U.S. NAVAL BASE, PEARL HARBOR, RED HILL UNDERGROUND FUEL STORAGE SYSTEM
(Joint Base Pearl Harbor-Hickam, Naval Supply Systems Command Fleet Logistics Center Pearl Harbor)
(Red Hill Pumphouse, Tanks, Tunnels, Adits, and Ventilation Structures)
Linear underground system extending from North Road to Icarus Way, Joint Base Pearl Harbor-Hickam
Honolulu
Honolulu County
Hawaii

HAER HI-123
HAER HI-123

PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

HISTORIC AMERICAN ENGINEERING RECORD
National Park Service
U.S. Department of the Interior
1849 C Street NW
Washington, DC 20240-0001

HISTORIC AMERICAN ENGINEERING RECORD

U.S. NAVAL BASE, PEARL HARBOR, RED HILL UNDERGROUND FUEL STORAGE SYSTEM (Joint Base Pearl Harbor-Hickam, Naval Supply Systems Command Fleet Logistics Center Pearl Harbor) (Red Hill Pumphouse, Tanks, Tunnels, Adits, and Ventilation Structures)

HAER No. HI-123

Location: Linear underground system extending from North Road to Icarus Way
Joint Base Pearl Harbor-Hickam
Honolulu County, Hawaii

Present Owner: U.S. Navy

Present Use: Fuel storage system, which includes the following facilities: Pumphouse (Facility No. 59), Surge Tanks (Facility Nos. 1224 to 1227), Fuel Tanks (Facility Nos. 328 to 347), Lower Tunnel (Facility No. S-21), Upper Access Tunnel (no Facility No.), Stand-by Power Plant (Facility No. S-308), Powder Magazines (Facility Nos. 350 to 353), Adits 1 through 6 (Facility Nos. S-275, S-312, S-314 and three with no Facility Nos.), and Ventilation Structures (Facility Nos. S-197, S-213, S-315, 348, 354, and one with no Facility No.)

Significance: The Red Hill Underground Fuel Storage system is significant as a unique engineering design and for its association with the build-up to and years of World War II (WWII). The planning for massive underground fuel storage had started as early as the late 1930s, since the Navy recognized the vulnerability and quantity inadequacies of its aboveground fuel tanks, dating from the 1920s. The required fuel storage capacity was enormous and the design solution was unprecedented. The unpredictable layers of the island's lava rock made excavation difficult, yet the Contractors Pacific Naval Air Bases (CPNAB) carved twenty vertically orientated tanks, measuring 100' in diameter and 250' in height, out of the Red Hill ridge in record time, in response to wartime needs. Part of the significance of the fuel system is its contribution to the Allied WWII victory in the Pacific. Initially, it supplied the ships and submarines going to the forward lines, as well as all the Navy's support activities in Hawaii. In later years, it supplied ships and aircraft. It has provided fuel for the Navy continuously since completion in 1943.

Prepared by: Ann Yoklavich, Dee Ruzicka, and Polly Cosson Tice
Architectural Historians, Mason Architects, Inc.
and
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Map assistance by Andrew Tomlinson, Pacific Consulting Services, Inc.

Large-format photographs by David Franzen Photography

Date prepared 2015

Project Information: This HAER report was prepared simultaneously with an ongoing Fire Suppression and Ventilation System improvement project. Funding for that life safety project is through the Defense Logistics Agency. The Navy is donating this HAER documentation to the National Park Service.

PART I. HISTORICAL INFORMATION

A. PHYSICAL HISTORY

Date of Construction: August19, 1940 to September 30, 1943[1]

Engineers: Key Professionals associated with project:[2, 3]
James Growden – Consulting Engineer, Aluminum Company of America
George l. Youmans – Vice President & Project Manager, Morrison-Knudsen
B. A. Peters – General Superintendent, Morrison-Knudsen
H. L. Leveton – General Superintendent, Morrison-Knudsen
Charles P. Dunn – Chief Engineer, Morrison-Knudsen
John L. Savage – Chief Designing Engineer, Bureau of Reclamation
H. S. Austin – Standard Oil Company of New York [
C. R. Rankin – Consulting Engineer, U.S. Reclamation Service
Dr. Harold T. Stearns – Consulting Geologist, U.S. Geological Service
J. H. A. Brahtz, Lt. Comdr. – Civil Engineers Corps, U.S. Navy Reserve
R. McBeanfield – Designing Engineer, Contractors Pacific Naval Air Bases

Builders/ Contractors/ Suppliers: Major companies associated with project:[2, 3]
Contractors Pacific Naval Air Bases (CPNAB) consortium included:
Morrison-Knudsen Co., Inc.
Raymond Concrete Pile Co.
Hawaiian Dredging Co., Ltd.
Turner Construction Co.
J. H. Pomeroy and Co., Inc.
W. A. Bechtel Co.
The Utah Construction Co.
The Byrne Organization

Original Plans and Construction: CPNAB prepared the original plans and built the Red Hill fuel system.

Alterations and Additions: The Navy has issued several contracts for improvements, alterations, maintenance, and repair of the Red Hill facilities over the decades. The structures added to the system in the 1960s include the Vent Structure atop Utility Shaft #73, plus Adit 6 and its tunnel. See discussion under each facility or facility type description.

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[1] Contractors Pacific Naval Air Bases, "Technical Report and Project History, Contacts, NOy3550 and NOy-4173," Chapter XV, Red Hill, in Appendix A. Typescript report on microform, from library of Naval Facilities Engineering Command, Pacific [1945]. p. A-633. (Hereafter CPNAB, "Technical Report").

[2] American Society of Civil Engineers, Hawaii Section, "National Historic Civil Engineering Landmark nomination form for Red Hill Underground Fuel Storage Facility." Typescript obtained in pdf format from American Society of Civil Engineers. Submitted 1993. p. 5. (Hereafter ASCE -HS, "NHCEL nomination form").

[3] CPNAB, "Technical Report" [1945]. pp. Basic 14, A-641 & A-647.

B. HISTORICAL CONTEXT

1. Design Purpose

The purpose of the Red Hill Underground Fuel Storage System was to provide a hidden and protected set of tanks and related fuel facilities. The project was kept secret until after WWII, although thousands of personnel worked on it. Plans were completed and construction initiated before the December 7, 1941 Japanese attack on Pearl Harbor.

2. Construction History

The following construction history is quoted from the National Historic Civil Engineering Landmark (NHCEL) nomination form.[4] The history portion of the NHCEL form was prepared by James E. Murray, the Public Affairs Officer of the Fleet and Industrial Supply Center.[5] The writing does not follow some of the style suggestions for HAER reports. For instance, "feet" is spelled out, rather than using the single quote mark after dimension numbers. These are left as in the nomination form, since it is a quotation.

> **Introduction**
>
> The construction of the U.S. Navy's Red Hill Underground Fuel Storage … began as a crude sketch on a cocktail napkin and evolved into one of the most remarkable engineering feats of World War II. Greeted initially with doubt, it eventually sparked the transformation of a hill of volcanic rock into an elaborate honeycomb of immense fuel tanks. Shrouded in secrecy and constructed during the darkest days of World War II, it was known simply as "the Underground." Today we refer to it as the Red Hill Underground Fuel Storage Facility and recognize it as the foremost system of underground storage tanks of its time. Still in use and virtually unchanged over a span of 50 years, Red Hill remains a superb symbol of the innovative engineering that built America.
>
> **The Need Develops**
>
> War clouds were looming on the horizon when, in 1938, the Navy Shore Development Board expressed grave concern over the "adequacy and security of fuel oil storage at Pearl Harbor." The board's concerns were not unfounded. The entire fuel supply for the Pacific fleet was contained in above-ground fuel tanks located throughout the naval base. Prominent and vulnerable, they all but beckoned enemy pilots.
>
> The Board's fears were later echoed by Admiral Chester Nimitz, Commander-in-Chief of the U.S. Pacific Fleet. Said the admiral: "We had about 4,500,000 barrels of oil out there and all of it was vulnerable to .50 caliber bullets. Had the Japanese destroyed the oil, it would have prolonged the war another two years." Today, war historians believe that the destruction of Pearl Harbor's fuel tanks would have deterred the Allies' advance across the Pacific far more than the damage inflicted on the fleet during the December 7, 1941 attack.
>
> Aside from their vulnerability, the tanks had one other drawback: they simply did not provide adequate storage capacity.
>
> In view of these deficiencies, the Fuel Storage Board recommended to the Secretary of the Navy "that the present tank farms be removed as rapidly as appropriations can be obtained to place the oil underground at least to the point of concealment."

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[4] ASCE-HS, "NHCEL nomination form."

[5] James A. Gammon, Source information in Comment 3b of e-mail attachment from former Supply Center Fuel Department Superintendent to Ann Yoklavich of Mason Architects, Inc., February 19, 2015.

The board's recommendation, which came on June 25, 1940, sparked a plan that called for the construction of four 300,000-barrel capacity horizontal storage tanks, each 1,123 feet long, 20 feet wide, and 42 feet high. The tanks would be set deep into the earth so that they would be impregnable to assault by enemy aircraft. Additionally, the tanks were to be situated away from Pearl Harbor so as not to interfere with future expansion plans for the base and to reduce the possibility that a single attack could wreak devastation upon the fleet and its fuel supply.

The plan also called for the construction of facilities to unload tankers and refuel ships.

Just days after the Fuel storage Board released its report citing the inadequacies of Pearl Harbor's fuel storage, initial design and construction funds of $4 million were provided; an additional $2.25 million was appropriated in September 1940. Regarding the facility's design, the Navy was adamant that the fuel be stored underground; other than that stipulation, the on-site engineers were given a free hand in determining the optimal design of the tanks. Time was of the essence. With each passing day, war became more of a possibility, and there was no exaggerating the clear and urgent need for a secure fuel supply.

The Planning Begins

The fundamental principle behind the design of the facility was that the basic structure of the tanks would be the rock enveloping them. The reinforced concrete tank walls and quarter-inch steel plate lining would be consolidated with the surrounding rock mass by grouting. This would provide the principal strength of the tanks; in effect, the rock would become the tanks' outer wall.

The Navy's Bureau of Yards and Docks retained the services of Contractors, Pacific Naval Air Bases (CPNAB), a joint venture comprised of Raymond Concrete Pile Company, Hawaiian Dredging Limited, and Turner Construction Company. Recognizing that the Red Hill project was primarily a mining job and cognizant of the difficulties inherent to tunneling operations, CPNAB promptly called upon one of the preeminent tunneling specialists - Morrison-Knudsen Company. Eventually, Morrison-Knudsen [M-K] was designated as the prime contractor for the facility.

Studies were undertaken to locate a suitable site for the project. Specifications were hammered out, maps were pored over, ground-studies were conducted, and, in the hills surrounding Pearl Harbor, core borings were taken at the various sites that came the closest to meeting all requirements. After a month-long search, the contractors found what they wanted – a long ridge of volcanic rock, which stretched from the Koolau Mountains to very near the shores of Pearl Harbor. This was Red Hill.

The excellence of the site was apparent. It afforded ample coverage for the facility as well as the necessary elevation to allow gravity flow of fuel from the tanks to Pearl Harbor. Additionally, the hill's great length allowed ample room for expansion. In a notable example of foresight, George Youmans, the M-K project manager, guessed that the Navy would call for the project to be expanded. It did. Four additional tanks were requested. Before the project was completed, it would ask for seven more and, finally, five more. In all, 20 tanks were ordered and delivered, making the selection of the Red Hill site a prescient one.

Some of the greatest engineering minds in America were recruited to work on the project. Among them was James Growden, a consultant with Aluminum Company of America. It was he who developed the concept that would revolutionize the project, transforming it from a common underground tank facility to an underground storage system without precedent.

The Innovative Design is Adopted

One evening after work, Youmans and Growden had dinner at Waikiki's Halekulani Hotel. It was here that Growden unveiled the daring idea which had been running through his mind.

He suggested to Youmans that rather than build the tanks horizontally, they should construct vertical tanks; in effect, a series of immense underground wells having twice the diameter of the horizontal tanks. On a cocktail napkin, he excitedly sketched a diagram of the project.

The two debated the idea late into the night, and Youmans could find few flaws. As an added advantage, Growden's innovative approach solved a problem that had long been the bane of tunnelers – removal of excavated material. When tunneling horizontally, loosened rock must be picked up and loaded onto trucks or other earth moving equipment and then moved out of the passageway and reloaded for disposal. It's a primitive, time-consuming task that requires large gangs of laborers and heavy machinery, all crammed into the confines of the work area. With the tanks in a vertical position, gravity would assist in moving the loosened rock down and out of the excavations and onto a conveyor belt for a short ride to the disposal area. Considering the urgency of the project, any method of shortening its construction was worth exploring.

Growden's concept was surprisingly simple, yet he believed it would have numerous benefits, among them being: 1) it would require less investment in construction equipment; 2) fewer workmen would be needed, thereby minimizing housing and personnel difficulties; 3) it would insure oil-tight storage; 4) it would significantly shorten construction time; and, 5) it would greatly reduce the ultimate cost of the project.

Growden visualized each tank as looking like a vertical capsule inside the mountain. As the initial step in excavating a huge vault – which would eventually become one of the twenty tanks – a shaft would be driven from the top of Red Hill's ridge, down the imaginary centerline of the tank, and out its bottom. Excavation of the tank would then begin at the top. As each shovelful of dirt was removed, there would be no need to truck it out – it would merely be dropped down the vertical shaft. At the shaft's bottom, a belt conveyor would mechanically transport the excavated material outside the mountain to a nearby aggregate plant.

On the very next day, the two presented the radical design to the Officer in Charge of the project at Pearl Harbor. The proposal was scrutinized extensively, not only at the naval base, but also in cables that flew back and forth between Pearl Harbor and Washington, D.C. After being examined from every possible angle, it was enthusiastically approved by Admiral Ben Moreell, then chief of the Bureau of Yards and Docks. Admiral Moreell firmly believed that contractors should be permitted to draw on their own experience and ingenuity in devising innovative ways of accomplishing tasks as long as "integrity of intent" was not sacrificed. Today, Red Hill's pronounced success provides ample confirmation of his beliefs.

The Workforce

Red Hill's construction required a special breed of worker, and when the call went out, they answered from across the nation. They were rugged and gritty tunnel men with the nerve to work hundreds of feet underground, and they arose from the black depths of Colorado copper mines, the gold mines of California, Montana, and the Dakotas, from the silver mines of Idaho and Nevada, and the coal and lead mines of Missouri and Arkansas. Many were fresh from work on other marvels of American engineering - Boulder and Grand Coulee Dams, the Golden Gate, the Los Angeles Aqueduct, and TVA projects.

Not all the workers were recruited from the mainland. Of the local hires, about 800 were Japanese-Americans, despite an unfounded wartime belief that they could not be trusted (for the duration of the war, they were forbidden from working at Pearl Harbor). At Red Hill, Japanese-American workmen were required to wear distinctive "restricted" badges. Other security measures barred them from the tunnels that ran beneath the tanks and prohibited them from testing for leaks in completed tanks.

Despite these indignities, Japanese-Americans were among Red Hill's most loyal and competent workers. Skilled craftsmen, their ranks included many welders, a trade vital to the successful completion of Red Hill's tanks and pipelines. Not a single instance of sabotage was ever uncovered.

An equal number of the workers were Filipinos, who were prized, according to old Red Hill literature, because their "size and nimbleness ideally fitted them for structural work in cramped places."

As the threat of war heightened, the massive undertaking at Red Hill became one of the nation's most guarded secrets. All workers were required to sign affidavits stating that they would not reveal the project to anyone. Civilian guards, hired by the contractor, patrolled the hillside surrounding the site.

The actual construction work on this mammoth undertaking began the day after Christmas, 1940. As the first "tunnel rats" reported to their new work site, they had no idea that they were about to embark on an engineering project without parallel.

A Massive Undertaking

To best comprehend the work that was done, one must mentally picture the site at its completion. Imagine a long, gently sloping ridge, its sides steep and brush-covered, which runs from the cloudy heights of a distant mountain range to a point about two miles from the coastline. Picture yourself standing in the valley to one side of this ridge and viewing a section, which runs about 2,000 feet in length and 400 feet in height.

If you were to peer closely through the brush, you might sight three large steel doors leading into the mountain. Otherwise, nothing above or on the sides of the ridge would provide any indication of the vast honeycomb far beneath the surface.

Imagine, however, that the layers of brush, soil, and rock are peeled away. Clearly visible under the tons of rock and dirt are 20 vertical fuel tanks, set like marching soldiers in two rows of ten. Shaped like immense cylindrical capsules, with a hemispherical dome at each end of the cylinder, the tanks each have a diameter of 100 feet and a height of 250 feet. A 20-story building could fit easily inside each one. They are buried deep in the earth, sheltered by more than 100 feet of hard rock. Each tank is 100 feet from the next (200 feet centerline to centerline) •

Snaking throughout the honeycomb are a series of tunnels. A short cross tunnel connects each pair of tanks at their bottoms, making ten cross tunnels altogether. Similarly, another ten cross tunnels connect the tanks at their springline, the base of the upper dome.

At the exact halfway point of each of the ten lower cross tunnels, they are bisected by the "lower access tunnel." Heading in the direction of Pearl Harbor, this tunnel extends a quarter-mile beyond Tanks #1 and #2, where it connects with the "harbor tunnel." The lengthy harbor tunnel extends for an additional two and one-third miles before finally rising to the surface at a secluded and bombproof underground pumphouse on Pearl Harbor Naval Base. One of Hawaii's last trains (and its only underground train) runs through this tunnel.

Besides the Pearl Harbor portal, the lower tunnel also has another exit at Red Hill. It was through this Red Hill portal that rock excavated from the vaults was removed from the hill on conveyor belts.

A similar access tunnel bisects the ten upper cross tunnels; however, this tunnel does not extend to the Naval Base. It exits at a nearby point outside Red Hill. The upper tunnel runs directly above the lower tunnel, but is separated by 200 feet of volcanic rock.

It was on these two access tunnels that work on the facility began.

In order to reach the ridge's centerline, along which the upper and lower access tunnels would progress, the miners first had to burrow their way into the ridge's interior. This was done via two short approach tunnels, one leading to the beginning of the upper tunnel and one to the lower.

When surveyors determined that the central vertical plane had been reached, the tunnelers turned at right angles and began laboriously working their way up the interior of the ridge. The two passageways, roughly the size of standard railroad tunnels, required considerable blasting. The sequence of operation in driving the tunnels was drill, load (dynamite), blast, muck out, timber, and repeat. Progress was hampered by the presence of cinder pockets and irregular rock stratifications.

As the miners inched their way through their subterranean passageway, gangs of track-laying crews followed at their heels. As fast as the tunnel moved forward, rail lines were laid and the excavated rock and earth was rolled away in miniature rail cars. Tunnels through softer rock required pre-fabricated arch-shaped steel ribs with heavy timbers between the ribs to make the tunnel safe for work to proceed. Tunnels through harder rock were simply coated with Gunite to consolidate any loose rock.

As the sweltering miners wormed their way through the ridge's interior, work began on the top of Red Hill. Using jackhammers and dynamite, crews began driving a vertical shaft down the imaginary centerline of each of the 20 proposed tanks. When the shafts were completed, they extended from the ridgetop to a point just below the bottom of the proposed tanks. These 400-foot shafts measured four by six feet from the surface to the future top of the tank and twelve by twelve feet from there to the bottom. They were the key to Growden's design and would play a vital role in the construction of the underground tanks.

Meanwhile, the lower access tunnel had reached the proposed site of the first pair of tanks. When this point was-reached, gangs of miners turned at right angles and began to excavate new tunnels toward the future tanks, eventually meeting the bottom of the vertical shaft coming down from the ridgetop.

When workers in the upper tunnel reached the site of the first tanks, they, too, began excavating cross tunnels toward the future tanks; however, their tunnels intentionally stopped short of the vertical shaft. Instead, they excavated to the spring line of the upper dome (the point at which the curve of the dome "springs" away from the vertical wall of the cylinder).

It was at this point that the actual construction of the tanks began.

To one unfamiliar with tunneling, the task now facing the miners appeared to be a formidable one. Deep inside the mountain ridge, the miners at the end of the upper cross tunnel faced a wall of solid rock. They had no visible bearings, nor landmarks of any kind - they could see only rock. Despite this, they would attempt to build a tunnel that would encircle the entire spring line of the dome.

This ring tunnel, as it was called, would be 314 feet long and eight feet wide, the eight feet being comprised of the proposed three-foot thick tank wall plus another five-foot wide ledge. The ledge would support the dome while the vault was excavated and the tank lining constructed.

At the end of the upper cross tunnel, two gangs of miners stood back to back and began burrowing blindly into the rock. Heading in different directions and relying only on the guidance of surveyors, they cut their way in a vast circle. Halfway around, the two gangs met. The ring tunnel was complete.

At this point, the workers stoped upward in raises to the crown of the dome, opening a six-foot wide space in the shape of a hemisphere. In effect, they were excavating a life-size mold of the tank's upper dome that would later be filled with a quarter-inch steel plate liner and reinforced concrete. Surveying was not used in hollowing out the dome-shaped space; it would have been unnecessarily difficult. Instead, the timber shoring was prefabricated to the desired dome shape and then used as a template for guiding the excavation.

Foremost in the thoughts of every miner was the relentless, pressing weight of the mountain, just inches overhead. Shattered by the ceaseless blasting, the rock ceiling was weak and threatening. The entire weight of the mountain pressed upon it, and as each shovelful of rock was removed, the danger of collapse became ever greater.

Every square foot of the ceiling was shored with thick lengths of timber. As the miners neared the dome's apex, which had a thickness of only four feet, the work area became so confining that they literally had to squeeze through an intricate latticework of timber.

Backs bent, using little more than picks and shovels, the miners worked around the clock, often in temperatures that reached 120-degrees. Dust never seemed to settle; it filled the air, caking the sweat upon their bodies. Together, the heat and the dust produced an atmosphere that was so thick and unbearable that many men could not complete their shifts.

War had broken out, and due to its demands, it was impossible to obtain more ventilators. Eventually, old wooden airplane propellors [sic] were belted to electric motors as a means of supplementing the ventilation system.

When the stoping[6] was finally completed, the miners had hollowed out an area that is best pictured as an enormous upside down soup bowl, buried under tons of rock and dirt. This hollowed out section did not include the area "inside the bowl" – just the actual bowl itself. The area "inside the bowl" was left as a dome of rock. Now the "difficult" work began.

A framework of pre-cut, pre-drilled H-beams [I-beams] was erected over the remaining dome of rock and affixed to the floor of the ring tunnel. This dome-shaped steel frame would temporarily support the quarter-inch steel plates comprising the inner liner of the dome. In a fabricating yard alongside Red Hill, 144 sections of quarter-inch steel plate were cut to the exact shape and carried through the upper access tunnel to the dome. There, workmen tack welded them into position on the steel frame and butt welded the plates together. The plates had to fit so perfectly that not a pinhole would exist. Imagine constructing a gigantic underground steel Tiffany lampshade, 100 feet in diameter – from a kit. In a sense, this is what the contractor did. Next, a massive amount of reinforcing steel was tied into position in the dome-shaped space.

When completed, the huge form had rock on the upper side, H-beam supported steel plate below, and rebar in between. The hollowed dome was ready to be filled with concrete.

A surface hopper was placed at the top of the vertical shaft and elephant trunks were extended through the shaft and into the excavated area. As the concrete mixture poured into the dome, gangs -of-nimble workmen ripped out the shoring just above the·rising pool of concrete. The pour – 5,000 cubic yards in all -went on continuously for three days – 70 hours in all.

Unfortunately, the completion of a pour did not signal a time of rest for the concrete gang. In planning the work, the contractors had taken a chapter from the Ford Motor Company manual, and an odd, but effective, variation of the assembly line method was used. As fast as the crews finished one dome, they moved on to the next. The assembly line method made it unnecessary to train workmen in all phases of construction.

When the pour had been completed and the concrete had set, grouting was begun. One-hundred and twenty-five grout holes ran throughout the concrete and into the rock. Grout was pumped at 350 pounds per square inch until all the seams and spaces between the concrete and rock were filled. Approximately 34,000 sacks of cement were needed, which was far more than had been anticipated, primarily due to seams and lava tubes in the rock formation. Carried through the ubiquitous lava tubes, grout was liable to appear anywhere.

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[6] "Stoping" is a mining term for "the opening of large underground rooms, or stopes, by excavation." Encyclopedia Britannica, Inc. (Entry on website http://dictionary.reference.com/browse/stoping, accessed March 25, 2015) 2008.

In one instance, it traveled through an extensive lava seam before finally leaking into the upper access tunnel, 200 feet away. Despite these setbacks, the task was successfully completed, and the concrete and steel dome was grouted tightly to the surrounding rock.

With the primary work on the dome completed, the miners now could enjoy the relative security provided by the solid roof overhead. Their attention was then directed to the excavation of the vault in which the tank would eventually be constructed. It was time to see if Growden's novel idea would work.

The initial step in the excavation required an enlargement of the vertical shaft from 12 by 12-feet to 30-feet in diameter. This had been anticipated when the shaft was driven, and 12 foot deep holes for blasting had been pre-drilled. These were now dynamited, and the shaft, referred to as a "glory hole" by the miners, was enlarged.

Hoppers were built at the shaft's bottom, and feeders for these hoppers fed a conveyor belt located in the short cross tunnel that began directly beneath the shaft. This rubber and fabric belt was part of an elaborate system developed by Goodrich Tire Company in Akron, Ohio and built exclusively for use at the Red Hill project. More than five miles of conveyor belts ran in various directions throughout the job site. Some were as wide as four feet and had the strength to handle boulders with diameters of an equal size.

The conveyor belt at the bottom of the shaft, which would receive cascading rock from high inside the tank, led down the cross tunnel to the access tunnel, where it dumped its load of rocks onto another belt. This belt led to a jaw crusher capable of breaking rocks into manageable pieces not exceeding ten inches. The rock was then carried, still on belts, through the portal to rotary screens outside the lower access tunnel. The screens separated waste rock from rock suitable for aggregate.

When excavation on the vault was ready to begin, a gang of miners was lowered through the vertical shaft until they were just under the crown of the dome. Here they began to hollow out the vault. The first step in doing so was to remove the dome of rock that remained when the space for the dome roof was stoped out.

Once-they had cut themselves sufficient-elbow room and the excavation reached the spring line, a circular wooden work platform was suspended in the dome. Approximately six feet wide and 100 feet in diameter, the "catwalk" was capable of being raised and lowered with hand winches. The platform, which extended around the entire wall of the tank, was reached by an accordion [sic] stairway suspended from the end of the upper cross tunnel. All work was done from this platform, which held floodlights and air and water lines.

As the miners blasted and cut the earth, they intentionally sculpted the ever-deepening pit into the shape of a funnel. The earth was at its highest directly beneath the catwalk, wherepon [sic] it sloped sharply toward the "glory hole" in the pit's center. This was all part of Growden's grand vision.

The rock, loosened by controlled blasting, tumbled down the pit's slope and into the shaft. There it plunged to the waiting conveyor belt far below.

Growden's plan worked remarkably well. From the time the blasted rock began its fall, until the moment the conveyor belts carried it outside the hill to the aggregate plant, the rock was untouched. It is estimated that 75 percent of the rock was removed in this manner; the remainder was "hand-mucked" to the shaft.

The amount of time and labor this saved was tremendous. It eliminated the need for heavy machinery and greatly reduced the amount of men, money, and time necessary to complete the project.

Perceptive readers might imagine that if a miner were to ever fall from the catwalk then he, too, would plunge horribly down the steep slope and into the shaft. Regrettably this was the case. Despite safety belts, one or two men did meet a grisly fate in just this manner.

As a safety precaution, a six-inch coat of Gunite was applied to the wall of the vault above the catwalk. Each time the catwalk was lowered another 20-feet, more Gunite was applied to protect the men from loosened rocks.

When the entire vault had been hollowed out, a steel construction tower was erected in its center. The tower stretched from the very bottom of the vault to the top of the upper dome. The tower supported concrete chutes, power cables, and other equipment necessary for the installation of reinforced concrete and steel lining. In addition, four booms suspended from the tower were used to hoist steel plates and rebar into position. Pre-fabricated on forms in the yard outside, the plates would provide the vault's inner lining.

Upon completion of the tower, piping connections were installed from the lower tunnel to the vault; these included fuel lines, drain lines, grout pipe, tell-tale pipe, etc. Cooling coils were included in all except the first vaults.

Once the reinforcing steel had been set, the enormous concrete plug upon which the tank sits was poured to within a few feet of the eventual tank bottom. Construction of the vault lining could now begin.

For the first (bottom) section, template steel was set carefully along the joint lines of the future steel lining. Reinforcing steel was added. A fairly stiff mix of concrete was poured to the top of the first section and screeded to the proper slope, using the template steel as screeds. For the remaining bottom sections (each ring sloping more steeply than its predecessor) the procedure differed; after a template had been set, and reinforcing steel placed, the cut-to-shape steel plates forming the inner lining were installed and welded to both the template steel and to each other; thus they became the form for the next lift of concrete. This concrete was poured rather wet, and the forms were well vibrated, to insure complete penetration of concrete to corners under the plates.

The cylindrical barrel of the tank would be lined with concrete varying from four feet thick at the bottom to two and one-half feet at the springline of the upper dome and with a quarter-inch steel plate inner lining. In constructing it, the method employed was as follows. The wall was built in five-foot lifts, using the quarter-inch steel lining plates as the inside form. Reinforcing steel for each lift was first set and tied in place; steel plate was then placed and welded, a cantilever stiffening form of steel studs and walers was raised, and pouring began.

Concrete was brought down a ten-inch pipe to a hopper, which could be moved around the steel tower to supply anyone of four boom-suspended concrete chutes, each of which could be swung through a 90-degree arc. The last step in each pour was to set a plywood grout stop near the center of the wall, to prevent grout from escaping through the joints during the pre-stressing operation, and blowing in the steel lining.

This·cycle of operations was repeated by pours until the upper dome was reached. Here, an expansion joint was introduced at the junction of the steel linings. The joint would take up possible settlement and prevent rupture of the lining. Initial grouting consolidated the rock beneath the tank; approximately 15,000 sacks of cement were used for each task. Prestress grouting could now begin .

At the base of the vault, where the pressure would be greatest, the concrete was four feet thick. At its uppermost point, it was less than three feet. As expected, the cured concrete shrank away from the gunited rock wall. Into the narrow opening that resulted, grout was pumped until not an iota of empty space remained between the concrete and the rock (grout injection and relief pipes had been installed as the tank walls were constructed). High pressure grouting to pre-stress the tank wall was another of the key elements in Growden's plan.

As previously stated, the tanks were designed in such a manner that the liquid pressure in the tank would be resisted by the rock walls rather than by the man-made walls. High pressure grouting was designed to pre-stress the concrete and provide an inward push that would be greater than the outward push expected from a full tank of oil. This would prevent the hydrostatic pressure of the oil in the 250-foot deep tank from bursting the welded seams of the steel plate. Grout was pumped under a pressure 20 percent greater than that expected from the oil.

Once the grouting was done, a tank was basically completed; it was time to check for leaks.

As the initial step in leak detection, the tank lining was scrubbed down, with particular emphasis placed on the joints. The central bottom section of steel plate was set and welded, and leak testing began. Air was introduced under pressure beneath the steel lining; soapy water was applied to each joint, and leaks were located by telltale bubbles. Bad welds and leaky joints were chipped out and rewelded. Telltale pipes for pinpointing of future leaks were installed. The pipes tapped each five-foot section behind the steel lining, and led to an inspection point in the lower access tunnel.

As testing of the bottom section was completed, water was introduced into the tank and testing crews worked their way around the walls in boats. In order to test horizontal joints, the rise of inflow was arrested every five feet. If water appeared at the telltale pipes in the lower tunnel, the level was lowered until the leak was discovered and sealed. As a final check, after all disclosed leaks had been stopped, the vault was filled with water. To the surprise of observers, instead of maintaining its level, or dropping due to leakage, the first phenomenon observed was a rise in the water level. This was attributed to the temperature increase after the water entered the tank.

Once when three welders were checking for leaks, their boat capsized. Two could not swim, and they both drowned – ironically, inside a mountain. In all, 17 men died on the Red Hill job.

Wartime Working Conditions

Readers should not forget that the attack on Pearl Harbor, just three miles away, occurred about one year into the project. The attack, itself, had little impact on the site; the Japanese had their sights set on ships and airfields. Five workmen, however, were wounded by shrapnel, and one man died from bullet wounds. Ironically, the attack indirectly caused a greater number of deaths after it had ended.

A blackout was put immediately into effect. Since 90 percent of Red Hill's work was done underground, the blackout had little effect on those who labored inside the mountain; however, the outside crew worked under the "light" of a 20-watt bulb placed inside an upside down tin can and suspended at a height of three feet. Under such conditions, safety precautions suffered; several fatal accidents were directly attributable to inadequate lighting.

The attack affected the project in other ways. Workmen were pulled from the job and put to salvage or repair work. The critical need for skilled labor at Pearl Harbor significantly reduced the supply available for Red Hill. In particular, there was a shortage of qualified welders, who were obviously very much in demand at Pearl Harbor's ship repair facilities. To make matters worse, welding torches and other equipment were loaned to the war effort.

Rigid security measures resulting from the war, particularly curfews, affected more than the progress of the work, it also affected the morale of the men. Following the attack, a Marine detachment was sent to Red Hill and remained there until the project was completed. Some of the workers were apparently unprepared for the tightened security; one was shot and killed when a car he was in did not halt for the Marine sentry.

Success

Despite the exigencies of war and the many other difficulties, expected and unexpected, that assailed the project, the first tank was completed in September of 1942 and received its first oil on September 28 of the same year. The entire project was delivered on September 30, 1943 – nine months ahead of schedule.

Using a design that some viewed as preposterous and inconceivable, the intrepid builders had taken less than three years to transform a hill of volcanic rock into a vast honeycomb of fuel tanks. In so doing, they had battled unusual hazards posed by rugged construction, the shortages of men and material caused by the war, and the doubts of their peers (as late as May of 1941, a call was raised to return to the horizontal tank design).

The job's total cost came to approximately $43 million; however, that included facilities other than the fuel storage tanks and tunnels. The primary ones were a bombproof, underground pumphouse located at Pearl Harbor and a 54-foot by 1300-foot reinforced concrete fueling pier. In addition, a cavern was excavated alongside the lower access tunnel, and a shaft was driven down and then horizontally into the fresh water table. An underground pumping station was built to handle the water flow of 30 million gallons per day. All these facilities remain in use today.

The core of the project, of course, was the Red Hill Underground Fuel Storage facility. Construction of its tanks involved numerous features for which no -precedent was found in design or construction. Although numerous tunnels had been built in the lava of surrounding mountains, no construction project had ever been attempted, in Hawaii or elsewhere, which required the 100-foot rock span necessary in the building of these 20 immense vaults.

When completed, the tanks, each 250 feet high, 100 feet in diameter, and buried more than 100 feet in a mountain ridge, stored and protected 252 million gallons of fuel, the lifeblood of the Pacific fleet.

The Red Hill facility was constructed so skillfully and with such foresight that major alterations have been virtually unnecessary. Although it took 3,900 men working around the clock nearly three years to build it, it requires only four personnel to operate it today.

Safe from every known sort of enemy action, yet available for dock-side refueling at the rate of 20,000 barrels an hour, the facility was one of America's greatest in respect to the security of the nation; in addition, it had a decisive role in America's eventual victory in World War II.

As American forces battled their way across the Pacific, painstakingly regaining territory that had been lost in a few violent weeks in late 1941 and early 1942, they did so with fuel from the Red Hill facility. It comes as no surprise that, at the height of the war, Admiral Chester Nimitz referred to the Pearl Harbor Naval Supply Depot (the depot had control of the tanks) as "the secret weapon of the Pacific."

The major alteration project at Red Hill, after the initial construction, was the conversion of four tanks to store aviation fuel (jet fuel and aviation gasoline) in the early 1960s. A report by the Navy about the project noted the architects and engineers for the project were Earl and Wright of San Francisco. The construction contract was awarded to "Red Hill Contractors, a joint venture of Gunther & Shirley Company, E. V. Lane Corporation, and Gibbons & Reed Company."[7] Parts II and III provide further information about this conversion project.

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[7] District Public Works Office, Fourteenth Naval District, "Conversion of POL Facilities at Red Hill, Hawaii, Contract NBy 25540. " Typescript report in Technical Library of Fuel Department, at Pearl Harbor, Fleet Logistics Center. Prepared for the Bureau of Yards and Docks, Department of the Navy, [1960]. p. 4.

PART II. STRUCTURAL/DESIGN/EQUIPMENT INFORMATION

A. GENERAL STATEMENT

1. Character of Red Hill System

The Red Hill underground fuel storage system is a linear complex of interconnected facilities. It comprises forty-four facilities, grouped into five categories and eighteen facility types, all of which are covered in this report. Table 1 shows the facility names and numbers.

Table 1. List of Extant Historic Facilities in Red Hill Underground Fuel System, by Categories

Fac. No.	Fac. Name
Fuel Pumphouse	
59	Underground Fuel Oil Pumphouse (includes 11 portions)
Fuel Tanks	
1224 to 1227	Surge Tank Type (4 tanks)
328 to 347	Fuel Tank Type (20 tanks)
Tunnels/Underground Spaces	
S-21	Lower Tunnel (includes Harbor Tunnel, Makalapa Tunnel & Lower Access Tunnel sections)
None	Upper Access Tunnel
S-308	Stand-by Power Plant (not in use)
350 to 353	Powder Magazine Type (not in use)

Fac. No.	Fac. Name
Adits (Entrances and connecting tunnels)	
none	Adit 1 (to Lower Tunnel)
S-275	Adit 2 (to Lower Tunnel)
S-312	Adit 3 (to Lower Tunnel)
S-314	Adit 4 (to Upper Tunnel)
none	Adit 5 (to Upper Tunnel)
none	Adit 6 (to elevator 73)
Ventilation Structures	
S-197 & S-213	Bombproof Tank Vent Type
S-315	Tunnel Air Intake / Elevator #72 Shaft
348	Altered Bombproof Tank Vent
354	Main Tunnel Exhaust Port/Shaft
none	Vent Structure on Utility Shaft #73

2. Condition of Fabric

The extant original fabric is in good condition and well-maintained. Replacement of some original mechanical equipment has been required over the years to accommodate newer and safer systems. The numerous conduits, fire-protection-system pipes, and modern mechanical control devices added, especially to the Lower Tunnel and to the Pumphouse, have obscured some of the original character of those historic facilities.

B. SITE LAYOUT

The overall site map at the end of the text section of this report shows the linear and interconnected nature of this underground fuel system. The vertical elements are illustrated in the isometric of the tank area that follows the overall site map. The 20 vertical tanks are connected horizontally by both the Lower Tunnel and Upper Access Tunnel. Two elevators (#72 and #73) connect those tunnels, and the Adit 6 tunnel is at an elevation between them. Vertical shafts from the tunnels or tanks connect to the six ventilation facilities on the Red Hill ridge.

C. DESCRIPTIONS

Note that most dimensions given in this report are those on original or alteration drawings of the underground fuel system. Hand measurements could not be made in most instances. There is a note on original Y&D Drawing No. 294048: "Dimensions for excavation in rock are minimum dimensions. Actual surfaces will be irregular."

1. UNDERGROUND FUEL OIL PUMPHOUSE, FACILITY NO. 59

This large facility is a critical part of the Red Hill fuel storage system. It is a complicated structure, mostly underground except for a few portions that are visible above ground. The portions of this facility consist of:

a. Exhaust fan enclosure (part above grade and part underground, northwest of Adit 1),
b. Valve house, also called Valve Chamber 1 or VC-1 (largely underground, south of Adit 1),
c. Pipe gallery (below entrance tunnel, underground between exhaust fan enclosure and pump room),
d. Entrance tunnel (underground between Adit 1 and main rectangular portion of facility),
e. Air intake vent (rising from entrance tunnel, with part of it above grade),
f. Main rectangular portion (all underground), which contains the following spaces:
    1. Transformer room (multi-level space),
    2. Control room suite (including control room, private office, bathroom, and closets),
    3. Ventilation ducts and spaces for pipes and wiring (below control room),
    4. Passageway (between entrance tunnel and pump room), and
    5. Pump room (the upper space and the foundation level with air ducts and piping).
g. Storage room (a trapezoidal-plan underground space on the north side of pump room),
h. Two layers of thick reinforced-concrete roofs over the main portion and storage room,
i. Concussion chamber (empty space between roofs) over the main portion and storage room,
j. Three relief vents (partly above ground elements, connected to concussion chamber), and
k. Surge tank tunnel extending from pump room to Surge Tank No. 4
   (the four surge tanks, Facility Nos. 1224-1227, are described under "Fuel Tanks" heading).

The main rectangular portion and the storage room of Facility No. 59 are protected by the two layers of bombproof reinforced-concrete roofs, the concussion chamber, and several feet of earth cover. [The word bombproof is used, rather than the more accurate adjective "bomb-resistant, " because the Navy Bureau of Yards & Docks used the word "bombproof" for facilities classified as resistant to a direct hit by a 2000-pound, or smaller, bomb. This is in contrast to facilities designed as "splinterproof," which were resistant to the shrapnel and other debris sent flying by near-miss bombs[8].] These elements shield the important pumping equipment linking supply ships and receiving vessels berthed at Pearl Harbor to the underground tanks within the Red Hill ridge. The other underground portions have the protection of thick earth cover and bombproof roofs of reinforced concrete. This facility has only a few architectural features visible above ground, as noted in the list above.

[8] Barbara Shideler and Ann Yoklavich, "U.S. Naval Base, Pearl Harbor, Bombproof Facilities," HABS HI-391, Historic American Buildings Survey, National Park Service, 2004. p. 3.

Facility No. 59, Overall Dimensions

Exhaust Fan Enclosure: This portion of Facility No. 59, located west of Adit 1, is partially above and partially below grade. The footprint of the new enclosure measures 16'-0" square and the height of its roof is approximately 10'. The four fans on top of the concrete roof rise another 6'-5". The new concrete enclosure and four exhaust fans were installed in the late 1990s/early 2000s under project PRL 98-08.[9] Inside the new enclosure is the original sump, which measures 9'-0" x 7'-0" in plan, and extends about 12' below grade.

Valve House (VC-1): The footprint of the valve house measures 21'-2" x 13'-6", including its 10"-thick walls. It abuts the wall of the underground pipe gallery. The 8'-0" interior height of the valve house plus its 10"-thick ceiling raises its top slightly above the level of the slightly sloping asphalt paving in front of Adit 1. An angled access section rises another 3'-10" above the top of the valve house, in its southeast corner.

Pipe Gallery and Entrance Tunnel: The pipe gallery is almost 300' long, with a width of about 20', including the concrete walls, which are approximately 1' thick. The entrance tunnel, located directly above the pipe gallery, is shorter by about 30', but typically the same width. However, the eastern end of the entrance tunnel is approximately 40' wide, to create a space for Fan No. 5 (space now holds two replacement fans) and to incorporate walls about 2' thick. The clear height of the pipe gallery is typically about 8', but the ceiling of the pipe gallery slopes down at its western end, where the lowest clearance is approximately 4'. In the entrance tunnel, the highest part of its arched ceiling is 12'-9" above the floor. The reinforced-concrete, barrel-arched roof over the entrance tunnel/pipe gallery is 6'-0" thick, a measurement typical of bombproof roofs.

Air Intake Vent: This vent rises above the entrance tunnel at about its midpoint. Measured from the top of the tunnel's arch, this portion of the facility extends upwards approximately 23'. The part seen above grade is only about 12' in height; the observable elements are the approximately 6'-thick bombproof roof, columns supporting the roof, screens over the air intake openings, and some of the vent's foundations. The plan dimensions of the air intake vent's bombproof roof are 50'-0" x 43'-0".

Main Rectangular Portion: The footprint dimensions of the main rectangular portion of Facility No. 59 are 252'-9" x 63'-0", including the 5'-0" thick walls. The total overall height of this portion of Facility No. 59, from the lower concrete floor to the suspended ceiling level is about 20'. Of that overall height, the distance between the concrete foundation slab and the large area of steel-grate flooring in the pump room is 7'-5". There is a distance of 4'-0" between the suspended ceiling and the highest point on the underside of the arched roof above it. [The space between the suspended ceiling and the underside of the arched roof above is the plenum. Its purpose is to receive and distribute incoming fresh air throughout the spaces below the suspended ceiling.] The largest space in the main rectangular portion of Facility No. 59 is the pump room; it measures 185'-8" x 53'-0" in plan, not including the wall thickness. The remaining area, about 57' x 53' (not including outer walls), is at the west end of the main rectangular portion. It contains the other spaces: transformer room, control room, private office, bathroom, passageway between the entrance tunnel and pump room, and the area below the control room and adjacent rooms.

Storage Room: Along the north side of the main rectangular portion there is a trapezoid-plan storage room, whose width (projection beyond the pump room wall) is 19'-0", including its 4'-0" thick wall. So the width of the room between the walls is 15'-0". The median length is approximately 45' or about 37' of interior length between the 4'-0"-thick, angled end walls. The height from floor to ceiling of the storage room is about 24'.

Two roof layers: The lower arched roof is 4'-0" thick concrete, very densely reinforced. It covers the main rectangular portion of Facility No. 59, the storeroom on the north side, and the space for Fan No. 5 to the

[9] James A. Gammon, Comment in e-mail attachment from former Supply Center Fuel Department Superintendent to Ann Yoklavich of Mason Architects, Inc., December 29, 2014.

west of this portion. The length and width of this roof are, respectively, approximately 270' x 67'. It is longer than the length of the main rectangular portion because the roof extends over Fan No. 5 space. Some of the roof's additional width is due to bulges measuring about 2' beyond both of the 5'-thick walls (the concrete bulges fill the areas on each side of the excavation termed "continuous hitch cuts" on a structural drawing). Also, this lower roof has an additional width extension of 19' over the storage room. Both upper and lower arched roofs have flat extensions over this room. Over the Fan No. 5 space the lower roof has varying thickness (up to 12'), due to the large air duct between the fan and the rooms in the main rectangular portion. The top of the upper roof is about 42' above the floor of the pump room and 13'-6" above the top of the lower arched roof. At least 3' of rock and dirt lie over the upper roof. The bombproof upper roof is 6'-0"-thick, densely reinforced concrete; its length and width are 272'-9" x 83'-0". There are 10'-0"-wide, eave-like extensions beyond the walls of the rectangular main portion. The upper roof's flat extension over the storage room measures about 72' x 20'.

Concussion Chamber: The concussion chamber, the air space between the two arched roofs, is 7'-6" high. It covers the entire main rectangular portion and the storage room and extends into the three relief vents. The distance between the retaining walls of the east and west relief vents measures about 285', but the length of the concussion chamber, if measuring between the outer faces of the east and west sets of piers, is approximately 253'. The typical width of the concussion chamber is 53'-0" between the north and south walls; however, where the space extends to the north, over the storage room, the width is about 94'.

Relief Vents: The depth of western and northern relief vents is approximately 18', while the depth of the eastern relief vent is about 22'. All three vents have steel-grated openings at grade, measuring 52'-0" x 6'-0". The walls surrounding these openings, and extending below grade, are 1'-0" thick; their height above grade varies. Due to the 10'-0" overhang of the upper roof, the width of each relief vent's lower section is 16'-0", measured between the retaining wall and the outer face of the piers that support the roof.

Surge Tank Tunnel: This portion of Facility No. 59 is L-shaped in plan, with a curved section at the inner angle of the L to accommodate the piping between the pump room and the surge tanks. The short part of this tunnel extends south 59'-0" from the pump room, and the longer leg, connecting the four surge tanks, has a length of approximately 252'. The tunnel width is 12'-8", except at the bend, where the width averages about 16'. The height of the surge tank tunnel is 14'-6". Dimensions and other descriptive information about the small tunnels connected to the surge tanks (south of this tunnel) are under the section heading "Fuel Tanks."

Facility No. 59, Foundations

The facility has reinforced-concrete foundations with spread footings and concrete slabs. A few isolated (single spread) footings are used. The line of columns down the center of the pipe gallery are spaced 14'-0" on center and typically are supported by 1'-thick footings that are either 3'-square or 4'-square in plan. Generally, there are continuous footings supporting series of columns, or strip footings under foundation walls. The foundation design is complicated, especially in the pump room and transformer room for support of heavy equipment. In addition, the varied floor slab levels of those rooms incorporate air ducts. Other areas with unique foundation details are where the different sections of Facility No. 59 join, such as the junctions of the main rectangular portion with the storage room, with the entrance tunnel/pipe gallery, and with the surge tank tunnel. The concrete footings extending under the 5'-0" thick perimeter walls of the main rectangular portion are 7'-0" wide with a thickness of at least 12"; these footings taper down to 8"-thick or 6"-thick where meeting the concrete slab floors. The facility's air intake vent has the thickest foundation; at its outer edges the concrete perimeter foundation tapers in thickness from about 7' down to 5'. This foundation merges into the vertical air shaft's walls, whose thickness steps down from 6'-0" to 4'-0", before reaching the roof or the typical 1'-0" thick walls of the entrance tunnel.

Facility No. 59, Structural System

The structural system of Facility No. 59 is typically reinforced concrete. The dimensions of the numerous portions of this facility are noted in a section above. The construction technique for this underground pumphouse facility involved cut-and-cover excavations of various widths. The original drawings indicate the walls planes of the underground portions generally bear directly on the adjacent soil or rock. Y&D Drawing No. 294056 shows the east end of the facility's entrance tunnel with five 2'-0"-thick buttresses at right angles to its walls, and a note saying "field conditions to govern any additional buttresses." The drawings show a dense pattern of reinforcing rods in roofs of the entrance tunnel, intake vent, and the double roof over the main rectangular portion of Facility No. 59. The design of the double-roofs, with concussion chamber and relief vents, is the most unusual part of the facility's structural system.

The combination of two thick, reinforced-concrete, arched roofs, above and below a concussion chamber, renders the lower spaces bomb-resistant. The intent was to make the structure as bombproof as possible to the enemy bombs that existed at the 1941 date of construction. Above the upper roof is a 2'-6"-thick layer of hand-placed rock, then soil, on top of that arched layer of rock, to level the grade. The combined soil and rock are about 3'-6" thick at the top of the roof's arch and about 7' thick at the sides of the upper roof. The upper roof acts as a bursting slab when hit by a bomb. The air space of the concussion chamber is designed to cushion the blast and greatly reduce the bomb's force on the lower arched roof.[10]

The three relief vents (open-top pits), connected to the concussion chamber on its north side and at both ends, also assist in that function. At both the east and west ends of the concussion chamber there are five reinforced-concrete piers, each 5'-0" x 2'-0" in plan, with six 7'-0" wide openings. On the concussion chamber's north side, there are four piers with five openings, all with the same measurements. The openings on the north side connect the concussion chamber with a trapezoidal space above the storage room. On the north side of the trapezoidal space are three piers (4'-0" x 2'-0" in plan) and four 7'-0" wide openings. Within the trapezoidal space, the top foot or so of the north-side piers are canted inward, reflecting the cant of the beam above the piers on the south side. These openings and spaces link the concussion chamber to the relief vents, which are located just beyond the east, west, and north edges of the upper roof. The upper roof and relief vents absorb and dissipate some of the bomb's energy reaching the concussion chamber; the vents channel energy out and up to the surface. The relief vents help prevent fracture of the lower roof and, thus, protect the interior spaces. Concrete walls about 1' thick and 16'-0" long connect every other relief-vent pier to the outer (retaining) wall. The inner 10'-0" of these connecting walls rise to height of the arched upper roof's overhangs, and rise approximately 6" to 12" higher in the 6'-0" wide unroofed areas.

Unlike the entrance tunnel portion, the surge tank tunnel does not have a 6'-0" thick reinforced concrete roof. The earth cover over the surge tank tunnel is over 26'. The supports of the barrel arch in the surge tank tunnel include 6"-wide steel sets (arched with a radius of 6'-4") and Gunite (a mixture of sand, cement and water) pumped through a hose at high velocity) applied over welded wire mesh.

Facility No. 59, Floor Plan

The many portions of Facility No. 59 create a very complicated floor plan. The mostly underground pumphouse is roughly a series of horizontally oriented rectangular shapes, with several portions stacked on top of others. However, there are projections, both underground and above-grade, that are exceptions to this characterization, as detailed below.

Exhaust Fan: The first exception is the vertically oriented exhaust fan portion, at the western end of Facility No. 59. This simple blocky exterior shape, topped by four metal cylindrical fans, is offset from and not

[10] Keith Mallory and Arvid Ottar, *The Architecture of War* (New York: Pantheon Books) 1973. p. 59.

obviously connected to the rest of the largely underground pumphouse. Inside this above-grade concrete enclosure is the original sump, a smaller rectangular-plan shape that is mostly below grade. The exhaust fan portion connects underground to the adjacent western end of the pipe gallery.

Valve House (VC-1): This small rectangular room abuts and is connected to the pipe gallery underground. There is a section of metal grating about 2' above the floor, and just above some pipes, measuring 3'-0" x 5'-8" in the southeast corner of the room.

Pipe Gallery: The underground pipe gallery extends east approximately 300' as a continuous space, punctuated only by a line of 10" x 10" columns, typically spaced 14'-0" on center down its length. The columns' alignment is offset a few inches from the centerline of the 18'-6"-wide pipe gallery. The columns and the top beam connecting them support the paving in front of Adit 1 and the entrance tunnel's floor slab above the pipe gallery. This portion of the facility also serves as the exhaust air duct for Facility No. 59.

Entrance Tunnel: The opening to the entrance tunnel is Adit 1 (see "Adit" section for description of this first portion), which is built at an angle to the orthogonal lines of this facility. The entrance tunnel extends east about 270' and is generally 18'-0" wide, but has two 19'-0" wide sections plus an area 36'-2"wide at its eastern end to accommodate Fan No. 5, which now has two fans in the area of the original fan. These fans occupy an excavated area, measuring 15'-8" x 17'-6", at the southeast corner of the entrance tunnel. The fan's floor level is 5'-4" lower than the tunnel floor, accessed by a concrete stair. On the east side of the stair, a concrete ramp allows movement of equipment between the two floor levels. The stair and ramp intrude approximately 6' into the entrance tunnel's width. On the west side of the stair there is a modern metal cover over a square opening, which has a ladder down to a landing in the pipe gallery level. Interior doorways along the entrance tunnel divide it into four spaces. In the space between the first and second doorways is a container-size metal enclosure that contains the emergency generator for Facility No. 59.

Air Intake Vent: Unlike the mostly horizontal portions of this facility, the air intake vent is a vertically oriented portion of the structure; it rises from the ceiling of the entrance tunnel, above the western 19'-0"-wide section. Its airshaft opening is 19'-0" x 10'-0" in plan, and extends up about 17' to the bottom of the vent's bombproof roof. The vent opening passes through the arched roof of the tunnel and it is surrounded by the foundation supporting the above-grade roof over it. The 6'-0"-wide perimeter of this concrete roof rises 1'-0" higher than the rest of 6'-0" thick roof; turf and soil has been placed inside this rectangular rim, over three layer of roofing felt mopped with tar.

Main Rectangular Portion: The main rectangular portion of Facility No. 59 is entirely underground, at the east end of the entrance tunnel. It includes the large pump room that occupies about 75% of the overall space. To the west of the pump room, there are several smaller rooms and spaces in the remaining quarter. The 9'-0" wide passageway, between the pump room and the entrance tunnel, occupies the northern part of that quarter. The smaller rooms of Facility No. 59, south of this passageway, are the transformer room and the control room suite. The transformer room, in the southwest corner of that quarter, has a footprint of approximately 36' x 44', with an L-shaped part of that rectangle at a lower level. The transformer equipment on the western side of the room is on this lower floor level and behind an enclosure of steel mesh. Electrical switchgear machinery is also on the lower level of the transformer room. Two stairways in this room accommodate the approximately 3' difference between the lower level and the floor of the passageway and other rooms. The control room suite includes the control room, a smaller room previously called "private office," a bathroom, and two closets. This suite occupies an area measuring approximately 20' x 44', between the transformer and pump rooms. Several layout changes occurred in this suite of rooms, in the decades since the facility's initial construction. For instance, removal of the original control board in the control room freed up some space, but a new closet for electrical wiring and panels occupies some of the room. The lockers and circular wash fountain shown on the original drawing are gone and the footprint of the bathroom is smaller. Reducing the bathroom space allowed enlargement of one closet and extension of the room labelled "private office" on the original floor plan. A short hall, with doors at both ends, now exists between the control room and the pump room, created by using the northern end of that "private office." The remodeled "private office" now houses automated fuel handling and pollution control equipment.[11] Below the control room suite, at the level of the pipe gallery, are spaces for ducts, piping, wiring, and other systems.

The pump room in the main rectangular portion has three floor levels. The foundation-level concrete floor slab is at the same elevation as that of the pipe gallery. The upper part of the pump room has two floor levels. The upper concrete floor, at the level of the passageway and control room, has small sections of inset steel grating. There is a complex layout of the upper concrete floor at the east and west ends and along the south wall of the room. The concrete foundations for the pumps and electric motors along the south wall are typically higher than the upper concrete floor level. A large portion of the pump room, measuring approximately 167' x 36', has steel-grate flooring that is about 1' lower than the upper concrete floor. The grating allows visual checks of the machinery -- the fuel valves and their associated piping -- as well as facilitating operation of the valves.[12] The steel-grate flooring is 7'-5" above the foundation floor level. Piping, air ducts, and the lower part of valves occupy much of the space below the grating. Two sets of metal stairs lead down from the steel-grate floor area to the foundation level. One stair to the foundation level is located near the west end of the pump room. The other stair, located at the east end, provides access both to the lower level and to the passage between the pump room (part of Facility No. 59) and the Harbor Tunnel (part of Facility S-21). A concrete enclosure, measuring 14'-6" x 16'-8" in plan and rising 6'-3"above the upper concrete floor level, occupies the southwest corner of the pump room. The original drawings show this was for Fan No. 6, but the fan equipment is not extant. [Fan No. 6 was replaced by the four fans in the new Exhaust Fan enclosure outside Adit 1. These fans now pull air down the pipe gallery tunnel, whereas Fan No. 6 used to push air down that tunnel.] This enclosure has a doorway at the upper level of the pump room. The floor level of the enclosure is at the pump room's foundation slab level, about 8' below the doorway level. A modern landing and alternating-tread stair now replace the fixed metal ladder that originally provided access between levels.

