RESEARCH PROGRAM

on

OIL BURNING

STEAM LOCOMOTIVES

****

D E S C R I P T I O N   O F
S A C R A M E N T O   L O C O M O T I V E
S T A N D I N G   T E S T   P L A N T

****

S A C R A M E N T O   C A L I F O R N I A

****

OFFICE GENL. SUPT. MOTIVE POWER
SOUTHERN PACIFIC COMPANY
SAN FRANCISCO, CALIFORNIA

REPORT ST
DATED: NOVEMBER 15, 1950

TABLE OF CONTENTS

* Diagrams, Calculating, Data, Correction Chart and Graph Groups are bound separately on back of front cover for convenience of reference.

Index of Text

INDEX OF PHOTOGRAPHS

INDEX OF DIAGRAMS

INDEX OF CALCULATING & DATA SHEETS

INDEX OF CORRECTION CHARTS

INDEX OF GRAPHS

FOREWORD

This report covers description of the Locomotive Test Plant erected under authority of GMO-35006 dated September 6, 1946 at Sacramento General Shops during the latter part of 1946 and the early part of 1947 for the purpose of conducting extensive research into the more effective utilization of fuel oil in steam locomotives through standing tests on a locomotive representative of the latest design.

Battelle Memorial Institute was engaged to assist in the program of research and to conduct certain investigations at their Columbus, Ohio laboratories.

The standing tests were supplemented by preliminary dynamometer car tests to establish basic data on locomotive operation and by follow-up dynamometer car tests to obtain actual operating information on improvements developed by standing tests.

Standing tests were made in order to exclude the many undesirable influences on test conditions interposed by road operation and to permit a wider study of combustion conditions and methods than would be possible in road service.

This plant employed an advanced principle of testing to assure reproducibility of test results in actual service.

Former practice in combustion tests on standing locomotives was to reduce the boiler pressure to the exhaust steam pressure desired or to throttle the main steam down to exhaust pressure, in each case removing the main piston valves so that the superheated steam passed directly from steam pipe outlet in chest to the exhaust passages and thence to the nozzle.

In a locomotive in operation, a part of the heat energy in the steam to the cylinders is transformed into the mechanical work of moving the pistons and the train. This transformation of some of the energy causes a "heat drop" or reduction in the heat content of the steam and at the end of the piston stroke the steam to the exhaust is at some lower temperature and pressure depending on the work done and the initial condition of the steam.

During standing tests the steam does no work on the pistons and therefore, under the usual test methods, the exhaust steam is at a much higher temperature than occurs in actual service and for a given rate of evaporation in the boiler the draft produced will greatly exceed that obtainable in service. Hence the test performance of the essential combination of oil burning arrangement and front end is not representative of road service results.

In this plant appropriate heat drops as established from the preliminary dynamometer tests were caused by the controlled injection of water into the steam as it passed through the cylinder and the steam was hence cooled an amount it would have been if its energy were being used to drive the locomotive. With the instrumentation and equipment provided, the exhaust steam to the nozzle could be automatically maintained at temperatures corresponding to those in actual service for the nozzle pressure concerned, by desuperheating the steam to the exhaust and the road performance could then be predicted without either the difficulties of procedure or the uncertainty in the results of road tests.

Figure 1 - The Test Plant - General Arrangement.

Test plant building was of frame construction, 32' x 120', and was located near the Laboratory at Sacramento General Shops. The building was large enough to house an AC class locomotive without tender as well as smaller types of steam motive power.

General arrangement of the test plant was as shown on Figure No.1. The control panel, shown near smoke box, had to be located so that control piping, draft and pressure gage lines had proper slope to gages, recording and control equipment but when possible, location of the instrument panel nearer the firing deck would be somewhat more convenient during operation.

