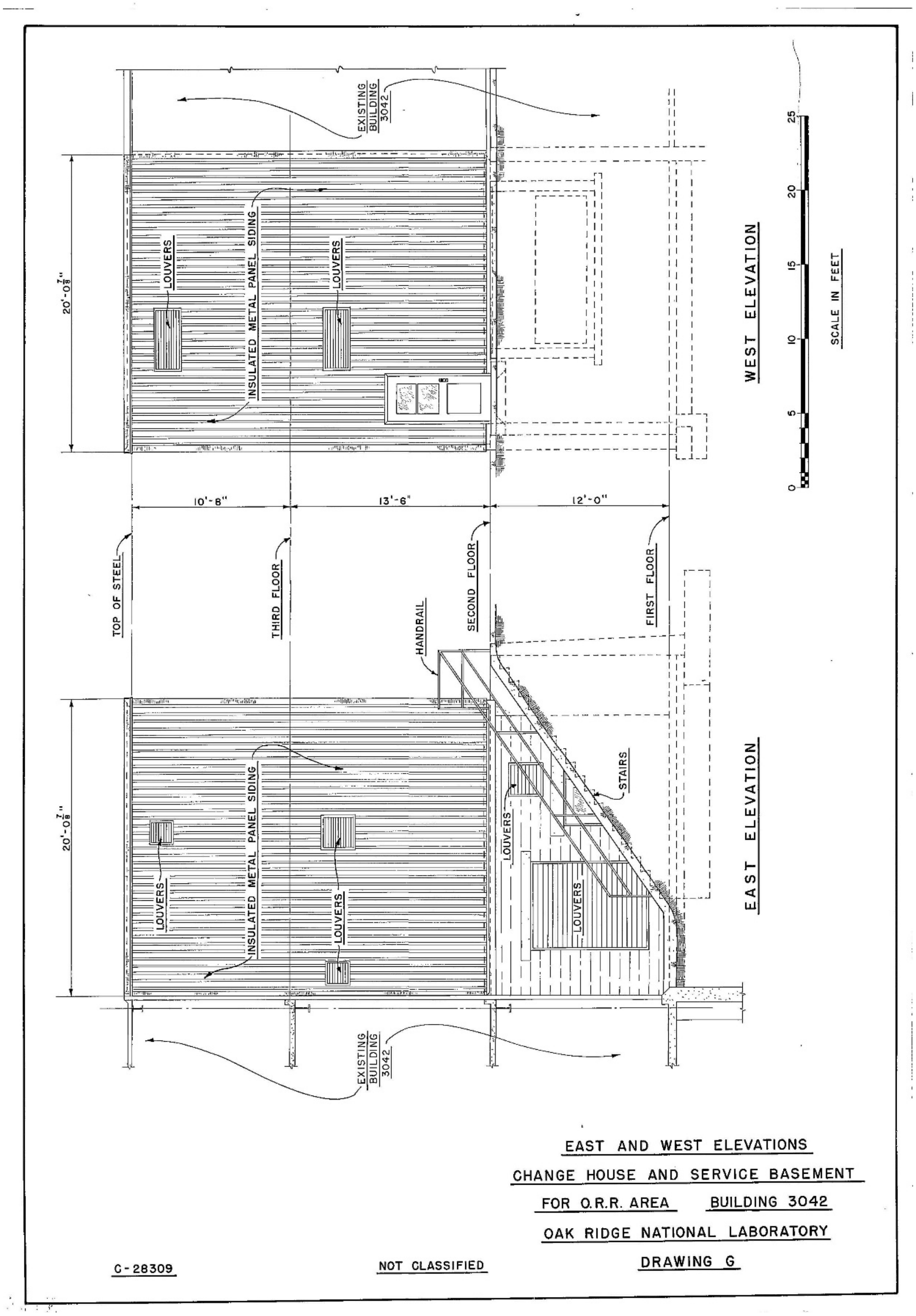


Figure B-27. East and west elevations of the circa 1957 Change House and Service Basement addition to the north elevation of Building 3042 (Oak Ridge National Laboratory, n.d.).

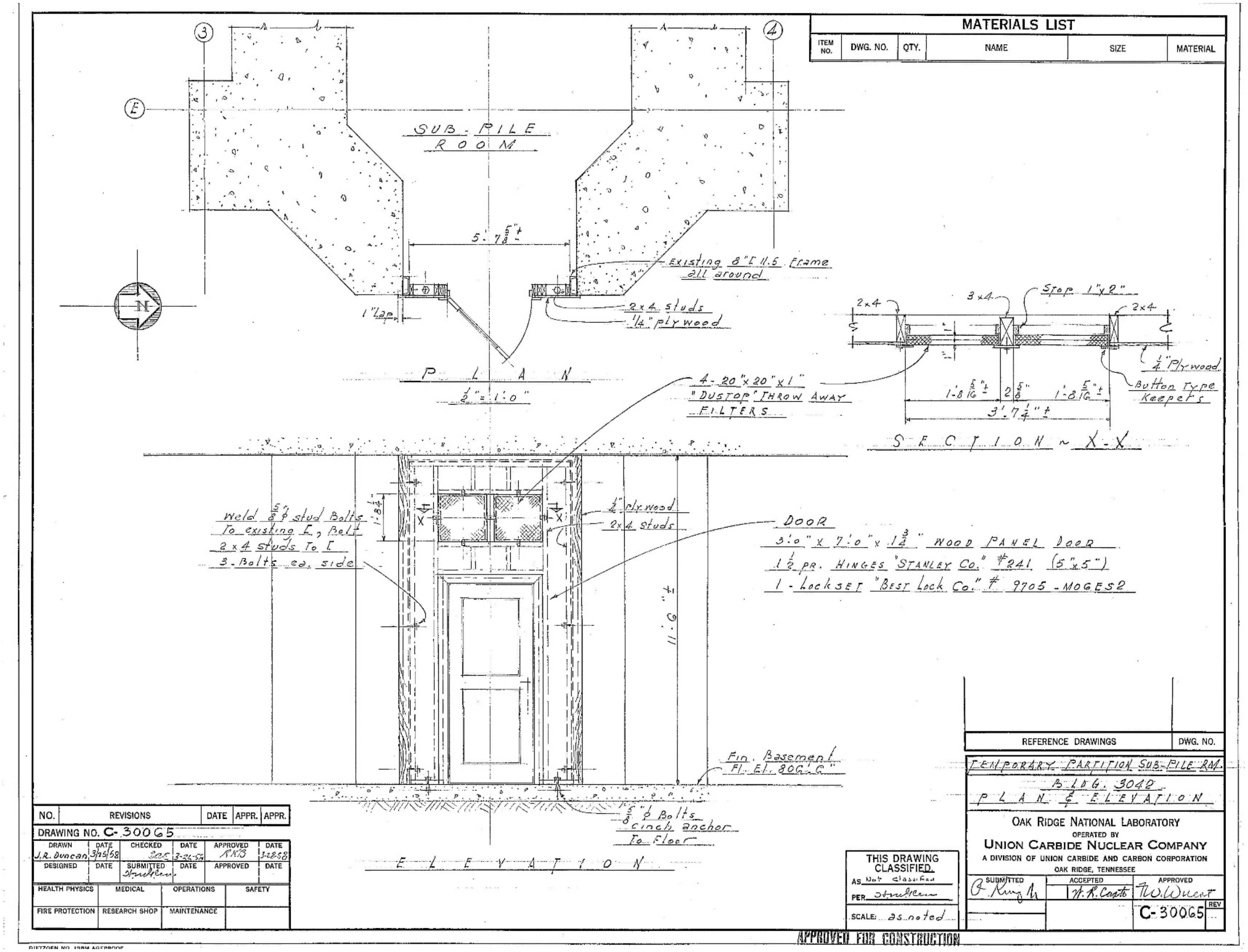


Figure B-28. Plan and Elevation for the temporary partition in the sub-pile room in the basement of Building 3042 (Oak Ridge National Laboratory, March 25, 1958).

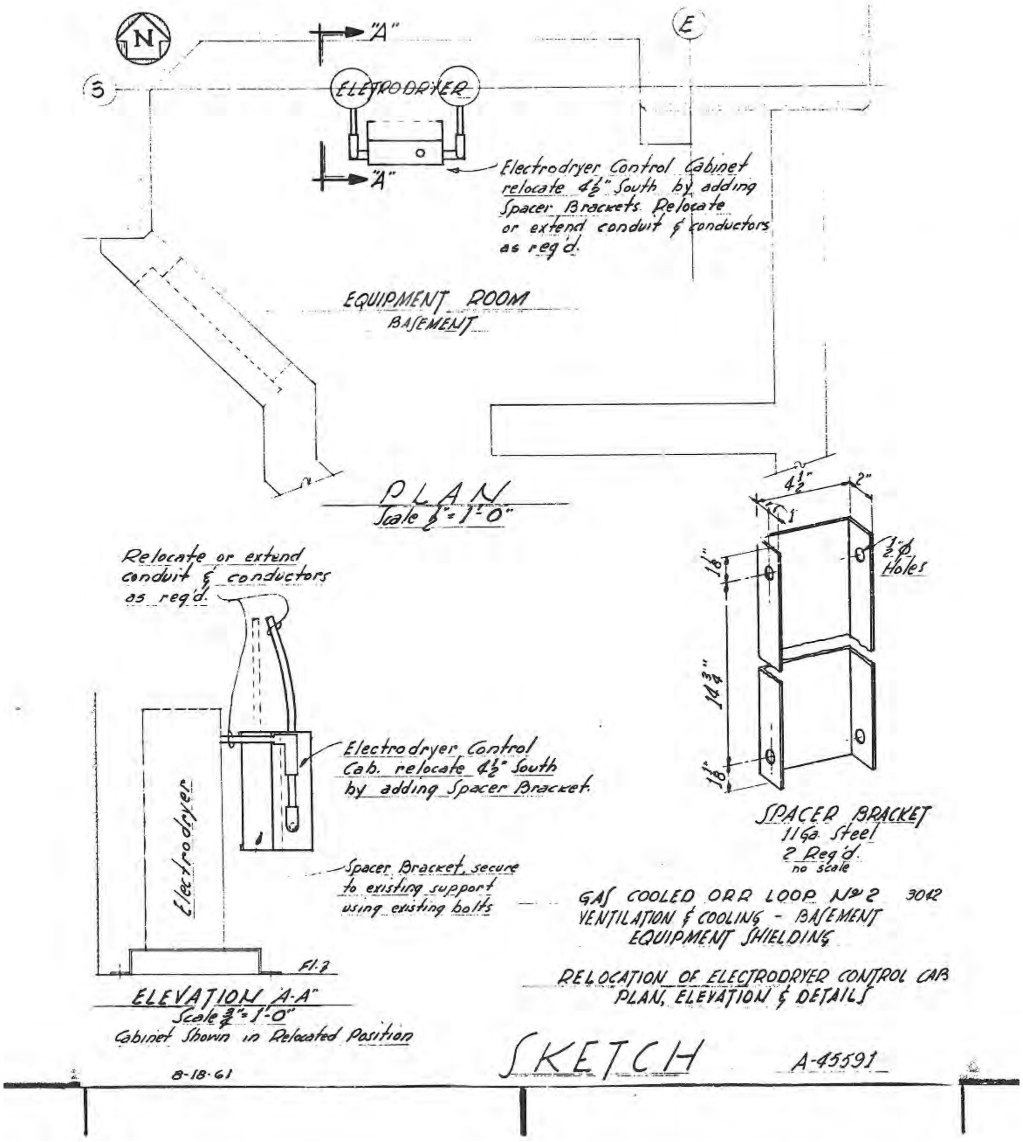


Figure B-29. Plan for the relocation of the electrodryer control cabinet at Building 3042 (Oak Ridge National Laboratory, August 18, 1961).

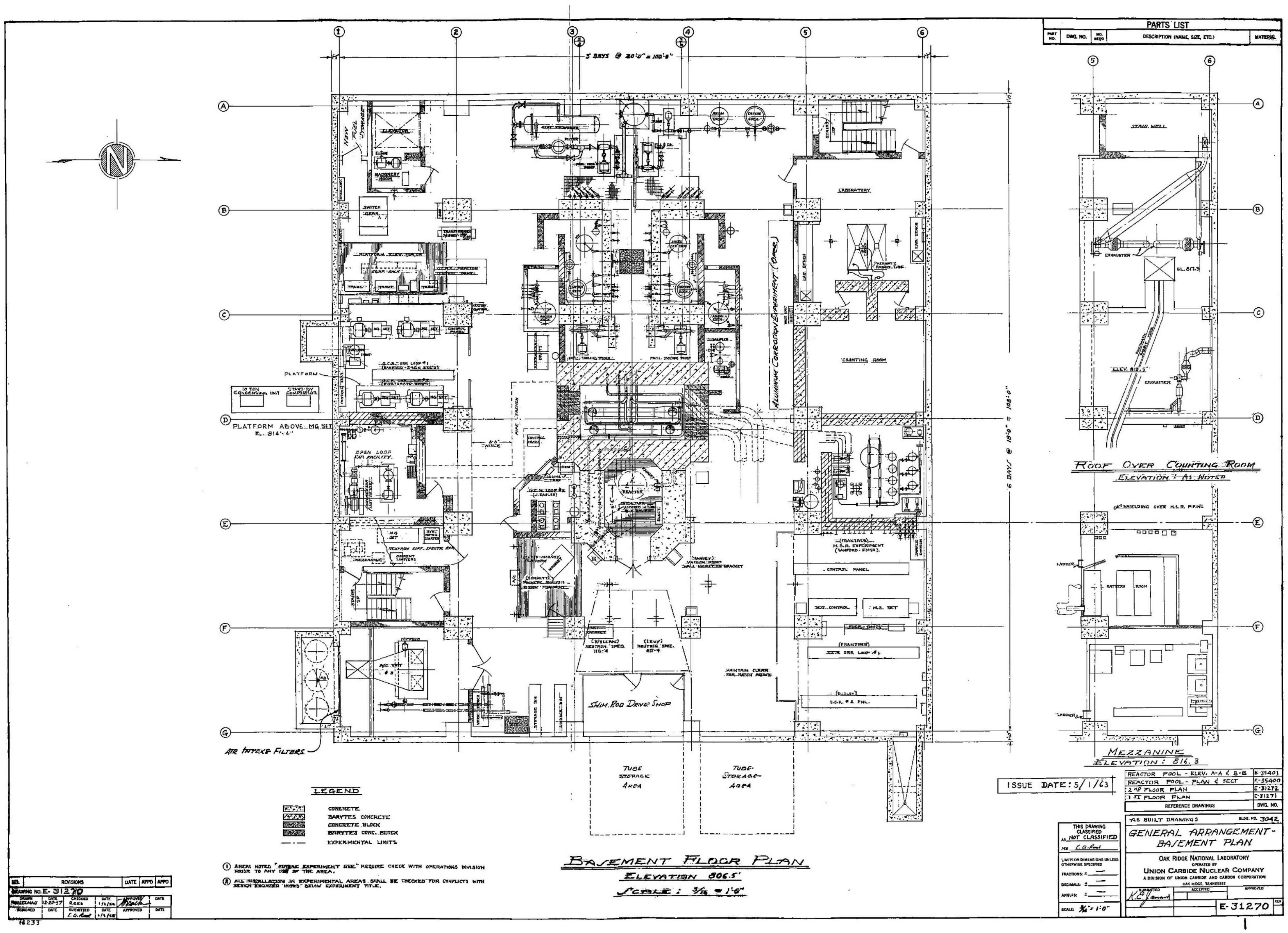


Figure B-30. As built drawing showing the general arrangement of the basement plan in Building 3042 (Oak Ridge National Laboratory, December 20, 1957 [drawn date], May 1, 1963 [issue date, with revisions]).

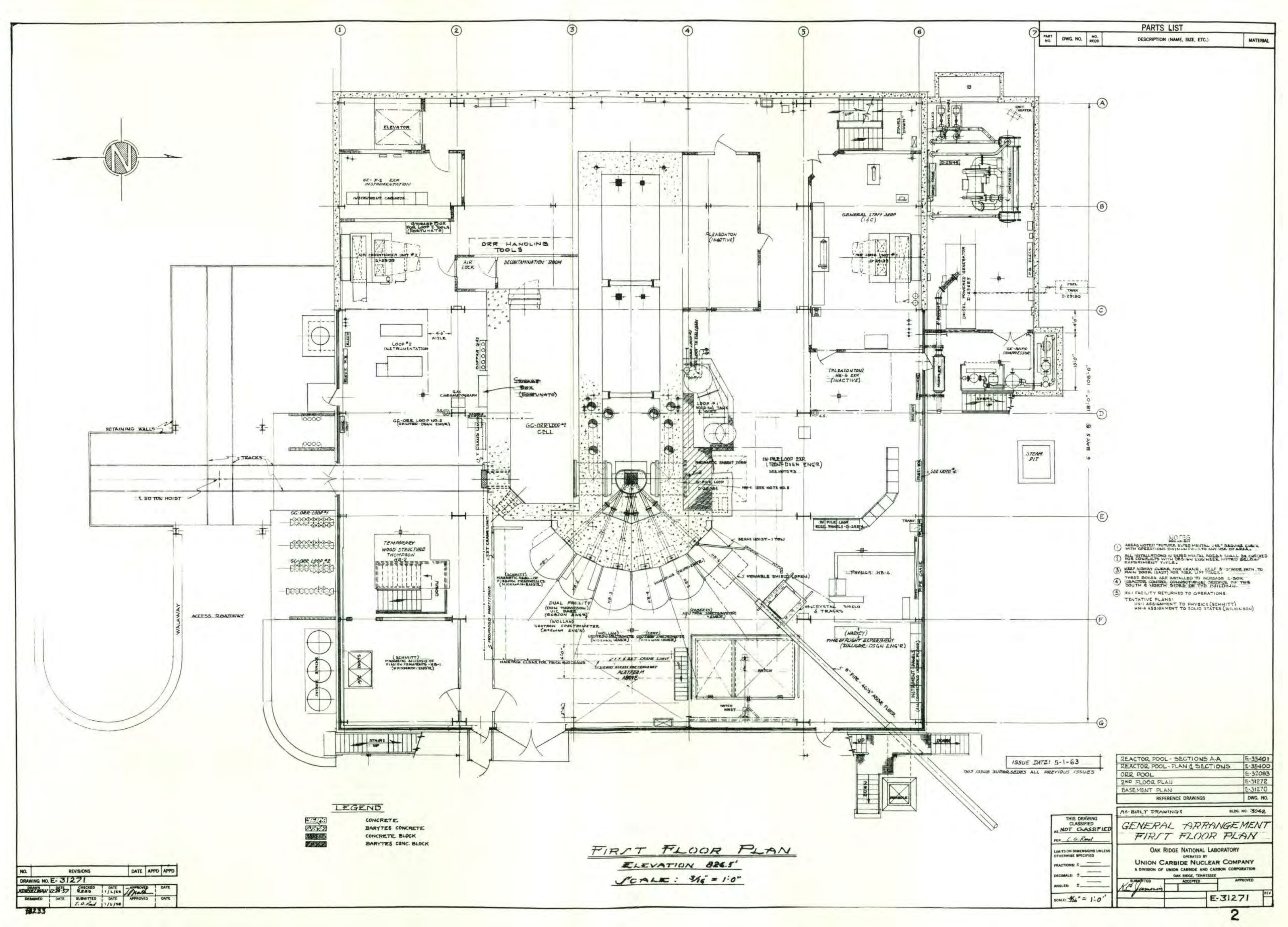


Figure B-31. As built drawing showing the general arrangement of the first floor plan in Building 3042 (Oak Ridge National Laboratory, December 24, 1957 [drawn date], May 1, 1963 [issue date, with revisions]).

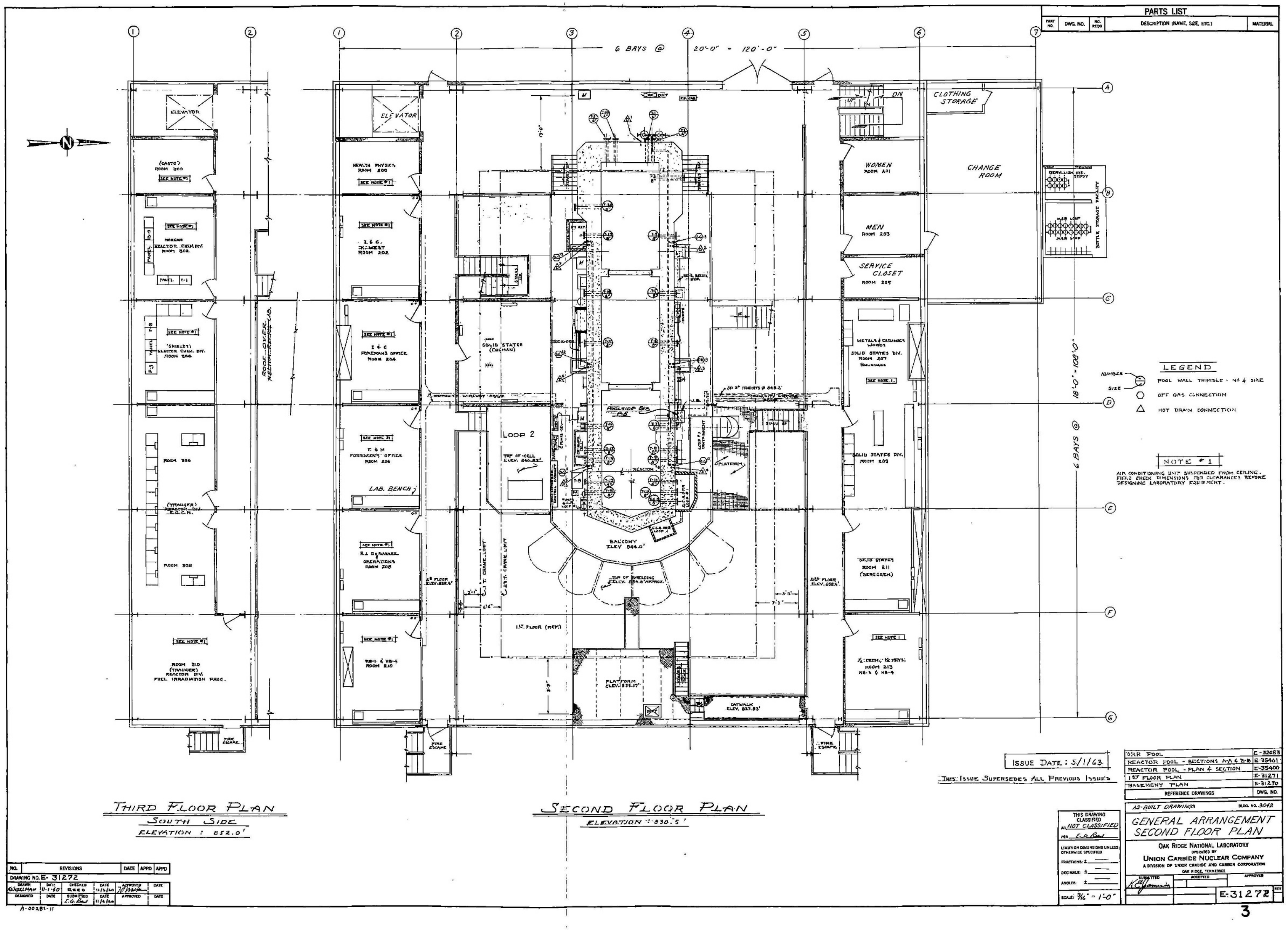


Figure B-32. As built drawing showing the general arrangement of the second floor plan as well as the third floor plan for the south wing in Building 3042 (Oak Ridge National Laboratory, November 1, 1960 [drawn date], May 1, 1963 [issue date, with revisions]).

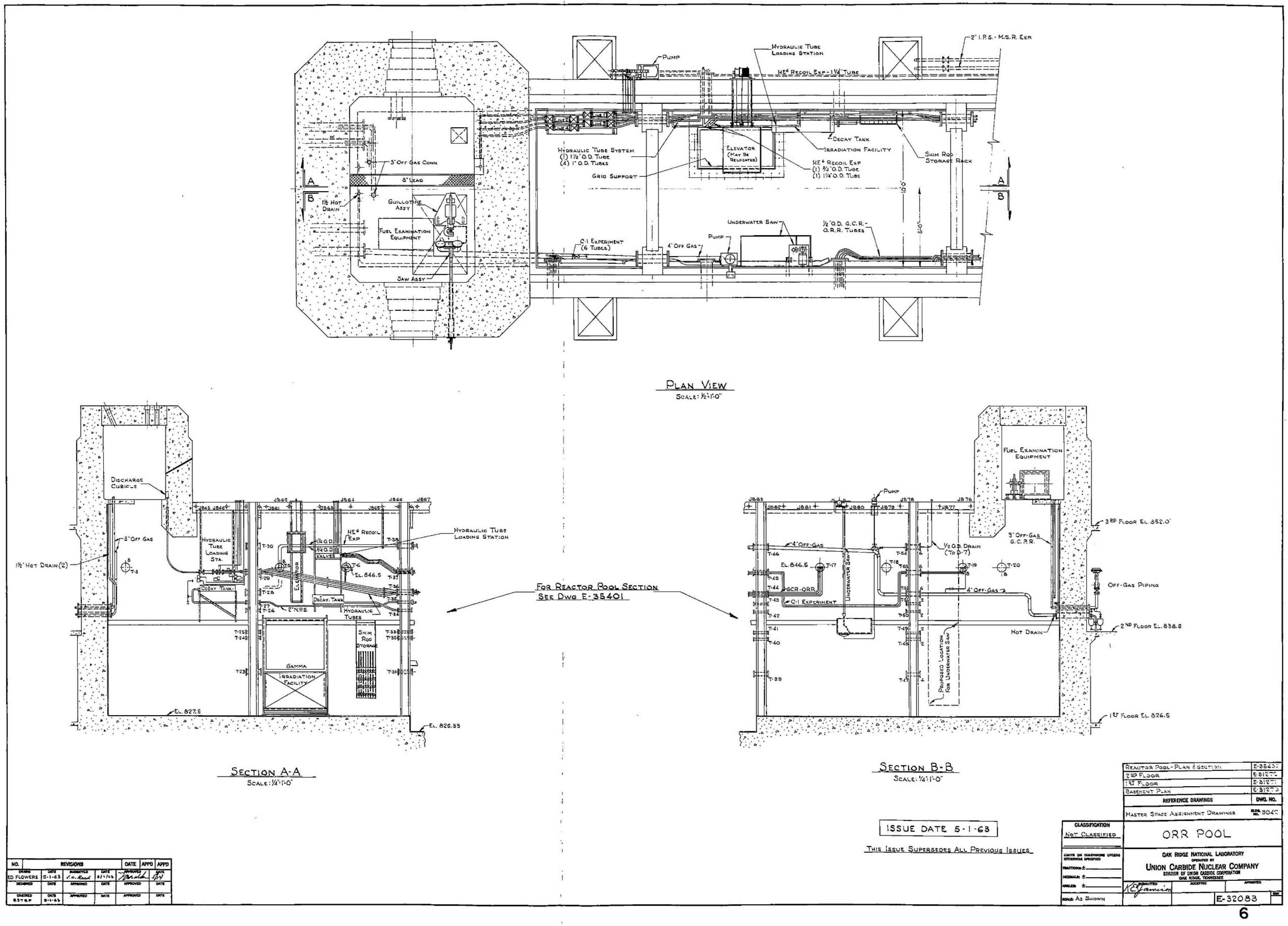


Figure B-33. Master space assignment drawing of the Oak Ridge Research Reactor Pool in Building 3042 (Oak Ridge National Laboratory, May 1, 1963).

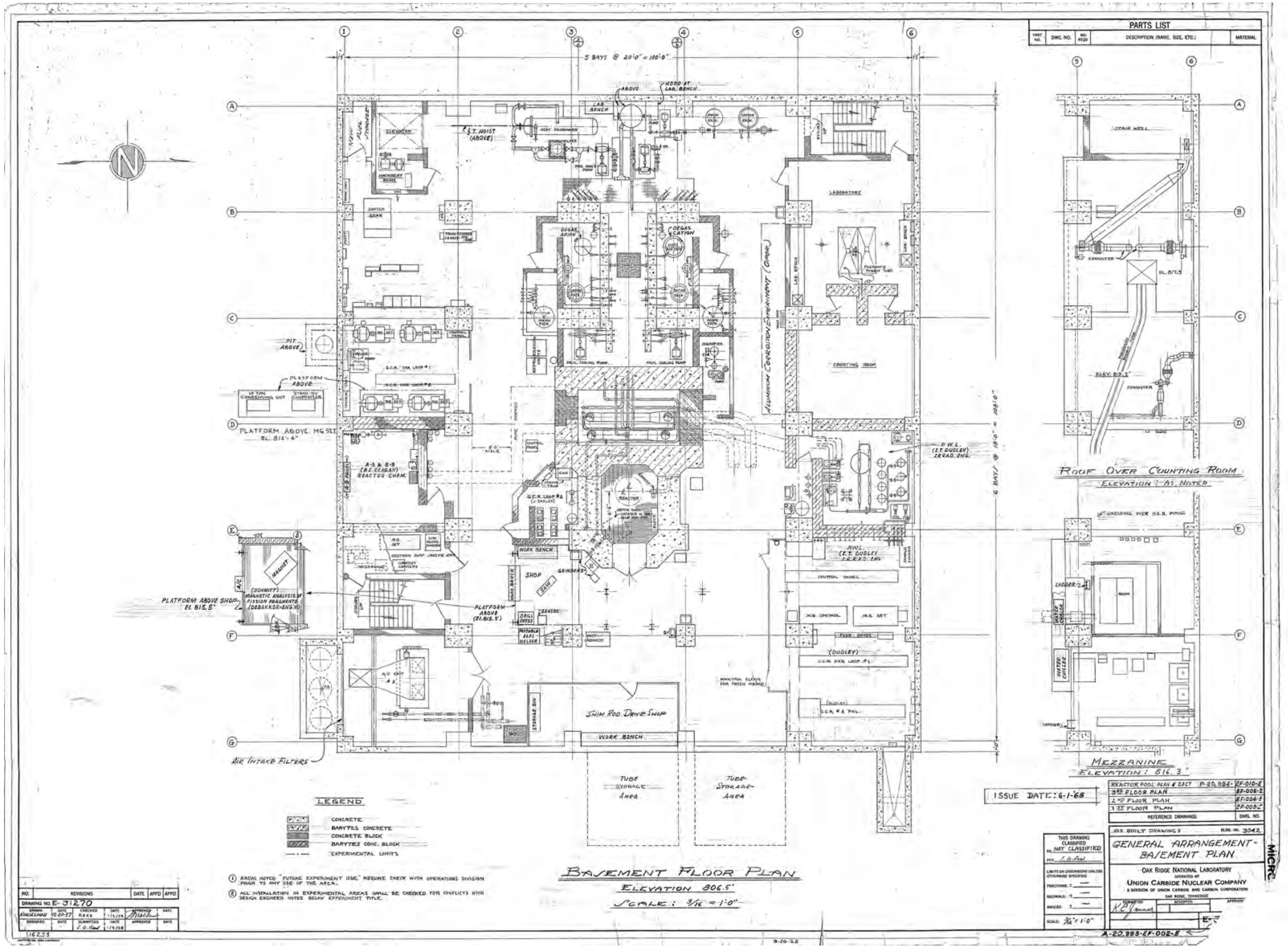


Figure B-34. As built drawing showing the general arrangement of the basement plan in Building 3042 (Oak Ridge National Laboratory, December 20, 1957 [drawn date], June 1, 1968 [issue date, with revisions]).

