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WHERE HAVE THE NEUTRONS GONE - A HISTORY OF THE TOWER SHIELDING FACILITY

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Where Have the Neutrons Gone - A History of the Tower Shielding Facility

ABSTRACT

In the early 1950's, the concept of the unit shield for the nuclear powered aircraft reactor changed to one of the divided shield concept where the reactor and crew compartment shared the shielding load. Design calculations for the divided shield were being made based on data obtained in studies for the unit shield. It was believed that these divided shield designs were subject to error, the magnitude of which could not be estimated. This belief led to the design of the Tower Shielding Facility where divided-shield-type measurements could be made without interference from ground or structural scattering. This paper discusses that facility, its reactors, and some chosen experiments from the list of many that were performed at that facility during the past 38 years.

INTRODUCTION

The Tower Shielding Facility (TSF) at the Oak Ridge National Laboratory (ORNL) has been the only reactor facility in the United States (U.S.) designed and built for radiation-shielding studies in which both the reactor source and shield samples could be raised into the air to provide measurements without ground scattering or other spurious effects. Although the Aircraft Nuclear Propulsion (ANP) program was terminated in 1961, the remarkable versatility and usefulness of the facility continued to make it a valuable tool in resolving other problems in shielding research. It is my intention here today to point out that versatility with brief descriptions of the type of work that has been done over the past 38 years and could be continued into the future.

FACILITY DEVELOPMENT

In 1946, the U.S. Air Force decided to implement an ambitious program to produce a nuclear-powered long-range bomber. After some early studies showed that one of the more difficult problems to solve was that of shielding the reactor for the crew's benefit without sinking the airplane, and realizing that the ability to design shields with any degree of confidence was minimal, it was decided to enlarge the existing shielding program at ORNL. As a result of these concerns ORNL management decided to increase the scope of the shielding work under the direction of E. P. Blizard, T. Rockwell, and others with support from the Air Force. One result was the construction of the Bulk Shielding Reactor in order to test the large shields that would be required for a reactor that would power an airplane that could weigh up to a half a million pounds.

Further design studies done by the NEPA project personnel strongly indicated, however, that to reduce the weight of the reactor shield to reasonable levels, the shielding should be divided between the reactor and the crew compartment of the aircraft. Since it was not possible to do experiments on a divided shield in either the Bulk Shielding Reactor (BSR) or the Lid Tank, a new research tool was proposed by ORNL, later to be known as the TSF.

Design requirements were established, seeking to limit the ground and structure scattering of neutron and gamma rays into the crew compartment of the aircraft to 15% of the air-scattered dose for an airplane weighing up to 125 tons and having a reactor to crew compartment separation between 60 and 100 feet.

Several concepts were given consideration, but the first serious preliminary design for the TSF is shown in Figure 1, where the hoisting tower had two legs that were 200 feet high and were placed

200 feet apart. These legs supported a bridge and two hoists for raising and lowering the reactor and crew shield. The swimming-pool-type reactor was to be placed in a 12-foot-diameter tank of water which weighed 60 tons. The reactor could be lowered into a 25-foot-deep water pool for servicing. The crew shield, including aircraft components, could weight up to 75 tons. The operations building was to be underground, covered with at least five feet of dirt. This building was to house the reactor controls, the data-taking equipment, and the hoist controls. This design was developed by C. Clifford as project manager with the aid of the Architect Engineering firm of Knappen, Tibbets, Abbot, and McCarthy.

The above design was evaluated for the effects of neutron scattering from the massive steel structure and the ground by A. Simon who had joined Blizzard's group for this purpose. Simon predicted that the scattering from these two sources would be too large for this structure, which led to a second generation design, shown in Figure 2, by Clifford and others using Simon's input to reduce the unwanted effects. This structure used guyed tower legs to minimize the structure required for wind loads and extended the height of the towers to 315 feet so that the experiment could be lifted to 200 feet. A 1/60 scale model of this configuration was built by Clifford and Jack Estabrook that demonstrated the ability of the six operating hoists to position the reactor and crew shield independently and to permit storage of the reactor in the pool. This design met the nuclear requirements stated previously because there were no structures required near the reactor other than the lifting cables.

ORNL submitted a preliminary proposal for the facility which was accepted by the AEC and the design work was started in July 1952. The construction was begun at a site shown in Figure 3 in March 1953 and completed in February 1954. The reactor and instrument installations were completed in June of 1954. The total cost of construction was just slightly under the two million dollar budget allowed.

The first TSF reactor (TSR-I) was nearly a duplicate of the first swimming pool reactor using removable aluminum alloy fuel elements in a rectangular array. Figure 4 shows the reactor which was supported from a travelling dolly which ran on tracks spanning the 12 foot water-filled tank. The tank had a spherical bottom. The reactor could be positioned anywhere on the horizontal midplane of the tank. The tank full of water weighed 60 tons. The reactor was also designed so that it could be removed from the tank remotely and be placed in a shield mockup.

EARLY SHIELDING EXPERIMENTS

Since the facility was built to perform experiments with a divided shield free from excessive background from ground-scattered radiation, it was fitting and proper that the first shielding-type measurement should demonstrate that the facility did indeed provide that capability. Results from these measurements indicated the ground scattering component at 195 feet was about 2% of the total scattered neutrons.

In late 1954, the first experiments using a specially designed reactor shield tank were initiated. The reactor was placed in the GE-designed ANPR-1 vessel and both neutron and gamma-ray dose rate measurements were made with the detectors in a square, water-filled tank. By 1955, the program became more concerned with performance of differential-type dose rate measurements.

In early 1956 a study was made of the neutron capture gamma rays produced in air. Prior to this experiment, all gamma measurements at the TSF were made using dosimeters. For this work, it was desirable to measure the spectra of these gamma rays. This was done with a three-inch sodium iodide crystal using a three-channel analyzer with 1 MeV energy resolution. This crude approach showed promise so that the method was later improved by using a five-inch sodium iodide detector and advanced electronics.

In 1957, this experiment was repeated using a more controlled approach as shown in Figure 5. A collimated beam of neutrons was allowed to escape into the atmosphere and the resulting gamma-ray production measured with a well collimated sodium iodide crystal. The end of the reactor collimator was either bare or covered with borated plexiglass to obtain spectra for both thermal- and fast-neutron interactions with air.

In early 1958, an Aircraft Shield Test Reactor (ASTR) experiment was performed in cooperation with Convair/Fort Worth to obtain data for comparison with that obtained from their own Nuclear Test Airplane program. For this mockup (see Figure 6) the ASTR was attached to an aluminum frame and the crew compartment attached at the other end 65 feet away. This combination was then raised to 200 feet to simulate flight conditions.

An experimental method for the optimization of a divided neutron shield was developed for the TSF using reactor shield and simulated crew shield tanks, each having compartments that could be filled with water or drained remotely (see Figures 7 and 8). Results from these measurements were used to determine the degree of asymmetry of the reactor shield that would give a minimum shield weight.