The building was wired for both 110 volt single phase Lighting circuits, and 440 volt three phase power for operating motor equipment and for the welding machines. For convenience, steam, air, and water lines extended around three sides of the test building. The test locomotive was on the track extending down the longitudinal center of the building. On each side were concrete floors, sloped to drains near and on each side of the track. These drains were concrete, covered by cast iron gratings flush with floor surface, and extended for the full length of the locomotive. "Blacktop" was applied over ties and ballast for flooring between drains and rail. Heavy wood walkways were used to fill in between rails where necessary.

A water hose with fog nozzle and a steam hose were arranged on brackets at a strategic point near fire box for fire protection and a fire alarm station was installed near the test building.

Two rows of nine light sash windows were provided down the long sides of the building, the upper row being fixed and the lower hinged.

This lower row of sash and the end doors were opened as required to furnish ventilation and unrestricted supply of air for the locomotive.

A venting jack over the safety valves extended through roof to carry off the steam from valves and the boiler blow down steam, to prevent condensation in building.

Water tank for calibrating the water meters, and a 140 gallon oil tank for calibrating the oil meter were located on the south side of the test building, as were the fuel and water supply tanks and the bleed off muffler.

The feedwater heater air-vent-drain was piped outside through south wall of the building. The exhaust from the turbine driven Worthington Type S cold water pump was also piped to the outside. The other vents and drains on the feedwater equipment were left as in service since the amounts of steam exhausted were small and did not cause noticeable condensation in building and on instruments.

On completion of building, test engine SP-4401 was moved in on the track to the predetermined point where the flanges on the wye pipe for bleed-off steam could be connected with the front of the piston valve chambers, and stack would be under the smoke jack. The cab had previously been removed from the engine. Platforms were built at the rear, level with the cab floor and on each side of the firebox. Others were built on top the smoke box at the right side, and on the boiler near the steam dome, the latter being for the servicing of the steam calorimeters, etc. Suitable steps, ladders, and protective railings were built where required for the convenience and safety of the test crew.

The frame and tanks of a then spare, semi-cylindrical tender, No. 7984, class 120-SC-1, were set on concrete supports outside of the test building about opposite to the cab platform, as shown on general plan. This tender was not of the type or capacity of the tender regularly assigned to engine 4401, class GS-1, type 4-8-4, but it had a pressure type oil tank.

The capacity of the water tank was 12,000 gallons. The water tank was equipped with gage glass tubes and scales on each corner and was calibrated so that outages could be taken directly if desired, by noting the change in water level. A similar water level gage with a colored float was placed inside the building at location convenient for observation by the Stationary Engineer.

The oil tank of approximately 3500 gallons capacity, was heated by a steam coil controlled by a thermosyphon type thermostatic valve installed on the front of the oil tank as shown in photograph section following. Air pressure, regulated to 10 psig, was maintained in the oil tank when in service to compensate for the pressure drop through the oil meter and pipe line. Since the oil tank was pressurized, it was equipped with a series of gage cocks for checking the height of the oil supply, and a duplex steam pump was installed for the purpose of expeditiously filling the tank from the supply line.

A large pipe from the main water softener discharge line conveyed water to the filling inlet at top of the tender tank, and a branch of this line was connected directly to the injector as a precaution against the possibility of water in tender inadvertently becoming too low. The line to the injector had a ball feeder for introducing the proper amount of water treatment compounds in the feed water when not using the locomotive feed water pump, which alone took similarly treated water from the tender tank.

Antifoam and other compounds were also added to the water in the tender tank in the required amount. Water from this tank was piped to the No. 5-S Worthington feedwater pump with which the locomotive was equipped.

Because of the nature of the raw water supply the cylinder spray water also was taken from the main Zeolite water softener discharge line to minimize scale deposits on valves, desuperheating baffles, and cylinder walls.

The wye pipe, made from suitable lengths of 6", 8" and 10" pipe, discharged into a muffler fabricated from a scrap tank car shell located outside the building. Boiler blow-off also discharged into this tank, which had an outlet to a sewer line.