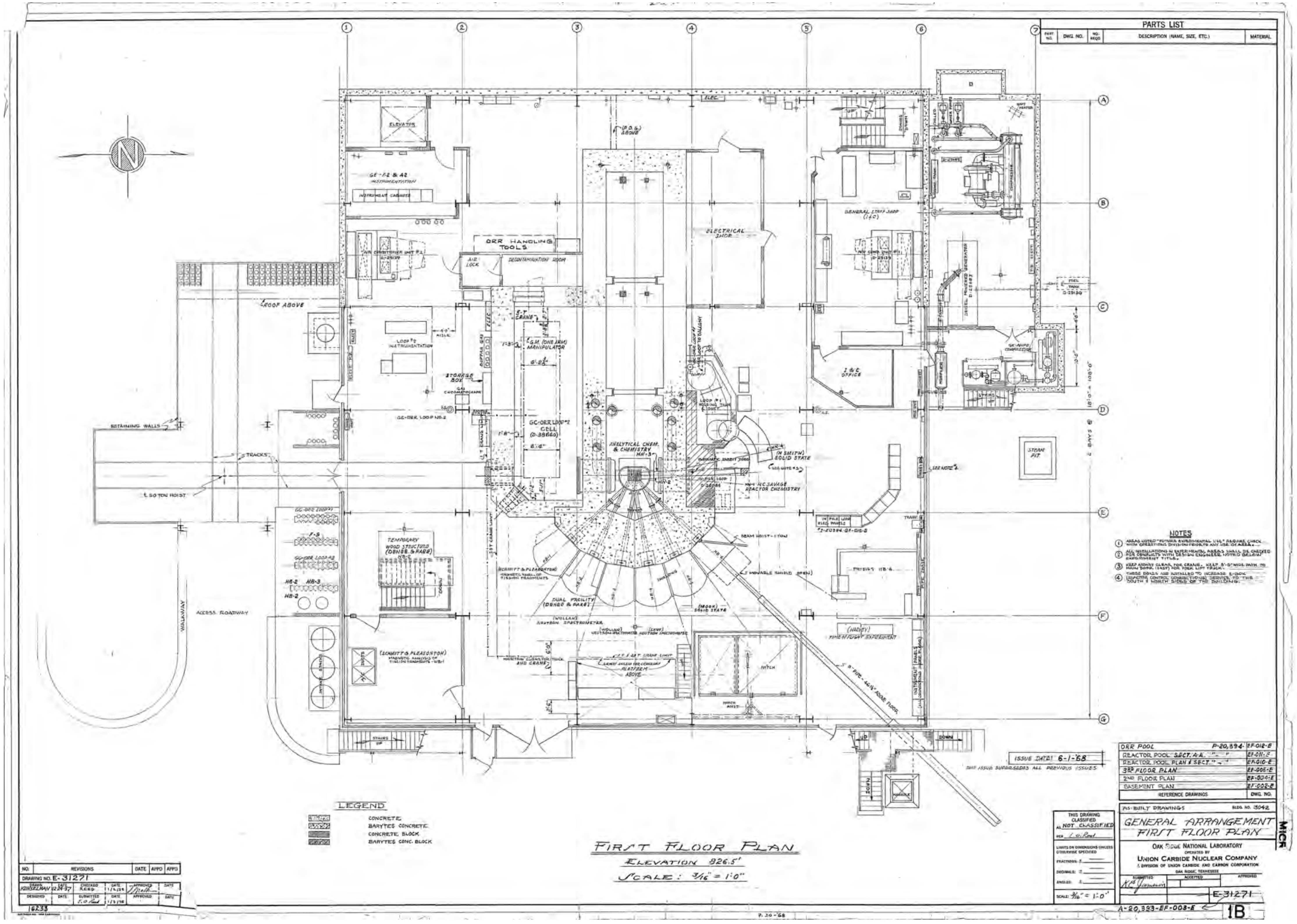


Figure B-35. As built drawing showing the general arrangement of the first floor plan in Building 3042 (Oak Ridge National Laboratory, December 24, 1957 [drawn date], June 1, 1968 [issue date, with revisions]).

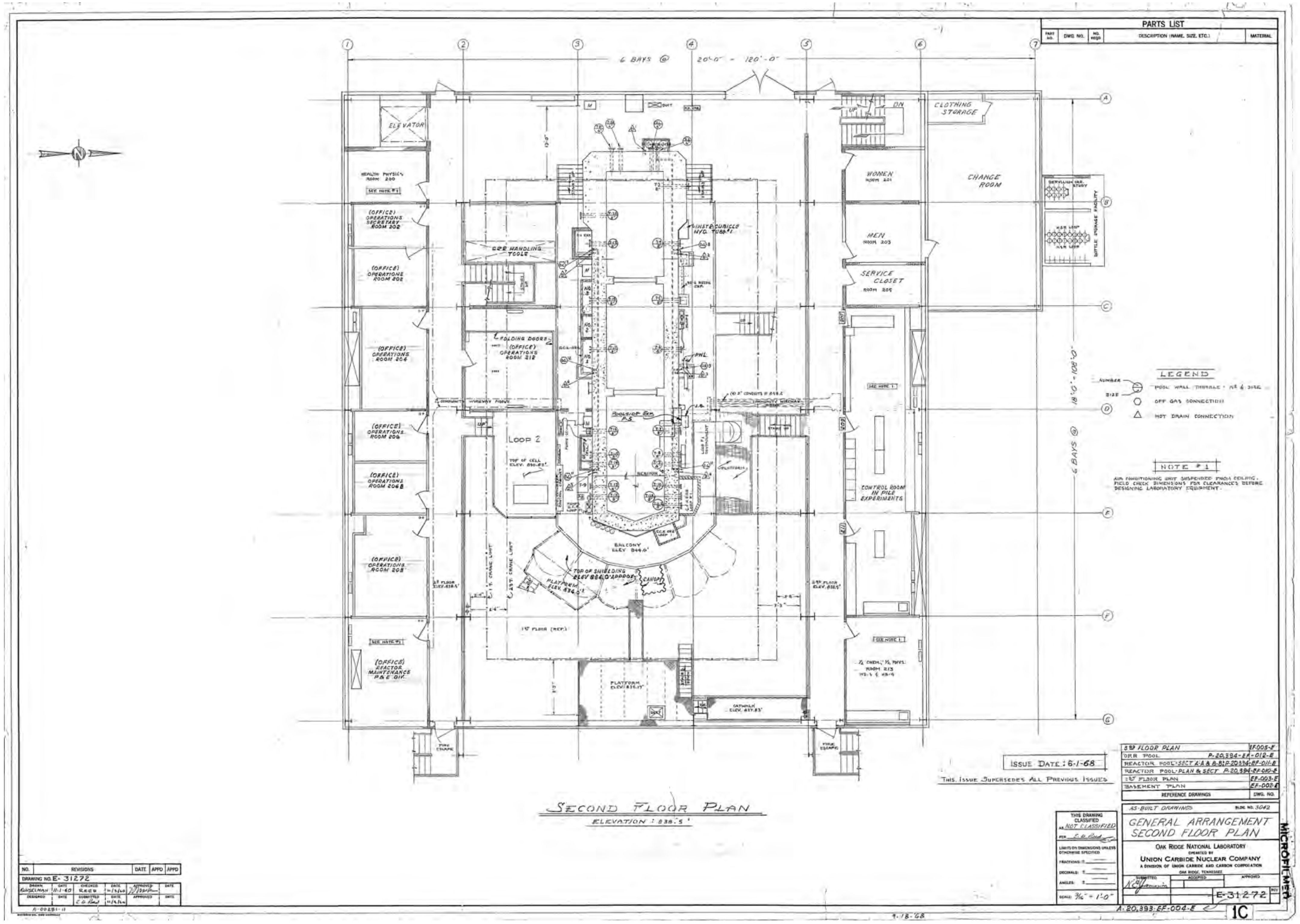


Figure B-36. As built drawing showing the general arrangement of the second floor plan in Building 3042 (Oak Ridge National Laboratory, November 1, 1960 [drawn date], June 1, 1968 [issue date, with revisions]).

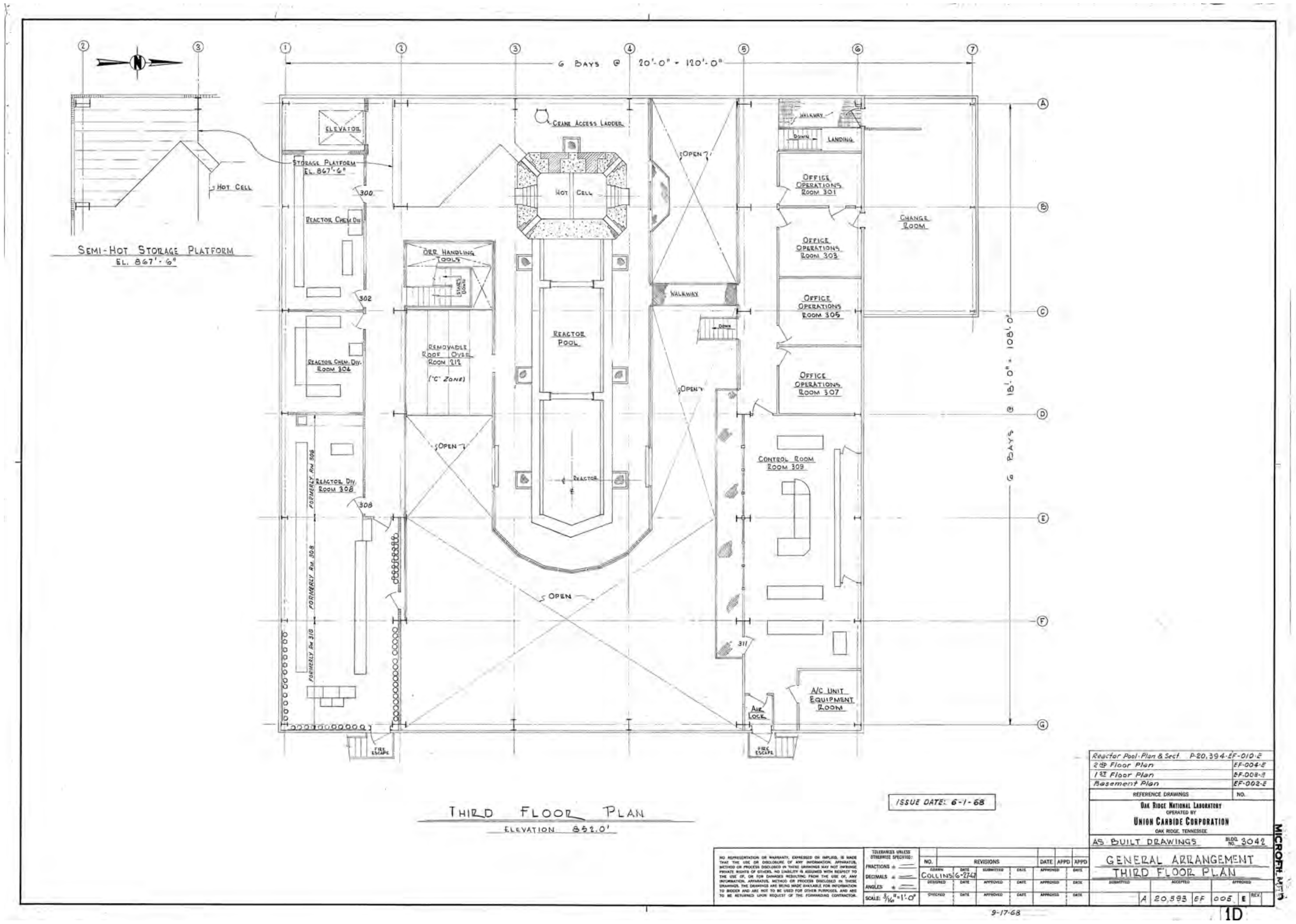


Figure B-37. As built drawing showing the general arrangement of the third floor plan in Building 3042 (Oak Ridge National Laboratory, June 27, 1967 [drawn date], June 1, 1968 [issue date, with revisions]).

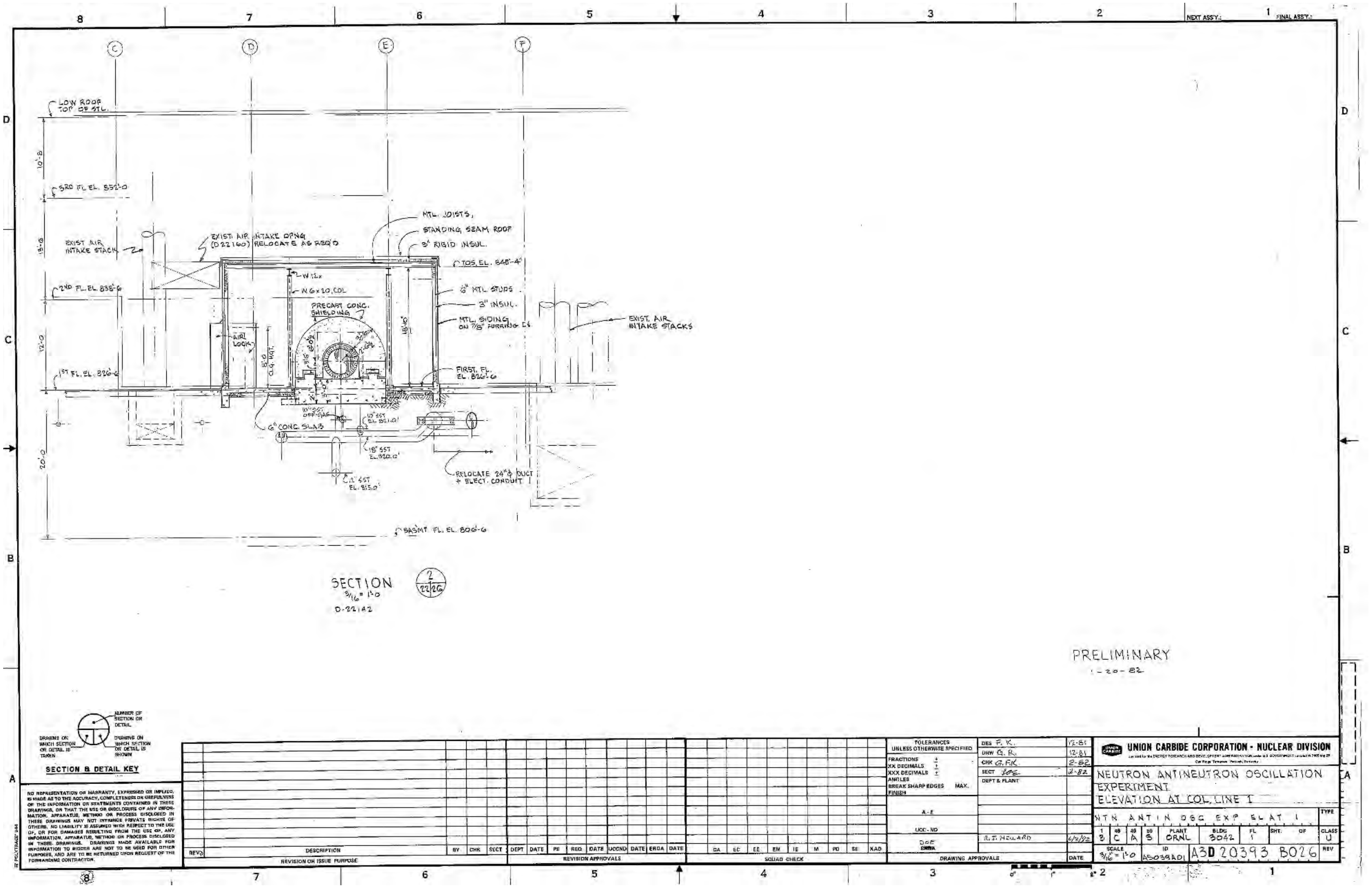


Figure B-38. Preliminary drawing of an elevation pertaining to the neutron antineutron oscillation experiment proposed for construction on the south elevation of Building 3042 (Union Carbide Corporation, December 1981).

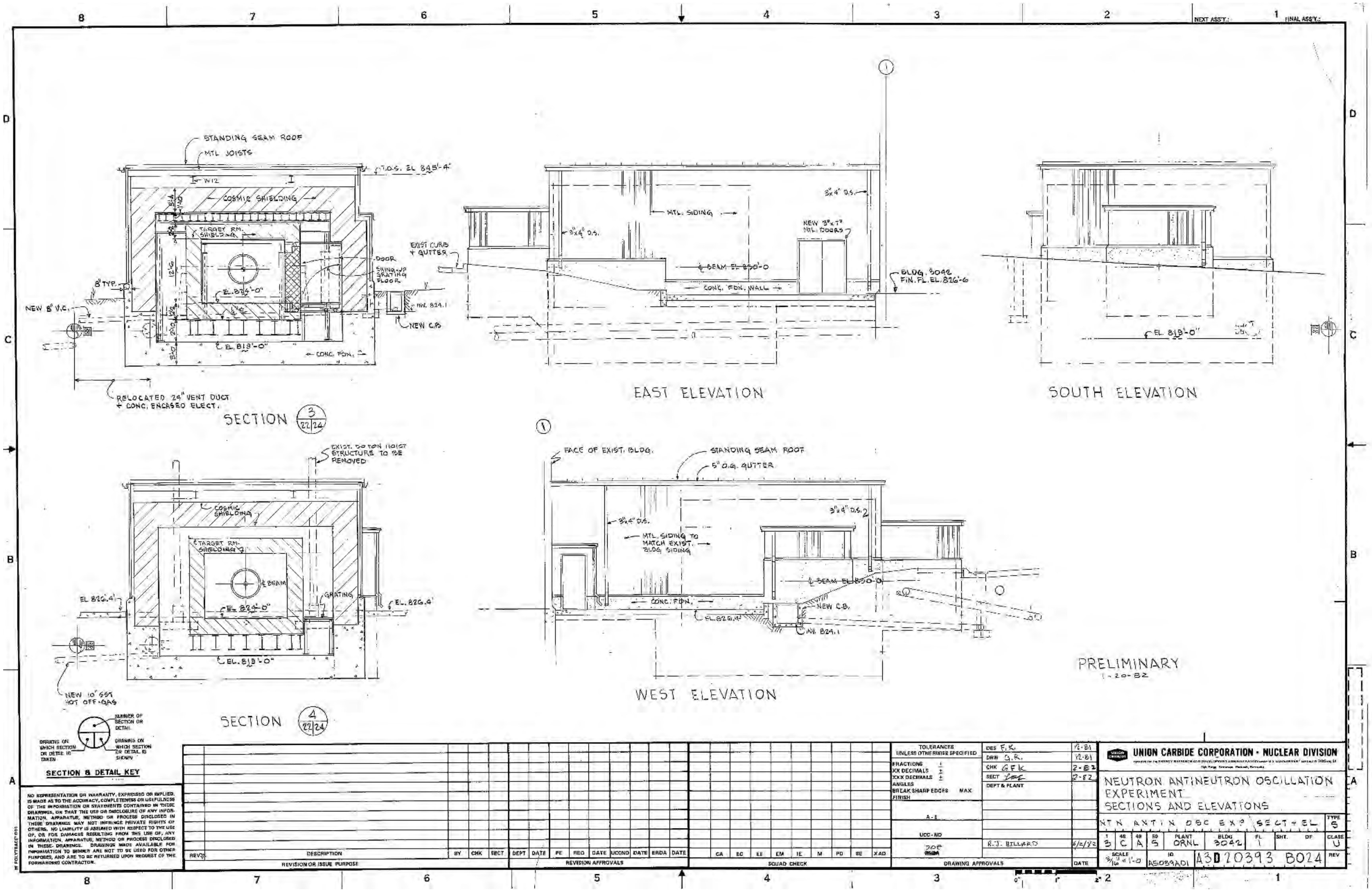
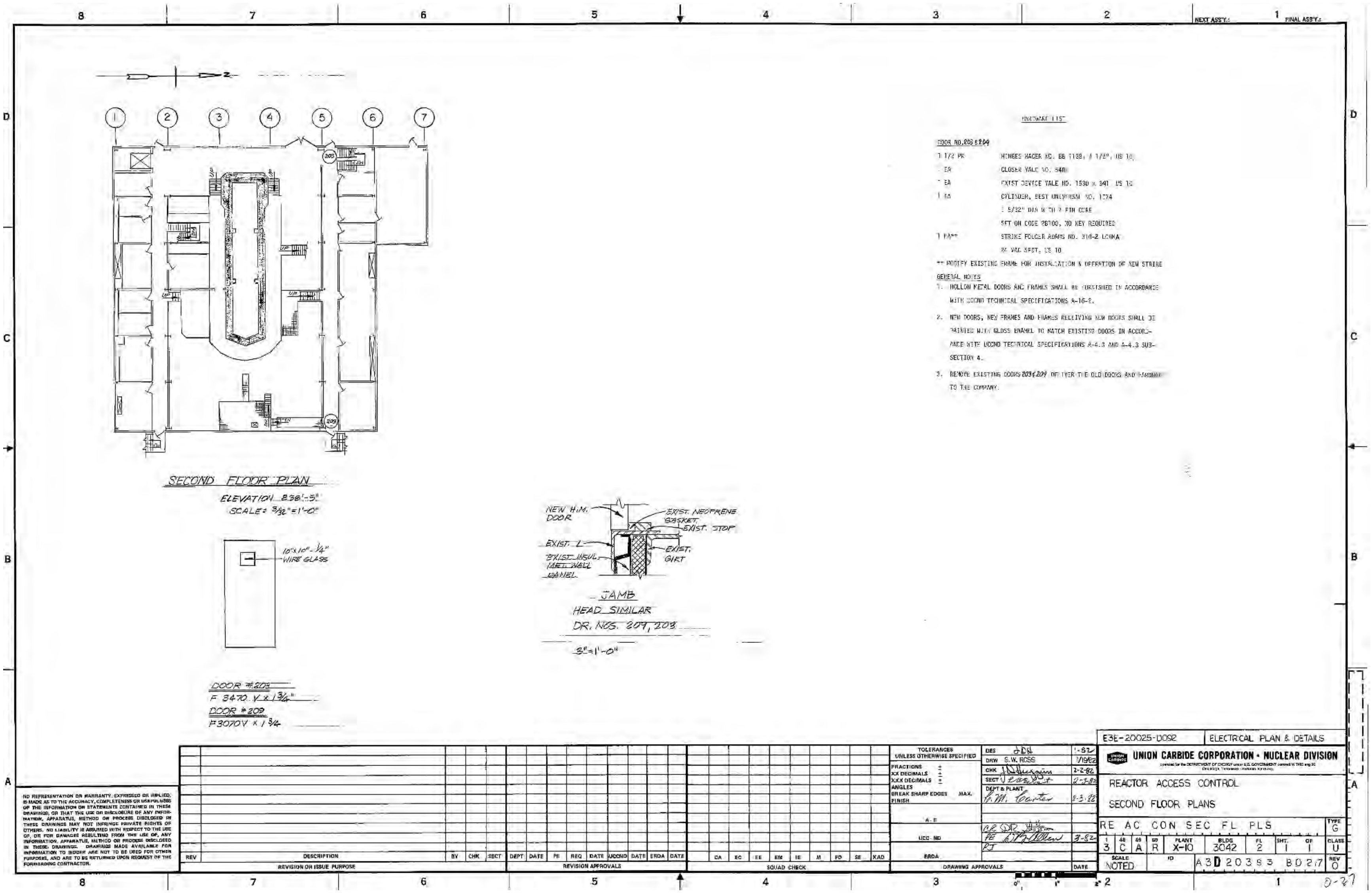


Figure B-39. Preliminary drawing of sections and elevations pertaining to the neutron antineutron oscillation experiment proposed for construction on the south elevation of Building 3042 (Union Carbide Corporation, December 1981).



HARDWARE LIST

DOOR NO. 203 & 209

1 1/2 PR	HINGES HAGER NO. BB 1139, 4 1/2", US 10
1 EA	CLOSER YALE NO. 54RH
1 EA	EXIST DEVICE YALE NO. 1530 x 341 US 10
1 EA	CYLINDER, BEST UNIVERSAL NO. 1E74 1 5/32" DIA WITH 7 PIN CORE SET ON CODE 2B100, NO KEY REQUIRED
1 EA**	STRIKE FOLGER ADAMS NO. 310-2 LOCKA 24 VAC SPDT, US 10

** MODIFY EXISTING FRAME FOR INSTALLATION & OPERATION OF NEW STRIKE

GENERAL NOTES

1. HOLLOW METAL DOORS AND FRAMES SHALL BE FURNISHED IN ACCORDANCE WITH UCCND TECHNICAL SPECIFICATIONS A-16-2.
2. NEW DOORS, NEW FRAMES AND FRAMES RECEIVING NEW DOORS SHALL BE PAINTED WITH GLOSS ENAMEL TO MATCH EXISTING DOORS IN ACCORDANCE WITH UCCND TECHNICAL SPECIFICATIONS A-4.3 AND A-4.3 SUB-SECTION 4.
3. REMOVE EXISTING DOORS 203 & 209 DELIVER THE OLD DOORS AND HARDWARE TO THE COMPANY.

Figure B-40. Reactor access control plans pertaining to replacing the second floor doors in the single-leaf entries on the east and west elevation of the north wing of Building 3042 (Union Carbide Corporation, January 19, 1982).

APPENDIX C. ORAL HISTORY

An Interview with Donald B. Trauger
Interviewed by Stephen H. Stow and Marilyn Z. McLaughlin (assistant)
February 20, 2003
Transcript by Brian Varner
Oak Ridge National Laboratory Oral History Project
The Department of Energy Oral History Presentation Program

Summary of Transcript

Hailing from Nebraska, Donald Trauger became interested in physics and electrical engineering while in high school. He recalled that when his family's farm first acquired a tractor, to replace the horses as a source of energy, he became interested in energy sources. In college at Nebraska Wesleyan University, the discovery of fission excited him as he believed eventually humankind would exhaust fossil fuel resources and, therefore, the discovery of a new source of energy held great potential. While majoring in physics, Trauger continued to keep up with all advancements in the nuclear energy field throughout his college career.

Dr. John Dunning, a professor at Columbia University and a fellow graduate of Nebraska Wesleyan University, contacted Trauger to invite him to work on a "secret project" related to the ongoing war effort. Trauger accepted the offer and began work with the Manhattan District Project at Columbia University in New York regarding the uranium hexafluoride enrichment process. Due to compartmentalization efforts, he became aware of the gaseous diffusion plant planned for Oak Ridge but only heard of the other attributes of the Project through the "grapevine." When the United States dropped the atomic bomb in August 1945, Trauger knew about the majority of the Project, including the construction of the Graphite Reactor.

Trauger and his wife moved to Oak Ridge in 1946 for him to work a six-month commitment at K-25. He remembered their surprise upon discovering the Methodist Church convened in the town theater. They did, however, enjoy the "cemesto house" they purchased, a term for the cement-asbestos paneled pre-fabricated homes. After the initial six-month commitment turned into a full year in Oak Ridge, they were fond of East Tennessee.

Trauger spent his first six months at K-25 re-establishing the laboratory he had organized in New York at Columbia. Once his initial mission was accomplished, he continued work at K-25 in "broader" roles, including lithium isotope separation for hydrogen weapon development. While at K-25, Trauger became involved with the ANP Project, working with high temperatures and corrosive materials in the mid-1950s. Afterwards, he was asked to move to ORNL to continue ANP research. Despite believing the ANP Project was a foolish notion, he hoped the Project could inspire the more useful goal of energy production for electric power generation. Ultimately, the ANP Project advanced material research at ORNL and helped establish the Metallurgy Division as well as the Instruments and Controls Division.

During his ANP research, Trauger worked with the MTR in Idaho, including testing the nuclear fuel for the GCR. Once completed in 1958, the ORR provided a more convenient location for capsule experiments with the candidate GCR fuels. Trauger recalled the AEC desired to move the GCR along quickly, so him and his team also worked with a helium-cooled fuel test loop in the ORR. Eventually, they discovered "coated particles" for the GCR, a novel technology at that time for reactor fuel. Trauger ultimately worked with almost every AEC reactor.

These experiments, along with collaboration with the Germans regarding their design of a Pebble-Bed Reactor, led to further growth of ORNL's radiation engineering operation. Trauger's research took him all over the world. He conducted research alongside German and English scientists, solidifying mutually beneficial relationships allowing each country to share data rather than be solely responsible for developing the "total picture."

During a reorganization of ORNL in 1970, Weinberg requested Trauger, who was serving as director of the High-Temperature Gas-Cooled Reactor Program at the time, to accept the role of Associate Laboratory Director. He quickly took the position, which he kept for fourteen years. This position sent him to Washington monthly to visit with the ORNL funders in order to keep the money rolling in and programs afloat. Trauger also sought to rekindle relationships with Argonne National Laboratory, rather than promote competition between the National Laboratories.

In his role as Associate Laboratory Director, Trauger participated in the Emergency Core Cooling System hearings directed by the AEC in 1972. These resulted from challenges to the safety programs in the nuclear industry instigated by the Union of Concerned Scientists in New England. These hearings led to the establishment of new organizations including the Institute of Nuclear Power Operations, tasked with assessing the safety aspects of utility companies, and the expansion of the Electric Power Research Institute. Shortly after these hearings, the U.S. government dissolved the AEC and replaced it with the Nuclear Regulatory Commission and the Energy Research and Development Administration, presently known as the DOE.

In 1984 Trauger changed roles at ORNL and became the Technical Assistant to the Laboratory Director. In that role, he focused on broad improvements to nuclear energy. Eventually this program generated multiple volumes of documents geared towards launching nuclear sustainable energy systems. While sustainability in nuclear energy systems had, at the time of his interview, yet to emerge, Trauger successfully instigated the organization of the Friends of Oak Ridge National Laboratory, which remained an active group.

Reminiscing on his career, Trauger believed he promoted an effective work environment at ORNL, with steady resource availability and safety in mind. He predicted that, by bringing research groups physically together on one campus, ORNL increased the potential of the Laboratory as "the whole is much greater than the parts." As quoted in the *ORNL Review* 50th anniversary addition, Trauger encouraged scientists to look further in to the future, perhaps even a hundred years. He attempted to do so in his book, *Horse Power to Nuclear Power*, discussing the prospect of new energy systems as oil and natural gas resources continue to be depleted.