TSR-II DESIGN

Because of the difficulties in calculating shield performance in the early years, it became the practice to test shield designs using a known neutron source and full scale mockups of the as-designed shield. The effectiveness of this shield in conjunction with the reactor design would then be predicted by making corrections for the differences in source terms. The power source selected for propulsion of the aircraft early in the program was a circulating-fuel, reflector-moderated reactor (CFRMR) being designed by Pratt and Whitney Aircraft, something considerably different than the swimming-pool-type reactor used at the TSF. This difference in reactor shapes and compositions would have made it very difficult to apply the proper corrections. It was proposed that the shield measurements should be made with a source whose radiation leakage was similar to that from the CFRMR. It was also suggested that a new Shield Mockup Reactor be built having a beryllium reflector shaped like the proposed CFRMR. A design was submitted to Laboratory management but this concept was rejected. Research Director Alvin Weinberg suggested that the new reactor should be a general purpose source, something that could be used to cover problems of importance to shields for any reactor cycle that might present itself. All of the requirements mentioned led E. P. Blizard to suggest that the reactor be spherical to provide an isotropic source. If spherical, reactor controls would present a problem and C. E. Clifford proposed that the control plates be internal to the core to minimize perturbation of the leakage flux. Its design was directed by Clifford with the assistance of L. B. Holland and Charles Angel. What materialized became known as TSR-II, a schematic of which is shown in Figure 9. The new reactor became operational in February 1961 at the approved maximum power of 100 kW. Eleven years later, approval was given to operate the reactor at 1 MW, the maximum power achieved during its lifetime. The reactor was used for only one experiment in the ANP program, a divided shield mockup study for Pratt and Whitney Aircraft Company, before the ANP program was canceled in June 1961.

FOLLOW-ON EXPERIMENTAL PROGRAMS

The loss of ANP support was not "deadly" to the TSF as its usefulness had already attracted attention from other programs. An agreement had been reached between the United Kingdom and the U.S. Defense Atomic Support Agency (DASA) to measure the attenuation characteristic of specific military vehicles and research models of mutual interest during 1961. These measurements involved personnel from the U.S. Army Tank Automotive Center, General Dynamics/Fort Worth, and ORNL. A specific series of measurements were made for the DASA and Office of Civil Defense in 1961-62 to study the shielding effectiveness of the covers being designed for missile silos that were under construction. Concern was centered on reducing costs while maintaining the safety of personnel and equipment in the silos. Other experiments for DASA followed, including measurement of the angular dependence of fast-neutron dose rate and thermal-neutron flux reflected from concrete, using a mockup shown in Figure 10. Analytical methods that were verified in that experiment were used to calculate the neutron flux as measured in large concrete ducts containing one, two, and three bends as shown in Figure 11.

About 1964, the NE-213 spectrometer being developed by V. V. Verbinski was introduced at the TSF as a useful tool to measure neutron spectra above about 800 keV. Its presence was soon joined by that of the specially designed Benjamin-type hydrogen-filled detectors for measurement of the neutron energies from about 40 keV to 1.5 MeV. With the advent of these spectrometers, the value of the data used for testing the analytical methods, such as Mynatt's Discrete Ordinates Methods, was greatly improved. Later in 1970, the Bonner ball detector system was developed to provide a measurement of the integral neutron flux. The BF_3-filled spherical detector was surrounded by spheres of polyethylene having different thicknesses, each combination being sensitive to a given neutron energy region. The presence of this combination of detectors eliminated the need for dose rate measurements.

Considerable time and effort was spent performing further programs for DASA that included: (1) the thermal-neutron capture gamma-ray spectral intensities from various shielding materials; (2) investigation of the minima in total cross sections for nitrogen, oxygen, carbon, and lead; (3) measurement of the angle-dependent neutron energy spectra emergent from large lead, polyethylene, depleted uranium, and laminated slab shields; and (4) gamma-ray spectra arising from thermal-neutron capture in elements found in soils, concrete, and structural materials.

In the late 1960's, work was initiated in support of the Space Nuclear Auxiliary Power (SNAP) program. Measurements were made of the scattered neutrons from support tabs and beryllium control drums that would be extended beyond the shadow shield when the SNAP reactor was in flight. This work was extended to include measurement of the fast-neutron transmission through an "infinite" slab of lithium hydride and measurement of the fast-neutron dose rate transmitted through a conical-shaped lithium hydride shield.

In 1965, it was proposed that the TSF install a modified SNAP 2/10A reactor to provide experimental results for comparison with Monte Carlo calculations of the radiation penetration through shadow shields. The reactor was designed and fabricated by Atomics International. The reactor went critical at the TSF in April 1967. Measurements were made of the neutron spectra above 1 MeV transmitted through typical SNAP shielding materials placed beneath the reactor. These materials included lead, ^{238}U, tungsten powder, hevimet, lithium hydride, and laminated slabs of those materials. This was followed by measurement of the gamma-ray spectra transmitted through these same materials before the SNAP program at the TSF was terminated in 1971.

From late 1970 to 1975, a large portion of the Tower's time was devoted to the Fast Flux Test Facility (FFTF) program as part of the Liquid Metal Fast Breeder Reactor program. Experiments were proposed to aid in the development of analytical techniques for calculating the neutron penetration through specific areas of the FFTF. Of particular interest were measurements of neutron streaming through planar and cylindrical annular slits in thick iron shields that represented the top head of the reactor shield. Various integral experiments were done that included demonstration plant shield studies proposed by GE and Westinghouse. Experiments were run to test the calculations by GE that radiation transport through shields of large diameter stainless steel or boron-carbide filled rods could be adequately described using a homogeneous model. By 1974, that work was completed and further efforts in the LMFBR program were applied to the Clinch River Breeder Reactor (CRBR) program.

The experimental capabilities at the TSF were greatly improved in 1975 by addition of a new reactor shield. Prior to this, the reactor was contained in the reactor shield ball that was faced by concrete to minimize scattering and provide a flat surface against which the mockups could be placed. The new shield permitted placement of the mockups much closer to the reactor and, with an increase in collimator diameter, the source strength incident upon the mockups increased by a factor of 200. The change altered the description of the source term from a previously considered point source to a disk source.

The first experiment using the new shield was a measurement of the CRBR upper axial shield mockup. The full strength of the new source term was used to measure neutron transport through 18 inches of stainless steel, 15 feet of sodium, followed by 35 inches of iron. Measurements followed of the neutron streaming in a CRBR prototypic coolant pipe chaseway (see Figure 12) and the program ended with comparison measurements of the neutron attenuation through stainless steel and inconel when used as a radial blanket shield.

By 1977, the Gas Cooled Fast Reactor program replaced the CRBR work with a designated program of eight specific experiments that included measurements for the Grid-Plate Shield Design Confirmation experiment, and followed by tests of the Radial Blanket Configuration, the Shield Heterogeneity Mockup, and ended with the Exit Shield experiment and the Plenum Shield design experiment in 1980.

In 1983, studies for the High Temperature Gas Cooled Reactor program were initiated to provide data for verification of the analytical methods used to calculate the radiation transported through the bottom reflector and core support structure and to predict the radiation damage at the support structure.

During 1984, the TSF became involved in studies of the radiation exposures received from the atom bomb explosions over Hiroshima and Nagasaki by mocking up a concrete structure simulating a small single-story concrete block house over that area and making internal measurements. The data provided verification of the discrete ordinates Three-dimensional Oak Ridge Transport Computer Code (TORT) being developed at ORNL.