Storage Room: The storage room (labelled "Shop & Storage Space" on the original drawings) is the trapezoidal space on the north side of Facility No. 59. There is a 6'-0" wide doorway to this storage room, which passes through the 5'-0" thick north wall of the pump room/main rectangular portion of the facility. The walls of the storage room are 4'-0" thick. Five concrete steps lead down to the floor of the storage room, which is about halfway between the levels of the pump room's steel-grate floor and the concrete foundation floor.

Concussion Chamber: The floor plan of the concussion chamber floor encompasses the trapezoidal area above the storage room and the rectangle above the main rectangular portion of the facility. The floor plan of the three relief vents includes the 6'-0"-wide unroofed areas plus the 10'-0"-wide areas under the roof overhangs. Due to their connecting walls, each relief vent has three separate cells at their lower sections. However, each relief vent's upper section is a single pit.

Surge Tank Tunnel: The L-shaped surge tank tunnel has a curve at the inner junction of the long and short legs. The floor level of this tunnel is about 5' lower than the upper concrete floor of the pump room, so a metal walkway along the short leg of the tunnel and two metal stairways at the junction of the L provide access between the two levels. Metal stairways also provide access from the surge tank tunnel to the short

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[11] James A. Gammon, e-mail from former Supply Center Fuel Department Superintendent to Ann Yoklavich of Mason Architects, Inc., Oct. 21, 2014.

[12] CPNAB, "Technical Report" [1945]. p. A-663.

tunnels on the north side of each surge tank. Metal stairways and walkways are necessary at Surge Tanks 2 and 3 (Facility Nos. 1225 and 1226) to provide access cross the large-diameter pipes (largest pipe is 32" diameter) on the floor of this tunnel. There are shorter metal stairs to reach the floor levels of Surge Tanks 1 and 4 (Facility Nos. 1224 and 1227), which are, respectively, about 2' or 3' higher than the floor of the surge tank tunnel. Most of the piping connected to the surge tanks is positioned near the floor level in this tunnel, but a large vent pipe is supported from the ceiling. The four short tunnels that join the south side of L-shaped tunnel are part of the surge tanks (see "Tanks" section of this report).

Facility No. 59, Wall, Ceiling and Floor Finishes

For the occupied portions of Facility No. 59, the interior finish is typically paint on smooth concrete walls and ceilings. There are three conditions for the concrete floors – unfinished, clear sealer, or painted. However, the heavily trafficked areas often have a worn paint finish that exposes some of the concrete underneath. Unless noted otherwise, paint is the standard wall and ceiling finish for the entrance tunnel, main rectangular portion, storage room, and surge tank tunnel. The other portions usually have no finish on their concrete walls, ceilings and floors.

Exhaust Fan Enclosure: Its relatively recent concrete, including all the exterior and interior walls plus interior ceiling, is unpainted. The older sump, inside that new enclosure, has a painted concrete ceiling as well as exterior and interior walls; however, the paint has worn off the lower half of the interior walls. The "roof" of the sump (now a floor-like platform within the exhaust fan enclosure) is made of textured, galvanized metal plate, with an access cover and ventilation opening.

Valve House (VC-1): The concrete of this portion of Facility No. 59 is painted.

Entrance Tunnel: This space has paint on its concrete walls and arched ceiling. In much of this tunnel, about 3' of the lower wall surfaces are painted dark brown, while the upper walls, curve into the ceiling, are painted white. Most areas of these concrete surfaces show the impressions of the horizontal boards used in forming them. The floor of the entrance tunnel has either a clear sealer or a worn paint finish that exposes much of the underlying concrete.

Pipe Gallery and Air Intake Vent: The pipe gallery's western end (an area measuring about 12' x 18') has a "ceiling" of "subway grating" panels. This grating consists of 4" x ¾" metal bar stock, positioned vertically and spaced 2-¼" apart, which are connected by 7/8"-diameter steel tie rods, spaced 8" on center. Around the tie rods are 3"-diameter steel spacers, reducing the openings to 5" between spacers. This "ceiling" was originally open to the air above, and was the point at which exhaust air from Facility No. 59 discharged from the pipe gallery tunnel to the atmosphere. Metal plates now cover the grating, and the exhaust air goes out the top of the new exhaust fan enclosure. The rest of the pipe gallery has unpainted concrete walls, ceiling, and floor. The same is true of the observable walls of the air intake vent (the ceiling is inaccessible and it has no floor).

Main Rectangular Portion: Most of the spaces in the upper part of the main rectangular portion of the facility have painted walls, but the ceiling and floor finishes vary. The passageway to the pump room has painted concrete walls, ceiling, and floor (much of the floor paint is worn off). The wall between the passageway and the control room is built with 6"-wide concrete masonry units (CMU), as are the partition walls of the private office and toilet room, and the wall between the pump room and the spaces to its west. Some recent partition walls have been constructed of gypsum wallboard over metal studs. The control room, private office, and restroom have dropped ceilings with acoustic-panels in grids and vinyl composition tile floors. Above the dropped ceiling of those rooms, and visible in the transformer room, is the original ceiling of plaster on expanded metal lath. The transformer room's floor has the remains of a painted finish.

The pump room has painted concrete walls. There are concrete brackets integral with the north and south walls, at a height about 20' above the lowest floor level, which support the outer ends of the pump room overhead cranes. Now there are multiple conduits and pipes installed over the brackets, obscuring their decorative detailing. Original drawings show that along their length, each bracket has two decorative indentations (½" depth and 2-¾" height, spaced 3" apart) and two rounded shapes in place of a right-angled lower edge. On the east and west walls, there are two indentations which align with those on the brackets. At a height of 3'-8-¾" above the concrete or steel grate floors in the pump room there is an indentation designated as a "wainscot strip." This wainscot line, which marks the boundary between the lower and upper walls (painted dark brown and white, respectively), is ½" deep, and 1-½" high, with 60-degree angled top and bottom surfaces of the indentation, unlike the other decorative grooves in the room, which have right-angled profiles. The pump room's ceiling consists of 1"-thick plaster on metal lath, suspended from the arched underside of the lower roof. At the long sides of the pump room, the ceiling has a slight chamfer where it angles due to the roof shape. This is because the height of the ceiling is slightly higher than the spring line of the arched roof. At the center of the ceiling, down the length of the room, are supports for the I-beams that have rails for the inner ends of the overhead cranes. There are decorative bands in the ceiling of the pump room, two bands along the length and six bands (in three pairs) across the ceiling width. Each band is a set of three grooves (or "recessed stripping" -- as labelled on the drawing -- a possible a typo for "recessed striping"). The grooves do not end at the walls, but continue down a bit ending in points. The center groove of each set descends about twice as far as the adjacent ones – the lowest points approximately 3' below the level of the crane rail brackets. The three grooves in the two long bands (along the length of the room) are each 4-½" wide with 7" spaces between. There is a space of about 8' between the bands and the north and south walls of the pump room. The spacing is not symmetrical for the three pairs of decorative bands across the width of the room: either 48' or 55' spacing between pairs, approximately 20' between the west wall and the band closest to it, and almost 22' between the east wall of the pump room and its closest band. The grooves in these transverse bands are narrower (3-½") and more closely spaced (6") than the two longitudinal bands. Each transverse pair has a 10'-8" space between bands. These transverse bands emphasize the chamfer at the sides of the ceiling. The crossings of the transverse and longitudinal grooves create interesting orthogonal patterns on the ceiling. The geometric ceiling pattern is somewhat masked by the red piping added for fire suppression, but the Art Deco style design is still evident. Use of this style was not uncommon in industrial settings during the 1930s, but this is a rare application of Art Deco in a 1940s military utility system structure. The upper pump room space has both clear-sealed concrete floor sections and areas of steel-grate flooring. The original portion of the steel grating has an interesting design with straight pieces of metal edging alternating with pieces that curve between the two straight ones. All the steel grating has a black paint finish. In the lower part of the pump room (including the Fan No. 6 room) the walls, ceiling, and floor are unpainted concrete.

Storage Room: The storage room on the north side of the pump room has unfinished concrete walls and ceilings. Its floor has a much worn painted finish.

Bombproof Roofs and Concussion Chamber: The top of the arched lower roof, which is the "floor" of the concussion chamber, has a layer of fabric-like sheeting, probably roofing material of some kind. Fine air-borne silt now covers the sheeting. The material appears to be a later improvement, since the original drawing called for a roof finish ("2-ply felt, mopped with asphalt") only on the upper roof's top surface; that roof finish is topped with soil. There is no finish on the visible concrete surfaces (ceiling, walls and other vertical faces) of the two layers of roof, the concussion chamber, and the relief vents.

Surge Tank Tunnel: The floor of the surge tank tunnel is unpainted concrete. The walls and ceiling of the tunnel are Gunite.

Facility No. 59, Doorways and Doors

Exhaust Fan and Valve House: The exhaust fan enclosure has double modern metal flush doors that open outward. The hardware consists of three hinges on each door, a round door knob on the south door, a simple U-shaped door handle on each door, which are secured with a chain and padlock, plus a hasp, which currently has no padlock. The sump inside is accessed by a roof hatch rather than a door. The valve house also has a hatch-like opening, but in the inclined surface of its raised access section. The valve house entry is a 3'-8" square door of ¼"-thick metal plate.

Entrance Tunnel: The entrance tunnel has four doorways between Adit 1 and the main rectangular portion of the facility. The first entrance barrier at Adit 1 is the expanded-metal mesh filling the arched portal opening. In that metal screening there are two openings: a large-scale doorway, about 12' wide x 12' high, with hinged, double doors of expanded metal mesh, and on the south side of that is a human scale, hinged, flush-metal door. About 20' inside the entrance tunnel is second doorway, also a set of large-scale double doors with an adjacent human-scale door. These are 7"-thick doors, constructed of heavy metal plate, that open outward. Framing these doors, on the north and south sides of the tunnel, are blast-resistant concrete walls, about 2'-4" thick. The large double-door opening measures 10'-10" wide x 6'-10" high. These heavy doors have substantial strap hinges and hardware, as well as metal rollers on their bottom edges, running on metal arc tracks set in the concrete floor. These doors secure from the inside with a pair of sliding door bolts. Above the double doors are four metal sections that are labeled "removable panels" on an original drawing. Apparently, they were removable to allow transport of materials down the entrance tunnel on the trolley beam. However, now the number of conduits and pipes extending through the sections makes removal difficult. The human-scale door in this second barrier is in an opening 2'-6" wide x 6'-10" high; it is set within the concrete wall on the south side of the large doors. This smaller plate-metal door has no rollers or track and closes with a lever handle on both inside and outside. The third doorway is located about 90' in from Adit 1, and its opening measures roughly 9' wide x 7' high. It has modern, flush-metal double doors, set in a wall of concrete masonry units (CMU). These double doors are about 2" thick and have modern push-bar hardware. Due to the CMU wall at this third door, the hoist on the trolley beam can now only operate in the eastern end of the tunnel.

> The CMU wall and modern double doors were installed in the late 1990s/early 2000s under project PRL 98-08. The purpose was to stop incoming ventilation air from entering through Adit 1 and force it to enter via the Air Intake Vent over … the Entrance Tunnel, where it passes through a bank of air filter panels to remove dirt and debris.[13]

The fourth doorway is located about 56' from the eastern end of the entrance tunnel and has the most interesting construction. It is labelled "Grille & Doors" on an original drawing, since it is composed of vertical steel I-beams that are set in a frame of larger steel I-beams. The I-beams composing the frame have 10"-wide flanges and the I-beams of the grille have 6"-wide flanges. The latter are set vertically in an overlapping staggered pattern, with an inner and outer row of I-beams, which have 4" spacing between the beams. Thus, the inner flanges of the two rows overlap by about 1" but are not in the same plane; this means air can flow through, but there is no visible opening. There are three hinged sections, and all originally opened outward. Above the larger door is a hinged section curved to fit the arch of the tunnel; when opened it allowed transport of materials on the trolley beam. This upper section may no longer be operable, due to the number of conduits and pipes installed along the entrance tunnel ceiling. The larger door is 5'-0" x 8'-0". This door has a 1'-0' long section of 3"-diameter pipe, inserted as a lookout hole. The large door secures from the inside using four eyes with corresponding pins that fit across the edges of the door frame. The

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[13] James A. Gammon, Comment in e-mail attachment from former Supply Center Fuel Department Superintendent to Ann Yoklavich of Mason Architects, Inc., December 29, 2014.

smaller door, labelled "pilot door" on the original drawing, is 3'-5-¾" wide x 7' -0" high. This door secures with a lever latch from both sides and also has four eyes and pins on the inside. The pilot door has a 3"-high gun slot, covered on the inside by a rotating steel plate.

Main Rectangular Portion: The doorway at the junction of the entrance tunnel and the main rectangular portion of the facility has modern, flush-metal double doors that open towards Adit 1, into the tunnel. The hardware on these doors includes push bars. This approximately 7'-wide doorway opens to the 9'-0" wide passageway to the pump room. Three doorways are along the south wall of the passageway. The two westernmost doors lead to the transformer room. The first doorway has a single-panel metal door measuring 2'-6" x approximately 7'. The second transformer room doorway has double doors in an opening that is approximately 8' wide and high, and each leaf is metal with a single-panel design. Although these two doors to the transformer room appear original, modern hardware is installed. The wide opening allows for moving equipment into the transformer room. The third door on the south side of the passageway is a modern flush metal one, leading to the control room. Between the east end of the passageway and the pump room, there are metal double doors with large vision panels. These are modern doors with push-bar hardware.

Within the suite of rooms to the west of the pump room, most doors are modern, flush metal. The door to the small room originally called "private office" has a security pad above the doorknob. The historic doors in this suite are the single-panel metal door to the transformer room and the door with two-light vision panel and round brass doorknob that originally connected the private office and the control room. The latter door measures 2'-6" wide x 6'-8" tall. A hallway has been created from this end of the private office space; the doorway at the pump room end of this hallway (originally connecting the private office to the pump room) has a modern flush-metal replacement door.

Both the control room and the locked smaller office room have an interior window between them and the pump room. These are the only windows in Facility No. 59. The steel-frame, fixed-sash window in the control room has wire-glass lights. Each light is about 1' high x 2'-6" wide. The window originally had twelve lights, but the northern "column" of lights is covered over; nine lights remain. The smaller room's window, is the same type with six lights. This smaller window is not usually visible, due to the security lock on the door and the metal roll-up cover on the window. Both windows have a modern metal roll-up cover on the pump-room side. The roll-up shutters were part of a fire protection project in the 1980s. They have fusible links, which, when activated by the heat of a fire, allow the shutters to close.[14]

On the south wall of the pump room, a modern flush-metal door with a round doorknob leads to the surge tank tunnel. Another door is on the surge tank side of the 5'-0" thick concrete wall. The label on an original drawing for this historic oil-tight steel-plate door is "self-closing bulkhead pressure door." It has a gasket seal, steel-angle reinforcing, three substantial hinges, and door handles made from metal rods, bent into shallow U shapes and welded to the steel plate. There is magnetic closure hardware on the surge-tank side of the door. This original door is designed to prevent fuel from entering the pump room, in the event of a pipeline break in the surge tank tunnel.[15] It has six metal protrusions from the door that correspond to similar protrusions on the door frame, all with slots; wedges hanging from chains on the door frame could be inserted in these slots and were part of the design to keep the door oil-tight.

On the north wall of the pump room, the 6'-0" wide doorway to the shop/ storage space room has double metal doors with large panels of expanded-metal screening. The enclosure designed for Fan No. 6 has a single-panel metal door, similar to the original transformer room doors, but less than 6' in height.

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[14] Ibid.

[15] Ibid.

The doorway at the east end of the pump room has doors on both sides of the 5'-0" thick wall between Facility No. 59 and the Harbor Tunnel (part of Facility S-21). It is accessed by metal stairs that go down from the metal-grate flooring level of the pump room to the concrete slab floor of the foundation level. The doorway to the Harbor Tunnel is about 3' above the foundation-level floor. The door on the pump-room (west) side is modern flush metal with closer, kick plate and round doorknob; it also has a U-shaped handle of rebar welded to the plate above its west side doorknob. The door on the east side of the 5'-0" wall is the same oil-tight type ("self-closing bulkhead pressure door") as on the south side of the wall between the pump room and the surge tunnel (see above). As with the surge tunnel door, magnetic closure hardware has been added. Both doors between the pump room and the Harbor Tunnel are approximately 6' tall; the east (Harbor Tunnel side) door's width is 3'-6", which is slightly wider than the door on the west (pump room side).

Other Portions: There are no doors in the air intake or concussion chamber portions of Facility No. 59. There are no doors to the relief vents, but there is a hinged section in the metal grating of the western one for entry.

Facility No. 59, Mechanical Equipment

There are numerous panels and junction boxes on the south wall between the Adit 1 grille and the second door. These are mostly controls for modern systems, such as fire alarm, security locks, and cameras.

Piping and vent ducts extend throughout Facility No. 59. However, the majority of the mechanical equipment is in the pump room. This room contains the motors, pumps and valves that move fuel up to the twenty large storage tanks, located under Red Hill. The valves also help control the downhill gravity flow of the fuel from these tanks. This equipment is located on various levels of the pump room. Most of the pump and valve piping is located under the steel-grate flooring, in the space between it and the concrete slab foundation.

There are eleven pumps in the pump room, each powered by a replacement electric motor, with various horsepower (hp) ratings. Unlike the original motors with open windings, the new ones are totally enclosed and fan-cooled, dating from the mid 1990s. The pumps date from the early 1940s; the original equipment manufacturer, Byron Jackson, completely overhauled them in the mid 1990s.[16] They are aligned along the south wall of the pump room, on a portion of the concrete floor. The five pumps nearest to the control room, numbered Pumps 201 to 205 (counting from the control room towards the east, or toward the Lower Tunnel) pump the No. 2 diesel fuel used by the Navy, referred to as F-76. Each of these five pumps has a capacity of 5,600 gallons per minute (gpm), each driven by a 500-hp electric motor. The next three pumps, numbered Pumps 206 to 208, handle a type of naval aviation fuel, JP-5. These three pumps, run by 400-hp electric motors, each have a capacity of 3,500 gpm. The three pumps farthest from the control room, numbered Pumps 209 to 211, are for the JP-8 type of aviation fuel. Each of these pumps has a capacity of 3,500 gpm and has a 300-hp electric motor. (See Part III for overview of fuel operations and fuel types stored.)

Valves in the pump room that control the flow of fuel are remotely controlled and electric-motor-operated; they are located in the area with steel-grate flooring, aligned opposite their respective pumps. There is a group of valves for each fuel type, two valves per pump. The valves are positioned on vertically oriented pipes that ascend from beneath the steel-grate flooring. An overhead manifold connects the vertical pipes

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[16] James A. Gammon, Comment 11b, in e-mail attachment from former Supply Center Fuel Department Superintendent to Ann Yoklavich of Mason Architects, Inc., February 19, 2015.

from the valves of each group, with one manifold for each of the three groups. Additional valves, both manual and electronically operated, are located on the steel-grated area of the pump room.

The pump room is equipped with two, five-ton-capacity traveling cranes. Each crane extends transversely across about half the width of the room and both move up and down the length of the pump room. Each is a top-running bridge crane with an underhung trolley hoist. There are two crane rails extending down the length of the pump room near its center and there is a rail on each side wall. Another trolley beam for a traveling hoist is located in the entrance tunnel. This 1'-3" high I-beam extends the length of the tunnel, several feet north of the centerline. A manual chain hoist rides on this beam in the section between the third and fourth tunnel doors; it is unable to travel to western sections of the entrance tunnel due to the CMU wall at the third door.

Air ducts are in the pump room's lower flooring level, and an exhaust tunnel is located under the control room area on the original drawings. Two large fans in the entrance tunnel, in the location of the original Fan No. 5, pull fresh air in through the air intake vent and push it into the plenum over the main rectangular portion. The fresh air then flows from the vents in the suspended ceiling to the spaces below. There are 39 vents in the ceiling of the pump room, 37 of them on the north half. The air is drawn over the pumps on the north side to help cool them (they are water-cooled also).[17] There are six ceiling vents in the transformer room. Fan No. 7, located in the Storage Room, is also a supply fan, providing air that flows across the lower level of the pump room. Fan No. 8 located in the pump room, next to the door to the Surge Tank Tunnel, pulls air out from that tunnel via a duct system and discharges it into the pipe gallery exhaust tunnel. This causes fresh air from the pump room to flow into the surge tank tunnel. Exhaust Fan 9, under the Control Room suite, also discharges into the pipe gallery / exhaust tunnel. The exhaust air travels through the pipe gallery, pulled by Fan Nos. 6a to 6d in the exhaust fan enclosure. This exhaust air exits through the top of that enclosure, located to the side of Adit 1. Originally, the exhaust air was pushed by former Fan No. 6 in the pump room, exiting through the grating, at pavement level in front of Adit 1.

The control room and smaller adjacent office is full of computerized equipment that monitors and manages the flow of fuel, as well as operating the pumps and valves. This room also has video feeds that show traffic and conditions in areas of the fuel system, including the exterior of Facility No. 59 and the Pearl Harbor fueling pier (Hotel Pier). Typically, one person staffs the control room. The transformer room has electrical switches and transformers that supply power to the components of the fuel system. Over the decades since the fuel system's construction, new electrical equipment has been installed. There is a recess in the transformer room's south wall, with a curved metal bar embedded in the concrete; another one is located in the north wall of the passageway just outside the transformer room's large doors. Ropes passed through these rings can help move equipment in and out.

No original lighting fixtures are generally visible in this facility. There is an interesting, possibly original, light fixture in the space between the old and new ceilings over the small office room adjacent to the control room. This fixture's lamp, on a long stem that can rotate to various angles and heights, is reported to be a type seen in hospital operating rooms. The original drawings show an air-conditioning (ac) unit was installed in the ceiling of the control room. As with the lighting, the Navy has upgraded the ac system in the decades since WWII. They have also added many conduits and pipes to the ceiling and walls of the facility over the years.

[17] Derek Wong, Personal communication from Fleet Logistics Center Pearl Harbor, Supply Information Systems Analyst to Ann Yoklavich of Mason Architects, Inc., January 20, 2015.

2. FUEL TANKS

There are four surge tanks and twenty fuel tanks located, respectively, near the west and east ends of the Red Hill underground fuel storage system.

a. SURGE TANK TYPE, FACILITY NOS. 1224 TO 1227

Facility Nos. 1224 to 1227, Overall Dimensions

The four surge tanks have an inside diameter measurement of 60'-0" and a height of 21'-0" from floor to ceiling. The drawings show a 6'-0" thick, reinforced-concrete roof design for each tank, with a minimum overhang of 6'. A construction photo from 1942 indicates that all the roof slabs were poured as a continuous roof slab, rather than as four circular roofs.[18] On the top of each tank there is a small access area, measuring approximately 7' wide x 10" long, and about 6' high. These access areas have roofs about 6' higher than the main roof over the four tanks and require sloping transition sections between the two roof levels. A pipe trench, containing an overflow pipe from each tank to the above-ground ballast tank, extends under the roof overhang, along the south curves of the tanks numbered Facility Nos. 1224 to 1226. This trench widens from a minimum width of 1'-10", where it contains only the overflow pipe from Facility No. 1227, to the maximum width of 6'-6" at Facility No. 1224, as pipes from each tank join the trench.

Each surge tank has a short connecting tunnel that links the surge tank tunnel at right angles. Each measures 12'-8" in width and 12'-6" in height to the top of the tunnel arch. Each connecting tunnel is less than 10' in length (depth from surge tank tunnel to exterior wall of surge tank).

Facility Nos. 1224 to 1227, Foundations

One foundation design assumption, shown in a drawing for these tanks, is that the bearing on the excavated rock under the footings was 5,000 pounds per square foot. The perimeter footings under the tanks are all 4'-0" wide and minimum of 1'-6" high. At the north side of the tanks, the footings are 6' high or more, depending on the floor level of each short tunnel that connects to the surge tank tunnel. Where they are higher than 1'-6", the footings step to a width of 2'-6", above the 4'-0" wide bottom section.

Facility Nos. 1224 to 1227, Structural System

The contractors constructed the tanks in four cylindrical excavations, so the tanks' reinforced- concrete walls and floor slabs bear on the surrounding rock. Each tank holds 10,041 barrels of oil, which constitutes a considerable weight when full. The four circular floor slabs are 4" thick, with a 6"-wide rim that is 5-¾" thick. A steel-plate floor sits on a layer of sand, in the 1-¾" rim that rises above the floor slab, per an original drawing. The concrete walls of the tank were designed to fill the distance between the required 60'-0" interior diameter and the surrounding excavated rock walls, with drawings noting their minimum thickness as 12", 8", or 2'-0". The concrete tank walls at the short connecting tunnels are at least 12" thick for their entire height; on the remaining perimeter of the tanks, where the concrete fills the space between tanks and rock walls, only the lower parts of the walls are a minimum of 12" thick, with the upper walls required to be 8" or more thick. In areas near the top of tanks, where the excavation resulted in no supporting rock, the walls are 2'-0" thick. The bombproof, reinforced-concrete roof over the four surge tanks is a minimum of 6'-0" thick. The supports of the barrel arches of the connecting tunnels include 6"-wide steel sets (arched with a radius of 6'-4") and Gunite over welded wire mesh.

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[18] Fourteenth Naval District, Contract NOy 4173 photos, "Underground Fuel Storage Project, Red Hill, Top of completed 6' concrete roof slab over 4 surge tanks," Photo #15344, April 27, 1942.

Facility Nos. 1224 to 1227, Floor Plan

The surge tanks are circular in plan; an arc of each circle abuts a short connecting tunnel's footprint, which is rectangular on the other three sides. The footprint of the vertical shaft, which contains the steel access ladder and several large pipes, is approximately 7' x 4'. Each working platform at the top of a tank is 7'-0" wide x approximately 5' long, with its footprint reflecting a segment of the tank's curved perimeter.

Facility Nos. 1224 to 1227, Finishes

The interior of the tank is lined with ¼" steel plate measuring 5'-0" x 24'-0". The plates are welded together, with vertical joints in a staggered pattern. In a 1978 renovation project, a 1/8" fiberglass-reinforced, polyester-resin liner was added to the bottom of the surge tanks, and the inner walls got a polyurethane coating. The floors of the connecting tunnel are unpainted concrete. The walls and ceilings of those tunnels are unpainted Gunite.

Facility Nos. 1224 to 1227, Openings

There are no doors or windows into the surge tanks. Most openings are for pipe penetrations and they are kept sealed, unless the tank is emptied and shut down for maintenance. A note on an original drawing lists the penetrations: "shell manhole, top manhole, relief line nozzle, swing pipe shell nozzle, overflow nozzle, high & low level alarm nipples, water draw pipe, [and] automatic gauge nipple." At the top of the tank, the manhole opening cover has a diameter of 2'-0".

Facility Nos. 1224 to 1227, Mechanical Equipment

The section above lists some of the mechanical equipment associated with the surge tanks. This is in addition to the ventilation and fuel piping, electrical and other conduits, pumps and other electrical equipment necessary to the functioning of these tanks. Each surge tank originally had a swing pipe for suction (discharge) of fuel, with a line to raise it to different heights inside. Fuel oil delivered by tankers could accumulate seawater in the crossing to Hawaii, and it would be pumped off the ship along with the fuel. Eventually such seawater settles to the bottom of tanks. These adjustable swing pipes avoided the problem of re-entraining any seawater that settled on the bottom of the surge tanks. The Navy had these swing pipes removed about 1978.

b. FUEL TANK TYPE, FACILITY NOS. 328 TO 347

In their chapter on the underground fuel storage project, CPNAB uses the term "fuel vault," during the initial construction period. This is the term they used for their excavations, which were not the typical horizontal excavations for underground fuel storage. However, the structure built inside each vault is a "tank." This is also the word used in the captions on the construction-period photos by the Navy. It is also a more common term for a fuel-containing structure.

The twenty fuel tanks, arranged in ten pairs, are located at the east end of the Red Hill Underground Fuel Storage System, on either side of the Upper Access Tunnel (UAT) and Lower Access Tunnel (LAT). The tanks are located underneath the Red Hill ridge, between South Halawa Valley and Moanalua Valley. They are normally referred to by tank numbers, rather than by facility numbers, which were not assigned until after WWII. The odd-numbered tanks are on the north side of the tunnels and the even numbered ones are on the south. The odd and even facility numbers are the opposite. The following chart shows the correlations.

North Side		South Side	
Tank Number	Facility No.	Tank Number	Facility No.
1	328	2	329
3	330	4	331
5	332	6	333
7	334	8	335
9	336	10	337
11	338	12	339
13	340	14	341
15	342	16	343
17	344	18	345
19	346	20	347

Facility Nos. 328 to 347, Overall Dimensions

The total footprint of the area occupied by the twenty fuel tanks is approximately 1,900' x 300'. The earth cover above the tanks ranges from about 115' to about 180'. The shape of each tank is a vertical cylinder with hemispherical ends, like a pill capsule. Each tank cylinder is 139'-5" in height with a diameter of 100'-0". Each tank cylinder has hemispherical domes at top and bottom, both with 50'-0" radius. Tanks 5 to 20 have a cylindrical-shaped upper-dome extension, which adds 11'-10" between the top of the cylinder and the spring line of the upper dome, giving these tanks an overall height measurement of 251"-3". Note: The spring line is the point at which the upper dome "springs" away from the top of the cylindrical section below. Tanks 1-4 have no dome extension, so their spring line is lower and their overall height is 239'-5".

Facility Nos. 328 to 347, Foundations

The tank vaults were excavated out of bedrock. At the bottom of each tank, a thick mass of concrete was poured into the excavation under the lower dome to support the tank. During the construction of the tanks, each lower cross tunnel, extending a little beyond the vertical axis of its tank, was the exit for material excavated to create the tank. About 75' of the end of each cross tunnel became part of the foundation for each tank. Approximately 40' at the end of each cross-tunnel excavation was wider, about 18', compared to the typical cross-tunnel width. This end was in the area beneath the nadir of the lower dome. The mass of concrete had a minimum thickness of about 18' under the tank's nadir. The concrete in the bottom mass also filled the cup shape that joined the excavated sides of the vault. This resulted in a flat bottomed mass of concrete cradling the lower dome. The minimum thickness of the concrete at the sides of the cup for lower dome is 4'-0". When it was poured, this concrete mass had three loops of 1"-diameter pipe embedded, to circulate water that cooled the concrete as it cured. "The mass of concrete beneath each tank also contained piping that would eventually be used for fuel receiving and issuing, tank bottom water drain, steam, steam condensate, and leak detection."[19]

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[19] James A. Gammon, Comment in e-mail attachment from former Supply Center Fuel Department Superintendent to Ann Yoklavich of Mason Architects, Inc., January 29, 2015.

Facility Nos. 328 to 347, Structural System

The structure of each tank is a steel lining backed up by reinforced concrete and the rock around the concrete. Welded sections of ¼" steel plate typically form the lining of the tank cylinder and domes. A 20'-0" diameter section at the base of the lower dome is ½" steel plate. A poured, reinforced-concrete shell, with a typical thickness ranging from about 2'-6" to 4', surrounds the steel lining of the tanks. The bedrock sides of the tank excavation were coated with Gunite, approximately 6" thick, consolidating "any loose rock to protect the workers excavating the vault and building the tank inside the vault."[20] The original contractors filled the joint between the reinforced-concrete shell and the Gunite on the bedrock with pressurized grout, after the concrete shell had cured. A former Supply Center Fuel Department Superintendent provided further explanation about the purpose and steps of Gunite and grout placement:

> The purpose of grouting was to seal any cold joints in the reinforced concrete shell or in the gunited rock, … AND to pre-stress the tank structure with a compressive force that would counter the force of the hydrostatic pressure when the tank was filled with fuel…. [In] some areas of the vault that were not gunited during excavation [the step of] grouting would have consolidated the rock as well as sealed the joint between the rock and the reinforced concrete.[21]

Facility Nos. 328 to 347, Floor Plan

The twenty fuel tanks are in two parallel rows of ten, which pairs the tanks across the upper and lower access tunnels. This puts the tanks on a grid spacing of approximately 200' o. c. and provides about 100' spacing between the tanks, both along the tunnels and across them. The UAT and LAT run between the two rows of ten tanks. Cross tunnels branch out from the access tunnels to each tank. Right-angled cross tunnels connect the areas near the tanks' bottoms to the LAT. There are pairs of short tunnels, in mirrored angles of about 45 degrees, between the UAT and the tanks' entry hatches, which are approximately at the springline of their upper domes.

At the lower cross tunnels the tanks have piping for receiving and issuing fuel and for sampling fuel. Some tanks have the remains of a 1960s version of tell-tale piping, designed to detect leaks. See further description under the following "Mechanical Equipment" heading.

At the upper cross tunnels, the tanks have an 8'-0" diameter entrance tube that is sealed by a domed steel cover (dished head), which contains a smaller manway hatch in the lower half of the domed cover. The bottom of this entrance tube is about 3' above the level of the top of the tank cylinder. The upper cross tunnels also have steep metal stairs that lead up through an access gallery to the gauging chamber above the apex of the upper dome.

Each tank has a tunnel arching over its upper dome, labelled both as a "manway" and as an "access gallery" on the original drawings, which leads to the gauging chamber on top of the tank. The width and height dimensions of the arched access galleries vary; the width minimum is about 6', while the height ranges from about 7' to 10'. The radius of the arch over the access galleries is approximately 3'. The protrusion of a Gunite-covered, 24"-diameter, tank vent pipe reduces the width of each gallery. Each access gallery also contains a 10"-diameter ventilation pipe under the larger tank vent pipe. This smaller pipe is to provide air to workers in the gauging chamber. The access gallery ascends at varying angles as it follows the outside curvature of the upper tank dome. There are metal stairs at the steepest parts, and concrete sloping sections are used near the top, where the curvature of the tank is flatter.

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[20] Ibid.

[21] Ibid.

The gauging chamber is a small, concrete-lined dome-like space above the top of each tank, containing the gauges for measuring the fuel level in the tank. In Tanks 13 to 20, the large-diameter tank vent piping is also in the gauging chamber (for Tanks 1 to 12 that vent pipe is embedded in the concrete above the gauging chamber). The access gallery enters the gauging chamber, so the space is about three-quarters of a dome, whose diameter is about 15' wide, and its height is about 7'-6". The section of the gauging chamber closest to the access stair has a flat ceiling, rather than the arched walls and ceiling typical of this space. Near the center of the gauging chamber floor is a 5'-0"-diameter opening, which goes down into the fuel tank. An access shaft penetrates the approximately 6'-2" thick concrete between the floor of the gauging chamber and the top of tank dome.

Two emptied tanks were entered for this report, Tanks 5 and 19, via their 8' diameter entry tube, with dished-head covers removed. The interior of these two fuel tanks, and each of the other tanks, contains a four-legged metal tower that extends full height up the center of the tank. In each tank, a steel catwalk extends from the entry tube to the tower. Each tower has a 7'-2" square footprint. Tower legs are 6 x 6 x ⅜ steel angles, horizontally braced about 10' on center, with nominal 6 x 2 steel channels (c6x8.2). Diagonal X bracing, consisting of 4 x 4 x 5/16 and 2½ x 2 x ¼ steel angles, spans each of the 10' high sections on all four sides of the tower. Tank 19 is fitted with ladders and landings on the outer sides of the tower.

> From 1979 to 1984 the upper section of the center towers in Tanks 1 to 16 were strengthened with additional bracing to allow for the temporary installation of a rotating boom truss. [M]an baskets [on the boom truss allowed close access to] the upper dome for inspection and repair. Additionally, two opposing legs of each center tower in Tanks 1 to 16 were equipped with mounting plates. [These plates were] for temporary installation of telescoping booms with man-baskets, to access the walls in the upper dome and cylindrical sections of the tanks for re-work inspection and repair.[22]

The interior surface of the tanks is made up of the numerous steel plates welded together to form the tank lining. Plates that form the body of the tank cylinder are rectangular shapes joined to form the curve of the cylinder. The plates forming the upper and lower domes are trapezoids with their narrower ends oriented toward the apex of each dome. This gives a much more faceted appearance to the domes than to the more gently curving cylinder. This faceted effect of the domes is most visible at the angles where the trapezoidal plates join.

Circling the interior circumference of each tank, at the top of the tank cylinder, are two thin steel bands of an expansion joint that protrude about 6" into the interior of the tank. Each band is about ¼" to ½" thick. The bands are about 1'-6" apart.

> The expansion joint is at the junction between the upper dome, which includes the extra 11'-10" high section on Tanks 5-20, and the top of the cylindrical section of the tank. The expansion joint, which is part of the ¼" thick steel liner plate, is designed to accommodate up and down movement of the tank resulting from earth movement.[23]

The interior surfaces of Tanks 5 and 19 (the only tanks available for entry) were not uniformly smooth, but had various bits and nubs of steel attachment and support points. These are primarily located around the tank at about the level of the entrance tube and above; these include eyes and short sections of horizontal I-beams and steel channels. Some of these support points are in use to rig the catwalks in Tanks 5 and 19.

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[22] Ibid.

[23] Ibid.

> The short sections of horizontal I-beams were used in the original construction to hang the circular work platform seen in [historic] photos. In FY78 MILCON Project P-060 they were used to support a trolley beam around the perimeter of the tank, from which work platforms were hung to access the tank wall. Pipe end caps are welded to the tank walls to cover grout and grout relief pipes. Hundreds of small steel plates are welded to the tank walls to cover small holes through the liner plates that remained when the tell-tale pipes were removed under Project P-060.[24]

Facility Nos. 328 to 347, Tank Lining Finishes

The interiors of the steel lining of Tanks 5 and 19 have a green-colored coating, which is worn away in many areas of the tanks. This exposes the bare metal of the lining, which is typically corroded with a layer of surface rust. The interior of the lower dome of Tank 5 has a relatively unblemished white coating. The steel tower in the center of both tanks has a heavily worn, green coating with rust corrosion on most of the exposed metal. This green coating, on both tanks' towers and on the interior of Tank 19, "is an early 1960s formulation of a polyurethane coating that was developed by the Naval Research Lab specifically for the interior of fuel storage tanks."[25] Tank 5's green finish is a mid-1970s formulation of the same coating.[26] The walls and ceiling of the access galleries typically have an unpainted Gunite finish. The metal ladders in the access galleries are painted, and the galleries each have a section of unfinished concrete sloping floor. The upper and lower cross tunnels at each tank have unpainted Gunite walls and ceilings and unfinished concrete floors.

Facility Nos. 328 to 347, Access Opening

The tanks are not normally entered and there are no doorways as such. Two circular openings are available to enter each tank when needed. An 8'-0" diameter entrance tube opening is located at the upper cross tunnel to each tank, and a 5'-0"-diameter dome-access shaft is located in the gauging chamber, extending to the apex of the top dome.

The 8'-0" diameter entrance tube has a domed steel cover (dished head) that is secured by bolting it to a flange using a ring with 104 1" bolts on an 8'-3-½"-diameter bolt circle. The domed steel cover has a 1'-8"-diameter manhole opening/entry hatch that is covered by a flat steel plate secured by twenty eight ¾" bolts on a 2'-4-¼"-diameter bolt circle. The manhole cover has two fixed handles. The lower edge of the steel-lined entrance tube is about 3' above the top edge of the tank cylinder.

A circular steel plate, with an approximate 5'-3" diameter, secured by forty eight bolts, covers the 5'-0"-diameter dome access shaft in the gauging chamber. In this steel-plate dome access shaft cover there is a 2'-6"-diameter manhole opening. The manhole opening is also covered by a circular steel plate, with an approximate 2'-9" diameter, secured by twenty ½" bolts. Drawings indicate that during the 1970s there was a metal ladder extending down from this manhole to the steel tower in the tank below. The only gauging chamber accessed for this report, at Tank 19, did not have a ladder here.

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[24] Ibid.

[25] Ibid.

[26] James A. Gammon, Comment 15a, in e-mail attachment from former Supply Center Fuel Department Superintendent to Ann Yoklavich of Mason Architects, Inc., February 19, 2015.

Facility Nos. 328 to 347, Mechanical Equipment

James A. Gammon wrote this section on the Mechanical Equipment associated with the fuel tanks. From 1980 to 2004, he served as Superintendent and/or Chief Engineer at Pearl Harbor's Naval Supply Center Fuel Department. This section first discusses the mechanical equipment near the top of the tanks. The next two subheadings cover the mechanical equipment near the bottom of the tanks. The final subheading discussion is about the tell-tale leak-detection system inside the tanks.

At the top of each tank is a 24"-diameter vent pipe to ventilate the tank. It exits the tank near the top of the upper dome. This vent pipe passes vertically through the reinforced concrete shell of the upper dome, at first rising parallel to the 5'-0"-diameter dome-access shaft. There are two variations in how this vent turns above the top of the tank. At Tanks 13 to 20 this vent pipe curves through the gauging chamber on its way to the access gallery. At Tanks 1 to 12 this vent pipe curves through the concrete dome over the gauging chamber before extending down the access gallery. In both cases, the vent pipe extends down an upper corner of the access gallery to the UAT side tunnel. Along its entire length to the side tunnel this vent pipe is covered by a thick layer of Gunite. The vent pipe from each tank extends out of the access gallery, and vertically through the side tunnel's floor, where it turns to join the main vent pipe under the UAT's floor. On Tanks 2, 3, and 19 a vertical ventilation shaft extends up to the surface from the 24"-diameter vent pipe. These pipes "daylight" at Facility Nos. S-197, S-213 and 348, respectively. For further information, see those facility descriptions. Part III also has a discussion of the tank vent system.

Tanks 3 and 19 are equipped with a hand-operated remote control for opening and closing a 24" blast-gate valve. Such a valve is located in both 24"-diameter tank-vent lines, which extend vertically from the tops of Tanks 3 and 19 up to the tank vent structures on the Red Hill ridge. The hand-operated remote control is in the side tunnels of the UAT, near the entrance to Tanks 3 and 19.

<u>Mechanical Equipment at Bottom of Tanks: As Originally Constructed and as Operated until Early-1960s</u>

As originally constructed in 1942 all twenty tanks were filled and drained via two nozzle pipes that begin inside the tank, at the bottom of the lower dome. These pipes extended vertically down through the 20'-diameter ½"-thick steel floor plate to about 6' to 7' below the floor plate, inside the solid mass of concrete beneath each tank (18'-high x 85'-long); here, they turned 90-degrees and ran horizontally 44' to 57' through the concrete mass, and out into the end of the LAT cross tunnels. The first valve on each pipe, as it enters the LAT cross tunnel, is called the skin valve. From the LAT cross tunnel the two fill and drain pipes connected to the main fuel pipelines, which extend down to the pumphouse (Facility No. 59). Also, there are three smaller pipes (a tank-bottom drain pipe, a steam-line casing pipe, and a steam-condensate-return-line casing pipe) that follow the same path from the tank bottom through the concrete to the end of the LAT cross tunnel.

Inside the bottom of each tank a 32"-diameter nozzle pipe originally stood vertically about 6' high, with a horizontal 4'-diameter vortex-breaker plate about 1' above the open end of the pipe. The nozzle was designed primarily for issuing fuel from the tank, but could be used for both receipts and issues. The vertical center of the 32"-diameter pipe penetrated the ½"-thick flat steel plate at the bottom of the lower dome 6'-6" from the vertical center of the tank, on the side toward the LAT cross tunnel and 13" east from the tank centerline. As the 32"-diameter pipe "daylights" through the concrete wall at the end of the LAT cross tunnel it reduced from 32"- to 20"-diameter. The pipe connected to a manually operated 20" gate valve, the skin valve, in the LAT cross tunnel. Next to the skin valve was a remotely controlled electric-motor-operated 20" gate valve.

The other main pipe inside the bottom of each tank was, and in most cases still is, an 18"-diameter nozzle pipe. It passed through the tank bottom plate, rose vertically about 4' above the tank bottom, turning to an angle 12-degrees above horizontal and extended about 20' toward the upward sloping surface of the lower dome. The 18"-diameter pipe terminated in an upward facing elongated nozzle close to the curving dome, about 8' above the tank bottom. The nozzle was designed primarily for receiving fuel into the tank, but could be used for both receipts and issues. The vertical center of the 18"-diameter pipe penetrated the ½"-thick flat steel plate at the bottom of the lower dome 7'-0" from the vertical center of the tank, on the side away from the LAT cross tunnel and 3'-10" west of the tank centerline. As the 18"-diameter pipe "daylights" through the concrete wall at the end of the LAT cross tunnel it reduced from 18"- to 12"-diameter. The pipe connected to a manually operated 12" gate valve, the skin valve, in the LAT cross tunnel. Next to the skin valve is a remotely controlled electric-motor-operated 12" gate valve.

Inside the bottom of each tank, originally, was an 8"-diameter tank-bottom drain pipe. There was no nozzle inside the tank for this pipe. The 8"-diameter opening of the pipe was flush with the tank bottom plate, to enable it to drain the maximum amount of water that settles out of the fuel to the bottom of the tank. The pipe extended from the ½"-thick flat steel plate at the bottom of the lower dome, down through the concrete, and out into the end of the LAT cross tunnel. The vertical center of the 8"-diameter pipe penetrated the ½"-thick bottom plate 8'-6" from the vertical center of the tank on the side toward the LAT cross tunnel and 2'-4" west of the tank centerline. As the 8"-diameter pipe "daylights" through the concrete wall at the end of the LAT cross tunnel, it connected to a manually operated 8" gate valve, the skin valve. Due to the constant exposure to tank bottom water, holes corroded through the pipe walls of several of the bottom drain pipes; these rusted pipes were removed from service.

Originally, a 6"-diameter steam-line casing pipe was installed inside the bottom of each tank. A short, approximately 8"-long, section of the 6"-diameter pipe extended above the tank bottom plate. From the lower dome, the pipe extended down through the ½"-thick flat steel plate at the bottom of the lower dome, down through the concrete, and out into the end of the LAT cross tunnel. The vertical center of the 6"-diameter pipe penetrates the ½"-thick bottom plate 7'-10" from the vertical center of the tank on the side toward the LAT cross tunnel and 4'-7" east of the tank centerline. Because the steam line was never used, the ends of the pipe were capped and seal welded inside the tank and in the LAT cross tunnel. However, several of the casing pipes were put into service later, to replace failed bottom-drain pipes.

The third small-diameter piper inside the bottom of each tank was an 8"-diameter casing pipe for steam-condensate-return line. A short, approximately 8"-long, section of the 8"-diameter pipe extended above the tank bottom plate. From inside the lower dome, the pipe extended down through the ½"-thick flat steel plate at the bottom of the lower dome, down through the concrete, and out into the end of the LAT cross tunnel . The vertical center of the 8"-diameter pipe penetrated the ½"-thick bottom plate 3'-8" from the vertical center of the tank on the side toward the LAT cross tunnel and 4'-7" east of the tank centerline. Because the steam-condensate-return line was never used, the ends of the pipe were capped and seal welded inside the tank and in the LAT cross tunnel. Several of these casing pipes were put into service later, also to replace failed bottom-drain pipes.

Each LAT cross tunnel had, and still has, two pipes extending across the LAT from one tank to another. Originally, one pipe connected the two opposing 32"-diameter nozzles pipes from skin valve to skin valve. The other pipe connected two opposing 18"-diameter nozzle pipes from skin valve to skin valve.

- At Tanks 1 and 2, a 16"-diameter LAT cross tunnel pipe connected the two 32"-diameter nozzle pipes and an 18"-diameter LAT cross tunnel pipe connected the two 18"-diameter nozzle pipes.
- From Tanks 3 and 4 to Tanks 19 and 20, a 32"-diameter LAT cross tunnel pipe connected the two 32"-diameter nozzle pipes and an 18"-diameter LAT cross tunnel pipe connected the two 18"-diameter nozzle pipes.

For each pair of tanks, where the two LAT cross tunnel pipes passed over the 32", 18", and 16"-diameter main pipelines, cross connections between them were made. As originally constructed in 1942, the 32" and 18"-diameter main pipelines extended all the way to the cross tunnels for Tanks 19 and 20, but the 16"-diameter main pipeline extended only as far as the cross tunnels to Tanks 1 and 2.

- At Tanks 1 and 2, the 16"-diameter main pipeline cross connected with the 16"-diameter LAT cross tunnel pipe.
- From Tanks 3 and 4 to Tanks 19 and 20, the 32"-diameter main pipeline cross connected with every 32"-diameter LAT cross tunnel pipe.
- From Tanks 1 and 2 to Tanks 19 and 20, the 18"-diameter main pipeline cross connected with every 18"-diameter LAT cross tunnel pipe.

Each tank was originally equipped with a permanently installed automatic tape-float-counterweight fuel-level gauge. These had Selsyn Transmitters with an accuracy to the nearest 1/4".

Each tank was originally equipped with a tell-tale leak-detection system (see discussion under that subheading, at end of this section).

From 1942 to the early-1960s, Tanks 1 and 2 were in diesel fuel service, Tanks 3 to 20 were in NSFO service, and the main pipelines connecting to the Underground Pumphouse via the HT were in service as follows:

- 32"-diameter – NSFO,
- 18"-diameter – NSFO, and
- 16"-diameter – diesel fuel.

All three pipelines could be used for both receipts and issues.

Mechanical Equipment at Bottom of Tanks: Modifications and Operations from 1960 to Present

As part of the project to convert Tanks 17 to 20 from non-volatile to volatile fuel storage the following piping changes took place from 1960 to 1963:

- The 32"-diameter LAT cross tunnel pipes at Tanks 17 and 18 and Tanks 19 and 20 were disconnected from the 32"-diameter nozzle pipes and removed.
- The 18"-diameter LAT cross tunnel pipes at Tanks 17 and 18 and Tanks 19 and 20 were disconnected from the 18"-diameter nozzle pipes and re-connected to the 32"-diameter nozzle pipes.
- The 32"-diameter main pipeline was removed from just east of Tanks 15 and 16 to the original end of the pipeline at Tanks 19 and 20, leaving Tanks 17 to 20 connected only to the 18"-diameter main pipeline.
- The manually operated 20" skin valves and the adjacent electric-motor-driven 20" gate valves at the 32"-diameter nozzle pipes on Tanks 17 to 20 were replaced with smaller valves.
- The sections of the 18"-diameter nozzle pipes in the bottom of the lower domes of Tanks 17 to 20 were cut flush with the ½"-thick tank bottom plates and removed.
- The 18"-diameter nozzle pipes on Tanks 17 to 20 were modified to carry new tell-tale leak-detection pipes and new fuel-sampling pipes from the tank bottoms to the LAT cross tunnels, and modified to function as the tank bottom drain.
- The 8"-diameter tank-bottom drain line was modified to serve as a fresh-water line for periodic tank cleaning and washdown.

- Asteroid Corporation outfitted Tanks 17 to 20 with new tape-float-counterweight fuel-level gauges, each equipped with a remotely readable telemeter with an accuracy to the nearest 0.001', twenty times more accurate than the previous gauging system.
- Tanks 17 to 20 had the 1942-vintage tell-tale leak-detection pipes removed and new improved tell-tale pipes installed.
- Tanks 17 to 20 have static-charge collection pipes installed down the inside walls of the tanks.
- A volatile fuel pump station was installed in the LAT west of Tanks 17 and 18.
- A 16"-diameter 6-mile long cross-country pipeline was installed, from the new volatile fuel pump station at Red Hill to a new volatile fuel pump station at Pearl City Fuel Annex.

From 1964 to 1965, various Red Hill tanks were in NSFO, diesel, JP-5, and gasoline service. Pipeline blinds were inserted or removed from the cross connections between the LAT cross tunnel pipes and the main pipelines in order to connect each tank with the main pipeline carrying the same fuel. Pipelines were in service as follows:

- 32"-diameter – NSFO,
- 18"-diameter – JP-5,
- 16"-diameter – diesel fuel, and
- 16"-diameter Red Hill to Pearl City – gasoline.

All four pipelines could be used for both receipts and issues.

From 1970 to 1972 the following modifications were made to the tanks and piping system:

- Installation of an auxiliary water pumping and piping system connected to Tanks 1 to 16. It is used to fill the tanks with water for leak testing. The water source is the Water Pumping Station.
- Tanks 5, 6, and 12 are emptied, cleaned, repaired, and outfitted with a new and improved tell-tale leak-detection system (see following subheading for more detail).

In the mid-1970s, Asteroid Corporation outfitted Tanks 1 to 16 with new tape-float-counterweight tank level gauges each equipped with a remotely readable telemeter with an accuracy of plus or minus 0.001' which is twenty times more accurate than the previous gauging system.

From 1965 to 1975, various Red Hill tanks were in NSFO, diesel, and JP-5 service. Pipelines were in service as follows:

- 32"-diameter – NSFO,
- 18"-diameter – JP-5,
- 16"-diameter – diesel fuel, and
- 16"-diameter Red Hill to Pearl City – JP-5.

In the mid to late-1970s an in-house project by the Fuel Department Maintenance Branch installed a new 12"-diameter main pipeline, starting from a connection with the 16"-diameter main pipeline (which originally ended at Tanks 1 and 2) and extending to the LAT cross tunnel at Tanks 15 and 16.

- From Tanks 3 and 4 to Tanks 15 and 16, the new 12"-diameter main pipeline was connected with every 18"-diameter LAT cross tunnel pipe.

From 1979 to 1983 the following modifications were made to the tanks:

- Surge Tanks 1 to 4 were emptied, cleaned, repaired, and coated.

- Red Hill Tanks 1 to 16 were emptied, cleaned, repaired (both the 1942-vintage and 1972-vintage tell-tale systems are removed and not replaced), and coated

In the mid-1990s on Tanks 1 to 16, the 20" and 12" manually operated gate-type skin valves were replaced with 20" and 12" remote-controlled, electric-motor-operated, double-sealing rising-stem plug valves, and the 20" and 12" remote-controlled, electric-motor-operated gate valves next to the skin valves were replaced with 20" and 12"remote-controlled, electric-motor-operated globe valves.

In the mid to late-1990s borings were made in the concrete and rock beneath Tanks 1 to 20, and the rock cores were checked for the presence of petroleum hydrocarbons that may have leaked from the tanks.

In the late-1990s the LAT cross tunnel pipes from Tanks 1 to 16 were replaced with new smaller-diameter pipes. The cross connections to the main pipelines remained the same.

From 1975 to early-2000s, various Red Hill tanks were in diesel and JP-5 service. Pipelines were in service as follows:

- 32"-diameter – diesel fuel,
- 18"-diameter – JP-5,
- 16"-diameter – diesel fuel, and
- 16"-diameter Red Hill to Pearl City – JP-5.

From early-2000s to mid-2000s, various Red Hill tanks were in diesel, JP-5, and JP-8 service. Pipelines were in service as follows:

- 32"-diameter – diesel fuel,
- 18"-diameter – JP-5,
- 16"-diameter – JP-8,
- 16"-diameter Red Hill to Pearl City – JP-5.

In the early-2000s, the skin valves on Tanks 17 to 20 were replaced with electric-motor-operated double-sealing rising-stem plug valves.

From the mid-2000s to present, various Red Hill tanks are in diesel, JP-5, and JP-8 service. Pipelines are in service as follows:

- 32"-diameter – diesel fuel,
- 18"-diameter – JP-5,
- 16"-diameter – JP-8, and
- 16"-diameter Red Hill to Pearl City – out of service, de-commissioned, and abandoned in place.

In the LAT cross tunnel at each tank there is a fuel sampling system, typically consisting of a horizontal manifold fed by seven vertical pipes of ½" and ¾" diameter. All of the vertical pipes have ball-type shut off valves as they approach the manifold. Below that shut off valve, five of these pipes are sampling lines and have tees with sampling spigots controlled by another ball valve. Each of these spigotted pipes has a wired metal tag that is inscribed with a height measurement, typically: either 10', bottom, 75', 135', or 200'. The other, non-spigotted pipes have no label. All seven pipes have another ball-type shut off valve just above the manifold, which is a section of metal pipe approximately 2' in diameter. This manifold flows into a single pipe that drains to a PVC pipe in a small floor trench.

For Tanks 1 to 16, above the manifold, the sampling lines route through an 8"-diameter pipe. This was originally installed as the casing pipe for the steam-condensate-return line. Inside each tank, the sampling lines extend up the central tower to the appropriate sampling height.

Tell-Tale Leak-Detection System and History of Design Improvements

The original tell-tale leak-detection system consisted of a series of 12 vertical pipes, equally spaced around the perimeter of each tank. See the sketches of the tell-tale system following the text and map pages. The pipes ran vertically down the tank wall (inside the tank), penetrated the lower dome, ran through the concrete plug under the tank, and ended at a monitoring station in the LAT cross tunnel near the skin valves for each tank. Small holes cut through the steel shell plates, located just above each horizontal butt-welded joint between shell plates, were connected to each vertical tell-tale pipe. In this way, the tell-tales pipes were designed to collect any fuel that leaked through a hole in a shell plate (or through a hole in a shell-plate weld) into the tiny space between the back side of the steel shell plates and the inner side of the reinforced concrete wall. The tell-tale pipe would then deliver the collected fuel to the LAT cross tunnel, to indicate the presence of a leak. During the original construction of the tanks, the tell-tale pipes were used in reverse, i.e., compressed air was introduced into the tell-tales in the Lower Access Tunnel and the tell-tales delivered the compressed into the space behind the steel shell plates. With water in the tank, any air coming through a hole in a shell plate, or through a hole through a shell-plate weld, manifested itself in the form of bubbles, which could be readily detected, and the hole(s) then marked for patching. The tell-tale leak-detection system worked. However, there were several problems with its design, which prevented optimal performance:

- The tell-tale pipes were only ¾" diameter and, in the event of a tank leak, could become plugged with the solid materials contained in the heavy fuel oil typically stored in the tanks in the early years. This would prevent the tell-tale pipe from identifying the leak. There was no way to blow out or flush out a plugged tell-tale pipe without first draining, cleaning, ventilating, and scaffolding a tank to allow the tell-tale pipe to be cut, cleaned, and repaired.
- The tell-tale pipes were standard pipe wall thickness; and they extended to the very bottom of the tanks, where they were exposed to water that settled out of the fuel. Due to the relatively thin pipe wall, the tank bottom water eventually corroded holes through the tell-tale pipes, thereby causing the tell-tale pipe to indicate a tank leak, when actually it was a leak in the tell-tale pipe itself.