An Interview with James K. Weir, Jr.
Interviewed by Stephen H. Stow and Marilyn Z. McLaughlin (assistant)
January 28, 2003
Transcript by Brian Varner
Oak Ridge National Laboratory Oral History Project
The Department of Energy Oral History Presentation Program

Summary of Transcript

Jim Weir attended the University of Cincinnati as a co-op student while also working in the steel industry. He later obtained a Masters' degree in metallurgical engineering from the University of Tennessee. Bored with the steel business, Weir interviewed around and accepted a position at Oak Ridge in 1955. By the time he arrived Oak Ridge had modernized considerably from its humble "wild, wild West" beginnings.

When Weir joined ORNL, the ANP Project was still at the forefront. The ANP Reactor (known as the ARE) led researchers to study containment alloy corrosion in the presence of fused salt and high temperatures. For this reactor experiment, as well as for the MSRE, they needed to determine a nickel-based alloy capable of withstanding high temperatures that was resistant to oxidation as well as lacked chromium, which could be sucked out from inside the vessel by the molten salts. Weir and the Metallurgical Division, later the Metals and Ceramics Division, created a new alloy they named Hastelloy N, or INOR-8, the abbreviation used for the eighth alloy investigated by the International Nickel (Company) Oak Ridge.

In low-temperature reactors fast neutrons would displace atoms, making defects in the metals, known as a type of embrittlement. The embrittlement caused by high-temperatures remained mysterious. After learning of some theories developing in the Solid State Division, they conducted some experiments using various enrichments of boron-10 separated in the Y-12 calutrons. This led to their consideration of titanium boride as a potential additive to the stainless steel, which proved successful as they found no radiation effects at high temperatures. Weir received an E. O. Lawrence Award in 1973 for this discovery. He recalled that the first and only woman chair of the AEC, Dixie Lee Ray, presented him with the E. O. Lawrence Award. Her famous dogs were also on stage for the ceremony.

The ORNL reactor programs waned in the 1970s and, coupled with the 1973 oil embargo, the division's focus shifted to other forms of energy production. Using data compiled during research with uranium oxide, they compared various materials' thermal conductivity for potential use as insulation for houses and appliances. They also contributed to the examination of possible construction materials for coal liquefaction plants, intended to produce gasoline out of coal like Germany had during World War II. After the construction of coal liquefaction and gasification plants, the Metals and Ceramics Division assembled a corrosion assessment team that would travel to plants struggling with component failures. They would search for corroded pieces to bring back to ORNL for further study in order to determine the problem and report back to the plant.

Reminiscing over the beginnings of the Metals and Ceramics Division and ORNL more broadly, Weir explained that in graphite-moderated reactors the graphite would swell due to the neutron flux and instability. They referred to this occurrence as "Wigner Growth" as Wigner understood and anticipated graphite's reaction. Gathering together all of the metallurgists at ORNL, Wigner created the Metallurgy Division, later the Metals and Ceramics Division, in 1946. As ORNL entered the "test reactor" phase in its history, this division helped to develop fuel elements including those for the MTR, built in Idaho, as

well as the BSR, LITR, and ORR. The Division conducted numerous tests on metals and ceramics in the ORR where they had access to instrumented facilities. Originally, experiments were conducted “pool side” or outside the ORR reactor vessel. Wanting to obtain higher neutron fluxes, Weir’s team generated the first instrumented materials radiation facility inside the ORR fuel core. The two best aluminum welders at ORNL spent three twelve-hour days curving the heavy, thick plates and welding the seams in order to fit them into the fuel element receivers. Ultimately, they switched to a single piece extruded aluminum can that would be used by anyone wanting to conduct an experiment within the core.

Weir became the Division Director of the Metals and Ceramics Division in 1973. Shortly thereafter the AEC transitioned to the Energy Research and Development Administration (also known as the ERDA). During his tenure, the Division created the High Temperature Materials Laboratory to study high temperature materials in the context of energy production. The idea for this Laboratory emerged in the late 1970s and it took ten years to formulate and begin operation. This Laboratory would become primarily focused on ceramics and attracted attention from around the world.

An Interview with Michael K. Wilkinson, Frederick W. Young, and Ralph M. Moon
Interviewed by Stephen H. Stow and Marilyn Z. McLaughlin (assistant)
April 30, 2003
Transcript by Brian Varner
Oak Ridge National Laboratory Oral History Project
The Department of Energy Oral History Presentation Program

Summary of Transcript

In graduate school, Fred Young wanted to pursue research rather than teach and, around that same time, Oak Ridge Associate Universities (ORAU) began a summer program for students and faculty. In 1950, Young received approval from ORAU for him to work at ORNL for a year, after which he returned to the University of Virginia, where he had graduated. He returned to ORNL in 1956. Young joined the Solid State Division, formed in 1951 to study the impact of radiation on solids, where he participated in the origins of this research, particularly investigating potential reactor construction materials by irradiating them in the Graphite Reactor. He became the division director in 1988.

Mike Wilkinson originally wanted to become a chemist, but in college he was inspired to pursue physics instead. Graduating from the Citadel, he joined the Army and was sent to radar school at Harvard and MIT and continued into the Army as a radar officer. After World War II, he returned to MIT to complete radar school. Intent on pursuing research before beginning a teaching career, Wilkinson moved to Oak Ridge. His experience at that time complemented the Neutron Scattering Program at ORNL, for which there was no formal training at that time. Wilkinson became the director of the Solid State Division in 1972, a position he maintained into the 1980s.

The son and brother of engineers, Ralph Moon enjoyed math and science in high school. During his freshman year in engineering school at the University of Kansas, he switched his trajectory to physics. He completed graduate school at MIT prior to moving to Oak Ridge in 1963. Moon later became the temporary acting director of the Solid State Division and contributed to the polarization analysis technique developed in the HFIR.

Wilkinson, Young, and Moon all worked in neutron scattering and materials analysis at ORNL. All three men agreed that neutron scattering originated at ORNL with the Graphite Reactor. This research began in November 1945, pioneered by Ernie Wollan and later assisted by Cliff Shull. After Wollan’s death, Shull would win the 1994 Nobel Prize in Physics for his role in the program. Using an x-ray spectrometer sent from the University of Chicago, they calculated the scattering power of atoms by neutrons; neutron scattering necessitated measurement by experimentation. This work established a foundation for reactor-based neutron scattering research, as well as originated a technique utilized for experiments in nuclear physics, crystallography, and magnetism. In brief, neutron scattering allows the study of material properties and material characterization which is used to benefit physics, chemistry, biology, engineering and medicine. At the time of this interview, the American Museum of Science and Energy in Oak Ridge had on display the original spectrometer used in these pioneering experiments.

After the completion of the ORR, the Neutron Scattering Program benefited from a neutron flux 300 times greater than that available at the Graphite Reactor. The increased flux did not simply accelerate experimentation, it allowed for more complex experiments due to a larger quantity of neutrons. With the ORR, researchers began inelastic scattering, measuring both the number of neutrons as well as their change in energy. Later, at the HFIR, they added neutron spin measurements to these analyses. Originally, the HFIR design concentrated on the production of transuranic isotopes but did not include beam holes for neutron scattering experiments. Due to Weinberg's insistence, four beam holes were ultimately included, providing a tremendous boost to the Neutron Scattering Program.

In the 1960s, the Solid State Division created a Research Materials Information Center in order to streamline the production of "very-high-quality" materials to prevent the possibility of confusion as to the origin of any defects. Samples exhibiting defects prior to irradiation compromised the validity of the results. Lists of locations preparing the materials and their characteristics circulated amongst producers and researchers, providing information on how to procure necessary samples while also avoiding duplication. About this same time, the Division discovered ion channeling, a phenomenon regarding atom penetration into crystals that led to the basis of silicon technology.

After the creation of the DOE in 1977, the restrictions of research conducted in the Solid State Division loosened. Under the AEC, the Division focused on materials intended to be used for fission and fusion reactors. After the dissolution of the AEC, the Energy Research and Development Administration and DOE missions, however, prioritized research in all energy technologies. One of the results of that mission shift was the formation of the High Temperature Materials Laboratory to investigate materials for all energy technologies as the use of fuel was found to be most efficient during high temperature machine operation. Studies regarding identification and generation of materials that could withstand high temperatures for long durations of time became paramount. This Laboratory would eventually fall under the umbrella of the Metals and Ceramics Division.

After the HFIR commenced operation, the AEC, later the DOE, started to consider the possibilities of "next-generation neutron sources" in the 1970s. After a National Research Council meeting in 1984 considering multiple options, including upgrading the HFIR, the committee decided to build the Advanced Photon Source, an X-ray synchrotron source, at Argonne, as well as the Advanced Neutron Source reactor at ORNL. Ultimately, the Advanced Neutron Source (also known as the ANS) proved too expensive at that time, however, the argument for a new neutron source had achieved the spotlight. A conceptual design for an accelerator-based spallation source appeared at a time when funding was available, leading to the construction of the Spallation Neutron Source (also known as the SNS).

While neutron scattering research originated and evolved at ORNL, all three scientists agreed that, at the time of the interview, the research centered in Europe. Specifically, the Institut Laue-Langevin located in Grenoble, France built a reactor for the sole purpose of neutron scattering research. Wilkinson speculated that would change with the construction of the Spallation Neutron Source and modifications to the HFIR and that ORNL would once again be the "world's center of neutron scattering research."

APPENDIX D. HISTORICAL DOCUMENTS

The following appendix of historical documents contains excerpts from:

Barkelew, C. H.

1953 The Shield of the ORNL Research Reactor. ORNL-CF-53-5-225. Correspondence. To J. P. Gill. From C. H. Barkelew. May 26, 1953. Oak Ridge National Laboratory. Oak Ridge, Tennessee.

Cole, T. E. and J. P. Gill

1957 The Oak Ridge National Laboratory Research Reactor (ORR), a General Description. ORNL-2240. Research Reactor Design Group. Issued January 21, 1957. Contract No. W-7405-eng26. Oak Ridge National Laboratory. Oak Ridge, Tennessee.

George, Kenneth D.

1962 The Oak Ridge Research Reactor (ORR), The Low-Intensity Testing Reactor (LITR), and the Oak Ridge Graphite Reactor (OGR) as Experiment Facilities. ORNL-TM-279. Paper presented at Conference on Light-Water-Moderated Research Reactors June 11-14, 1962 in Gatlinburg, Tennessee. Issued August 28, 1962. Contract No. W-7405-eng-26. Oak Ridge National Laboratory. Oak Ridge, Tennessee.

Hamrick, T. P. and J. H. Swanks

1968 The Oak Ridge Research Reactor – A Functional Description. ORNL-4169. Operations Division. September 1968. Contract No. W-7405-eng-26. Oak Ridge National Laboratory. Oak Ridge, Tennessee.

Snell, A. H. and A. M. Weinberg

1950 Proposal for a Research and Isotope Reactor at ORNL. AECD-3818. United States Atomic Energy Commission. Edited by A. H. Snell and A. M. Weinberg. Issued August 17, 1950. Technical Information Service, Oak Ridge National Laboratory. Oak Ridge, Tennessee.

Tabor, W. H. and R. A. Costner, Jr.

1962 Problems Encountered During Four Years of ORR Operation. ORNL-TM-275. Paper presented at Conference on Light-Water-Moderated Research Reactors June 11-14, 1962 in Gatlinburg, Tennessee. Issued 1962. Contract No. W-7405-eng-26. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Trauger, D. B.

1964 Some Major Fuel-Irradiation Test Facilities of the Oak Ridge National Laboratory. ORNL-3574. Reactor Division. April 1964. Contract No. W-7405-eng-26. Oak Ridge National Laboratory. Oak Ridge, Tennessee.

X-426 (Revised 1-52)

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ORNL
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TO: J. P. Gill

FROM: C. H. Barkelew

"This document consists of 28 pages.
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[illegible]

The Shield of the ORNL Research Reactor

C. H. Barkelew

For the design of the components of the proposed Research-Reactor shield, it has been presumed that the reactor will be operated eventually at 30 megawatts, although the present cooling system will allow a maximum of 5 megawatts. It has been supposed that the additional shield required for the 30 megawatts will be relatively inexpensive, if it is installed when the reactor is constructed. If, on the other hand, the shield were designed for only 5 megawatts, supplemental shielding for higher-power operation would be expensive and difficult to install, and inconvenient in use.

The basis for the design has been the principle that nowhere in the reactor building (the sub-pile room excepted) shall the radiation level exceed one-tenth the accepted biological tolerance. The design thus calls for a maximum dose of 0.75 mr/hr of photons, 0.075 mrep of fast neutrons, or a linear combination if both are present.

It has been assumed that operation of the cooling system will not require personnel to be in its area at all times, and that dose rates somewhat above health tolerance can be allowed. 50-60 mr/hr is found in similar areas around the LITR, and it will be assumed that intensities of this order will be satisfactory for the ORR installation.

A description of the reactor is to be found in report ORNL-1475, issued in January 1953. In the three months since the issue of this report, several important changes in the design have been made. The most important of these in a discussion of the shield are:

The internal diameter of the beam holes has been increased from 6 inches to 8 inches.

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The control instruments have been moved so that their leads come out of the shield at the balcony level.

The thermal shield has been thickened to 3 inches of lead, cased in 1/2 inch steel.

Figure 1 is a horizontal section of the reactor as presently conceived.

In this report, the discussion will fall into four sections. These are: a discussion of the properties of shield materials; a discussion of the main shield; a discussion of shielding problems connected with the cooling system; and a discussion of the singular directions. The last includes: the sub-pile room, the beam holes, and the instrument channels.

Section 1. The Shield Materials

Water:

The core of the Research Reactor is similar to those of the MTR and BSF. It has been assumed, therefore, that the neutron and photon spectra are the same, and that the attenuation through water is the same as observed in the BSF. The data have been published in the form of a chart, Drawing 13769. Subsequent data have appeared in the Quarterly Progress Reports of the ANP Project. All attenuations through water have been calculated by scaling the numbers from the chart by a factor of 3×10^7.

Barytes Concrete:

The design of the shield for the MTR was based on the assumption that the attenuation of γ-radiation by concrete is determined by its density. The e-folding lengths used for barytes were 10 cm for photons and 8.2 cm for fast neutrons. Since the MTR has operated satisfactorily without supplemental shielding, we may be sure that these figures are not low.

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There is some evidence, in the form of measurements on the BEPO, that barytes concrete may attenuate photons even more strongly than its density would indicate. B. T. Price in report AERE R/R872 reports a 9-cm relaxation length. The spectrum was different, however, from that of the ORR, and the geometry is more like that of a point source. For these reasons, and since it is proper to be conservative in doubtful cases, the 10-cm relaxation length for photons in concrete has been used.

We may hope that, at some future date, measurements on the MTR shield will clarify this uncertainty.

Metallic Components:

The relaxation lengths used for the calculations of this report were:

	for photons	for fast neutrons
lead	2.5 cm	equal to water
iron	4 cm	6 cm

The term "fast neutron" refers to the dose measured by the instruments of the BSF. It has been assumed, conservatively, that all neutrons above thermal are removed from a beam according to an "effective-removal cross section," defined in report ORNL 51-10-70. It has been experimentally observed in the BSF that the substitution of lead for water does not change the fast neutron dose significantly, so long as any mixture is at least one-half water.

Section 2. The Main Shield

The core is at the center of a cylindrical tank of water, 8 feet in diameter. The concentric thermal shield is 4 ft 6 inches in diameter and 5 feet high. The concrete is in an approximate annulus, 7 ft thick. The lead and concrete are pierced by ten beam holes, each approximately 9 inches in diameter, and by eight through-facility holes, each 4 inches square. Two instrument channels from the balcony terminate halfway through the thermal shield.

Earlier calculations on the shield, reported in ORNL 52-3-134, indicated that a thinner thermal shield would be adequate. The present calculations are in substantial agreement, except that in a few places the uncertainty is high and a more conservative shield has been recommended. It will be shown that the reason lies in the heating of the concrete rather than in the biological dose.

There are two principal differences between the calculations reported here and those reported previously. Here, a "buildup" equal to the number of relaxation lengths has been used. This is, practically, a factor of two over what was used before. The other difference is that for these calculations the BSF data were used to estimate the attenuation through water. The earlier calculations were made on the basis of an approximate spectrum, with attenuation of each component calculated. This makes again a factor of about two.

The geometric factor was computed on the assumption that the core was a disc source with a cosine distribution of emergent photons. The results were almost identical with the factor calculated by Lane, reported in ORNL 52-3-134. He considered the source to be an assembly of self-absorbent line sources.

The computed γ-dose at several positions along a path through the shield is tabulated below.

Position	Dose, r/watt	Dose at 30 megawatts
Core face	74	
Inside tank B	4	
Outside thermal shield	.170	

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Engineering cy. 3

THE OAK RIDGE NATIONAL LABORATORY RESEARCH REACTOR (ORR)

A GENERAL DESCRIPTION

T. E. Cole
J. P. Gill

U.S. ATOMIC ENERGY COMMISSION

OAK RIDGE NATIONAL LABORATORY
OPERATED BY
UNION CARBIDE NUCLEAR COMPANY
A Division of Union Carbide and Carbon Corporation

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ORNL-2240

Contract No. W-7405-eng26

THE OAK RIDGE NATIONAL LABORATORY RESEARCH REACTOR (ORR)

A GENERAL DESCRIPTION

Research Reactor Design Group

T. E. Cole
J. P. Gill

DATE ISSUED

JAN 21 1957

OAK RIDGE NATIONAL LABORATORY
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FOREWORD

This report is issued primarily to make available a general description of the Oak Ridge Research Reactor (ORR) in its present 20 Mw form.

I. ABSTRACT

The proposed ORNL Research Reactor is designed to serve as a general purpose research tool delivering an average thermal neutron flux of 1.3×10^{14} n/cm^2-sec at the initial power level of twenty megawatts. Operation at power levels up to thirty megawatts is proposed for such times as sufficient cooling capacity is available to handle the increased heat load.

The reactor will use MTR type fuel elements and beryllium reflector pieces in a 7 x 9 grid with moderation and cooling provided by forced circulation of demineralized water. The reactor tank is submerged in a pool filled with water with walls and bottom of barytes concrete which serves as a biological shield. Experimental facilities include two "Engineering Test Facilities" approximately 19" x 25" and six 6" diameter beam holes. In addition, access to the core is available through the water of the pool.

II. INTRODUCTION

The history of the ORR (ORNL Research Reactor) Project began in the early part of 1950 when it was determined that a permanent reactor facility was required at the Oak Ridge National Laboratory in order to carry out successfully the various research programs then being undertaken. The reactor selected was a simplified version of the MTR (Materials Testing Reactor), to operate at a power level of five megawatts, which would require a minimum of design and development. Preliminary design work on the ORR was supported by the Atomic Energy Commission. During the initial phase the proposed design changed considerably as required by the shift in emphasis on the experimental programs. With the operating experience of the MTR and other reactors as a guide and the additional data now available in the field of reactor technology a number of improvements have been made in the basic design.

The need for improved facilities for experiments requiring neutron beams, expanded facilities for isotope production, and the necessity for an irradiation facility to permit engineering tests of the materials and components of liquid fuel reactors has become increasingly urgent. Construction and operation of the ORR in conjunction with existing facilities will help meet the requirements for neutron irradiation space of both the basic and applied research programs of the Laboratory and will help meet the expanding requirements for radioisotope production at this location.

A preliminary Proposal(1) which outlined the basic features of the reactor was submitted to the Atomic Energy Commission in March, 1954. This proposal was approved, and a directive was issued permitting the use of funds to secure the services of an Architect Engineer for the purpose of preparing a design on the basis of five megawatt operation. A contract, calling for the definitive design of the building, reactor shielding structure, and cooling system was executed, on July 21, 1954, with The McPherson Company of Greenville, S. C. On August 25, 1954 a modification of this directive was issued authorizing design and procurement of the reactor and controls by the Oak Ridge National Laboratory. A subsequent modification was issued early in 1955 providing funds to allow design and installation of equipment necessary for initial operation at twenty megawatts. Construction of the building, reactor shielding structure, and cooling system is being performed by Blount Brothers Construction Company of Montgomery, Alabama, a contractor who was selected on a competitive "lump-sum" bid basis. It is estimated that the reactor will be placed in service in the summer of 1957.

Copies of the Preliminary Proposal were sent to members of the Advisory Committee on Reactor Safeguards. A further description of the facility was given at a meeting of this Committee held at Cincinnati, Ohio on April 21, 1954.

On December 15, 1954 a review was made of the status of the ORR Project coupled with a review of the requirements for irradiation space by the ANP and HRP. One result of this review was the decision that sufficient justification existed to warrant an increase from 5 - 10 MW initial power level to 20 MW. This increase in initial power level was discussed with members of the Advisory Committe on Reactor Safeguards and in March, 1955, the following modifications were agreed to constitute adequate safeguard measures considering the design of the reactor, the location and the proposed use:

a) Containment is to be provided to the extent that an accident releasing the volatile fission product gases from the reactor core will not constitute a widespread hazard.

b) Available excess reactivity is to be minimized in so far as practical.

c) That the experimental installation in the engineering test facilities be restricted so that upon failure or malfunction of the installation no more than 1.4% reactivity will be added to the reactor.

III. DESCRIPTION OF FACILITY

A. General Description of the Reactor

The Oak Ridge National Laboratory has proposed (1) that a research reactor of intermediate power be built and operated in support of its basic and applied research programs. It is now proposed that this system be operated at a power level of twenty megawatts corresponding to an estimated average thermal neutron flux of 1.3×10^{14} neutrons/cm.^{2} sec. It is further proposed that at such times as adequate cooling is available the system be operated at power levels up to thirty megawatts.

The design of the ORR incorporates a heterogeneous core which utilizes enriched uranium fuel with ordinary water as coolant and moderator. The reflector will be a relatively thin layer (3 to 6 inches) of beryllium metal, backed by a thick layer (approximately 4') of water. A plan view of the core is shown in Fig. 1.

The core arrangement, fuel elements, and methods of shim and control are similar to those used in the MTR(2). The reactor core is housed near the bottom of an aluminum tank approximately fifteen feet in overall height.

and approximately five feet in diameter as shown in Fig. 2. Control drives are operated from below the reactor through a large shielding plug as illustrated in Fig. 3. This assembly, together with a top cover plate, constitutes the reactor unit which may be completely removed (with considerable effort) should the occasion arise, see Fig. 4. The design of this reactor unit incorporates many features which have already been tested or which are now being used in other installations(2),(3),(4),(5).

The reactor unit is located in a pool of demineralized water which is approximately twenty-one feet long, ten feet wide, and twenty-eight feet-eight inches deep, as illustrated in Figs. 3, 5 and 6. The twenty-four feet of water above the core centerline provides the main shielding above the reactor during operation and also provides the shielding required for the transfer of fuel elements, control rods, and vertical experiments from the reactor to the storage areas of the pool. These storage areas are adjacent to the reactor pool itself and are separated from it by removable aluminum gates. The entire series of pools are to be lined with ¼" welded aluminum plate in order to help maintain high water purity and to insure against leakage through the pool walls and floor.

Although the pool water is normally independent of the reactor cooling system, provision is made for circulation of this large volume of water through the reactor core should such a procedure be necessary under emergency conditions.

The structure above the sub-pile room ceiling and the adjacent storage pools is designed to meet biological shielding requirements during reactor operation and also to permit safe transfer of fuel and experimental equipment between pool sections. The pool walls are to be constructed of high density barytes concrete. The barytes concrete shielding will be a minimum of four feet thick in the vicinity of the reactor core. Immediately adjacent to the six beam holes, the shield is nine feet thick.

Each of the three pool sections is approximately the same size (see Fig. 6) with a total capacity of 150,000 gallons. The sections are separated by removable aluminum gates and can be filled and drained independently. There is sufficient water provided between the reactor and the walls in most cases to prevent serious activation of the concrete. The concrete closest to the reactor will be protected by thermal shields to prevent excessive heating.

B. Reactor Site

The construction site for the ORR is located in the north central portion of the Oak Ridge National Laboratory as indicated in Fig. 7. This location is approximately 650 feet south of the nearest periphery fence. Other buildings in the general vicinity (see Fig. 8) are as follows:

Building	Location
Bulk Shielding Facility (3010)	80' NE
X-10 Graphite Reactor (3001)	110' W
LITR (3005)	80' N
Rolling Mill (3012)	125' E

The building housing the ORR is to be located on the side of a hill which slopes in an easterly direction from elevation 835' to a small creek at elevation 800', approximately 350' east of the reactor site. This particular location was chosen because of the availability of services already in the area, integration of operations with currently existing similar facilities, and the availability of space for future expansion and for conducting neutron experiments at some distance from the neutron source. The cooling system for the pool water is located east of Building 3010, the Bulk Shielding Facility, and the cooling system for the core is located approximately 300' northeast of the reactor building as shown in Fig. 8.

C. Reactor Controls

The reactor control and safety system resembles the system installed on the MTR.(2), (6) However, experience with control systems on similar reactors, particularly the LITR and the Geneva Conference Reactor, has given sufficient confidence in the instruments to permit an instrument-controlled startup, leaving the operator free to concern himself with things not amenable to reactor controls, such as the cooling system, the experiments, and any unusual or abnormal conditions that might occur. Actions of the operator and of the automatic controls are monitored continuously by instruments independent of the safety system. The automatic start is terminated at about 300 kw; at powers above this level the operator must take into account the requirements of the experiments and the condition of the cooling system before proceeding. The automatic start is not used above 300 kw.

The Level Safety System is counted on to shut the reactor down in case of malfunction of operator or controls, but considerable effort is made to forestall a scram caused by an operating error or a false signal by equipping the control system with less drastic modes of corrective action, which can correct many potentially dangerous situations before a scram becomes necessary.

The control of the reactor is effected by the accurate vertical positioning of four or more removable elements within the reactor core. These elements are approximately twice the length of the reactor core, the lower half of the element consisting of fuel of the same shape and essential composition as the fixed fuel elements of the core and the upper half consisting of a poison at this point through which this highly radioactive water may be removed. The "spare" lines may be used to take this water to a decay tank and then to the pool demineralizer, or to any alternate disposal system.

F. Building and Services

The facility will be housed in a structural steel framed, insulated metal panel sided, mill-type building 108 feet long, consisting of a central crane bay area 60' wide with a service wing on each side 20' wide. The height of the mill-type structure, measured from the first floor, (see Fig. 14) is about 36' for the service wings and about 71' for the crane bay. The area grade contour is such that a truck entrance to the building at street level has been provided at the second floor level on the west side of the building, and a second street-level truck entrance on the east side of the building at the first floor level. All construction below grade level will be reinforced concrete. The basement floor is 20' below the first floor level. Approximately 30' of shale and earth below the existing grade will be excavated to place the structure on a rock foundation.

The reactor pool structure will be of barytes concrete with walls of various thickness. Thick walls of reinforced concrete enclosing the basement sub-pile room and pipe chase support the reactor pool, and concrete columns support the storage pools.

The building will be divided into four working levels as follows:
(1) A full basement of 11,400 square feet (see Fig. 15) which will include a fan and filter room, the sub-pile room, shielded demineralizer rooms, reactor sub-structure, electrical load center, and future cell areas.
(2) A first floor of 9,500 square feet (see Fig. 16) which will contain the reactor beam hole areas, general experimental area, and truck access.

(3) A second floor of 3,000 square feet (see Fig. 17) which will contain truck access to the building, office, rest rooms, and balcony access around the reactor pool at an intermediate level 5' -6" above the second floor. (4) A third floor of 6,800 square feet (see Fig. 18) which will contain four offices, six laboratories, control room, equipment and instrument repair shop, access around the pool, and a future hot cell to be located over the west end of the pool.

The total floor area is 30,700 square feet and the gross building volume is 831,000 cubic feet.

A twenty-ton bridge crane with auxiliary one-ton hook will be provided as illustrated in Fig. 14.

Heating and ventilating will be provided by forced draft units having steam heating coils, and power roof exhausters(9). Auxiliary summer ventilation will be provided by forced draft from the fan and filter room, located in the basement. As a fire prevention measure, the basement is sealed off from the floors above by hatch covers and fire walls around the stair wells. Air in the basement will be exhausted from the building through a vertical tunnel. Air conditioning will initially be limited to the third floor control room, offices, and equipment and instrument repair rooms.

Services provided to the reactor include plant process water, demineralized water, compressed air, "hot" off-gas exhaust which connects with the existing "3039" 250' stack(10), "hot" drains which connect with the existing ORNL waste disposal plant(11), and process drains. These services are provided to convenient locations on the third floor walkway around the pool, on the second floor at the back of the pool convenient to the "rabbit" stations, and to all the experimental stations around the face of the reactor structure at the first floor level. Supply and return lines from the main reactor cooling circuit are provided to the first floor experimental stations for cooling purposes. These lines are imbedded in the pool wall in order to provide adequate shielding from N^{16} activity. Both 440 volt and 120/208 volt convenience outlets are provided around the reactor structure. In addition, ten 50 amp. distribution boxes on the 115/230 volt special service line are provided to the experimental areas for instruments. All services in the experimental areas are arranged to provide a high degree of flexibility. Numerous sleeves, pipe chases, and empty conduits are provided.

Initially, services to the six third floor laboratories will include plant water, compressed air, special and normal electrical services and process drains.

IV. OPERATING PROCEDURE

It is anticipated that the ORR will be operated on a basic 24 hour day probably with a scheduled shut-down one day per week. It will be necessary to modify this schedule in accordance with the requirements of the experimental program.

Operation of the reactor will be the responsibility of the Reactor Operations Department of the Oak Ridge National Laboratory Operations Division. This department is currently responsible for operation of both the LITR and the X-10 Graphite Reactor. Operating personnel will be chosen from this organization, which has gained several years experience in operating a reactor of similar design, the LITR, and will report through their supervisor to the department superintendent.

At least two persons will be present at all times during operation; an operator to perform the required manual tasks, including manipulation of the control mechanisms, observation of instruments, recording of operational data, etc.; an experienced reactor foreman will be available to oversee the reactor operations and give instruction in the event of some atypical behavior of the machine. Since the Reactor Operations Department maintains a crew of four or five on all shifts, assistance is available for the performance of operations requiring additional personnel.

Initial operation of the ORR will be accomplised by the Reactor Operations Department with the assistance of experienced members of the Laboratory staff and in accordance with official procedures. Major changes in operating procedure, modifications or fuel loading, etc., will be reviewed by the Reactor Operations Review Committee which consists of five senior members of the Laboratory staff.

It is not contemplated to change an entire loading at any one time. A tentative fueling plan, similar to that used in the LITR, calls for the shifting of the elements, at intervals of about two weeks, in such a way as to achieve uniform burnout. At the time this shifting is done those elements, having a calculated burnout such that the minimum excess reactivity required will be unavailable before the next scheduled shutdown, will be replaced.