In November 1985, the TSF began participation in a cooperative experimental program between the Japanese Power Reactor and Nuclear Fuel Development Corporation (PNC) and the U.S. DOE. The program, entitled JASPER for Japanese-American Shielding Program of Experimental Research, was designed to meet the needs of both participants. Eight experiments were planned, with the first two reaching completion before the TSF was shut down in 1987. The remaining six experiments were completed this September following resumption of reactor operation in 1990.

ACKNOWLEDGEMENTS

The success of the operation of the TSF throughout its lifetime can only be attributed to the efforts of the people involved, both those employed at ORNL and people from outside vendors who became extensively involved in various aspects of the many programs. Changes in personnel occurred as time went on, expanding and decreasing in numbers as the effort required. Outside vendors, such as General Electric (GE), the National Advisory Committee for Aeronautics, and the Boeing Airplane Company, to name a few, provided personnel soon after the facility was built to aid in the experiments and performance of the data analysis. Support from outside the Laboratory continued to increase as personnel from other companies like Consolidated Vultec Aircraft Corporation, Glenn L. Martin Company, Pratt and Whitney, Convair/San Diego and Convair/Fort Worth, the Lockheed Aircraft Company, and others added their contributions.

However, with the loss of the ANP program, this outside participation dwindled since a majority of the supporting companies were also left without ANP funding. Participation by the TSF in new and diversified programs also brought some changes in the vendors collaborating in the TSF work, such as Westinghouse, General Atomics (now called GA Technologies), Atomics International (now known as Rockwell International), GE, General Dynamics, Radiation Research, the University of Tennessee, SAIC, and personnel from the Japanese Power Reactor and Nuclear Fuel Development Corporation (PNC). All who have participated in the programs have been generous in their efforts to promote the welfare of the facility. It is to all of them that I want to say thank you for helping to make the facility what it has been throughout all these years.

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Figure 1. Early concept for the Tower Shielding Facility.

Figure 2. Final concept for the Tower Shielding Facility.

Figure 3. Aerial view of the Tower Shielding Facility site.

Figure 4. Photograph of the first TSF reactor (TSR-1) within its water-filled tank suspended above the maintenance pool.

Figure 5. Experimental configuration for measuring gamma rays produced from neutron captures in air.

Figure 6. The ASTR suspended in air at the TSF.

Figure 7. Compartmentalized reactor shield tank.

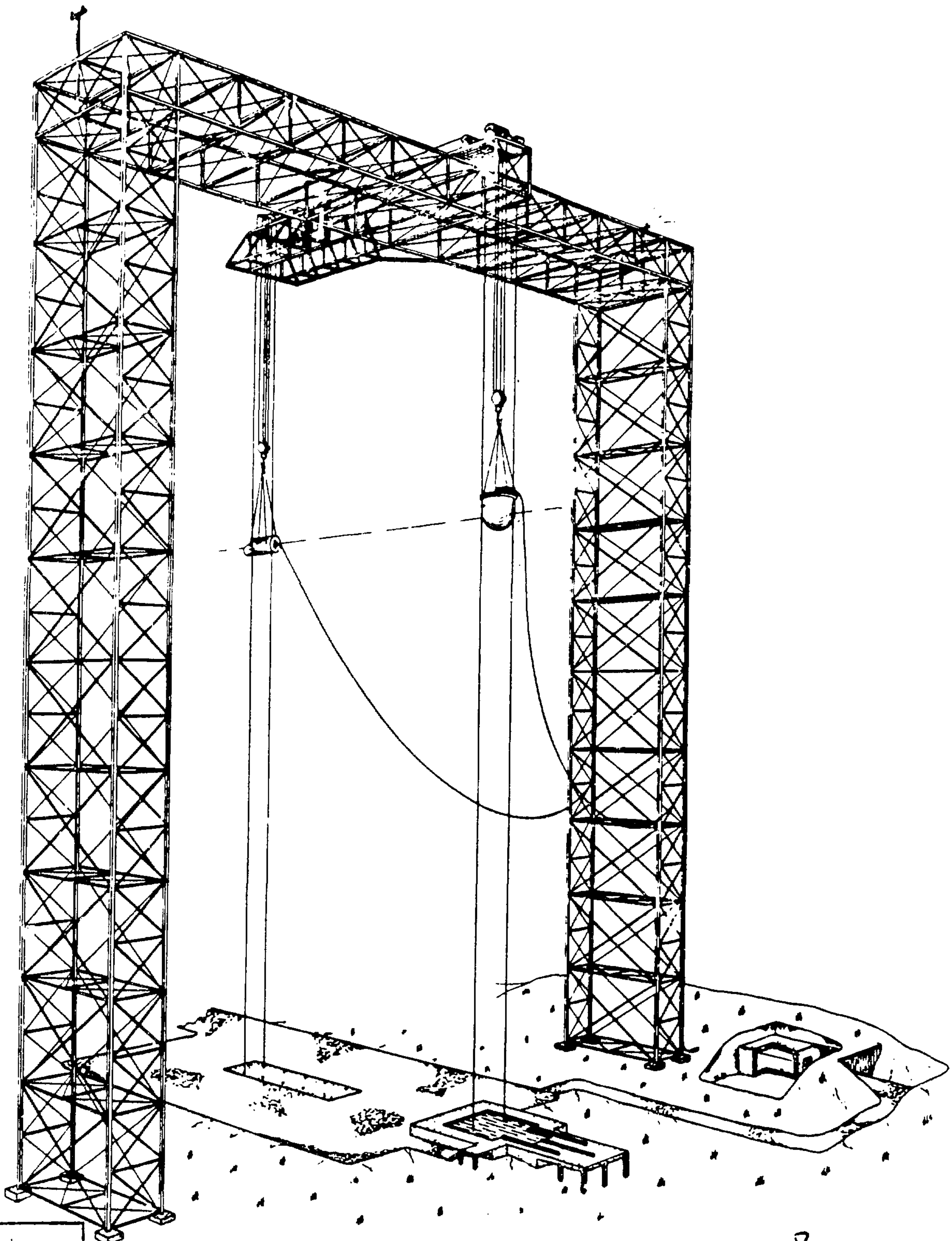
Figure 8. Compartmentalized crew compartment tank.

Figure 9. Schematic of second TSF reactor (TSR-II).

Figure 10. Experimental arrangement for measurements of fast neutrons reflected from concrete.

Figure 11. Experimental arrangement for measurements within a duct with two bends.

Figure 12. Schematic of pipe chaseway configuration.