Melvin Miller was the Fuel Superintendent from the late-1940s through early-1970s, and the POL Laboratory Building was named after him. He understood the problems with the tell-tales and worked to correct them with two separate rehab projects. In 1960-1963 the tell-tales were modified and improved in Tanks 17 to 20, which included increasing the pipe diameter to prevent clogging, and increasing the pipe wall thickness to Schedule 80, to provide corrosion allowance. Tank 19 retains these tell-tale pipe improvements from the 1960-1963. It is not known if any of the improved tell-tales remain in Tanks 17, 18, or 20. During 1971-1973, two more improvements to the tell-tale design were installed in Tanks 5, 6 and 12. The additional upgrades included extending the pipes up into the Gauging Gallery at the top of the tank where they could be readily accessed for flushing and cleaning. The other correction to the design was relocating the exit point of the tell-tale pipes. They were routed through the side of the hemispherical lower tank section, above the previous bottom exit point. This way they would not be exposed to the corrosive effect of the tank bottom water.

Unfortunately, Mr. Miller died in the early 1970s, before he retired. He could not defend the improvements he made to the tell-tale system in Tanks 5, 6, and 12 when the design for MILCON P-060 to rehabilitate Tanks 1 to16 started in 1977. Subsequently, a design decision was made that MILCON P-060 should remove the tell-tale systems from Tanks 1 to 16 altogether. In hindsight, removal of the tell-tale systems created two problems. First and most obvious, it removed a tool for potentially identifying and locating fuel leaks. Second, removal of the tell-tales eliminated a way to drain off any rainwater that percolates down through the lava rock and finds its way into the space between the back side of the steel shell plates and the inner side of the concrete wall. The standing water could cause accelerated corrosion of the back side of the steel shell plate.

3. Tunnels and Underground Spaces

a. Lower Tunnel, Facility No. S-21

Three tunnel sections comprise the Lower Tunnel (Facility No. S-21): Harbor Tunnel (HT) section, Makalapa Tunnel (MT) section , and Lower Access Tunnel (LAT) section. The HT section extends from the eastern end of the Underground Pumphouse (Facility No. 59) to its connection with the LAT section; this HT-LAT junction is near the Water Pumping Station (Facility No. 307) and "commonly referred to as the 'water shaft Y'."[27]. At the junction of HT and the LAT, there is an additional curved link tunnel, leading towards the Adit 3 end of the LAT section; this curved link creates the A-plan shape of the junction. Nevertheless, the junction is referred to as the "Y".[28] The MT section extends between Adit 2 (Facility No. S-275) and the intersection with the HT section. The LAT section extends from Adit 3 (Facility No. S-312) to the east end, near Tanks 19 and 20 (Facility Nos. 346 and 347). Three fuel pipes (typically with diameters of 16", 18" and 32") extend through the LAT and HT sections. A 30"-diameter (originally constructed as a 32"-diameter) water pipe extends through the eastern part of the HT and the MT section of the Lower Tunnel.[29] There is a set of narrow–gauge (2' width) steel rail tracks embedded in the concrete; the tracks extend along the length of all the tunnel sections.

Facility No. S-21, Overall Dimensions

The overall length of the Lower Tunnel, including all three sections, is about 3.5 miles. The MT section is the shortest, with a length of roughly 240'. The HT section is the longest, measuring approximately 2.5 miles. The LAT section's length is slightly less than a mile. The typical width is 12'-8", but there are wider sections. See the following "Floor Plan" subsection for discussion of the wider areas of the Lower Tunnel. At the intersections of the tunnel sections, the width tapers from 25'-4" (double the 12'-8") down to typical width. The height of the Lower Tunnel ranges from 10'-5" to 12'-0". Typically, the tunnel height includes the lower part with vertical walls a little more than 4' tall and the arched upper part with a radius of 6'-4".

Facility No. S-21, Foundations

The foundations for the Lower Tunnel are not uniform, but change in various areas from unreinforced concrete, to concrete reinforced with 6"x 6" wire mesh, or to concrete reinforced with rebar. Observations about the foundations follow, starting at the east end of the tunnel and moving west.

For the eastern part of the LAT section, few foundation details were found. The tunnel floor, at least near the Gaugers Station, is concrete with 6"-grid wire mesh reinforcing. The Gaugers Station has isolated footings under the I-beams of its wall; the footings measuring 2'-6" square x 12" deep, spaced 6'-4" on center. Foundations for the concrete overhead pipe anchors, in this part of the LAT section, are probably substantial, but no detail drawings were located for them. The I-beams of the overhead pipe supports for the fuel lines, in the eastern part of the LAT section, rest on 12" square concrete piers, extending from the concrete tunnel floor down to solid rock.

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[27] James A. Gammon, Comment in e-mail attachment from former Supply Center Fuel Department Superintendent to Ann Yoklavich of Mason Architects, Inc., January 27, 2015.

[28] Ibid.

[29] Ibid.

Once the fuel lines transition from overhead to the south wall of the tunnel, the foundations details change also. This is the area of the Lower Tunnel with pipe anchors and pipe supports on its south side (see descriptions of the various pipe anchors, piers, and supports under following heading). This area consists of the middle part of the LAT section, from the sump to the "Y" junction, and the HT section. A construction drawing shows the typical floor/foundation slab of the LAT part consist of unreinforced concrete about 10" thick, poured directly onto the rock base of the excavated tunnel. There is wire fabric reinforcing under the rail tracks, per a drawing note. Each side of the tunnel floor slopes slightly towards the rail tracks. The slope between the two rails is greater, creating a V shape for drainage. The foundations under the concrete pipe anchors are reinforced with ½"-diameter rods. The concrete foundations adjacent to each pipe anchor are 12"-thick slabs. These slabs, measuring 3'-8" wide, extend to the next concrete pipe support pier (both up-tunnel and down-tunnel). The foundations under the concrete pipe anchors are about 2' deep. Another note on drawing states: "Undercut gunite lining [of the walls] 8" for anchor slab." The footings for the steel pipe supports measure 2'-0" x 3'-0" and are 8" thick.

In the HT section of the Lower Tunnel, construction drawings show the concrete foundation slab is only about 6" deep; but in the part of the tunnel with a buried drain pipe, this slab is on top of a 3" base of No. 2 rock. The foundations for and around the pipe anchors are the same as described above for the LAT section. The HT also has, for most of its length, a large-diameter (originally 32"-diameter, now 30" diameter) water pipe extending along its north side. The foundations for the water pipe anchors and piers are the same as for the oil pipe anchors and piers.

The water pipe alignment extends along the upper part of the HT, then into the MT section of the Lower Tunnel. There is no detailed construction drawing for the foundation of the MT section of the Lower Tunnel, but section sketches suggest the foundations are similar in the HT and MT sections. There is an interesting note on that drawing, which shows the intersection of these two tunnel sections. Just west of the MT-HT intersection, there is a rectangle, measuring 1'-0" x approximately 13', shown with dashed lines and labelled: "Concrete cut-off wall in tunnel floor. Carry down to firm, unshattered material." The cut-off wall design aids in controlling "the movement of water under the concrete floor of the tunnel."[30]

Facility No. S-21, Structural System

The typical structural section design, in all sections of the Lower Tunnel, consists of steel ribs (I-beams with 6" flange) following the barrel-vaulted shape of tunnel, under a layer of galvanized wire fabric and ½"-diameter rods. That structural metal is covered by a lining of Gunite. The steel ribs are typically spaced 5'-0" on center. The reinforcing rods, spaced 12" apart in the arch of the tunnel and 24" apart on the vertical walls of the tunnel, are tack welded to the steel ribs. The galvanized 4"-square No. 12 wire fabric is wired to the rods before applying Gunite over that. Typically, the excavated tunnel radius, from the spring line, is 7'-3", but the finish radius is 6'-4", after placing the structural steel, wire reinforcing, and Gunite.

In the HT section of the Lower Tunnel, there is a section with additional structural steel support. This section with exposed steel supports is probably under the Moanalua Freeway. Here, there are arched I-beams, spaced about 5' on center, connected by steel angles spaced approximately 2' apart. There are similar added structural steel supports in the section of the LAT between Adit 3 and the LAT-HT junction.

The eastern half of the LAT is wider and has the ten cross tunnels to areas below the bottom of the tanks, so the structural system is different. Instead of rounded steel arches, the upper structural I-beams meet at 15-degree interior angles to create a shallower arch-like shape. There are other unique elements in this section of the LAT, which appear to be structural. There are arches and beams at the cross tunnels that appear

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[30] Ibid.

constructed from large-diameter pipes (about 18") covered with Gunite. These pipe-like supports do not appear on the 1940s design drawings. They might be a structural solution devised during construction, since they are seen in historic photos of the Lower Tunnel.[31]

The other notable structural elements in the Lower Tunnel are the pipe anchors and pipe supports for the fuel and water pipes. There are approximately 22 reinforced-concrete anchors for the fuel pipes, and fewer for the water line, since it extends only along the HT and MT sections. These anchors surround the pipes, to hold them securely. The pipe anchors are sited on either side of a bend in the tunnel alignment, but spaced approximately 600' to over 1,200' apart in the straight portions of the tunnel. The pipe anchors for the 32"-diameter water pipe are simple blocky shapes of reinforced concrete, with corners having 3" chamfers. The footprint dimensions of the water-pipe anchors are 4'-1" x 5'-0", and their height is typically about 5' above the tunnel floor. One new water-pipe anchor is only 4' tall. The original contractors built the pipe anchors before building the tunnel lining and floor, so the pipe-anchor keyways (not visible) extend about another 2' to 4' into the tunnel wall and below the tunnel floor. As a note on a construction drawing explains: "Anchors must be located in good solid rock. In poor material increase depth of key to 4'-0"."

That keyway note also applies to the more dramatically shaped pipe anchors for the three fuel lines. The positions of these fuel lines dictate the shapes of the pipe anchors. The pipe anchors for fuel lines are vertical shapes on the south side of the Lower Tunnel (the HT section and part of the LAT section). The 32"-diameter pipe (the largest) is in the lowest position on the pipe anchors. The 18"-diameter pipe is in the middle-height position (about 6' above the tunnel floor), but its vertical centerline is not aligned with that of the bottom pipe, since it is above the spring line of the arch, where the tunnel width has started to narrow. The 16"-diameter pipe, at the top position, is located much closer to the centerline of the tunnel, due to the arch of the tunnel ceiling. Thus, each typical pipe anchor for the fuel lines, surrounding all three pipes, has an angled projection at the top. The clear height, to where the projection in each anchor starts, is 6'-7". Every pipe anchor has footprint dimensions of 4'-1" x 5'-0"; however, the projection at the top extends, 0'-11" in the middle part of the LAT section and 1'-3" in the HT section, respectively, towards the Lower Tunnel center line.

The pipe anchors for the water line and for the fuel lines are usually in directly opposite pairs, on the north and south sides of the tunnel, respectively. Their dimensions leave only a little more than 4' width between them for passage of pedestrians, carts, and rail cars. In one instance (near Station 112 + 69), the pair of pipe anchors are slightly offset. Some of the typical fuel-line pipe anchors have a concrete "thrust block", as such is named on a construction drawing, at the corner of their base closest to the tunnel wall.

In the tank area of the LAT, the fuel lines pass through three concrete support "beams." These "overhead anchors," as labelled in a construction drawing, function like the pipe anchors described in the other parts of the Lower Tunnel. The overhead anchor sited just west of the sump area follows the design in an original drawing, with haunched beam. Apparently, a change made during construction resulted in the other two overhead anchors each having an intermediate pier.

For the 32"-diameter water pipe and fuel pipe, there are concrete piers under them at a spacing of about 25'. There are two design types of these concrete support piers. Type A is a reinforced-concrete pier with two inclined (batter = 1:6) faces. The footprint of this type measures 2'-8" x about 2', and its height is 1'-6" above the tunnel floor. The top surface of each Type A support has a curved steel cradle plate, which is not visible because the 32"-diameter pipe covers it. The Type B pipe pier, also of reinforced concrete, has four straight sides and a footprint of 2'-8" x 1'-6". The height of this concrete pier is 1'-3" above the tunnel floor, topped

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[31] Fourteenth Naval District, Photograph of Underground Fuel Storage, Red Hill, Lower Tunnel at Cross Tunnel #18, Photo #16609, July 8, 1943 (and in other photos, but this is the clearest).

by a visible steel cradle composed of eight pieces of steel plate welded together: shoe plate, base plate, two steel plates with curved cutouts, and four triangular pieces to brace the two with cutouts. This steel cradle raises the pipe about 3" above the top of the concrete. For both Type A and Type B pipe piers, their actual heights are greater than the visible portions, since the concrete extends below the tunnel floor to bedrock. A note on a construction drawing states: "Type A piers to be used on straight runs of 32" pipe for both oil and water lines. Type B piers to be used on curves for both 32" lines."

There is a Type C pipe support for the 16"- and 18"-diameter fuel pipes. This type is also spaced about 25' along the south tunnel wall. It consists of welded steel angles and gusset plates, not concrete. The vertical element of this type consists of two joined angle bars, and the horizontal angle bars splay towards the wall in V-plan, bearing each of the two upper pipes and bracing the vertical element. The heights of the V-plan braces above the tunnel floor are 7'-5-½" and 5'-4-½" for the 16"-diameter fuel pipe and 18"-diameter fuel pipe, respectively. Between each steel support post's base and its footing, there is a small concrete block for leveling, since the tunnel floor slopes slightly.

One example of another metal pipe support, consisting of I-beams and numbered 651, is located at intersection of HT and MT sections of Lower Tunnel. This either supplemented Type C pipe supports or replaced one. This type is not on the original drawings and its installation date is unknown.

There are also steel pipe supports in the tank area of the LAT that hold the pipe lines overhead. These are discussed in the following Floor Plan section, since they divide the width of the LAT, and affect the space division of that section of the Lower Tunnel.

Facility No. S-21, Floor Plan

Overall, the Lower Tunnel is a linear shape with spur segments, curves, and bends. The MT section is the shortest spur, located close to the west end, while the Adit 3 segment of the LAT section is the second spur. There are curves in the tunnel where the spurs meet. In addition, there are four noticeable bends in the HT section and one additional bend in the LAT section of the Lower Tunnel. At the MT-HT intersection, the MT section curves to accommodate a railway spur and the 32"-diameter water pipe. At the "Y" junction of the HT and LAT sections, there is a curved link section and a curve in the HT as it meets the LAT. These curves allow for optimal railway and pipeline layouts. Generally, the railway tracks are just slightly off center through all sections of the tunnel. In the eastern LAT, however, the tracks are along the north side of this part of the tunnel, due to the line of posts for the overhead pipe supports. There is a sidetrack of the railway for parking engines or cars, just west of the first post in this line.

Several minor and major spaces enlarge the Lower Tunnel beyond its typical 12'-8" width at various points. The following paragraphs discuss the major spaces. The minor spaces include the following:

- Additional excavated spaces for sectional valve wheels at the MT-HT intersection and at the HT-LAT junction [both rectilinear excavations on the south side of the tunnel have footprints measuring about 10' x 8', and ceiling heights of 7'-6"].
- Additional excavated spaces for large ventilation fans: one is located west and one is east of the HT-LAT junction [the arch-roofed excavations for the fans are on the north side of the HT and LAT sections of the Lower Tunnel, respectively; the former has a footprint of approximately 11' x 14', and the latter's footprint measures 10'-3" x 15'-0", between two doors in the LAT section.]
- Two triangular-footprint additional excavations adjacent to the two fans discussed above [the HT space measures about 16' long and tapers from a maximum width of about 8', while the LAT space has an approximate length of 14' and a maximum width of about 6'].

- A small toilet and shower room is located on the south side of the LAT, just east of the Water Pumping Station (Facility S-307) [the room is not in use and closed off].
- The excavated tunnel width at the bend in LAT is wider than is typical, by approximately 6' at the widest point; at the bend there is also an empty trapezoidal-footprint niche [the shape resulted from the installation of a conveyor transfer station in the early 1940s].
- The eastern LAT, where the twenty tanks are located, has a typical width of 17'-8" [note that the central part of the arched roof has a much shallower curve in this part of the LAT, with a radius of 29'-8", and a tunnel height of 11'-5"].
- Also within the eastern LAT, at the ten intersections of spur tunnels (cross-tunnels leading to areas under tank bottoms) the height of both LAT and cross tunnels is 13'-11" and the LAT tunnel width is 24'-4" [the tunnel footprint tapers, with the increase only on the south side of the LAT, between the typical 17'-8" width and the maximum 24'-4" width].

In the east part of the LAT and in the cross tunnels the fuel lines from the tanks extend overhead, on I-beams supported by two vertical I-beam posts. In the cross tunnels an original drawing shows the posts as buried under the Gunite lining of their walls. However, most posts are visible in the cross tunnels. It is not known if this was a change made during construction or during a later renovation project. In the eastern LAT, overhead pipe supports typically span the south part of the tunnel width, with one of each pair of vertical I-beams aligned about 9' from the north tunnel wall. The other vertical I-beam of each support pair is buried in the south tunnel wall of eastern LAT. In the Red Hill fuel system's early years or decades, the northern 8' to 9' of width in the eastern LAT had no obstruction between floor and ceiling. [See under "Mechanical Equipment" heading for current condition.] Except for the bays of the ten cross tunnels, there is typically cross-bracing in the longitudinal bays. Pipe support and cross bracing connections are all welded. This cross bracing, as well as the lower clearance (about 6') beneath the pipe supports, creates a division between the north and south sides of the eastern LAT. The reinforced-concrete center piers of the overhead pipe anchors also contribute to the space division between north and south tunnel spaces. These piers are aligned with the I-beam posts of the pipe supports; however, they are much thicker and wider, with a footprint roughly 1' x 5'.

West of Tanks 1 and 2, there is a wider section of the LAT, where the oily waste sump and sump pumps are located. "During the construction of Red Hill this location housed the primary rock crusher."[32] The fuel lines transition from overhead to the south side of the tunnel wall just west of the sump area. In this small segment of the LAT, four overhead I-beam pipe supports span the entire tunnel width. The vertical I-beam supports for these are in the north and south walls of the tunnel.

The additional excavation for the sump pit, on the north side of the tunnel has a footprint about 32' x 13'. The floor level of the pit's pump equipment is about 6' below the tunnel's floor, but the lowest part of the sump is approximately 8' lower than that. A pipe railing borders the pit on its west side. Along that side there is a concrete stair between the tunnel and pump floors. When the primary rock crusher was here in the early 1940s, its floor level was a few feet lower than the sump pit level and about 18' lower than the tunnel floor.

The largest additional excavation adjacent to the Lower Tunnel includes the spaces for the Gaugers Station, its bathroom, Elevator #72, and former Fan No. 9 room – all on the north side of the tunnel between Tanks 15 and 17 (Facility Nos. 342 & 344). Overall, the footprint of these spaces measures about 64' x 13'. All the spaces have the same 13' width, with the bathroom occupying 6'-4" of the overall length, the Gaugers Station filling the largest space with 38'-0" of the length, the elevator shaft having 9'-8" of the overall length, and the

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[32] James A. Gammon, Comment in e-mail attachment from former Supply Center Fuel Department Superintendent to Ann Yoklavich of Mason Architects, Inc., January 27, 2015.

fan room taking up the remaining 10'-0". The ceiling shape of the Gaugers Station and its bathroom is flat for about 7' on the south (tunnel side) of these rooms, and arched (with a 6'-4" radius) on their north sides.

One of the six bays in the Gaugers Station, measuring 6'-4" x 13', was originally a separate room, demarcated by metal mesh partitions that are partly removed. This space is now a kitchen on the west end of the Gaugers Station; the original use, based on the partition remnants, could have been for storage or control equipment. Most of the original 1940s equipment in the Gaugers Station is updated with modern controls.

The floor height of the bathroom west of the Gaugers Station is about 8" higher than the tunnel floor. This is not indicated on the original construction drawing, but the date of the change is unknown.

The pit below Elevator #72 extends 6'-6" below the tunnel floor. The elevator operates between the Upper and Lower tunnels, but the shaft rises several hundred more feet to the surface of Red Hill Ridge. An Air Intake structure (see description under "Facility No. S-315" heading) is at the top of the shaft.

Since the floor of the former Fan No. 9 Room is a few feet above the tunnel floor, a metal ladder provides access. "The fan was removed as part of the 1964 conversion of Tanks 17 to 20 to store volatile fuel."[33]

On the south side of the tunnel, between Tanks 16 and 18 and near the Gaugers Station, are two rooms that enclose part of the tunnel, rather than being excavations into the side of the tunnel. Because of these rooms, the tunnel width of the LAT at its narrowest is about 8'. Both rooms house equipment for recent upgrades of the electrical systems in the tunnel. The transformer room is across from the former Fan No. 9 Room, and measures approximately 17' x 11'. The larger electrical room, labeled "Formerly Battery Room", is close to the Tank 16 cross tunnel, slightly west of the Gaugers Station's Bathroom. It has an irregular footprint, due to the tapered width of the tunnel; it measures approximately 40' in length and has a width varying from 13'-6"' at its wide end to about 9' at its narrow end.

In an excavation on the north side of the tunnel, between Tanks 17 & 19, is Elevator #73 and adjacent rooms. The rectangular excavation measures approximately 25' x 18'. This excavated area includes a bathroom and storage room, as well as the elevator shaft and vestibule in front of the elevator.

The grade of the tunnel changes as it moves from the pumphouse to the tank area. The grade is fairly level for the first 3,000' of the tunnel, ranging from 0.1 to 0.2%. For the next approximately 2,000' the tunnel grade is between 0.3% and 0.6%. Then the grade increases to 1.18% for about a mile and a half in the middle. The grade levels off again, to less than 0.1%, for another 3,000' or so. Between the cross tunnel to Tanks 3 and 4 and the one to Tanks 5 and 6, the grade increases to 2% and continues until the tunnel end.

Facility No. S-21, Tunnel and Floor Finishes

The original tunnel walls are Gunite (sprayed concrete) over metal reinforcing, as discussed under the "Structural System" heading above. The tunnel floors are generally bare concrete with embedded steel rail tracks. Remnants of paint are visible on the floor of the tunnel near the Gaugers Station. In the LAT section, there is a modern steel grating over wash-water collection trenches in the tunnel floor. The main trench extends along the south side of the LAT, with floor trenches at right angles in the ten cross tunnels. The floor trenches deliver the oily wash water to the sump in the LAT west of Tanks 1 and 2. The most notable modern finishes are the stainless steel ceiling panels, recently added to some areas of the LAT, including near Tanks 19 & 20 at the eastern end of the tunnel. The ceiling panels function as diversion gutters, gathering water that drips through the rock above and keeping it off the pipes and pipe supports. Some parts of the tunnel just have steel panels applied to the arch of the ceiling and upper walls. These perform the same function of diverting water drips away from pipes and supports to a side wall and floor.

Walls of concrete (or cement plaster over CMU) enclose the larger electrical room near the Gaugers Station. Although a portion of the ceiling is the original tunnel arch, most of this room has a shed ceiling of stainless steel. Modern textured panels enclose the smaller electrical equipment room across from the former Fan No.9 Room, but do not reach the tunnel ceiling. Since that smaller room was locked, the ceiling material was not inspected.

A few spaces in the Lower Tunnel, such as the Gaugers Station, have painted floor and wall finishes. The bathroom adjacent to the Gaugers Station has ceramic tile on its floors and on the walls, to a height of about 6'. All the doors and door frames in the tunnel are painted, typically bright yellow.

Facility No. S-21, Doors

See descriptions under "Adits" headings [Adit 2 (Facility No. S-275) and Adit 3 (Facility No. S-312)] for those two entrance doors. See the "Doors" heading under Facility No. 59 for the two doors between the pumphouse and the west end of the Lower Tunnel. Descriptions of the doors within the three tunnel sections follow. For ease of reference, labels include the tunnel section abbreviation, then a letter assigned by location, with A being the one in each section that is closest to its western or northern end. (For example, HT-A is the first door in the Harbor Tunnel section, if approaching from the Pumphouse, heading up-tunnel, or east. Similarly, MT-A is the first door in the Makalapa Tunnel section, if approaching from Adit 2 at its northern end, heading south towards the HT-MT intersection.)

There are only two doors in the HT section of the Lower Tunnel, plus one frame without a door. Door HT-A is located about 50' east of the HT-MT intersection, in a wall that is labelled "oil-tight bulkhead," which is 18"-thick Gunite over reinforcing per an original drawing. The concrete pipe anchors, for the fuel line and for the water pipe, abut the west side of the bulkhead wall, creating a narrow passage when approaching the door from that side. The door, labelled a "pressure door," measures approximately 4' x 7'. It is made of steel plate, with 6"-flange I-beams welded to its eastern side (two horizontally positioned and segments centered vertically). The door handle on the western side is a round metal bar bent into a flattened U shape and welded to the steel plate. There are two protrusions from the door for insertion of wedges, if ever needed for oil-tight closure. However, four other protrusions have been cut off. There is newer magnetic control hardware for automatic door closure in case of emergency.

There are two cross-tunnel walls to the east and west of an area with two large fan units, about 55' west of the blocked-up former entry from the HT section of the Lower Tunnel to Facility No. S-307 (Water Pumping Station). There is a frame for a door, measuring about 4' x 7', in the wall to the west, but the door is removed. The wall to the east of the fans is longer, due to the excavation on the north side of the tunnel for the fans. This wall contains Door HT-B and a large ventilation opening with screen, on the north side of the door. Door HT-B is made of steel plate, with one vertical and three horizontal thin metal bars welded to the steel plate, only on the east side. The central vertical bar and the three horizontal bars, with approximately equal spacing, create the appearance of an eight-panel door. The door has three heavy strap hinges; two of the three hinge pieces attached to the concrete wall are triangular, to accommodate the fuel pipes passing through the wall close to the door. The lowest surface hinge on this wall is rectangular.

There were originally three doors in the MT section of the Lower Tunnel. On an original drawing the names for the doors are "Screen Door" (called Door MT-A in this report), "Steel Grille Door" (Door MT-B in this report), and "Fire Door." The door in the frame for the Fire Door is not extant, so is not numbered or described. Door MT-A is in an arched frame of metal angles with Galvanized Iron (GI) expanded metal mesh. The door, built of the same materials, measures 5'-7" x 9'-0". The door has a vertical and a horizontal

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[33] Ibid.

stiffener; the latter is built of two welded angles measuring 2" x 2" x ¼". The handles on each side of the screen door are round steel bars bent into shallow U shapes. The 30"-diameter water pipe and a small-diameter pipe pass through the expanded metal on the northeast side of the door. A circular frame, 2'-0" in diameter, is in the mesh above the water pipe. All the metal framing and expanded mesh has a coat of black paint.

Door MT-B is similar to the fourth door in from the entrance to Facility No. 59. It is composed of vertical steel I-beams, set in a frame of larger steel I-beams. The I-beams of the frame have 10"-wide flanges and the grille I-beams have 6"-wide flanges. The latter are set vertically in an overlapping staggered pattern, with an inner and outer row of I-beams, which have 4" spacing between the beams. Thus, the inner flanges of the two rows overlap by about 1" but are not in the same plane; the design allows air to flow through, but nothing is visible. The door is now removed from the opening, and stored along the tunnel wall, between Doors HT-A and HT-B. The door and the frame are painted black. The door measures 5'-0" x 9'-0" and has three heavy-duty hinges built from ½" steel plate, with 7/8" steel pins.

There are eight doors in the LAT section of the Lower Tunnel; two of these are in the section between Adit 3 and the HT-LAT junction. Door LAT-A is a screen door similar to the one in the MT section. This screen door with steel-angle framing and expanded metal mesh is located about 70' east of the entry to Facility S-307, the Water Pumping Station. Door LAT-A does not have the vertical stiffener seen in Door MT-A. It has modern aluminum rounded door knobs. It measures roughly 5' x 8', and has a coat of yellow paint. Door LAT-B has ¼" steel-plate covers over a door composed of five steel I-beams with 6" wide flanges. There are heavy-duty three hinges built from ½" steel plate, with 7/8" steel pins. The door opening measures 5'-0" x 8'-0" and is set in a wall of reinforced concrete. The original drawing for this door shows it had an interesting detail on the bottom – a section mounted on the Adit 3 side of the door could be lowered to cover the slightly concave gap between the rail tracks. This was to make the door oil tight. The tank side of the door has a coat of yellow paint and an Exit sign.

The six doorways in the section of the LAT, between the HT-LAT junction and the east end, include three simple modern doors of flush metal. The two doors closest to the HT-LAT junction date from the 1940s while the other appears to date from the 1960s or later.

Doors LAT-C and LAT-D are located just east of the HT-LAT junction, on either side of Fan No. 2. Door LAT-C is on the west side of the fan, in a wall that is labelled a "ventilation bulkhead" on an original drawing. The 6"-thick concrete "ventilation bulkhead" contains a ventilation opening, with a fan duct attached on the east side, as well as the door. Door LAT-C is a fire door, called a "Kalamein door" on an original drawing; the definition of this type of door is one with galvanized sheet metal over a core of solid wood or over a wood-frame with insulated panels.[34] Door LAT-C measures 4'-4" x 6'-6" and is 2-¼" thick. It has three heavy-duty strap hinges that are bolted to the concrete wall. Door LAT-D, to the east of the fan, is in an "oil-tight bulkhead" wall that is about 2' thick; the fuel pipe anchor at this position is part of the wall thickness and extends an additional 3' on the west side of the wall. The door opening in the wall is 6'-6" x 6'-6" and the door measurements are 6'-9" x 6'-9". Similar to Door HT-A but larger, Door LAT-D is a "pressure door," built of ½" steel plate, reinforced by a grid of I-beams with 8" flanges. For both of these doors, the door handles are round bars bent into shallow U shapes. Door LAT-D and Door HT-A have additional hardware for automatic door closure in case of emergency. An automatic float switch in the drain under each door operates a door release and counterweights close the door when necessary.

[34] Cyril M. Harris, ed., *Dictionary of Architecture & Construction* (New York: McGraw-Hill, Inc.) 1993. [Entry: "metal-clad fire door, Kalamein fire door"] p. 527

Door LAT-E is located just west of the Gaugers Station, installed in a reinforced concrete wall 4'-0" thick. The door looks similar to those in a 1961 drawing for "blast resistant doors." However, that drawing showed double doors, and other design details differ slightly. "The reinforced concrete wall was constructed in 1964 without a door. A hole was cut through the wall and the door was installed in the late 1990s."[35] Door LAT-E measures approximately 4' x 8'. It is constructed of steel plate at least ½" thick. On the door's west face, steel-plate segments are welded at right angles to the door plate in a grid pattern (two vertical and seven horizontal). Mounted on this grid is a handwheel door operator and lever linkages to the locking hardware. The east face of the door just has a handwheel operator on the steel plate. There are two massive hinges on this side, plus a door frame about 8" wide around the sides and top of the door. About twenty bolts secure the frame to the concrete wall.

Doors LAT-F, LAT-G, and LAT-H are all very similar modern ones. They are flush metal doors, measuring 4'-0" x 6'-8"; they have simple lever handles. A 1963 drawing shows a sketch location map with these three doors and labels them fire doors. They were among the alterations made when the four tanks at the end were modified to hold volatile fuel. These three doors were "part of the CARDOX carbon dioxide fire-fighting system. In the event of a fire the doors would automatically close and isolate the area in the tunnel where the fire was located. To conserve carbon dioxide, the discharge was limited only to the isolated fire area."[36] The current doors are simpler than the fire door shown in a 1960 drawing. For instance, there are no mechanisms, such as fusible links and counterweights, to close the doors automatically. This probably represents either a substitution made during construction in the 1960s or during installation later of replacement doors.

In addition to the doors that are in walls perpendicular to the tunnel length, there are several doors to the spaces along the sides of Facility No. S-21. There is no door along the sides of the HT section. In the MT section, on its southwest side, there is a stairway leading to an access tunnel from Facility 250. A CMU wall and its modern double doors of flush metal now limit entry to that access tunnel.

The LAT section has three unusual doors along its sides. The most unusual door is on the north side of the LAT, located about 150' east of Door LAT-D. This steel door used to open inward to an access shaft connecting the Lower Tunnel and the Standby Power Plant (Facility No. S-308). Since the Power Plant is long abandoned, the shaft is now blocked. An original drawing shows the access door construction consists of two ¼" steel plates and five I-beams, with 6" flanges, welded between the plates. The access door is painted black and measures approximately 3' x 6'. The bottom of the access door is about 2-½' above the tunnel floor, since it had to clear the oily waste pipe and electrical conduits extending along the north side of the LAT. Since the end of WWII, additional pipes and conduits have been added along the tunnel. The door handle is a simple round metal bar, bent into a shallow U shape, welded to the steel plate. For fasteners, the door has four steel pins (¾"-diameter x 2" length) on chains, which are inserted into hasps with 13/16"-diameter holes welded to the door and receptacles created from 1-½"-diameter pipes sunk into the tunnel wall and welded to the door frame.

Two other unusual doors along the sides of the tunnel are in the Adit 3 end of the LAT, near the HT-LAT junction. The not-in-use toilet / shower room, located on the LAT's south side – east of the Water Pumping Station (Facility S-307), has a partition-type door of plywood. The door measures about 3' x 5' and is positioned about 3' above the tunnel floor, inset slightly, over the second step up to the room. The Water Pumping Station's door to the LAT is much more complex. Due to the angle created by the axis of the LAT and the Water Pumping Station, and to the rail track that curves from one to the other, this door is set at an

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[35] James A. Gammon, Comment in e-mail attachment from former Supply Center Fuel Department Superintendent to Ann Yoklavich of Mason Architects, Inc., January 27, 2015.

[36] Ibid.

unusual angle. The dimensions of the opening are approximately 15' wide and 10'-6" tall. The upper part (about 2') is a fixed section. In the lower part, there are also fixed sections at both ends of the wide opening; the fixed section at the east end is about 2' wide, while the one on the west end is approximately 4' wide. In between are unequal double door sections, about 3' and 6' wide. The narrow door section is made of flush metal, and is the human entry. The larger door section, or the entire double door, opens for equipment entry. The fixed sections and larger door section have a grid-like metal frame, covered by metal mesh, with inserted air-filter panels.

The other doors along the sides of the LAT are more typical. The Gaugers Station door is flush metal with glazing in the upper half. The bathroom door is similar, but has a small vent opening near the top with louvers. These two doors are painted grey, but their frames are bright yellow.

The door between the Elevator #72 lobby and the tunnel is a modern flush-metal door. The original larger opening for the double doors to that lobby has been infilled with CMU. The original sliding fire door (panels operated vertically with counterweights) between Elevator #72 and Fan Room is gone, and a fixed louvered opening is in its place. The flush-metal double doors to the former Fan No. 9 Room are modern. The doors to the two electrical equipment rooms near the Gaugers Station are both modern double doors of flush metal. The smaller room for electrical equipment has doors painted off-white, unlike the other modern flush-metal doors mentioned in this paragraph, which are yellow.

There are two doors between the Elevator #73 lobby and the LAT. The person-sized entry to the Elevator #73 lobby is a modern flush-metal type. The larger equipment entry from the tunnel to that lobby has an overhead metal roll-up door. The roll-up door is unpainted. The doors for the Elevator #73 cab are modern panels of unpainted metal that operate vertically with counterweights. The other doors near Elevator #73 are painted yellow. These include the entry door to the lobby from the tunnel and two similar modern flush-metal doors in the lobby.

Facility No. S-21, Mechanical Equipment

The complicated mechanical equipment arrangements at the bottom of the connecting tunnels under the tanks are part of those facilities and discussed under the "Fuel Tank Type" heading. There are many more pipes and conduits now positioned near the ceilings and walls than in the original design, due to safety regulations and technological developments. Some of the electrical machinery that controls the tunnel lighting and power for other mechanical systems are located in the Water Pumping Station (Facility No. S-307) near the HT/LAT junction.

b. Upper Access Tunnel (No Facility Number)

There are three components of the Upper Access Tunnel (UAT). The main section of the UAT extends from Adit 4 to the tunnel terminus near Tanks 19 and 20. Angling from this main section are twenty side tunnels (ten on each side of the main section), one side tunnel to each tank's entrance portal. The UAT also includes a spur tunnel that extends from Adit 5 to the intersection of this spur with the main section; the intersection is located between Tanks 13 and 15.

Upper Access Tunnel, Overall Dimensions

The UAT is approximately 2,320' in overall length, from the Adit 4 doorway to the terminus of the tunnel. Each side tunnel to a tank entry is about 40' in length. The Adit 5 spur tunnel measures about 460' long . The bores of all the upper tunnel sections have roughly arched ceilings, relatively straight walls, and a concrete floor. The bores have undulating surfaces following the unevenly excavated rock. These tunnel bores are typically about 14' wide and about 12' to 14' high. Where the pairs of side tunnels angle from the main section of the UAT, the bore width increases to as much as 40'.

Upper Access Tunnel, Foundations

The UAT was excavated from the lava rock (basalt) of the Red Hill ridge. Its floor is a concrete slab approximately 4"-thick over the bedrock base. Across its width, the tunnel floor slopes from both edges towards the center of the tunnel, where there is a set of narrow–gauge (2' width) steel rail tracks. These tracks, embedded in the concrete floor, extend along the length of the UAT (main section and spur tunnel). The slope between the two rails is greater, creating a V-shape for drainage. "The wooden ties that support the rails underlie the concrete floor. In the years since they were originally constructed some of the ties have rotted away leaving the rails unsupported."[37]

Upper Access Tunnel, Structural System

The UAT excavation required no structural system, other than the arch of the bore. As the caption for a 1941 historic photo noted, its "blocky gray basalt … needs no support."[38] The only exception is an area of the UAT near Adit 4. Its smooth walls and ceiling indicate structural steel sets underlie the Gunite surface here.

Upper Access Tunnel, Floor Plan

The UAT is entirely within the Red Hill ridge, unlike the Lower Tunnel (Facility No. S-21) that extends several miles and connects to the underground pumphouse on the Naval Base at Pearl Harbor. Of the UAT's three components, the main section of the UAT is the longest. It is composed of two straight sections joined with a gentle bend. From the entrance at Adit 4, the main section of the UAT extends straight to the southeast for a distance of about 415'. Then the main section bends slightly to the northeast and its main spine extends about 1,907' to its terminus just beyond the side tunnels to Tanks 19 and 20. The UAT's main section has four bulkheads with doorways along its length, which divide the linear tunnel space into smaller compartments. These doors and bulkhead walls are described under the "Door" heading below.

The twenty short side tunnels to the tanks entrances are set at 45-degree angles from the long spine of the UAT's main section. The construction history in Part IB of this report explains how the side tunnels were connections to ring tunnels around the outer perimeter of the tanks, at the springline. The ring tunnels were the initial step in the excavation work, followed by construction of the upper domes of the tanks.

The Adit 5 spur tunnel section has two gentle bends. The first bend in the spur is about 100' in from Adit 5 and the second is at the spur's intersection with the UAT's main section. The axis of the spur tunnel's long part is at a right angle to the axis of the UAT's main section, but the bend at the intersection accommodates the curve of the rail tracks in the floor. The spur joins the north side of the UAT's main section about three-quarters of the way up from its bend. There is no door within the spur tunnel section. However, after construction of the Red Hill Fuel System, this spur tunnel was blocked off with a concrete bulkhead, just north of its intersection with the main part of the UAT. "The spur tunnel remained blocked off from 1942 to

[37] James A. Gammon, Comment in e-mail attachments from former Supply Center Fuel Department Superintendent to Ann Yoklavich of Mason Architects, Inc., January 29, 2015.

[38] CPNAB, Contract NOy 4173 photos, "Underground Fuel Storage Project, Curve on Upper Access Tunnel," Photo #14082, March 3, 1941.

1964 ,when it was re-opened for installation of a new tank vent pipe serving Tanks 3 to 16."[39] There are remnants of the concrete wall and its rebar near the commemorative marker.

Twenty side tunnels, leading to the entries of the fuel tanks, angle from the spine of the UAT's main section. The side tunnels are in ten symmetrical pairs, spaced about 200' apart. Each side tunnel is about 40' long and ends at "an 8'-diameter flanged steel dished head which is the main entryway into the tank. The invert of each dished head is at or slightly above the tank spring line."[40] In front of each tank's dished head (cover of the entrance tube), a metal ladder leads up to an access tunnel arching over the tank's upper dome to the gauging chamber on top of the tank.

The western third of the UAT floor is generally level, but rises slightly at its eastern two-thirds. The UAT's floor is approximately level from Adit 4, through the bend to the northeast, and for an additional 350'. At a point east of Tanks 3 and 4, the tunnel floor begins a gentle rise. This rise parallels the rise in the LAT, since the height difference between the lower and upper tunnels is consistently about 200'. Over the remaining 1557' of the UAT's main section, the floor level rises about 30'. The fuel tank pairs are numbered consecutively, starting with Tanks 1 and 2 at the west of the main section's long spine and ending with Tanks 19 and 20 at the east terminus, which is also labelled the tunnel heading. The odd-numbered tanks are on the north side of the tunnel and the even-numbered tanks are on the south side.

Adit 4 is at about 327' elevation above sea level on the northern slope of the Red Hill ridge. The entry part of the UAT, from Adit 4 to the 135-degree bend has a level grade, as does the western part of the long spine of UAT's main section. The long spine of the UAT aligns approximately with the undulating surface of the ridge crest. At the point where the grade of the UAT's floor begins to rise, east of Tanks 3 and 4, the tunnel floor is about 180' beneath the crest of the ridge. At its terminus at Tanks 19 and 20, the UAT is about 210' beneath the crest of the ridge. The Adit 5 opening is located at an approximate elevation of 345', also on the northern slope of the Red Hill ridge. The grade of the spur tunnel from Adit 5 to the main tunnel is approximately level.

In addition to Adit 4 and Adit 5, there are two elevators providing access to the UAT. Elevator #72 is located between Tanks 15 and 17, on the UAT's north wall. It connects the UAT and the Lower Tunnel. Elevator #73 is also on the north side of the UAT between Tanks 17 and 19. That elevator not only links the UAT and Lower Tunnel, but also is connected to Adit 6 and its spur tunnel.

At Elevator #72 the elevator door opens directly into the UAT, without a vestibule such as exists in the Lower Tunnel for this elevator. Adjacent to Elevator #72, on its east side, is an opening with double doors to a space that originally held fan equipment. That space now provides access to an area on the north of the elevator. This area has a subway grating and ship's stairs to the elevator machine room about 18' above the UAT floor level. The widest footprint measurements of the Elevator #72 shaft, at the level of the elevator machine room, including the 12"-thick concrete walls, are approximately 15'x 20'. The elevator shaft's normal interior dimensions are roughly 8' x 8'. A ladder extends up the shaft from the roof of the machine room to the Air Intake Structure (Facility No. S-315), more than a hundred feet above. There are also ladder sections and landing platforms in the shaft between the UAT and LAT, which are 206' apart.

There is a steel roll-up door between the UAT and the small vestibule for Elevator #73. Adjacent to the roll-up door, on its west side, is a door that provides access to the stairway and ventilation/elevator shaft, and to the vestibule in front of Elevator #73. The widest footprint measurements of the Elevator #73 shaft,

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[39] James A. Gammon, Comment in e-mail attachments from former Supply Center Fuel Department Superintendent to Ann Yoklavich of Mason Architects, Inc., January 29, 2015.

[40] Ibid.

including the 12"-thick concrete walls, are about 16' x 18'. The elevator shaft's normal interior dimensions, between the UAT and LAT, are roughly 9' x 16'. The utility shaft from the fan room to the surface is about 5' in diameter and 160' tall. This part of the shaft is discussed further in the Ventilation section, under the heading "Tank Vent Structure atop Utility Shaft #73." In addition to connecting the upper and lower tunnels, Elevator #73 also provides access to the Adit 6 tunnel, which is located about 65' below the level of the upper tunnel.

In the north wall of the UAT, to the west side of Elevator #72, is a cabinet with double doors of plate metal; remnants of disconnected meters and other equipment are inside, perhaps parts of the original tank gauging system. East of Elevator #72 and west of Tanks 17 and 18, the tunnel widens slightly, to about 16'.

Upper Access Tunnel, Tunnel and Floor Finishes

Generally, the ceiling of the UAT is a rough barrel vault, and the walls are approximately vertical. They were excavated from the bedrock, so they typically have an uneven surface with protrusions and depressions of up to several feet. The usual surface finish is an undulating layer of Gunite that follows the uneven contour of the underlying bedrock.

The part of the UAT near Adit 4 has smooth wall and ceiling surfaces, and historic photos show that condition is original. This part has Gunite over arched steel ribs, probably because the rock was softer near the hillside surface. The UAT's wall around the Elevator #72 door is painted CMU.

The UAT has a concrete floor. Most of the floor has a natural concrete surface. At some places, the rail tracks at the center of the tunnel have heavily worn yellow paint, used to denote caution areas.

Upper Access Tunnel, Doors

For descriptions of the entry doors to the UAT see the "Adit 4" and "Adit 5" headings. The UAT's main section has four doors. These are metal doors of various widths and configurations. For ease of reference, the doors are identified by the UAT abbreviation, then a letter assigned in order of location (Door UAT-A being the one closest to Adit 4 and Door UAT-D being the door farthest east). Door UAT-A is located at the main section's bend, which is about 415' from Adit 4. Door UAT-B is east of Elevator #72, just west of the side tunnels for Tanks 17 and 18. Door UAT-C is east of the side tunnels for Tanks 17 and 18. Door UAT-D is east of elevator #73, just west of the side tunnels for Tanks 19 and 20.

Door UAT-A is in a bulkhead wall, approximately 4" thick, that could be concrete or frame construction with a concrete plaster finish. The modern, hollow-metal double door measures approximately 5' x 7'. It has a crash bar on one interior leaf and a lever handle on the exterior side of that leaf. "The purpose of the bulkhead wall and the [normally closed] door … [is] to allow tunnel ventilation Fan No. 1 to pull air down the UAT and exhaust it out Adit 4."[41]

Door UAT-B is in a bulkhead wall of reinforced concrete, about 4' thick. The concrete threshold of the doorway is cast over the rail tracks, making passage on the tracks further east impossible. The door opening measures 3'-6" x 7'-0", with a blast-resistant metal door that opens towards the west (down-tunnel). Several 1960s drawings indicate this door and its concrete bulkhead were constructed in that decade. The metal door is about 6" thick, constructed of two heavy steel plates over wide-flange I-beams and other internal operating mechanisms. Each exterior face of the door has a hand wheel, which operates sliding metal rods that fit into the door jamb to secure it. The door has three very large hinges. "The concrete bulkhead and the door,

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[41] Ibid.

which is normally closed, are designed to be oil-tight. Their purpose is to stop the flow of fuel down the UAT in the event of a tank leak or overflow."[42]

Door UAT-C is in a concrete bulkhead wall that is about 6" thick. This steel door swings east, towards the end of the tunnel. It measures 4'-0" x 6'-8". The door has four steel angles bolted across its width at an even spacing. The door has a lever handle to operate three metal guides, which extend beyond the door edge and rotate down into corresponding notches in the doorjamb to latch the door. Since the door has a 6" sill, metal ramps cover the transition from floor level to the bottom of the door opening.

Door UAT-D swings west, but is otherwise identical to Door UAT-C. Both doors have fusible links for automatic closure in case of a fire. "Doors UAT-C and D were installed as part of the CARDOX firefighting system in 1964. They were designed to isolate areas of the tunnel in order minimize the quantity of carbon dioxide needed to extinguish the fire. They are no longer in service."[43]

At Elevator #72, the sliding door of the passenger cab has a brushed metal finish. Adjacent to the elevator is a modern hollow-metal double door.

At Elevator #73, there is a metal roll-up door to provide equipment access to the elevator's small vestibule space from the tunnel. Adjacent to the roll-up door is a modern hollow-metal door providing personnel access to the vestibule, stairway and shaft of this elevator.

Upper Access Tunnel, Mechanical Equipment

Extending the entire length of the UAT, from Adit 4 to its terminus, and along the length of the Adit 5 spur tunnel, are narrow-gauge steel rail tracks (2' apart). These tracks are occasionally used with flat cars that are pulled manually, but were previously used for a small rail engine to transport material. There is no longer any rail engine or car/cart with rail wheels stationed in the upper tunnel.

The upper tunnel has two elevators that connect it with the lower tunnel. The Elevator #72 shaft also functions as part of the Air Intake Vent (Facility No. S-315) and is discussed under that heading. The shaft for Elevator #73 is part of the ventilation system for Tanks 17 through 30, as well as functioning as a utility shaft. The Tank Vent Structure (no facility number) at the surface and this elevator/utility shaft are discussed in the Ventilation section of this report.

The UAT is lit by modern fluorescent light fixtures suspended from the ceiling, spaced about every 40' in the main section and in the Adit 5 spur section. Each side tunnel, off the main spine to a tank, typically has two of these fixtures.

The UAT has separate tunnel ventilation and tank ventilation systems. For the tunnel ventilation, air circulates through the UAT via the Air Intake Structure (Facility S-315) atop the Elevator #72 shaft. That structure draws fresh air down the elevator shaft to the tunnel. Fresh air is also brought into the tunnel through Adit 5. Exhaust air is blown out through a duct that passes through the first bulkhead wall (around Door UAT-A) and extends out the doorway at Adit 4. Just east of the second bulkhead (around Door UAT-B) is a large, rectangular, sheet-metal air duct that handles air in the spaces around Tanks 17 through 20.

The UAT's original tank ventilation system served Tanks 1 to 20; from 1964 to the present, the original system, with some modifications, is serving Tanks 1 to 16. The current system includes the original 24"-diameter vent piping that collects tank vapors and routes them outside via two tank vents (Facility Nos. S-197 and S-213) above Tanks 2 and 3, respectively. In 1964 a 16"-diameter vent pipe was added to the system,

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[42] Ibid.

[43] Ibid.

extending along the west side of the Adit 5 spur tunnel and out past the Adit 5 bulkhead wall. The 24"-diameter vent pipe is routed under the floor of the UAT and up the arched access gallery to the top of each tank. "For Tanks 17 to 20, from 1964 to the present, the tank ventilation system consists of the original 24"-diameter piping from the top of each tank down to the UAT. "[44] These original vent pipes connect to 1964-era 20"-diameter and 12"-diameter pipes in the UAT, which vent through a 12"-diameter pipe extending up utility shaft #73 to the vent structure on the top of Red Hill

Renovations are underway in several tanks. Temporary, large-diameter (approximately 2'-diameter), flexible ducts are used for ventilating the tanks. These flexible ducts extend along the UAT's main and spur sections and through the Adit 4 and Adit 5 bulkhead walls to exhaust the air directly to the outside.

The upper tunnel contains numerous electrical conduits and controls for the various fans, tank gauging, and valves of the tank system. Through most of the UAT's main section, from the first bulkhead (around Door UAT-A) to near Elevator #72, a series of conduits and piping extends along the south side of the tunnel. These are grouped together in a large bundle that is elevated about 7' above the tunnel floor by metal posts with a short T-shaped top. In the area of Tanks 17 to 20, the steel frames that carry conduits and piping span the width of the UAT. These wider frames consist of paired vertical steel I-beams, with 6" flanges, connected at their tops by a horizontal I-beam, about 8' above the tunnel floor. In the Adit 5 spur tunnel section, conduits extend along the west side of the tunnel, about 8' above floor level. Brackets suspended from this section's ceiling support these conduits.

At most junctions of the side tunnels with the main spine of the UAT, electrical control panels for the tanks are located at the west corners of these intersections. Across the main spine, at the northwest corners of these junctions, there is typically a fan, which provides fresh air when workers are at the top of the tanks. A metal framework holds each fan above the floor, usually about 4' or 7' high. "The lower frames were installed in the 2011-2014 Red Hill Ventilation Repair project."[45] The fans move air through the ventilation ducts that extend to the gauging galleries at the tops of the tanks.

Abandoned brackets are located at various places along the north wall of the UAT's main section. These are typically vertical brackets of flat steel stock, suspended from the tunnel ceiling, with their lower ends curved. The brackets "formerly supported the original 51 pair Parkway control cable and the original electrical cable."[46] These brackets extend down about 1'-6" from the points of attachment. At some places along the north wall there are vestigial remains of abandoned metal piping (approximately 1-½" pipe) protruding from the Gunite lining. Worn drill bits also stick out of the wall, especially in the Adit 5 spur tunnel. The drill ends of the bit are visible, so they were deliberately inserted in the wall, not stuck during drilling operations. These protruding pipes and drill bits were used to hold wires or conduits during the construction period; these are visible in historic photo.

A water line for the UAT's fire protection system enters the upper tunnel through the Adit 4 bulkhead and extends along the south side of the tunnel to the second bulkhead (UAT-B) where it terminates. In July 2014, there was an abandoned annunciator panel for the fire control system on the south wall of the UAT, across from Elevator #73. This is likely removed, along with many other electrical control panels and receptacles. Throughout the UAT, older electrical equipment was marked for removal, as part of the 2011-2014 Red Hill Ventilation Repair project. One electrical cover, by manufacturer Crouse Hinds, has the words (in all capital letters) on it: "in hazardous atmospheres this cover must be kept tight while circuits are alive."

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[44] Ibid.

[45] Ibid.

[46] Ibid.

Upper Access Tunnel, Commemorative Marker

In the Adit 5 spur tunnel section of the UAT, near its intersection with the main section, is a marker dedicated to the workers who built the Red Hill Underground Fuel Storage system. This rectangular marker, built of lava rock and concrete mortar, is embedded in the northeast side wall. It measures about 7' high and 4' wide and projects about 10" from the tunnel wall. The marker has two bronze or brass plaques. The top one identifies the "Red Hill Underground Fuel Storage Facility, Completed 1943" as a National Historic Civil Engineering Landmark, which was designated by the American Society of Civil Engineers in 1995. The lower plaque reads:

> Red Hill Dedication. To the thousands of loyal "Red Hillers" who participated in the construction of this mighty wartime project from August 1940 to September 1943, this effort stands as one of the proudest of American achievements. On the far-flung outpost of the Pacific theatre of War, this great army of defense workers labored day and night on the home front, in the pursuit of a gigantic War effort, fusing their behind-the-scenes strength in the great united struggle for Liberty, Freedom, the Principles of Democracy and the Right to enjoy the American Way of Life.

c. STAND-BY POWER PLANT, FACILITY NO. S-308

Facility S-308 is an abandoned Stand-by Power Plant, situated above, and connected via an access shaft to, the LAT section of the Lower Tunnel (Facility No. S-21). This tunnel-like underground structure is oriented roughly on a north/south axis, with its north-facing entry facade exposed at the level of the access road that runs between the Red Hill entry gate and Adit 3 (Facility No. S-312). The power plant's entry is set into the base of a steep hillside.

Facility No. S-308, Overall Dimensions

Facility S-308 contains four spaces – the entry area, the main room, and two arched excavations at right angles, one on each side of the main space. The maximum length and width measurements of the facility are either 229'-3" x 85'-0" or 233'-0" x 83'-0", per 1942 and 1960 drawings, respectively. The main room has the highest arched ceiling with a height of 28'-6", according to a 1942 drawing. See "Floor Plan" section below, for names and dimensions of each of the four spaces.

Facility No. S-308, Foundations

The sets of wood-framed and steel-framed arches rest on a level concrete slab, but do not require footings. The original machinery (diesel-driven generators and other equipment) had individual foundations originally. About 1960 all those foundations were removed, and a new, 12"-thick concrete slab floor was installed.

Facility No. S-308, Structural System

The structure consists of the three arched tunnels excavated from the rock. In the main space the arched frames are massive 12" by 12" timber sets, spaced 6'-0" on center. The post-WWII CPNAB report states that, "to save time, the timber framing used during construction to carry the overhead rock, was given a flash coat of [G]unite for fireproofing and left in place, instead of being replaced by fireproof supports."[47] Several fires, caused by generator exhausts, occurred in the ceiling after the plant operations started.[48]

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[47] CPNAB, "Technical Report" [1945]: p. A-1043.

[48] Ibid.

A 1960 drawing, labelled "Modification to Diesel Power Tunnel, Preliminary Plan," shows a design to remove the arched timber frames in the main space and to replace them with new, fireproof steel 10"-flange I-beams, with maximum 6'-0" spacing. However, it is not clear that this project was completed, since there are no "as-built" notations on the drawing. The engine foundations are gone, but not all the timber framing was replaced.

Some of the arched frames in the three rooms are now visible, where Gunite coating is missing. It is evident that some of the exposed ones, especially in the lower-height side tunnels, have segmented steel I-beam frames. However, along the wall of the engine room a few deteriorated timber sets are exposed where the coating has fallen off. The installation date of the steel arches in the side tunnels is not known; it could have been in the 1960 project or earlier.

Facility No. S-308, Floor and Ceiling Plan

The original design for the 10'-0" wide entry space to the main room was defined by two 4'-0" thick walls, with various gates and doors (see "Openings" heading below). Entry involved a zig-zag path, since the inner doors were protected by the outer thick concrete wall. A trolley beam with a gently curving S-shape could help bring heavy equipment around the two walls and through the large double door of the inner entry wall.

The remainder of the floor plan of Facility S-308 is relatively simple, and rectilinear. Perpendicular to the long axis of the large engine room, are two smaller rooms; all three rooms have rectangular footprints. The engine room's length and width measurements on a 1942 drawing are 211'-3" x 28'-0" in width. At its peak, the arched ceiling was originally 28'-6" high. In the northwest corner of the engine room there was originally a toilet, sink, and shower. The walls for these were removed, probably in the 1960s.

The switch room and auxiliary room are arched excavations on either side of the engine room. The switch room, to the east of the engine room, has a footprint of 35'-0" x 24'-0" and an approximate height of 16'. The auxiliary room, on the west side of the engine room, is the smallest excavation, with length and width dimensions of 22'-0" x 24'-0"; its height is also about 16'.