Elements having a burnout equal to the maximum determined to be permissible will be placed in racks in one of the storage pools for a time sufficient to permit cooling to a level which will allow their safe transfer in shielded shipping containers to the processing plant at the National Reactor Testing Station at Arco, Idaho.

V. EXPERIMENTAL PROGRAM

A. Types of Experiments

The ORR is to be constructed to serve as a permanent general purpose irradiation facility for use in the experimental and production programs at the Oak Ridge National Laboratory. The experiments anticipated, therefore, may be expected to be quite varied, including the conventional "in-pile" irradiation of small samples as well as complicated circulating fuel loops which release large amounts of energy during irradiation.

The following types of experiments are expected to form a large part of the operational load of the ORR:

1. Dynamic loop tests to determine the effect on fluid fuels, and on the engineering equipment associated with them.

2. The irradiation of fluid fuels in quantities large enough to permit chemical studies of continuous fuel processing systems.

3. "Conventional" neutron experiments in which the reactor is utilized as a source of neutrons.

4. Radio-isotope production.

5. Solid-State physics and metallurgy investigations of the effects of radiation on engineering materials and basic studies of the properties of metals, alloys and ceramics.

B. Limitations to be Placed on Experiments

Generalization of the limitations to be placed on experiments would serve little purpose here. It is obvious, however, that in addition to the specific problems directly concerned with the safety of the experimental apparatus, any effect that the experiments may have on the reactor must be governed by the same basic safety considerations as govern operation of the reactor itself. The reactor control and safety system will be provided with means whereby information concerning the experiments can be introduced. All experiments will be carefully reviewed in order to avoid violation of basic safety criteria. Experiments to be installed in the engineering test facilities will be designed so that any mishap in the experiment cannot introduce a reactivity change of more than 1.4% as set forth by the Advisory Committee on Reactor Safeguards. In addition the experiments must be treated individually and collectively with respect to their effect on the overall operation of the facility.

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THE OAK RIDGE RESEARCH REACTOR (ORR), THE LOW-INTENSITY TESTING REACTOR (LITR) AND THE OAK RIDGE GRAPHITE REACTOR (OGR) AS EXPERIMENT FACILITIES

Kenneth D. George

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Kenneth D. George*

ABSTRACT

Those characteristics of the ORR, LITR, and OGR that experimenters have found to be important are listed. The results of a survey conducted among experimenters on the utility of the reactors for various types of experiments are discussed, and some changes which might be made to improve the utilization are listed. A brief outline, with references, of most of the experiments currently being performed is given in an Appendix.

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*On loan from U. S. Army Ordnance Corps, Picatinny Arsenal, Dover, N.J.

INTRODUCTION

At the Oak Ridge National Laboratory (ORNL) three general-purpose research reactors are currently being operated, by the Operations Division, on a continuous 24-hours-per-day basis in order to provide irradiation services for experimenters. These reactors are the Oak Ridge Research Reactor (ORR), the Low Intensity Testing Reactor (LITR), and the Oak Ridge Graphite Reactor (OGR). The ORR has been in operation for the past four years, the LITR for eleven years, and the OGR for about nineteen years.

It was felt that, in view of this unique situation, a survey of experiments might reveal the factors that led to the choice of the reactor most favorable for each experiment. It is realized that factors other than purely technical ones may be overriding in the choice of the reactor for some experiments. For example, relocation of expensive built-in equipment may be uneconomical, space in one of the newer reactors may not be available for allocation to a particular experiment, and budget limitations for particular experiments may not permit the use of more costly irradiation facilities. This paper presents the results of a survey of experimenters using the reactors and gives brief descriptions of most of the experiments currently being performed. Information on a few experiments that are no longer being performed is also included. References to publications giving detailed descriptions and the results of the experiments are included where available. It should be pointed out that for many of the experiments now in the ORR, initial exploratory work was performed in the OGR and/or the LITR.

DESCRIPTIONS OF THE REACTORS

Oak Ridge Research Reactor

This reactor uses MTR-type, enriched-uranium fuel elements and beryllium reflector pieces in a 7-element x 9-element rectangular lattice with moderation and cooling provided by forced circulation of demineralized water.[1] The reactor tank is submerged in a water-filled pool having walls and bottom of barytes concrete which serves as a biological shield as well as the pool container. Control-rod drives are operated from below the reactor (Fig. 1). The reactor is housed in a building about 100 ft x 108 ft in area with four floors, including a basement. A reactor balcony 6 ft wide extends around the outside of the pool structure at an elevation roughly midway between the first- and second-floor elevations (Fig. 2).

The main reactor characteristics of importance to experimenters are as follows:

1. Operating power: 30 Mw
2. Thermal-neutron flux: 1.6×10^{14} n/cm^2-sec (average); 5×10^{14} n/cm^2-sec (maximum).
3. Neutron flux distribution: see Ref. 2.
4. Gamma heating: 3-10 watt/gm depending on material and lattice position.
5. Coolant temperature: reactor cooling-water inlet temperature--120°F.
6. Coolant pressures: about 11 psig below core; 36 psig above core (full flow).
7. Operating cycle: 8 weeks, comprising 7 weeks at full power and 1 week of shutdown for maintenance, experiment changes, and refueling.

8. Refueling cycle: about 12 days; within each operating cycle there are three short ($\sim \frac{1}{2}$ day) shutdowns for refueling.
9. Operating time: about 80%.
10. Unscheduled shutdown frequency: average of about four per month.
11. Operating costs: $80,000 per month (includes labor, overhead, materials, fuel fabrication cost; but no U^{235} cost, reprocessing cost, nor depreciation).

The irradiation facilities[3] available at the reactor for the performance of experiments are:

Lattice Positions

These provide the highest neutron fluxes (up to 5×10^{14} n/cm^2-sec) available in the reactor. Access is through flanges in the reactor tank top, but the reactor can be refueled without disturbing experiments (Fig.3). A typical, but not current, allocation of lattice positions and access flanges to experiments is shown in Fig. 4. Lattice positions are identified by a combination of a letter (A through G) and a numeral (1 through 9).

Horizontal Beam Holes

Six beam holes, each 6 in. in diameter, are provided. The beam can be shut off by flooding the 6.4-ft-long collimator section of the hole with water and rotating a 2-ft-thick steel shutter (Fig. 30).

Engineering-Test Facilities

These two large facilities (Fig. 5), located on the north and the south sides of the reactor, each have 19 x 25 in. obround access holes to the side of the lattice and are closed with $5\frac{1}{2}$-ft-diam. shielding plugs. These plugs may be penetrated with several smaller holes for experiments that individually do not require the use of the entire hole. Such penetrations are designated HN-1, HN-2, etc. (for the north facility). The maximum thermal neutron flux in these facilities is about 7×10^{13} n/cm^2-sec.

Poolside Irradiation Facility

In this, the most accessible facility in the reactor (Fig. 5), experiments may be placed on the flat, west side of the reactor tank close to the lattice. The maximum thermal and fast (> 0.4 Mev) neutron fluxes available at this facility are each approximately 4×10^{13} n/cm^2-sec.

Hydraulic-Tube Facility

Four sample tubes are provided for transporting 5/8-in.-OD (3 tubes) and 1 1/8-in.-OD (1 tube) aluminum sample containers (or "rabbits") from a loading station in the pool to lattice position F-8 (Fig.6). Up to two rabbits may be loaded in each tube. Samples may be sealed either in an unperforated rabbit or in smaller containers which are then placed inside a perforated rabbit (Fig. 7). While in the reactor core, the rabbits are continuously cooled by water flowing through the hydraulic tubes. Irradiated rabbits can be unloaded in an adjacent hot cell, if desired. The thermal neutron flux in lattice position F-8 is $1 - 2 \times 10^{14}$ n/cm^2-sec.

Pneumatic Tube Facility

This facility allows small (5/8-in.-OD by 1 1/8-in.-long) sample containers, or "rabbits", of high-density polyethylene plastic (Fig. 7) to be transferred to or from the reactor with a transit time of 2-3 seconds. The sample space within each rabbit is about 1.3 ml. The reactor terminus of the facility is at the reactor end of a small penetration (HN-3) in the north engineering test facility. The maximum thermal neutron flux in HN-3 is 6.5×10^{13} n/cm^2-sec. While under irradiation, the rabbits are cooled by forced air flow. Irradiation time is limited to about 40 min. because of the possibility of rabbit failure due to radiation damage. The rabbit loading station is within a hood in a chemistry laboratory located in the reactor-building basement.

Low-Intensity Testing Reactor

The LITR was the original hydraulic-test mock-up of the MTR. It was converted to a training reactor for the operating staff of the MTR in 1951 and subsequently has been used as a testing reactor.[4]

This reactor (Fig. 8) uses MTR-type, enriched-uranium fuel elements and beryllium-reflector pieces in a 5-element x 9-element lattice with moderation and cooling provided by forced circulation of demineralized water. The reactor tank is surrounded with concrete block shielding. Control-rod drives are mounted on the top of the reactor tank. The reactor is flanked on two sides with two large rooms for housing experiment equipment (Fig. 9). The beam holes open into these rooms. Two higher levels around the tank, called the "midriff" and the "top level", are enclosed for the shelter of experiments and of operating personnel.

The main reactor characteristics of importance for experiments are as follows:

1. Operating power: 3 Mw
2. Thermal-neutron flux: 1.7×10^{13} n/cm^2-sec (average); 5×10^{13} n/cm^2-sec (maximum).
3. Gamma heating: 0.8 - 1.6 watt/gm, depending on material and lattice position.
4. Coolant temperature: water inlet temperature--approximately 95°F.

a. In-pile irradiations at very low temperatures ($\sim$0 to 100°K);
b. Basic solid-state research on semiconductors and other highly radiation-sensitive materials requiring a low and constant rate of defect introduction;
c. Studies where neutron-induced effects are to be distinguished from gamma effects, and, therefore, where very pure fluxes of neutrons relatively free from gammas are required;
d. Fission product radiochemistry (yields and decay characteristics);
e. Studies on radiation effects in material in which annealing during irradiation is to be minimized;
f. Activation analysis of very heat-sensitive biological specimens.

Advantages, Disadvantages and Improvements

As found in this survey of experimenters, the main advantages and disadvantages of the three reactors from the viewpoint of their utility for experiments and some of the possible improvements which might be made are as follows:

ORR Facility Advantages

1. The neutron flux is an order of magnitude greater than at the LITR, and two orders of magnitude above that of the OGR. This permits some experiments to be done which can not be done at all at the other reactors; it also allows some experiments to be performed more rapidly or with results of higher quality.

2. Access to the reactor core is particularly good, by reason of the bottom-mounted control-rod drives. Experiments penetrating the tank are undisturbed by refueling operations.
3. The flexibility afforded by water shielding in the reactor pool during the placement, removal, and disassembly of experiments is a great convenience.
4. The 8-week operating schedule is optimum for the many experiments of a long-term nature that are performed at a high-flux reactor.
5. The large neutron-flux space gradient permits wide control of the irradiating flux by movement of the experiment.

ORR Facility Disadvantages

1. Generally the fabrication and installation costs of an experiment will be higher than for a lower-flux facility. This arises from a variety of causes and is particularly applicable to in-core experiments. High radiation levels increase the amounts of shielding required; high gamma-heating rates require effective and sometimes complex means of heat removal from the samples and the structure of an experiment; offsets or complex bends are required in access tubes to minimize radiation streaming; hydrodynamic forces arising from greater coolant-flow rates require strong and vibration-free access tubes; and the potentially greater amounts of activation or fission products in an experiment require greater structural integrity and usually double containment of the experiment.
2. The 8-week reactor operating cycle may be too long for some experiments. These then have to be designed so that their samples

can be withdrawn from the flux, removed during one of the brief refueling shutdowns that occur within the operating cycle, or completely removed while the reactor is operating. Adopting any of these alternatives generally results in a costlier experiment design.

3. Short shutdowns for experiment convenience are not practical. Quite apart from their undesirable effects on long-term experiments, short shutdowns (<1 hr) can very easily develop into long shutdowns (1-2 days) due to xenon poisoning. The alternative to this long shutdown (namely, an immediate refueling to remove poisoned fuel) could, if done frequently, entail an increase in the operating costs of the reactor because of the larger fuel inventory needed. It is necessary to adhere strictly to the established operating cycle in order to realize maximum reactor operating time. Short shutdown privileges granted to one experiment will, if extended to others, generally result in an unfavorable cycle for all.
4. Neutron-flux space gradients and mutual flux disturbances between experiments tend to be large for the relatively small-volume (~ 100 liter) ORR core. The neutron flux gradient at the poolside facility is quite steep.
5. The large gamma-heating rate (typically 3 - 10 watt/gm) often requires that cooling, additional to that normally provided by convection of the reactor or pool water, has to be provided. In the case of gas-cooled experiments, complex equipment may have to be used to provide this additional cooling.

6. Insufficient space exists in the reactor pool over the top of the reactor tank for the access tubes of the many complex in-core experiments currently installed.
7. Insufficient space exists on the reactor balcony for the installation and maintenance of the out-of-pile components of experiments being performed in the core and at the poolside facility.
8. There are no convenient provisions for making shielded connection between in-pool sections of experiments and those sections housed in shielded cubicles in the building basement. This lack is of concern mainly in those experiments in which large pieces of equipment need to be housed in a shielded cubicle. Due, however, to lack of space on the reactor balcony, other experiments can also be involved.
9. There is insufficient space in the beam-hole area for the equipment and instrument cabinets of experiments being performed at the six beam holes.
10. Acoustic and electrical noise, dirt, mechanical disturbances, and traffic from nearby work (construction, maintenance, welding, and crane operations) adversely affect experiments and delicate apparatus at the beam holes.
11. Thermal disturbances from nearby truck and personnel doors adversely affect electronic equipment at the beam holes.
12. The fast-neutron (epi-thermal) and gamma fluxes at the beam-hole ports are large enough to cause detector background problems and to require massive shielding around experiments. The presence of this shielding further aggravates the space problem.
13. The system for beam-hole flooding by experimenters (provided to

shut off the beam) is awkward.

14. The capacity of the building-exhaust ventilation system is too small to provide the ventilation required for large experiment-equipment cells.

15. The recessed window at the poolside irradiation facility restricts the size of some types of experiments and complicates the design of experiment conduits.

ORR Facility Possible Improvements

Only in a new reactor facility would it be practical to make some of the improvements listed below:

1. Make the pool above the reactor tank wider to relieve congestion in this area.

2. Provide additional pool-wall penetrations at various levels. More of these are needed for taking experiment conduits from the pool out to the balcony.

3. Provide additional floor space in the reactor building, particularly on the reactor balcony and at the beam-hole experiment areas. An additional 20 ft or so of radial space could be used at the beam holes. Additional building space in the basement could be used for shielded facilities to house loop equipment.

4. Provide a number of shielded pipe chases or trenches for running experiment lines and loop connections between basement cells and the reactor pool and balcony.

5. Increase the capacity of the cell-ventilation system.

6. As a reactor building service to experiments, provide a source of reliable electric power for use in experiments during normal-power outages.

7. At the poolside irradiation facility, provide forced-convection cooling for experiments; also reduce the magnitude of the neutron-flux gradient, possibly through use of neutron reflector materials other than light water.
8. In conjunction with 3 above, construct one or more rooms to enclose the beam-hole experiment area completely. These rooms should be sound-proofed and air-conditioned. Hatches would be needed so that shielding blocks close to the beam-hole ports can be moved when necessary. Traffic around the reactor should be external to these rooms.
9. Provide a simpler means for experimenters to flood beam holes when they desire to shut off the beams.
10. To save space at the beam-hole area, use a design in which the reactor and the experiment shields are integrated. It may be possible in this way at some beam holes to eliminate entirely the massive shields presently used.
11. Make provision for multiple use of each neutron beam, possibly by providing additional levels for setting up experiment equipment.
12. Increase the thermal-neutron flux at the beam holes, either by an increase in reactor power or by a fuel distribution favoring those beam holes where the flux is marginal for the experiments. The latter course would be at the expense of the neutron flux in other facilities and usually is impractical for this reason.
13. Reduce the high-frequency electrical interference emanating from arc welders and relay-operated equipment, especially in the neighborhood of the beam holes. To do this it may be necessary

to employ a variety of measures; for example, interference suppressors on relays, separate grounding systems for experiments, screened rooms around sensitive equipment, etc.

14. For thermal-neutron diffraction studies provide some beam holes tangential to the reactor core in order to reduce the unwanted fast-neutron and gamma backgrounds. This should also allow a reduction in beam-hole shielding and the consequent release of valuable floor space.
15. In a new reactor facility, take particular care to secure the as-built dimensions and relative locations of the reactor, pool, and experiment facilities. Without these data, design of experiments is difficult; and field measurements must be made, often in high radiation fields.

LITR Facility Advantages

1. The neutron flux is about the same as in many power reactors; its variation over a refueling cycle is moderately small (~ 2% in average flux).
2. The gamma heating is large enough to serve as a source of heat for achieving elevated in-pile sample temperatures, and yet is small enough that cooling of samples to room temperature, or below, is not difficult.
3. Direct access to the lattice for experiments is available.
4. After irradiation, experiments can be left in the reactor tank to decay prior to removal.
5. The operating cycle is both short (1 week) and flexible, permitting shutdowns at experiment convenience. The small magnitude of xenon poisoning allows this flexibility.

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UC-80 – Reactor Technology

MASTER

THE OAK RIDGE RESEARCH REACTOR – A FUNCTIONAL DESCRIPTION

T. P. Hamrick
J. H. Swanks

OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

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UC-80 – *Reactor Technology*

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OPERATIONS DIVISION

THE OAK RIDGE RESEARCH REACTOR – A FUNCTIONAL DESCRIPTION

T. P. Hamrick
J. H. Swanks

SEPTEMBER 1968

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee
operated by
UNION CARBIDE CORPORATION
for the
U. S. ATOMIC ENERGY COMMISSION

PREFACE

This description of the Oak Ridge Research Reactor (ORR) is intended to serve the twofold purpose of presenting a reasonably comprehensive picture of the system as a basis for other more specialized studies and of providing the necessary background material for the "Safety Analysis." The description presented here reflects the design as it was in January 1967.

This report is basically descriptive in nature and is for the purpose of acquainting the reader with just what the ORR is and how it operates. Except where necessary for clarity, design calculations are not included. The interested reader will find in Appendix E a bibliography of ORR reports that go into more detail on the many aspects of design and operation.

The information contained herein has been compiled from reports of studies performed by the various members of the ORR Project during the days of construction and by Operations Division personnel during the nine years of operation since March 1958. All the persons who contributed are too numerous to list, but special mention is made of F. T. Binford, C. D. Cagle, S. S. Hurt III, and W. H. Tabor for their guidance in the preparation of this report.

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THE OAK RIDGE RESEARCH REACTOR: A FUNCTIONAL DESCRIPTION

T. P. Hamrick **J. H. Swanks**

1. INTRODUCTION

1.1 Historical Background and Motivation

The history of the Oak Ridge Research Reactor (ORR) began in the early part of 1950, when it was determined that a higher-flux reactor facility was required at ORNL in order to successfully carry out the various research programs then being undertaken. The reactor originally selected was a simplified version of the Materials Testing Reactor (MTR) to operate at a power level of 5 Mw, which would require a minimum of design and development. During the initial phase, the proposed design changed considerably as required by the shift in emphasis on the experimental programs. With the operating experience of the MTR and other reactors as a guide and the additional data available in the field of reactor technology, a number of improvements were made in the basic design.

The need for improved facilities for experiments requiring neutron beams, for expanded isotope production, and for an irradiation facility to permit engineering tests of the materials and components of liquid fuel reactors became increasingly important. Construction and operation of the ORR helped meet the requirements for neutron irradiation space of both the basic and applied research programs of the Laboratory and met the expanding requirements for radioisotope production at ORNL.

A preliminary proposal which outlined the basic features of the desired reactor was submitted to the AEC in March 1954. This proposal was approved, and a directive was issued permitting the use of funds to retain an architect-engineer to prepare a reactor design on the basis of 5-Mw operation. A contract, calling for the definitive design of the building, reactor shielding structure, and cooling systems, was executed in July 1954 with the McPherson Company of Greenville, South Carolina. In August 1954, a modification of the AEC directive was issued authorizing the design and procurement of the reactor and controls by ORNL.

In December 1954, a review was made of the status of the ORR Project coupled with a review of the requirements for irradiation space. One result of this review was the decision that sufficient justification existed to warrant an increase from the 5-Mw power level to 20 Mw. This increase in power level was discussed with members of the Advisory Committee on Reactor Safeguards; and in March 1955, the following design modifications were agreed to constitute adequate safeguard measures considering the design of the reactor, the location, and the proposed use:

1. Gas containment was provided to an extent that an accident releasing the volatile fission product gases from the reactor core would not constitute a widespread hazard.
2. Available excess reactivity was to be minimized insofar as was practical.
3. The effects of experiments installed in the engineering test facilities would be limited so that upon failure or malfunction of the installation, no more than 1.4% reactivity could be added to the reactor.

A modification of the original directive was then issued providing additional funds to allow design and installation of equipment necessary for operation at 20 Mw. Construction of the building, reactor shielding structure, and cooling system was performed by Blount Brothers Construction Company of Montgomery, Alabama. This contractor was selected on a competitive lump-sum-bid basis.

Construction was completed in the spring of 1958, and the reactor achieved criticality on March 21, 1958. At the time the ORR was designed, air-cooled heat exchangers were provided to give 20 Mw of cooling capacity. Tests made during the summer of 1958 indicated that the capacity of the coolers was approximately 25% below their specified capacity. This meant that during the summer months the reactor was operated at 15 Mw, with 20-Mw operation possible only during the winter months. In many cases, experiments had been designed for a steady 20-Mw power level and, when power was reduced, could not be operated at the desired temperatures or neutron fluxes.

To provide experiments with a higher neutron flux and to realize more fully the potential capacity of the ORR as a research tool, it was proposed in September 1959 to increase the power level of the reactor by adding evaporative water cooling to provide as much as 30 Mw of heat-removal capacity.

The proposed power increase involved mainly the evaluation and/or establishment of the following: (1) increase in reactor primary coolant flow; (2) operation of the fuel plates at higher temperatures; (3) reduction of the uncertainties in the temperatures of hot spots which limit the power; (4) assurance that increased stress or heating would not damage the reactor tank or other structures; and (5) provision for emergency pumping capacity to cool the fuel in the event of an electrical power failure.

Permission to raise the power to 30 Mw was obtained from AEC, and modifications were completed in the summer of 1960. Since August 5, 1960, the ORR has been operated at a power level of 30 Mw.

1.2 Brief Description of the ORR

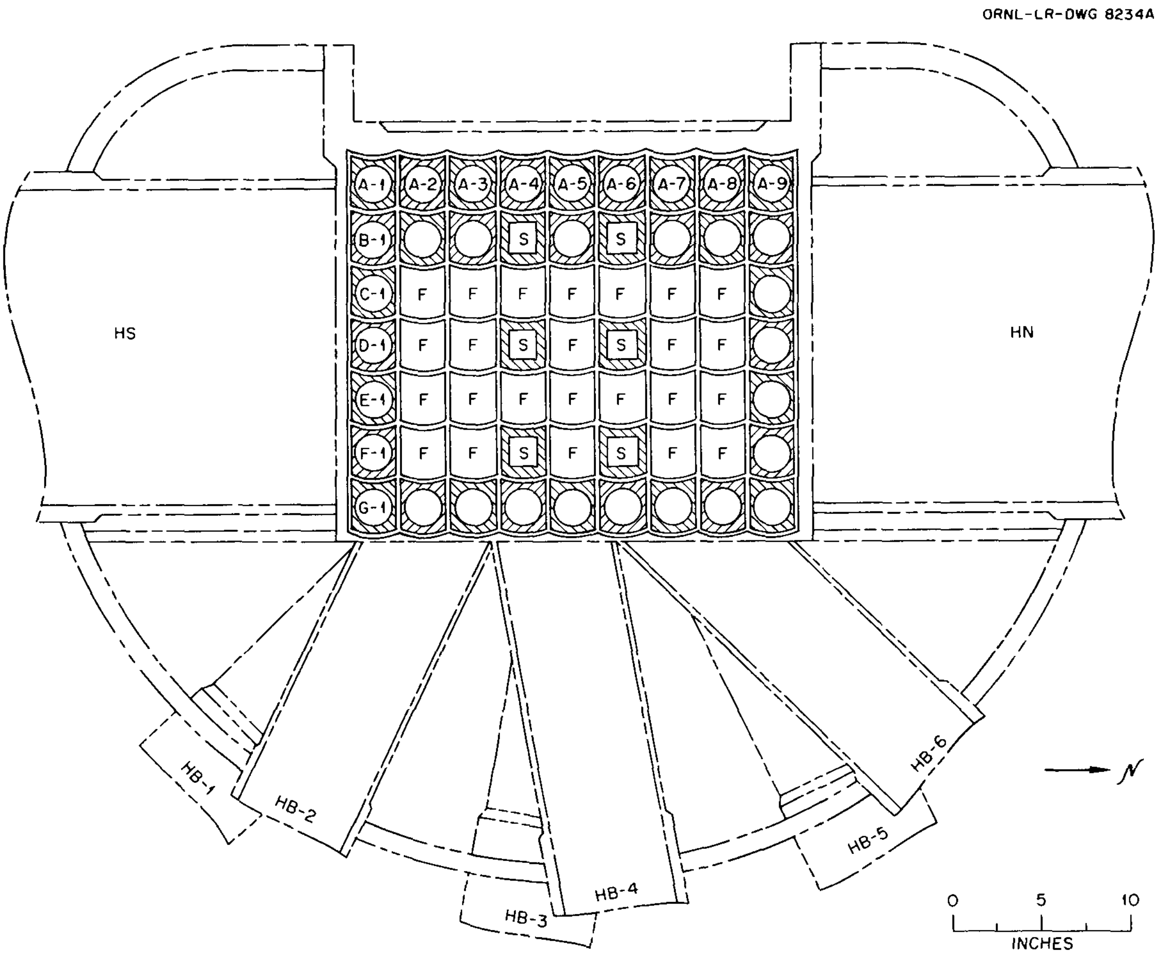
One of the unique features of the ORR is the location of the reactor tank in a pool of water. The water provides the necessary shielding for working above the reactor core and also makes access to the core as convenient as it is in low-power pool-type reactors. The majority of experimenters desire to place their experiment rigs in the very high-flux regions in the core and the reflector (Fig. 1.1); hence, an easy access to the core was stressed during the design. The control-rod drive mechanisms are located below the core, and the upper grid plate which is usually present in this type of reactor was replaced by two small, independent grids (Fig. 1.2). This last feature makes it possible to leave experiments in the core region while the reactor is being refueled.

The reactor core is a heterogeneous type which uses enriched uranium fuel in the form of aluminum-clad aluminum-uranium alloy fuel plates. A fuel element consists of an assembly of 19 fuel plates. Demineralized water serves as the reactor coolant and moderator. The reflector is composed of an arrangement of beryllium elements which are physically interchangeable with each other and with the fuel elements. The thickness of the reflector therefore varies according to the particular fuel and experiment arrangement in the core. About 4 ft of ordinary water surrounds the reflector. Figure 1.3 shows a cutaway view of the reactor core.

A rectangular aluminum box surrounds the core and beryllium reflector, and a grid plate is located below it to provide for the spacing and support of the fuel and beryllium elements. Fuel elements, control rods, experiments, and reflector elements are positioned in a 9 by 7 array by the grid plate (Fig. 1.1).

The reactor is controlled by vertically positioning control rods which are located in the fuel and reflector regions of the reactor core. Facilities for up to 12 control rods are provided, but only 6 of these positions are used. The poison sections of the control rods are approximately as long as the reactor core height and consist of an aluminum-jacketed cadmium sheet formed into a rectangular box. The lower half of the rod consists of a fuel section of the same composition and general type as the fuel elements, except that only 14 fuel plates are included in the assembly. The control rods may be used as combination shim-safety-regulating rods, and the follower sections may be chosen according to the amount of fuel or reflector material desired.

The heat-transfer calculations for the ORR were originally performed considering initial operation of the reactor at 20 Mw and possible future operation at the present power level of 30 Mw. Coolant flow requirements were established as 12,000 gpm for 20-Mw operation and 18,000 gpm for 30-Mw operation. A conservative design criterion was used which assumed the simultaneous occurrence



LATTICE PATTERN: F-FUEL S-SHIM ROD OTHERS-REFLECTORS
EXPERIMENT FACILITES: HN AND HS-LARGE FACILITIES HB-BEAM HOLES

Fig. 1.1. Horizontal Section Through Reactor Center Line.

of the worst possible mechanical, nuclear, hydraulic, and thermal conditions in the same physical location. Data from operating experience of the MTR were used as an aid in establishing criteria and as a basis for comparison of calculations with experimentally observed quantities. Hydraulic tests were performed on fuel elements, control rods, and reflector elements as an integral part of the design effort.

The cooling requirements for power operation of the ORR are provided by two separate cooling systems. One of these, the reactor cooling system, is designed to remove the ~30 Mw of energy produced in the core.

In this system demineralized water as the primary coolant is pumped through the reactor tank at a flow rate of about 18,000 gpm. It passes through the shell side of four heat exchangers, where it transfers its heat to the secondary coolant, which is circulated through the tube side of the heat exchangers. The secondary coolant, treated process water, is circulated through a conventional induced-draft cooling tower, which dissipates the heat to the atmosphere.

Approximately 0.6 Mw of reactor heat is transferred to the reactor pool by conduction from heated surfaces and by absorption of radiation. To dispose of this and up to 0.1 Mw of heat released by used fuel elements stored in the pool, a second cooling system, the pool cooling system, circulates 700 gpm of pool water through the tube side of a heat exchanger. Here the secondary coolant, treated process water, absorbs the heat while circulating through the shell side of the heat

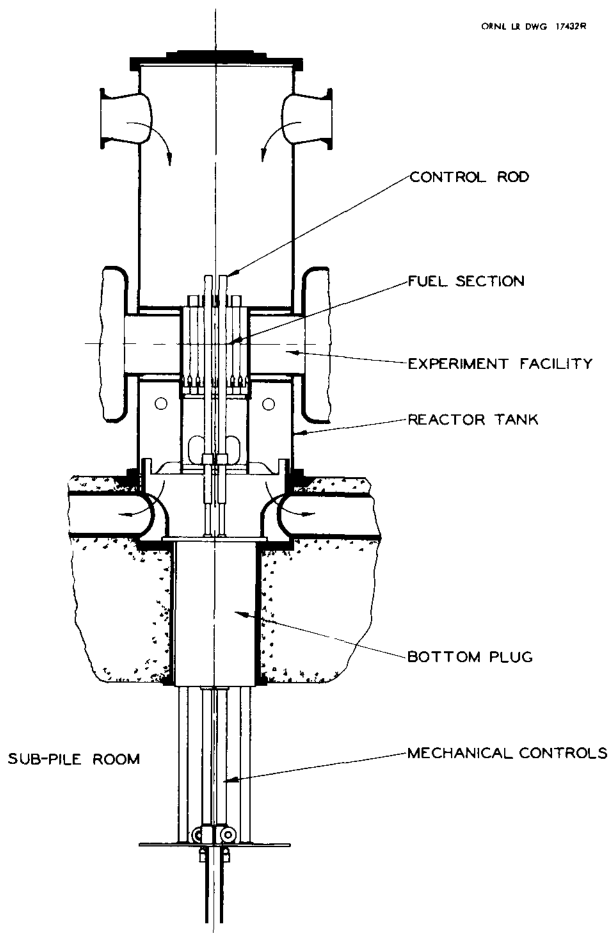


Fig. 1.2. Reactor Vertical Section.

exchanger. This secondary coolant is then circulated through a separate conventional induced-draft cooling tower, which dissipates this heat to the atmosphere.