Unarco, 3/4" Insubestos felt was used to cover the metal smoke jack below the roof line to reduce the noise from the resonating effect of the exhaust on the jack. Louvre type vents in the jack just above the roof, and canvas covered, 2" thick Glassbestos curtains, hung close to smokebox below the smoke jack were also used to absorb the noise. The louvres muffled the exterior noise considerably and reduced the amount and velocity of the air aspirated from the building into the smoke jack. Inside the plant, the curtains and the covering on the jack absorbed much of the piercing, irritating sound from the exhaust, but it was still necessary to provide suitable ear protection for test personnel.

Because of interfering piping and the design of the smoke jack over stack, it was not possible to view exhaust gases at locomotive stack from firing deck so a periscope arrangement was provided, permitting stationary engineer to view exhaust above smoke jack. However, when obtained, the smoke indicating meter was placed at firing deck for use in determining firing adjustments since observations above jack were not always conclusive particularly in cold weather when steam obscured the visual observations.

Figure 2 - Instrument and Control Panels.

Two panel boards were used and referred to as the main and auxiliary panel boards, the latter being at the left end, in the figure.

The main panel board contained the recorders, selector valves and the recorder-controllers, all of which are labeled and identified on the sketch. The details and use of these instruments and gages are covered in the several sketches and descriptions of the various phases of the test installation.

The auxiliary panel board contained the pressure gages, draft manometers, and the thermocouple potentiometer with selector switch from which most of the data for the calculations was obtained. These items are also labeled and identified.

Figure 2A-Air Supply for Control Instruments.

This figure covers a schematic arrangement of the air supply to the controllers for operating the various diaphragm type regulator valves. For this purpose the air must be dry and at a constant supply pressure.

Air from house line entered separator where moisture was removed. Air pressure was then reduced to 70 psig for supply to the relay on the bleed-off control valve. This air was filtered through felt pads and from this supply a portion went through a second reducing valve which furnished air at 28 psig to the control instruments on panel board.

Air at house line pressure was also taken from the separator to a regulator near tender oil tank, to supply air pressure to oil tank.

For convenience in piping, two 28 psig air supply manifolds were provided behind main instrument panel, one near top and one near bottom.

Figure 3 - Auxiliary - Steam Metering Manifold.

An arrangement for metering steam to auxiliaries, with steam supply obtainable either from house line or from test engine was provided with 1" and 3" steam flow metering nozzles, pressure gages, thermocouples, steam flow recorder and manifold with piping to the various auxiliaries, as indicated on sketch.

This manifold was designed so that steam used by auxiliaries could be metered using house steam or test engine steam either saturated or superheated. Also, steam could be used to operate these auxiliaries without passing through metering nozzles, as for example, when checking operation of auxiliaries at times engine was not under test.

With very low steam flows, temperature drop through this manifold was found to be excessive and the 1" size flow nozzle was temporarily moved to the engine piping for use in measuring atomizer steam and similar small steam flows during the actual tests.

While the flow nozzles are referred to as "one inch" and "three inch," these are actually the nominal size of the containing piping and the nozzles themselves are somewhat smaller. The smaller nozzle was designed for a maximum flow of 1000 lbs, of steam per hour and the larger for a maximum of 12,000 lbs. per hour. In each case the standard steam condition was 650°F and 250 psig. and correction factors were necessary for other steam conditions.

Figure 4 - Water Level and Feedwater Control System

Water level in boiler was maintained by a Bailey Recorder-Controller. Pressure differential between connection in steam dome and at a lower point below water level (each 15" above and 15" below desired normal water level line) actuated water level recorder-controller

This instrument in turn, regulated position of diaphragm control valve in the steam line to Worthington Type 5-S feedwater equipment. Thus by varying the steam pressure to feed pumps, the input of water to the boiler was regulated to maintain level selected by manually positioning the level selecting pointer on the controller-recorder.

The Bailey recorder-controller was provided with a selector valve permitting either manual or automatic operation of the feed water equipment from the panel board.

Tender water tank was filled with Zeolite treated water from engine house supply line. Additional treatment was added to water in tender tank as required. Water then went through cold water pump, through cold water meter and thence to feedwater heater chamber. Cold water meter was equipped with a tachometer-generator which actuated "Veriflow" meter on main panel board to indicate cold water flow rate.