A dropped ceiling originally extended over most of the main room. This functioned as an exhaust air plenum. It covered the width of the room and about 175' of its length. The dropped ceiling is gone, either removed or fallen due to deterioration. However, the 2"-thick "plaster wall" (label on original drawing) that marked the north end of it remains. Just south of that plenum wall, there is a vertical vent shaft. See further description under the "Opening" heading below.

Facility No. S-308, Finishes

Almost all the interior walls and ceiling of the structure are coated with unpainted Gunite. A significant amount of the finish coating on the ceiling has fallen over the years, littering the floor and exposing the natural rock above. In a few sections, the coating on the walls has also fallen off, and exposed portions of the original timbers arches. The concrete entry walls are mostly unpainted concrete. At the location of the original bathroom, in the northwest corner, a portion of the concrete wall retains white and gray paint. A small area of the adjacent Gunite-finished wall also has some of this paint. There is red paint on the concrete enclosure over the access shaft (see further description under "Openings" heading below). The surface of the rocky hillside surrounding the entry portal to the structure is coated with Gunite.

Facility No. S-308, Openings

This facility has three areas with openings – the main entrance, a vent shaft on the hillside above, and an access shaft to the Lower Access Tunnel below.

The main entrance has been modified. The original reinforced-concrete blast walls at the entry are of bombproof construction, 4'-0" thick, and anchored to the tunnel walls with 1" diameter dowels at 2'-0" on center. The reinforcing also uses 1"-diameter bars, spaced 12" on center both vertically and horizontally. The outer wall is about 20' in length. The remaining 8' or so of the tunnel width has a gate made of bars, covered by expanded metal mesh. The double gate is about 12' tall and metal screening fills the opening above the gate. The inner wall has a both an opening for equipment ("service door") and for personnel ("pilot door"). Both doors are made of two ½" steel plates. The service door opening measures 10'-0" x 12'-6"; this double door is topped by an air-intake grille composed of bars covered by expanded metal mesh. There is corroded operating hardware for the service door, on the interior. There is also an interior-mounted double screen door of metal mesh. The pilot door dimensions are 3'-0" x 7'-0" ; it has L-shaped bar handles on both interior and exterior, which operate 1"-diameter bolts for securing the door to the top and bottom of the door frame. The pilot door also has an interior metal-mesh screen mounted on the interior side of the 4'-thick wall. Above the former bathroom location is a circular opening, about 3' in diameter in that same wall. A plumbing pipe and conduit, perhaps electrical, pass through this opening. Its original function is unknown, since it is not on any drawing.

The "preliminary" 1960 drawing shows both entrance walls were "to be removed," and a new wall with an F-plan to be built in the general location of the original outer wall. Instead, a rough opening, approximately 9'x 12', was made in the outer wall segment. The unfinished opening exposes the internal rebar of the original bombproof wall.

A shaft vent opening is about 25' above the structure's ceiling. This hillside exhaust portal is the end of the vent that starts in the ceiling of the engine room. The vertical vent shaft tapers in width as it extends upward. The opening is about 13' x 5' in plan at the bottom and tapers to approximately 8' x 5' at the point where it makes a turn to run horizontally. The horizontal tunnel extending toward the exhaust grille wall is 6'-2" high and about 10' wide. The screened exhaust grille is indicated on a 1942 drawing as removable, with height and width measurements of 5'-6" x 8'-6".

There is a vertical access shaft near the main entrance of the engine room. A 1942 drawing shows it contains a series of ladders and landings that lead down to the Lower Access Tunnel. The depth of the shaft is about 55' and it measures 5'-8" square in plan, except at the bottom, where an added triangular space connects it to the side of the tunnel. A 1948 revision of an original drawing shows a concrete cover was added over the access shaft. This measures 4'-4"x 3'-6" in plan and approximately 4' high. "In the original design the vertical access shaft was to have a fuel line to deliver diesel to the engines and electrical lines to carry electricity from the generators to the Water Pumping Station."[49].

Facility No. S-308, Equipment

All the equipment shown on an original drawing has been removed from the engine room. This includes five original diesel-driven generators, their exhaust mufflers, fan equipment, an overhead crane and its rails. Some round metal flanges on the wall indicated the former locations of the exhaust mufflers. The toilet and sink fixtures are other remaining remnants. A trolley beam remains in the vestibule between the two entrance walls. The switch room has no switchgear. The auxiliary room has none of the water pumps, compressors, air tanks, oil tanks, and other equipment shown on an original drawing.

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[49] James A. Gammon, Comment in e-mail attachment from former Supply Center Fuel Department Superintendent to Ann Yoklavich of Mason Architects, Inc., January 22, 2015.

Many light fixtures remain, including warehouse-type pendant fixtures hanging from the arched ceilings, which may be original. The engine room has remnants of fluorescent lighting fixtures previously affixed to a dropped ceiling.

d. POWDER MAGAZINE TYPE, FACILITY NOS. 350 TO 353

The four powder magazines are located on the north side of Red Hill, adjacent to the road between the adits to the Upper Tunnel. These underground structures stored the dynamite needed to build the system of tunnels and tanks. The CPNAB report notes that they had originally

> desired to store construction explosives in the upper part of South Halawa Gulch. The Commandant objected to this location for magazines for security purposes, and the Contractors were directed to construct explosive magazines in the Army Ammunition Area located in [nearby] Aliamanu Crater. Shortly after Dec. 7, 1941, the Army insisted that these explosives be moved elsewhere. It then became necessary for the Contractors to construct four tunnels in the hillside of South Halawa Gulch and transport all of the explosives stored in Aliamanu Crater to this new location.[50]

These powder magazines have not been in use for decades; vegetation had overgrown their entries, but one was cleared to take a large-format HAER photograph. The interior is not accessible, but an opening in the rusted door allows some observation of the tunnel space.

Facility Nos. 350 to 353, Overall Dimensions

The only drawing of the powder magazines is a location map with the length of each magazine noted: Magazine 1 (Facility No. 350) – 112'; Magazine 2 (Facility No. 351) – 107'; Magazines 3 & 4 (Facility Nos. 352 & 353) – 106'. The interior of each is rough excavated rock, so only approximate average measurements are possible. The interior width is less than 15' and the height is about 12'.

Facility Nos. 350 to 353, Foundations

The excavated interior spaces require no foundations. Each concrete entrance wall probably has foundations and some method of anchoring the concrete to the surrounding rock. No drawings for the powder magazines were located, and it is likely none were drawn, given the urgency of this project.

Facility Nos. 350 to 353, Structural System

The entrance wall of the magazine is reinforced concrete. As noted, the urgency of this project and the lack of drawings suggest the magazine entrance walls were quickly erected without a detailed structural design.

Facility Nos. 350 to 353, Floor Plan

Each powder magazine has a roughly rectangular floor plan, measuring slightly more than 100' in length and less than 15' in width. They were not excavated at a 90-degree angle to the face of the cliff; Facility Nos. 352 and 353 have a short, obtuse-angle concrete wall joining the entrance plane to the rock of the hillside.

Facility Nos. 350 to 353, Doors and other Openings

Each magazine had a steel-plate double door with heavy-duty hinges welded to each door leaf with triangular flags. Steel plates, welded in place, now replace one deteriorated leaf, or cover the entire opening. Facility No. 353 has welded steel plates over the whole doorway. Facility No. 352 has the original double door, with

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[50] CPNAB, "Technical Report" [1945]. p. A-693.

no replacement steel plate. Facility Nos. 351 and 350 each have one original door leaf and one replacement steel plate over the other half of the opening. Each door opening measures 8'-0" x 7'-6". Above each doorway, an opening, measuring about 4' x 3', is covered by steel plate; this projects about 4" out from the plane of the door, to allow ventilation. On each original door leaf, there is a similar projecting cover for ventilation. There are also irregular slot openings in the concrete over each doorway.

Facility Nos. 350 to 353, Mechanical Equipment

No mechanical equipment remains.

4. Adits (Tunnel Entrances)

Each of the six adits to the various tunnels of the Red Hill Underground Fuel Storage System is unique. Three of them have facility numbers, while three do not. Adits 4 and 5 lead to the Upper Tunnel, which also lacks a facility number. Similarly, the tunnel at Adit 6 has no facility number.

Name	Facility No.	Entrance to:	General Area
Adit 1	none	Entrance tunnel portion of Pumphouse (Facility No. 59)	Main Base, near North Road
Adit 2	S-275	MT section of Lower Tunnel (Facility No. S-21)	Makalapa, near gatehouse & JICPAC (Facility No. 352)
Adit 3	S-312	LAT section of Lower Tunnel (Facility No. S-21)	Red Hill
Adit 4	S-314	Upper Access Tunnel, west end	Red Hill
Adit 5	none	Spur tunnel to Upper Access Tunnel	Red Hill
Adit 6	none	Spur tunnel to Elevator #73; between Lower & Upper Tunnels	Red Hill

Generally, the boundary is clear between each Adit and the tunnel for which it provides entry. The tunnels were described in the previous section. The exception is the spur tunnel from Adit 6 to Elevator #73, which is located midway in elevation between the Lower and Upper Tunnels. The description of this tunnel is under the "Adit 6" heading.

a. Adit 1, Part of Facility No. 59 – Entrance to Pumphouse

The portal at Adit 1 is an arched opening of reinforced concrete, at the beginning of the entrance tunnel portion of Facility 59. The plane of the entrance wall is not at right angles to the centerline of the tunnel. Adit 1 encompasses the triangular space between the angled face of the entrance wall and the doors of expanded metal at the west end of the Facility 59 entrance tunnel.

Adit 1, Overall Dimensions

The entrance wall of Adit 1 is 2'-0"-thick reinforced concrete. The upper line of the Adit entrance wall is a segmental arch with a radius of about 35' (measured from a point well below grade, as shown on drawing # 294056). Unlike the stepped shape of the north part of the wall shown on that drawing, the north end of the arch transitions into a wing wall about 6' in height. The arch of the wall on the south side of the opening terminates at a point about 16' in height. Due to its arched shape and the different details at each end of the wall, only maximum dimensions are given: maximum length is about 50' and maximum height is 17'-3". The opening is not centered on the wall. On the north side, the arched part of the wall extends approximately 15' until it meets a wing wall that is about 6' additional in length. To the south side of the opening the length of the entrance wall is also about 15'; however, due to the skewed plane of the entrance wall, the arch terminates at a much higher elevation. Due to this skew, there is a distance of about 10' between the south-side entrance wall and the expanded metal doors, compared to approximately 1' distance on the north side. The arched opening has a 9'-0" radius that springs from the vertical planes of the lower part of the opening, at an elevation 5'-0" above the paving at the entry, with the maximum height of the opening at 14'-0". The top of the segmental arch is 3'-3" above the top of the arched opening, the narrowest part of the entrance wall.

Adit 1, Foundations

The concrete slab under Adit 1 is supported by the underground pipe gallery portion of Facility No. 59. The foundations under the side walls of the pipe gallery have continuous 12"-deep footings that widen to 2'-8" at columns. In the 2' between the footings and the 6"-thick slab there is a taper between the 12" and 6" thicknesses.

Adit 1, Structural System

Reinforcing bars structurally tie the concrete entrance wall of Adit 1 to the concrete entrance tunnel of Facility No. 59. As indicated on a drawing, there may also be buried sections of concrete that are keyed into the surrounding rock.

Adit 1, Floor Plan

Due to the skew of the entrance wall plane, Adit 1 has a triangular floor plan, measuring about 10' on its south side and 18'-0" on its east side.

Adit 1, Finishes

Adit 1 has blue-green paint on its concrete surfaces.

Adit 1, Door

See the description for the door of expanded metal, located between Adit 1 and the entrance tunnel, in the "Underground Fuel Oil Pumphouse" (Facility No. 59) section.

Adit 1, Equipment

There are various pipes and conduits passing through Adit 1, as well as several boxes or valves mounted on its walls. On the north side of the entrance is a modern security camera and a fire alarm box. On the south wall near the expanded metal doors, there is an emergency call box, a security code keypad plus card reader, and a wired informational box for the recent fire protection improvements.

b. ADIT 2, FACILITY NO. S-275 – ENTRANCE TO MAKALAPA SECTION OF LOWER TUNNEL

Adit 2 is boxy structure of reinforced concrete, with a CMU addition on its roof. There is no internal connection between the original structure and the addition. Adit 2 connects to the northwest end of the Makalapa section of the Lower Tunnel, Facility S-21.

Adit 2, Overall Dimensions

The widths and lengths of both the original structure and the addition are 20'-0" x 28'-0", measured outer wall to outer wall. There are wing extensions of the front wall that slope down from about 4' above grade, to a distance of 4'-6" on each side. The original roof overhang, on the front and sides is 1'-6". The roof overhang, on all four sides of the addition is 3'-0". The interior height of the structure, a portion of which extends below grade, is 17'-5-½". The exterior height at the front facade is 12'-6", measured to the top of the original roof rim. The overall height, including the addition on the roof, is approximately 20', measured at the front facade.

Adit 2, Foundations

The side elevation and section drawings for Adit 2 show two different foundation designs. The section drawing implies that the front wall extends about 7' below grade to the level of the tunnel floor, while the elevation drawing shows the front wall resting on a footing just below grade. Both show a 12"-thick perimeter footing that is 3'-0" wide (extending an additional 12" out from both sides of the front wall). A plan drawing shows similar footings under the side walls, for the approximately 8' sections closest to the front wall. The concrete floor slab at the tunnel level is 12" thick and extends a few feet into the tunnel before it tapers to the thinner tunnel floor thickness. The concrete slab at the entry-grade level is 6" thick.

Adit 2, Structural System

The floor, walls, and roof of the original Adit 2 structure are of reinforced concrete, typically 12" thick. In the corners closest to the tunnel, there are 12"-square-section columns that support an I-beam with 8" flange across the width of the interior. There are similar columns on either side of the entry doorway and another I-beam above. A trolley hoist, with 18"-flange I-beam, is supported by the two small ones; it is located along the centerline of the structure's length, for hoisting materials between the two levels.

The addition's walls are CMU, labelled "cement blox" on the 1944 drawing, apparently not reinforced. The addition's concrete roof slab has reinforcing.

Adit 2, Floor Plan

The original Adit 2 structure has two floor levels – the entry-grade level and the tunnel level. The entry-grade floor area measures 8'-0" x 18'-0". Along the south wall a 4'-0" wide concrete stair with pipe railing connects the two floor levels. A 2'-0" diameter water pipe extends along the north wall, transitioning from the tunnel level and exiting at the entry level. The unobstructed area of the tunnel-level floor area, between the stair and the water pipe, measures about 9' x 18'. The drawing of the addition shows an unobstructed interior rectangular space of 16'-0" x 26'-0", with a raised pad for a generator measuring about 6' x 10' in one corner. Originally, the way to access the landing at the addition level, from the Adit door level, was via a steel ladder on the north wall. In recent decades, a metal stairway replaced the ladder.

Adit 2, Finishes

There is paint on the exterior concrete walls of Adit 2. The CMU walls of the addition have no finish, except for the north wall, which is painted. The concrete on the interior of the original structure is generally unfinished, but a few parts of the interior walls have paint. Locks on the addition prevented inspection of its interior. The roof finish on the addition is tar and gravel on built-up roofing.

Adit 2, Doors and Ventilation Openings

There are double metal doors and double metal grilles in the original Adit 2 structure. The opening measures 8'-0" x 8'-0". The double doors that swing outward consist of ½" plate steel welded to an interior frame of

5" U-channels. Between the steel plates, the doors have 1"-diameter steel locking pins operated by L-shaped door handles made of 1"-diameter steel rod. There are double metal grilles inside the doorframe that open inward. The grilles consist of vertical 1"-diameter bars, with a frame and horizontal members of ½" x 2" bars. The original Adit 2 structure had six ventilation openings, but one on the south side is now filled in with concrete. The five openings remaining measure approximately 6' x 3'. These openings retain their original fixed metal louvers on the exterior and the interior security grids, which consist of 1"-diameter bars horizontally placed, spaced 6" on center, and ½" x 2" vertical bars, spaced 12" on center.

The door to the addition is on the north wall, not in the position or the type of the door shown on the 1944 drawing. This modern flush metal door, measuring 3'-0" x 6'-3", is not original. The addition's original louvered ventilation opening on the east wall, measuring approximately 3' x 6', is now filled by CMU. The 1944 drawing for the addition shows nine of the CMU on each side wall installed in a rotated position, so that their voids originally created ventilation openings. Concrete now fills these CMU voids. Two window openings in the addition, measuring about 3' x 5', on the west end wall above the Adit 2 original doorway, are not shown on the 1944 addition drawing. There is no recorded date for the filling of the eighteen CMU openings and the creation of the two window openings. These windows have expanded metal screens over them, but now the openings are boarded up, with a small louver inserted in one of them.

Adit 2, Equipment

The equipment on the exterior of Adit 2 includes a security camera and lighting fixtures, as well as numerous conduits and piping. There are large air conditioning units on the roof of the addition. The large 2'-0" diameter water pipe exits from the front wall of the structure and then curves back underground. The interior of Adit 2's original portion has conduits and piping extending along its interior walls. There are two modern fluorescent light fixtures mounted on the ceiling; one modern floodlight is on the wall above a louvered opening.

c. ADIT 3, FACILITY NO. S-312 – ENTRANCE TO LAT SECTION OF LOWER TUNNEL

The Adit 3 portal is a boxy structure of reinforced concrete. A pair of sloping retaining walls project from the main boxy structure, due to the topography around this entrance. Adit 3 is the entry to the LAT section of the Lower Tunnel (Facility S-21). During the initial "excavation of the tunnels and tanks, Adit 3 served as the primary exit point for excavated rock. A rock crusher and concrete batch plant was located above the … wall adjacent to Adit 3. Following excavation, Adit 3 became an entry point for construction materials and equipment."[51]

Adit 3, Overall Dimensions

The maximum dimensions of Adit 3 are 28'-8" x 58'-0", including the buried roof overhangs (over the rear and side walls of the entry room) and the retaining walls that project 23'-0" beyond the front roof overhang. The reinforced-concrete roof is 3'-6" thick (except the front edge is 5'-0" thick) and the walls are 3'-0" thick. The roof overhangs the walls by 5'-0". The interior space measures 12'-8" x 24'-0", with a height of approximately 25'. The height at the entrance level is about 18', including the roof.

[51] James A. Gammon, Comment in e-mail attachment from former Supply Center Fuel Department Superintendent to Ann Yoklavich of Mason Architects, Inc., January 23, 2015.

Adit 3, Foundations

The continuous spread footings, under all the walls, are 5'-0" wide, wider than the walls by 12" on each side. The footings are about 12" thick.

Adit 3, Structural System

The foundations, floor, walls and roof are of reinforced concrete, from 1' to 5' thick.

Adit 3, Floor Plan

Adit 3 is a single room, with two levels. At the entrance door level, there is a concrete landing, measuring 5'-0" x 12'-8". The landing is generally 5"-thick, but there is an integral concrete beam at its interior edge, which is 1'-6" thick and 12" deep. At this edge, there is a removable railing, so that equipment can be brought into the tunnel. On the ceiling, a trolley beam with 15" flange holds a ten-ton hoist that is used for bringing in equipment. A metal stair provides access between the two levels. The tunnel-level space has rail tracks slightly off-center.

Adit 3, Finishes

The concrete has no paint or other finishes. Most of the metal elements (doors, stair, and trolley beam) are painted, or have remnants of paint (railing).

Adit 3, Opening

There is a large metal door of ¼" steel plate that covers the entire opening; it is labelled "flood gate" on the original 1943 drawing. "The "flood gate" could provide protection from an external flood from nearby South Halawa Stream, or could contain a flood of fuel and/or water from damaged pipeline(s) in the tunnels."[52] The frame inside the two steel plate surfaces consists of 6" channels and I-beams. This door measures 11'-2" x 11'-6-½". There is one 6"-diameter roller, on a 1-½" roller bearing at the bottom of the door, in the lower right corner (when facing the flood gate). This door has three large hinges (about 10" tall) and two wedge locks. Each side of the door has a handle, bent from 1"-diameter bar stock into a shallow U-shape.

The double door inside of the flood gate measures 12'-8" x 10'-0". It consists of I-beams with 6" flanges sets in a staggered pattern inside a frame of 10" channels. The four corners of each door leaf have welded triangles of steel plate welded to the frame, and a 10" wide piece of steel plate covers the gap at the center. The hinges and door handles on the double door are like the ones on the flood gate. The double door originally closed with three bolt locks, but now has an electronic system to lock it.

Originally, there was a grille between Adit 3 (Facility S-312) and the start of the LAT section (part of Facility S-21). This consisted of ¾" bars, spaced 6" on center vertically, running through or welded to 2" steel plates, spaced 1'-6" on center horizontally. The grille filled the arch of the tunnel opening, with a gate measuring 5'-1" x 8'-10-¾". The date of the grille removal is unknown.

Adit 3, Equipment

There is an overhead trolley beam with an electric hoist; the trolley beam is original but the hoist may be a replacement. When originally built, only one 6"-diameter sewer line and one 10"-diameter sludge line was attached to the inner walls of Adit 3. Currently many pipes, conduits, and panels for numerous security, lighting, safety and similar systems are fastened to the interior of this adit. The narrow-gauge rail tracks end at

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[52] Ibid.

the adit's head wall. Although the original drawings called for car stops to be welded to the rails, there are none currently.

Modern floodlights, an emergency call box, a security code keypad plus card reader, and a security camera are affixed to the exterior of the Adit structure. Near the Adit is a valve chamber for oily waste pump and piping. There are other modern buildings, structures, an oily waste tank, and a shelter for emergency power-generating equipment near this adit.

d. Adit 4, Facility No. S-314 – Entrance to Northwest End of Upper Access Tunnel

Adit 4 is a bulkhead of reinforced concrete with a door of solid steel plate that provides entry to the Upper Access Tunnel at its western end. The facility includes the narrow space between the inside face of the portal and the start of the Upper Access Tunnel bore. It also includes the large concrete block on the exterior of the doorway (see "Door and Openings" heading below for its function).

Adit 4, Overall Dimensions

The bulkhead is a concrete wall about 5' thick and almost 18' high. The cornice at the top is a plain band of concrete, measuring about 22' in width, 12" high and projecting about 4" from the face of the wall. Because the bulkhead was constructed between angled excavations of the hillside, the visible width of the bulkhead varies from about 22' at the base to 28'-8" along the top edge. The cornice does not extend the whole width of the upper concrete edge.

The Adit includes an interior space, 5'-0" in depth, between the bulkhead and the start of the arched bore of the tunnel. The width of this space is about 19' and its height is approximately 13' high.

Adit 4, Foundations

Adit 4 rests on a reinforced-concrete floor slab at least 12" thick.

Adit 4, Structural System

Adit 4 is built of reinforced concrete, with a complex stepped-plan shape at the bulkhead wall, visible only on the drawing of the facility. The thickness of this adit's side walls diminish in three steps: from a 3'-0" exterior thickness, to an inner wall thickness of 1'-6". The back wall of the entry space and the walls of the tunnel are 12" thick. The reinforced concrete roof over the entry space is typically 3'-6" thick, and thicker at the haunched corners.

Adit 4, Floor Plan

The approximately 5'-thick bulkhead of Adit 4 is located 5'-0" from the start of the tunnel bore. This 5'-0" deep space measures about 19' wide between concrete side walls, and approximately 13' tall from floor to ceiling. The 4'-0" wide doorway is centered in the bulkhead and aligns with the center of the 12'-8" wide Upper Access Tunnel. Narrow-gauge (2'-0" between tracks) rail tracks extend from the tunnel, across the 5'-0" deep Adit entry space, and to the doorway opening, where they disappear into the ground.

Adit 4, Finishes

The exterior surface of the Adit 4 is paint over concrete. The steel door is also painted. The welded frame on the door's interior surface and the welded edge of a circle in the steel plate appear unpainted. The interior of the bulkhead, as well as the walls and ceiling of the 5'-0" deep space between the bulkhead and the Upper Access Tunnel, are all unfinished concrete that shows the impressions of the forming boards. The floor of the Adit is unfinished concrete with embedded rail tracks.

Adit 4, Opening

Mounted on the interior surface of the Adit 4 bulkhead is a steel plate door, measuring 4'-3" x 6'-0", hinged to open inward. An electronically operated mechanism opens and closes this door, and there are no door handles. On both sides of the bulkhead doorway, on the interior, there are two steel I-beams with 6" flanges protruding horizontally about 6" from the concrete. These I-beams are about 2' and 3'-6" above the floor, and are about 1' from the edges of the doorway.

The 4'-thick bulkhead also has narrow vertical openings, measuring 6" wide, spaced 2'-0" on center. These ventilation openings are located above and to both sides of the doorway. Two rows of concrete piers, with cross-sections measuring 1'-6" x 2'-0", create the baffled openings; the exterior and interior rows are offset from each other. The openings above the door are 3'-5" tall, with six openings on the exterior and five on the interior. The openings flanking the doorway are about 11' tall, with three outside and three inside vertical openings on each side of the doorway. On the exterior of the bulkhead, sections of expanded metal mesh, in metal frames, cover most of these openings. A metal panel overlays the lower half of the openings on the southwest side of the door, where the duct and pipe pass through the bulkhead wall.

Outside of the bulkhead, about 20' from the doorway opening, is a large concrete block that is a trapezoidal solid in shape. Its depth is uniform at 4'-0", but its sides flare from a 4'-5" front width to 5'-0" wide at the rear; and the height at the inner face is an inch or two less than the 5'-8" height at the outer face. The block fits into the tapered doorway of the bulkhead. On the face of the block closest to the Adit 4 doorway, there are protruding I-beams. There were four originally, but one has broken off and the other three are highly corroded. On the side away from the Adit 4, there are two embedded steel loops, with a radius of 5", for moving the block. This concrete element, in the caption of a 1943 historic photo , is called a sealing block. The former Fuel Department Supervisor explained the former function and history of this block:

> With the block in place steel cross beams inside the Adit bolt to the beams protruding from the block and to the beams protruding from the wall inside the Adit to secure the block in place. Prior to 1979 … this was how Adit 4 was secured. Starting in 1979, Adit 4 was in nearly constant use as the main entrance into Red Hill by contractors and the concrete block was replaced by the existing steel door.[53]

Adit 4, Equipment

A large diameter (approximately 2') flexible ventilation duct extends out of the Upper Access Tunnel, through the Adit 4 bulkhead. "The duct provides ventilation air to the empty Red Hill tank or tanks being cleaned and/or repaired."[54] The duct and a water pipe pass through the lower portion of the concrete piers on the southwest side of the bulkhead; in 1979 removal of portions of the concrete piers in the baffled openings allowed room for piping and the duct. On that side of the door, plywood panels cover the interior of the bulkhead wall and a metal panel is on the lower part of the exterior wall.

On the interior of Adit 4, there are several electrical control panels. These are probably for the exterior lighting, entry lock, and security camera. The security camera is on a pole attached to the sealing block. On the exterior of Adit 4 a short loop of approximately 8"-diameter metal pipe for the Upper Access Tunnel waterline is routed above ground adjacent to the doorway. This section of pipe has two hand-wheel-operated gate valves. The original drawings show a floor drain routed through the bulkhead wall. Gravel now covers this area just inside of the door, between the rail tracks.

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[53] James A. Gammon, e-mail attachment from former Supply Center Fuel Department Superintendent to Ann Yoklavich of Mason Architects, Inc., January 18, 2015.

e. ADIT 5 – ENTRANCE TO SPUR TUNNEL SECTION OF UPPER ACCESS TUNNEL

Adit 5 consists of a reinforced-concrete entry wall with double door, which provides entry to the north end of the spur section of the Upper Access Tunnel. The abutting spur tunnel was part of the original WWII construction, but after construction of the Red Hill Fuel System, the spur tunnel was sealed with a concrete bulkhead, near its intersection with the UAT. Installation of this entry wall and door dates to the early 1960s. Removal of the bulkhead was also about that time, to allow installation of a new tank vent pipe, serving Tanks 3 through 16, through the spur tunnel to a point outside Adit 5.[55] "Halawa Adit" is the label for this entrance on some of the original drawings for the system.

Adit 5, Overall Dimensions

The entry wall is 3'-0" thick. The drawing for this Adit shows the entry wall as an arched shape, but due to the Gunite on the surrounding rock face, this shape is not visible. The concrete wall measures approximately 19' x 12', which is about the same height as the arch of spur tunnel, but slightly wider than the spur tunnel's typical width. This added width is due to the entry wall being set at an oblique angle to the tunnel axis.

Adit 5, Foundations

The foundations of the new entry wall rest on the original foundations. The new foundation matches the original 3'-0" width. The exact depths of the foundations, of the new and original parts, are unknown. The entry wall and new foundations were a monolithic cast.

Adit 5, Structural System

Adit 5 is built of reinforced concrete.

Adit 5, Floor Plan

The concrete entry wall of Adit 5 has an opening, measuring approximately 7' x 9', which is offset from the centerline of the tunnel, to the northeast. The facility consists of only the wall abutting the spur tunnel of the Upper Access Tunnel. Narrow gauge (2'-0" between tracks) rail tracks extend out of that tunnel, pass through the center of the doorway, and end about 25' outside the adit, without any wheel stops. The alignment and slight bend in the rail tracks resulted in the off-center door position.

Adit 5, Finishes

The interior and exterior entry wall is unpainted concrete. The double doors are painted plate metal. Beyond its concrete wall, the exterior surface around Adit 5 has a coating of Gunite. This extends 10' to 20' beyond the entry wall, to cover the surrounding rock of the hillside, which has an uneven surface. The interior of the spur tunnel also has a Gunite finish applied directly over rock (see more under "Upper Access Tunnel" heading.) The floor of the Adit is unfinished concrete with embedded rail tracks.

Adit 5, Doors and Opening

Adit 5 has an outward swinging, hinged, double door of ¼" steel plate, set at the outer plane of the 3'-0" thick Adit wall. The opening in the Adit wall is smaller on the interior plane than the exterior, stepping in on the sides and top. The overall dimensions of the door opening are 7'-3" x 9'-2". The double door is slightly wider than the opening, but it does not extend all the way to the floor, to leave clearance for the rail tracks. On the interior of the steel plate, each door leaf has framing, formed from angles and straps, appearing to

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[54] Ibid.

[55] Ibid.

divide them into three panels. From the exterior, facing the adit, the door leaf on the left has an electronically controlled locking mechanism that unlatches the right door leaf, the one used for normal entry and exit. The west door leaf has a handle, on both exterior and interior, made from round metal bar, bent into a shallow U-shape. On the interior, the left door leaf has cane bolts at top and bottom that secure it closed for normal operation, but can retract to allow opening of the east leaf.

There are two other openings through the entry wall. These are approximately 2' diameter and 1'-4" diameter openings for ventilation ducts, which are located at grade level, to the southwest of the door opening. The smaller opening connects to the tank vent pipe inside the spur tunnel. The larger opening is for a flexible, temporary duct.

Adit 5, Equipment

A flexible ventilation duct about 2' in diameter extends from the tunnel through the entry wall via a grade-level opening on the southwest side of the doorway. The flexible duct discharges about 30' from the doorway. It serves to ventilate a tank that is under repair. The 1964 tank vent pipe, with a 16"-diameter, runs from the tunnel through the entry wall via an opening adjacent to the flexible duct. Immediately after exiting the entry wall, the vent pipe goes underground. It daylights on the hillside, about 50' from the doorway. On the interior, this pipe extends along the west side of the Adit 5 tunnel section to the Upper Access Tunnel, where it bends to go under the floor.

Equipment on the exterior of Adit 5 includes fire alarm control panel, new fan control panel, exterior lighting, emergency call box, security code keypad with card reader, and a security camera. Interior equipment includes a large annunciator panel for the fire system, several other electrical control panels, and a telephone. The drawing for this adit shows a floor drain near the entry; it may remain under a metal plate between the rails in this area.

f. ADIT 6 AND SPUR TUNNEL TO ELEVATOR #73

As originally constructed in 1964, Adit 6 consisted of the 5'-0"-thick concrete bulkhead with a blast-proof steel double door, plus a large arched concrete-lined tunnel section, measuring about 16' x 50', behind it. Alterations in 2014 changed that concrete section, which a CMU wall and doorway now divides in two (other modifications discussed below). The smaller Adit 6 tunnel, attached to the arched concrete space, extends about 450' to Elevator #73. There is also a small roofless enclosure on the exterior of the bulkhead, east of the blast doors. The enclosure's three walls surround a 3'-diameter air-intake opening through the 5'-thick bulkhead wall.

Construction of this adit, its tunnel, and the blast valve enclosure dates to 1964, when Tanks 17 to 20 were isolated from the other tanks, and modified to hold aviation fuel. In that period, there was concern about nuclear attacks, so the reason for the small enclosure was to house a blast valve. This valve "was designed to instantaneously close off the 3'- diameter air intake opening before the arrival of the pressure wave from a nuclear detonation." [56]

Adit 6 and its tunnel are at an elevation between the UAT and LAT, so they connect only with Elevator #73 (also built in 1964), which then provides access to the tunnels above and below. The shaft of Elevator #73 is located between Tanks 17 and 19. Above the machine room for this elevator, the shaft continues to the surface of Red Hill ridge, identified as Utility Shaft #73. From 1964 to 2014 the exhaust duct for tunnel air

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[56] James A. Gammon, Comments in e-mail attachment from former Supply Center Fuel Department Superintendent to Ann Yoklavich of Mason Architects, Inc., January 27, 2015.

extended up the entire elevator/utility shaft, to exhaust at the ridge-top structure atop this shaft. Ventilation improvements in 2014 involved several changes, described below, to create a new tunnel exhaust point outside Adit 6.

Adit 6 and Spur Tunnel, Overall Dimensions

The Adit 6 bulkhead is built between the angled excavations of the hillside. Drawings show its width as 24'-6" flaring near the top to 27'-6" wide. Due to the earth cover of the adjoining slopes, only 18' of the adit facade is visible near its base, but almost the full width is apparent at the cornice. The overall exterior height of the adit facade is 19'-0". The upper 5'-0" of the facade is a parapet functioning like a retaining wall; it tapers from 5'-0" to 2'-6" in thickness. Concrete, gravel and soil now fill the space behind that parapet. A chain link fence, about 7' in height, on the top of the parapet helps prevent rock falls at the entry.

The three walls of the blast-valve enclosure are an end wall, 6'-0" in width, and side walls, which are 7'-6" in length. The enclosure's side walls abut and are connected to the 5'-0"-thick Adit 6 bulkhead wall. The enclosure is approximately 8' tall.

The larger arched concrete-lined tunnel section just inside the Adit 6 bulkhead originally measured 16'-6" wide x 11'-0" high x 50' -0" long. The south end of the concrete-lined tunnel section joins the bore of the smaller Gunite-lined Adit 6 tunnel, which originally measured 10'-0" wide at the base and 11'-0" high at the center of the arch. This arched concrete-lined tunnel section is partitioned into a front vestibule and a rear space by a new transverse CMU wall with double doors, built 11'-0" in from the Adit 6 bulkhead wall. The rear space is approximately 38' in length; for about 25' of that length the width is only 12', reduced from 16' by a new partition wall constructed along the west wall of the tunnel.

The bore of the Adit 6 Tunnel begins at the rear of the concrete section. Unlike the smooth walls of the arched concrete section, the tunnel has an undulating surface following the unevenly excavated rock. The tunnel bore has an arched ceiling typically about 11' high. Originally, the tunnel was about 10' wide; in 2014, a vertical partition along its length reduced its width. This partition closes off the western side of the tunnel as an exhaust duct, leaving approximately 6' of the width for pedestrian passage.

Adit 6 and Spur Tunnel, Foundations

The Adit 6 bulkhead is built on bedrock, above a reinforced-concrete floor about 2' thick. The concrete section and the tunnel are excavated out of bedrock and have a concrete floor with a minimum 6" thickness (thicker near the bulkhead). The arched steel sets in the concrete section and tunnel rest on 1'-0" square footings, at least 4" thick.

Adit 6 and Spur Tunnel, Structural System

The Adit 6 bulkhead, arched concrete section, and blast-valve enclosure are built of reinforced concrete. The Adit 6 Tunnel is a barrel-vaulted excavation in the rock with arched steel sets; the sets consist of I-beams with 6"- or 8"-wide flanges, on 8'-0" maximum spacing. The entire tunnel has a lining of air-blown mortar or Gunite over those steel sets. The southern end, approximately 12' of the tunnel's length, has the steel sets with 8" flanges and a 12" minimum thickness of Gunite over rebar. The rest of the tunnel length has steel sets with 6"-wide flanges and a lining of air-blown mortar with a minimum 4" thickness.

Adit 6 and Spur Tunnel, Floor Plan

On the exterior of the bulkhead, to the east of the doorway, is the blast valve enclosure; this space has a single metal door on its west side. This "room" has no roof and originally entry was via an opening in the top grate and metal bar ladder rungs on the west wall of the enclosure. There was a 12" thick concrete ledge, projecting 2'-6" and filling the 4'-0" space between walls, over the 3'-diameter hole thru the bulkhead wall.

Removal of the blast-closure valve was in the 1990s, and the 2014 ventilation improvement project required removal of the ledge. After removal of the blast valve, the 3'-diameter opening continued in use as the entry point for tunnel ventilating air. In the 2014 project, that opening became part of the tunnel exhaust system. (See under "Equipment" heading for additional information on function change from intake to exhaust).
The bulkhead of Adit 6 has an 8'-0" square doorway opening with a double door. A corrugated metal awning, about 10' x 22' and supported by metal brackets, projects over the door and the adjacent blast valve enclosure. There is a modern metal ladder attached to the bulkhead wall, east of the blast valve enclosure. It provides access to the two fans with curved exhaust ducts on the platform grating, located over the metal awning.

There is an arched concrete section, 16'-6- wide, just inside the Adit 6 bulkhead. The additional width, on the east wall of this section, originally housed an insulated carbon-dioxide storage tank, part of the CARDOX fire-fighting system for the tank areas storing volatile fuel. That system "was in operation from 1964, when it was installed, until the mid-1980s, when it was removed from service. The tank and its ancillary support equipment were demolished and removed in 2013."[57] A transverse CMU wall now divides the arched concrete section into two areas. The front vestibule occupies about 12' of the length (including the CMU wall), and the rear part of the arched concrete section is about 38' in length. In this rear part, the 2014 ventilation-improvements project installed ducting that bridges across the ceiling from the exhaust partition on the west wall to the east wall. Then the duct passes through the CMU wall and into the vestibule where it attaches to the 3'-diameter opening.

Originally, the arched bore of the Adit 6 tunnel was 10' wide x 11' tall. The tunnel extends southwest from the inner end of the arched concrete section , an additional 447' (497' total from inside of the adit's bulkhead wall). The tunnel ends at Elevator #73; starting about 12' north of the end until about 6' from the elevator, the original tunnel width flares from 10' to 16'-0". The rectangular landing area immediately in front of the elevator door originally measured 6'-2" x 16'-0". Here a 16"-diameter pipe emerges from the floor, extends along a portion of the west tunnel wall, and descends again below grade. This pipe, now cleaned and abandoned, was part of the original 1964 construction and carried aviation fuel from Tanks 17 to 20 out to the Pearl City Fuel Annex. Since 2014, the partition wall on the west side of the tunnel encloses most of this pipe. It also created an enclosure for utilities and tunnel exhaust. This partition wall leaves a passage space 6'-0" wide on the east side of the tunnel. At the elevator end of the partition wall a 4'-wide sheet metal duct carries the exhaust, in the area where the tunnel wall widens and the exhaust duct has to make two turns.

The interior plan dimensions of the Elevator #73 shaft are 9'-0" x 16'-0". The shaft has three components: the elevator hoistway, plus two vertical compartments with ladders and platforms. The platforms are metal grating that allows air passage. The compartment closest to the elevator functions, along with the elevator hoistway space, as the tunnel air supply duct; its plan dimension are 9'-0" x 2'-6". The vertical compartment on the west side of the shaft measures 9'-0" x 4'-6" and functions as the tunnel exhaust duct. The elevator shaft is approximately 225' tall, between the LAT and the floor of the elevator machine room over the UAT. Above the machine room is the fan room, then the shaft of what was originally for tunnel exhaust and utilities, but now is for utilities only. The height from the machine room floor to ground level at the Red Hill ridge is about 200'.

Adit 6 and Spur Tunnel, Finishes

The exterior concrete of Adit 6 has a painted finish. Above the doorway and the roofless blast-valve enclosure is a slightly sloping awning of painted corrugated sheet metal, supported by painted metal brackets fixed to the front wall of the adit. This awning projects about 8' or 9' from the front wall and is

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[57] Ibid.

approximately 16' long. The sides and soffit of the doorway opening through the bulkhead are painted concrete. The interior wall of the bulkhead and the arched surfaces of the concrete section's front and rear rooms are unfinished concrete. The CMU of the transverse wall between the front and rear rooms is painted.

The arched surface of the Adit 6 Tunnel is unpainted sprayed mortar/Gunite that undulates with the contour of the underlying rock and covers the arched wide-flange steel sets. The vertical partition wall of the tunnel bore is painted gypsum board or plaster. The north wall of the small room adjacent to Elevator #73, at the end of the tunnel, is unfinished concrete; its southeast wall is gypsum board or plaster. All floor finishes are unfinished concrete.

Adit 6 and Spur Tunnel, Doors and Openings

The original door at the Adit 6 bulkhead is labelled as blast proof on a 1964 drawing. Each leaf is approximately 4' x 8' and 7" thick. The door is mounted at the outside edge of the door opening and each leaf swings outward on three massive hinges. Each leaf has a hand wheel that operates a pinon gear, rack, and levers to slide lock plungers into bolt holes in the door head and sill. There are three plungers on the top and three on the bottom of each leaf. A metal bracket with a hydraulic-cylinder door opener, originally fixed to the soffit of the doorway opening and attached to the west door leaf, is now removed.

The CMU wall dividing the arched concrete section into front and rear rooms has a modern, flush-metal double door, measuring 6'-0" x 7'-6". On a 2013 drawing, the note under it requires this door to be "2-hour rated, maximum security steel double door, rated to withstand small arms, Level 3 (.44 caliber) and a forced entry of at least 30 minutes."[58] Each door leaf has fixed pulls, an electronic locking mechanism opens and closes the door. An electronic keypad/card reader and a telephone are mounted on the exterior side of the CMU wall. To the east of the double door, the 3'-diameter ventilation duct penetrates the CMU wall. The west side of the CMU wall has a panel of fixed aluminum louvers. Both of these air penetrations have security bars.

At the end of the Adit 6 Tunnel, Elevator #73 has a vertically bi-parting freight door, measuring 6'-0" x 8'-0". Adjacent to the elevator is a hinged, flush metal door , measuring 2'-6" x 7'-0", that leads to one of the two vertical compartment in the shaft containing ladders and platforms to access the upper and lower tunnels. This compartment, closest to the elevator hoistway, is also part of the tunnel air intake compartment. Expanded metal mesh covers the openings above the elevator and adjacent door. Inside this compartment, there is a modern, flush metal door to the tunnel exhaust compartment on the west side of the shaft.

A door, measuring about 2'-6" x 7', was added to the blast-valve enclosure sometime between 1964 and 1982. The added door is flush metal, with a fixed pull and a hasp. Inside the blast-valve enclosure, the 3'-diameter opening through the bulkhead retained the attachment hardware for the blast-closure valve, as of July 2014. There is an extant blast valve in the structure on the Red Hill ridge at the top of the Utility Shaft #73 (see description under "Ventilation Structures" section). That blast valve is mounted over a horizontal, rather than a vertical, hole.

Adit 6 and Spur Tunnel, Equipment

Ducting for the 2014 ventilation improvements required removal of the original equipment in the blast valve enclosure. New fans on a new support structure are installed over this enclosure. Equipment near the Adit 6 entry includes fire alarm control panel, modern exterior floodlights, emergency call box, a security code keypad plus card reader, and security camera.

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[58] InSynergy Engineering and ITSI Gilbane, Red Hill Fuel Facility, Repair Red Hill Tunnel Ventilation. Prepared for Fleet Logistics Center Pearl Harbor, 21 August 2013. Sheet A-102 by INK Architects, LLC.

From 1964 to the mid-1980s the Adit 6 tunnel was the location for the carbon dioxide storage tank for the CARDOX fire extinguishing system. The CARDOX system was decommissioned in the mid-1980s and demolished in 2014. From 1964 to the present, the Adit 6 tunnel has contained the 16"-diameter fuel pipeline to Pearl City Fuel Annex and the 6"-diameter oily waste line to the now-demolished 10,000-barrel-capacity slop tank (Facility No. S-355). The pipelines were decommissioned and abandoned-in-place in the mid-2000s.[59]

Adit 6 and its tunnel are now part of intake and exhaust systems for tunnel ventilation of the LAT and UAT areas around Tanks 17 to 20. From construction in 1964 until 2014, the adit and tunnel only functioned as part of the air intake system. In those years, the air could only enter through the 3'-diameter opening with the blast valve (normally open), then it passed down the Adit 6 tunnel to the air intake compartment in the Elevator #73 shaft. Fans in the LAT and UAT would draw the air into their respective areas. The air intake function remains and the main difference, after the 2014 project, is that the air now enters through the new louvered opening adjacent to the new doors. The original blast doors are fixed in an open position. The 2104 project added a vertical partition and ducting along the whole length of the Adit 6 tunnel, mostly along the west side. This partitioned area serves as the exhaust duct for the tunnel areas around Tanks 17 to 20. The 3'-diameter blast-valve opening originally for air intake now has the exhaust ducting connected to it. "The new CMU wall and the partition enable the Adit 6 tunnel to transport both supply and exhaust air."[60]

5. VENTILATION STRUCTURES

Throughout the Red Hill underground fuel storage complex there are air intake and exhaust ducts to provide a constant supply of safe breathable air for personnel working in the pumphouse and tunnels. There are separate piping systems for venting air in and out of fuel tanks, as they are emptied and filled. The tank venting and the tunnel ventilation arrangements have also changed over the decades since initial construction. Sketches by the former Supply Center Fuel Department Superintendent, following the text section and location maps of this report, show the two systems, in their original, in-between and current forms. He explained:

> In order to protect personnel working in the tunnels from hazardous fuel vapors, tank venting systems are, and have always been, completely separate from tunnel ventilation systems. Each point of a tank venting system, where it "daylights" to outside ambient air, functions as both supply and exhaust. Each point of a tunnel or pumphouse ventilation system, where it "daylights" to outside ambient air, functions as either supply or exhaust, but not both. None of the points where the tank venting systems "daylight" to outside ambient air is co-located with tunnel or pumphouse ventilation points. However, for the tunnel ventilation systems, four of the supply points (Adits 2, 3, 5, and 6) and two of the exhaust points (Adits 4 and 6) serve as entry and exit points for personnel.[61]

This section on ventilation structures describes the dedicated facilities, those whose main purpose is tank venting or tunnel ventilation. The machinery, piping or ducts for the parts of the tank venting and tunnel

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[59] James A. Gammon, Comment 27c, in e-mail attachment from former Supply Center Fuel Department Superintendent to Ann Yoklavich of Mason Architects, Inc., February 19, 2015.

[60] James A. Gammon, Comments in e-mail attachment from former Supply Center Fuel Department Superintendent to Ann Yoklavich of Mason Architects, Inc., January 27, 2015.

[61] James A. Gammon, Comments in e-mail attachments from former Supply Center Fuel Department Superintendent to Ann Yoklavich of Mason Architects, Inc., January 25–27, 2015.

ventilation systems, which are located within other facilities (e.g., the tunnels and other underground structures), are discussed under the "Mechanical Equipment" sub-heading of those facilities.

There are four tank ventilation structures, three with their own facility number, on the top of the Red Hill ridge. The ridge-top tank vent structure without a facility number is atop the Utility Shaft #73 (above Elevator #73). That structure plus Facility Nos. S-197, S-213, and 348 are all part of the ventilation system for the tanks. As originally configured for service when constructed in 1942, Tanks 1 and 2 stored diesel fuel for submarines; these tanks vented via Facility No. S-197, located above Tank 2. The others (Tanks 3 through 20) held NSFO for ships; they originally vented via Facility Nos. S-213 and 348. After the 1964 conversion of Tanks 17 to 20 to store volatile (aviation) fuel, those four tanks vented via both Facility No. 348 and the then newly constructed vent atop the Utility Shaft #73 (above Elevator #73). After the 1964 conversion project for the four upper tanks, Tanks 1 and 2 still vented via Facility S-197; Tanks 3 to 16 vented via Facility S-213 and via a new vent added in 1964. That 1964 vent point is the end of the pipe extending along the Adit 5 spur tunnel and exiting outside Adit 5, on the north side of the Red Hill ridge.[62]

There were three tunnel ventilation structures built on the Red Hill ridge, and two (Facility No. S-315 and 354) still serve that function. As originally configured for service when constructed in 1942, the ridge-top tunnel air intake structure (Facility No. S-315) supplied air to the entire UAT and LAT. The main tunnel exhaust portal (Facility No. 354) located on the north side of the Red Hill ridge discharged air from the entire Lower Tunnel (including LAT, HT, and MT sections) and from the Water Pumping Station at the HT/LAT junction.

> After the 1964 conversion of Tanks 17-20 to store volatile fuel, the sections of the Upper and Lower Access Tunnels that serve Tanks 17-20 were no longer ventilated via Facility Nos. S-315 and 354. They were ventilated via a new air intake structure, … newly constructed Adit 6, and [via] a newly constructed exhaust structure … atop the Elevator 73 shaft [Utility Shaft #73].[63]

Since 2014, the structure on top of Utility Shaft #73 (above Elevator #73) does not function as an exhaust portal for the upper and lower tunnel areas around Tanks 17 to 20. As noted above, this structure does still vent Tanks 17 to 20. Now, the exhaust route from the upper and lower tunnel areas around Tanks 17 to 20 is through the new ducts and partition walls in the Adit 6 tunnel to the exhaust fans outside the Adit 6 entry.

a. BOMBPROOF TANK VENT TYPE, FACILITY NOS. S-197 & S-213

Facility No. S-197 is located over Tank 2 and vents that tank and Tank 1 (Facility Nos. 329 and 328). Facility No. S-213, located over Tank 3, is almost identical in form; it now vents Tanks 3 through 16 (Facility Nos. 330 through 343).

Facility Nos. S-197 & S-213, Overall Dimensions

Most of the portions of these tank vents are underground, so the information about them derives largely from a 1942 drawing. The bombproof portions of these two ventilation facilities are all under earth cover, from over 100' underground to a few feet below grade. This dimension subsection describes: 1) the pipes rising from the tanks to the bombproof slabs, 2) the bombproof vent outlet portion, including its exhaust portal wall, 3) the surface vent pit with slotted concrete cover, and 4) the visible portion of the tank vents.

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[62] Ibid., December 29, 2014 and January 25, 2015.

[63] Ibid., January 25 & 26, 2015.

The 24"-diameter tank vent pipes rise from the upper tunnel, turn vertically above the tops of Tanks 2 and 3, and at a point about 10' below the surface of the Red Hill ridge each vent pipe turns 90 degrees. The pipe over Tank 2 turns towards the west, while the pipe over Tank 3 turns north. Directly over Tanks 2 and 3, above the right-angle turn of the ventilation pipe, are bombproof slabs of 6'-0" thick reinforced concrete, with 15'-6" x 22'-6" footprints. Under each bombproof slab the 24"-diameter ventilation pipe abuts a 36"-diameter concrete pipe, which extends horizontally out to a bombproof vent outlet. The distance of the bombproof vent outlet from its bombproof slab varies, depending on the topography of the ridge.

The concrete top of each bombproof vent outlet is a few feet underground, and the height (depth, from the top) is approximately 16'. The footprint of the vent outlet, not including the wing walls, is approximately 12' x 24'. Its 6'-0"-thick bombproof roof overhangs its footprint by 2'-0", on the side where the concrete pipe enters, so the roof footprint is about 14' x 24'. In each vent outlet, the exhaust portal wall (wall opposite the pipe entry wall) has three openings and wing walls. Two of the openings are 3'-0"-diameter ventilation openings, originally with wire mesh insect screening. The third opening has a diameter of 2'-6" with a manhole cover. Including the wing walls, the width of each exhaust portal wall is approximately 32' measured at its base. The lower part of the portal has wing walls about 4'-wide on each side; these taper in the middle section, with minimum 1'-0" wide wing walls at the top. The exhaust portal wall is about 26' wide at the top, and the wing portions are 2'-0" thick. All walls around the cavity for the 3'-0"–diameter vent openings and manhole are at least 4' thick.

A pit with slotted concrete cover, U-shaped in plan, abuts the exhaust portal wall of each bombproof vent outlet; the 3'-0"–diameter vent openings and 2'-6"-diameter manhole "daylight" into this pit. Each slotted cover slab is at grade. The pit is about 16' deep (including cover and floor) and its three walls, not including the adjoining thick exhaust portal wall, have a footprint measuring about 5' x 19'. The internal dimensions of the pit are approximately 4' x 17' and 14' deep. The concrete walls and floor of the pit are 12" thick. The concrete cover slab, also 12" thick, measures approximately 7' x 19', since this cover slab overhangs the plane where the pit and the bombproof vent outlet portions abut. A 4'-0" x 5'-0" removable concrete lid, with metal lifting bars embedded, is at one end of the cover slab, located slightly off-center. On each cover slab, adjacent to its removable lid, are eight vent slots, each slot measuring 3" x 36", spaced 12" on center. The slotted cover slab was originally the only visible part of each facility.

Sometime after initial construction, the Navy built gable-roofed corrugated-metal shelters over the slotted part of the cover slabs for both Facility Nos. S-197 and S-213. The footprint dimensions of the shelters are about 4'-6" x 9' and their height is just over 10'.

Facility Nos. S-197 & S-213, Foundations

The bombproof portions described under the heading above relied on the thickness of their concrete floors to serve as their foundations. The wall of each pit portion that is opposite the exhaust portal wall does have a spread footing, measuring 2'-6" wide by about 12" deep. Each corrugated metal shelter has a perimeter foundation wall, about 1' thick and 2' tall, enclosing the slotted section of its cover slab. These shelters and their foundations appear to have been constructed later, since they are not on the original drawings, or in 1940s photographs. In addition, the concrete in their foundations is different from that seen in the cover slabs.

Facility Nos. S-197 & S-213, Structural System

The bombproof slabs of these facilities have the typical dense reinforcing design seen in the bombproof roof sections of the pumphouse (Facility No. 59) and in other bombproof structures at Pearl Harbor. The structural systems of the corrugated metal shelters are made of welded steel angles.

Facility Nos. S-197 & S-213, Floor Plan

The floor plans of the bombproof slabs, surface vent structures, and shelters are all rectangular, and the dimension notes are in the first heading above. The basic footprints of the bombproof vent outlets are somewhat T-shaped (with the wing walls included). The only interiors are the space enclosed by the metal shelters, the hollow within the surface vent structures and the cavity in the bombproof vent outlets. The interior dimensions of the metal shelters are only slightly less than the exterior measurements noted above. The hollow spaces, below the slotted vents of the surface vent structures, are 4'-0" x 17'-0", with height (depth) approximately 14'. The cavities in the bombproof vent outlets are not rectangular due to angled corners and slight splays in their exhaust portal wall; they are about 3' x 15' and roughly 6' tall.

Facility Nos. S-197 & S-213, Exterior Finishes

The cover slabs, exhaust portals, and shelter foundations are unfinished concrete. The corrugated-metal siding and roofing of the shelters is painted.

Facility Nos. S-197 & S-213, Doorway and Other Openings

Each cover slab has a removable concrete lid to access the pit, and the dimensions are noted above. Each shelter has screened vent openings along the tops of its side walls, protected by the roof overhangs. In each metal shelter, there also is a round manhole opening on one end wall. Each manhole has two covers over the opening: an exterior steel cover with numerous bolts and fastening hardware, and an interior cover of glass about 1" thick in a metal ring about 2" thick. The glass in the interior cover of Facility S-197's manhole is broken, but shards remain. The covers have several hooks and fastening hardware that lock to the pivoting bolts with eyenuts, which are in the fixed ring on the shelter's end wall.

Facility Nos. S-197 & S-213, Mechanical Equipment

There is no visible mechanical or electrical equipment at these facilities.

b. ALTERED BOMBPROOF TANK VENT, FACILITY NO. 348

Originally, this facility was the same type of bombproof tank vent as Facility Nos. S-197 & S-213 (see description above). The only difference noted on the original drawing was the deletion of the wing walls for the exhaust portal on this facility. From 1942 until 1964, this vent and Facility S-213 vented Tanks 3 through 20. The current appearance of the above-ground portions of Facility 348 is not at all like Facility Nos. S-197 & S-213.

Changes were made to this facility about 1964, due to the modifications of Tanks 17 to 20 to store volatile fuel. This included removal of the above- and below-grade parts of the pit portion. A new reinforced-concrete pit, with 8'-0" square footprint (9'-4"square, including the 8"-thick walls) replaced it. The elements on top of this pit's concrete roof originally included a 24"-diameter manhole and two projecting pipes with return bends, both 12"-diameter pipes with screened ends. One pipe is the vent. It was originally connected to the breather valves with flame arresters in the pit. That 1964 machinery was attached to one of the ventilation openings in the exhaust portal wall of the bombproof vent outlet. The other pipe with a return bend provided intake air to the pit. The straight part of both pipes originally was 3'-0" above the concrete roof of the pit. Added chain-link security fencing encloses the sides and top of the pit area. The only change made to the underground bombproof vent outlet portion was filling the second ventilation opening and the manhole opening with concrete. This was necessary, since the new concrete pit was smaller than the original surface vent's pit. Following all the alterations made as part of that tank conversion project, this facility plus a new one, the tank vent structure above Utility Shaft #73 (see following description), vented Tanks 17 to 20.

Both facilities continue to perform this function, but only vent Tanks, 17, 18 and 20, because Tank 19 has been out of service since the mid-1980s.