Because of the heat generated by the fission product inventory in the core, it is necessary to cool the core for a short time following shutdown. Under normal circumstances, this is done by the normal cooling system, but in the event of a failure of power to the main pump motors, adequate coolant flow is maintained by battery-powered dc motors attached to the shafts of the main coolant pumps. Any one of these three small motors can provide a coolant flow sufficient to prevent core damage due to afterheat.

In a reactor cooling system, the radioactivity level, corrosion rate, and deposit formation rate must be closely controlled. At the ORR, these objectives are met by demineralizing the cooling water with multiple-bed ion exchange columns. There are two reactor demineralizer systems, one on stream and the other on standby, regenerated and ready for service. Both can be used simultaneously if conditions warrant it, for example, after a long shutdown, when the water may contain more impurities than during normal operation.

It is essential that the primary water have as few impurities as possible, since it passes through the high-neutron-flux core region, where impurities become highly activated, so some cooling water is continually bypassed through the demineralizers to remove trace impurities. Most of the components in the reactor cooling loop are made of aluminum, although some of the smaller items are stainless steel. Corrosion products, dissolved gases, and fission products which result from surface uranium contamination on the fuel plates constitute most of the impurities found in the primary cooling loop.

The radioactivity in the ORR pool water would also build up to an appreciable level if a method were not provided to remove radioactive ions. The neutron flux in the pool just outside the reactor tank wall is on the order of 10^{13} neutrons cm^{-2} sec^{-1} and produces radioactive ^{24}Na, ^{16}N, and other unstable nuclides; therefore, a bypass demineralizer is used to remove these nuclides from the pool water.

An additional demineralizer unit, consisting of separate anion and cation columns, is used in the reactor primary water system on the effluent from the degasifier. The primary function of this system is to decontaminate any water that expands from the reactor water system into the pool. An additional advantage is extra demineralizer capacity for the reactor water system.

The ORR bypass degasifier is designed to remove entrapped or dissolved gases from the water in the reactor primary cooling system. The air radioactivity in the reactor building was reduced significantly when the degasifier was installed.

In addition to the degasifier the ORR gas-removal system includes several ball-float traps, which are located above, and connected to, parts of the reactor water system where gases naturally collect. These ball-float traps, normally full of water, contain valves which open when gas is collected, thus allowing the gas to bleed into the interconnected off-gas system.

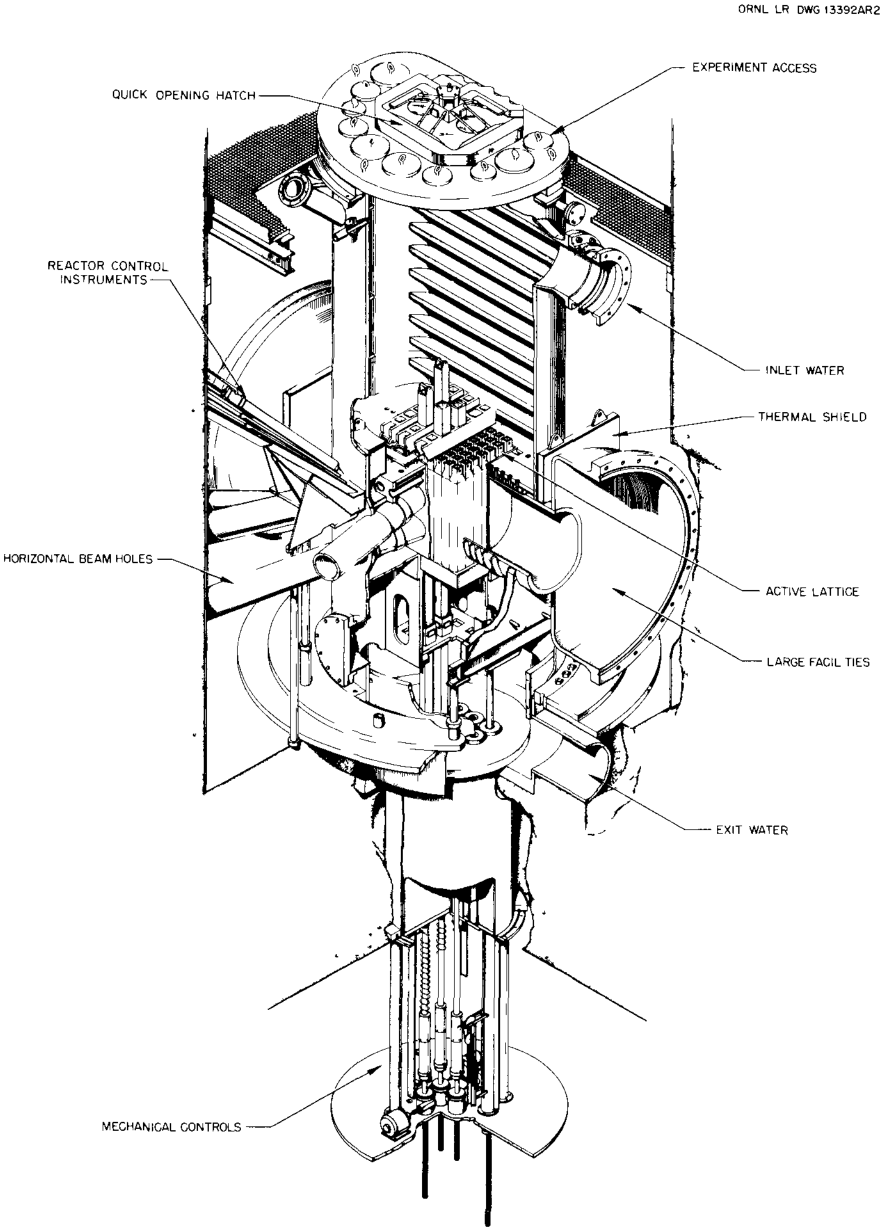


Fig. 1.3. View of the ORR Core and Tank.

A continuous supply of demineralized water is necessary to supply the shim-rod-drive seals and the bottom-plug seal in the subpile room, to service those reactor experiments for which an uninterrupted supply of demineralized water is required, to supply the reactor pools when makeup is needed, and to replace water lost from the primary system through cooling and sealing of various bearings and glands. Flow diagrams of the reactor and pool cooling systems are shown in Fig. 1.4 and 1.5.

The ORR safety and control systems have been designed to provide for safe and orderly operation of the reactor from a central control room. Essentially all routine operations, including startup and shutdown, can be monitored and/or controlled from this location.

The control system is designed to relieve the operator of routine manipulations by enabling the instruments which sense changes in the system parameters also to initiate the required corrective action. This approach is consistent with the philosophy of using the operator to supervise the functions of the control system rather than to include him as an integral part of it. Nevertheless, certain actions are required of the operator. In particular, any increase in reactivity beyond that allotted to the power regulation system will require concurrence of both the operator and the control system. The safety system is designed to seize the initiative from both the operator and the control system and to initiate immediate corrective action should any of the significant operating parameters indicate the onset of an unsafe condition. Because of certain features incorporated in the control system, the safety system is very infrequently called upon; however, it is independent of the control system and capable of very fast response when needed.

The ORR control system and instrumentation were designed and safety limits determined after careful analysis of pertinent reactor parameters such as fuel loadings, shim-rod worth and motion, moderator, coolant, etc. This design resulted in the use of instrumentation similar to that installed in both the LITR and the MTR and, in addition, contains a provision for an automatic start mode.

Process instrumentation monitors reactor coolant flow, reactor coolant differential temperature, and reactor coolant outlet temperature. Signals from these monitoring instruments initiate a power reduction by setback, reverse, or slow scram as dictated by the relative magnitude of the error signals. Reactor coolant temperature control during a reactor power increase is performed automatically by step-function control of the reactor cooling system (Fig. 1.6).

The experiments in the reactor are provided with reactor power-reduction circuits, if required. These circuits are capable of initiating a setback, reverse, or slow scram if a particular experiment parameter should exceed preset control limits.

As previously pointed out, one of the main objectives of the ORR operation is to continuously maintain the reactor at full power level as long as this is consistent with safety requirements such as the available coolant flow. To accomplish this, heat power has been chosen as the basic control parameter, although it is used indirectly. The instruments which measure flow and temperature difference are quite accurate but are characterized by an inconveniently long response time – several seconds. Even though an exceptionally fast response time is not intrinsically required of the control system, it is desirable that it be able to initiate corrective action sufficiently rapidly so that fast safety action will be only rarely necessary. The required speed of response is obtained by using the accurate, but delayed, heat-power information to continually calibrate neutron-flux measuring devices by adjusting them to agree with the heat-power information. Block diagrams of the ORR control system are shown in Fig. 1.7 and 1.8.

The shielding was designed to satisfy the permissible radiation dose limitations to individuals established by the National Bureau of Standards for a steady operating power of 30 Mw. In unlimited access areas, the shield design is such as to limit the maximum dose rate to 0.75 millirem/hr. This intensity includes the combined effects of all radiations, and, based upon a 40-hr week and a 50-week year, it represents 30% of the annual permissible dose of 5 rems recommended by the NBS handbooks as an acceptable amount for workers handling radioactive materials. In limited access areas, sustained exposure is unlikely and can be administratively controlled, so higher radiation levels are permitted there. This fact makes possible some economy in shield design.

Adequate shielding is provided not only for the reactor itself but for portions of the primary coolant loop and for the primary and pool coolant cleanup systems as well. Shielding is also provided where necessary for the various components of the off-gas and ventilation systems. The demineralizers, filters, degasifier, and other equipment are also located in individually shielded cells or cubicles. Shielding provided for the cells is supplemented in some cases with direct lead shielding on the equipment.

The ORR employs the concept of dynamic containment to prevent the escape of radioactive gases to the atmosphere. The ORR building is not sealed airtight to retain radioactive gases that might be released. Instead, it is maintained as a partially leak-tight structure. The cell ventilation system maintains the containment by the controlled exhaust of air from the building at a rate sufficient to ensure that there is always an inflow of air at leakage points. The cell ventilation system is not a start-on-demand system, but rather it operates continuously, so that the building is always under a slight vacuum.

Table 2.16. Community Water Systems in Tennessee Downstream from ORNL, Supplied by Intakes on the Clinch and Tennessee Rivers or Tributaries[a]

Community	Population	Intake Source Stream	Approximate Location	Remarks
ORGDP (K-25 area)	2,678[b]	Clinch River	CR mile 14	Industrial plant water system
Harriman	5,931[c]	Emory River	ER mile 12	Mouth of Emory River is at CR mile 4.4
Kingston Steam Plant (TVA)	500[d]	Clinch River	CR mile 4.4	
Kingston	2,000[d]	Tennessee River	TR mile 570	River used for supplementary supply
Watts Bar Dam (Resort village and TVA steam plant)	1,000[d]	Tennessee River	TR mile 530	
Dayton	3,500[c]	Richland Creek	RC mile 3	Opposite TR mile 505
Cleveland	16,196[c]	Hiwassee River	HR mile 15	Mouth of Hiwassee River is at TR mile 500
Soddy	2,000[d]	Tennessee River	TR mile 488	
Chattanooga	130,009[c]	Tennessee River	TR mile 465	Metropolitan area served by City Water Company
South Pittsburg	4,130[c]	Tennessee River	TR mile 435	
Total	168,061			

[a] *EGCR Hazards Summary Report*, ORO-586, Oct. 10, 1962.

[b] Based on May 1963 data.

[c] 1960 Report of U. S. Bureau of the Census.

[d] Based on published 1957 estimates.

3. BUILDINGS

3.1 Introduction

The ORR facility is composed primarily of three buildings: the reactor building, the reactor primary-water pumphouse, and the reactor secondary-water pumphouse and cooling tower. In addition to these, several small structures housing ancillary components are located throughout the area. They consist of structures such as the pool secondary pumphouse and cooling tower, the pressurizable off-gas (POG) filter pit, the cell-ventilation filter pit, the heat-exchanger pit, and the primary-coolant bypass-valve pit.

3.2 Reactor Building

The reactor building is a mill-type semiairtight steel-framed structure covered with insulated metal panels. The building covers an area 111 ft 8 in. long by 102 ft 10 in. wide. The floor level of the full basement is 20 ft below the first-floor level. The height of the 60-ft-wide center high-bay area is 64 ft 2 in. from the first-floor level to the bottom of the roof trusses. The second floor is actually at street level on the west end of the building and extends the full width and length of the first floor. It is 12 ft 6 in. above the first floor. The third floor is the top level in the low-bay areas, extending the full length of the building, 25 ft 6 in. above the first floor. It is not a solid construction covering the entire area of the building, but rather it is similar to a balcony running along the north and south sides and the west end of the reactor building. The building is windowless to eliminate glare on the pool surface and to aid in making the building more airtight under emergency conditions. Figure 3.1 shows a partial cutaway perspective view of the structure.

The interior finish of the building is similar to that used in light manufacturing construction.

Roof beams and steel framing are exposed but painted. Utility conduit and pipe runs are exposed. Basement walls are painted only around the reactor substructure, and there only for better light reflection characteristics. Floor finishes are hardened concrete, integrally color coded for safe floor loading identification. The third-floor office and control-room wing has a refined construction finish only to the extent that the floors have asphalt tile. Air conditioning in this area ensures proper operation of the reactor control equipment. Toilet areas have quarry tile floors and painted masonry walls.

3.2.1 Basement

The basement floor space includes facilities for pool cooling, experiment cooling, and miscellaneous pumping operations, pool- and reactor-water demineralizer units, pool fill and drain pumps, electric-power distribution center, auxiliary ventilating fans and air filter banks, subpile room, plug storage facility, and experimental work and storage areas (see Fig. 3.2).

The water-system components are located underneath the storage pools to take advantage of the overhead shielding provided by the pool water. Shielding walls around the "hot" pumping equipment are of stacked barytes block with labyrinth doors where flexibility is necessary for removing or repairing pumps and of poured reinforced concrete where permanent walls are required. The basement sump (which is provided with a collection tank and a sump pump) is located in the water-system area. All basement drain lines lead into the sump collection tank. Since gravity drain from the basement to the plant process system is impractical, the sump pump discharge is directed into the first-floor drainage system.

The subpile room and adjacent pipe chase were designed on the basis of structural characteristics, which were required to support the reactor structure, and the wall thickness required to provide sufficient biological shielding. Due to the latter requirement, barytes concrete walls were used for the pipe chase to provide shielding from the radiation from the reactor exit cooling-water line. Since about 6 ft of barytes aggregate covering was required where the 24-in. cooling-water lines passed under the basement floor out from under the pools, the bottom of the pipe chase was located at an elevation 8 ft 6 in. below the basement floor. The subpile room footings could have been stepped up above the pipe chase footings to prevent excavating some rock; but, due to the sloping shelf rock formation prevailing in the area, this was deemed inadvisable. The 13 ft 6 in. by 10 ft subpile room has an 8 ft 6 in. basement which is necessary to allow removal of the control-rod drives from the reactor.

The subpile room houses the mounting plate for all the reactor control mechanisms. Certain utilities provided for use in experiments are described elsewhere. The pipe chase contains most of the cooling-system line interconnections and serves as a convenient location for cooling-system instrumentation. The lowest points of all cooling-system lines are in the pipe chase, and draining of all the lines for maintenance is performed at this point. The north wall of the pipe chase, through which the cooling-water lines pass, is constructed of stacked barytes concrete block above the first-floor level. A 4-ft-square manhole filled with stacked barytes concrete block is provided in the solid wall on the opposite side for pipe chase access. A removable instrumentation plug is located near the manhole.

Cylindrical cavities are provided in the basement wall for storing 32 plugs used in the reactor beam holes and for 6 somewhat larger plugs used in the large-facility beam holes during some stages of reactor and experiment operation. Each plug storage cavity has a connection to the normal off-gas suction line.

A water-collection tank is located in a pit at the west wall at the low point of the off-gas system. Condensate in the off-gas system drains into the tank and is discharged into the intermediate-level waste (ILW) line underneath the basement floor. The tank must be drained periodically by closing the valve in the line to the off-gas header, opening the line to the ILW system, and introducing compressed air reduced to 5 psig. A valve in the line from the off-gas header to the plug storage spaces is also located in this drain pit.

All basement construction is reinforced concrete except for the 12-in. concrete-block walls around the building-ventilation fan room and stairwells and the stacked-block concrete shielding walls around reactor components and experimental apparatus. The floor is designed for a live load of 1000 psf. Special service installations include a safety shower and two utility sinks.

3.2.2 First Floor

The entire floor area is free for research work except for the space occupied by the reactor structure, instrument shop, stairwells, elevator, and floor hatch for access to the basement. See Fig. 3.3 for a plan view of the first-floor area. The floor is of ordinary reinforced concrete construction and has a flat slab design except for framed openings. The slab thicknesses, live design load, and color codes are described in Table 3.1.

The reactor structure covers an area 18 ft wide by 55 ft long west of the reactor center line and a semicircle about 32 ft in diameter to the east. This structure is described elsewhere. Directly in front of each of the two large-facility openings in the reactor structure is an 8- by 10-ft hatch to the basement in a depression in the floor slab 17 ft 2 in. long, 11 ft wide, and 2 ft deep. The purpose of this design was to allow a cell of stacked-block construction to be built around an experimental rig at the large-facility location on the first floor and to make it possible to lower this rig by remote control into a second shielded cell in the basement for dismantling or for storage during radiation decay. Concrete plugs fitting flush with the depressed slab surface are provided for the hatch openings.

Numerous sleeves are provided through the first floor for connecting instrumentation, experimental apparatus, and utilities connections with the basement. Four-inch-diameter sleeves on about 9-ft centers are located around all the walls. Six 12-in. sleeves are located about 15 ft from the face of the reactor structure, 2 ft off each beam-hole center line. Four additional 12-in. sleeves are located near column line 2 in the beam-hole experimental area for general purpose use. Four 6-in. sleeves are located in the depressed floor slab at each large-facility installation and two additional ones convenient to the area around the floor depressions. Seven 6-in. sleeves and eight 12-in. sleeves are spaced at the base of the storage pools.

The 4-in. sleeves along the walls around the building project 3 in. above the floor level. All other sleeves are fitted with sealed covers that fit flush with the floor.

A 10 ft by 16 ft 6 in. hatch with a hinged steel cover provides access to the basement with the bridge crane. This hatch cover normally remains closed for fire-retarding purposes. There is a

Table 3.1. Floor Loading Specifications – First Floor

Area[a]	Thickness (in.)	Design Load	Color Code
2 bays A-B × 1-3	7	200 psf uniform or a 5-ton concentrated load on 6 ft^2 in any bay	Terra cotta
$\frac{1}{2}$ bay A-B × 3-4	7		
4 bays A-C × 4-6	7		
2 bays B-D × 1-2	7		
1 bay C-D × 5-6	7		
3 bays B-E × 2-3	54	Floor designed for 3500 psf uniform load, beams designed for $\frac{1}{3}$ this value	Brown
1 bay D-C × 1-2	11		
2 bays C-E × 4-5	54		
1 bay D-E × 5-6	11		
3 bays E-F × 2-5	11	10-ton concentrated load on 10 ft^2 adjacent to beam holes plus a 20-ton rolling load	Red
5 bays F-G × 1-6	11	20-ton[b] rolling load	Gray
1 bay E-F × 1-2	11		
1 bay E-F × 5-1	11		

[a] See Fig. 3.3.

[b] The 20-ton design rolling load is based on a 5-ft-long row of steel wheels carrying 16 tons and 4 tons concentrated on one steel wheel 7 ft from the main axle. This is an approximate description of the beam-hole-plug shield.

truck door in the east wall, 10 ft wide by 16 ft high, to allow entry of equipment that is to be used in the beam-hole experimental area.

A 4-in. curb all around the first-floor area is intended to prevent area contamination in case of a leak in the reactor structure or a water release from any other cause. There is a 4-in. ramp at all first-floor doors. This curb will direct water flow to the basement, except in the case of a catastrophic pool leakage.

Personnel doors are located in each side of the east wall of the building, the personnel doors that are approximately in the middle of the north and south walls are intended as emergency escapes and are not used for normal pedestrian traffic.

Special service installations include two service sinks with cold water only, two safety showers, and a drinking fountain.

3.2.3 Second Floor

The second-floor level coincides with the ground level on the west side of the building. The floor space is occupied by offices, men's and women's toilet facilities, a janitor's closet, and a truck-loading area to accommodate equipment to be placed in the storage pools. See Fig. 3.4 for a floor plan. The floor is a reinforced ordinary concrete slab on steel framing with the slab thicknesses, live design load, and color coding shown in Table 3.2.

The janitor's service closet contains a service sink with hot and cold water, a hot water heater for the toilets, and space for cleaning equipment, floor polishers, etc.

Four-inch sleeves through the floor for service connections to the first floor have been provided along the west wall, similar to those on the first floor.

Walls around the toilet area are designed to be permanent and are of 8-in. concrete-block construction. Walls around the second-floor offices are of the removable metal partition type, as some degree of flexibility of area enclosure is desirable in this region.

Personnel entrance doors are provided in each side of the west wall. Steps up to the balcony walkway around the reactor structure are located on each side of the pool. The only special service installation on the second floor is one safety shower.

3.2.4 Third Floor

On the third floor are the reactor control room and four offices on one side of the high-bay area, laboratory working space on the other side of the high-bay area, a hot cell which is constructed at the west end of the reactor structure, and a walkway all around the reactor structure (see Fig. 3.5). A steel walkway extends from the control-room wing of the third floor to the third-floor-level walkway around the reactor structure. Adjacent to this walkway are steel stairs down to the balcony walkway around the reactor structure. Although these walkways make for awkward maneuvering of the pendant-controlled crane, this inconvenience is not serious and does not warrant providing removable stair and walkway connections.

Table 3.2. Floor Loading Specifications – Second Floor

Area[a]	Thickness (in.)	Design Load	Color Code
1 bay A-B × 1-2	4	75 psf	Tan
2 bays A-B × 2-4	$7\frac{1}{2}$	200 psf or a 5-ton concentrated load on 6 ft^2	Terra cotta
2 bays A-C × 4-5	$8\frac{1}{2}$	25-ton highway truck or a 10-ton concentrated load on 10 ft^2	Maroon
2 bays A-C × 5-6	$4\frac{1}{2}$	75 psf	Tan[b]

[a] See Fig. 3.4.

[b] The toilet areas have a quarry tile floor.

Table 3.3. Floor Loading Specifications – Third Floor

Area[a]	Thickness (in.)	Design Load	Color Code
6 bays A-G × 1-2	7	150 psf uniform load or a 3-ton concentrated load on 6 ft^2 in any bay	Tile red
3 bays A-D × 5-6	4	75 psf uniform load	No color code[b]
3 bays D-G × 5-6	4	150 psf uniform load	No color code[b]
1 bay A-B × 2-3	$7\frac{1}{2}$	160-ton uniform load or 5-ton concentrated load on 10 ft^2 in any bay	Terra cotta

[a] See Fig 3 5.

[b] These bays have an asphalt tile floor covering.

Furthermore, the location and size of the reactor structure itself make special treatment of the crane control pendant necessary.

All of the third floor is of reinforced ordinary concrete construction on steel framing, with slab thicknesses, live design load, and color coding as shown in Table 3.3.

Since no concept of the specific nature of the work to be done in the laboratories in the building was available at the time of its design, no conventional laboratory equipment or furniture was initially installed. However, building utilities headers are provided in the rooms and have tees in the lines where connections may be made to them.

The laboratory area is divided into individual rooms by removable-type insulated metal partitions, which can be rearranged to suit work-space requirements, if necessary. This same type of removable panel is used to partition the four offices and the control room. Insulated panels were chosen because the control room, the offices, and the laboratories are air conditioned. The front of the control room contains plate-glass sections in the wall to enable the reactor operator to have a full view of the reactor structure and to provide a visitors' observation area. The glass panels have a 5° slope to eliminate glare from the building lights.

The area at the west end of the reactor structure, where the hot cell is located, is designed to support 3-ft-thick barytes concrete shielding walls around the cell. The inside dimensions of the cells are 3 ft 6 in. wide by 7 ft long by 7 ft high.

Four-inch pipe sleeves similar to those on the first floor are located in the floor along the outside wall of the laboratory wing and the hot cell area. Floor slots of varying widths with steel cover plates are provided through the floor along the back wall of the control room and next to the adjacent offices. In addition to the conduit sleeves in the control-room floor required for initial installations, additional sleeves have been provided through the control-room floor where possible future control expansion is envisioned. These extra sleeves have plugs flush with the concrete floor and are covered by the asphalt tile.

Special service installations include an emergency shower in the hot-cell area, two drinking fountains, and a service sink. Outside stairs for emergency exit are located at the east end of both the laboratory and control-room wings. The crane access ladder terminates on the third floor.

3 3 Auxiliary Buildings

3.3.1 Primary-Coolant Pumphouse

The primary-coolant pumphouse is a concrete-block structure located approximately 300 ft northeast of the reactor building. The overall size of the building is 68 ft by 42 ft. It is divided into five pump cells and an electrical

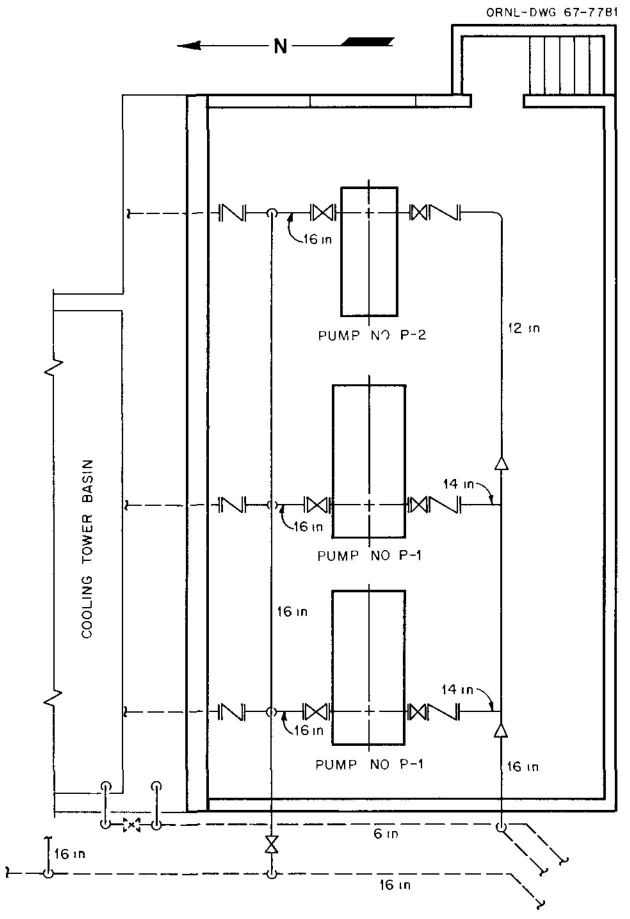


Fig. 3.8. Schematic View of Secondary Pump House.

4. CONTAINMENT, VENTILATION, AND AIR CONDITIONING

4.1 Introduction

The ORR containment, ventilation, and air-conditioning systems have been designed to minimize the dissemination of contamination and radioactive gases into the area surrounding the reactor building in the event of an accidental release of radioactive materials. There are three separate systems which are used for the decontamination and disposal of potentially radioactive gases. The cell-ventilation system provides dynamic containment for the building and provides a method for the decontamination and subsequent controlled release of large quantities of potentially radioactive gases. Two separate off-gas systems are used to handle routine low-volume disposal of gaseous wastes from experimental facilities and reactor system components. The two systems are the pressurizable off-gas system (POG) and the normal off-gas system (NOG). Although the off-gas systems are not specifically a part of the building containment system, they are somewhat related and are described in this section to aid in the overall understanding of the air-handling systems. The control room, certain offices, and other normally clean areas are served by an air-conditioning system which is separate from the building's ventilation system.

Additional ventilation of the reactor bay and experimental areas is provided by two roof fans, each of which exhausts building air at the rate of 7000 cfm. These automatically controlled fans also aid in maintaining the negative pressure in the building during normal conditions.

Ventilation of the basement area is provided by a centrifugal blower, which exhausts basement air through a louvered opening located in the northeast corner of the basement.

The cell-ventilation system provides a flow of air through areas of the main ORR building in which potential sources of radioactive gases exist. These areas include the reactor-bay area, the basement area, the Loop 2 decontamination cell and equipment room, the pipe chase, the hot cells over the reactor pool, the B-9 experiment cubicle in the basement, and other areas. The air from these areas is drawn through ducts into a filtering system and discharged into the atmosphere from the 250-ft-high 3039 stack.

The off-gas systems are designed to handle routine high-concentration radioactive gaseous releases and are connected directly to the components which are capable of releasing these effluents. The pressurizable off-gas system is connected to components which may become pressurized, whereas the normal off-gas system collects gaseous wastes only from components which are not subject to becoming pressurized.

4.2 Containment

The ORR employs the concept of dynamic containment to prevent the escape of radioactive gases to the atmosphere.[1] The ORR building is not sealed airtight to retain radioactive gases that might be released. Instead, it is maintained as a partially leak-tight structure. The cell-ventilation system maintains the containment by the controlled exhaust of air from the building at a rate sufficient to ensure that there is always an inflow of air at leakage points. The cell-ventilation system is not a start-on-demand system, but rather it operates continuously, so that the building is always under a slight vacuum.

When the building ventilation is placed in the emergency containment mode, all air entering the building enters by leakage paths. Heating and ventilating units, exhaust fans, and air-cooling equipment are shut down, and their related louvers are automatically closed. At the same time, the roof fans and the basement exhaust fans are shut off, and their louvers are closed so that all air leaves the building through the ducts of the cell-ventilation system. The air exhausted from the building is decontaminated by a filtration system and discharged into the atmosphere at a height sufficient to ensure atmospheric dispersion.