In the feed water heater chamber, exhaust steam from the main cylinders heated the feedwater. The reciprocating hot water pump then pumped the heated water thru hot water meter and thence to the boiler check. The hot water meter was also equipped with a tachometer-generator to indicate flow rates, remotely, at the main panel board by means of a "Veriflow" meter. Between hot water pump discharge and meter inlet there was a toe connection to a 16 foot by 8" diameter surge chamber to reduce and cushion the pulsations from the reciprocating hot water pump. The piping to this chamber was designed to assure retention of cool water in chamber and thereby preclude loss of cushioning air.

Hot water piping was so arranged that the water after leaving meter could be directed to either the top, steam space spray check, the side check, or the meter calibrating tank outside the building. This permitted study of the effects of the steam space spray check on boiler sheet temperatures and in addition the hot water meter could be calibrated under conditions similar to service conditions.

When calibrating cold water meter, steam to the hot water pump was blanked off, and the water was pumped through the meter by the regular feedwater cold pump, the flow being diverted from heater to the calibrating tank.

Normally, in service, the exhaust steam from the feedwater hot pump is piped into the feedwater heater chamber, contributing some heat to the water during periods pump is used while there is little or no main exhaust steam. It was however, found that during standing tests this caused an undesirable pulsating disturbance to the main locomotive exhaust pressure and related items. Rearrangement of the piping so that exhuast from the hot pump discharged to atmosphere in the smoke jack, smoothed out the performance of the boiler very successfully and caused no change to feedwater temperatures as far as could be determined. This change was solely for the standing tests and not intended for use in road service.

Figure 5 - Fuel Oil Control System.

This sketch shows oil supply tank with steam lines, oil lines, oil meter with tachometer-generator, sampling valve, gear type pressure pump, diaphragm regulating valve and thermostatic controls for steam heat supply.

Because of the resistance of the extra piping and the meter, the tender oil tank was operated under 10 psig air pressure to assure adequate flow to burner. Oil lines were heated with external steam coils and were also insulated to assist in maintaining oil temperature. In addition, a portion of the oil line was steam jacketed, with thermostatic control of heating steam, to provide further control of oil temperature.

Boiler steam pressure recorder-controller recorded boiler pressure and controlled the diaphragm regulating valve in oil line to vary oil flow as required to maintain preset value of boiler pressure.

Gear pump shown was used only for those burners requiring more pressure at burner than was available through use of the 10 psig air pressure in oil tank. The gear pump was equipped with a by-pass pressure regulator which could be set to maintain desired pressures up to 150 psig at pump.

This figure also shows a diaphragm control valve in atomizing steam line to burner with a note "not used." The diaphragm control valve, operated by control air supply to fuel regulating diaphragm valve, was included in the original installation because usually,the practice is to vary atomizing steam in proportion to oil flow. However, with the "drooling type" locomotive oil burners it was found that this method of atomizing control could not be used and it was necessary to manually adjust atomizing steam in accordance with the particular combustion conditions.

Figure 6 - Exhaust Steam Control System

This sketch illustrates the desuperheating arrangement used to assure reproducibility of standing test results in road service by simulating service conditions of exhaust steam temperature and pressure at the nozzle, and thereby provide induced drafts under test conditions, consistent with those obtained in road service. The idea of desuperheating the engine steam by means of water sprays in the main cylinders for standing tests was developed and patented by Mr. W. F. Collins, Engineer of Tests, New York Central System and the method was modified for use at Sacramento Test Plant by the addition of automatic controls to maintain the temperature and a unity ratio between bleed-off steam and cylinder spray water.

The standard locomotive piston valve rings and bushings were replaced with those designed for precision control of the flow of the high pressure superheated steam to the cylinders. Steam flow to cylinders was controlled by use of a micrometric valve positioning gear arrangement on the valve stems. Main locomotive pistons were removed from cylinders and replaced by multiple water spray nozzles and baffles to mix thoroughly the superheated steam and desuperheating water.