In 1992, Phase I repairs of Tank 19 started. This project installed a 24"-diameter duct over the manhole; the 1960s manhole cover and two of its three wing bolts remain within the fencing. The duct connected to added fan equipment, sited outside the chain link fence. Only the return bend portion of one of the pipes is currently visible, so either the straight section was removed or it descended into the pit. "Upon completion of Phase I, Tank 19 was empty, clean, [and] well ventilated; [in addition] personnel safety improvements were completed to meet NAVOSH safety requirements. The Navy decided not to proceed with Phase II tank repairs and Tank 19 became the main attraction in tours of Red Hill conducted by the Supply Center."[64]

c. TANK VENT STRUCTURE ATOP UTILITY SHAFT #73 (ABOVE ELEVATOR #73)

This reinforced-concrete structure, located on a sloping hillside on the south side of the access road along the Red Hill ridge, is partially below grade. It has no facility number. Constructed in the 1960s, it was originally part of both the tunnel exhaust and the tank vent systems, for Tanks 17 to 20 and for the UAT and LAT areas near those tanks. Now this un-numbered facility functions, along with Facility No. 348, to vent Tanks 17, 18 and 20 (as noted above, Tank 19 is no longer in service). The 1960 drawing for this structure labels the shaft that it sits atop as "Exhaust Shaft;" however, its use for tunnel exhaust was discontinued in 2014. Now tank exhaust piping and conduits extend through the space, now called Utility Shaft #73. This 1960s structure has an entirely different design from that of the 1940s Bombproof Tank Vents (Facility Nos. S-197 and S-213).

Tank Vent Structure atop Utility Shaft #73, Overall Dimensions

The footprint of this structure measures 10'-0" x 20'-8" and its overall height, including below-grade portions, is 15'-0". Two "rooms" comprise the lower level of this structure, which is mostly below grade; one is labelled "breather pit" and the other "room" is the space at the top of the shaft (which will be called the "shaft room"). The height of both rooms is about 8', with the breather pit height about 4" higher, due to a roof thickness of 8", compared to the 12"-thick roof of the shaft room. The breather pit has an 8'-0" x 8"-4" interior footprint (not including the 8"-thick walls), while the interior of shaft room measures 8'-0" x 10'-0" (not including its 12"-thick walls). On the roof, above the shaft room, is a three-sided shelter over two round openings – a manhole and a mushroom-shaped blast valve. This shelter's footprint is 7'-0" x 7'-6", and its height is 6'-0" (5'-0" to its ceiling). The walls and roof of the shelter are 12" thick, with added concrete bevels at the interior and exterior corners. The shelter is open on the south side, with a removable screen of expanded metal mesh in a metal frame. The 8"-wide concrete parapet around the roof of the tank vent varies in height, in accordance with the sloping hillside. On the north (uphill) side, the parapet is 6'-0" high, matching the rooftop of the shelter. The parapet height on the south side is 12". The east and west parapets slope between those two heights. The 2'-4" wide space between the shelter and the eastern parapet wall has a corrugated metal roof supported by metal framing, which is a later addition. A similar metal roof also extends over the south side of the shelter.

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[64] James A. Gammon, Comment in e-mail attachment from former Supply Center Fuel Department Superintendent to Ann Yoklavich of Mason Architects, Inc., January 28, 2015.

Tank Vent Structure atop Utility Shaft #73, Foundations

On the original 1960 drawing, no additional concrete is shown for foundations under the breather pit, other than the 8"-thick reinforced-concrete floor under the breather pit and the similar 12"-thick floor under the shaft room. The 5'-0" diameter shaft, which has 12"-thick walls, also supports the structure.

Tank Vent Structure atop Utility Shaft #73, Structural System

This is a simple concrete structure, with mostly orthogonal spaces and round openings; reinforcing bars are typically arranged in the floors, walls and roofs. An addition, on the east side of the concrete shelter has a metal frame structure consisting of pipes plus steel angles and straps.

Tank Vent Structure atop Utility Shaft #73, Floor Plan

Inside the breather pit, are two 8"-breather valves with flame arresters. Below these valves is a 12"-diameter vent pipe that makes a 90-degree turn to extend through the concrete wall between the pit and the shaft room and turns 90-degrees again down the shaft. On the roof of the breather pit are two 12"-diameter pipes with return bends and a 24"-diameter manhole. There is also a metal ship's stair to the roof of the shelter. Inside the shaft room is the 5'-0"-diameter shaft opening, covered by a metal grating. In addition to the 12"-diameter vent pipe coming up the shaft towards to the breather pit, there is also a 3"-diameter sump. In the floor of the shelter (the roof of the shaft room) there is a 24"-diameter manhole and a blast valve opening with a diameter of approximately 3'.

Tank Vent Structure atop Utility Shaft #73, Finishes

The exterior and interior of this tank vent structure is mostly unfinished concrete. The only exceptions are the galvanized, corrugated sheet-metal roofing and siding on the addition. The siding is a triangular piece between the eastern parapet wall and the roof.

Tank Vent Structure atop Utility Shaft #73, Doorway and Other Openings

The two manhole covers to the breather pit and to the shaft room have the same design. The diameter of both covers is 2'-10-¾", to span the 24"-diameter openings. To secure the top of each cover there were originally three wing bolts, made of 5/8"-diameter steel rods, equally spaced around the rim. On the breather pit manhole, one of the wing bolts is missing.

The diameter of the blast valve cover is about 3'-2", to span the approximately 3'-diameter blast valve opening. This cover, called a mushroom cap, has a central stem that can descend into a larger-diameter cylinder. The mushroom resemblance is also due to the radial ribs under the cap. Thirty equally spaced bolts secure the metal border of the opening to the concrete floor of the shelter. The indentation in the edge of the mushroom cap seats it securely on the projecting rim of the opening's border. The blast valve cover has an elaborate mechanism under it, designed for automatic closure in the event of an atomic bomb explosion.

The diameter of the utility shaft is a minimum of 5'. Its opening, in the shaft-room floor of this vent structure, is covered by a slightly larger metal grating made of 1" x 3/16" steel bars, at 1-3/16" spacing. An I-beam with 6"flange, which is about 5'-10" long, underlies the grating and spans the 5'-diameter opening. Its ends fit in recesses in the shaft room's concrete floor. This floor is about 175' above the fan room for Elevator #73. One way to transit this space is via a metal ladder attached to the shaft wall. An equally daunting way is via a personnel hoist, raised and lowered from a loop in the shaft-room's ceiling.

There are two gates in the chain-link enclosure around this facility. One is on the north side, close to the access road, and the other is on the top of the enclosure, just south of the shelter portion.

Tank Vent Structure atop Utility Shaft #73, Mechanical Equipment

One of the most interesting, but non-operative, pieces of mechanical equipment on this structure is the nuclear blast sensor – a Cold War-era element. Mounted on a pipe attached to the top of the shelter portion of the facility, the light sensor is approximately 1" in diameter, under a 2"-diameter metal cap, which is bolted to the cap of the wider metal pipe. The light sensor controlled the automatic closure of the blast valve cover in the shelter portion. "The sensor and the blast valve system were installed in 1964 in conjunction with the conversion of Tanks 17 to 20 to store volatile fuel. The sensor and blast valve system was removed from service sometime prior to 1980."[65]

Electrical panels are sheltered under the addition's roof, on the east side of the shelter. Other mechanical equipment in this facility includes pressure vacuum valve on the tank vent line, exterior lighting, and security camera.[66]

There is a fan room above the machine room of Elevator #73; above the fan room is the shaft rising to the surface. In 2014 the fan, which exhausted tunnel ventilation air from the UAT and LAT around Tanks 17 to 20 through the #73 shaft to the top of Red Hill , was removed. The concrete walls and ceiling of the fan room have visible impressions of the forming boards. The fan room's inclined ceiling surfaces taper to meet the bottom of the 5'-diameter vertical shaft. "In 2014 the 5'-diameter opening to the vertical shaft was closed [by] a permanent metal cover."[67]

d. TUNNEL AIR INTAKE STRUCTURE, FACILITY NO. S-315

Facility S-315 is comprised of a bombproof air intake structure and a below-grade air shaft, which connects to the Elevator #72 shaft. The facility is located between Tanks 15 and 17. The base of the elevator shaft is slightly below the Lower Access Tunnel floor and this part of the shaft extends to an elevator machine room about 18' higher than the level of the Upper Tunnel's floor. Above this room, the continuation of this vertical space functions solely as an air shaft, which connects to the air intake structure. The south facade of the air intake structure is visible; most the remainder of the facility (portions of the sides, all of the rear, most of the top, and the entire connecting shaft) is either covered with earth fill or completely underground. The design of this structure is similar to another part of the Red Hill ventilation system, the main tunnel exhaust port, Facility No. 354.

Facility No. S-315, Overall Dimensions

The visible south face of the air intake is 22'-0" in height and 47'-6" in width, including both 4'-0"-thick retaining walls. The roof overhangs the side walls by 5'-0" (most of the roof has earth over it, but near the south face the roof thickness is visible). Across the intake's front are two bays, measuring 19'-9" each, and divided by a reinforced-concrete wall 2'-6"-thick. The length of the structure is not visible, but overall roof length is shown as 55'-0" on the original drawing. The retaining walls, projecting out from the north facade, add 31'-9" to the length.

The air shaft is near the rear (north) end of the air intake structure. The shaft is 10'-0" square in plan. The upper walls of the shaft, within the air intake structure, are 4'-0"-thick reinforced concrete. This wall thickness extends down to wherever bedrock was encountered during construction, an unknown depth. The

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[65] Ibid.

[66] Ibid., December 29, 2014.

[67] Ibid., January 28, 2015.

walls of the air shaft below this point are much thinner, lined with Gunite, which is typically less than a foot thick.

Facility No. S-315, Foundations

The retaining walls and bay division wall of the air intake structure have continuous spread footings; the footings for the former measure 2'-0"-deep and 6'-0"-wide and the latter's footing is about 2' x 4'. Bedrock supports the 4'-0" thick walls at the top of the shaft. The air intake has a sloping concrete slab floor, noted as 18" thick on the original drawing.

Facility No. S-315, Structural System

The air intake structure is built of reinforced concrete; its walls are 4'-0"-thick, and its roof is 6'-0"-thick, which are typical dimensions for bombproof structures. There are two symmetrical bays, one on either side of a central 2'-6"-thick wall of reinforced concrete. The sloping retaining walls on both sides of the structure project approximately 32' out from the plane of the roof overhang.

Facility No. S-315, Floor Plan

There is no accessible interior space in the air intake structure. The original drawing shows its plan is roughly in the shape of a funnel, with a narrow air shaft connecting to a wide air intake opening. Not including exterior walls, the wide south-facing opening of the air intake measures 39'-6". The interior width tapers to 10'-0"above the air/elevator shaft on the north end. The 2'-6" thick wall between the bays at the facade extends 9'-0" toward the air shaft and 3'-9" out, from the rear and front planes of the facade's pillars (see "Openings" heading below for further description).

The installation date of the added chain link fence at the top of the air intake structure is unknown. The chain link fence encloses the visible roof edge, both its sides and over it, and connects to a frame with metal mesh that fences off the front of the air intake.

The underground air shaft is situated north of the visible air intake facade. It is square in plan and measures 8'-4"x 8'-4". The overall depth of the air/elevator shaft is over 300'. It extends down to the elevator machine room near the Upper Access Tunnel, where it meets the Elevator #72 shaft, and continues down to a pit slightly below the Lower Access Tunnel. There is a small sump pit in the corner of the elevator pit, both lower than the level of the tunnel floor. The plan of the air/elevator shaft widens above the Upper Tunnel to accommodate the elevator machine room and access to that room. Below the Upper Access Tunnel, the floor plan of the shaft returns to its typical plan dimensions, which include space for ladders and landings behind the elevator cab.

Facility No. S-315, Finishes

The air intake structure has an unpainted, concrete surface. Impressions from board forms, made during the original concrete pour, are visible on its surface. A drawing indicates that the air shaft is lined with Gunite until just below the upper tunnel. From this point, until approximately 10' above the Lower Tunnel, it is lined with concrete. The lowest part of the shaft has Gunite lining again.

Facility No. S-315, Openings

Filling the two bays on the front facade are the air intake openings. These openings appear as "slits" in the concrete, but are the spaces between two lines of staggered, reinforced-concrete pillars, each measuring 1'-6" x 2'-0" in cross section. Each bay has three rows of nine intake slits. Each row is covered with a screen of rusted expanded metal mesh; there is white paint on the frames of the mesh screens. The width of the slits is uniform throughout the front elevation, at 6"-wide, whereas the height varies: 4'-9" high slits in the top row and 3'-0" high slits in the lower two rows.

The schematic section drawing indicates that the interior of the intake also has baffles. Two staggered half walls affect the air flow; one is attached to the ceiling a few feet in from the air intake front, and another rises from the concrete floor. The latter is located several feet towards the shaft from the ceiling-attached half wall. "The two half walls create a chamber where dirt and debris that is entrained in the incoming air stream can settle out before going down the shaft into the tunnels."[68].

Facility No. S-315, Mechanical Equipment

A fan was added to the air intake structure recently. This is a temporary installment during an ongoing or recently completed project to replace original 1942 fans in the ventilation system. The temporary fan is located above grade near the front facade, outside of the area enclosed with metal mesh. Within the air/elevator shaft, there is an abandoned 6" water pipe that "formerly connected the water tank on top of Red Hill with water lines in the Upper and Lower Access Tunnels. New regulations prohibit water lines in an elevator shaft."[69] Between the Upper Tunnel and the Lower Tunnel is the Elevator #72 shaft, which includes an elevator, an elevator machine room, and related mechanical systems.

e. MAIN TUNNEL EXHAUST PORT, FACILITY NO. 354

Facility No. 354 is comprised of a bombproof exhaust port on top of the Red Hill ridge and a below-grade ventilation shaft. The location of the facility is above the water pump station (Facility No. S-307); however, the ventilation shaft curves near its bottom to connect to the Lower Tunnel (Facility No. S-21), at a point a little east of its HT/LAT junction. The exhaust port's north face is visible, and some of the east and west sides, however the remainder of the facility (rear, top, and vent shaft) are either covered with earth fill or completely underground.

Facility No. 354, Overall Dimensions

The visible north face of the exhaust port is about 25' in height and 74'-6" in width, including the 4'-0"-thick retaining walls. The roof overhangs the side walls by 5'-0" (most of the roof has fill on it, but near the north face the roof thickness is visible). Across the port's front are three bays, measuring 20'-6" each, and divided by 2'-6"-thick reinforced-concrete walls. The wall of the north face extends below grade "down to rock" as indicated on the original drawing, so this dimension cannot be determined. The length of the structure is not visible, but overall roof length is shown as 53'-0" on the original drawing. The retaining walls, projecting out from the north facade, add approximately 20' to the length.

The ventilation shaft is near the rear (south) end of the port structure. The shaft is rectangular in plan, measuring 18'-0" by 8'-0". The upper walls of the shaft, within the exhaust port, are 4'-0"-thick reinforced concrete. This wall thickness also extends down to wherever bedrock was encountered during construction, an unknown depth. Typically, the walls of the ventilation shaft are less massive, about 1' thick. The elevation of the above-ground portion of the structure is approximately 200' and the Lower Access Tunnel has an elevation of about 100', so the shaft height is approximately 100'.

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[68] James A. Gammon, Comment in e-mail attachment from former Supply Center Fuel Department Superintendent to Ann Yoklavich of Mason Architects, Inc., January 23, 2015.

[69] Ibid.

Facility No. 354, Foundations

The retaining walls and bay division walls of the exhaust port have continuous spread footings; the footings for the former measure 2'-0"-deep and 6'-0"-wide and the latter's footings are about 2' x 4'. Bedrock supports the structure's other 4'-0" thick walls. The port has a sloping concrete slab floor that tapers in thickness from about 4'-6", where it meets the vent shaft wall, to approximately 3' at the opening on the north face.

Facility No. 354, Structural System

The exhaust port is constructed of reinforced concrete; its walls are 4'-0"-thick, and its roof is 6'-0"-thick. These dimensions are typical for WWII bombproof construction. The three uniform bays are divided by 2'-6"-thick walls of reinforced concrete.

Facility No. 354, Floor Plan

The exhaust port has a floor plan roughly in the shape of a funnel, with a narrow underground shaft connecting to the wide opening at the surface. Not including exterior walls, the wide north opening of the port measures 66'-6". The interior width tapers to 15'-0"above the vent shaft on the south end. The two walls (2'-6" thick) dividing the bays at the facade extend 9'-0" toward the exhaust shaft and 3'-9" out, from the rear and front planes of the facade's pillars (see "Openings" heading below for further description). At the centerline of the port, beginning at the plane where the other dividing walls end, is another wall, whose footprint measures 2'-6" x 9'-0".

During initial construction of the exhaust shaft, it was a vertical space extending down to the water pumping station (Facility S-307). However, the opening to the water pump station was closed by 1942 and an S-curve was added near the bottom of the shaft, to connect it to the Lower Tunnel. The dimensions of the shaft vary in this lower end. The part closest to the Lower Tunnel has a square cross-section (12'-8" x 12-8"), then it transitions to an arched tunnel shape that is 12'-8" wide and 11'-8" high. The final transition is to the 15'-0" x 8'-0" interior dimensions of the vertical shaft.

Facility No. 354, Finishes

The exhaust port has an unpainted, concrete surface. Impressions from board forms, made during the original concrete pour, are visible on its surface. The ventilation shaft also has unpainted surfaces, either concrete or Gunite.

Facility No. 354, Openings

The port's exhaust openings fill the three uniform bays on the front facade. These openings appear as "slits" in the concrete, but are the spaces between two lines of staggered, reinforced-concrete pillars, each measuring 1'-6" x 2'-0" in cross section. Each bay's elevation has three rows of ten exhaust slits. Each row is covered with a screen of expanded metal mesh (although the lowest screen on the northeast end is missing). The width of the slits is uniform throughout the front elevation, at 6"-wide, whereas the height varies; the slits in the top row are 4'-9" high, and the slits in the lower two rows are 3'-0" high.

The section drawing indicates that the interior of the intake also has baffles. There are two staggered half walls; one that is attached to the ceiling 5'-0" in from the pillars at the exhaust port's north face, and another which is rises from the concrete floor. The latter is located 5'-0" further in from the ceiling-attached half wall.

Facility No. 354, Mechanical Equipment

The ventilation shaft contains a ladder along one wall with a safety climbing cable. Next to it is mounted a roughly 6"-diameter pipe. This is the "waterline connecting [the] PWC water tank on top of Red Hill to [the] waterline" in the Lower Tunnel.[70] No mechanical equipment is visible on the exterior of the exhaust port, or shown on its original drawing. "The exhaust pipe for the original diesel-driven generator in the Water Pumping Station discharged into the vertical shaft leading up to Facility No. 354. It has since been replaced by a generator located outside Adit 3."[71]

PART III. OPERATIONS AND PROCESS

James A. Gammon, Naval Supply Center Fuel Department Engineer and Superintendent at Pearl Harbor from 1980 to 2004, wrote this part on the fuel storage system's operations and processes.

A. FUELING OPERATIONS AND TYPES OF FUEL STORED

In the late 1930s and early 1940s when the Navy planned the bulk fuel storage layout for Pearl Harbor, the Underground Pumphouse, tunnels, and the Red Hill tanks were designed to pump, transport, and store non-volatile fuels for ships and submarines – Navy Special Fuel Oil (NSFO) and diesel oil. In later years, the original design did allow for handling and storage of non-volatile jet fuels – JP-5 and JP-8.[72] The Pearl City Fuel Annex, isolated on the Pearl City Peninsula on the opposite side of Ford Island from the main Naval Base, was the site chosen for handling and storage of volatile fuels, originally motor gasoline and aviation gasoline; and in later years JP-4 jet fuel. It should be noted that because the early aircraft carriers carried aviation gasoline, the carrier berthing and re-fueling wharves were also on the Pearl City Peninsula (see HAER No. HI-94).

At the start of operations in 1942, Red Hill Tanks 1 and 2 stored diesel fuel for submarines and Tanks 3 to 20 stored NSFO for ships. Tankers bringing fuel, primarily from the West Coast, would berth at the fuel pier, Hotel Pier; their shipboard pumps would offload fuel to one, or more, of the four Surge Tanks (Facility Nos. 1224 to 1227). These tanks are located adjacent to the Underground Pumphouse (Facility No. 59), at an elevation only a few feet above sea level. Since the quantity offloaded from the tanker was usually greater than the capacity of the Surge Tanks (each tank holds 10,000 barrels), simultaneous with the tanker offload, the high-capacity pumps in the Underground Pumphouse would pull fuel from the Surge Tank(s) and pump it up to a Red Hill tank. The bottoms of the Red Hill tanks range in elevation from 120' to 150' above sea level. The normal maximum fill level in the Red Hill tanks ranged from around 350' to 380' above sea level, depending on the tank. Because of the height of the tanks above sea level and their great depth ranging from 239' to 251', two pumps operating in series are required to generate the high pressure needed to top off a Red Hill tank. However, the height of the tanks is a great benefit for issuing fuel to vessels berthed at Pearl Harbor, since for most issues gravity flow produces a more than adequate flow rate. For fuel issues by gravity

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[70] James A. Gammon, Comment in e-mail attachment from former Supply Center Fuel Department Superintendent to Ann Yoklavich of Mason Architects, Inc., December 29, 2014.

[71] Ibid., January 22, 2015.

[72] JP-5 is the military jet fuel used aboard ships. Its flash point is a minimum 140 degrees Fahrenheit (F). JP-8 is the military jet fuel used at shore installations, with a lower flash point of minimum 100 degrees F. The higher flash point makes JP-5 is safer fuel for use on an aircraft carrier, where the risks and consequences of fire are greater. Both are in the non-volatile fuels category.

from Red Hill, the flow goes through the piping in the Underground Pumphouse, but the pumps and surge tanks are bypassed. The need for pumping is eliminated, unless the issue is from a Red Hill tank that is close to empty. The operational scenario for offloading tankers berthed at Hotel Pier continues to the present.

The original design labeled the three pipelines connecting the Red Hill tanks to the Underground Pumphouse as follows:

16" diameter – Diesel,

18" diameter – Topped Crude, and

32" diameter – Fuel Oil.

The design anticipated that the fuel oil used by Navy ships would be heavy oil, like Bunker C, because the design included steam coils in the bottoms of the tanks. These coils could heat the oil to increase the flow rate through the 32"-diameter line. However, NSFO, which is a lighter no. 6 fuel oil, was the Navy's choice for ship fuel; consequently, the heating coils were never needed. Topped crude was never stored at Red Hill, so the 18"-diameter line was also used for NSFO; having two NSFO pipelines provided the flexibility to issue and receive simultaneously. The 16"-diameter diesel line was used for diesel fuel as originally intended. Originally, eight of the pumps in the Underground Pumphouse were in NSFO service and three were in diesel fuel service. Three surge tanks were in NSFO service and one was in diesel service. This configuration of Red Hill tanks, surge tanks, pipelines, and pumps continued from the early 1940s through the early 1960s.

In 1962, the Chevron refinery at Barbers Point constructed a pipeline to downtown Honolulu with a branch line connecting to the Underground Pumphouse at Valve Chamber 1 outside Adit 1. This allowed the refinery to deliver diesel and NSFO through the Underground Pumphouse directly to Tanks 1 to 16. Work at that time was already underway to make changes to Tanks 17 to 20 and to other components of the Red Hill fuel system, as follows:

Between 1960 and late 1963 the following changes had taken place, under an Air Force-funded Military Construction project:

- Tanks 17 to 20 were made ready to store volatile fuel. These tanks were emptied of NSFO, cleaned, repaired, coated, and outfitted with a new tell-tale leak-detection system. They were also connected to a separate tank venting system and a separate slop oil system.
- The eastern ends of the LAT and UAT serving Tanks 17 to 20 were isolated from the rest of the tunnels. They were provided with separate access via the new Adit 6 tunnel and new Elevator #73. These tunnel areas also had a separate ventilation system and a separate fire-extinguishing system installed.
- A new volatile-fuel pumping station was installed in the LAT, west of Tanks 17 and 18.
- A new 16"-diameter pipeline was constructed from the new volatile-fuel pumping station in the Red Hill LAT to the Pearl City Fuel Annex, about six miles away.
- The 18"-diameter pipeline, in the LAT and HT from Red Hill to the Underground Pumphouse, was emptied of NSFO, cleaned, and converted to JP-5 jet fuel.
- One of the three Surge Tanks in NSFO service was emptied, cleaned, and converted to JP-5.
- Three of the eleven pumps in the Underground Pumphouse were converted from NSFO to JP-5.

Regarding Tanks 17 to 20, in the mid-1960s two of the four tanks were put in gasoline service and the other two tanks were put in JP-5 service. Gasoline was pumped to) the Red Hill tanks from the Pearl City Fuel Annex (and in the opposite direction) via the 16"-diameter pipeline. Gasoline was not pumped or run through the pipelines in the Lower Tunnel that served Tanks 1 to 16 or through the Underground Pumphouse, which was capable of handling only non-volatile fuels including NSFO, diesel, and JP-5. By the late-1960s the two Red Hill tanks in gasoline service were also converted to JP-5 service. The short-lived connection of Red Hill to the volatile fuel system at the Pearl City Fuel Annex completed the interconnection of all volatile bulk-fuel storage facilities on Oahu, known as the Joint Underground Gasoline System (JUGS). JUGS included storage tanks at Kipapa, Waikakalaua, Pearl City Fuel Annex, Ewa Junction, and Hickam Air Force Base. When the two Red Hill tanks in gasoline service were converted to JP-5 service, the 16"-diameter pipeline from Red Hill to Pearl City was also converted from gasoline to JP-5 service. With the 16"-diameter pipeline to Pearl City and Red Hill Tanks 17 to 20 in JP-5 service, JP-5 could be issued from Red Hill to Pearl City. There the 16"-diameter pipeline connected to an 8"-diameter pipeline to the Naval Air Station Barbers Point, for a total pipeline distance of 15 miles all by gravity flow.

Between 1970 and late 1972 the following changes had taken place, under Navy-funded Special Project No. R1-67:

- An auxiliary water pumping and piping system connected to Tanks 1 to 16 was installed. It was intended to fill the tanks with water for leak testing. The water source was the Water Pumping Station.
- Tanks 5, 6, and 12 were emptied, cleaned, repaired, and outfitted with a new and improved tell-tale leak-detection system.

In the mid-1970s the Red Hill tanks that remained in NSFO service were emptied, cleaned and converted to diesel fuel service. Emptying and cleaning the 32"-diameter pipeline was also part of this conversion. Five pumps in the Underground Pumphouse were converted from NSFO to diesel service. The two surge tanks that remained in NSFO service were emptied, cleaned, and converted to diesel service.

In 1970 construction of the second refinery on Oahu, Hawaiian Independent Refinery (later Tesoro), was completed. In the late 1970s/early 1980s the refinery leased the Chevron branch pipeline with the connection to the Underground Pumphouse. The refinery delivered both JP-5 and diesel through the Underground Pumphouse directly to the Red Hill tanks.

Between 1979 and late 1983 the following changes had taken place, under Navy funded Military Construction Project No. P-060:

- Pumps 1 to 11 in the Underground Pumphouse were repaired.
- Surge Tanks 1 to 4 were emptied, cleaned, repaired, and coated.
- Red Hill Tanks 1 to 16 were emptied, cleaned, repaired (both the 1942-vintage and the improved 1972-vintage tell-tale leak-detection systems were completely removed and not replaced), and coated.

In the late 1990s/early 2000s several JP-5 tanks at Red Hill were converted to JP-8 jet fuel. The 16"-diameter pipeline from the Underground Pumphouse to Red Hill was emptied of F-76 diesel fuel and converted to JP-8 jet fuel.

Currently Red Hill tanks store F-76 diesel fuel, JP-5 jet fuel, and JP-8 jet fuel. The three main pipelines are in dedicated service as follows:

16" diameter – JP-8 jet fuel,

18" diameter – JP-5 jet fuel, and

32" diameter – F-76 diesel fuel.

B. OPERATION OF TELL-TALE LEAK-DETECTION SYSTEM IN TANKS

Originally, all the tanks had a tell-tale leak-detection system of pipes along their interior shells. This system and its history of improvements are described under the Fuel Tanks' "Mechanical Equipment" heading. Tanks 1 to 16 have no tell-tale piping. As explained in that section, the tell-tale leak-detection piping was removed from Tanks 1 to 16, sometime after the mid-1970s. This removal included the original 1940s-era tell-tales, and the improved early-1970s tell-tale systems in Tanks 5, 6 and 12. Tank 19, which is not in operation, retains the tell-tale pipes from an early 1960s improvement project It is not known if the 1960s tell-tales remain in Tanks 17, 18, or 20. Two sketches of the tell-tale system follow the location maps in this HAER report.

The first sketch is a sectional view down the vertical centerline of a tank. The second sketch is a detail of a tell-tale pipe showing how the tell-tale pipe collects fuel, if it leaks through the ¼"-thick steel plate of a tank's shell.

In the original construction, each tank had 12 vertical tell-tale pipes equally spaced around the perimeter. Each pipe covered (collected leaks from) the upper dome and a vertical section of tank wall about 26' wide in the cylindrical part of the tank. To understand how the tell-tale leak-detection system was designed to work, you have to understand how the steel plates that line the tank walls were constructed. The ¼"-thick steel plates that formed the shell of the tank are rectangular (in the cylindrical part of the tank) and were butt welded together. To insure full-penetration welds between plates a backer strip was placed behind each vertical and horizontal butt weld. For the vertical butt welds the backer strip was a piece of flat bar. For the horizontal butt welds the backer strip was a piece of angle iron with one leg of the angle flush against the back side of the steel plates and the other leg embedded in the reinforced concrete surrounding the outside of the tank. Just above each horizontal butt weld a small hole was cut through the ¼"-thick shell plate and a tee was installed to connect the hole through the shell plate to the vertical tell-tale pipe. In operation, if fuel leaked through the shell plate (or through a weld in the shell plate) it would run down the back side of the plate until it came to the leg of an angle iron embedded in the concrete that surrounds the tank. The fuel would then collect on the angle leg and begin to flow horizontally along that leg until it reached a hole cut through the shell plate; then it flowed through the hole and into the tee connected to the tell-tale pipe. The fuel would then flow down the tell-tale pipe to the LAT cross tunnel, to indicate that there was a leak.

In the original construction, the tell-tale pipes started at the bottom of the upper dome of the tank and continued down the tank wall to the tank bottom where they exited the tank. The pipes were ¾"-diameter standard wall pipe. There were several problems with the original design of the tell-tales, which prevented optimal operation. The pipe diameter was too small and the tell-tale pipes could become plugged by the solid material in the heavy fuel oil that was stored in the tanks. The thin standard pipe wall and the exposure to water in the bottom of the tank resulted in holes in the tell-tale pipes from corrosion.

Improvements to the tell-tale leak-detection system were installed in Tanks 5, 6, and 12 in 1971-72. To prevent plugging, the diameter of the tell-tale pipes was increased. They also were extended up into the gauging chamber at the top of the tank; here, they were accessible and could be blown out or flushed out and cleared if plugging did occur. As a hedge against corrosion, the pipe wall thickness was increased and they were redirected to exit the tank above the tank bottom, to avoid exposure to water that settled out of the fuel.

C. FUNCTION AND OPERATION OF OIL-TIGHT DOORS

The original design and construction for the Red Hill system included five oil-tight doors. In the event of a pipeline leak or rupture or a tank overflow, the doors were designed to close and stop the uncontrolled flow of fuel or water through tunnels and out adits into the surrounding areas outside. The doors are located as follows:

- in the Underground Pumphouse (Facility No. 59), at the entrance to the Surge Tank Tunnel from the Pump Room
- in the Underground Pumphouse (Facility No. 59), at the east end of the Pump Room at the entrance to the HT section of the Lower Tunnel (Facility No. S-21).
- in the HT section of the Lower Tunnel (Facility No. S-21), just east of the intersection with the MT section (Door HT-A). In the late 1990s the door was modified, which changed its operation.
- in the LAT section of the Lower Tunnel (Facility No. S-21), east of the intersection with the HT section (Door LAT-D). This door also had modifications that changed its operation.
- at Adit 3 (Facility No. S-312), at the entrance to the LAT section of the Lower Tunnel (Facility No. S-21). On the original drawings, the door is labeled "Flood Gate."

The first four doors are located in the tunnels and are normally open. Closure was activated by a float-switch in a sump in the tunnel floor located on the "up-tunnel" side of the door. If water or oil flowed down the floor of the tunnel and filled up the sump, it activated the float-switch, which released the open oil-tight door. The door was pulled closed by a counterweight. Doors HT-A and LAT-D were referred to as "drop-track" doors; these two had a special mechanism to drop a short section of railroad track, adjacent to each door, into a shallow pit so the door could close completely. In the late-1990s, the doors were modified to eliminate the drop-track feature. It is not known if closure of the doors is still activated by a float-switch in a floor sump.

The fifth original oil-tight door is at Adit 3 and must be closed manually.

Two additional oil-tight doors were installed later.

- The 1964 tank conversion project constructed an oil-tight reinforced concrete bulkhead with an oil-tight door in the Upper Access Tunnel between Tanks 15/16 and Tanks17/18 (Door UAT-B) to isolate the eastern end of the tunnel serving Tanks 17 to 20. The door is normally closed; it is opened and closed manually.
- The 1964 tank conversion project constructed an oil-tight reinforced concrete bulkhead in the LAT section of the Lower Tunnel (Facility No. S-21) between Tanks 15/16 and Tanks17/18 to isolate the eastern end of the tunnel serving Tanks 17 to 20. The original construction did not include a doorway through the bulkhead. In the late 1990s a hole was cut through the bulkhead and an oil-tight door (Door LAT-E) was installed. This door is normally closed; it is opened and closed manually.

D. VENTILATION SYSTEMS FOR TUNNELS AND TANKS

As mentioned in the introduction to the Ventilation Structures description section, in Part II, the ventilation piping for the tanks and for the tunnels are entirely separate systems. The systems have changed since their initial construction. Sketches of the original, in-between, and current ventilation systems for tanks and for occupied spaces (tunnels and pumphouse) are included in this report, following the location maps and sketches of the tell-tale leak-detection system.

Table 2 summarizes which tanks the original tank vent structures served, and what changes were made when the 1964 tank vent additions were constructed. The changes in 1964 were all part of the project to isolate Tanks 17 to 20, in order to store volatile fuel.

Table 2. Tank Vents, history of tanks served

Facility No.	Location (all Red Hill)	Year Built	Tanks served (modification made)	Era Served
S-197	over Tank 2 (on ridge)	1942	Ventilates Tanks 1 and 2	1942 to present
S-213	over Tank 3 (on ridge)	1942	• Ventilates Tanks 3 to 20 • Ventilates Tanks 3 to 16	• 1942 to 1964 • 1964 to present
348	over Tank 19 (on ridge)	• 1942 • 1964	• Ventilates Tanks 3 to 20 • Ventilates Tanks 17 to 20 (pressure/vacuum valve added for venting volatile fuel)	• 1942 to 1964 • 1964 to present
none	outside Adit 5 (north hillside)	1964	Ventilates Tanks 3 to 16 (added 16"-diameter vent pipe)	1964 to present
none	atop Utility Shaft #73 (on ridge)	1964	Ventilates Tanks 17 to 20 (added 12"-diameter vent pipe)	1964 to present

Table 3 summarizes the tunnel ventilation system, as it changed over the years. It notes all the intake and exhaust points and what areas of the tunnels they served – originally, after 1964 alterations, and currently.

Table 3. Tunnel Vents, history of areas served and functions

Facility No.	Name / Location	Year Built	Function and Areas Served (See legend below for abbreviations)	Function Era
S-275	Adit 2 / Makalapa	1942	Intake for MT and HT	1942 to present
S-312	Adit 3 / north slope of Red Hill	1942	Intake for north end of LAT (Adit 3 to Water Pump Station)	1942 to present
S-314	Adit 4/ north slope of Red Hill	1942	• Exhaust for entire UAT (Tank 20 to Adit 4) • Exhaust for most of UAT (Tank 16 to Adit 4)	• 1942 to 1964 • 1964 to present
S-315	Tunnel Air Intake / Red Hill ridge over Elev. #72	1942	• Intake for entire UAT (Tank 20 to Adit 4) & most of LAT (Tank 20 to Water Pump Station) • Intake for most of UAT (Tank 16 to Adit 4) & part of LAT (Tank 16 to Water Pump Station)	• 1942 to 1964 • 1964 to present
S-354	Tunnel Exhaust / Red Hill ridge over Water Pump Station	1942	• Exhaust for MT and HT • Exhaust for north end of LAT (Adit 3 to Water Pump Station) • Exhaust for most of LAT (Tank 20 to Water Pump Station) • Exhaust for part of LAT (Tank 16 to Water Pump Station)	• 1942 to present • 1942 to present • 1942 to 1964 • 1964 to present
none	Tank Vent / atop Utility Shaft #73	1964	Exhaust for east ends of UAT and LAT (near Tanks 17 to 20)	1964 to 2014
none	Adit 5 / north slope of Red Hill	1964	Intake for most of UAT (Tank 16 to Adit 4)	1964 to present

none	Adit 6 / north slope of Red Hill	1964	Intake for east ends of UAT and LAT (near Tanks 17 to 20)	1964 to present
none	Exhaust Fans/ above Adit 6	2014	Exhaust for east ends of UAT and LAT (near Tanks 17 to 20)	2014 to present

MT = Makalapa Tunnel (Section of Lower Tunnel, Facility No. S-21)

HT = Harbor Tunnel (Section of Lower Tunnel, Facility No. S-21)

LAT = Lower Access Tunnel (Section of Lower Tunnel, Facility No. S-21)

UAT = Upper Access Tunnel (no Facility number)

PART IV. SOURCES OF INFORMATION

A. ARCHITECTURAL DRAWINGS

Most of the original 1940s drawings for the Red Hill underground fuel storage system are in two locations at Pearl Harbor. The Y&D drawing numbers for the original set are between # 293878 and # 294722. The drawings were mostly prepared by CPNAB for the Fourteenth Naval District, and in a few cases by the staff of the Fourteenth Naval District. The contractors and the Fourteenth Naval District had their own numbering systems, so each drawing typically has all three on the sheets. The Fuel Department of the Fleet Logistics Center has full-size prints on hanging files. The Naval Facilities Engineering Command, Pacific Division has scans of microfilmed drawings. There is almost total overlap between the drawings in the sets, but each collection has a few of the original drawings that the other does not. A very limited subset of the original Red Hill drawings is also filed at the National Archives II, in College Park, Maryland.

Alteration drawings of the Red Hill underground fuel storage system are in the same two Pearl Harbor locations, with the Fuel Department having the more comprehensive collection. All of the historic Red Hill system drawings were part of contracts with the U.S. Navy and are in the public domain.

B. EARLY VIEWS

The National Archives II Photographic Section has about 100 historic photographic prints of Red Hill taken by the Fourteenth Naval District, during 1941 to 1943, of construction project NOy-4173. The Fuel Department at Pearl Harbor has prints of the same historic photographs, plus approximately 120 more from the early 1940s. They also have photographs dating from 1960s improvement and repair projects. All the historic photographs were part of contracts with the U.S. Navy or taken by Navy personnel and are in the public domain.

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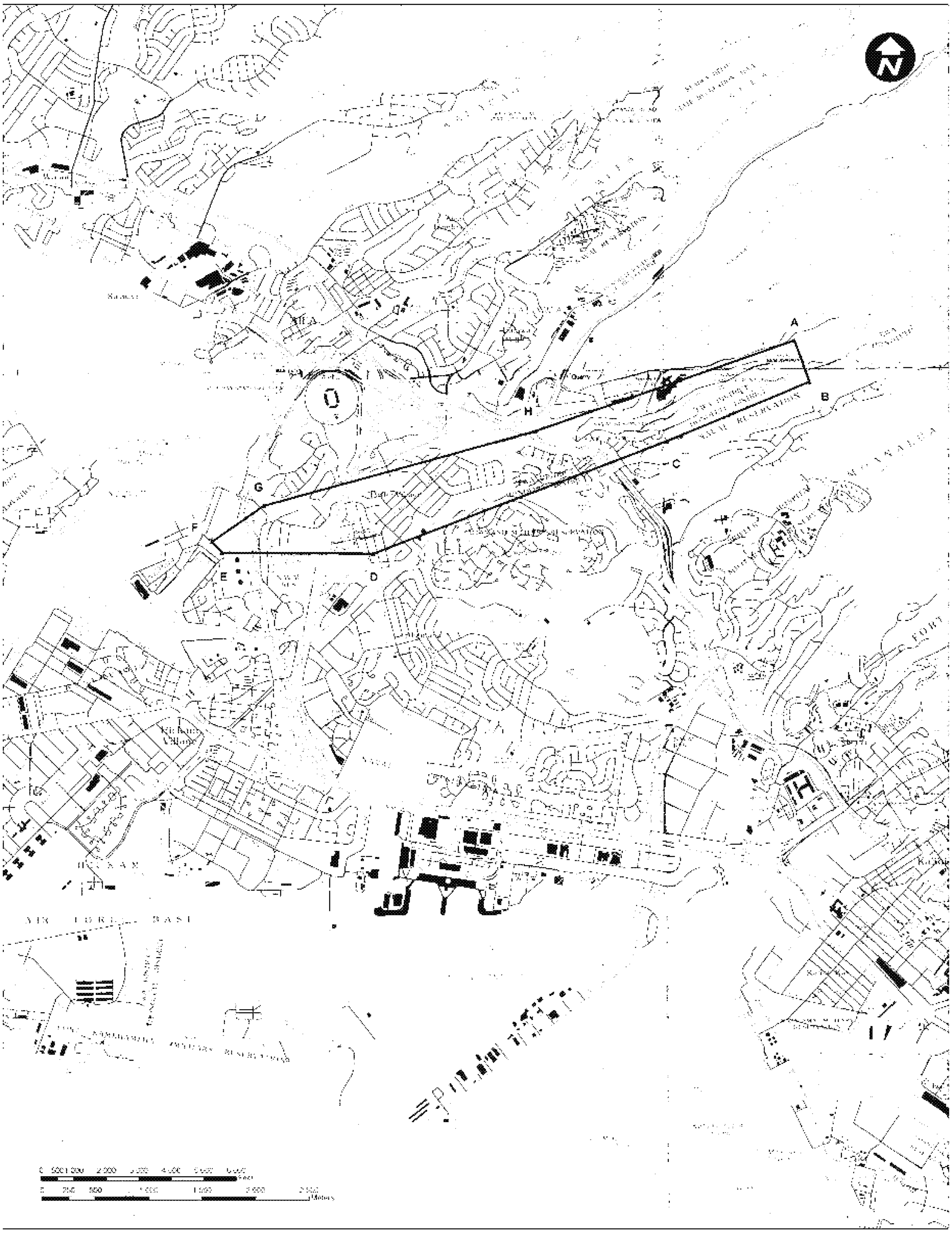
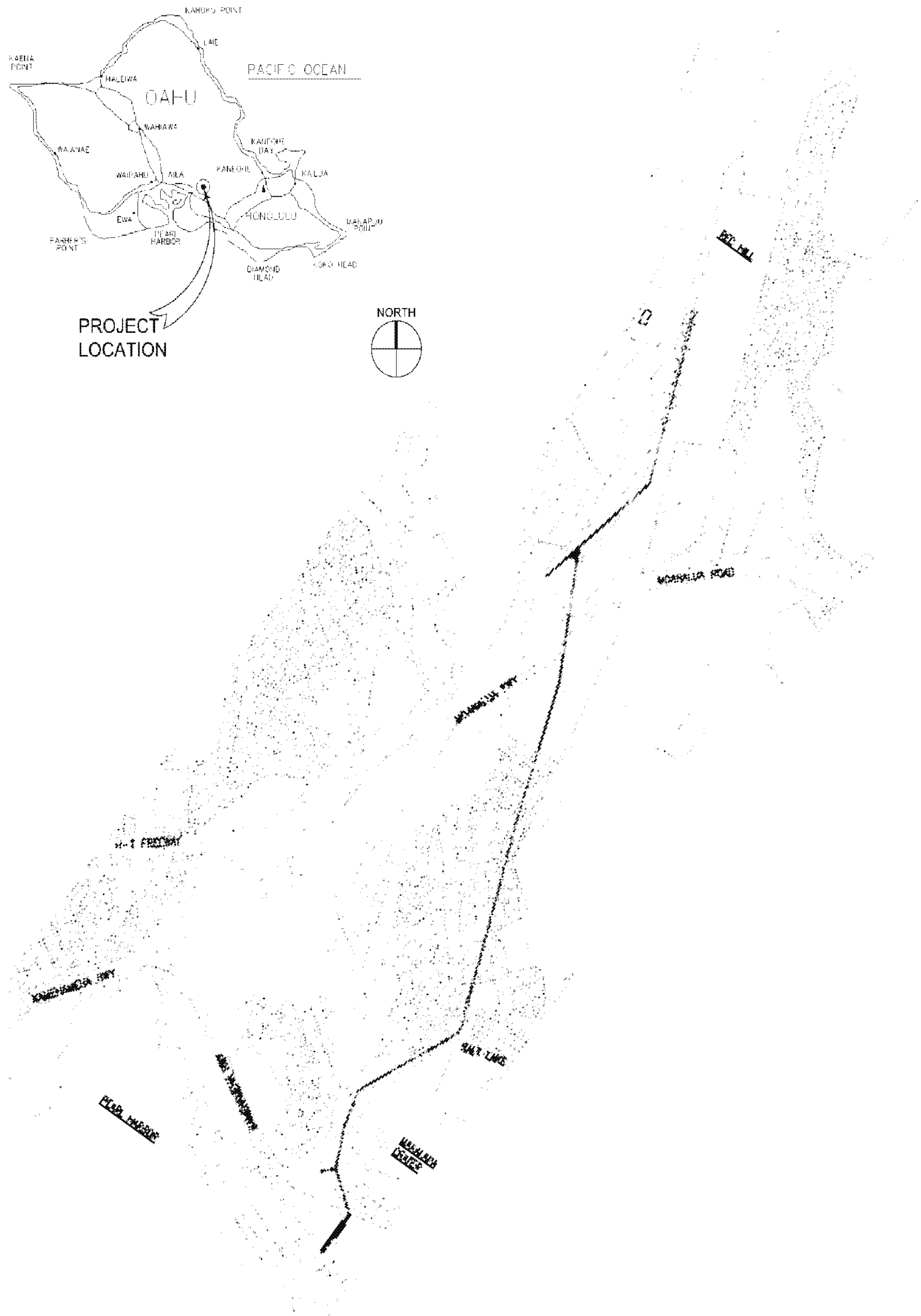
D. LIKELY SOURCES NOT YET INVESTIGATED

The Technical Library and files of the Pearl Harbor FLC, in the Fuel Department building (Facility 1757) contain additional reports, correspondence and photographs, especially about the alteration and improvement projects involving the Red Hill underground fuel storage system. The major changes are all discussed in this report, but there are undoubtedly unknown details to discover.

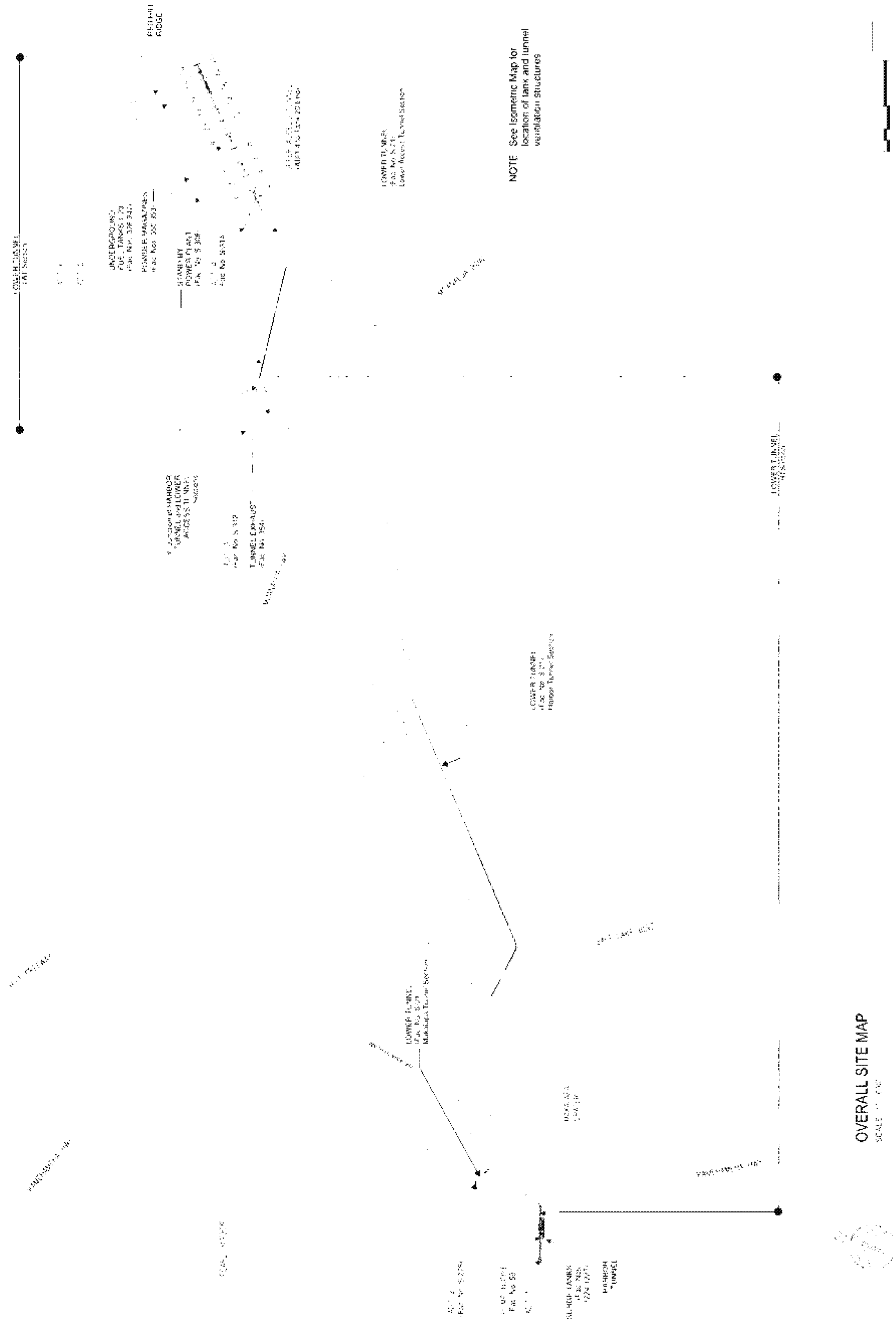
U.S.G.S. maps with polygon enclosing Red Hill Underground Fuel Storage System



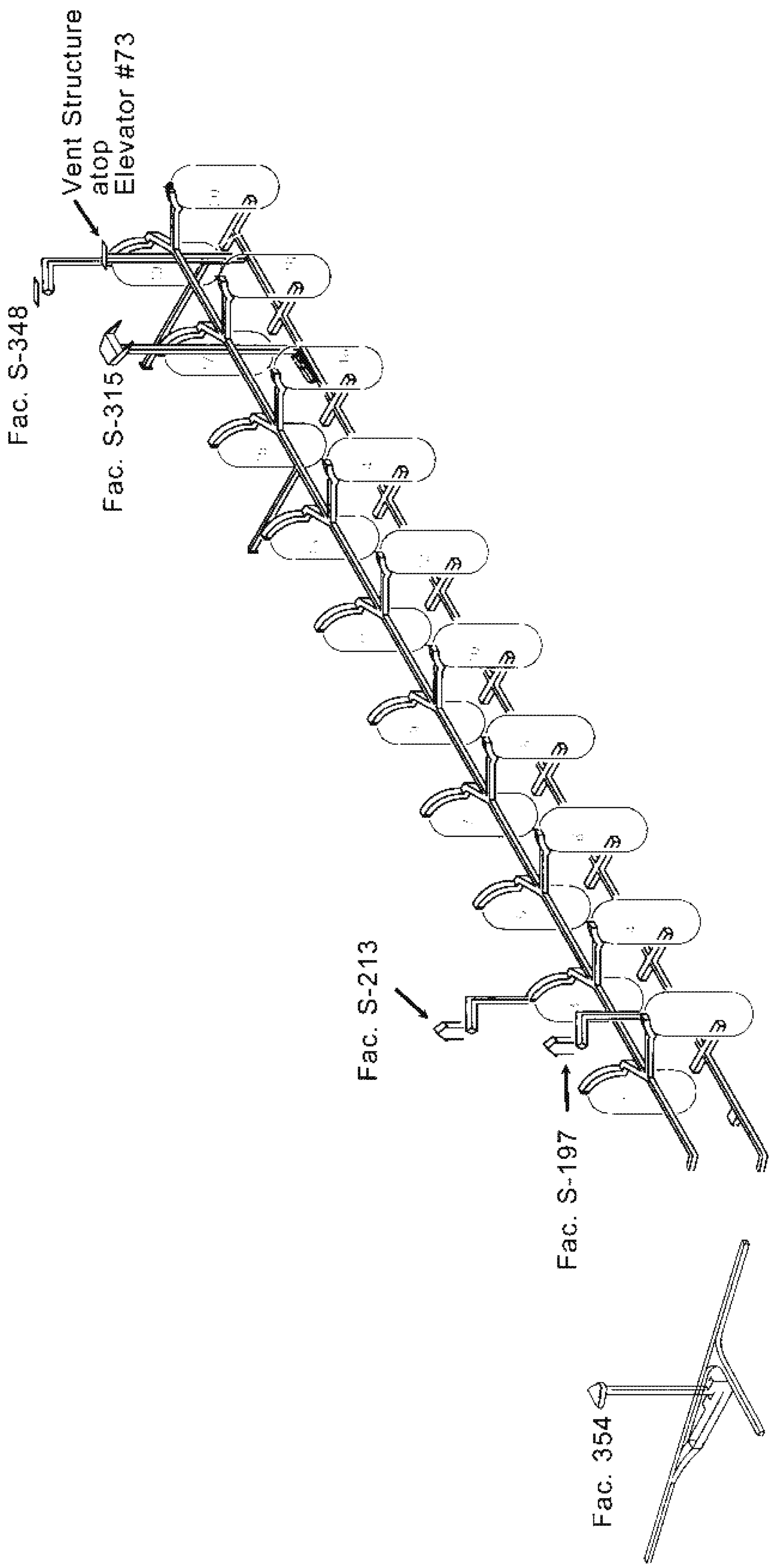
Location Map



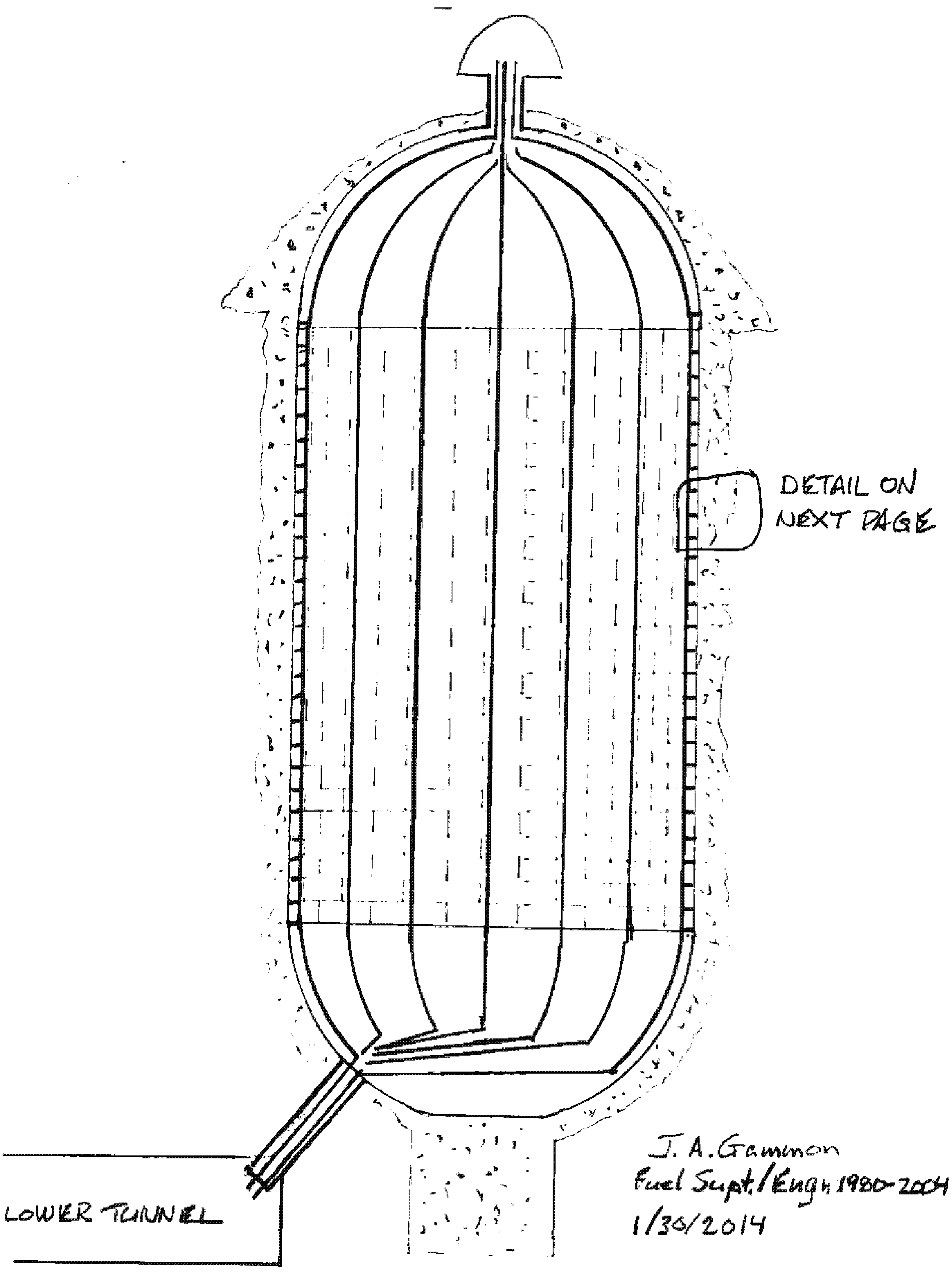
Overall Site Map



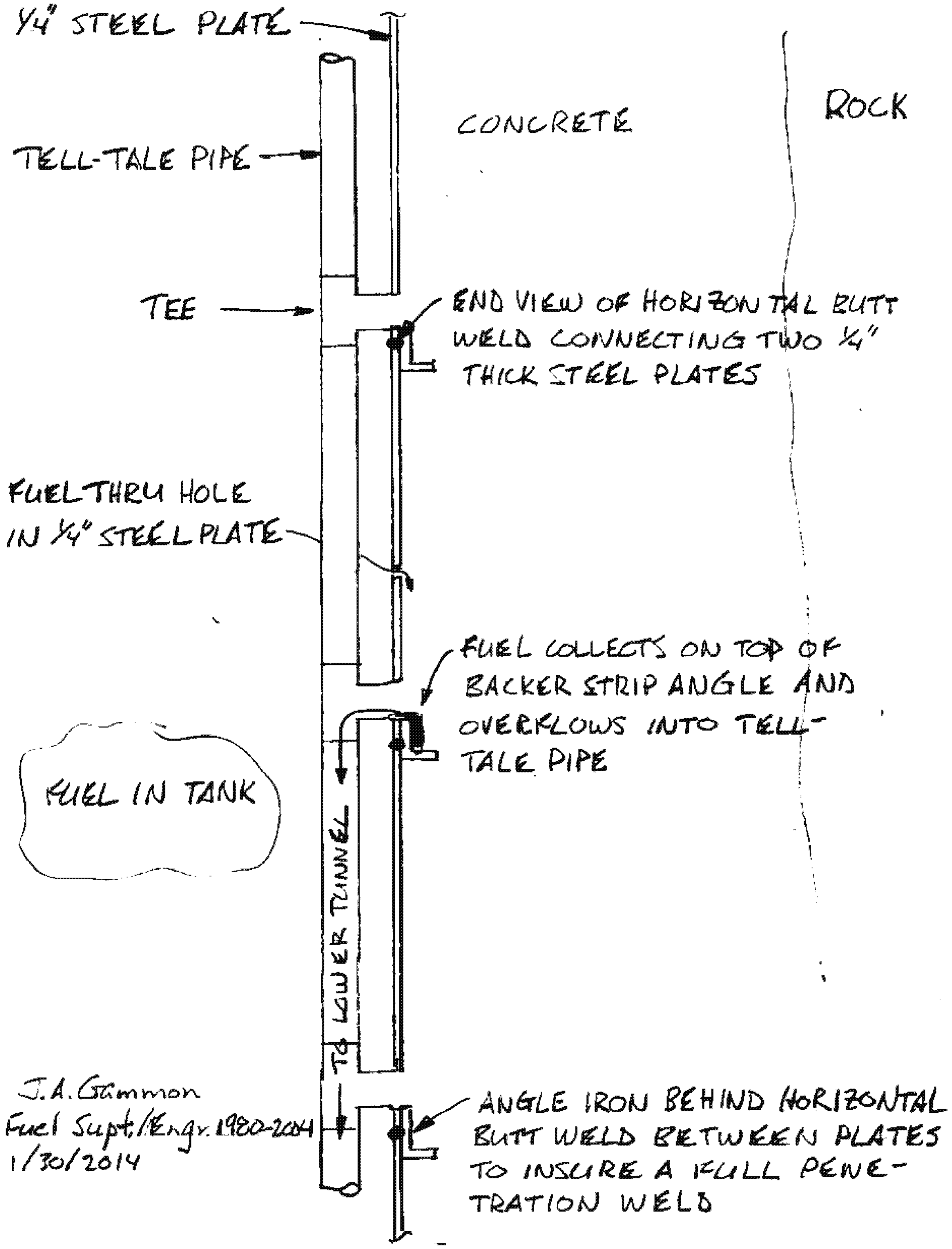
Isometric Map, showing locations of tank and tunnel ventilation structures