The building ventilation can be placed in the containment mode either manually or automatically through the use of three separate sets of controls. Within the first set of controls, designated as containment controls, manual actuation is initiated by a push button located in the control room. Automatic containment will occur when a high radiation level exists either in the building or in the cell-ventilation duct, as detected by the containment radiation monitors. A detector located just outside of the control room initiates containment if a level of 75 mr/hr exists. A detector on the cell-ventilation duct at the filter pit also initiates containment if a level of 7.5 mr/hr is detected. The two radiation detectors transmit signals to two electrometers located in the control room, and containment is initiated when set points on the electrometers are exceeded. The ventilation duct electrometer is a fail-safe unit in that containment is also initiated when the instrument fails.

Building containment can also be effected by the facility radiation and contamination alarm system (Sect. 8.7). This system will automatically actuate the building evacuation system if two monitrons or two continuous air monitors in the coincidence circuit alarm simultaneously at the high-level trip (23 mr/hr and 4000 counts/min respectively). Also, containment can be actuated by any one of three "manual" evacuation buttons (two in the control room and one outside a west personnel door).

The third method of automatically establishing building containment is provided by the fire-alarm system. If a fire alarm occurs in the building, containment is initiated by a relay in the building's master fire-alarm box.

In order to restore normal operating conditions, all of the building heating and ventilating controls must be manually reset. The truck doors can be opened with the building under containment and without the reset action; however, when this is done, an operator stands by the doors to close them if an emergency demands such action.

To assure that the personnel in the ORR control room and offices on the third level, north, have an independent air supply when the building is in containment, the air-conditioning unit serving these rooms does not exchange air from the building high-bay area with the office and control-room area. Instead, the unit exchanges air from the outside. The rooms are maintained at a pressure greater than that existing in the high-bay area.

Pressure conditions within the building are continuously indicated by four manometers located in various parts of the building and by flow indicators which monitor the exhaust flow in the cell-ventilation duct. A reduction of the duct flow below 2500 cfm results in a reactor power reduction to 300 kw.

4.3 General Ventilation and Air-Conditioning Systems

Ventilation and air conditioning of the ORR building are accomplished with several package-type air conditioners positioned in appropriate locations in the building. Chilled water is supplied to the various air-conditioning units by a single large unit which has a capacity of 2.15×10^6 Btu/hr (180 tons). Heat collected at the chiller is dissipated by a small cooling tower, which is used for that system only. Low-pressure steam (25 psi) for the air-conditioning units is obtained

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[1] F. T. Binford and T. H. J. Burnett, *A Method for the Disposal of Volatile Fission Products from an Accident in the ORR*, ORNL-2086 (Aug. 2, 1956).

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PROPOSAL FOR A RESEARCH AND ISOTOPE REACTOR AT ORNL

By
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August 17, 1950

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Oak Ridge, Tennessee

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PROPOSAL FOR A RESEARCH AND ISOTOPE REACTOR AT ORNL

The research and production program of Oak Ridge National Laboratory depends primarily upon the intense neutron fluxes available in the X-10 chain reactor. Since the original X-10 graphite reactor was built, those activities of ORNL which require neutrons have increased tremendously. These activities lie in the fields of isotope production, basic and applied physics, chemistry and biology, and reactor development. It is not surprising, therefore, that the Laboratory finds the present graphite reactor inadequate. In order to remedy this inadequacy, the Oak Ridge National Laboratory proposes that a general purpose Research and Isotope Reactor (RIR) be built at the X-10 site.

The RIR reactor would be a simplified version of the Arco MTR. It would require 3 Kg of U^{235}, would run at 3 megawatts, and would have a maximum slow neutron flux of between 2 and 4 x 10^{13} neutrons/cm^2/sec. Because of its lower power output, the auxiliary facilities of the RIR would be much less expensive than those of the MTR; the whole cost of the RIR project is estimated at less than $3,000,000.

Basic justification for an RIR in Oak Ridge at a time when the MTR is being built at Arco rests on the following grounds:

1.) The X-10 reactor is now being used to capacity both for isotopes and for research. If the research and production program at ORNL is to grow normally, an additional research reactor at Oak Ridge is a necessity.

2.) The location of the MTR at Arco, while offering the advantage of higher flux, makes the MTR difficult and inflexible to use. This disadvantage of the Arco location was recognized at the time the decision to build there was made. Thus the existence of very high flux at Arco, while extremely important, does not satisfy the need for moderately high flux right at the National Laboratories.

3.) The Arco MTR is a reactor for use in reactor development. There are many non reactor development researches at ORNL for which a more general facility not tied to reactor development would be very useful.

5.) The radioisotope program, which is one of the most successful enterprises in the Commission, cannot continue to meet growing demands unless more neutrons are devoted to it. Some of these neutrons can be found at other places; it is believed fundamentally sound, however, from the standpoint of operating economy, to maintain centralization of radioisotope production at Oak Ridge.

The following proposal for an RIR at Oak Ridge consists of four parts. Part I is a summary of the research utilization of the X-10 reactor, and a description of research projects which would be made possible by existence of an RIR. Part II is a summary of the radioisotope program at ORNL, and the increase in production which an RIR would make possible. Part III is a brief engineering description of the RIR, and Part IV is a cost estimate of the RIR project.

I. The Research Need for New Reactor Facilities at Oak Ridge National Laboratory

1. Present use of experimental facilities provided by Uranium-Graphite Reactor

The existing ORNL reactor was designed primarily for purposes other than experimentation with neutrons. Consequently, access to the neutron flux is in many cases very inconvenient. In spite of these limitations, the available pile facilities are being actively used to their maximum capacity. In many cases considerable expense and effort have gone into bringing into active use port holes which were considered in the past to be unsuitable for experimental purposes, by making construction alterations such as balcony extensions and shifting obstructing structural beams to less objectional locations. Experimental equipment has in general, been designed so that neighboring projects could proceed simultaneously in close quarters.

The reactor holes are currently being used as follows:

Use	No. of Holes
Pile Control	23
Isotope Production	15
Fundamental and Applied Physics and Chemistry	13
Biology	3
Solid State Studies	10
Pile Physics	2
Training Program	1
Shielding Studies	1
Miscellaneous	1
	69

To list the hole uses more specifically would require three pages of typescript; therefore, we content ourselves with the above summary, together with the assertion that all available holes are in active use.

2. Present Demand for Additional Pile Facilities; Waiting List of Experiments

At the present time there is a great general need for additional pile facilities. It is the opinion of the laboratory that if more holes were available they would very quickly be used for new and useful projects. In fact, there are on hand now the following specific requests for space, which cannot be satisfied at this time.

	Number of Holes	Proposed Use
	2	Homogeneous Pile Studies by Chemistry Division
	4	Radiation Damage
	1	Study of Possible Pile Coolants
	2	Neutron Diffraction
	1	Mechanical Velocity Selector
	2	School of Reactor Technology
	1	Crystal Velocity Selector
Total	13	

The possibility that some experiments could use common holes has always been borne in mind, and to some extent duplication of this kind has been useful; for example, the hole occupied by the fast pneumatic tube is serving also for activation experiments in the laboratory course of the

School of Reactor Technology. Arrangements of this kind are awkward at best, and for the most part have been found to be essentially impossible. Other examples of experiments in which it would be extremely inconvenient to use portable equipment are as follows:

(1) Long-term corrosion studies involving pipes through the pile, with exterior plumbing.

(2) Experiments in which the apparatus can be removed only with an attendant radiation hazard, special handling equipment, and a long pile shutdown. Examples are the "doughnut holes" used in radiation damage work, the uranium parts of which are extremely radioactive.

(3) Experiments which involve extreme accuracy in lining up of heavy equipment in relation to narrow neutron beams. The neutron diffraction equipment is a leading example.

This list might be extended to cover the separate experiments in detail, but these citations may suffice to illustrate the fact that almost none of the experiments are interchangeable on a week-to-week, or even a month-to-month basis.

We are left with the conclusion that the space in the old uranium-graphite reactor is no longer adequate for the current experimental demands.

(3) The Role of the New Reactor; Need for Higher Fast and Thermal Flux

The new reactor proposed herein would do far more than alleviate the shortage of experimental reactor facilities at ORNL. Designed from the beginning as an experimental, as well as isotope producing reactor, it would provide features such as the following, which are at present badly missed:

(1) Higher thermal flux

(2) Much higher fast flux

(3) Vertical experimental holes

(4) Experimental holes larger than 4" x 4"

(5) More intense neutron beams, as a result of both the higher flux and the shorter distance from outside of shield to reactor core.

The new possibilities which would be presented would recast the whole picture of experimentation now in progress in the Oak Ridge community. The following changes exemplify the strengthening of the research program which would result:

1 Radiation Damage Program: Nearly all of this would move from the old reactor to the new reactor, because of the higher fast flux. Specific experiments would be the following:

(1) "Reciprocity Law" studies: In radiation damage studies thus far the effects of fast neutrons have been considered as a function of n.v.t. One has, however, always been aware of the fact that many effects actually are proportional to the flux n.v. rather than the dosage n.v.t. This applies equally well to effects which reach saturation as to the influence on rate processes such as creep, diffusion, corrosion, chemical reaction. A high-flux reactor will not only give the important convenience of reaching a certain dosage in a shorter time, but it will extend the range of flux available for meaningful experimentation into a region where effects are at present unknown. These regions have

special significance both for the design of power reactors and for a fundamental understanding of the elementary processes of radiation damage.

(2) Creep in structural materials, metals and non-metals: Present facilities including those at Hanford and Chalk River, offer fast neutron fluxes far below those of future power reactors. This fact requires at present large extrapolation from experimental data and extreme accuracy of measurements and control of temperature, load, flux, etc., very difficult to achieve in the special circumstances obtaining inside narrow test or process tubes. A high-flux reactor with larger test holes will be ideally suited for this most important type of experiment. Its availability right at the site where several groups

are actively engaged in the study of creep under irradiation would very greatly expedite progress.

Because of large variations in the behavior of different samples of the same material, it has been proposed to study creep by measuring the creep rate of one individual specimen alternately outside and inside the reactor. Such a method will be much easier to apply in a reactor devoted predominantly or exclusively to research rather than to production, and at a location where an especially equipped "hot" laboratory is available such as will be at ORNL after January 1. (3 holes required)

(3) Thermal and electrical conductivity changes in materials in which such changes at presently available fluxes are comparatively slight (beryllium metal, oxide and others) will become much more accurately measurable, within reasonable time, in a high flux, and again the effect of

the magnitude of the flux itself will become measurable. (1 hole for Argonne group, 1 hole for Metallurgy Division, 1 hole for NEPA)

(4) Measurements of the energy stored on fast neutron and fission products bombardment, particularly in metals, will be greatly facilitated, if not actually made possible for the first time, by the availability of a high flux. (1 hole, probably containing pneumatic tube at low temperature)

(5) The effect of radiation on diffusion rates, the study of which is being initiated, and on corrosion resistance could be measured in much shorter time with a higher flux. (1 hole required)

(6) Extreme conditions of radiation damage could be investigated both at very low and very high temperatures. The "healing" during, and as a direct effect of, irradiations should be studied as a function of flux as well as of temperature in a much wider range than is possible now. For such studies, the Solid State Physics and Metallurgy groups could permanently use to great advantage at least one, and probably two large test holes maintained continuously at low, subnormal temperature, e.g. of liquid nitrogen. At present, even water-cooled holes have been available to these groups only for small fractions of the time. For instance, during the last two months, vertical hole #12, the only one suitable, was available for studies at dry ice temperature only for one hour every two weeks. All of the groups studying various phases of radiation damage at controlled temperatures would be greatly assisted in their work if more irradiation

facilities were made available at Oak Ridge. (2 holes at low temperature, 1 hole at high temperature)

(7) The study of single metal crystals, fundamental to an understanding of elementary processes in irradiation, requires very careful handling of specimens, and would actually become possible in high-flux reactor attached to a research laboratory. Internal friction measurements on single crystals, both during and after irradiation, already started here, should be extended into the region of larger fluxes. (1 hole required)

(8) Neutron diffraction as a tool to study radiation effects in solids will be useful only with higher flux than available. The possibility of determining the location of the lighter atoms in mixtures, alloys or compounds containing also heavier atoms, the ability of neutrons to penetrate large thicknesses of material, and the easier selection of neutrons from background radiation when very active specimens are under examination, are factors of considerable importance in weighing the advantages of high-flux neutron diffraction against x-ray diffraction in radiation damage studies. (1 hole required)

II <u>Reactor Development</u>

1. The problem of bubbling, solution stability and corrosion in a homogeneous reactor. This is still one of the most important problems in reactor technology, since from the standpoint of economics, homogeneous power breeders which have low reprocessing costs still appear to be very attractive. (1 vertical hole required)

2. Measurements of constants of fissionable materials in the low resonance region. A slow flux of 3 x 10^{13} neutrons per cm^2 per sec. will make it possible to use a neutron crystal velocity selector up to about 100 electron volts energy. Measurements of the total cross-section to fission cross-section in this range should become feasible. (1 hole required)
3. Measurement of fission product poisoning in thermal reactors. (1 hole required)

III <u>Neutron Beam Experiments</u>

1. Neutron diffraction. The resolution of the diffraction patterns would be improved. At present the beams must be kept wide for reasons of intensity; consequently the resolution is far poorer than that obtained in x-ray patterns. (3 holes required)
2. Extension of range of crystal spectrometers to higher energy. Highly collimated beams of neutrons in the few hundred volt energy range, which would be available at 3 x 10^{13} flux, would make practicable the studies of cross-sections of non-fissile as well as fissile nuclei in this important energy region.
3. Mechanical velocity selector. This apparatus, at present under construction, would benefit doubly (a) because the higher thermal flux will give better resolution by making possible longer paths of flight, (b) because the larger number of neutrons in the resonance energy region will compensate in part for the decreasing efficiency of the detector. (1 hole required)

4. Neutron radioactivity. The beta-proton angular correlation in neutron decay yields an ideally clean experiment for study of the recoil effect resulting from neutrino emission. Intensity considerations prohibit such an experiment at present. (1 hole required)

5. Capture gamma rays. The rapid development of the scintillation spectrometer opens the possibility of using it to measure capture gamma ray spectra. Such an instrument would be useful in energy regions below about 2 Mev, in which pair spectrometers (such as the Chalk River instrument) are useless. (1 hole required)

IV Induced Radioactivity. All radiochemical studies would, of course, be stepped up as regards intensity, but new fields would also be brought within reach. Examples are:

1. Isotopes made by second order capture.
2. Production of intense photoneutron sources.

Relationship with the MTR

The MTR offers the advantage of higher flux than the proposed RIR; it suffers the disadvantage of remoteness. It is, therefore, natural to expect that only those experiments will be sent to the MTR which require the very highest flux, and which do not require the day to day backing of a completely equipped national laboratory. In this category fall all those experiments which involve long term irradiation -- such as the current Chalk River fuel assembly exposure -- and which do not require continuous monitoring.

The foregoing list of experiments for the RIR left out long term irradiations which could better be done in the MTR. The emphasis instead has been placed upon

(a) experiments in which readings are frequently, if not continuously, taken;

(b) experiments for which the apparatus is in a state of development, requiring occasional modification;

(c) experiments requiring rather short exposures, perhaps repeatedly.

A fourth class:

(d) "quickie" experiments, impossible to foresee, for which the MTR can be hardly used at all has been omitted.

II. RADIOISOTOPE PROGRAM AT ORNL

I. Introduction

The following constitutes an attempt to analyze the current status of the ORNL Radioisotope Program and to estimate both the future demand and the adequacy of available facilities for meeting this demand. The major result of this analysis is that additional high flux irradiation volume is needed even to fulfill present requirements adequately.

II. Current Status

The reputation of ORNL as the main supply of radioactive isotopes in the country (if not in the world) is now sufficiently established as to require no further emphasis here. The Laboratory has equipped itself for efficient production, chemical processing, and shipment of the isotopes; it is, furthermore, practiced in the associated keeping of books and of technical records, and it is familiar with the various Health Physics regulations which have to be observed.

The following two tables summarize the accomplishments of the isotope production program as of June 30, 1950, in a self-explanatory manner:

Radioisotope	No. of Shipments
Iodine 131	4,240
Phosphorus 32	3,396
Carbon 14	487
Sodium 24	599
Sulphur 35	252
Calcium 45	171
Potassium 42	196
Gold 198	217
Iron 55, 59	159
Cobalt 60	169
Strontium 89, 90	100
Others	1,995
	11,981

Field of Utilization		No. of Shipments	Percent of Total
Medical Therapy		3,983	44.7
Animal Physiology		2,391	26.8
Physics		668	7.5
Chemistry		618	6.9
Plant Physiology		435	4.9
Industrial Research		326	3.7
Bacteriology		173	1.9
Others		318	3.6
	Total	8,912	100.0

Total number of different research projects to which isotopes have been supplied: 1100.

III. Predicted Demand

Having assembled the machinery for the isotope distribution program as described in the last paragraph, we consider it our responsibility to look ahead to see that we keep in a position to meet future demands.

The best that can be done in predicting future demand is to make a linear extrapolation of previous isotope production history. The distribution is shown in tabular form below. In general, it is anticipated that the January, 1950, production will be doubled within the next two years with an extremely large increase in cobalt 60 sales.

Date	I^{131} (mc)	P^{32} (mc)	C^{14} (mc)	Sr^{90} (c)	Other Fission Products (Actual)(mc)	Miscl. (mc)	Unprocessed Units	Co^{60} (c)
9-46	298	380	8	Negligible	100	50	15	--
9-47	2,107	2,256	61		351	85	38	--
5-48	4,500	3,500	70		700	30	60	--
7-49	*29,800	4,600	300		745	520	100	10
1-50	25,000	9,600	200		*170	820	140	0.5
				(Extrapolated)				
1-51	35,000	15,000	400	200	1,000	1,500	250	1,250
1-52	42,000	25,000	600	200	2,000	2,500	350	1,750
1-53	50,000	35,000	750	200	3,000	4,000	500	2,250
1-54	60,000	42,000	900	250	4,000	5,000	600	2,750
1-55	70,000	50,000	1,000	300	5,000	6,000	700	3,000

* Larger than May, 1948, basis by a factor of 1.75 because of a change in method of analysis.

The linear extrapolation attempted in the second half of the above table is, of course, at best, a guess. It is, nevertheless, true that as of today there is no indication that the demand for isotopes will level off for several years at least. We can see the following sources of increasing demands:

(1) Growth of radioactive research in universities, hospitals and other institutions.

(2) Growth in industrial uses (e.g., beta-ray thickness gauges).

(4) Substitution of strong gamma emitters (e.g., Co^{60}, Ta^{182}) for hard x-rays and radium in medicine and industry.

(5) Possible price reductions resulting from per millicurie economies which are to be expected as production increases.

(6) Availability of new isotopes, such as rare fission products, resulting from the use of higher neutron fluxes.

IV. Present Limitations in Relation to Future Demands

1. Space limitations

The stringers used for irradiation units (small isotope samples) are at present used to about 75% capacity. With some consolidation, demands can be filled for one to two years in the future.

The space required for isotopes produced by (n p) reactions is large, because bulky parent samples have to be used. There are two very important products which fall into this class: (a) P^{32}. At present made in the required high specific activity by (n p) reaction on sulphur. Two large holes now are devoted to this use, and no others are available without cutting into the research use of the pile. Production at present is approximately equal to demand. (b) C^{14}. At present made by loading 400 peripheral fuel channels with calcium nitrate. Production in X-10 reactor is below demand. Relief is being sought by Hanford irradiation of beryllium nitride.

Cobalt 60 production has adequate space for the estimated increased demands for at least the next two years.

Fission products (including I^{131}, our most vital single product) have essentially no limitations, so long as one is content to use the uranium metal rather inefficiently by irradiation in rather low flux.

2. Reactivity Limitations

At present there are 145 excess inhours in the X-10 reactor. If all of this were to be devoted to isotope production, the latter would rise to 167% of its present rate. A further increase of 25 inhours can be expected when the calcium nitrate is completely discharged and Hanford assumes all of the C^{14} production. This would increase the production capacity to 180% of the present rate. Any further increase will require loading of more uranium metal, to the extent of a few tons. If the canned metal can be made available, there would seem to be no pressing reactivity limitation on the isotope production in the graphite reactor.

3. Specific Activity Limitations

Slow neutron produced isotopes are limited in specific activity by the available slow flux. The maximum available slow flux (10^{12}) in the X-10 pile is even now insufficient to meet many current specific activity measurements. How badly we are outclassed by Chalk River is a matter of common knowledge.

Numerous requests are being received for higher specific activities than are available at ORNL. These can in principle be met in some cases (e.g., Ca^{45}, Fe^{59}, Co^{60}, $Hg^{203,205}$, Te^{204}) by making use of (n,p) reactions; in practice this device has limitations so serious as to make it essentially unusable.

The limitations arise from the circumstance that (n p) reactions require fast neutrons (exception: C^{14}) and have low cross sections; the yields in the (thermal) graphite pile are accordingly so low that large amounts of parent element must be used. This wastes pile space and pile reactivity. A second obstacle arises from the expensive "hot" chemical separation, which has to follow the irradiation.

Another class of isotopes, exemplified by Cl^{36}, Fe^{55}, Zn^{61}, Na^{24}, and K^{42} cannot be made by (n,p) reactions either because no appropriate $Z + 1$ parent isotope exists, or becuase the half-life is too short to permit the chemical separation. For these there is no choice but to use the $(n\gamma)$ reactions.

The above considerations lead to the conclusion that the best way to produce isotopes with acceptably high specific activity is to employ the $(n\gamma)$ reaction in a reactor which furnishes sufficiently high thermal flux.

The following table outlines the actual specific activities in current demand, and the conditions under which they could be attained in a reactor such as the RIR.

Radioisotope	Half-Life	Required Specific Activity, mc/Gram	Time Required if at Maximum Flux (3×10^{13}) 3-MW Pile
Na^{24}	14.8 h	7,500	43 hours
*Cl^{36}	4.4×10^5 y	2.5	4.2 years
K^{42}	12.4 h	500	17 hours
Fe^{55}	~ 4 y	5	1 month
Zn^{65}	250 d	1,500	1.5 years
Ca^{45}	180 d	10	0.6 month
Fe^{59}	46.3 d	5	1.3 month
Co^{60}	5.3 y	10,000	5.2 months
Hg^{203}	43.5 d	100	87 hours
Tl^{204}	2.7 y	1,000	1.0 year

* Arco can furnish this specific activity by a 7.3-month irradiation, but it is expected that this specific activity will be requested only rarely.

The need for high specific activity Co^{60} will be acute soon. It is expected that teletherapy units for medical research will require one to two thousand curies per month at a specific activity of ten curies per gram.

Chalk River is the only existing reactor which can produce this specific activity.

V. Summary of Current Isotope Production Situation

The present X-10 reactor will be at its production limit with respect to available irradiation space by the time a new RIR can be put into operation. It is now at its limit for P^{32} production, and it has been found inadequate to fulfill demands for C^{14}. It is far below modern requirements with respect to specific activity induced by $(n\ \gamma)$ reactions.

VI. Relief Afforded by RIR

The comparative fluxes in the present X-10 reactor and the proposed 3 MW RIR are as follows:

	X-10 Reactor	3 MW RIR	Ratio $\frac{RIR}{X-10}$
Thermal Flux	$5 \times 10^{11*}$n/cm /sec	$2 \times 10^{13\dagger}$	40
Fast Flux ($>$1 Mev)	$2 \times 10^{11**}$	$2 \times 10^{13\dagger\dagger}$	100

* Average flux position

** In hole inside uranium slug

† In beryllium reflector, assuming a realistic flux depression resulting from presence of absorbers.

†† In shim rod, presumed to contain the material under irradiation. Corresponding figure in the beryllium is about 3×10^{12}.

The improvement to be expected in specific activities is obvious; the thermal flux would be sufficient to abandon most thoughts of (n p) production in favor of more efficient (n γ) production. The space available for production is described in Section III of this paper; we shall state here that it would be sufficient to meet production requirements for as far ahead as we can see.

III. DESIGN CONSIDERATIONS

In submitting a proposal for a new experimental pile for research and isotope production it might be well to review briefly the general considerations involved in such a design. Inasmuch as it is imperative in an experimental pile to approach the maximum neutron flux per watt, materials suitable for the active lattice are decidedly limited in number. Highly enriched uranium appears to be the proper fissionable material. Fast piles appear to suffer from inflexibility without any compensating advantages even in fast neutron flux. It has been pointed out by Wigner that a thermal pile, moderated entirely or partially by light hydrogen, is a good source of 1 Mev as well as thermal neutrons. Experimental pile designs, using both light and, light plus heavy water, moderators, have been extensively considered by this laboratory. The design using both light and heavy water has been revived recently at ANL and forms the basis for a new experimental pile for that laboratory. Inasmuch as it is desirable that experimental piles exist in some variety, we have no sensible alternative to the choice of an experimental pile moderated entirely by light water. The design of such a pile has already been worked out in detail for the MTR and much effort and engineering cost may be saved by adopting that design insofar as it is applicable. This is particularly desirable in view of the heavy commitments of the laboratory to other parts of the reactor program. These commitments would make it extremely difficult to undertake the design of an entirely different type of experimental pile.

We propose the construction of a Research and Isotope-producing Reactor (RIR) to be operated at about 3 megawatts. At this power level the RIR will deliver a maximum thermal flux of about 2 to 3 x 10^{13} and a virgin fission neutron flux of about 1.5 x 10^{13}. It was assumed in the design of the MTR that any flux of 10^{13} or more should be exploited to as great an extent as possible. This condition required a complicated pattern of experimental holes which penetrated a large graphite block surrounding the active lattice and its beryllium reflector. When the MTR power is reduced by a factor of 10, this graphite block becomes essentially useless since the maximum flux in the graphite is then reduced well below 10^{13}. A further saving may be made in the quantity of beryllium reflector since the bulk of this material simply served as a neutron transmitter to the graphite block. On this basis the adaption of the MTR design involves some very considerable simplifications.

Fig. 1 is a horizontal cross section of the proposed RIR showing the active lattice, reflector, shield, and major experimental holes. Twelve experimental holes suitable for either beam or bombardment operations penetrate through a thick layer of water to the outside of a beryllium reflector 7-1/2 cm thick. It has been shown in critical experiments leading to the MTR design that 7-1/2 cm of beryllium plus 15 cm or more of water is almost as efficient a reflector as an infinitely thick layer of beryllium. We thus eliminate the bulk of the beryllium in the MTR at a saving of about half a million dollars. This may be accomplished without any sizeable increase in the critical mass of the active lattice.

Fig. 2 shows a vertical cross section of the pile. It will be noted that this section is nearly identical with the MTR except that the graphite block previously mentioned has been replaced by a thick layer of ordinary water. The discharge water from the pile flows upward through this region and cools a layer of iron thermal shielding. The arrangement in the drawing is adequate to form the basis for an estimate, but further study and some mock-up experimentation is planned to determine the optimum arrangement. Nine feet of ordinary concrete is provided for biological shielding. A column of water about twenty feet high and directly above the active lattice serves as a transparent shield for the manipulation of active samples while the pile is shut down.

Aside from the change in thermal shielding and the elimination of most of the beryllium, the design is identical with the MTR. It will be noted that the section also shows two of twelve experimental holes which penetrate to the surface of the beryllium but are inclined at an angle of 36° with the horizontal. One of these smaller holes is directly above each of the horizontal holes. Suitable balconies for the use of inclined holes will be built if and when the need arises. It is felt that 6 more holes about 4 inches in diameter will be needed for control instruments. They will be incorporated into the design after further study; smaller holes for special purposes will also be installed to about the same extent as the MTR. These additional holes have not been shown in the blueprints but were included in the cost estimate.

The fuel loading problem of a pile of the RIR power will be very much simpler than in the MTR because it will not be necessary to change the active assemblies more than once or twice a year. However, the isotope program will require frequent removal of highly activated samples, and for this purpose an outlet chute and a small canal have been included. It will be noted in Fig. 2 that the first 20 feet of this canal will have a width of only 2 feet and in Fig. 3 it will be seen that this portion of the canal slopes at a 45° angle so that a sample discharged from the active lattice slides down this inclined portion of the canal and reaches the bottom at a point considerably beyond the outside of the shield. At this point the canal widens to six feet and continues 15 feet beyond the wall of the building where shielded samples may be removed and loaded into trucks.

The controls of the proposed RIR may be simplified as compared to those in the MTR for several reasons: (1) Heat transfer at the active lattice is no longer a critical point of design and the instrumentation on the water system may be greatly simplified. (2) The total number of shim rods will be reduced from 8 to 4 and a very considerable part of the MTR control system may therefore be decreased by a factor of 2. (3) A servo mechanism for control does not appear to be strictly necessary. (4) In addition, since the active lattice will remain in the pile for long periods of time and therefore provide a very large source of neutrons even after a shut-down of considerable duration, some of the complicated interlocks intended to prevent start-up accidents in the MTR may be eliminated. The nuclear instrumentation will remain essentially unchanged but the simplifications mentioned should reduce the cost of the control system at least as much as indicated in the estimate. Three to six holes of special design for differential ion chambers may be necessary. The design of these holes must be worked out with the aid of mock-up experiments and cannot be indicated at this time.

Figs. 1 and 2 show the active lattice surrounded by the minimum amount of beryllium required to attain a loading of approximately two kg of U^{235}. It will be noticed that the experimental holes in Fig. 1 lead to the beryllium reflector and not directly to the active lattice. This arrangement will not be practical for all purposes inasmuch as the fission neutrons will suffer considerable moderation before reaching the experimental hole and the flux of neutrons of energies above a million volts will consequently decrease very markedly. Where it is desirable for the purposes of a particular experiment to have a high fast flux, the arrangement may be changed slightly and an active assembly exchanged with a piece of beryllium in front of the experimental hole in question. It is anticipated that the pile will be started up with the arrangement shown inasmuch as this makes it unnecessary to insert reflecting material into the experimental hole when the hole is not in use. Additional beryllium will be necessary both for the manufacture of isotopes and to increase the available flux in the experimental holes somewhat above that obtainable with the arrangement shown. An additional mass of beryllium equal to that shown in the drawings should be amply sufficient for these purposes at the present time and has been covered by the estimate. The detailed design of this beryllium arrangement will again require mock-up experiments and we have consequently not attempted to show the arrangements in these preliminary drawings. As the needs of the isotope program increase, additional beryllium may be added from time to time. If the demands from the isotope program warrant it, the complete block of beryllium (five feet in diameter as used in the MTR) may be installed. A block of this size will allow the exploitation of all neutrons at a flux of 10^{13} or more. Thus the desirability of utilizing fluxes above 10^{13} sets the diameter of 'D'of the tank and those above it at five feet as in the MTR. In any case, an appreciable reduction in this diameter would hinder underwater manipulation of active material. The reduction of power by a factor of 10 does not affect the height of the water column in tanks A, B and C to any great extent. Similarly the water passages in the MTR fuel assemblies contain about the optimum volume of water for moderation. It appears then that it is not only expedient to copy the MTR design for the fuel assemblies and tanks A, B, C and D and their contents, but that a reduction of MTR power by a factor of ten does not change the important dimensions enough to make a re-design desirable. These considerations lead us to a design which will permit a very large rate of flow of cooling water. If future developments make it desirable, the power may be increased to the maximum level consistent with the safety of the Oak Ridge area without any changes in the pile itself.