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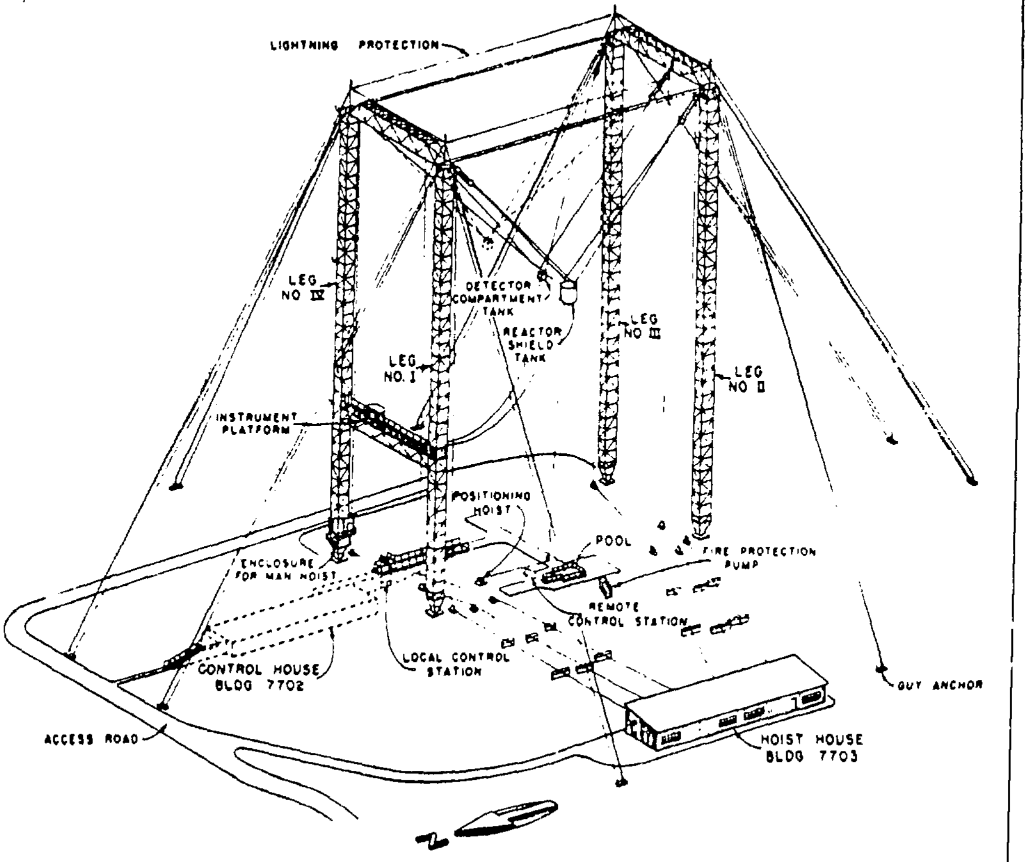

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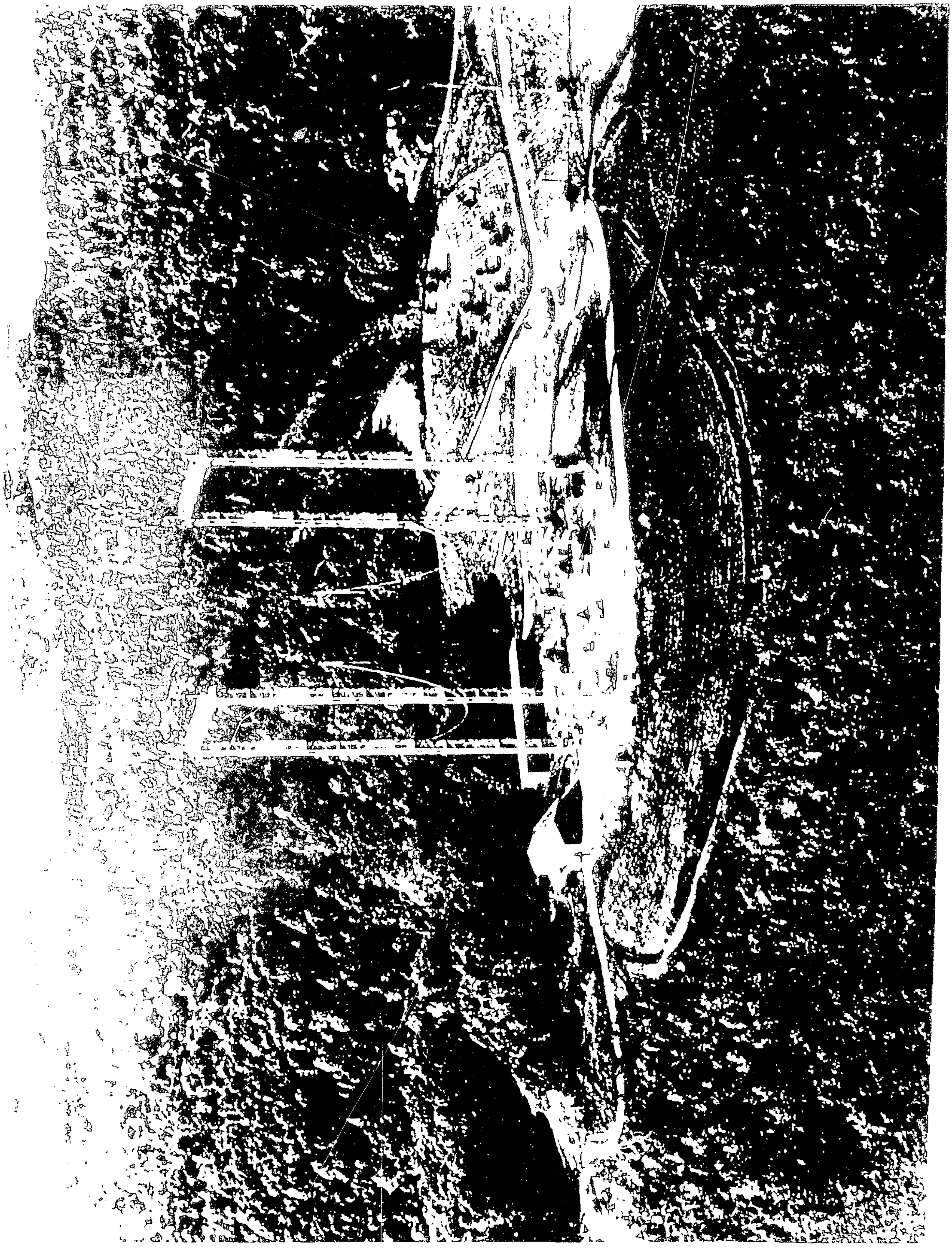
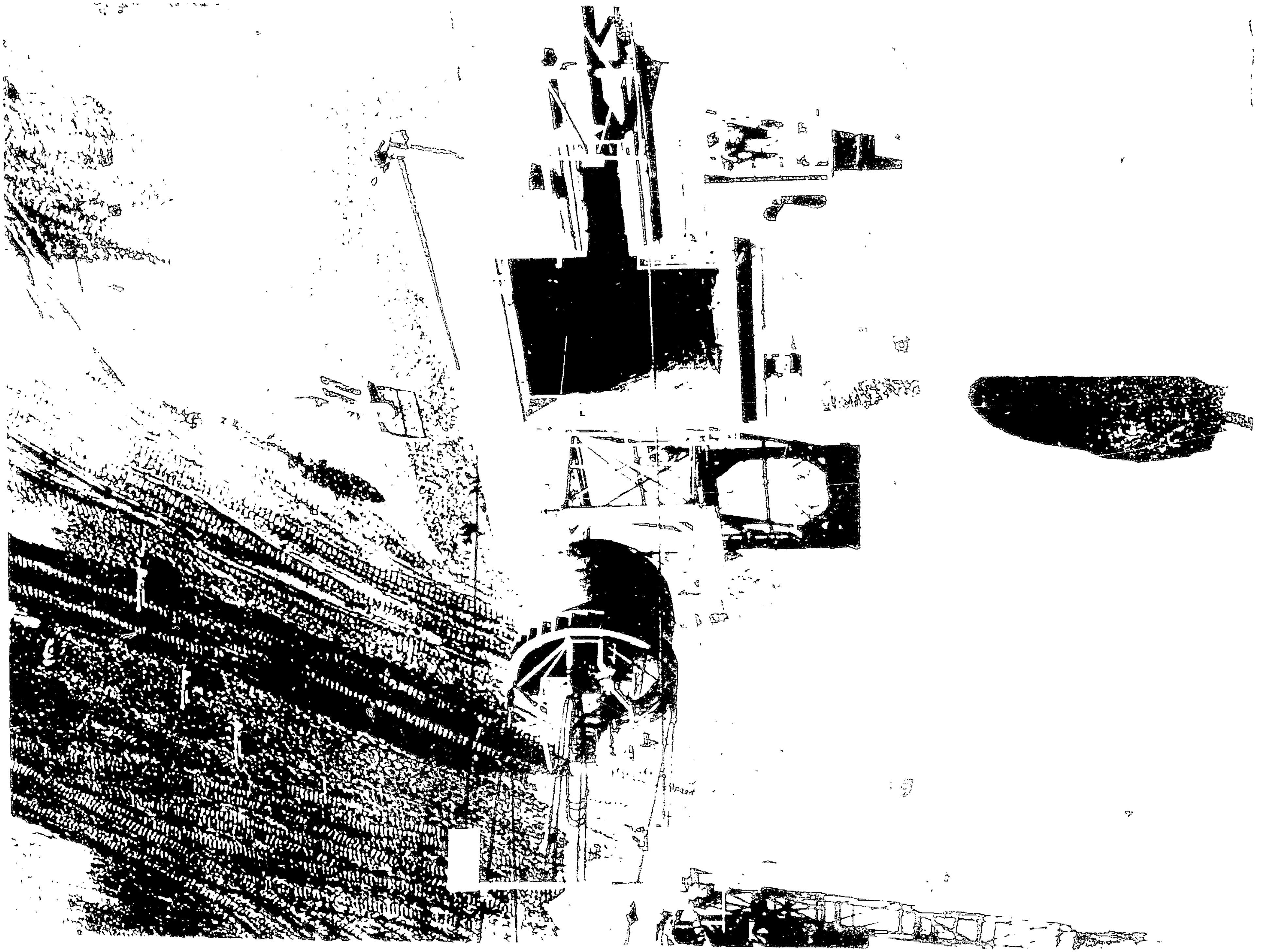
Map D – Trimetric View of General Placement in Three Dimensions.