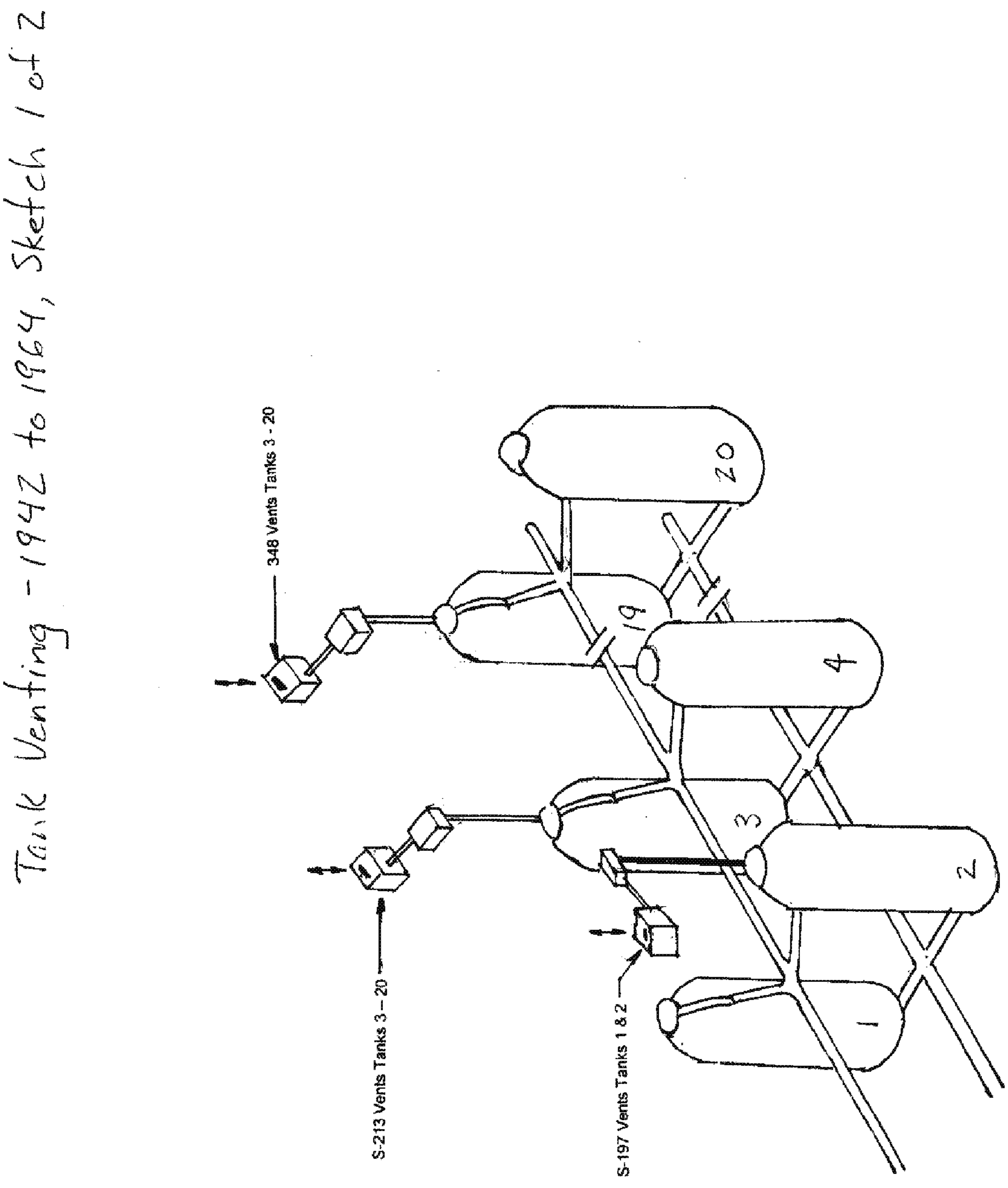
Tell-Tale Leak-Detection System, Sketch of typical tank with early 1970s improvements.
(James A. Gammon)



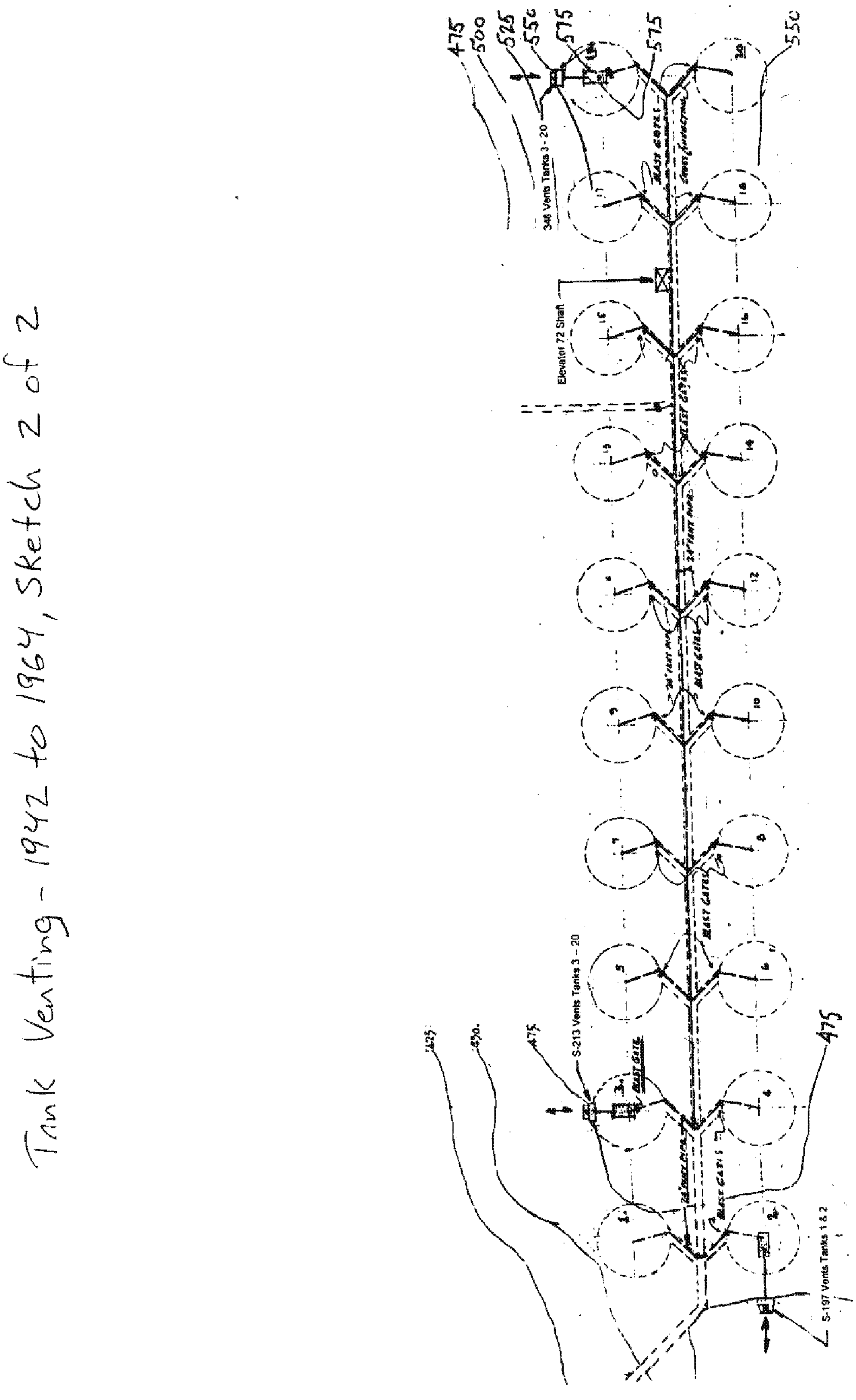
Tell-Tale Leak-Detection System, Sketch with detail of fuel collection. (James A. Gammon)



Tank venting system, 1942 to 1964 – Sketch 1 of 2. (James A. Gammon)



Tank venting system, 1942 to 1964 – Sketch 2 of 2. (James A. Gammon)



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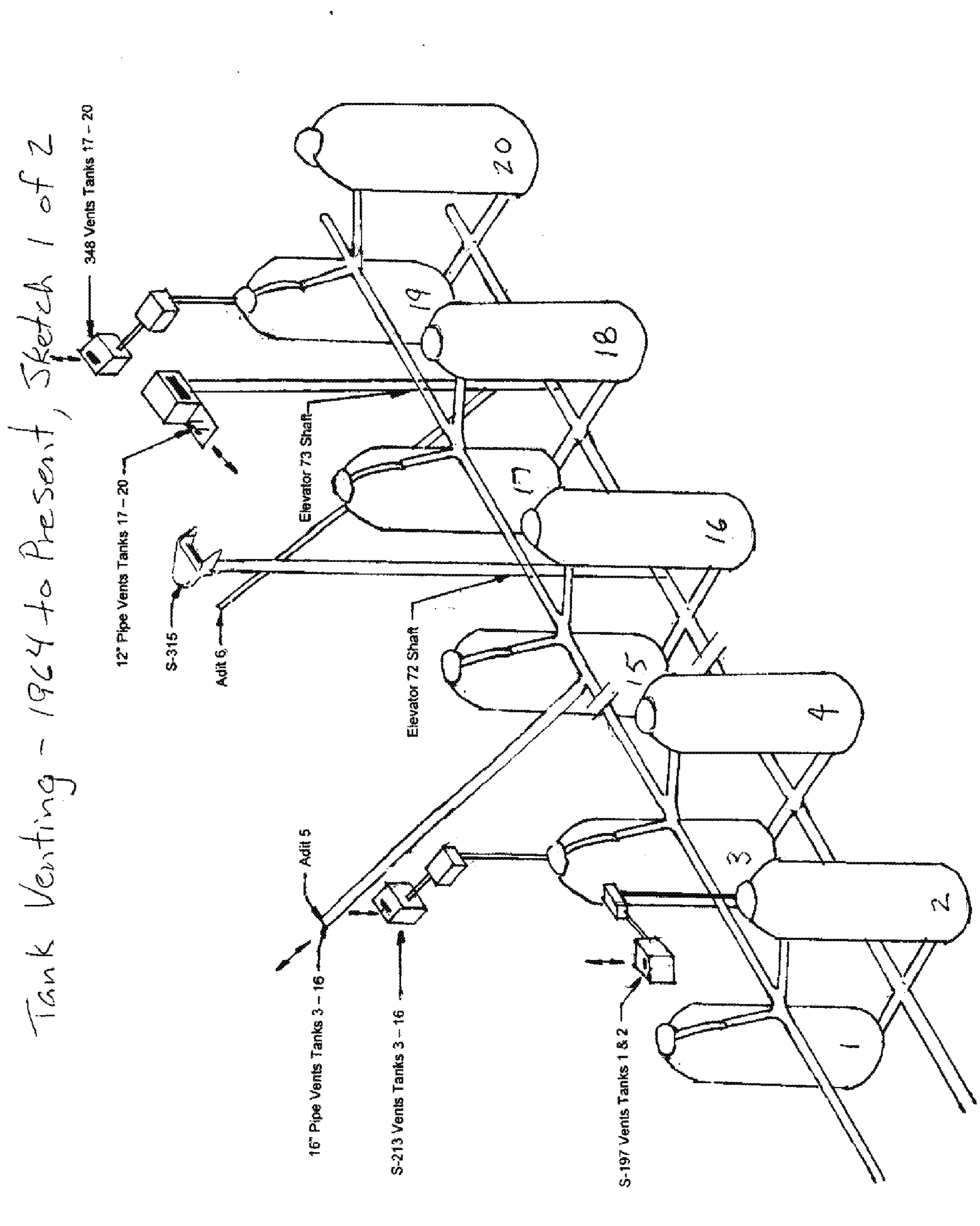
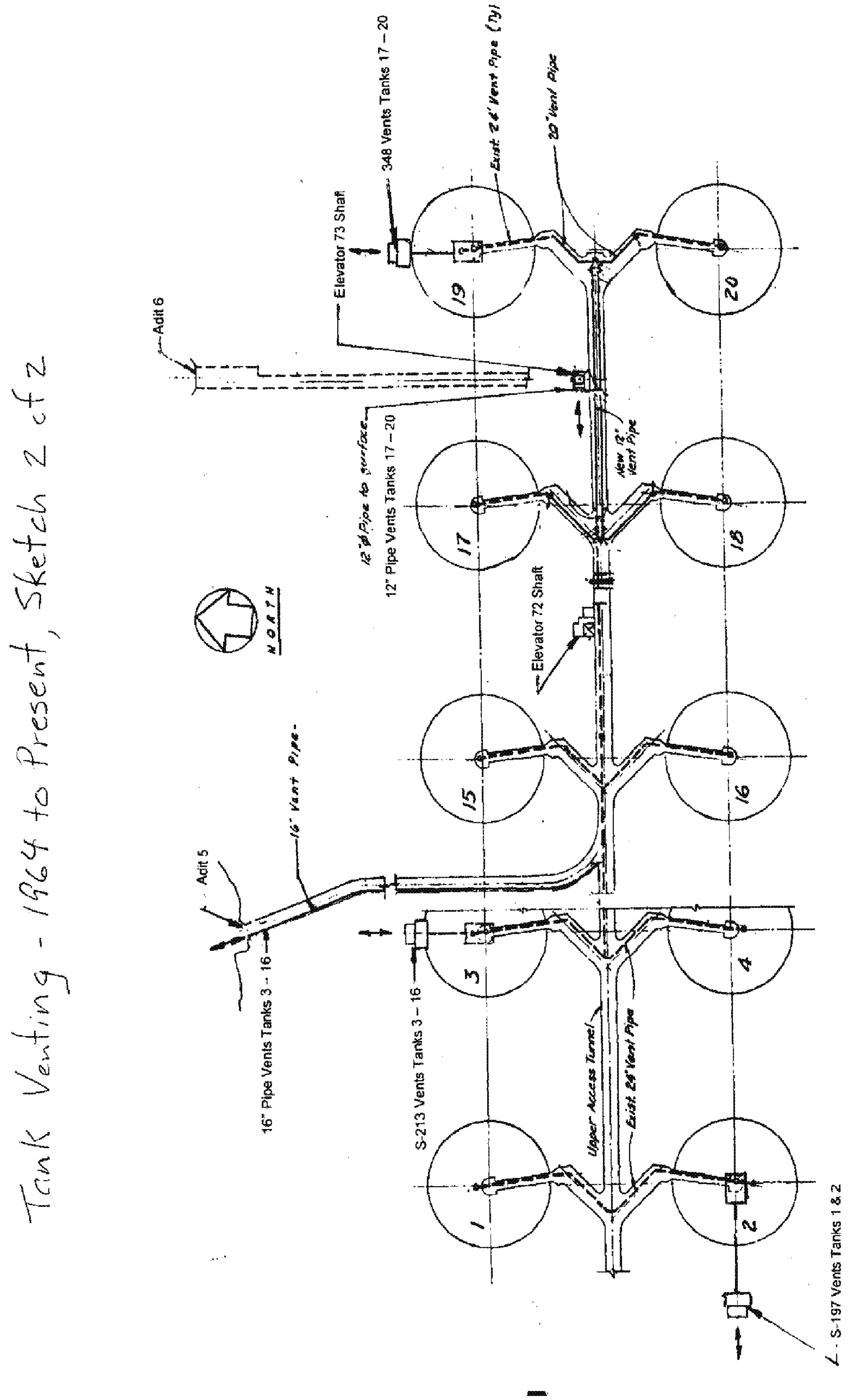
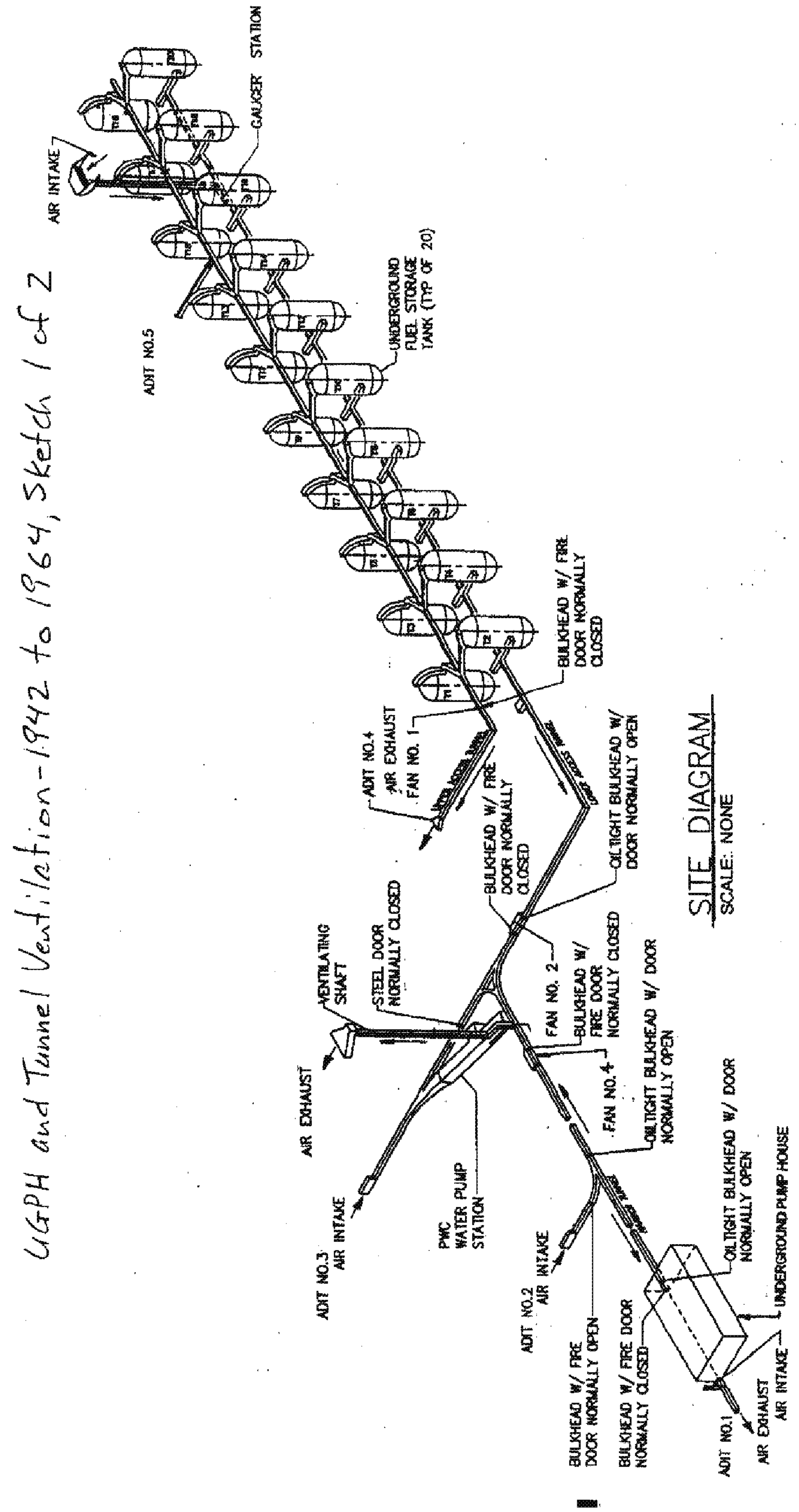
Tank venting system, 1964 to present – Sketch 1 of 2. (James A. Gammon)



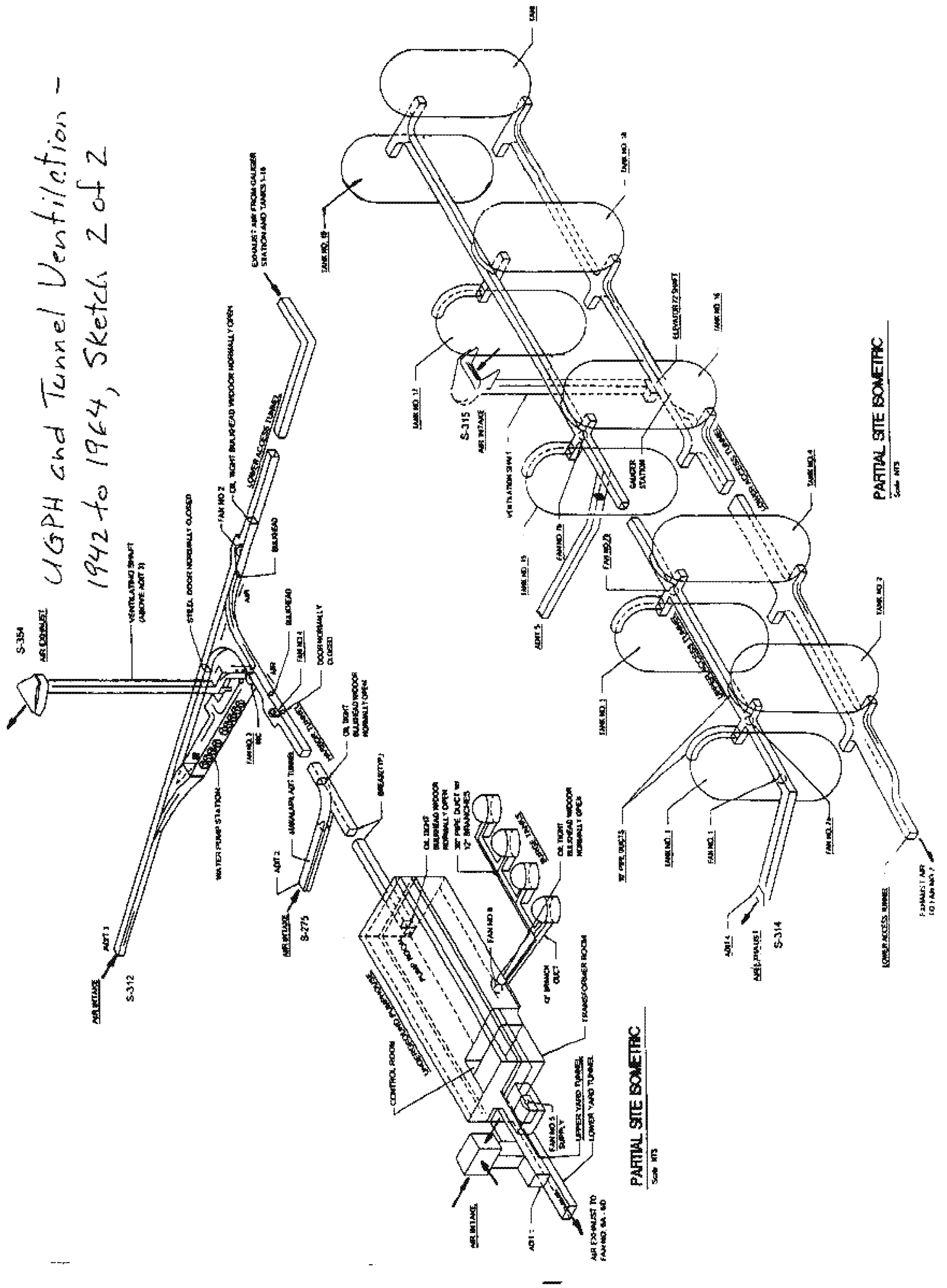
Tank venting system, 1964 to present – Sketch 2 of 2. (James A. Gammon)



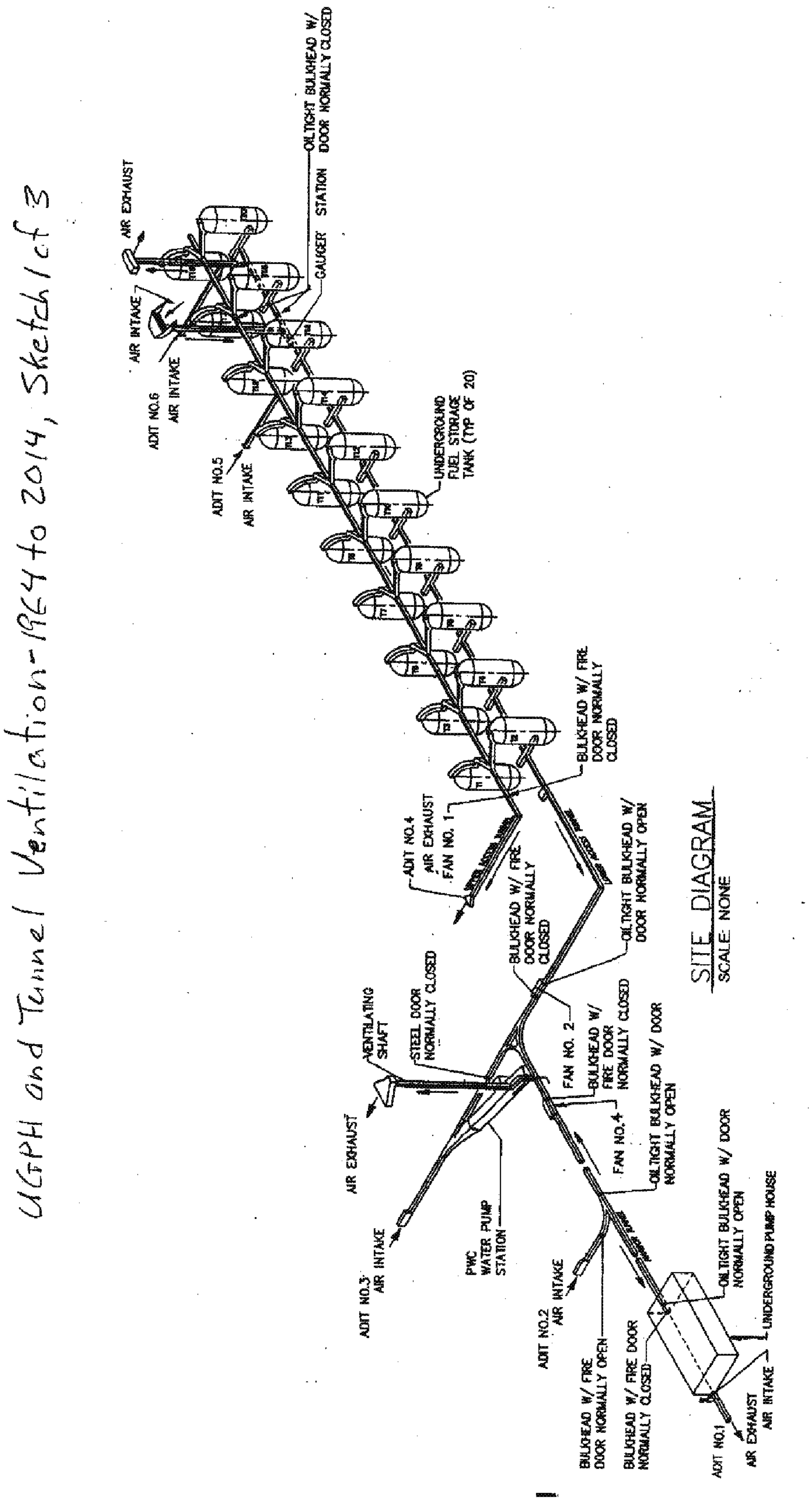
Underground Pumphouse and Tunnel Ventilation System, 1942 to 1964 – Sketch 1 of 2.
(James A. Gammon)



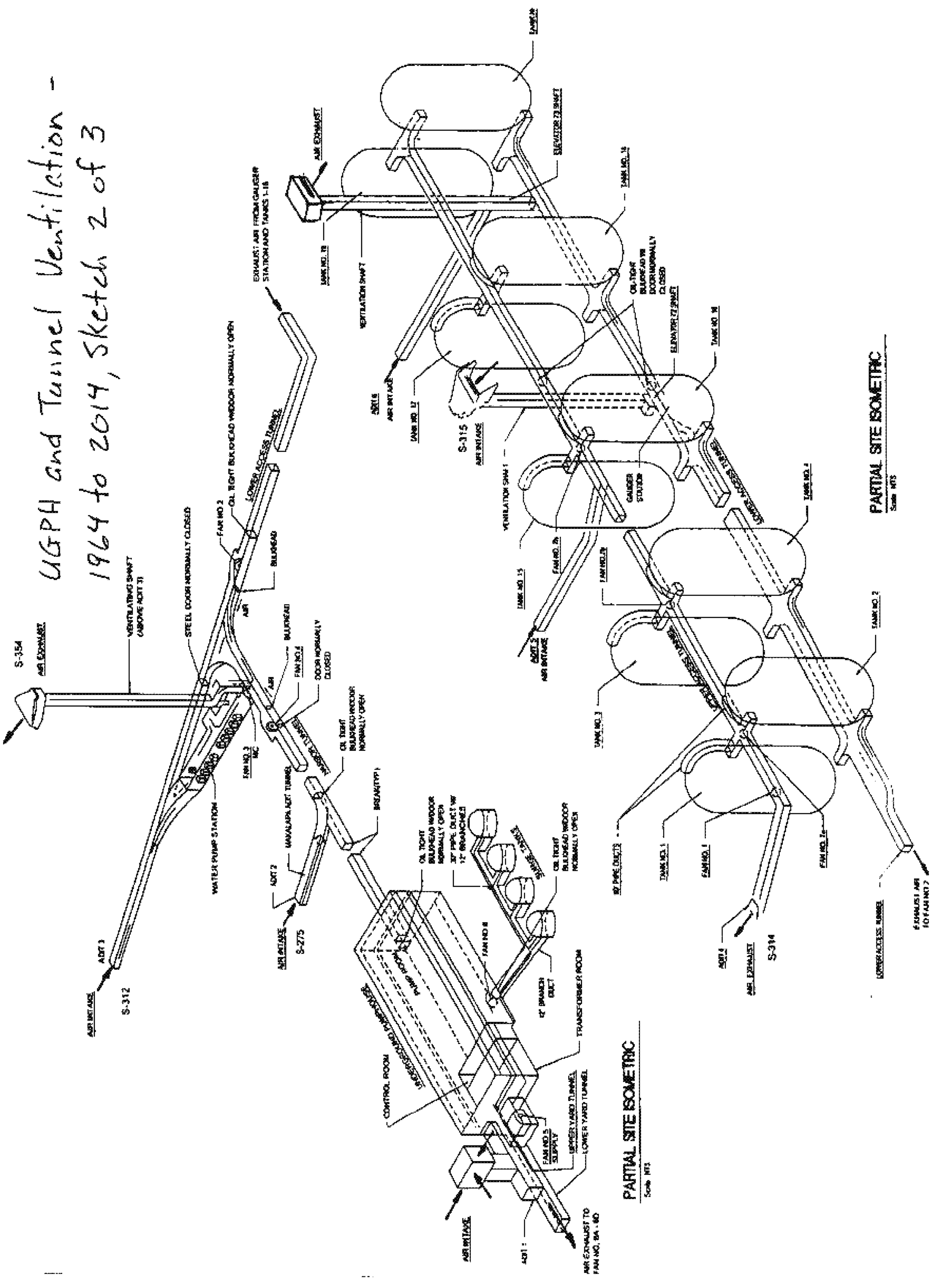
Underground Pumphouse and Tunnel Ventilation System, 1942 to 1964 – Sketch 2 of 2.
(James A. Gammon)



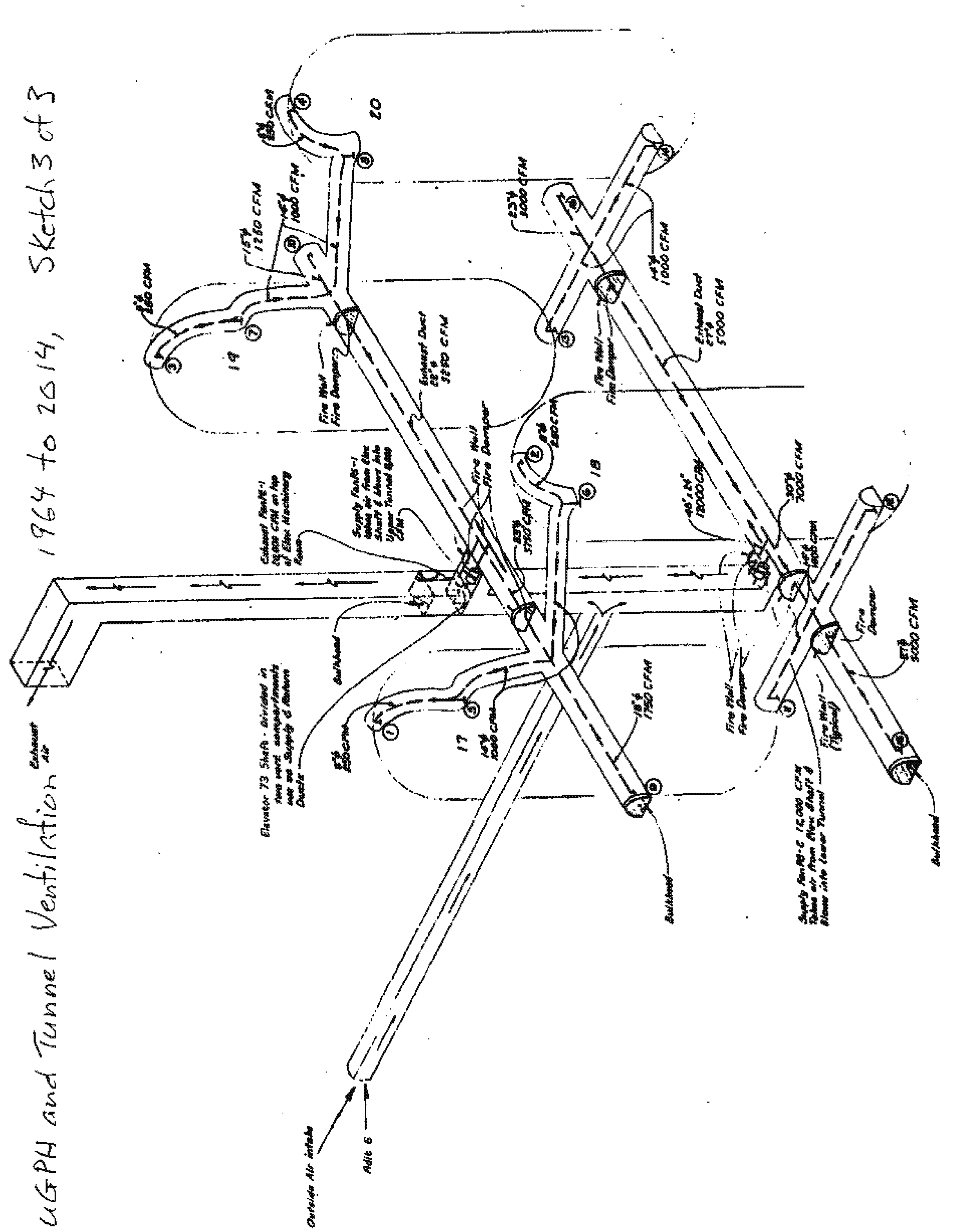
Underground Pumphouse and Tunnel Ventilation System, 1964 to 2014 – Sketch 1 of 3.
(James A. Gammon)



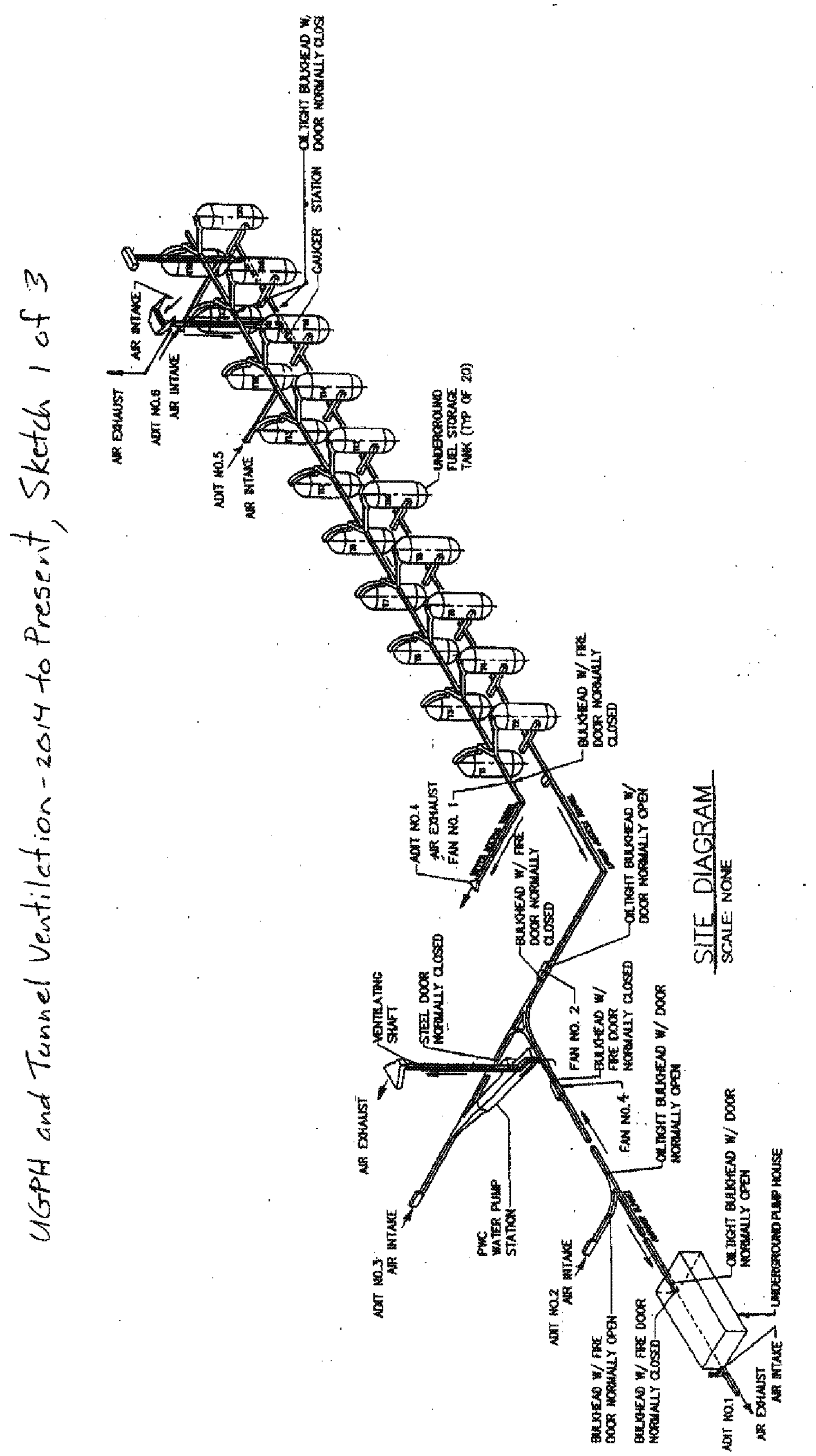
Underground Pumphouse and Tunnel Ventilation System, 1964 to 2014 – Sketch 2 of 3.
(James A. Gammon)



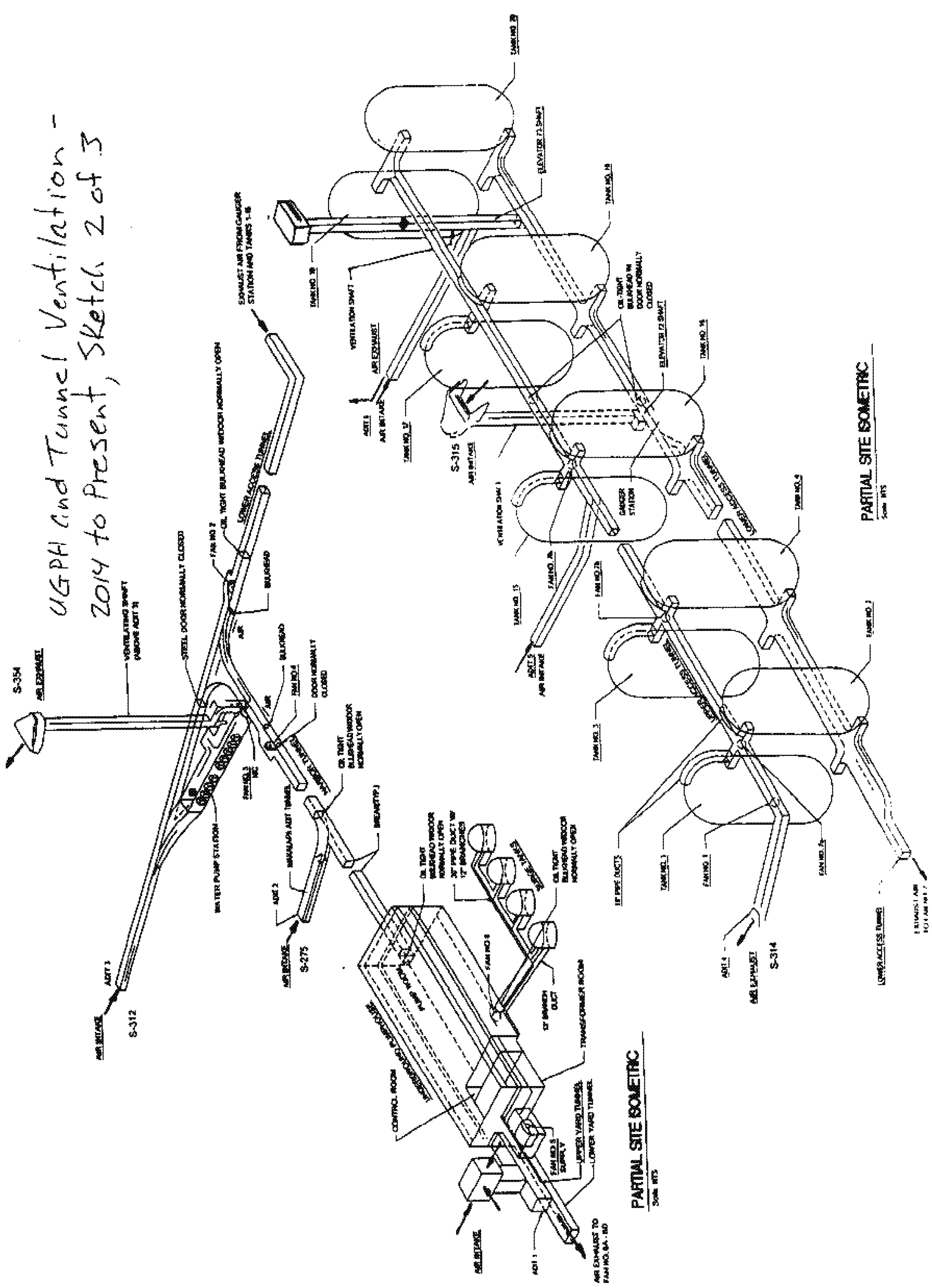
Underground Pumphouse and Tunnel Ventilation System, 1964 to 2014 – Sketch 3 of 3.
(James A. Gammon)



Underground Pumphouse and Tunnel Ventilation System, 2014 to present – Sketch 1 of 3.
(James A. Gammon)



Underground Pumphouse and Tunnel Ventilation System, 2014 to present – Sketch 2 of 3.
(James A. Gammon)



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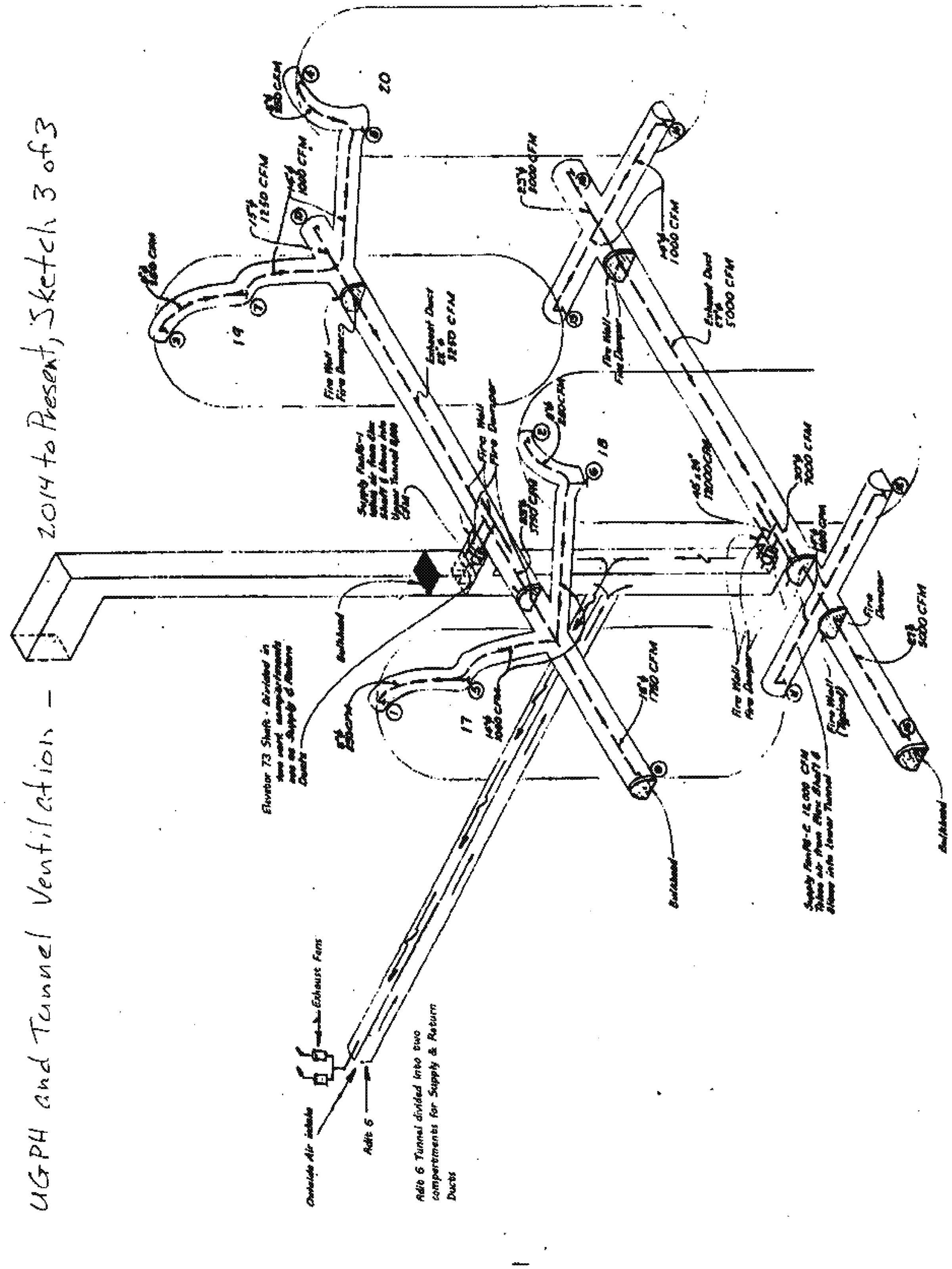
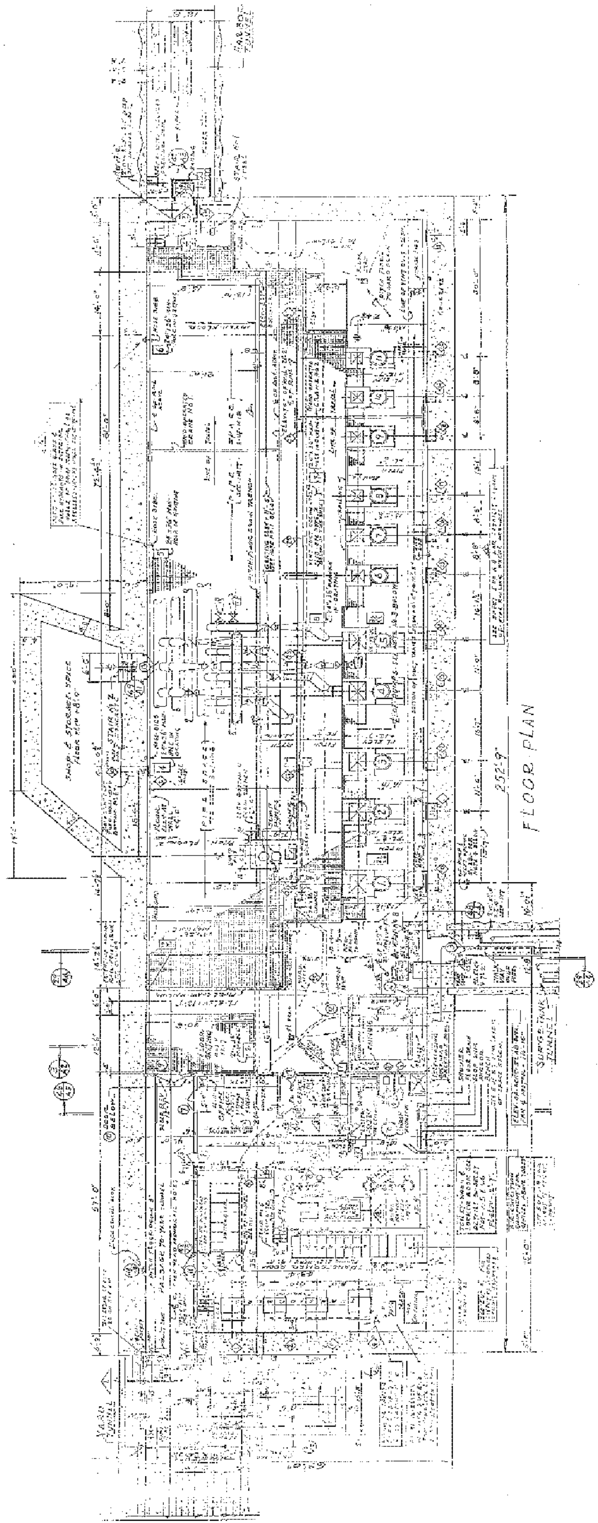
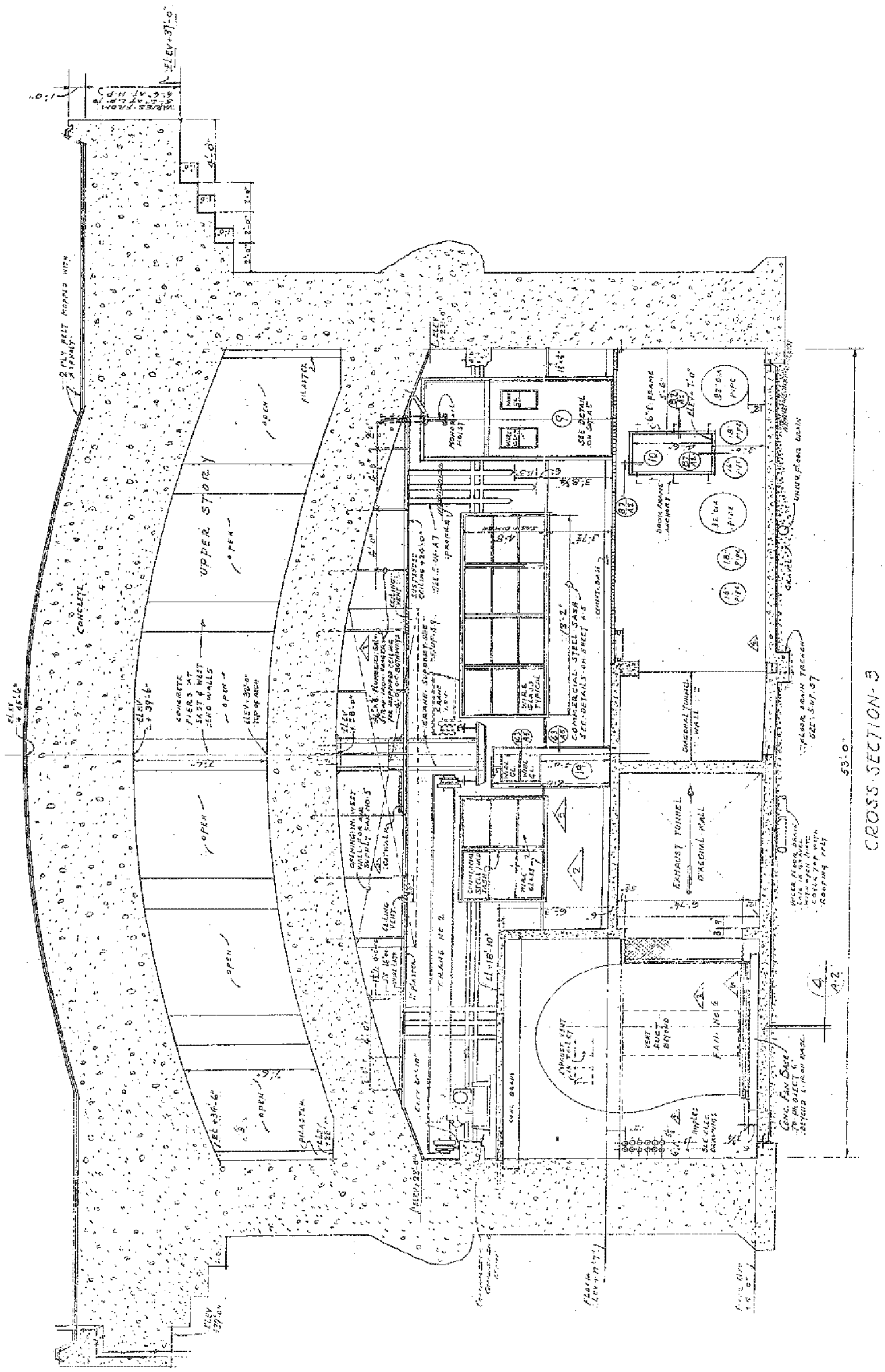
Underground Pumphouse and Tunnel Ventilation System, 2014 to present – Sketch 3 of 3.
(James A. Gammon)