In operation, the piston valves were first positioned approximately, and later after conditions stabilized were accurately adjusted to obtain desired loadings on boiler. The throttle was then slowly moved to fully opened position and superheated steam allowed to pass into cylinder through the diamond shaped valve ports in tool steel inserts in the rear bushings which controlled the flow. As the throttle was opened, the desuperheating system was also placed in operation and, as the highly superheated steam passed into the main cylinders, the water sprayed in became mixed with the engine steam and being converted thereby into additional steam, reduced the final temperature of the mixture to that of the exhaust steam condition desired.

The conversion of spray water into steam resulted in an excess of steam over that actually generated in the boiler. This excess or "surplus" was removed by bleeding off an amount equal to the water sprayed in so that steam to exhaust passages was equal to steam to cylinders. Otherwise the excess steam would raise the draft and the simulation of road service conditions would not exist and the results would be misleading.

In this test plant, the quantity of spray water was controlled automatically to maintain the selected exhuast steam temperature. The bleed off of surplus steam also was controlled automatically to a unity ratio with the amount of spray water. The surplus steam was bled-off thru special connections from steam chest heads into a "Y" shaped pipe and out thru a metering orifice and a control valve into the muffler located outside the test building.

The remaining steam, equal to that generated by the boiler less the amount used by auxiliaries, passed thru the exhaust passages to the nozzle stand, where, with the feedwater heater in operation, a portion was diverted into the heater chamber; the balance issued from the exhaust nozzle to create a draft in the smokebox that would be obtainable in actual road service.

Figure 6A shows a diagramatic view of the cylinders, piston valve chambers, and the steam and water flow. Superheated steam entered thru the main steam pipe into valve chamber. Valve always was so positioned that steam could only enter cylinder thru steam ports at rear bushing. The valve bushing at rear of chambers had tool steel inserts containing diamond shaped ports as shown on Figure 6C. The front outside and the rear inside and outside piston valve rings were stellited on outer edge to reduce the eroding effect of the steam flow on the rings and also to cut through scale deposited on bushings when spray water flashed into steam.

Sprays and baffles were located in cylinders so that spray water and superheated steam were thoroughly mixed. Many arrangements of sprays and baffles were tried before the desuperheating was satisfactory and a number of the modifications are shown in the photographs.

Desuperheated steam then passed through standard ports at front of cylinder to front of valve chamber. Here steam flow divided, the steam bled off going through wye pipe to muffler and remainder through exhaust steam passages to nozzle stand. Since the valve spools were hollow, some exhaust steam passed through valves and exhausted through rear exhaust passages.

In order to position piston valve accurately to obtain desired loading on boiler the main valve positioning device as shown on Figure 6B was developed. Valve steam extension with Acme threads was fitted to valve stem. When worm wheel was rotated, it being restrained by plates on each side, the valve, stem and extension were drawn out or pushed back as desired. Indicator on stem was arbitrarily graduated but it aided in positioning the valve. In order to rotate worm wheel, a worm gear was applied. This worm gear was rotated by ratchet handle or reversible air motor as desired and the arrangement permitted very fine adjustments of the valve position and the steam flow.

The adjustable orifice in the bleed off line was hand set for each steam rate so that meter correction factor would be unity for the steam temperature and pressure conditions at orifice. Thus the flow reading on recorder chart would be correct as read when multiplied by the chart factor common to both spray water and bleed off steam charts and the ratio linkage between spray and bleed-off instruments would exert its proper control.

The amount of water sprayed into the cylinders was controlled by the Pyrotron temperature recorder-controller and in turn, the spray water recorder which was linked with the bleed off steam meter had a controller which positioned the bleed off steam control valve so that the rate of steam flow through bleed off system was always equal to spray water rate during automatic operation.