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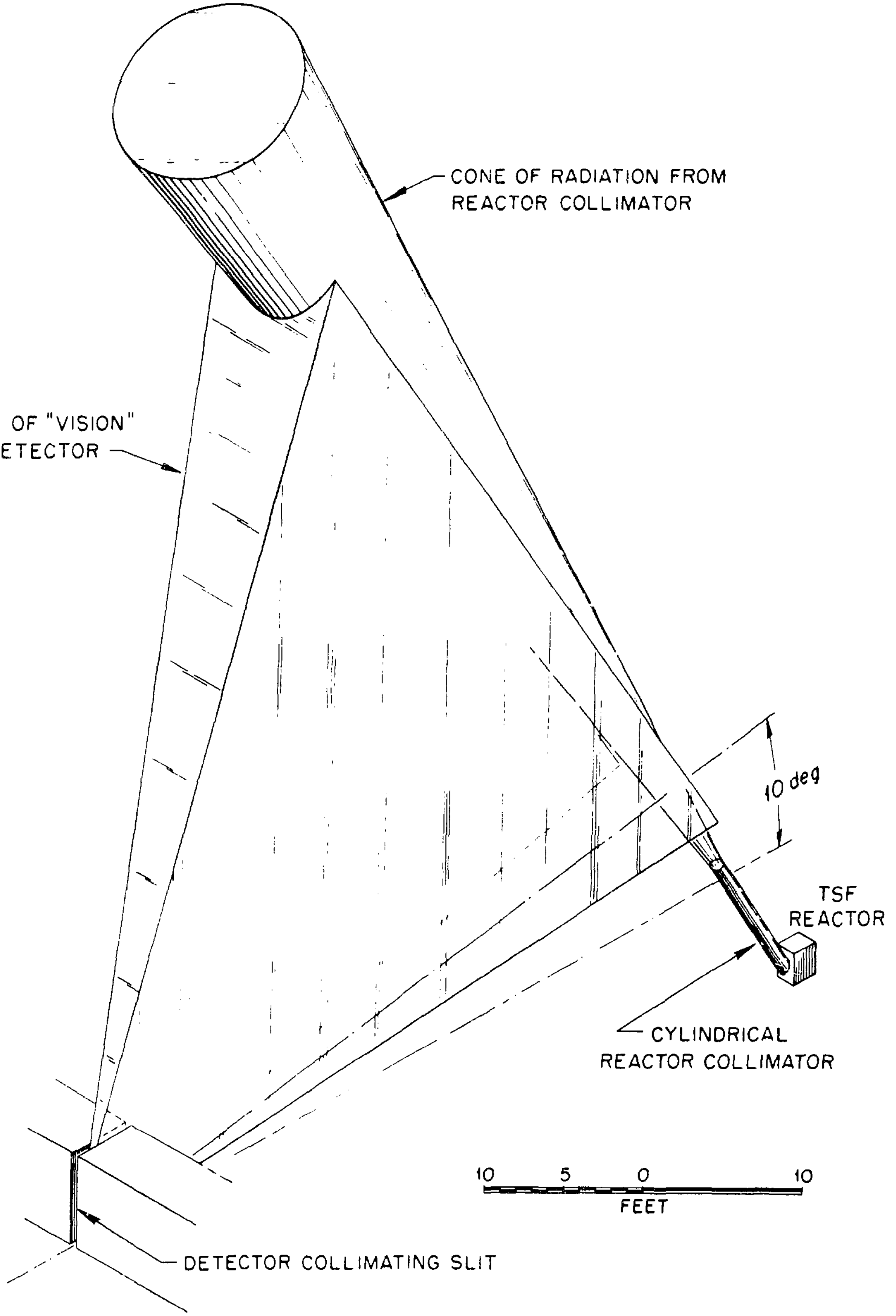