Space for Isotope Production

As implied in the last paragraph, materials for activation will be placed in the beryllium and will be loaded and unloaded from above. All of the flexibility of the MTR design is available for the purpose; that is, beryllium blocks can be removed from one place or another and replaced by isotope-bearing units, and the possibility of ultimate expansion to the limits of the tank will provide ample space for future needs.

Pile Coolant System

The design of the cooling system is similar in principle to the MTR cooling in that heat and gas removal are effected by a vacuum flash cooler. Heat is removed from the reactor by circulating 2000 gpm of demineralized water in a closed circuit of stainless steel. This heat is extracted from the pile coolant in the flash cooler condenser by 2000 gpm of filtered water which is circulated over an open cooling tower. The design capacity of the system is 3300 kw under severe summer conditions and with a temperature rise of 11.3°F in both circuits. There is sufficient capacity in the system to permit 5000 kw operation with no changes other than an increase in the temperature rise. Demineralized water will be piped to the system from an existing facility.

Housing for the water system is provided by a 20 ft. x 30 ft. x 50 ft. high addition to the reactor building. Part of the construction will be similar to that of the main building and the remainder will be concrete with walls 12 to 15 inches thick for shielding against radiation emitted by the process water. Space is provided in the structure for the service panels for the main building and for the blowers for the pile air system.

The cooling tower will be located at grade level adjacent to the process water building.

Air System

The air system for this reactor performs a limited function. Because none of the reactor is air cooled the air system is required only as a means of disposing of active gases produced in the beam holes and non-condensibles removed from pile coolant in the flash coolers. This is to be accomplished using two blowers, each capable of delivering 3500 cfm with a negative suction pressure of 10 to 15 inches of water, and necessary ducts. Gases will be filtered by filters simila to those used in the air system of the ORNL graphite pile and exhausted to the atmosphere thru one of the existing stacks. The blowers and filters will be located in the process water building.

Retention Basin

A simple retention basin is required to provide 24 to 48 hour holdup of the radioactive effluent from the reactor and emergency hold up of the entire volume of the coolant system. A 120,000 gal. basin formed by earthen dikes and divided into two sections is considered adequate to fulfill the requirements. Water leaving the basin will be monitored continuously and discharged thru the existing retention basin to White Oak Creek.

Location

The RIR will be housed in a 75' x 75' square building made of metal siding and will contain the essential services and utilities. One or two offices for the use of direct supervision will be required, but no laboratories are contemplated.

The building is to be located just east of the present Pile Building and on the location of the present 101 Shops. The Shops are scheduled to be removed under Plan 'H'. This location was chosen for the following reasons:

1. Demineralized water for pile cooling can be obtained from the 807 Demineralization Building which is located about 150 feet north of the proposed reactor site. No increase in the capacity of the demineralizers will be necessary.

2. The small amount of exhaust gas and cooling air from the reactor can be led to the 900 Area stack which is just south of the proposed site. Actually, the small amount of air to be handled in the RIR could probably be discharged into the ORNL graphite reactor exit air duct to be discharged through the Filter Building and 115 Stack without materially reducing the air flow through the ORNL reactor.

3. The location of the RIR in an established section of the Laboratory will eliminate the need for extensive additions to utility distribution systems. Fire water, process and potable water, steam, process and sanitary sewers, hot drains, and electrical distribution lines are already available for convenient tie-ins. No additional Security personnel would be required. Also, the unit would be convenient for maintenance work.

4. Since the operation of the RIR will be the responsibility of the Operations Division, a considerable saving in manpower could be realized if the two reactors were close together. A technical shift supervisor could be assigned to both reactors and the present day shift supervisor of the ORNL reactor could probably handle both reactors with the aid of possibly one more technical man. No more than two more operators on each shift and two more operators on straight days, added to the present Pile Depatment crews, would be required to operate both reactors and to handle peak load jobs such as shutdowns, provided the shutdowns were scheduled at different times for the two piles. The number of people required to operate the unit would not be increased appreciably if at some time a very large increase in power level were made.

Time Estimate

Approximately fifteen months would be required for the construction of the proposed reactor.

IV COST ESTIMATE

An estimate of the cost of the project has been made using current information on the costs of parts for the MTR and current construction costs at ORNL as the basis.

The estimate is divided into five sections. The first includes the reactor building, the building and pile foundations, the canal and all services. This part of the estimate was made by the Plant Engineering Division. It was revised upward to conform to differences between their estimates and bids on current construction of a similar nature and to take into account a 15 percent increase in construction costs expected during the next few months.

Reactor and controls are considered in the second section. Costs are based upon current procurement costs for the MTR and current construction data at ORNL corrected for expected price increases.

The water system, air system and retention basin are estimated in the remaining sections. Equipment costs for those items were obtained from manufacturers during the month of August and reflect price increases expected during the next few months. Construction costs were based upon ORNL construction data.

In addition to the direct cost, 50 percent of the direct cost has been added to cover contingencies, engineering, construction fees and overhead. Because much of the engineering has been done in designing the MTR and a minimum of special construction facilities will be required, about half of the added cost is available to meet contingencies.

Summary

Reactor Building, Foundations, Canal and Services	467,600
Reactor and Controls	1,053,400
Coolant System and Housing	266,400
Air System and Housing	42,500
Retention Basin and Effluent Control	35,000
TOTAL	1,864,900
Indirect Costs, Design and Contractor Fees and Contingencies 50%	932,500
TOTAL	2,797,400

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PROBLEMS ENCOUNTERED DURING FOUR YEARS OF ORR OPERATION

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R. A. Costner, Jr.

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ABSTRACT

The over-all design and operation is reviewed in the light of four years of operating experience. Items discussed consist of the reactor components and instrumentation, reactor and pool cooling systems (including system cleanup), the emergency systems for electric power and reactor cooling, the waste-disposal systems (liquid, gaseous, and solid), and the building, itself.

No effort is made to describe the features of the ORR which make it the useful research tool that it is.

The ORR was the first of a class of reactors which combined the features of both the pool-reactor and tank-reactor types. Four years of operation have indicated areas where problems of various degrees have developed. These are discussed to enable reactor operators who are operating or anticipate operating reactors similar to the ORR to avoid some of these problems.

INTRODUCTION

The Oak Ridge Research Reactor[1] (ORR) is highly enriched, light-water moderated and cooled, and beryllium-reflected. It is enclosed in a tank which is submerged in a pool of light water. Design emphasized accessibility to the core region by placing the reactor control drives below the reactor and using water as a primary shield in order to provide quick and easy access to in-reactor experiments.

The core arrangement, a 7 x 9 rectangular configuration using 63 spaces, contains fuel elements, control or shim rods (for the ORR, these words are synonymous), beryllium-reflector pieces, and experiment core pieces. The ORR uses four fuel-cadmium shim rods and two beryllium-cadmium auxiliary shim rods for control. A normal fuel loading uses 25 fuel elements, with the remaining core positions occupied with beryllium-reflector pieces, special beryllium pieces adapted for experiment usage, and isotope production units. The core is housed near the bottom of an aluminum reactor vessel which is about 15 ft in over-all height and approximately 5 ft in diameter.

The reactor vessel is located near the end of one of the three pools of demineralized water; each pool is approximately 20 ft long and 10 ft wide. These pools are identified as reactor, center, and west. The reactor pool is about 29 ft deep, while the other two pools are about 26 ft deep. The pools may be made into a common pool by removing the gates which separate them.

Located above the end of the west pool is a hot cell which is arranged to permit the transfer of samples and experiments from the pool into the hot cells through doors in the bottom of the cell. The hot cell is divided into two sections, each of which has walls of dense concrete 3.5-ft thick designed to shield 10^6 curies of Co^{60} or the equivalent so that the radiation level outside the cell will be less than 5 mr/hr. This hot cell is intended for preliminary inspection of experiments and samples.

The ORR offers a variety of experiment facilities. These include six horizontal beam holes (6.5-in. diameter); two large test facilities, approximately 25 x 19 in., located on the north and south sides of the core; a flat poolside face which permits access to the core from the pool on the west side; and a variable number of in-reactor positions which may be used for experiments.

The ORR was completed early in 1958, and cost about $4.7 million. Criticality was attained on March 21, 1958; 20-Mw power operation was begun on April 29, 1958; and 30-Mw power operation was achieved on July 29, 1960. The reactor is illustrated in Figures 1 and 2.

Operating costs of the ORR increased ~27% with the increase in power from 20 to 30 Mw. This is attributed to extra fuel costs, a more comprehensive preventive maintenance program, and additional tests and development work related to basic studies for high-power operation. Table 1 indicates typical annual operating costs, contrasting 20- and 30-Mw operation.

An analysis of administrative procedures on ORNL research reactors is presented in detail elsewhere.[2]

Personnel requirements for the ORR operation are met by utilizing a manpower "pool" which supplies two other reactors, the Oak Ridge Graphite Reactor and the Low-Intensity Testing Reactor. Many of the people are shared efficiently among the reactors, although each reactor is directly supervised by its own reactor supervisor. Two supporting departments of the Operations Division, the Technical Assistance and Technical Development Departments, assist the Reactor Operations Department with the three operating reactors; an organization chart is given in Figure 3. Supporting help for engineering and maintenance and special services is supplied by other divisions at the Laboratory, and it is unnecessary for the Operations Division to expand its organization to obtain such services.

ROUTINE OPERATION

The ORR began a routine, power-operating cycle of 20 Mw on July 20, 1958. It consisted of three weeks of operating at power followed by a one-week shutdown for experiment insertions and/or removals, refueling, isotope removals and/or insertions, and miscellaneous routine maintenance work. During early cycles of operation, the three-week operating cycle was interrupted frequently because of component malfunctions. Occasionally, as a result of such interruptions, refueling was required due to xenon poisoning.

The ORR was operated at 20 Mw during the cool season from about October to April of each year. During the remaining months, the reactor power was limited to 16 Mw due to inadequate heat-removal capacity. This inadequacy was in the water-to-air coolers which never performed at their rated capacity.

The experiment program at the Laboratory was being retarded by the lower operating level; and it was decided, after thorough technical investigations, to take the necessary steps to obtain 30-Mw operation. A detailed study resulted in the installation of shell-tube heat exchangers, using a spray tower in a secondary cooling loop for heat removal. This major modification was completed during the July 9-29, 1960, shutdown.

Operation at 30 Mw was begun on July 29, 1960. Concurrent with this higher power level, the operating cycle was altered to cover eight weeks--seven weeks of operation and one week of shutdown devoted to experiment insertions and/or removals and miscellaneous routine maintenance. Upon adopting the longer operating cycle and higher power level, it was necessary to interrupt the operating phase periodically for refueling and for isotope removals and insertions. Refuelings are necessary at a maximum of about every 18 days, with a specified date designated after four weeks of operation for isotope removals and insertions. Figure 4 indicates the percentage of operating time during each quarter of operation.

The scheduling of shutdown activities is a combined effort of staff members of Operations, Engineering and Mechanical, and Instrumentation and Controls Divisions. The large number of activities which require completion during each shutdown makes close coordination between the various jobs essential. Two formal meetings are held to organize the activities to be completed. During the first meeting, held about two weeks prior to the shutdown, the program engineers (i.e., those who are responsible for coordinating the design, fabrication, and installation of experiments) present detailed information on the job schedule. From this a preliminary schedule is derived. The second meeting is held one week before the shutdown. Plans for all jobs are finalized, and work to be completed during the shutdown must be indicated on drawings which are available for distribution to the crafts foremen of the Engineering and

Mechanical Division. This provides about a week for the foremen to become familiar with the jobs so that they can work efficiently during the shutdown week.

A formal shutdown schedule is prepared which includes pertinent information on all activities to be performed. This schedule is distributed to the persons interested about four days before the reactor is shut down. Alterations in the formal schedule may be made during the shutdown in order to expedite the over-all program; and this is quite often necessary due to unavoidable, last-minute cancellations of scheduled activities.

Following the shutdown, an evaluation study of the week's activities is made by a resident engineer; and recommendations are made to improve the job scheduling and handling in the future. This critique of the shutdown activities is a recent innovation which, it is hoped, will result in more efficient methods of handling them.

Many activities associated with operating a nuclear reactor depend upon administrative control. These activities are of varying degrees of complexity and affect the operating conditions of the reactor in many ways. In order to standardize operating techniques, formal procedures are written covering all aspects of operation.

Operating procedures for the ORR might be considered as falling into two categories--permanent and temporary. The permanent procedures are incorporated into the Operating Manual for Oak Ridge Research Reactor. Changes in operating conditions preclude the exclusive use of such a formal publication; therefore, revisions and additions to these permanent procedures, as well as temporary procedures, are provided in the form of "ORR Procedure Memoranda". These memoranda, which are submitted by the reactor supervisor and approved by the Department Superintendent, are circulated to operating and technical-support personnel. A complete set of these memoranda is maintained in the ORR control room and in division files.

Primary records maintained are the ORR Log Books and standard forms such as "ORR Hourly Readings" and "ORR Daily Water Checks". Secondary records such as daily, weekly, and quarterly reports are also maintained. The formality of presentation and the extent of distribution of these will be unnecessary when the shear is ready for use in the hot cells.

INADEQUACIES OF BUILDING AND STRUCTURE

Building

Four years of experience has been gained in operation of the ORR as related to the ORR building. For this experience to be useful to other reactor operators, consideration must be given to the conditions at ORNL which resulted in the necessity for, and design of, a general-purpose building to house the ORR. Since it was desirable to locate the building within the existing Laboratory complex and in the vicinity of the two similar-purpose reactors (i.e., OGR and LITR), the size of the available site dictated that space be provided in the building for some activities not directly related to ORR operation. Some examples of such additional space allocation are: office space for experimenters, for Instrumentation and Controls Division maintenance engineers (and foremen), and for Engineering and Mechanical Division maintenance foremen; clothing change-room facilities for those working in the building; an instrument shop; and, originally, a small shop for mechanical maintenance.

It can be seen that such experience would be of more use to those reactor operators having or constructing a general-purpose building than to those who plan to provide space in a separate structure for activities such as those outlined above. In this light, the inadequacies of the ORR building may be considered in three catagories: space limitations, lack of provision for isolation of different areas, and the difficulties resulting from the undesirable traffic patterns between certain working areas.

Space limitations in the ORR building have adversely affected experimenters and operating personnel primarily; however, maintenance and support workers have been affected to a lesser degree. Probably the most handicapped group due to limited space is composed of those involved in experimentation at the horizontal beam holes. The available working space between the reactor shielding face and the building was originally limited to 28 ft. The nature of the experiments necessitated the addition of large external shields which further limited the working space to 21 ft. From a practical standpoint, individual beam holes are more stringently limited due to such obstructions as columns, floor hatches, and the east truck entrance. These limitations have resulted in such expediencies as an open gallery for the instrumentation of one beam-hole experiment and an enclosure of temporary construction for another. At present a design for a two-story, 20-ft extension of this end of the reactor bay is being considered.

Another area of limited space of concern to both experimenters and reactor operators is the reactor pool. The original idea had been to locate bulky items such as heaters, compressors, large charcoal traps, etc., in shielded cubicles in the basement. As experiment installation progressed, it was realized that not only was access to the basement limited (one experiment required half of it)/ but the basement itself was soon almost fully occupied. In addition, some experiments required the location of bulky items, of the type described, much nearer to the reactor than the basement. Therefore, a large fraction of the relatively limited second-level balcony is occupied by shielded enclosures and some rather large items have been located in the reactor pool, making mechanical installation and modification of experiments more difficult. In retrospect, provision of an "experiment cubicle level" at, or slightly above, the level of the reactor tank top would be more desirable. Such a working level should be as extensive as the reactor bay itself and should include suitable, shielded pipe-chases to allow construction of shielded cubicles in any portion of the "level". Many of these cubicles could be of concrete-block-type construction to provide for alteration or removal for subsequent experiments. In general, the individual cubicles would be maintained under negative pressure with respect to the remainder of the "cubicle level", which in turn should be maintained at negative pressure with respect to the remainder of the building.

The space provided for the reactor supervisory staff is quite limited and consists primarily of three 10- x 13-ft and two 9- x 13-ft offices. Since the average occupancy exceeds 1 1/2 persons and since frequent meetings with experimenters and/or with maintenance-support personnel are required, one serious lack is that of suitable space for such meetings. Such space should be adjacent to the supervisory staff offices where files and blueprints are maintained. Further, since a major portion of each staff member's work involves brief consultations with one or two nonstaff members, a reduction of the average occupancy would also be desirable. The prior discussion does not include that of the shift engineers who supervise reactor operation on off-shifts. No suitable office space is available for these four men. One desk and one filing cabinet is provided adjacent to the control room in a space originally designated for equipment and instrument repair, but over half the space is occupied by an air-conditioning unit for the control and staff offices. It has recently been necessary to utilize a large portion of the remaining space for expansion of the reactor controls.

Problems confronting maintenance and support personnel are less immediate; however, when involved with a research reactor and experiment installation of the size and complexity of the ORR, such problems are not to be ignored. Mechanical maintenance requirements for the reactor and experiments soon exceeded the capacity of the small shop originally provided, and at one time this work could be found in progress in any unassigned space in the building. Predominantly, such work had, by necessity, to be preformed near the reactor building but could not, practically, be performed in the then existing Laboratory field shops. Therefore, a building was built adjacent to the ORR, and a field shop was relocated to this building. At present, the amount of such maintenance activities in the reactor building is being reduced and the original ORR mechanical shop being vacated; however, a small area for maintenance on shim-rod-drive units has been established in the basement.

The space required for the group that supports and maintains the instrument and control systems has gradually increased. The goal of this group has been to install and maintain instrumentation for a gradually increasing experiment program, to upgrade the reactor control system, and at the same time to continue to effect a high degree of reliability and operational continuity. For such a goal to be met successfully, not only the total effort but also the intensity of effort must be gradually increased. (A minor portion of the work of this group has involved support of the operation of the LITR, OGR, and associated experiments.) The original mechanical shop is now used as an instrument shop, and two offices are required for engineers and foremen. Although these offices are fairly large, the average occupancy is four.

There are two areas in the ORR building which, because of limited space, adversely affect the effort of a number of groups working in the building. These are the clothing change rooms and the truck entrances. The two change rooms are each about 19 x 37 ft and contain lockers, toilets, shower stalls, and storage space for work clothing. The capacity has been exceeded due to the number of personnel working in the building, especially during an end-of-cycle shutdown, and to the need for providing space for Laboratory personnel working in several other nearby buildings.

The two truck entrances are provided with 12-ft-wide doorways. The west entrance on the second floor has an associated area about 36 ft long and 15 ft wide to enable trucks to be unloaded with the doors closed. Since this is the entrance normally used for movement of transfer casks into the building, it has been necessary to provide a storage area for these casks which occupies a portion (about 10 ft long and 8 ft wide) of the unloading area. The east truck entrance on the first floor is similar, but the unloading area is limited to a length of about 19 ft and a width of 14 ft due to the proximity of the beam-hole area. Since these entrances must be capable of automatic closure in the event of an accident, there has been some difficulty in moving large items into the building with the reactor operating due to the limited size of the truck which can be accommodated. It appears that a generously sized truck lock or annex with sealed doors at each end would be useful, in particular for the west entrance. Such an annex could be external to the ORR building. Since this latter truck entrance also serves the hot cells, considerable time could have been saved had a supplementary bridge crane been provided.

One feature of the ORR building which has been quite unsatisfactory is the lack of isolation between various areas in the building. Although there have been no major releases of radioactive material into the building, the experience gained as a result of some minor releases from experiments indicates that such lack of isolation or compartmentalization results in wide-spread problems generating from what was originally a local release. In the event of a major release, costly decontamination of the entire building would unnecessarily result. The three levels of the reactor bay and the basement should be individual compartments separated from each other and from the laboratory and office space on the second and third floor. An additional advantage which would be realized from compartmentalization is the reduction of noise and vibration in individual experiment areas. Such modification of the ORR was recently investigated, but the resulting additional structural loading precluded such compartmentalization.

Another feature of the building, which is incidental to the question of space isolation but related to that of decontamination, is that of the abundance of internal surfaces. In the ORR building a majority of the wiring conduits and plant-services piping are exposed. This is also true of major structural members in the reactor bay. Experience such as that gained at the OGR following the plutonium release of 1959 showed that exposed surfaces greatly increase the cost and time required for decontamination.

During the design of a research reactor building, careful consideration should be given the purpose of various areas and the traffic patterns between them. In the ORR building several key areas have unfortunately become general thoroughfares. This could have been prevented in some instances by providing alternative passageways and in other instances by relocating the work or function performed to other areas. One example is the limited access on the third floor between the laboratory area on the south side and the operating staff office area on the north side. This access is limited to two routes: around the third-level, poolside balcony or west of the hot cells. Portions of the poolside balcony are often necessarily occupied by equipment; during end-of-cycle shutdown much of this area is designated a contamination zone. The available area west of the hot cells is required. The use of such areas as thoroughfares is undesirable, and on occasion both routes are blocked by contamination zones. The only remaining access is via the second floor.

A second example of an area which developed into a thoroughfare consists of the third-floor change room and adjacent stairwell on one end and the ORR control room on the other. Connecting these extremes is a hallway which provides access not only to the offices of the operating staff but also to the poolside balcony. Of primary concern was the traffic through the control room to stairs leading to the reactor-cooling-system area. Since this route was considerably shorter than any other available from the third floor, the control room itself became a thoroughfare. In addition to such traffic, the fact that no convenient space external to the control room was available for observers often resulted in the presence of groups of trainees and visitors in the control room. A gallery was constructed which, by serving as an alternate traffic route and observation area, has markedly reduced such undesirable use of the control room.

Although heaviest during the end-of-cycle shutdown, the traffic from the third-floor change room or the adjacent stairwell through the partially enclosed hallway to the poolside balcony has gradually increased. At present this hallway, which also provides access to the offices of the operating staff and to the control room, is the most heavily traveled area in the building. While the degree to which the working day of reactor supervisory personnel is subject to interruptions and distractions is probably unexceeded even in a research laboratory, it is apparently true that interruptions and distractions are inherent in such work and can be reduced in degree only. Had the hallway been fully enclosed and an alternative passage provided this situation would not exist.

Structure

There are some miscellaneous examples of inadequacies which have become apparent during four years of operation and which do not readily fit into any of the categories previously discussed. Since these examples primarily concern mechanical and physical properties of the reactor and pool structure, the term "structure" can serve as a heading for a brief listing of these examples.

The use of aluminum as a pool liner has, in addition to causing corrosion problems, complicated numerous operations due to concern about possible mechanical damage. Similar complication has resulted due to the absence of pool-floor areas capable of supporting large carriers. A difference in elevation between the top of the pool wall and the adjacent floor, which results in a parapet (as at the ORR), appears unnecessary (a removable guard rail would serve as well) and in many cases is a hindrance. Finally, the distance from the reactor building to the primary cooling pumps and to the present heat exchangers, which resulted from the original use of air-cooled heat exchangers in the particular area available for ORR construction, is excessive.

SUMMARY

Since this material was primarily prepared for reactor operations personnel, the emphasis was placed on problems and inadequacies which have been encountered during four years of ORR operation. No effort was made to describe those features which make the ORR the very useful research tool that it is.

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MASTER

SOME MAJOR FUEL-IRRADIATION TEST FACILITIES OF THE OAK RIDGE NATIONAL LABORATORY

ORNL

D. B. Trauger

OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

ORNL-3574

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Reactor Division

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D. B. Trauger

APRIL 1964

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee
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ABSTRACT

Irradiations of test fuel specimens and experimental fuel elements are conducted both in capsules and in forced-convection-cooled loops. The design of equipment suitable for irradiation tests pertinent to the development of boiling- and pressurized-water, gas-cooled, sodium-cooled, and molten-salt reactors is described briefly, with particular emphasis on test capability.

The capsules utilize thermal conduction through sodium or NaK, gas-filled annuli, and graphite for heat removal from the fuel element surface. Six basic designs have been employed, with many variations, in conducting over 125 separate irradiation experiments. Capsule features include external pressurization to 900 psia, sweep gas for fission-gas removal, fission-gas sampling and daughter-trap collection for gamma-ray spectrometer analysis, continuous flux monitoring and control, and measurement of temperatures up to 4000°F.

The loop facilities described are: (1) a pressurized-water loop for operation up to 2500 psia and 625°F with heat removal up to 300 kw; close control is provided over water chemistry; (2) two helium-cooled loops capable of operation up to a gas temperature of 1500°F, a system pressure of 300 psia, and fission and gamma heating of 60 kw; other coolants can be accommodated, and the loops are designed to operate with fission-product contamination when necessary; (3) a compact loop design for recirculating molten-salt fuels at high temperatures.

Design features to meet safety requirements, alteration of equipment to accommodate changing program needs, and factors affecting the economics of operation are discussed briefly. The close relationship needed between the irradiation test laboratory and fuel development programs is indicated. The usefulness of assistance from other related groups in a large laboratory complex is mentioned. Finally, shop facilities are described for meeting the exacting needs of irradiation capsule assembly.

SOME MAJOR FUEL-IRRADIATION TEST FACILITIES OF THE OAK RIDGE NATIONAL LABORATORY

D. B. Trauger

INTRODUCTION

The Oak Ridge National Laboratory from its inception has been engaged in the development of reactors and reactor fuels. Important to this phase of ORNL work is the testing of fuels under conditions which simulate the intended service in a power-producing reactor. Achievement of appropriate test conditions was first made possible by the development of test reactors which produce high neutron fluxes. Early tests were conducted in the LITR[1] and the MTR;[1-2] later experiments were designed to utilize the ORR[3] and the ETR,[4] which afford more versatile arrangements for engineering-scale tests. ORNL irradiation test rigs are now concentrated in the ORR and LITR, where various test positions are utilized, including in-core, poolside, and beam-hole facilities. Other reactor space is used as required to obtain additional space or particular features.

The text of this report is intended to provide a brief but basic description of the irradiation facilities. It is hoped that it will be particularly useful to those engaged in related fields, such as fuel development, and for program planning. This report also illustrates the diverse equipment which is available and indicates the capability of a national laboratory to conduct the irradiation-testing phase of reactor development programs. For those directly interested in irradiation test work, this report will serve only for reference purposes; it is not intended to provide the detail necessary for improvement or duplication of test equipment.

The fuel-irradiation test facilities described have been the responsibility of the Irradiation Engineering Department of the Reactor Division. They were designed to provide appropriate environments for several power-producing reactor systems, and their primary application has been to evaluate fuel and fuel element concepts which are advanced beyond proven practice. Experiments are conducted in these facilities to determine the effects of nuclear processes, including radiation damage, fission-product generation, and transmutation, particularly as related to other variables. Important nonnuclear factors include temperature, thermal stress, pressure stress, differential thermal expansion, and chemical and metallurgical properties. Specific problems involve changes in metallurgical structure, interactions between fuel and its cladding or container, buildup of pressure by volatile fission products, and the movement or redistribution of radioactive materials within the fuel system. The equipment described in this report has been used for the investigation of variables affecting fuel element design, for proof testing of prototype fuel assemblies, and for studies involving reactor coolants. Reference is made in the text to documents which describe the program requirements and fuel development work for which the irradiation facilities were designed.

Equipment is available for tests of both the solid and the liquid fuels under development for use in thermal and fast reactors. Both liquid and gas coolants can be employed. Most of the irradiation rigs have been utilized repetitively, with both major and minor revision to accommodate changing program needs. In each revision, capability for the earlier purpose was retained where possible, and thus highly versatile equipment has been developed. A list of the irradiation facilities, identified by the test reactor, and the number of experiment stations is given in Table 1. The ETR and MTR capsules are in the reactors of corresponding title, which are located at the National Reactor Testing Station in Idaho; the others are located at ORNL.

Varied technical skills are required to effectively plan irradiation test work. Designers, experienced analysts, project engineers, and trained operating crews comprise the team for conducting experiments. Extensive assistance from other groups at ORNL is used to complement the effort of the Irradiation Engineering Department and provide strong support. This includes work in reactor analysis, radiation shielding, metallurgy and ceramics, welding and brazing, inspection, analytical chemistry, instrumentation, health physics, and reactor operations. Related tests frequently are conducted by other groups and coordinated with the irradiation studies. Shop facilities and other services from the Y-12 and ORGDP plants are also used extensively. Test programs may be initiated and directed either by the Irradiation Engineering Department or, more frequently, by other ORNL groups engaged in reactor or fuel development.

Considerable attention is given to reliability of equipment and safety. The principle of double containment by use of independent vessels or structures is followed to ensure that radioactivity is not released in the event of accident or malfunction of equipment. Very few deviations from this principle are permitted, and monitoring normally is provided to show that both the primary and secondary vessels are intact. Most experiments utilize the reactor safety system to prevent serious accident conditions in the event of equipment malfunction, but ultimate safety is provided by containment. Vessels are built and inspected according to the standards of applicable codes.[5-8]

Irradiation test equipment in general is difficult or, in many cases, impossible to alter or repair during or following operation. Out-of-pile tests of both equipment and experimental elements are therefore conducted whenever practical and where significant conditions can be attained. Thorough checking and evaluation of in-pile equipment contribute greatly to reduction of costs by assurance of successful experiments through satisfactory operation. Despite precautions, many difficulties have been encountered in conducting the irradiation experiments described. It may be stated conservatively, however, that this equipment has performed well and, in general, has met its test requirements satisfactorily.

The design, and therefore description, of irradiation equipment necessarily includes consideration of hot-cell facilities and techniques. Although some reference is made to hot-cell requirements, detailed discussion of postirradiation examinations is outside the scope of this report. However, for completeness, references are listed which describe ORNL hot-cell equipment and the facilities used with this irradiation equipment. The ORR hot cell to which experimental equipment from the reactor core or poolside can be removed directly through the pool without the use of casks or shielding other than the pool water is described in ref. 9. This cell location provides convenient means for early inspection of irradiated equipment. A large cell has been provided for handling beam hole and other major assemblies and for temporary operation of radioactive equipment of small pilot-plant scale.[10] Specialized equipment for sectioning materials and detailed examination has been provided in cell No. 6, which can accommodate alpha contamination.[11] Smaller cells are available for radiography and other analytical work. A new facility is nearing completion which will accommodate a large volume of work, including close inspection, specialized disassembly, and detailed examination.[12]

Initial dismantling of equipment irradiated at the MTR is handled in cells at NRTS. Many of the experimental assemblies listed in this report were examined in hot cells at GEVAL (General Electric Vallecitos Atomic Laboratory) and at BMI (Battelle Memorial Institute).