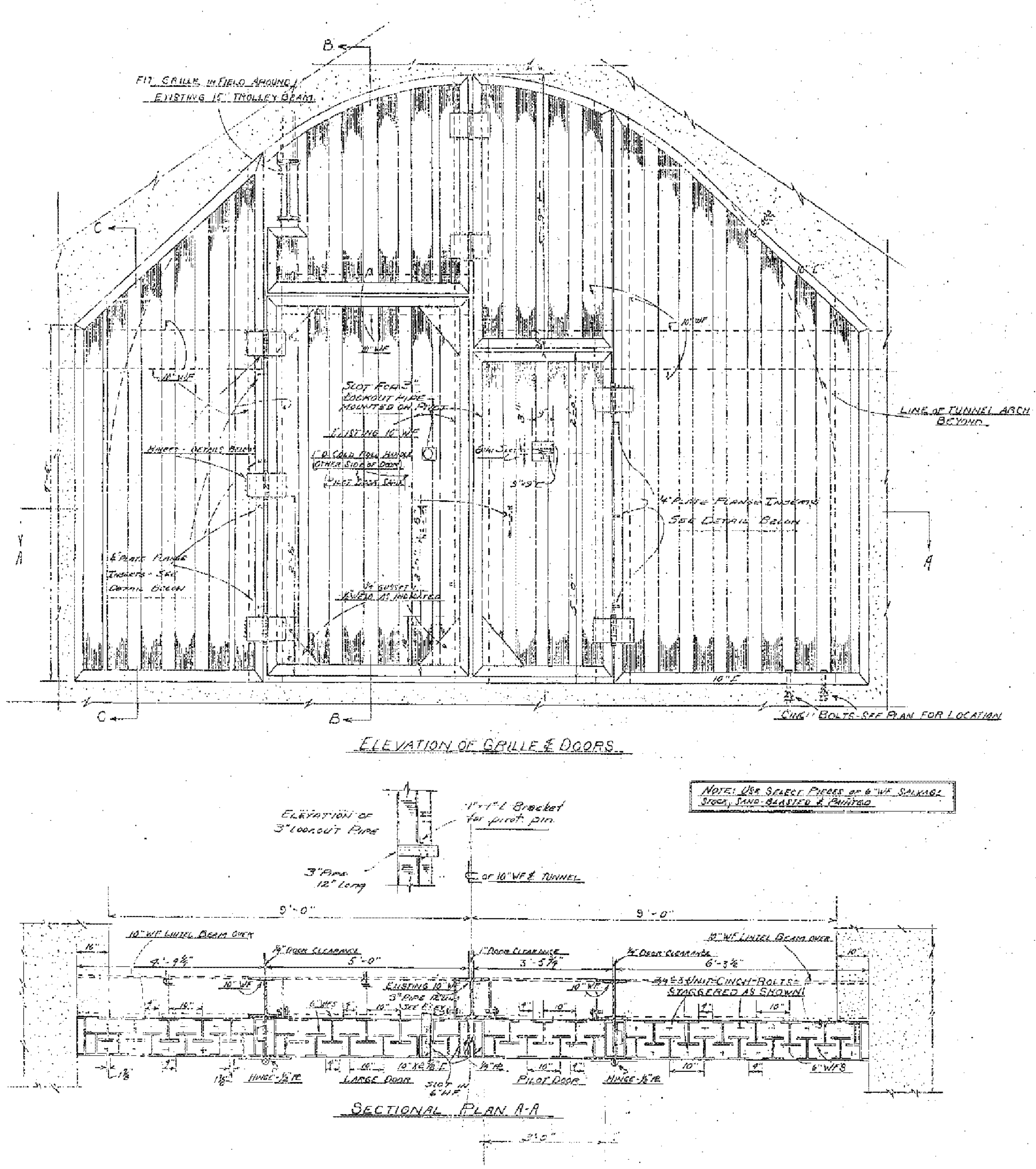
Portion of original drawing dated May 9, 1941 showing main rectangular portion of Pumphouse (Facility No. 59). (Drawing # 294037, NFP Plan Files)



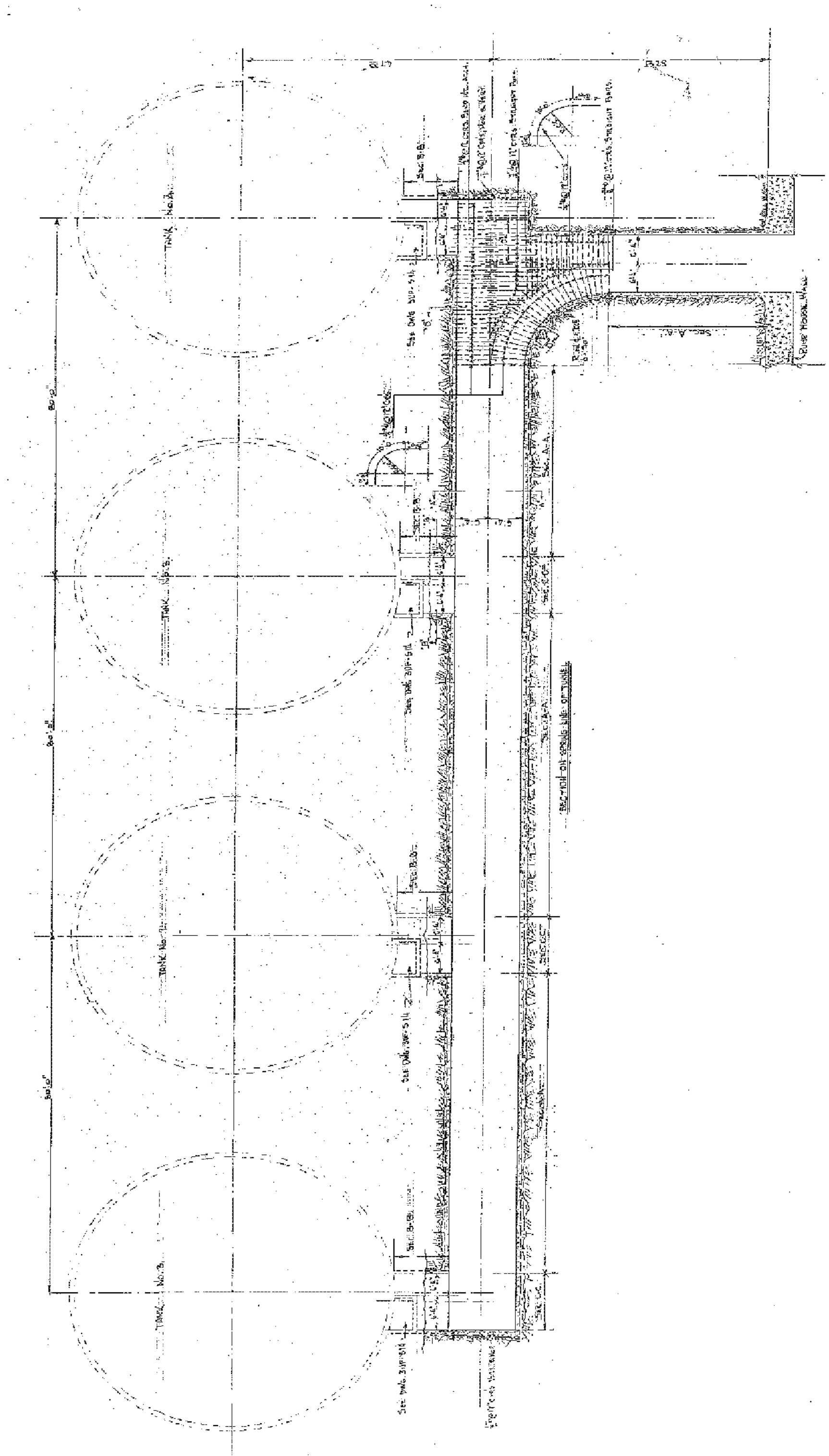
Portion of original drawing dated April 29, 1941 showing cross section of Pumphouse (Facility No. 59). Note two layers of bombproof roof. (Drawing # 294038, NFP Plan Files)



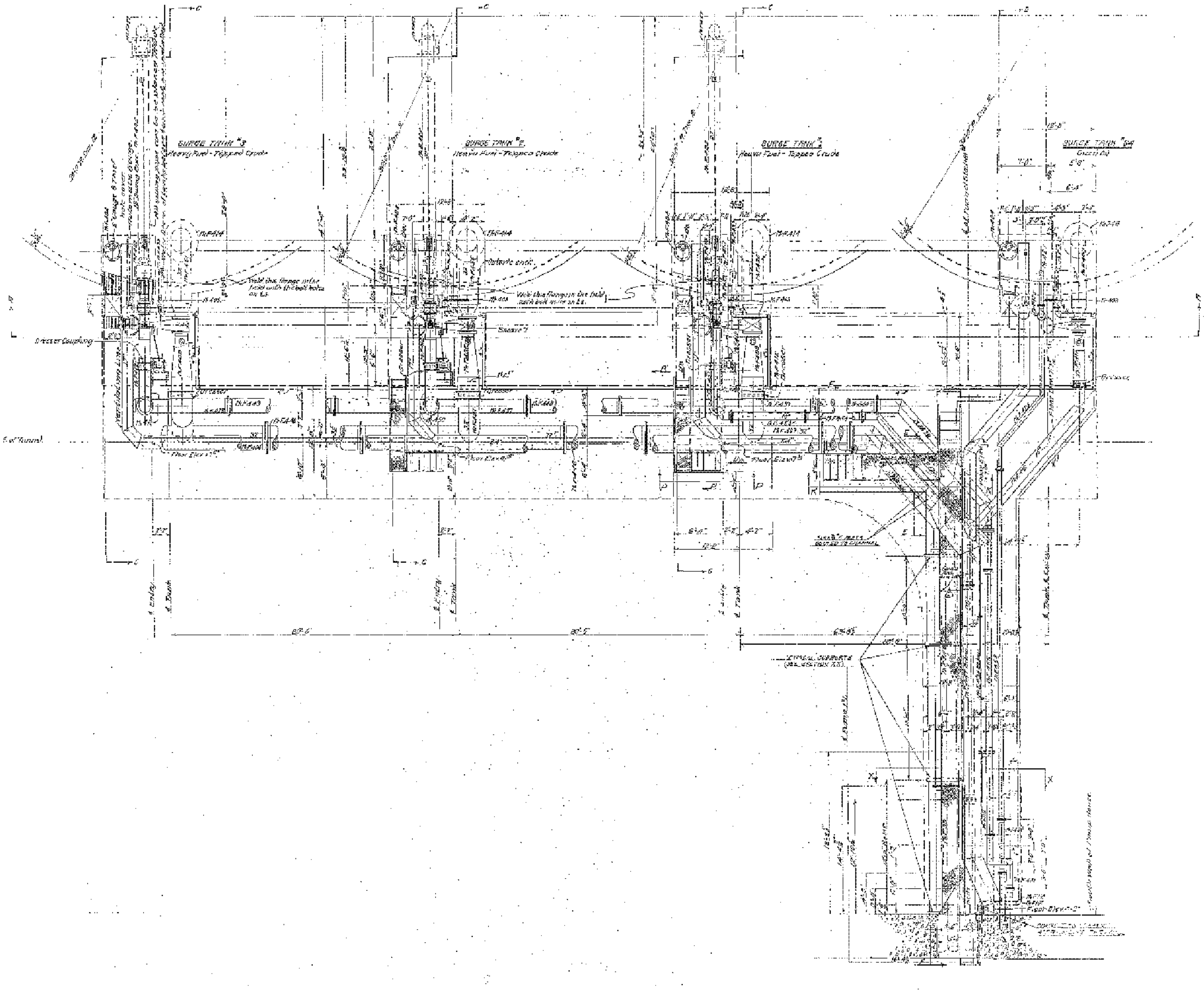
Portion of original drawing dated May 26, 1943 showing the grille door in entrance tunnel portion of Pumphouse (Facility No. 59). (Drawing # 294067, NFP Plan Files)



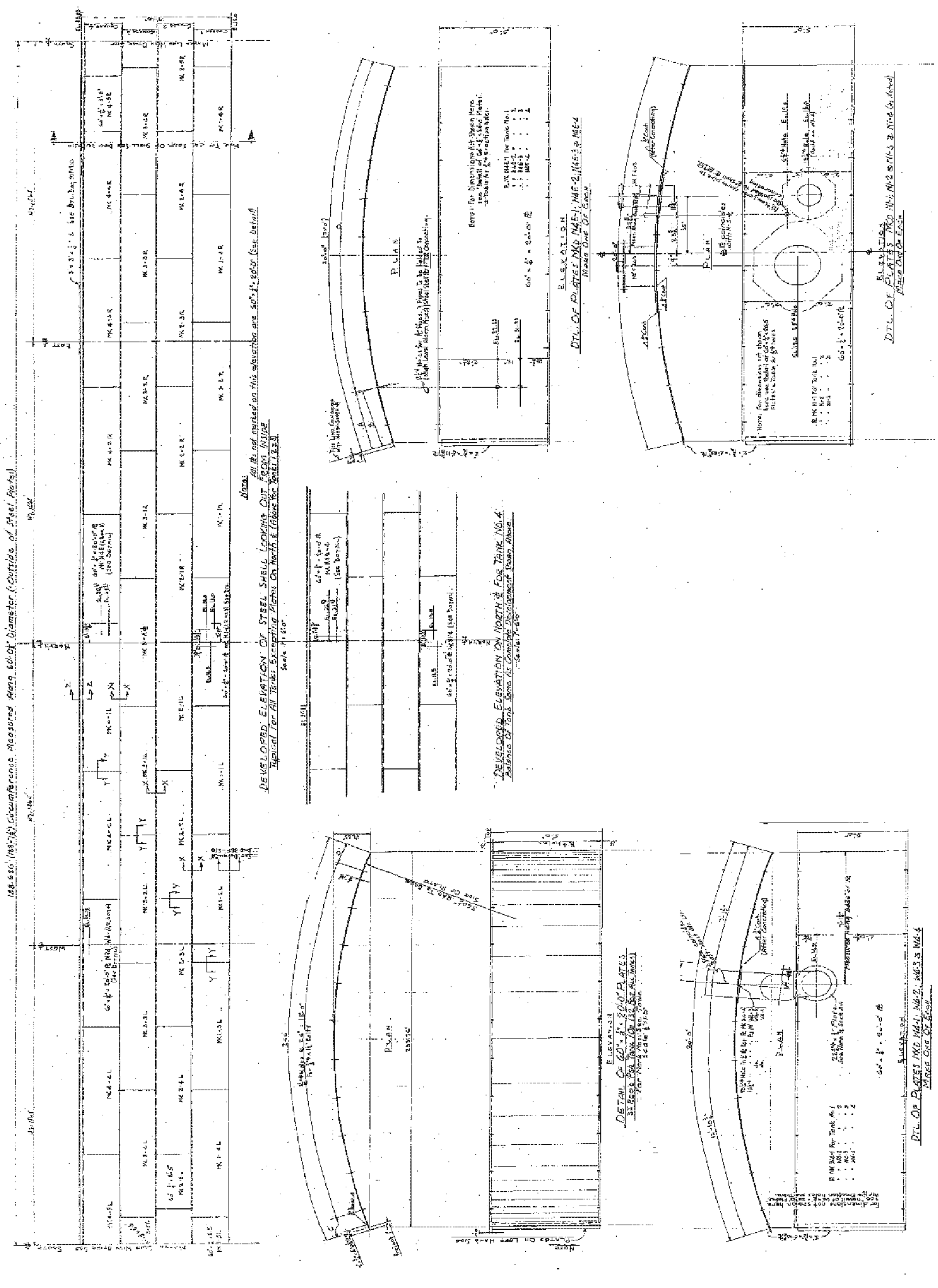
Portion of original drawing dated November 27, 1941 showing plan of Surge Tank Tunnel portion of Pumphouse (Facility No. 59). (Drawing # 294138, NFP Plan Files)



Portion of original drawing dated August 8, 1941 showing piping of the Surge Tanks (Facility Nos. 1224 to 1227). (Drawing # 294141, NFP Plan Files)



Portion of original drawing dated November 13, 1941 showing steel construction of the Surge Tanks (Facility Nos. 1224 to 1227). (Drawing # 294128, NFP Plan Files)



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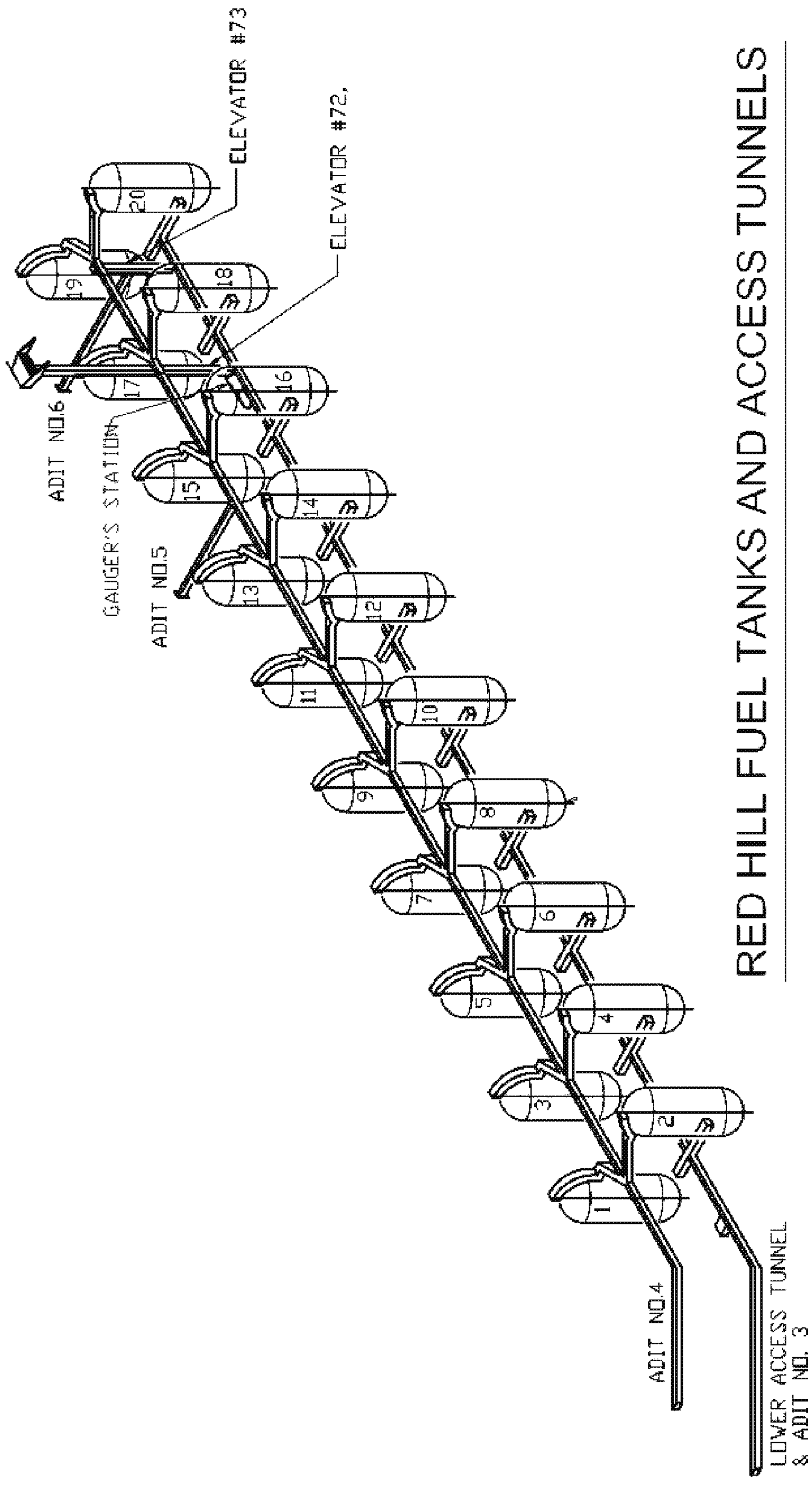
Portion of drawing dated December 30, 1960 showing the layout and orientation of the underground fuel tanks (Facility Nos. 328 to 347). (Drawing # 7923202, NFP CI Line)



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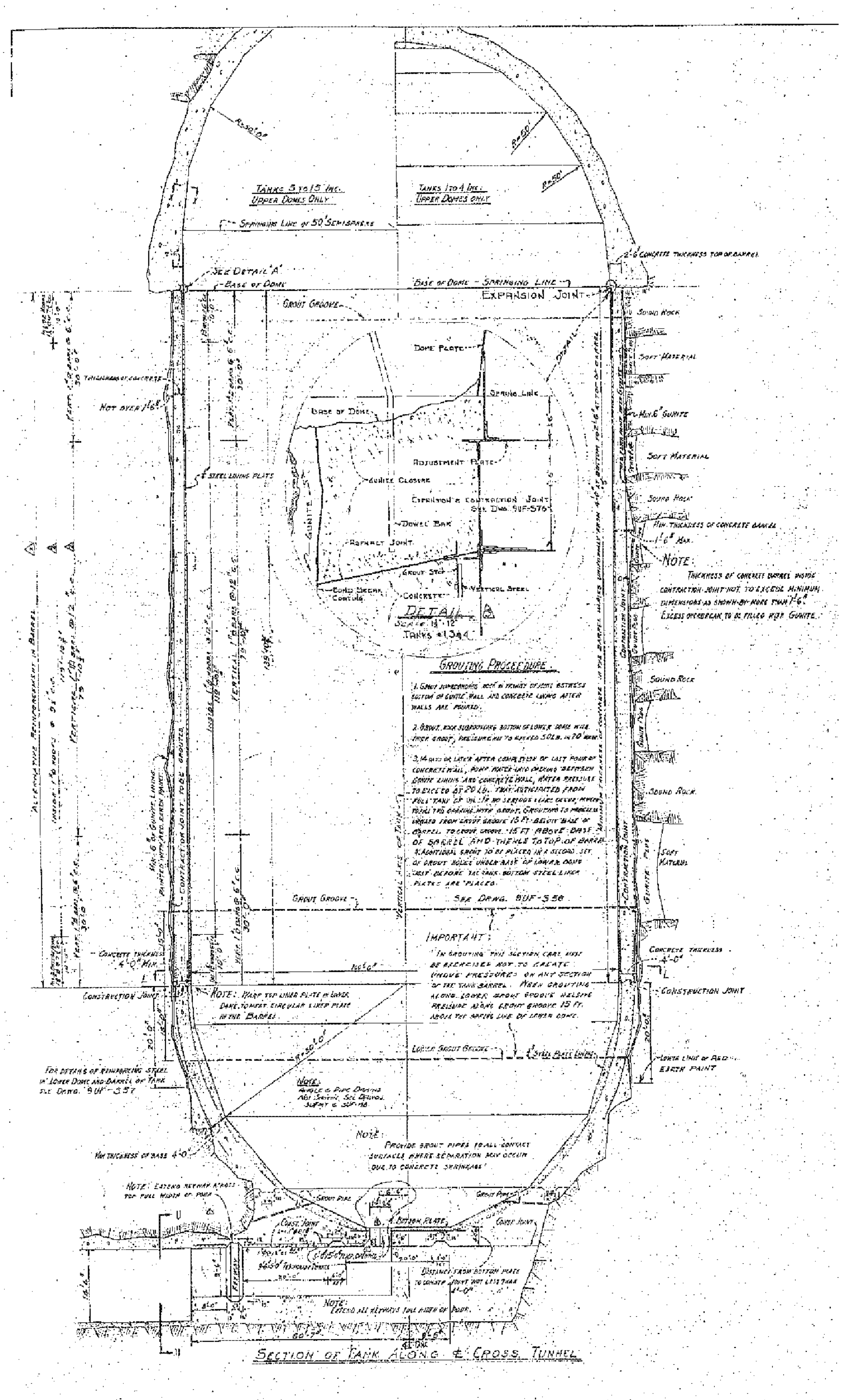
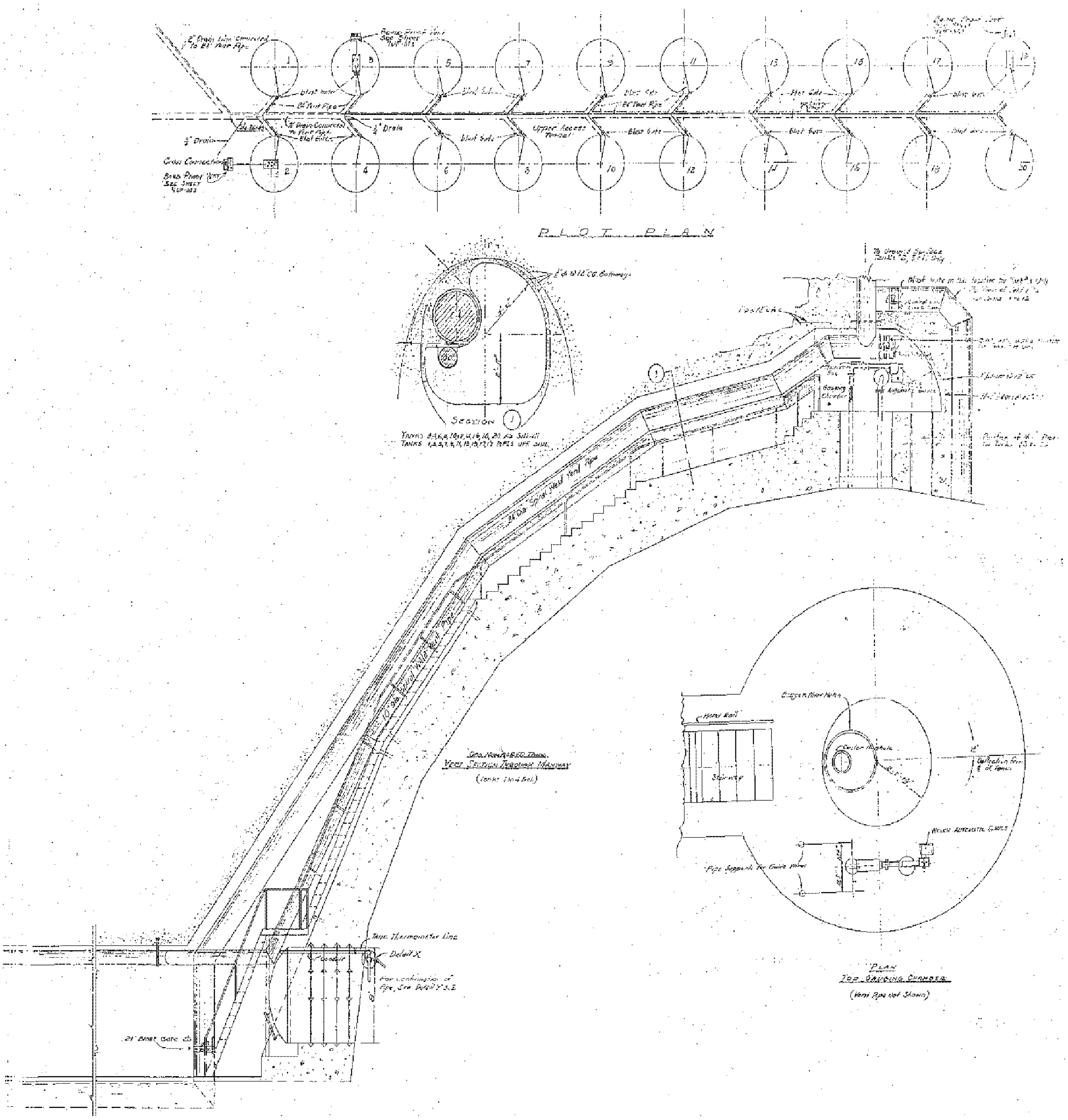
Portion of original drawing dated December 30, 1941 showing the general design and construction of typical underground fuel tank. (Drawing # 294305, NFP Plan Files)



Portion of original drawing dated September 21, 1943 showing typical access gallery and gauging chamber above fuel tanks. (Drawing # 294318, NFP Plan Files)



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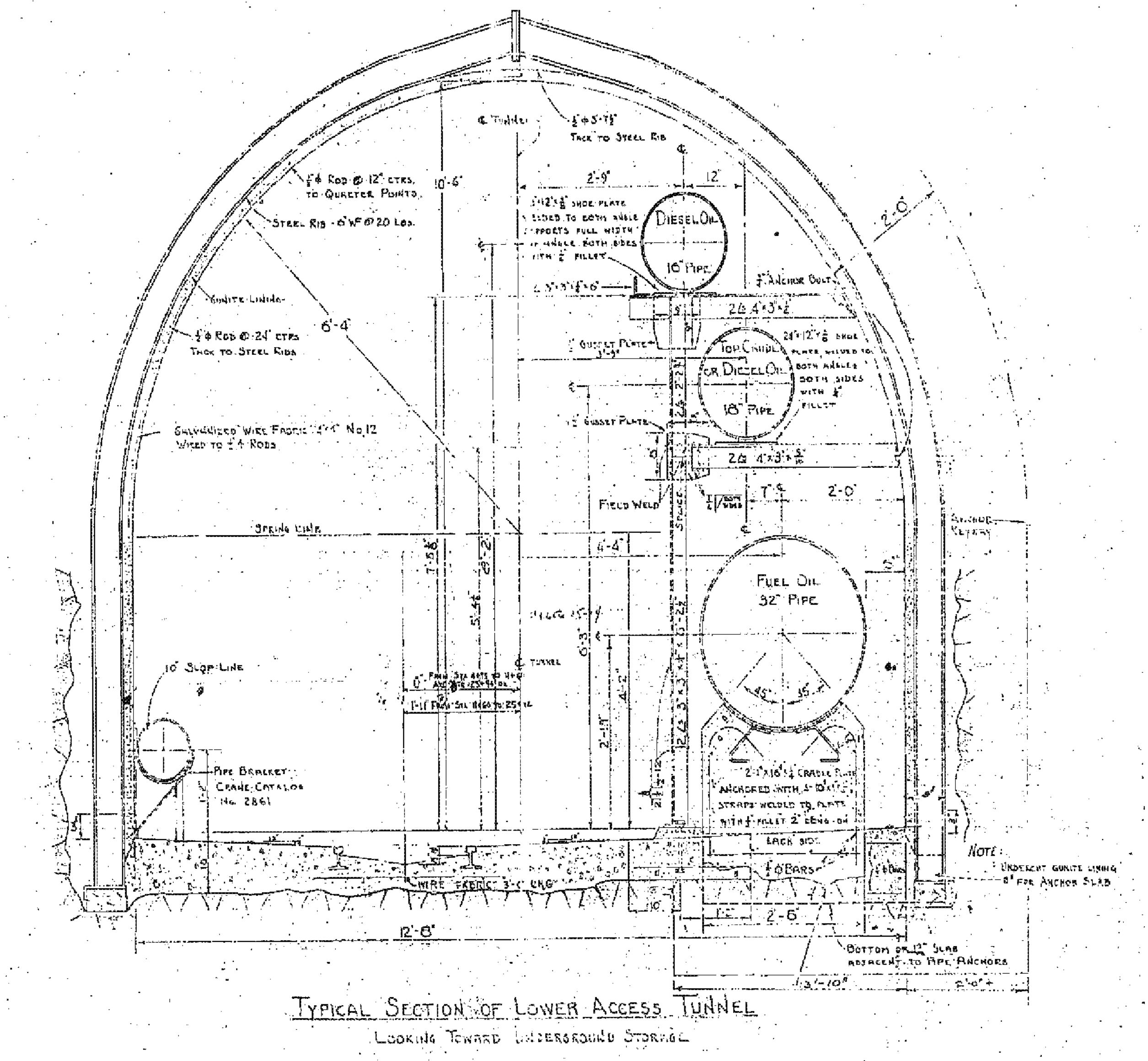
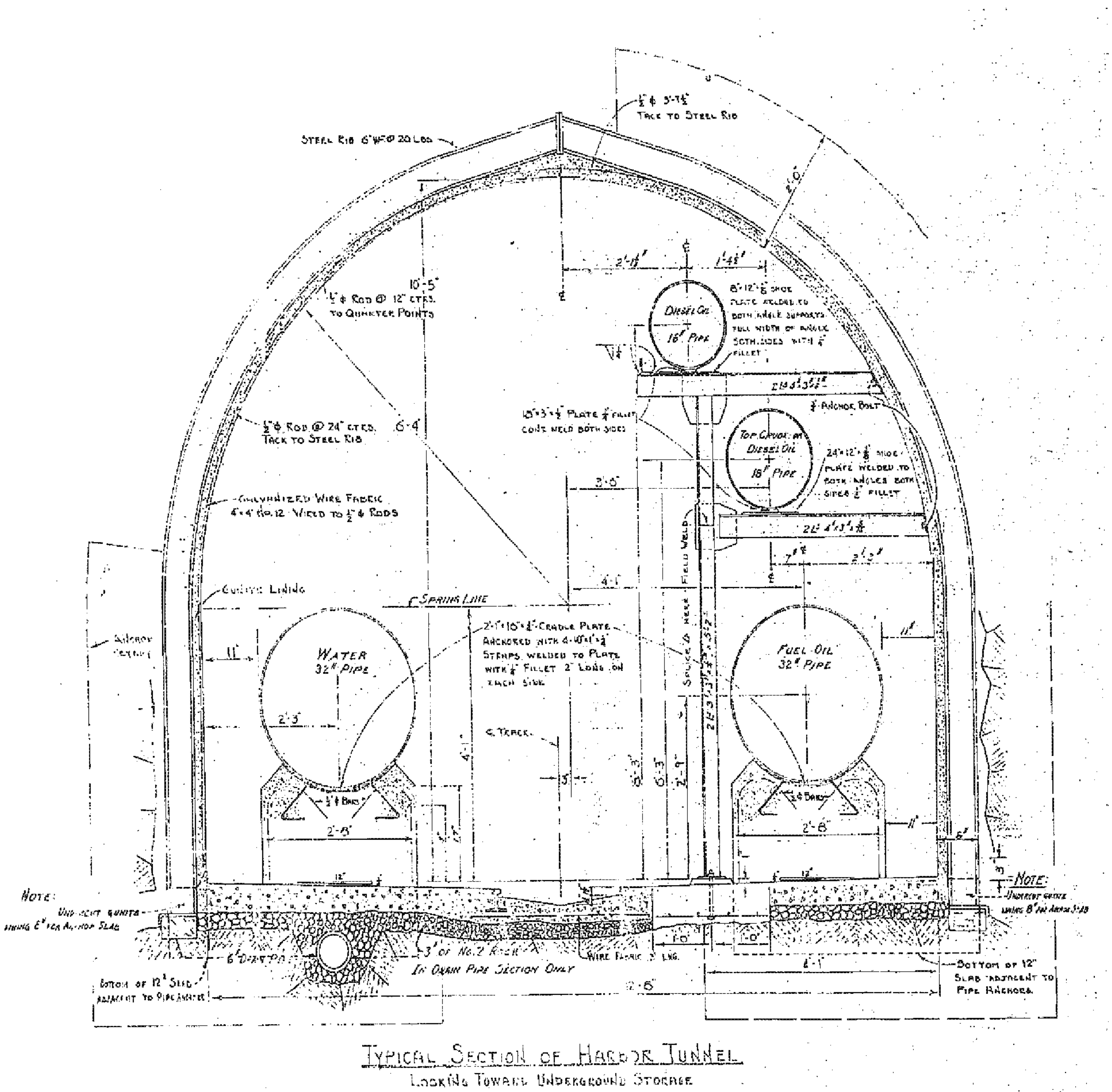
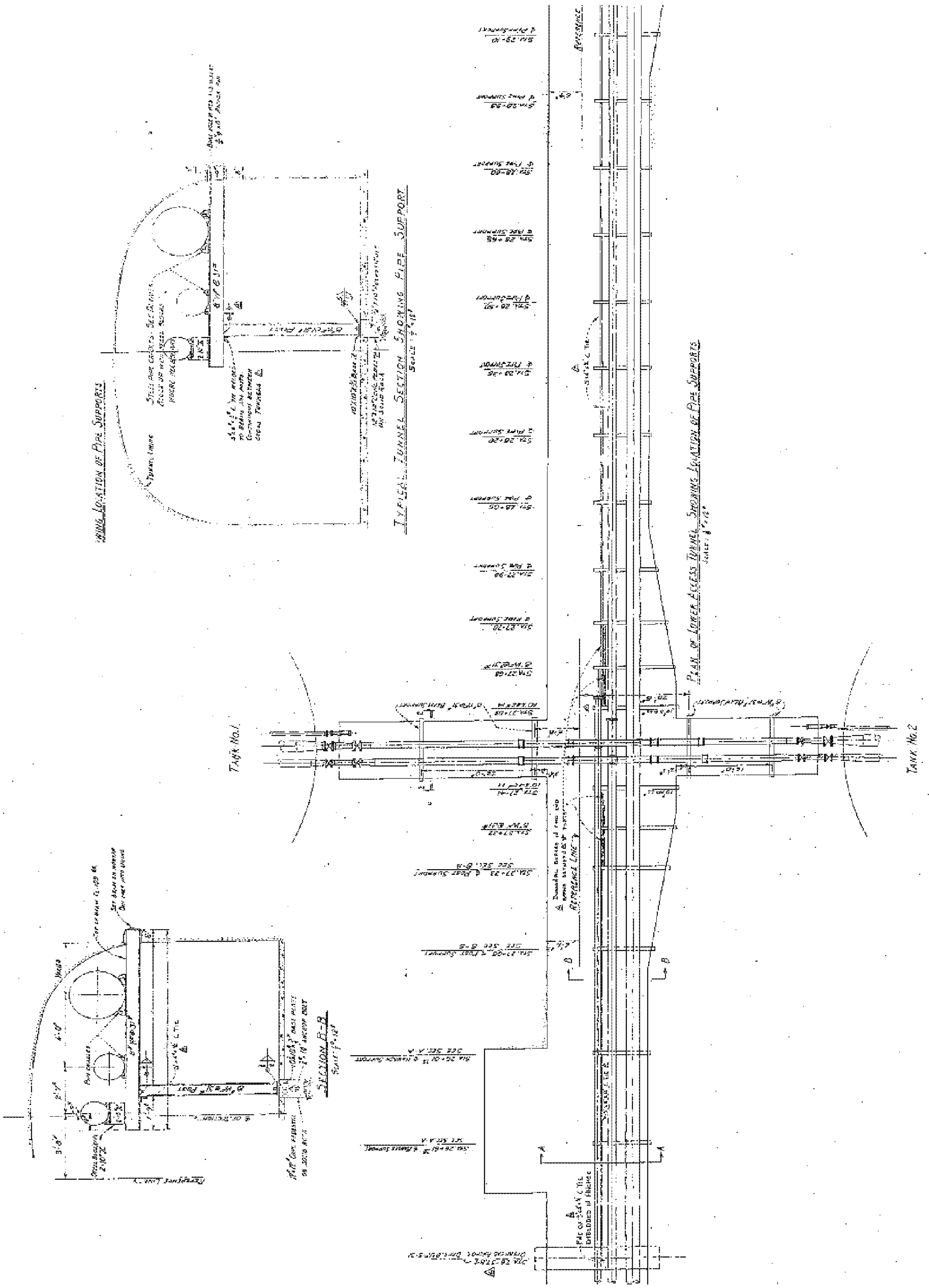
Portion of original drawing dated May 25, 1942 showing typical pipe support and pier in LAT section of Lower Tunnel (Facility No. S-21). (Drawing # 294161, NFP Plan Files).



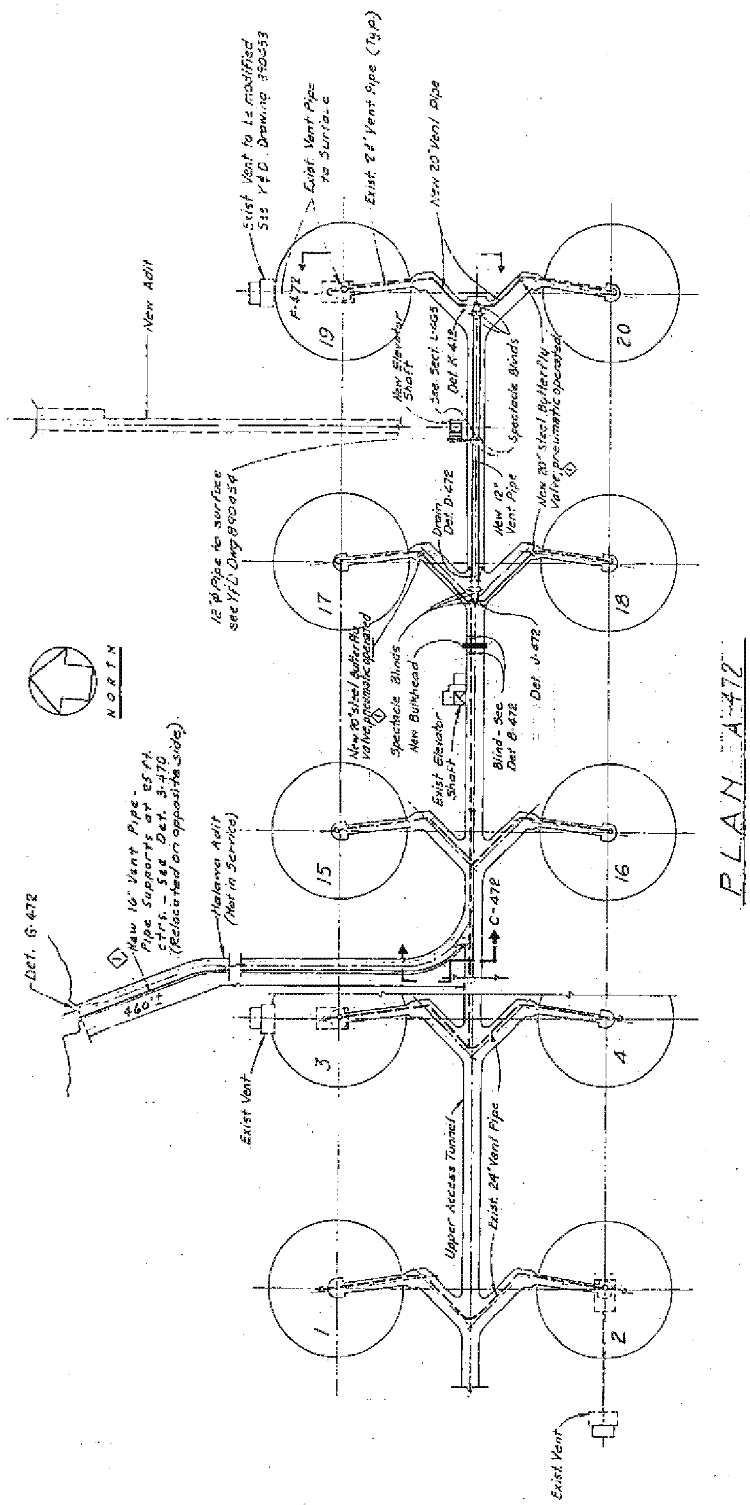
Portion of original drawing dated May 25, 1942 showing typical pipe support and piers in HT section of Lower Tunnel (Facility No. S-21). (Drawing # 294161, NFP Plan Files)



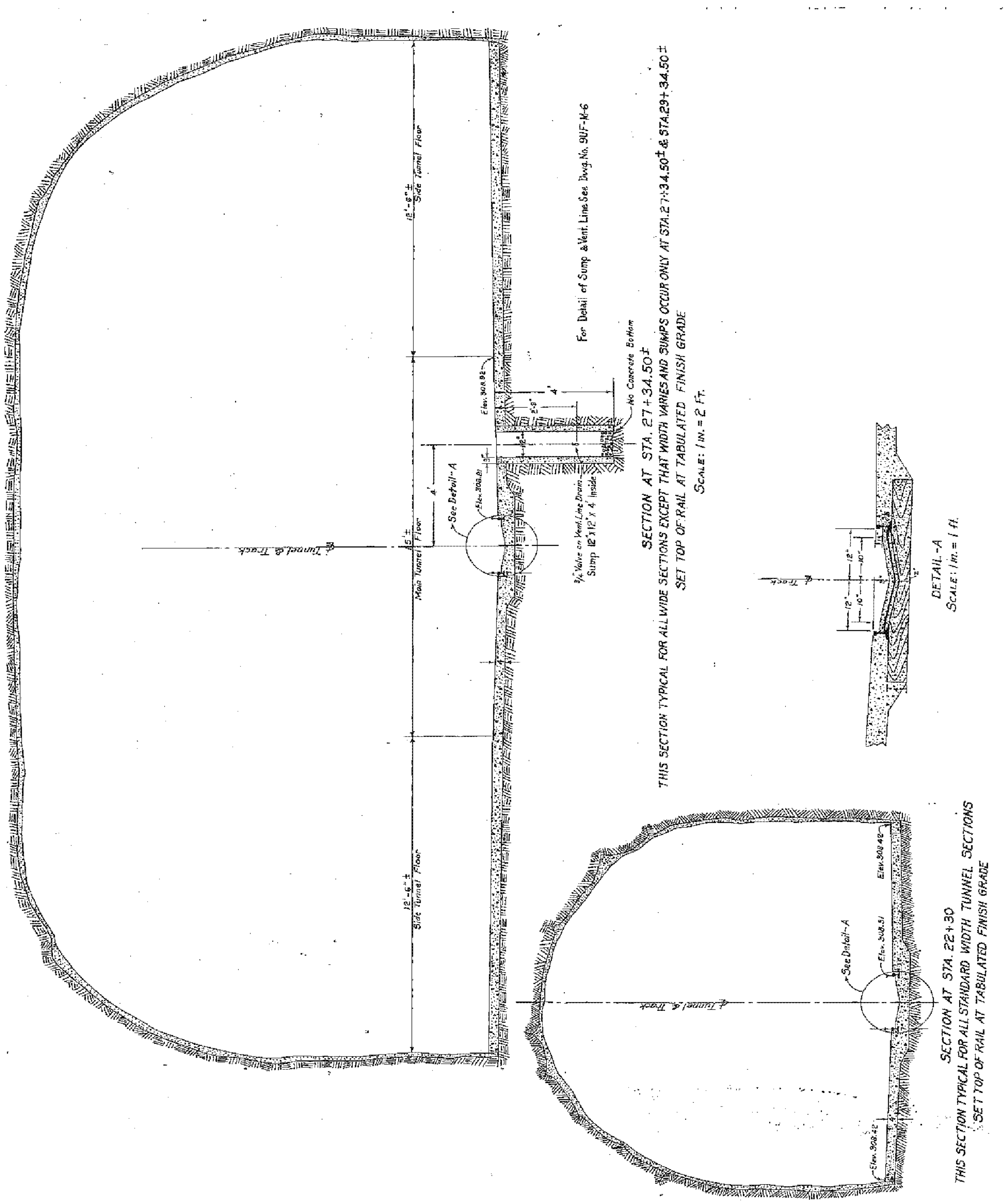
Portion of original drawing dated 1941 showing typical wider area in the eastern part of LAT section of Lower Tunnel (Facility No. S-21). (Drawing # 294160, NFP Plan Files)



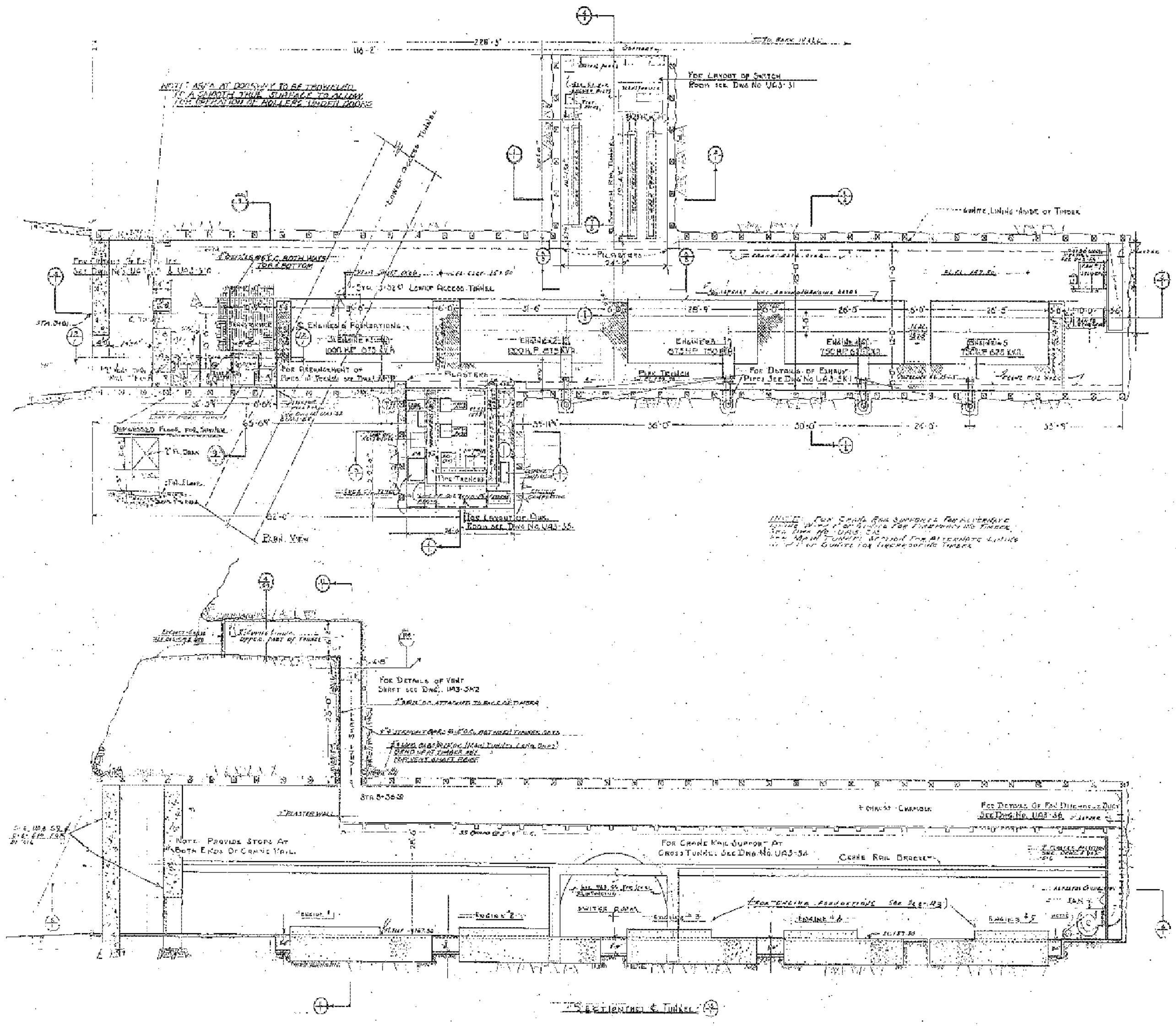
Portion of original drawing dated April 12, 1960 showing a plan view of Upper Access Tunnel, with cross tunnels and access galleries to the gauging chambers atop the tanks. Note that this also shows the tunnels at Adits 5 & 6. (Drawing # 890472, NFP Plan Files)



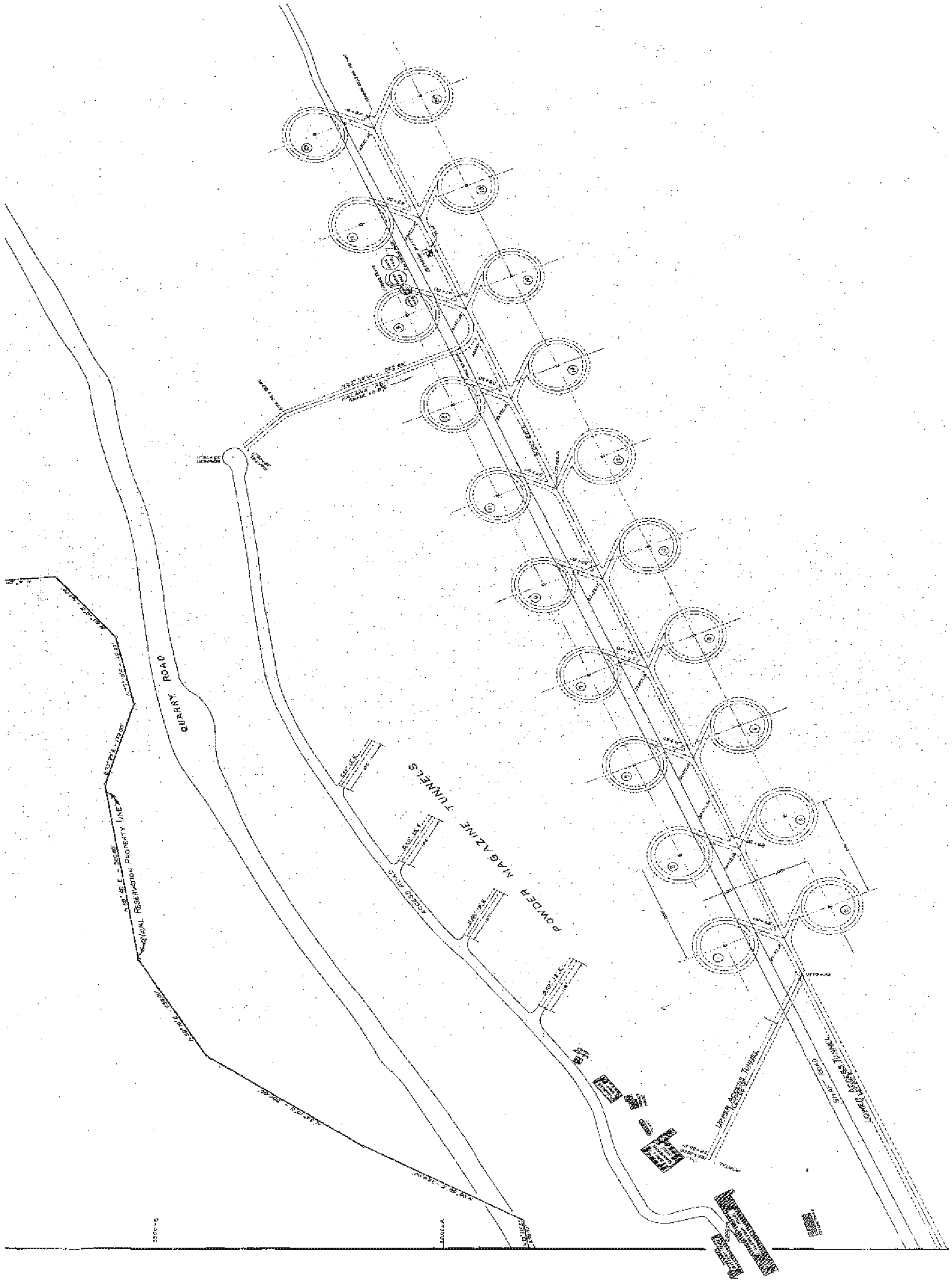
Portion of original drawing dated March 22, 1942 showing typical cross sections of the Upper Tunnel. (Drawing # 294183, NFP Plan Files)



Portion of original drawing dated May 28, 1942 showing plan and cross section of Facility No. S-308. (Drawing # 294406, NFP Plan Files)

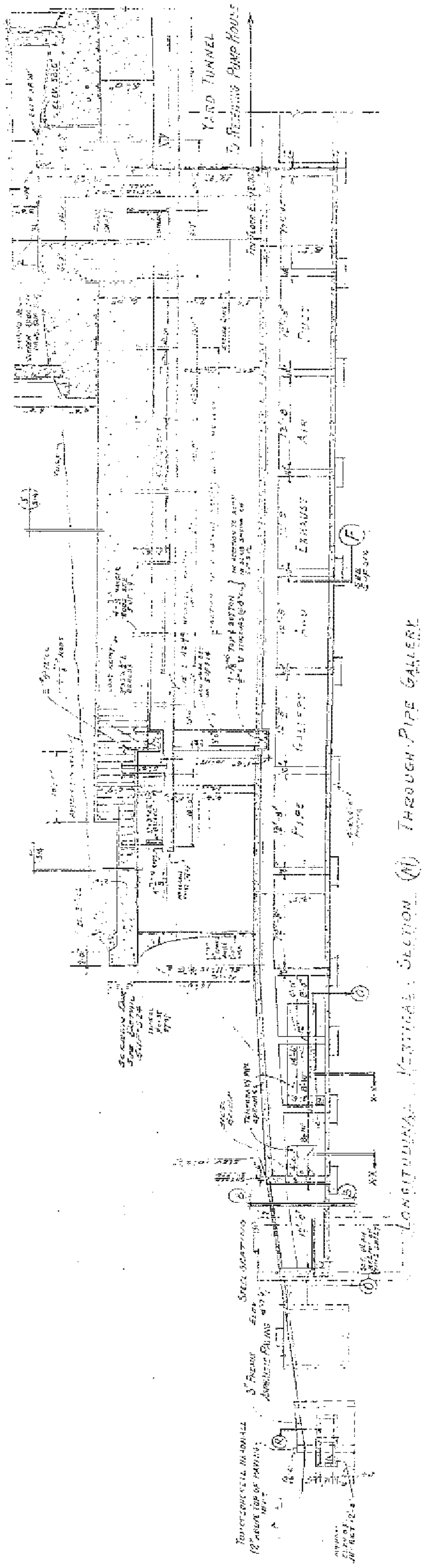


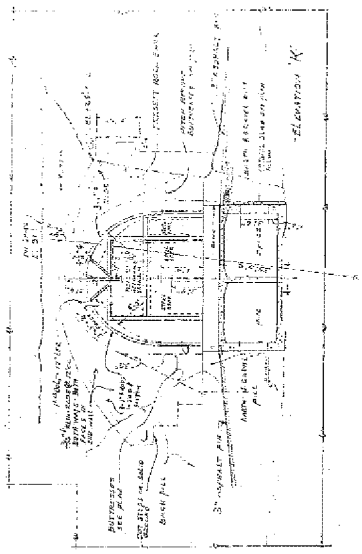
Portion of original drawing dated October 12, 1942 showing Powder Magazines (Facility Nos. 350 to 353) between Adits to Upper Access Tunnel. (Drawing # 293890, NFP Plan Files)

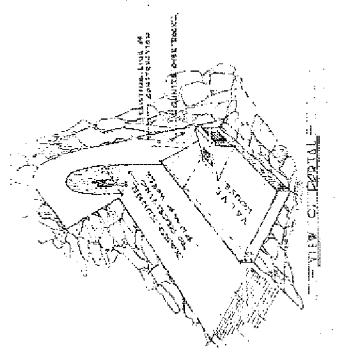


Note that the present Access Road has a different alignment.