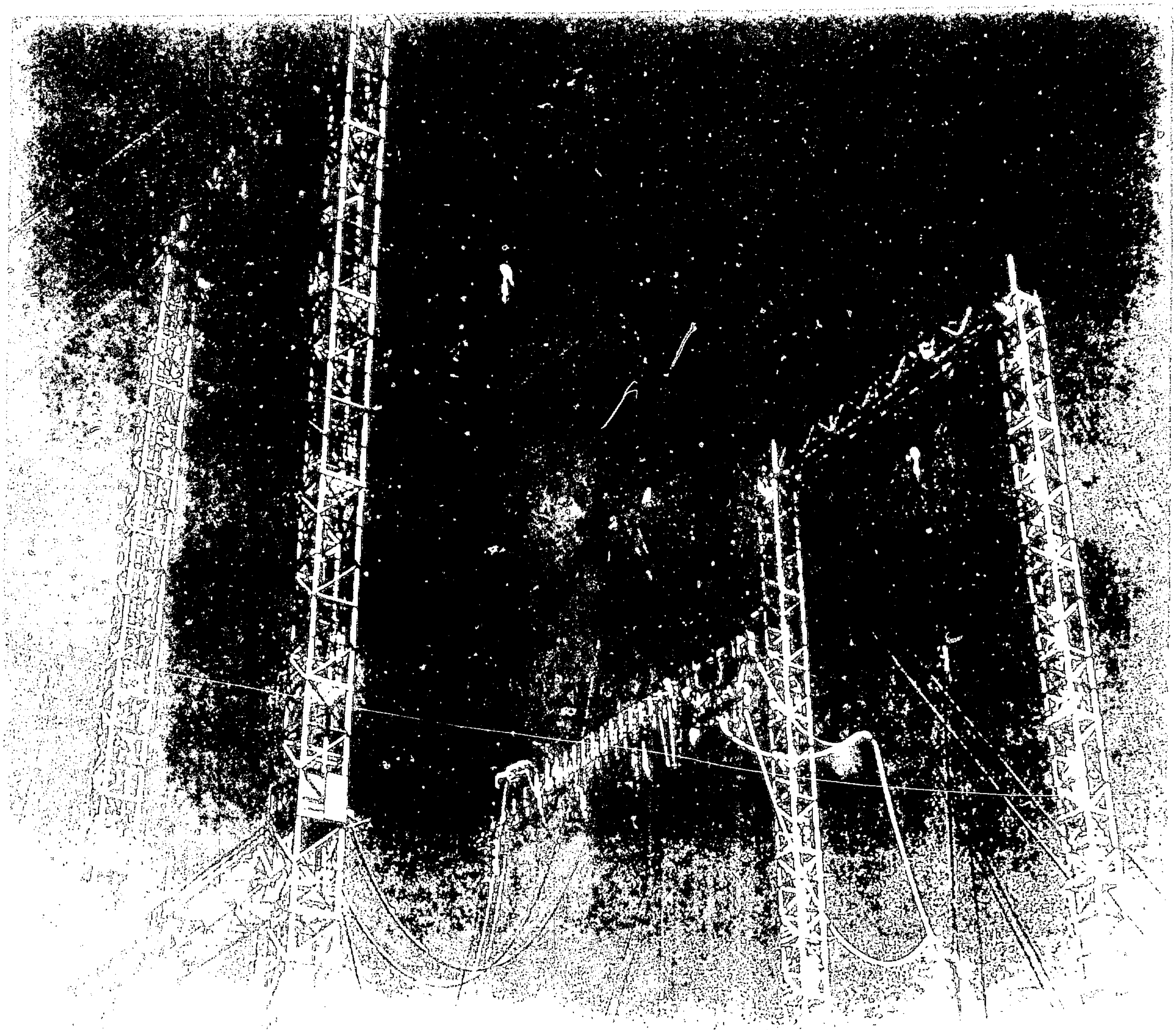

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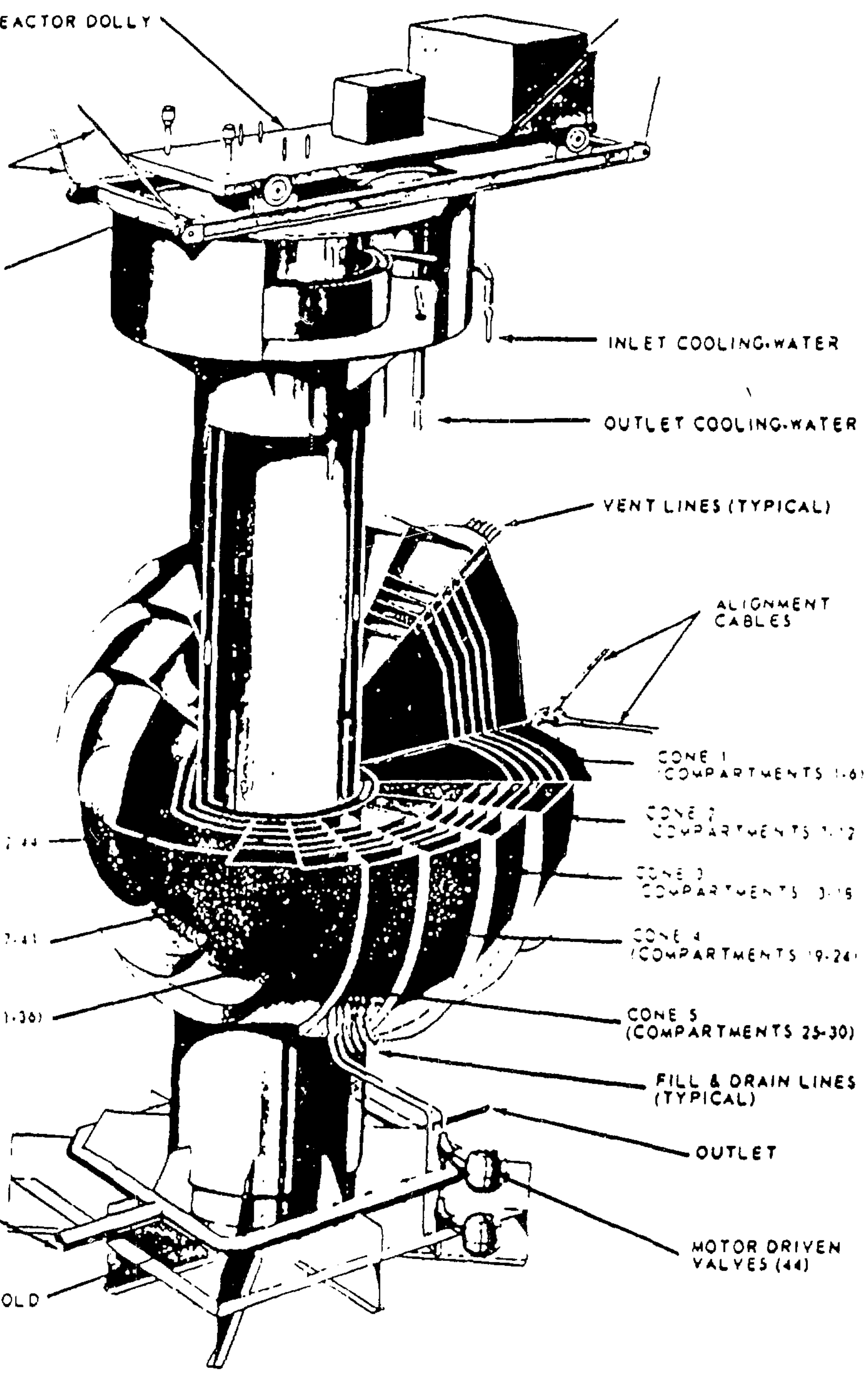