DESCRIPTION OF FACILITIES

The two classifications, capsules and loops, employed in describing irradiation test equipment are distinguished by the method of heat transfer from the fuel surface. In capsules, heat transfer is principally by conduction, whereas loops employ convection cooling, usually by a recirculating coolant forced by pumps or compressors. By their simplicity, capsule facilities are less costly to construct and operate, but they do not simulate the reactor service as realistically as loops. Various arrangements for both types of equipment are employed at ORNL. Each facility has been somewhat specialized to provide for specific test needs. The various units are complementary so that a major fuel development program can be conducted quickly with adequate irradiation test support. Replication of the simpler facilities provides capacity for handling several programs simultaneously.

The LITR capsules are small test systems designed particularly for accelerated experiments or for screening of materials. Although cooled by forced convection, the compressed air is used only for convenience. Seven stations are available, and each is capable of containing as many as four encapsulations of fuels, including metals, alloys, ceramics, such as UO_2, UC, and UN, and coated particles.

The ORR capsules are highly versatile units in which many different kinds of fuel can be irradiated under more complex test conditions. A wide range of environments can be provided for fuel elements, including gases and liquid metals, high external pressures, and thermal cycling. Full-size fuel sections (except as limited in some cases by length) can be accommodated so that highly definitive tests are possible. The ORR eight-ball and the ETR capsule units have similar capabilities but are limited in size and in neutron flux control by their locations in reactor core and reflector positions, respectively. However, these locations provide higher neutron flux levels and excellent heat-removal capabilities for conducting tests at high power densities.

The facility now at the MTR was developed for a complex loop operation before the ORR was available and has since been altered to provide diverse capability to meet many fuel test requirements. Both package loops and capsules can be accommodated at the MTR. The HB-3 beam hole has been used for the experiments; however, the out-of-pile equipment could be used with other test positions.

The ORR loops afford more complete simulation of reactor conditions, since dynamic forces, nonuniformity of cooling, and the effect of expected impurities in reactor coolants can be included. The two gas loops complement each other in providing a considerable range of neutron flux intensity, specimen size, heat removal, gas coolant chemistry, and simulation of reactor system features. The pressurized-water loop provides many features of both pressurized- and boiling-water reactors and can handle elements having large heat-generation ratings. Operation of the three loops in common effects considerable savings in operator and maintenance costs. Furthermore, the three loops and, to some extent, the capsules also utilize common equipment and services. When savings are accomplished in this manner, long-range planning is desirable because each facility is affected by the program for the others. Important advantages, however, are the justification of greater service facilities and pooling of technical talent. Experiences gained by one task engineer in a closely knit group directly strengthens the work of others.

Figures 1 through 4, respectively, show plan views of the ORR, LITR, MTR, and ETR reactors and the locations of equipment described. The complexity of an actual installation is illustrated in the photographs of the ORR pool in Figs. 5 and 6.

Capability now exists for conducting approximately 50 simultaneous engineering-scale irradiations of experimental nuclear reactor fuels. Each may be conducted under a unique set of conditions, although several may arbitrarily be made essentially identical for replication or for comparative experiments. The heat-removal capabilities of individual facilities and the available neutron fluxes are given in Table 1.

Tests may be conducted with various coolants in contact with fuel or cladding, including air, argon, CO_2, He, N_2, Na, NaK, and water. ORR loop No. 1 is adaptable to hydrogen cooling, although irradiation tests with this gas have not been conducted to date. Instrumentation is available to measure fuel temperatures reliably up to 3000°F and with less certainty to 4000°F. Independent control of both neutron flux and temperature has been achieved for some of the facilities, including both capsules and loops. The general capabilities are given in Table 1. The equipment described in this report has been utilized for the irradiation of more than 300 separate fuel capsules during the past five years.

In addition to the specialized facilities, hydraulic rabbit tubes and noninstrumented capsules in test reactor core positions may be used for irradiations. Rabbit facilities are satisfactory for many irradiations and are utilized when possible because relatively little cost is involved.[13] However, the limited range of conditions achievable and the obvious simplicity of the noninstrumented assemblies place them outside the scope of this report. Tests also may be conducted by placing experimental elements directly in the core of a reactor test facility or in a power reactor. Such tests are limited to relatively well-proven devices, since a large installation might be adversely affected by failure of the element. Also, it is not possible to vary test conditions in a power reactor adequately for many needs of development programs.

Not all irradiation equipment of ORNL has been included in this report. In general, the larger equipment currently utilized in direct support of Reactor Division programs is described. Many other facilities are available for materials studies and for testing specific properties of fuels.[13]

ORR Poolside Capsule Facility

The ORR has a large high-flux irradiation facility outside the reactor tank. This was achieved by providing a flattened and indented section of the reactor tank adjacent to one side of the core. Since the ORR tank is immersed in a large pool of water, direct access is available to a large volume having a high neutron flux density. The water shielding pool provides visibility and space for movement of equipment without restriction. This arrangement has proved most useful for conducting capsule tests.

The poolside capsule irradiation facility is shown diagramatically in Fig. 7. It was developed for the EGCR fuel-irradiation program[14,15] but has since been extended for testing several configurations and sizes of both clad and all-ceramic fuel elements.[16-19] As many as eight separate fuel assemblies can be accommodated simultaneously in separate containers; however, when the fuel specimens exceed 1 in. in diameter, their number must be reduced.

Basically, the irradiation capsules are of concentric double-wall metal construction and utilize either NaK or graphite to conduct heat from the fuel specimen to the inner container. A thermal barrier in the form of a gas gap between the inner and outer containers provides the resistance necessary to achieve high temperatures during irradiation. The heat energy is rejected from the outer wall to the reactor pool. Measurement of gas pressure in the annulus is a means for monitoring the integrity of the vessels, which also serve as containment for safety requirements. Fuel element cladding surface temperatures up to 1600°F can be attained in present capsules with the specimen immersed in NaK, as shown in Fig. 8. Higher surface temperatures can be achieved at the test fuel element surface by using other materials of construction or by placing the element inside a second gas-filled annulus. Temperatures are measured by thermocouples inserted in the NaK or the graphite inner structure.

Irradiations of fuel in a graphite matrix have been conducted at surface temperatures up to 2500°F. A capsule for irradiating fueled-graphite spheres is shown in Fig. 9. The basic design features of this capsule are similar to those for the eight-ball capsule described in a later section of this report. Heat ratings of 70,000 to 150,000 Btu/hr·lin ft, depending on the capsule diameter, can be accommodated. Thermal- and fast-neutron fluxes, of 7×10^{13} and 5×10^{13} neutrons/cm^2·sec respectively, are available.

For clad fuel elements, application of the external collapsing forces to be experienced in gas-cooled reactor atmospheres has been provided by pressurizing the helium over the NaK surface. Pressures as high as 850 psi have been used. For temperature measurement in hollow cylindrical fuel pellets, molybdenum thermocouple wells brazed into the element end cap extend to the midplane elevation. Tungsten-rhenium thermocouples have been used in these wells to measure UO_2 fuel central temperatures up to 3700°F. It is also possible to measure fuel central temperatures of graphite-matrix pellets and of fueled inserts within spheres at temperatures up to 2500°F. Pressure transducers installed to measure the equilibrium pressure inside clad fuel elements during irradiation have functioned well, but the lifetimes have been limited, possibly by radiation damage to components.

Helium sweep-gas facilities have been provided for either continuous or intermittent determination of fission-gas release. A schematic flow diagram of the sweep capsule control and sampling system is shown in Fig. 10. Gas samples are removed for gamma-ray spectrometer analysis with the equipment shown in Fig. 11. The ratios of gaseous fission-product-release rate to birth rate, R/B, measured to date have varied between 10^{-2} and 10^{-8} for different fuels. Daughter traps that use charged wires to collect solid decay products from noble gases in the sweep circuit, as shown in Fig. 12, provide a means for quantitative measurement of the short half-life noble gases.[20]

The thermal-neutron flux at each station in the irradiation facility can be monitored by argon activation,[21] using the gamma-ray spectrometer for analysis. Movement of the capsules within the flux gradient of the facility can be accomplished during irradiation by means of a gear-driven mechanism operable from the pool surface using tools with extended handles. Manual control has been used with this equipment to maintain nearly constant flux during irradiation, as evidenced by temperature measurements; for example, capsules operated at 1600°F have been held within ±30°F for extended periods.

The test systems described in Table 2 and shown as irradiated in the ORR, except the last one, were tested in this poolside facility. Fifty-six capsules have been irradiated since April 1958. No leakage of fission gases to the reactor room or failure of primary components, except instrumentation, has occurred. The facility has been utilized principally for Gas-Cooled Reactor Program irradiations, but it has flexibility to provide useful test information for many reactor programs. Additional drawings and photographs describing the equipment used are presented in Figs. 13 through 17.

ETR NaK-Cooled Capsules

Equipment installed in the ETR was designed to accommodate 14 capsules simultaneously for comparison of proposed fuel pellets having different configurations for use in the EGCR.[14] The irradiations programmed for these units involved long test periods of up to three and four years, so revisions in equipment have not been necessary, and the present capability is essentially that for EGCR capsules. Very little modification would be necessary to accommodate other capsules; for example, the eight-ball capsule (see next section) could be accommodated by preparation of a new reactor core piece and revision of the lead tubes. By redesign for the use of core positions instead of the reflector locations now occupied, the high fluxes for both fast and thermal neutrons of the ETR could be utilized. In particular, tests of sodium-cooled or gas-cooled fast-reactor fuels could be accomplished with very little alteration.

The capsule used is shown in Fig. 8, and the tests conducted at the ETR are listed in Tables 1 and 2. Work on the ETR capsules for the EGCR irradiation program was conducted jointly with the Phillips Petroleum Company.[22]

ORR Eight-Ball Capsule

A capsule was needed in which several spherical graphite elements containing coated-particle fuels could be irradiated simultaneously under similar conditions for comparative evaluation. The fabrication variables to be studied included (1) methods for preparing fuel particles and their coatings and (2) the type of graphite mix and techniques used in forming matrices and unfueled shells, that is, blending procedures, molding processes, heating rates, final treatment temperatures, and impregnation processes. A relatively high fast-neutron flux was desired to accumulate radiation damage in the graphite comparable to that expected for the fuel lifetime in a power reactor. Important considerations in design were measurement of temperature and simplicity in construction to minimize cost.

The capsule is located in core position F-1 of the ORR, which has the advantages of a relatively high fast-neutron flux, 1.3×10^{14} neutrons/cm^2·sec, a uniform thermal flux over a considerable vertical length (peak value, 1.5×10^{14} neutrons/cm^2·sec), and adequate cooling capacity for the spherical elements in a compact arrangement. The facility affords sufficient space to accommodate 1 1/2-in.-diam fuel elements. Based on this diameter and the ORR vertical flux profile, it was determined that suitable irradiation conditions could be achieved for eight spheres — hence, the title eight-ball.

The basic configuration chosen for the experimental assembly is shown in Figs. 18 and 19. The graphite parts are carefully machined and close fitting. Small spheroidal coke particles are used in a loose bed to enhance the heat transfer from the fuel spheres to the graphite structure without restraint on the surfaces of the spheres. The fuel spheres are centered in the cavities by small pins inserted in the graphite. Temperatures are measured by thermocouples inserted in the graphite structure and, when appropriate, inside the fuel spheres. A thermocouple can be installed conveniently in the top fuel sphere. Although the capsule was designed for spherical fuel elements, it could easily be redesigned for other configurations.

The gas gap between the graphite sleeve and the inner wall of the primary stainless steel containment vessel determines the operating temperatures of the graphite and the fuel relative to the primary containment structure. A second gas gap between the primary container and a secondary stainless steel container (not shown in Fig. 18 but arranged similarly to the configuration of the four-ball capsule shown in Fig. 9) was dimensioned to produce a temperature difference of several hundred degrees Fahrenheit when filled with a helium-nitrogen mixture. The gas mixture is varied to provide temperature control.

The experiments are operated from ORR poolside capsule instrument panel position No. 7 and share the same shielded valve-control box, sampling station, and gas supply, as shown in the schematic diagram of Fig. 10; thus all variables achievable in the poolside facility, except neutron flux adjustment, are available. The sharing of facilities provides the advantage of economical operation for this experiment, since very little additional operator coverage is required.

The overall performance of the capsule has been quite satisfactory. Temperatures in the graphite at the midplanes of fuel spheres have varied no more than ±50°F, with an approximately symmetrical pattern about the vertical center. The experiments that have been conducted in this facility are listed in Table 2.

LITR Air-Cooled Capsules

The equipment for LITR irradiations utilizes forced-air cooling of the capsule.[14,15] Two of the designs employed are shown in Fig. 20. One assembly accommodates a small specimen of solid fuel, such as UO_2, UC, or UN, which may be surrounded by a ceramic insulating sleeve to obtain higher temperatures, as shown in the parts display of Fig. 21. A third design provides small cans of noble or refractory metal to contain coated particle or granular fuels[23] (shown in Fig. 22). A gas annulus between the fuel or its container and the outer wall of the capsule permits operation at considerably higher temperatures than are possible for the capsule container. Two or more separately enclosed fuel containers can be accommodated in each half of the capsule. Containers made of graphite or of ceramics can be used where metals are not compatible with the fuels to be tested. The outer container for these capsules is designed only for convenience of the fuel irradiation, with no attempt to obtain information relative to encapsulation techniques. Figures 23 and 24, respectively, show the facility tube that directs the air flow over the capsules and a schematic diagram of the system and controls.

An important and common feature of most LITR capsule designs is the thermocouple for measuring the central temperature of the hollow fuel specimens. Tungsten vs rhenium or tungsten vs rhenium alloy thermocouples are normally employed with tantalum or a refractory metal sheath to prevent direct contact of the thermocouple junction with the fuel. Irradiations of UO_2 have been conducted at temperatures giving an indicated output of 37 mv with W–5% Re vs W–25% Re thermocouples. The temperature corresponding to this emf, as obtained by extrapolation of a calibration curve above its 4200°F limit,[24] is approximately 4400°F. At these temperatures, a rapid downward drift in emf occurs early in the irradiation period, but the cause cannot be determined precisely from these experiments. Changes in the fuel structure and thermal conductivity could be contributing factors, as well as thermocouple instability and insulation breakdown. Below 3200°F, the indicated temperatures are consistently quite stable, and stable operation is also observed in some instances at higher temperatures. Closure of the capsule is achieved with a commercially available metal-to-ceramic hermetic insulating seal through which the thermocouple lead wires pass.

Control is based on temperatures measured on the lower capsule wall, which operates at the higher equilibrium temperature, and is effected by varying the air velocity and corresponding heat transfer coefficient. Measurements of the air flow and its temperature above and below the capsule provide for determination of the total power generation.

These capsules have the advantage of simplicity and economy in construction. The small size permits operation at very high power densities, and thus high burnup is achieved in relatively short exposure times. The capsule control is automatic and requires little operator attention. Seven double capsules can be operated simultaneously with equipment presently available at the LITR. The thermal-neutron flux in the assigned LITR core position (shown in Fig. 2) varies between 5×10^{12} and 2×10^{13} neutrons/cm^2·sec; other capabilities are given in Table 1. Irradiations conducted in LITR capsules are listed in Table 2.

ORR Gas-Cooled Loop No. 1

Gas-cooled loop No. 1,[25] which is equipped to recirculate helium gas, was designed to test clad fuel elements appropriate to the EGCR or similar reactors of more advanced concept.[26] It also is quite suitable for tests of fuel elements for fast gas-cooled reactors. The overall capability of the loop is described in Table 3. Although designed for operation with helium, the loop can be used with several gas coolants. The principal components and their location in the ORR facility are shown in Fig. 25. Most of the loop is located within the ORR pool to utilize the shielding afforded by the water. The compressors, primary instrumentation, and some auxiliary equipment are located in a shielded cubicle on the lower balcony to provide access for maintenance.

The interrelationships of the main loop components are shown in the schematic flow diagram of Fig. 26. Helium coolant at flow rates up to 400 lb/hr is circulated through the loop at a nominal pressure of 300 psia by two turbine compressors, of the type shown in Fig. 27, piped in series. A typical loop temperature profile for operation with a fuel element having a heat rating of 35,000 Btu/hr·ft is shown in Fig. 28. The maximum allowable temperatures at critical points are 1400°F for

Table 3. Capacity of ORR Gas-Cooled In-Pile Loops

	Loop ORR-1	Loop ORR-2
Primary usage	Testing clad fuel[a]	Testing unclad fuel
Startup date	July 1961	January 1963
Thermal-neutron flux, neutrons/cm^2·sec	5×10^{13}	8×10^{12}
Fast-neutron (>0.1 Mev) flux, neutrons/cm^2·sec	5×10^{13}	4×10^{13}
Specimen size (max), in.		
Outside diameter	1	2.75
Length	19	9
Pressure (helium), psi	300	300
Fuel element temperature (max measured), °F	4000	2500
Coolant exit temperature (max), °F	1400	1500
Coolant inlet temperature (max), °F	1350	1200
Flow rate (max), lb/hr	400	980
Heat removal limit, kw	60	20[b]
Activity limitation, curies	5	100[c]

[a] Loop can also accommodate unclad ceramic, ventilated clad, or metal matrix elements.

[b] Heat generation is limited to 20 kw by present in-pile tube design; the loop has capability for removal of 60 kw.

[c] With revision of equipment for fuel-element removal, operation could be permitted with 1000 curies of mixed fission-product activity in the coolant.

stress limits of the in-pile structure of the primary containment vessel and 600 to 800°F at the compressor inlet, as limited by the turbine wheel design and motor windings. Heat losses to the pool and in the compressor cubicle are made up by a 60-kw heater. Primary heat removal from the loop is accomplished by a bayonet type of cooler utilizing an air and water mixture, with the primary temperature control provided by varying the amount of water introduced into the air. Regenerative heat transfer in the annular piping system is utilized to conserve energy while maintaining the inlet gas temperature to the fuel element as high as 1350°F. The piping is essentially an all-welded system except at the loading station, heater cover, and the cooler bulkhead joint, which are flanged assemblies. The loop is doubly contained in its entirety to permit the testing of fuel elements under severe conditions without hazard. Loop instrumentation provides for continuous monitoring of important variables, including fuel, gas and loop structure temperatures, radiation levels, and all other parameters essential to safe operation. Helium released from the loop through normal venting or by overpressure relief valves passes through water-cooled activated-charcoal traps before being discharged to the ORR offgas system.

Gas-sampling provisions are adequate for determination of both chemical and radioactive noble gas impurities at very low levels. The conduit support for the fuel elements affords considerable surface area to collect fission or gaseous corrosion products and considerable space is available there for insertion of corrosion specimens and other experimental devices.

The loop operates nearly automatically but is manned with technicians to provide close adherence to the design test conditions, to ensure corrective action in the event of trouble, and to compensate for off-design reactor operation resulting from control action by other experiments. During two years of operation, the loop has caused a reactor shutdown on only one occasion. This shutdown was necessitated by serious failure of a fuel element under test. Operation has been continuous throughout all other reactor operating periods.

Details of a typical fuel element for irradiation, equipment for installation and removal of hot elements, and sectional views of the in-pile position of the loop are shown in Figs. 29 through 32. Figure 33 shows the loop and other equipment in the ORR pool, and Fig. 34 shows the instrument control panel.

Recent studies have shown the fast-neutron flux ($E > 0.1$ Mev) to be about 5×10^{13} neutrons/cm$^2 \cdot$sec in the ORR B-1 core position of loop 1. Thus the facility is of interest for fuel studies of gas-cooled reactors operating in the epithermal flux region. A fuel element test has demonstrated capability of the loop for operation with unclad fuel elements. Approximately 1 curie of noble-gas fission products released from a deliberately vented clad element was circulated in the loop for an extended period.[27] Following this operation, the loop was opened both for changeout of fuel and replacement of both compressors. No spread of contamination was experienced, and the changeout was completed easily within a normal ORR shutdown period.

The fuel test program for the loop has been intensive. During a little more than two years of operation, the loop has irradiated a total of 14 test specimens. With one exception, each test was conducted with quite satisfactory loop operation, although some tests resulted in failure of the specimen. A list of the experiments, their nature, and the operating conditions is given in Table 4.

Table 4. Tests Conducted in Loop No. 1

Test Number	Sample	Power (Btu/hr·ft)	Maximum Cladding Temperature (°F)	Fuel Central Temperature (°F)
1	Pressure vessel steel		550	
2	Pressure vessel steel		550	
5	EGCR type fuel element	26,000	1450	1900
6B	EGCR type fuel element	26,000	1200	1900
7A	EGCR type fuel element	28,000	1450	2100
7B	EGCR type fuel element	28,000	1450	2100
7C	EGCR type fuel element	28,000	1450	2100
9	EGCR type fuel element	40,000	1540	2400
8	Fuel element with transverse fins	40,000	1540	2400
8S	Fuel element with transverse fins	40,000	1540	(a)
10P1	Fuel element with transverse fins	65,000	1540	3500
10P2	Fuel element with transverse fins	50,000	1300	2600
7D	Ventilated fuel element	26,000	1500	2100
11M	Fuel element with transverse fins	75,000	1500	3300

[a] Thermocouple failed.

ORR Gas-Cooled Loop No. 2

This facility provides for the irradiation of unclad fuel elements that may release fission products directly to the gas stream and for studies of fission-product behavior in a complex heat transfer system. A recirculating high-temperature helium loop is utilized for cooling the fuel and to simulate reactor systems.[28] The irradiation test region located in the south beam hole of the ORR will accommodate fuel specimens up to 2 3/4 in. in diameter and 9 in. long. The piping immediately behind the fuel test region is arranged to accommodate various separately cooled or heated surfaces for studies of fission-product deposition. These surfaces are built integrally with the fuel test assembly and are removed with the fuel for postirradiation examination. Sectional views of the loop test region are shown in Figs. 35 and 36. A heavily shielded carrier is provided for transfer of the irradiated specimen from the loop cell to a dismantling hot cell where critical parts are removed for examination in smaller cells.

The loop consists of 2 1/2-in.-diam, sched.-40, 300-series stainless steel pipe, compressors, an 80-kw electric heater, an evaporative cooler, a regenerative heat exchanger, a filter, the test section, and appropriate gas cleanup equipment. Instrumentation is provided to measure flows, pressures, temperatures, and radiation levels. Conversion of all gas-pressure signals to electric output is provided consistent with the design of the loop containment. Loop controls are automatic to the extent possible and provision is made for reactor shutdown prior to development of abnormal conditions which would jeopardize the experiment, the loop, or its containment. An overall flow diagram of the loop is shown in Fig. 37.

A shielded full-flow filter is provided for general cleanup of the loop gas and, particularly, to collect fragments of unclad fuel elements which might be circulated in the loop. A side-stream purification system removes chemical and radioactive contaminants from the helium during normal operation and, by proper valve settings, can be used to clean loop gas for discharge to the disposal stack. The design of the purification system is based on a limited flow of gas through a copper oxide bed, molecular sieve, and carbon trap. The carbon trap reduces activity by absorbing iodine and by delaying the noble fission gases for several half-lives of radioactive decay. Krypton holdup is approximately 40 hr.

A sampling system is provided to remove helium coolant for quantitative analysis of noble fission gases and corrosion impurities, such as CO, CO_2, H_2, H_2O, and CH_4. Radioactive components are analyzed with a scintillation detector and a multichannel analyzer, which are also used for fission-gas-release measurements in the ORR poolside capsules. A gas chromatograph is provided for on-line determination of chemical impurities. Impurity levels are easily maintained below 10 ppm during loop operation. The concentration of CO and CO_2 can be held below 1 ppm or increased (by additions) to very high values, if desired, for studies of carbon transport effects.

All primary system components, including compressors and heat transfer and gas cleanup equipment, are located in a shielded cell adjacent to the ORR reactor pool wall. The arrangements of equipment and the cell design are shown in Figs. 38 and 39. The instrument panel is shown in Fig. 40. A hot-cell window and an omniscope provide for observation of the loop equipment during operation. Certain remote operations can be handled by a manipulator and a cell crane, which are controlled at the cell window. Individual components, in addition to being located in the cell, are shielded to permit operation with heavily contaminated gas streams without buildup of activity to levels that would prevent access by operators and maintenance personnel during reactor shutdown periods.

Three experiments have been conducted in the loop, as listed in Table 5. The first utilized a small quantity of UO_2 as a calibration test sample for radioactivity release and for determining the operability of the loop equipment for handling and detecting fission products. The second and third tests involved spherical elements containing pyrolytic-carbon-coated UC_2 fuel in a graphite matrix structure.[17,18] Each test has proceeded smoothly during operation. Removal of the irradiated pieces following the first two tests has been accomplished routinely, and the third test is in progress.

Table 5. Fuel Tests Conducted in Loop No. 2

Type of Test	Fuel Element	Power (kw)	Fuel Central Temperature (°F)
Shakedown	UO_2 film	Negligible	1100
Fuel stability	Four spheres, 1 1/2 in. in diameter, consisting of pyrolytic-carbon-coated particles in a graphite matrix	4	1400
Fuel stability	Three spheres, 2.38 in. in diameter, consisting of pyrolytic-carbon-coated particles in a graphite matrix	5	1650

ORR Pressurized-Water Loop

This test facility, in which fuel and other materials can be subjected to radiation and other environmental conditions simulating a pressurized-water reactor system, has been operated in the Oak Ridge Research Reactor since December 1959. It was designed for tests of stainless steel-clad fuel elements containing UO_2 or other ceramic fuels. The initial tests in the loop were conducted to evaluate fuel elements for N.S. SAVANNAH replacement cores.[29,30] Pellets, swaged-powder, and vibration-compacted bulk fuels in cylindrical elements and dispersion fuels in flat coupons and hollow cylinders have been irradiated. The A-1 and A-2 core positions of the ORR are utilized to accommodate multiple element assemblies. The test loop is designed to recirculate water at 2500 psig, 650°F, and 80 gpm with a heat removal capacity of 300 kw.[31] The piping within the reactor is arranged as a U tube with straight vertical access through the reactor vessel cover. An isometric view of the loop as installed at the ORR is shown in Fig. 41, and a schematic flow diagram is presented in Fig. 42. The in-pile piping is type 316 stainless steel; elsewhere, type 347 stainless steel was used. The maximum perturbed thermal-neutron flux is 7×10^{13} neutrons/cm^2·sec, and the peak gamma heat is approximately 5 w/g.

The legs of the U tube are encased in stainless steel vacuum jackets, which provide thermal insulation and secondary containment. The assembly fits into two modified ORR experiment core-pieces, as shown in Fig. 43. Each is sealed with an O-ring gasket in a "breachlock" flange closure above the reactor vessel, which is opened for insertion and removal of test assemblies. Above this point, 11 ft of pool water serves as a shield during the removal operation. The arrangement of the ORR pool and hot cell is convenient and safe for test-specimen removal, storage, inspection, and preparation for shipment. A special containment vessel and equipment for removal of ruptured fuel specimens is available; however, no serious fuel failures have occurred. Photographs of typical test fuel element assemblies are shown in Figs. 44 and 45.

In order to ensure reliability of cooling for fuel elements, the three main loop pumps are arranged in parallel with check valves and an electrical control system that will start another pump automatically if the operating unit fails. A dc-ac motor-generator set with rectifier and batteries operates continuously and is available to provide the power needs for loop cooling. It also serves as a second power source for GCR-ORR loops 1 and 2. An isolated water system separates the loop primary system from the reactor pool cooling water system to which the heat generated in the loop is dissipated. The loop is pressurized from a separately heated tank equipped with vapor flash nozzles and vents for degassing. The loop is well equipped with fill, vent, and drain lines that terminate at the sampling station. In Fig. 46, the sampling station is in the background with the loop control panel on the right and the cell shielding wall with loop valve extension handles at the left.

An out-of-pile test section is located with the auxiliary equipment in a shielded cell in the basement of the ORR building. This provides convenient access for insertion of nonnuclear experimental equipment, such as electrically heated surfaces and special filters. Water samples can be removed at loop operating temperatures. Ion exchangers are provided in the loop fill system and in a bypass stream to maintain the necessary water purity and pH. Hydrogen additions can be made to scavenge oxygen and reduce radiolytic decomposition. A small high-temperature bypass stream makes possible tests of small filtration devices located at the sample station.

All loop components have operated satisfactorily. Leakage has been negligible, with makeup required only for replacement of the water removed by sampling. Oxygen concentrations are consistently below 0.020 ppm with addition of hydrogen. Particulate matter is also found to be at low levels of concentration: ~1 to 4 ppm. This has resulted in low contamination in the equipment room; the activity is usually below personnel tolerance levels. Direct radiation levels in the equipment room are near working tolerance levels at shutdown and have not exceeded 75 mr/hr during operation. The sample station area also is kept free from contamination by good sampling techniques.

Low leakage rates and excellent performance of the loop make possible carefully controlled water-chemistry experiments of long duration. Several experiments with water purification have been conducted, particularly with Magnetite filters for removing crud, and improved analytical techniques for water-chemistry measurements have been developed. The water chemistry program objective is development of improved equipment for the removal of impurities at concentrations less than 1 ppm.

A fixture has been provided in which a fuel specimen assembly irradiated in the loop can be removed from its support conduit for examination. The element can be rotated in two planes while in the fixture to provide for viewing and photographing of exposed surfaces through a periscope. Following examination, the assembly can be reattached to the support and reinserted in the loop for further irradiation. Should the element condition have deteriorated so that further irradiation is not desirable, it can be transferred from the fixture to the ORR hot cell. A photograph of the device is shown in Fig. 47.

Fuel tests presently under way are in support of the standard package, PM, Army reactor development with fuel specimens provided by the Martin Company Nuclear Division.[32] A summary of fuel elements and test conditions for experiments conducted in the loop is given in Table 6.

MTR Capsules and Loop Equipment

The MTR fuel irradiation test facility was originally developed to operate molten-salt loops for the Aircraft Nuclear Propulsion Program and later for the Molten-Salt Reactor Program,[33] and it has since been modified to accommodate irradiation capsules of various types.[34,35] The 6-in. beam hole at the MTR provides considerable volume at a rather high thermal-neutron flux, $\sim 1 \times 10^{14}$ neutrons/cm^2·sec. The high flux and the conveniences offered by the equipment installed facilitate testing a wide variety of fuel types and configurations.

MTR Loops

The loops as initially installed were compact forced-circulation units for obtaining corrosion data applicable to molten-salt reactors. They were designed to operate in the MTR (HB-3) beam hole. Several tests were conducted with two fused-salt mixtures (NaF-ZrF_4-UF_4 and Li^7-BeF_2-UF_4) in loops constructed, respectively, of Inconel and INOR-8 (nominal composition: 70% Ni, 16% Mo, 7% Co, 5% Fe, 2% other alloying elements). The conditions for these tests are presented in Table 7. Each loop contained a pump to circulate the molten salt through a hairpin-shaped length