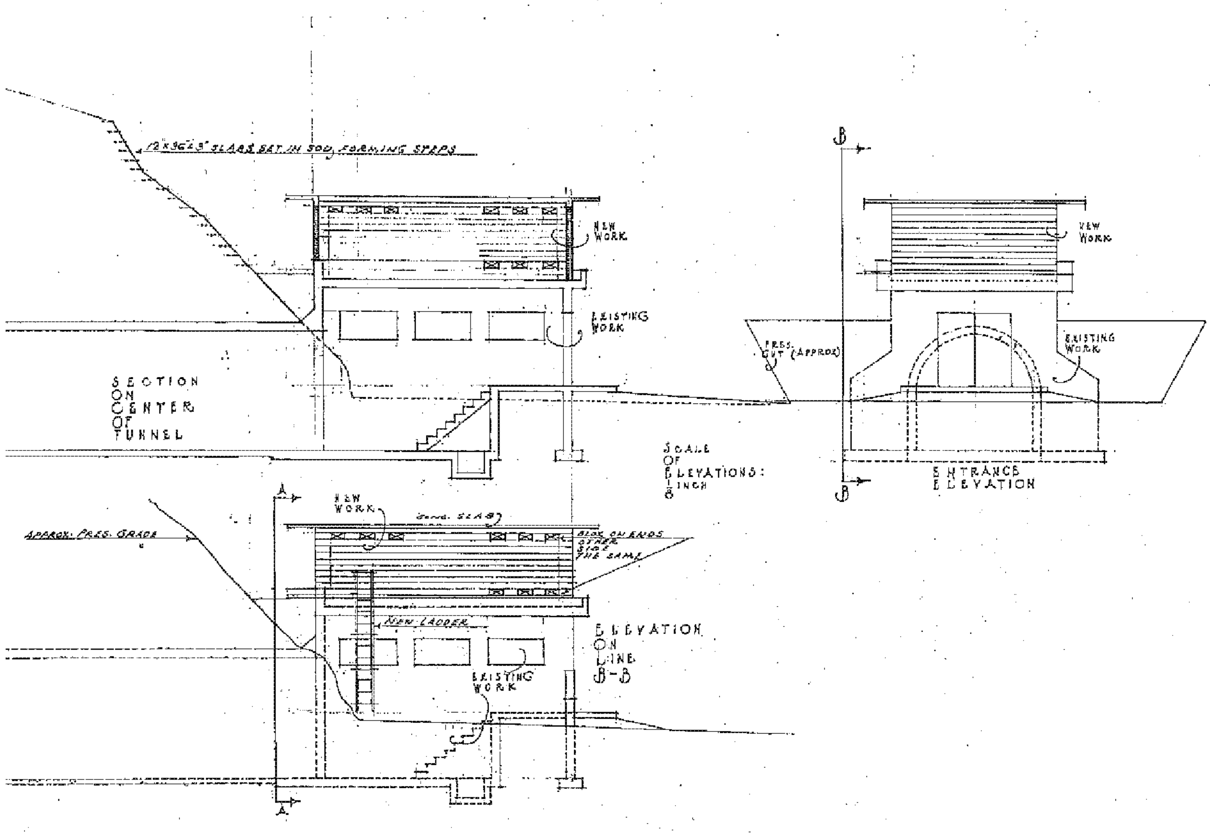
Portion of drawings dated December 6, 1941 and July 28, 1942 showing cross sections of Entrance Tunnel and Pipe Gallery (portions of Facility No. 59) and perspective of Adit 1.
(Drawing #s 294056 & 294062, NFP Plan Files)



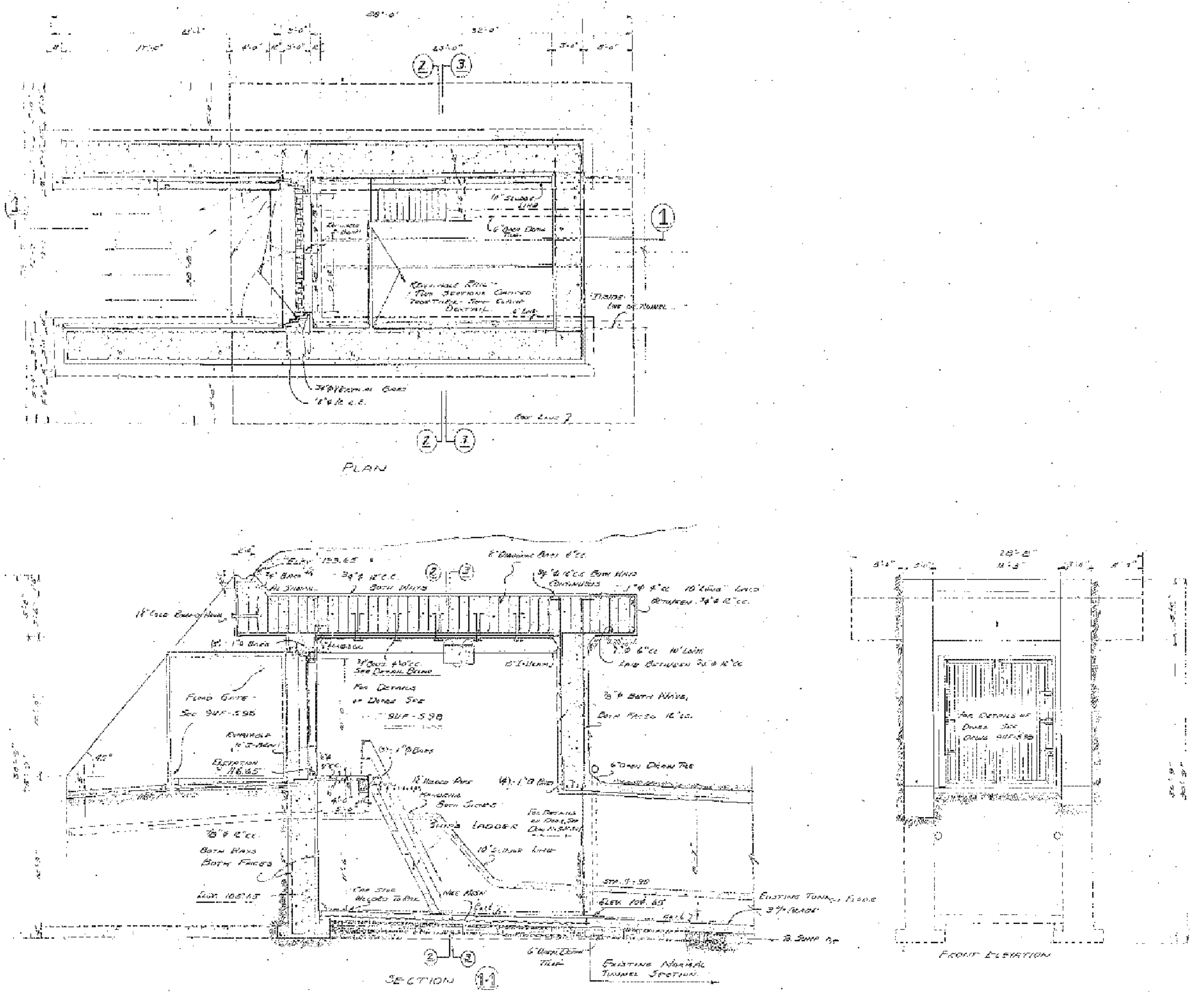




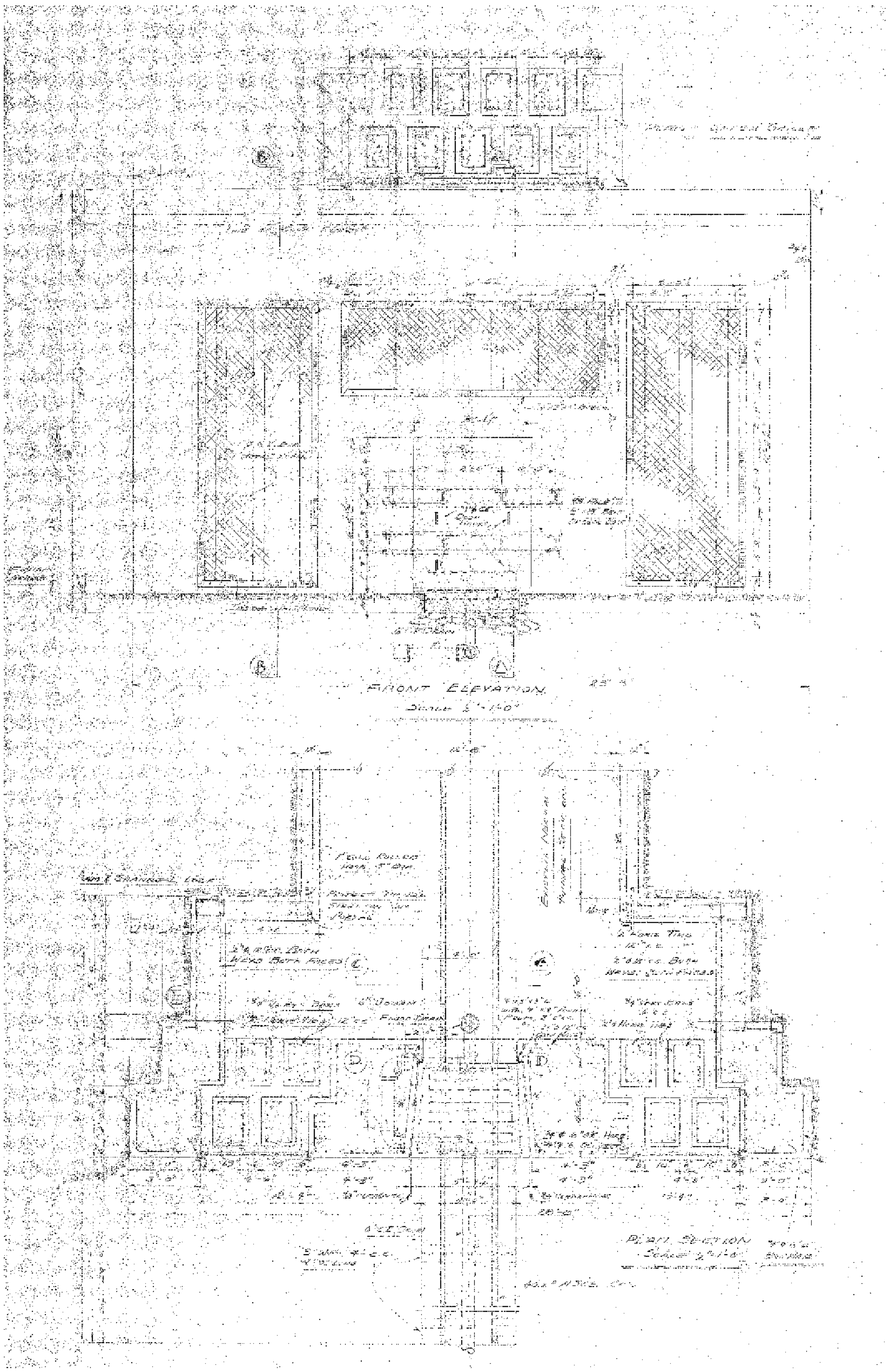
Portion of drawing dated April 8, 1944 showing addition atop Adit 2 (Facility No. S-275).
(Drawing # OA-N3-552 NFP Plan Files)



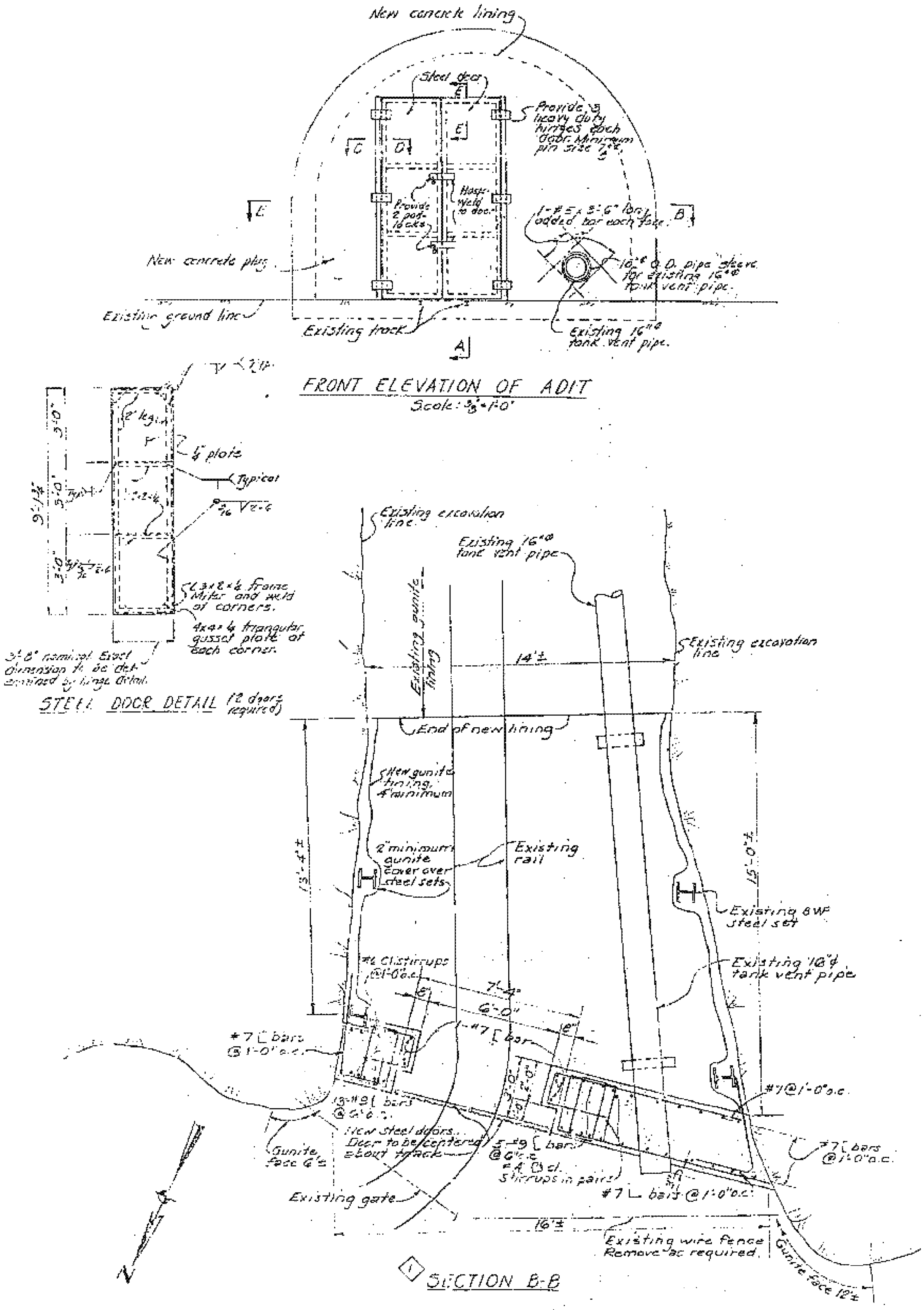
Portion of original drawing dated May 12, 1943 showing plan, elevation, and cross section of Adit 3 (Facility No. S-312). (Drawing # 294186, NFP Plan Files)



Portion of original drawing dated September 21, 1943 showing elevation, and sections of Adit 4 (Facility No. S-314). (Drawing # 294185, Fuel Department, PH FLC Plan Files)



Portion of original drawing dated March 17, 1961 showing plan, elevation, and detail of Adit 5. (Drawing # 956655, NFP Plan Files)



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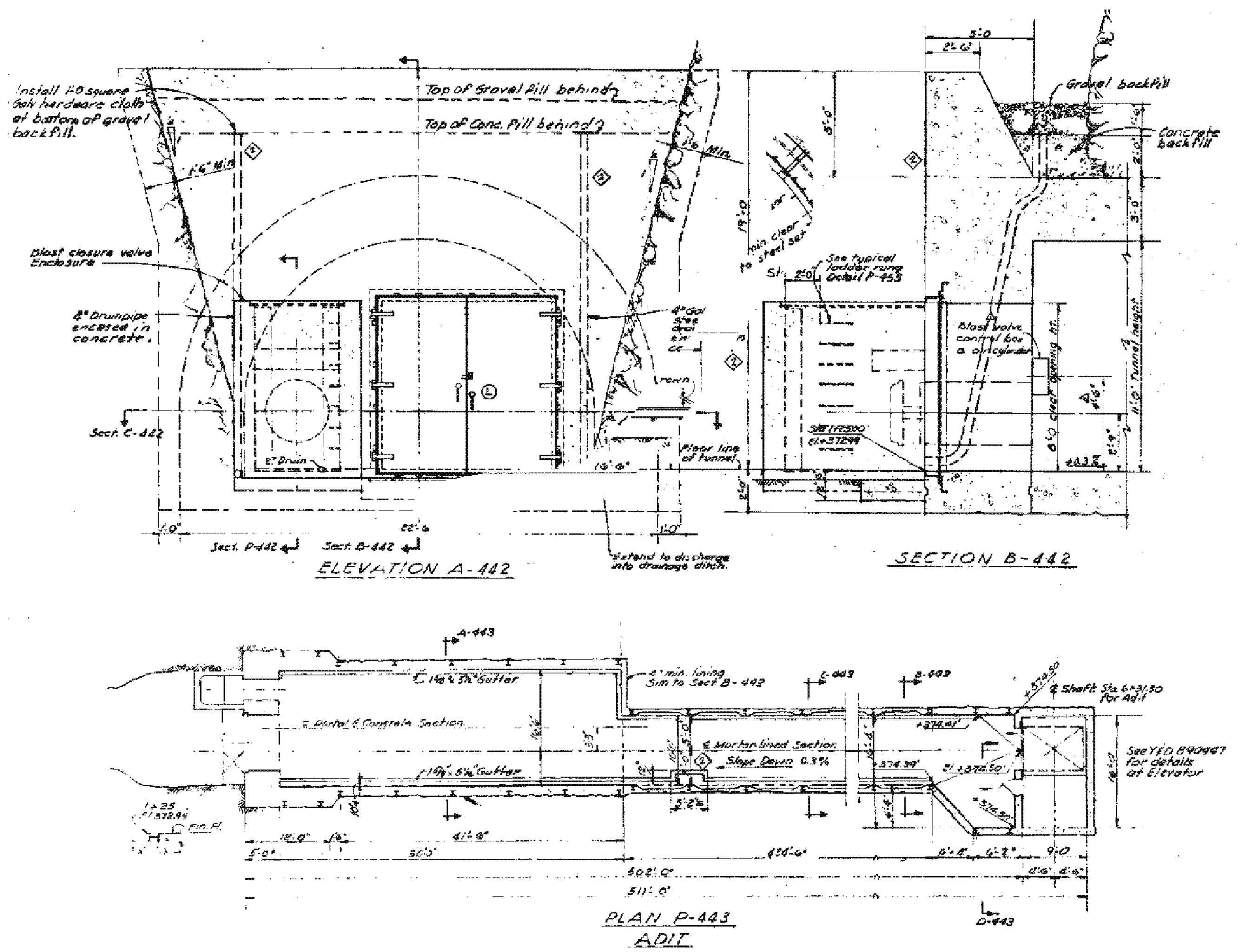
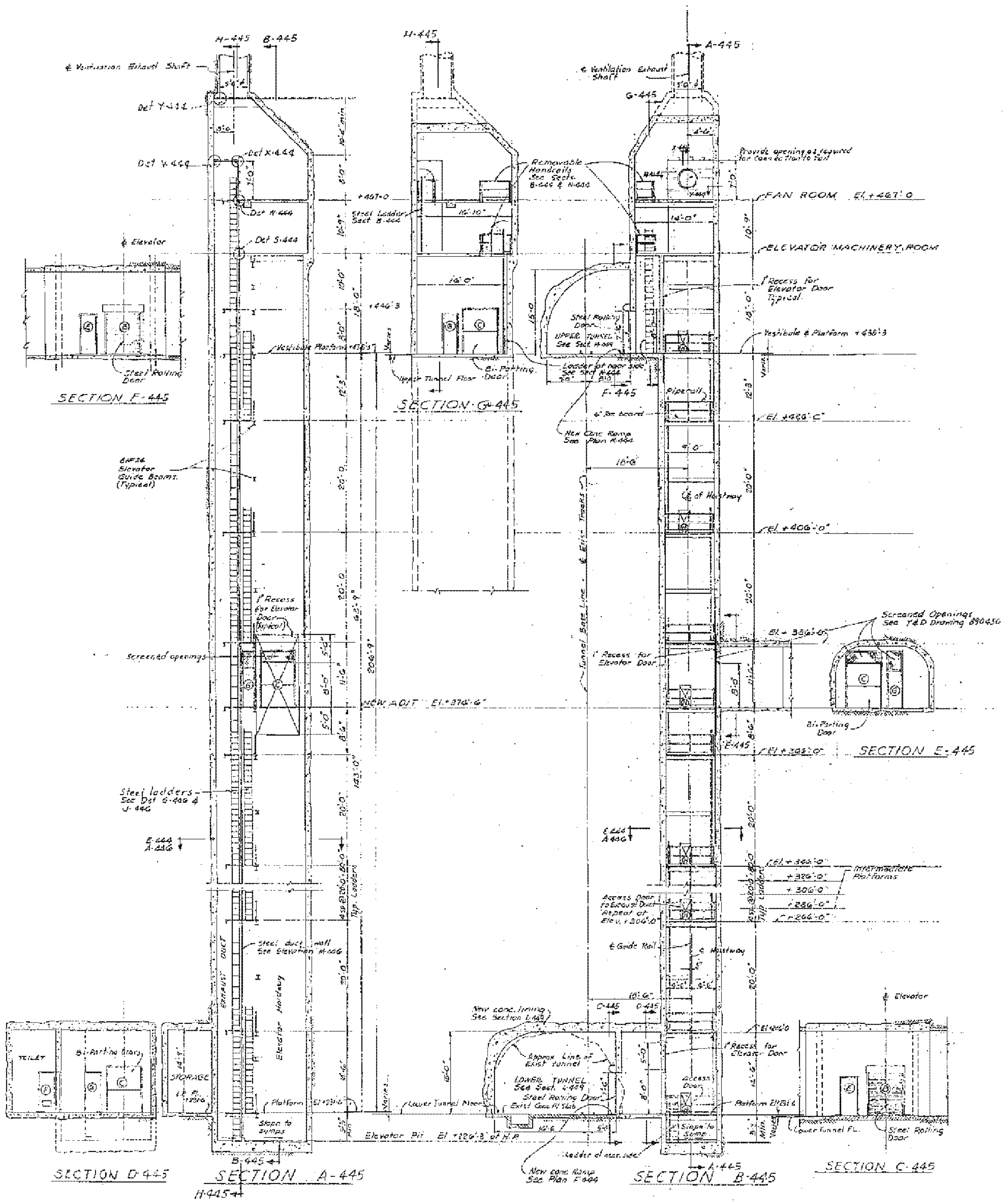
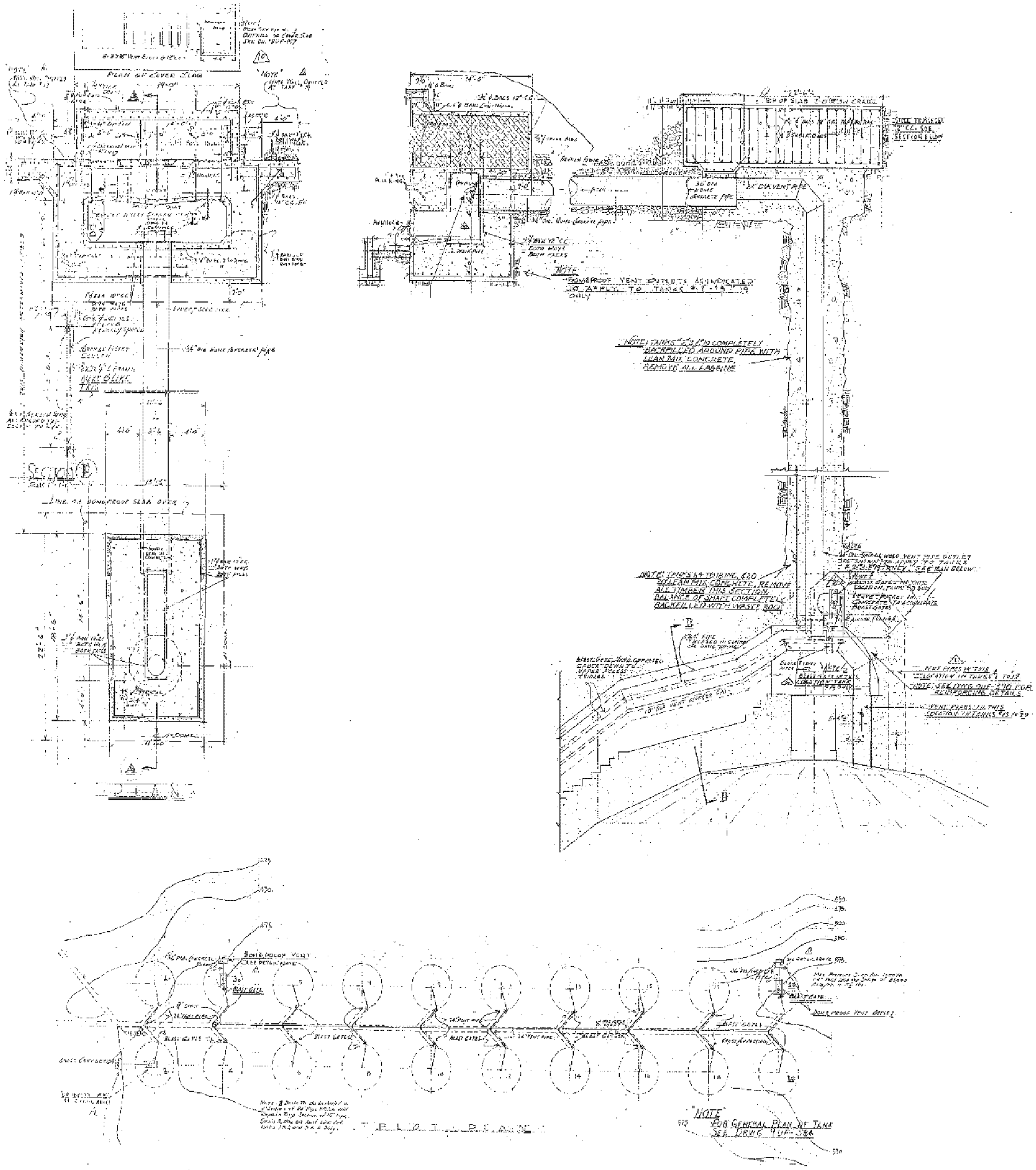
Portion of original drawings dated April 8, 1960 showing plan, elevation, and cross section of Adit 6. (Drawings #s 890442 & 890443, NFP Plan Files)



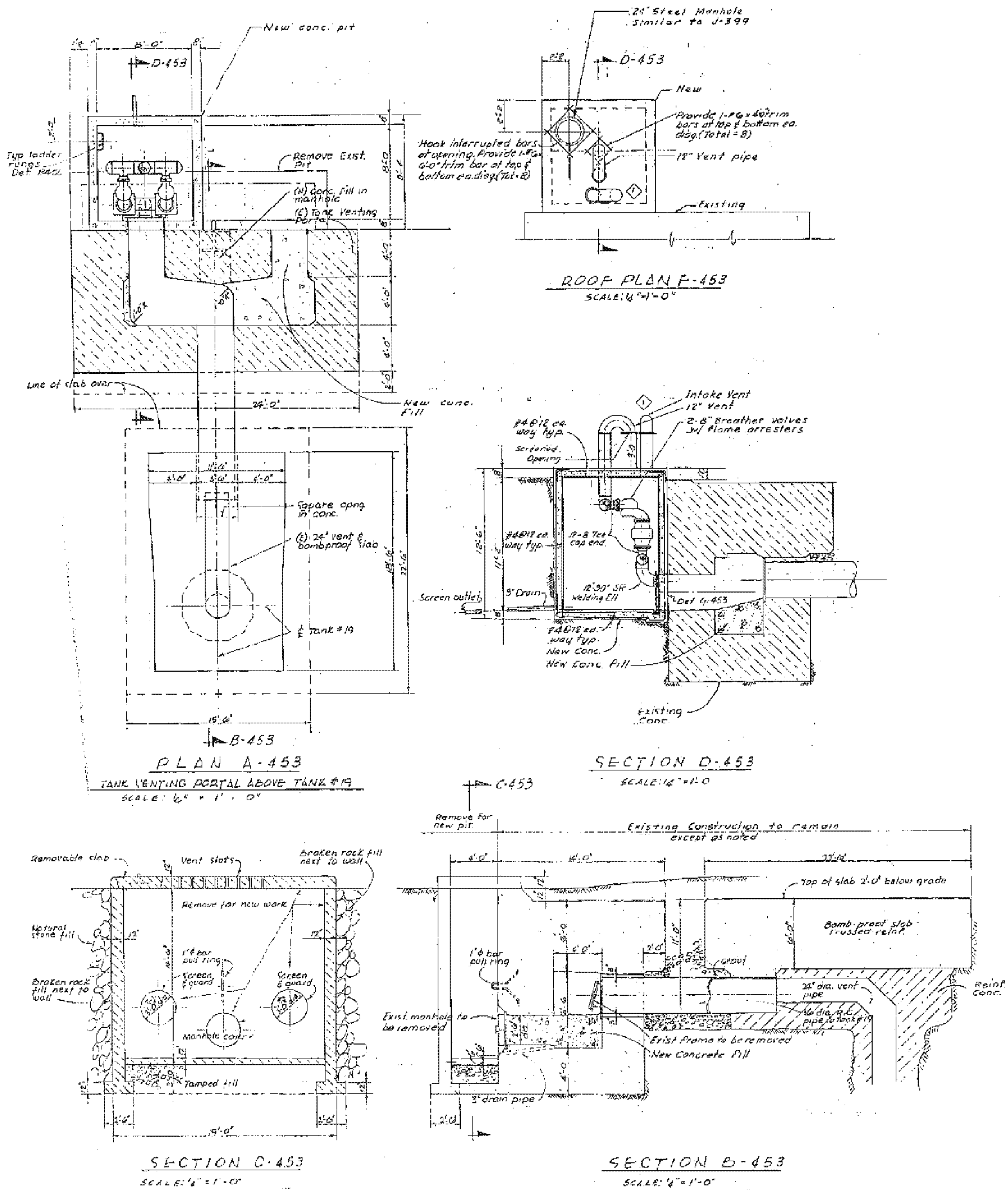
Portion of original drawing dated April 12, 1960 showing the shaft for Elevator #73 and its connections to UAT, LAT, and Adit 6 tunnel. Note that ventilation shaft above fan room extends to Vent Structure Atop Utility Shaft #73. (Drawing # 890445, NFP Plan Files)



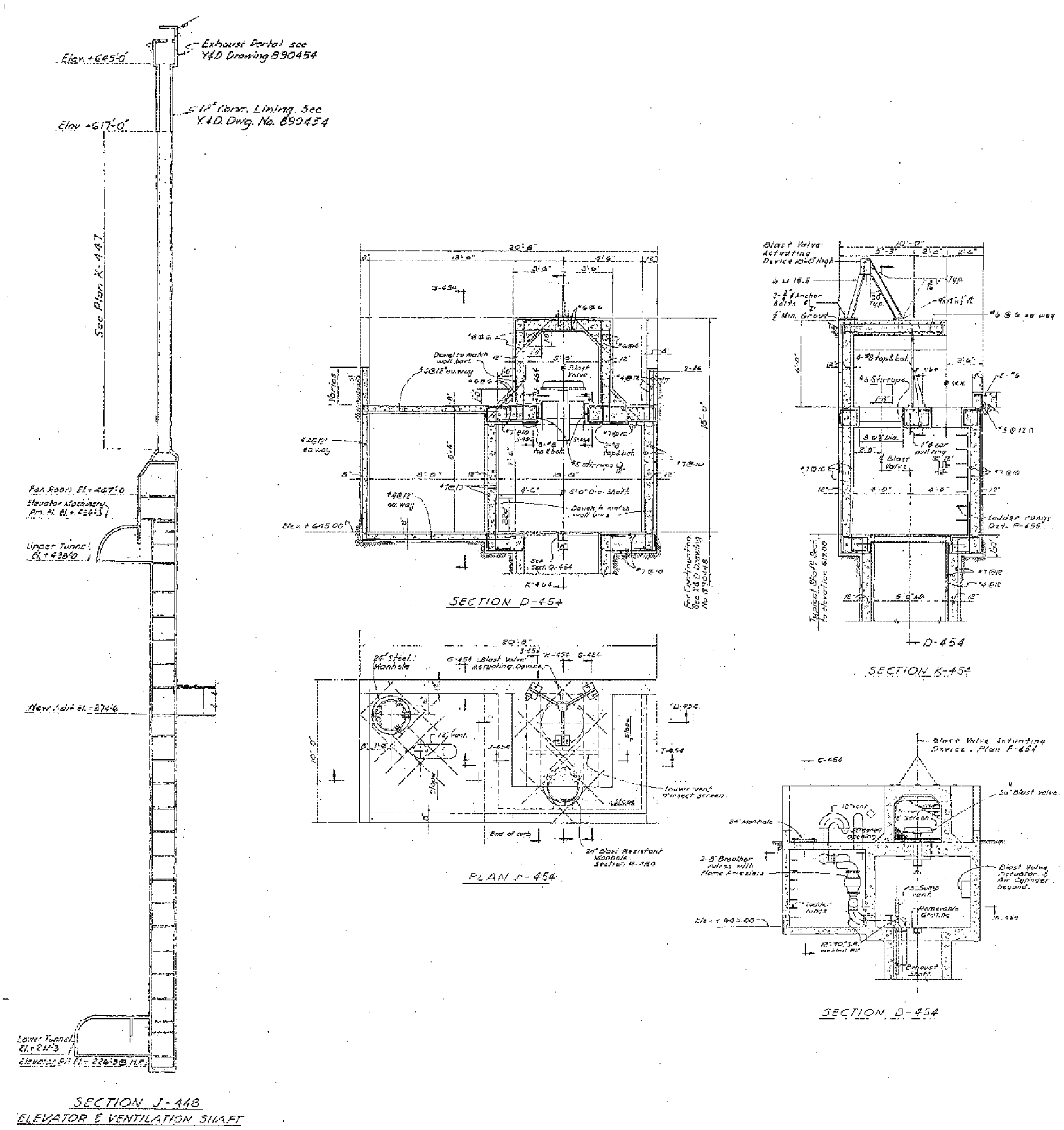
Portion of original drawing dated June 18, 1942 of Bombproof Tank Vents (Facility Nos. S-197, S-213, and 348). (Drawing # 294330, NFP Plan Files)



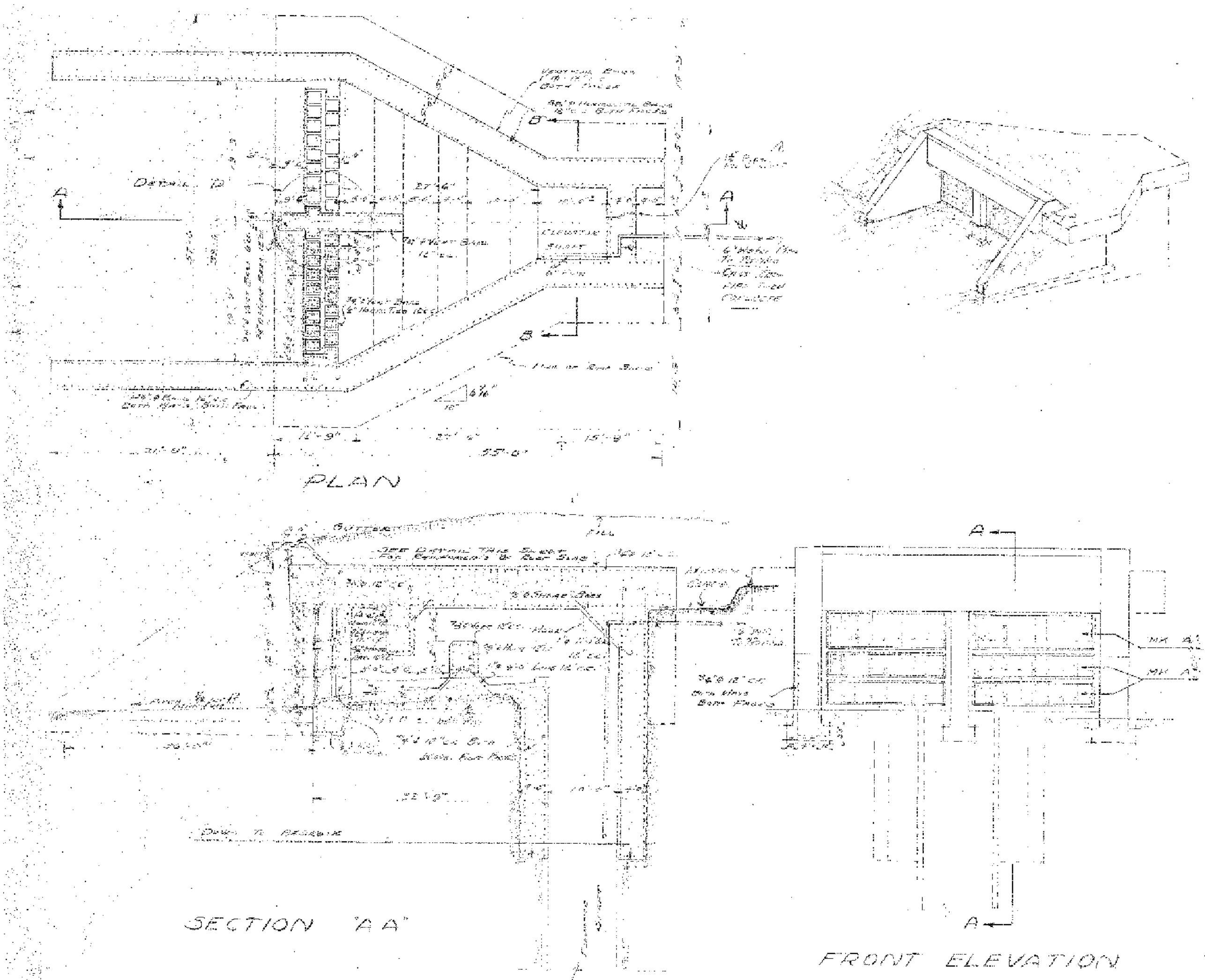
Portion of original drawing dated April 12, 1960 showing alterations to vent structure Facility 348. (Drawing # 890453, NFP Plan Files)



Portion of original drawings dated April 12, 1960 showing plan and cross sections of Vent Structure Atop Elevator #73 shaft. (Drawing #s 890448 & 890454, NFP Plan Files)

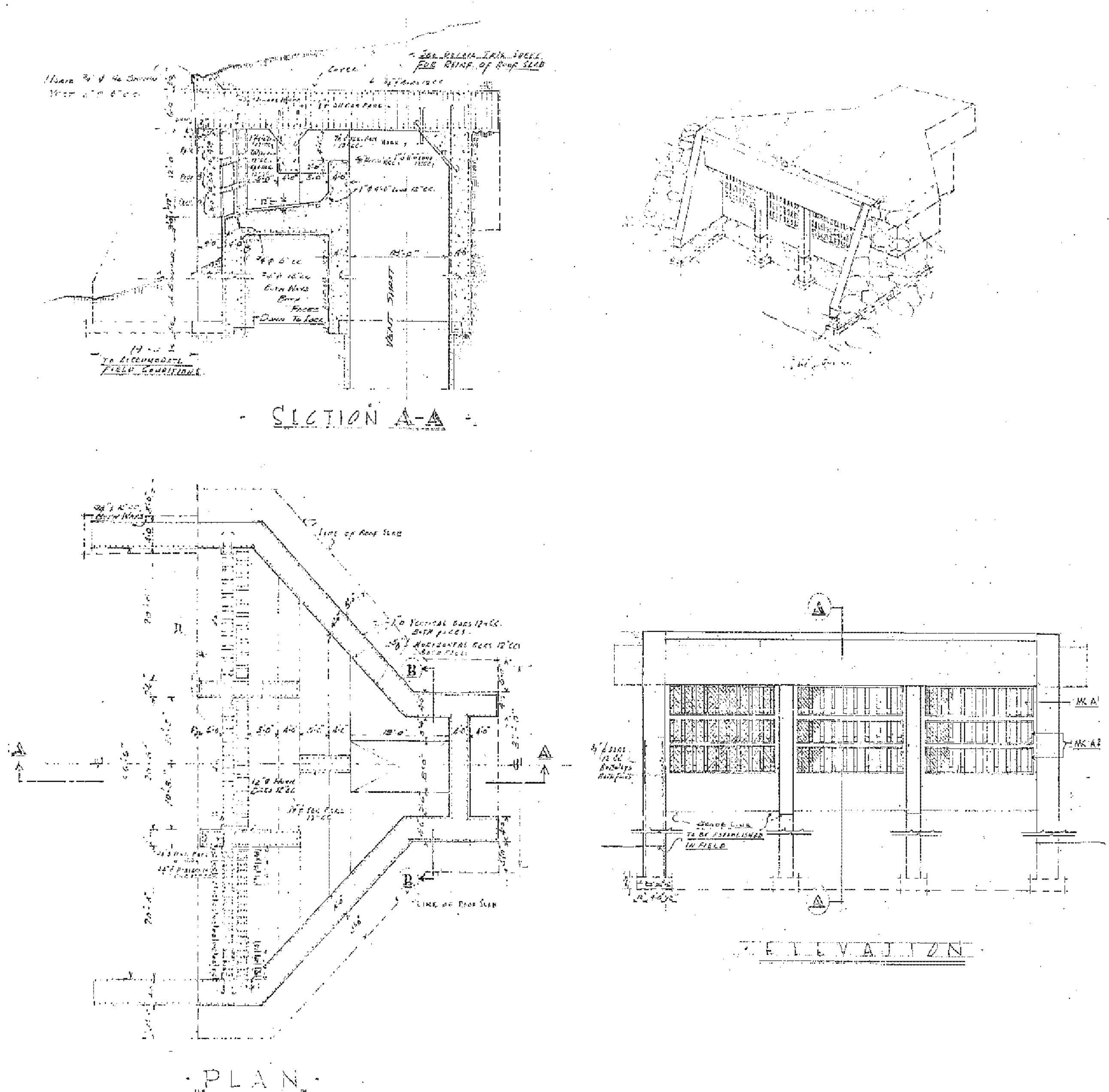


Portion of original drawing dated September 21, 1943 showing plan, perspective, elevation, and cross section of Tunnel Air Intake (Facility No. 315).
(Drawing # 249177, Fuel Department, PH FLC Plan Files)

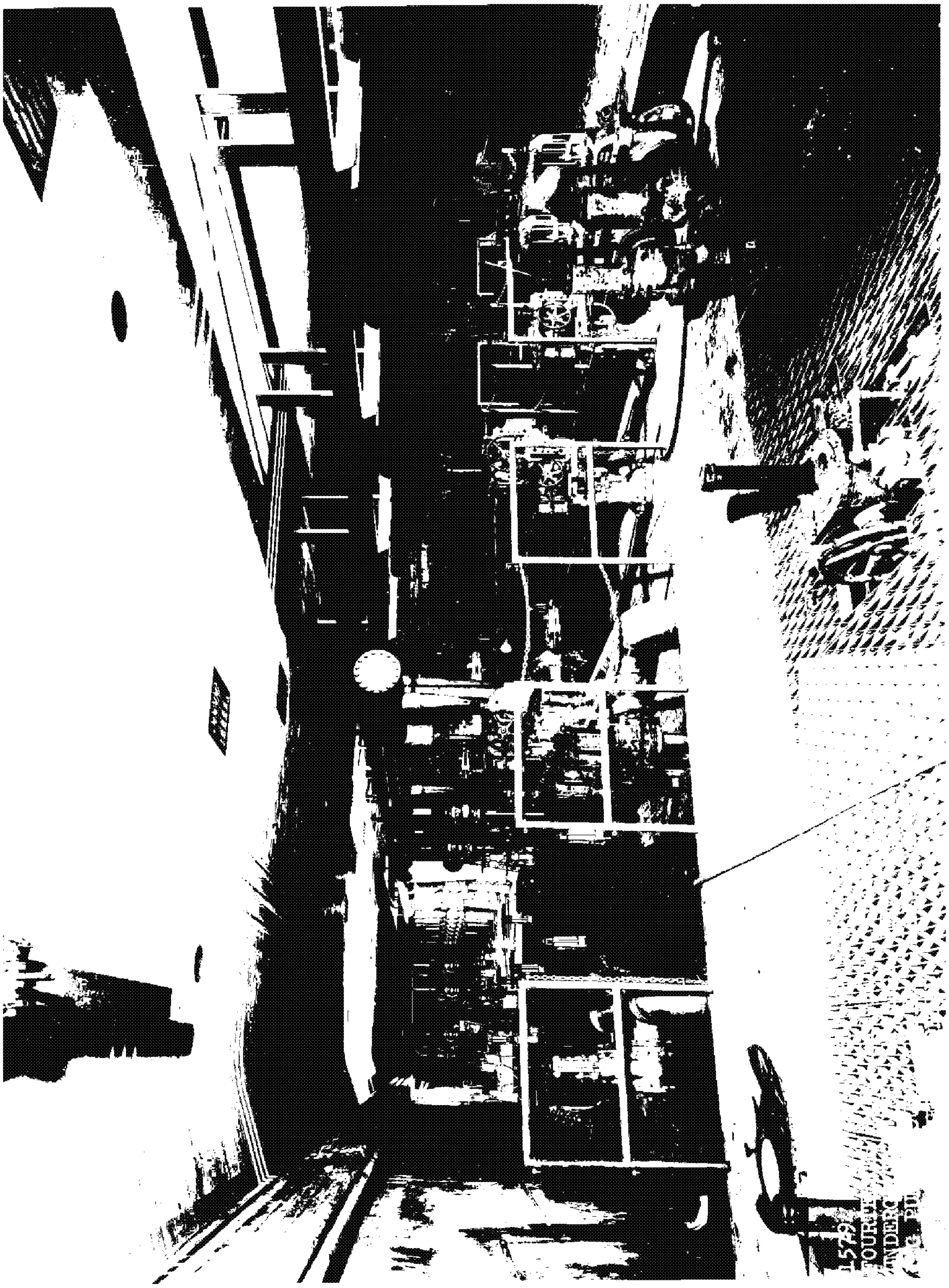


 BWS032581

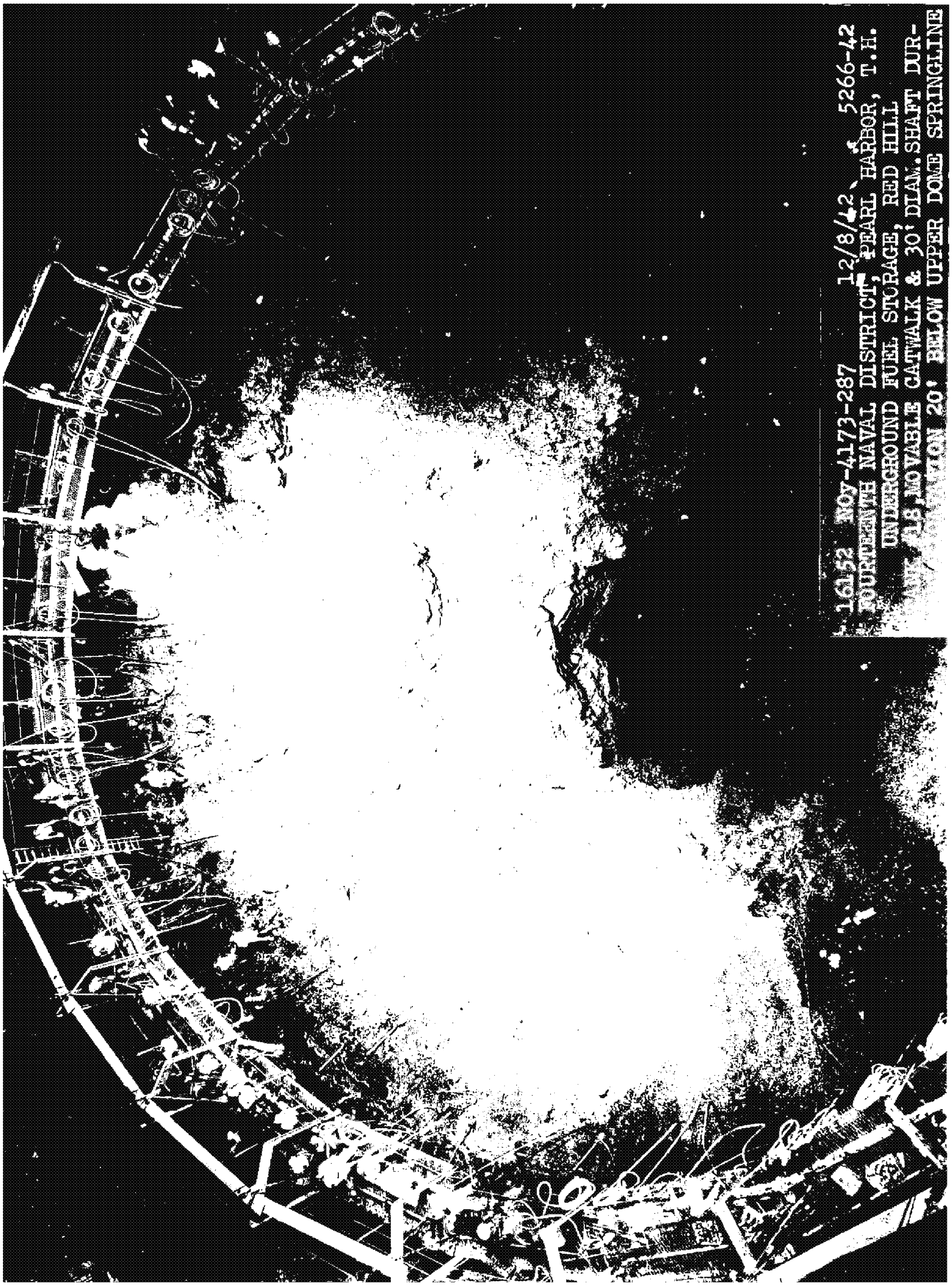
Portion of original drawing dated February 16, 1943, showing section, perspective, plan, and elevation of Main Tunnel Exhaust (Facility No. 354). (Drawing # 249163, NFP Plan Files)



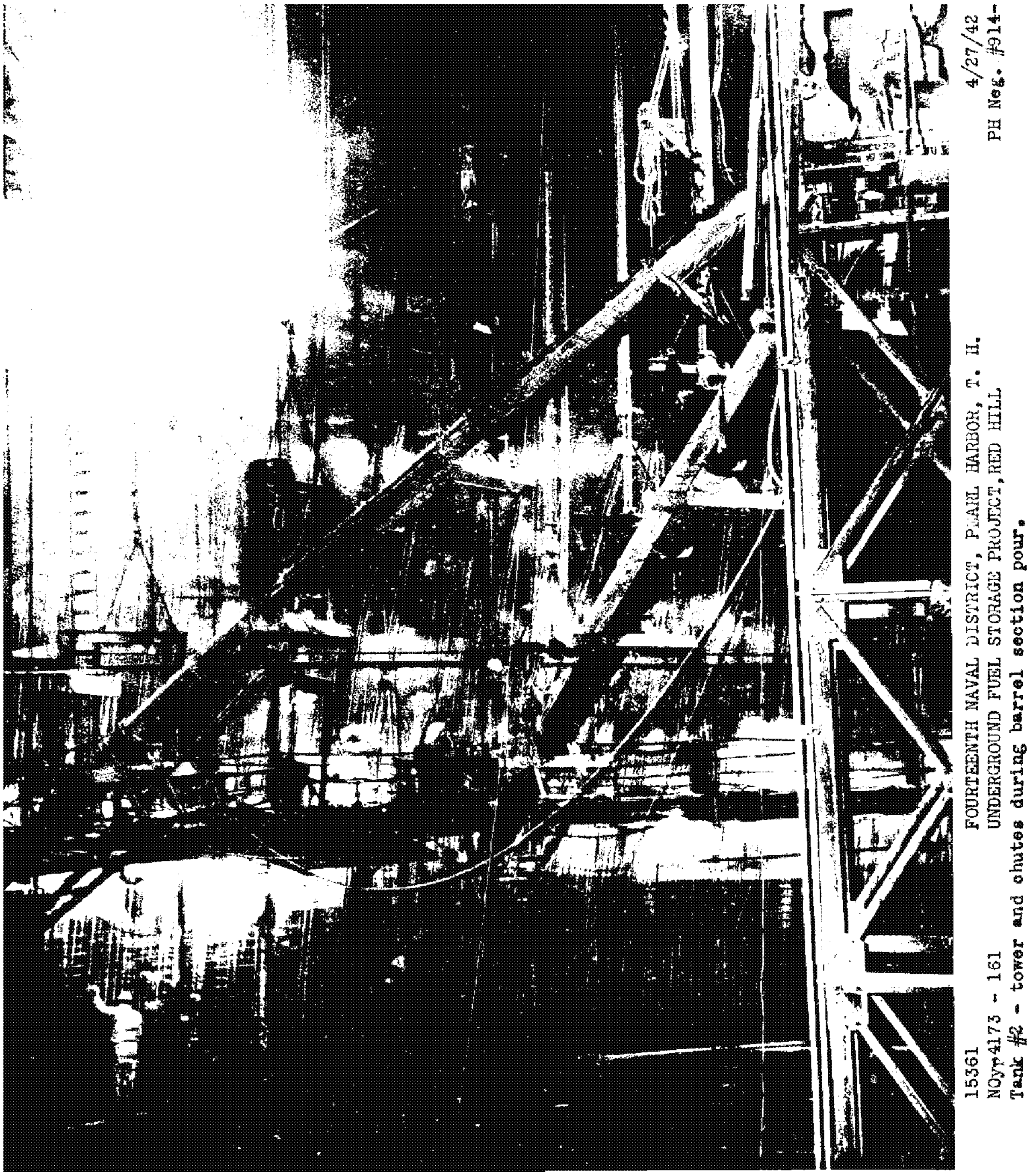
August 26, 1942 photo of Pump Room in Underground Pumphouse (Facility No. 59), looking east across equipment. (National Archives II #71-CA-180B-01)



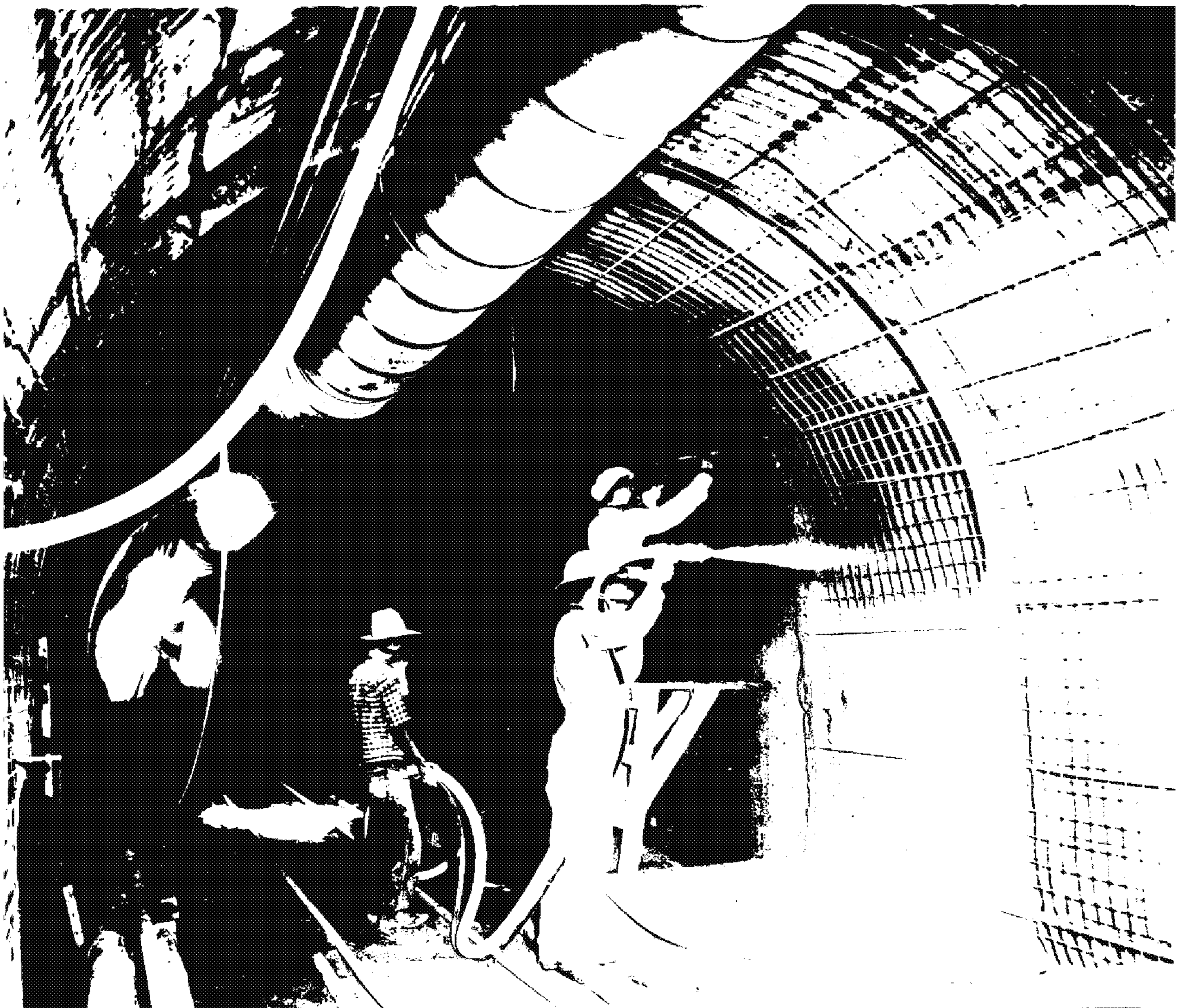
December 8, 1942 photo of Fuel Tank 18 (Facility No. 345), with movable catwalk and shaft for disposal of excavated rock below. (National Archives II #71-CB-103Z-16)



April 27, 1942 photo of Fuel Tank # 2 (Facility No. 329), tower and chutes during barrel section pour. (National Archives II #71-CA180C-28)



June 17, 1941 photo of Lower Tunnel (Facility No. S-21), LAT section near Adit 3 with Gunite being applied over metal structure. (National Archives II #71-CA-180C-25)



FOURTEENTH NAVAL DISTRICT, PEARL HARBOR, T. H. 17 June 1941
UNDERGROUND FUEL STORAGE - Showing gunite operation and sidewall finishing in tunnel between portal and intersection with pipeline tunnel.

April 6, 1943 Upper Access Tunnel at angled cross tunnels to Tanks 9 and 10, showing Gunite on walls. (National Archives II #71-CB-103Z-17)

August 26, 1942 photo of Pump Room in Underground Stand-by Power Plant (Facility No. S-308), five diesel units in operation. (National Archives II #71-CA-180B-05)

 BWS032588