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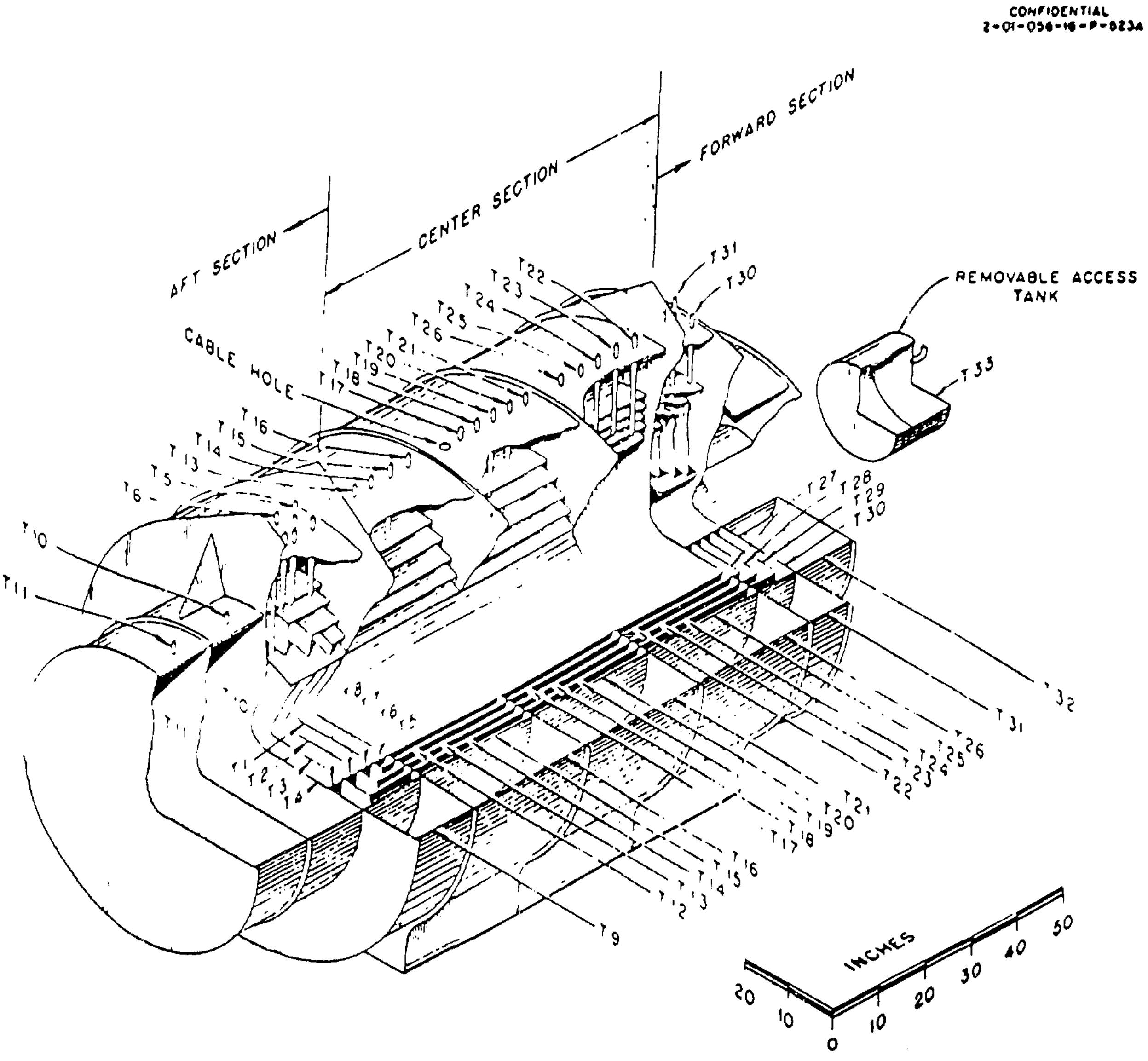

Fig. 6.2.45. Compartmentalized Crew-Compartment Tank.

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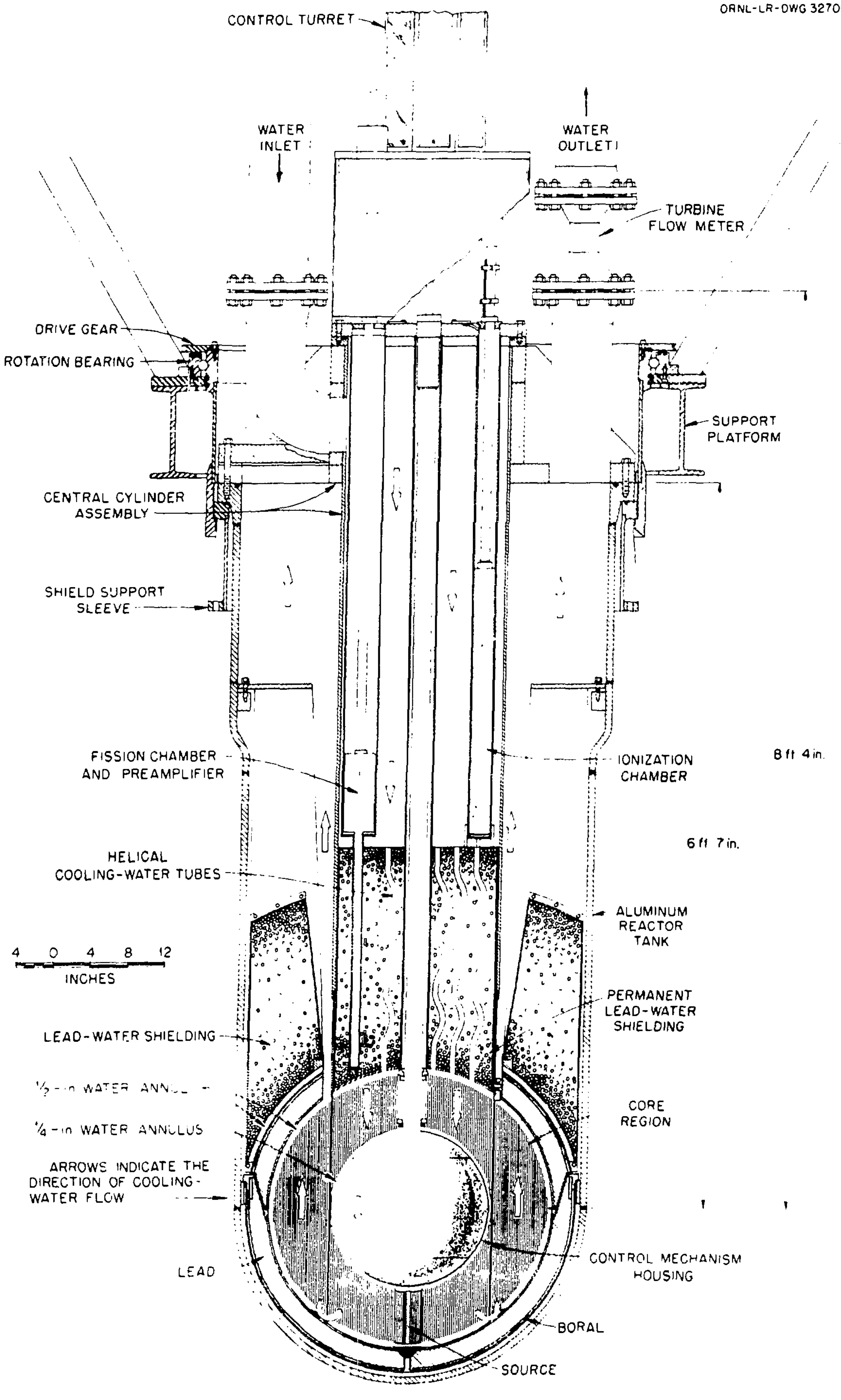

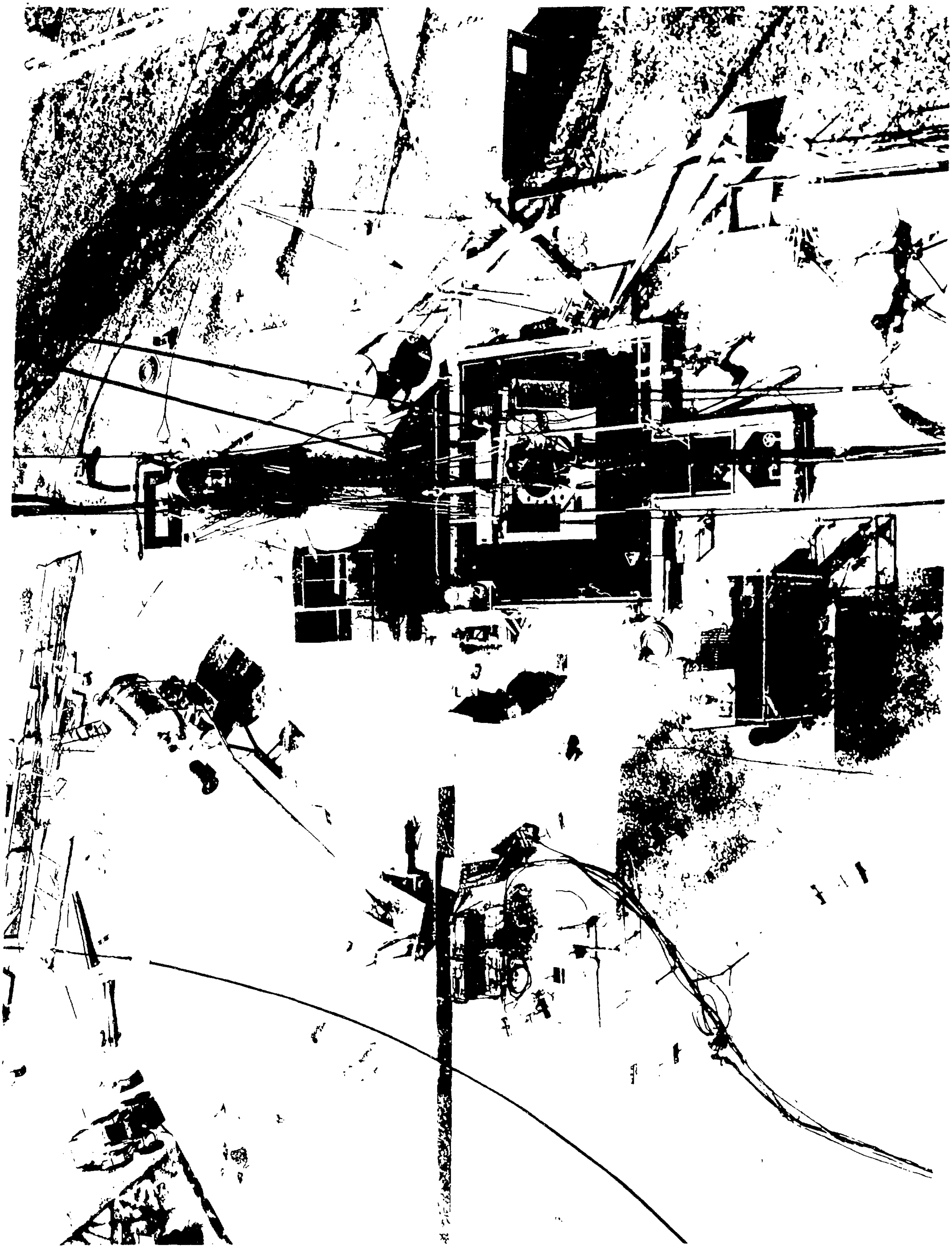

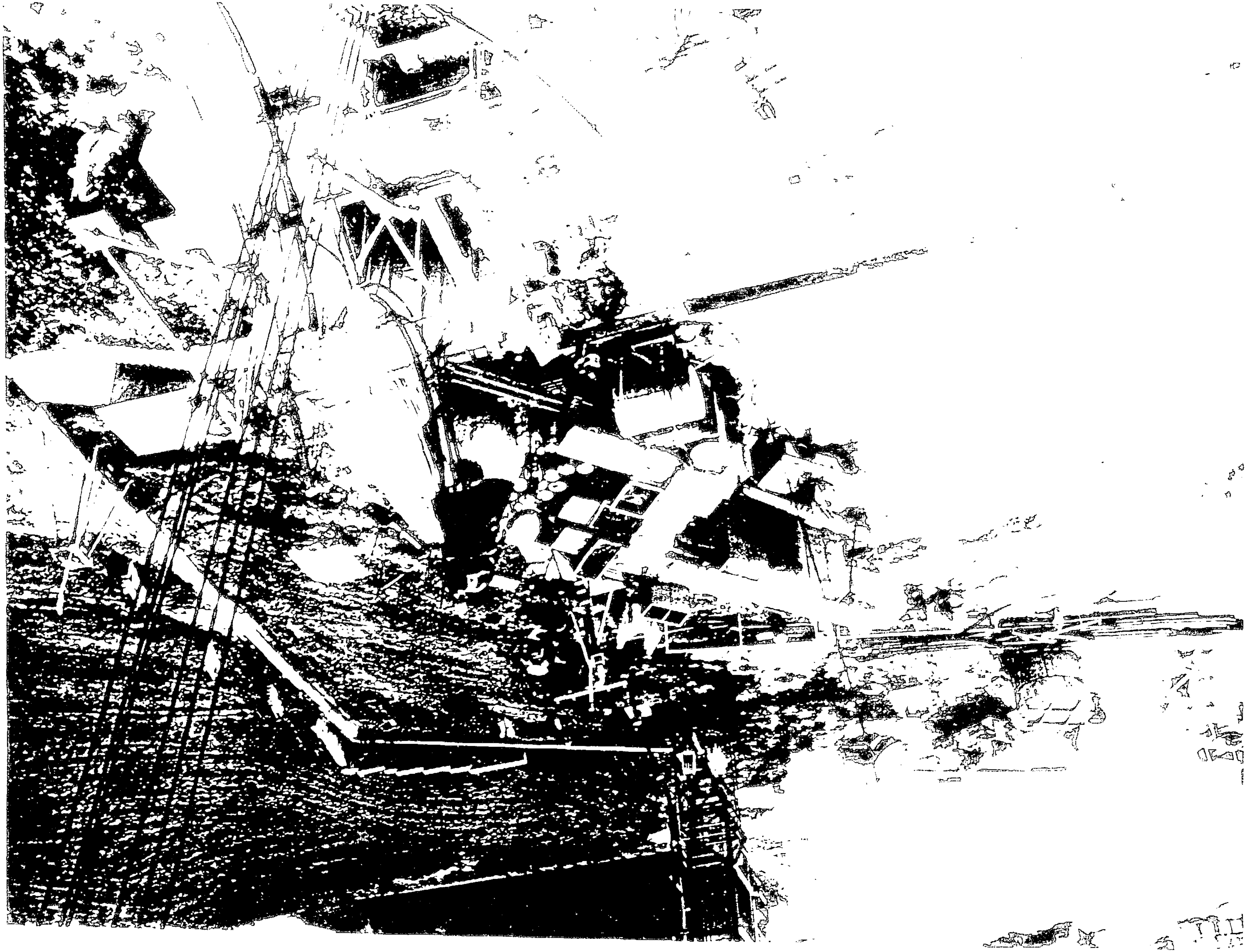

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