Spray water was taken from the Zeolite treated water supply to minimize scale. Spray pump motor was of a constant speed type and regulation of spray water pressure to the Bailey control valve was accomplished by means of a diaphgram operated valve which throttled water flow as required. The purpose of regulating spray water pressure to the actual control valve was to maintain steady state conditions over a wide range of spray water flow rates and to thereby provide for more uniform control at spray water controller which further throttled water supply as required to maintain desired steam temperature conditions.

Provision was made to proportion water flow to each cylinder individually by manually operated valves which were used to balance steam temperatures in the two cylinders.

A resistance type pyrotron temperature recorder was used to show steam temperatures in exhaust passages of each cylinder and provided a ready means of indicating temperature balance between the two cylinders. Recorder was equipped with a third pen to record spray water temperatures.

Spray water was filtered in special all brass manifolds on each side of engine and from this manifold on to the actual spray heads, only non-ferrous metals were used for piping and valves. Prior to developing this arrangement, minute particles of scale from the piping which was originally iron, lodged in the very small orifices in the spray heads and prevented satisfactory desuperheating. All piping and connections inside the cylinder were subjected to high steam velocities and had to be carefully secured and tightened.

Figure 7 - Temperature Measuring Arrangement.

This sketch shows the temperature measuring provisions. Figure 7A follows Figure 7 and identifies the various points where temperatures were taken.

The Brown Electronic push button type Indicating Potentiometer, labelled "M", had a range of 0 to 1000°F using Iron-Constantan thermocouples, and was used mainly to indicate temperatures required in calculations or for control and accordingly was mounted on auxiliary panel board. Figure 7A enumerates the temperatures taken and location. This instrument, originally for but 12 temperatures, had a selector switch added in series with one of the push buttons which combination permitted the selection of any one of 23 different thermocouples.

A Brown Electronik 12-point strip chart recording potentiometer, labelled "B", was used for recording boiler and firebox sheet temperatures as described in table, Figure 7A. This instrument had a range of 0 to 1200°F with Iron - Constantan thermocouples; chart speed was 20" per hour and printer operated through one cycle of 12 points in three minutes.

A Brown Electronik 16-point strip chart recording potentiometer, labelled "C", was used to record firebox gas temperatures and firebox sheet temperatures on fireside of sheet. This instrument had a range of 0 to 2400°F with Chromel-Alumel thermocouples. Chart speed was 13.2" per hour and printer operated through one cycle of 16 points in four minutes. For gas temperatures both Inconel and Sillimanite protecting tubes were used for the Chromel-Alumel thermocouple wires, but both proved unsatisfactory except in those probe holes near the rear tube sheet where temperatures were below 2000°F. The ceramic (Sillimanite) tubes failed account thermal shock, i.e. rapid changes in ambient gas temperature and sometimes possibly from boiler leakage. The Inconel was not satisfactory as the temperatures in the firebox proper were found to be too high. As described elsewhere, gas temperatures throughout the firebox were successfully obtained by means of water cooled aspirating probes containing shielded and protected noble metal couples.

A Brown Radiamatic Pyrometer (not shown on sketch) was also used successfully for some points in the firebox. This was a total radiation pyrometer which converts the radiant energy emitted by a heated object into electrical energy which can be measured in terms of temperature by a suitable meter.

The fireside temperatures on side sheets were most difficult to obtain and even the most successful means of protecting the thermocouples proved inadequate to assure reliable indications for more than a very brief time. Leakage of boiler water on the couples was a large factor in their rapid deterioration.

A Brown Electronik 8-point strip chart recording potentiometer, labelled "A", was used to record smokebox gas temperatures. This instrument had a range of 0 to 1000°F with Iron - Constantan thermocouples, chart speed was 10" per hour and printer operated through one cycle of 8-points in 4 minutes. The thermocouple wires were protected by steel tubing.

A resistance type thermometer, in wye pipe, connected to Bailey Pyrotron temperature recorder-controller labelled "RTC," indicated wye pipe steam temperature and operated controller used to maintain desired preset value of temperature by controlling spray water as noted elsewhere. This instrument had a range of 100°to 500°F with one complete rotation of recording chart occuring in 8 hours.

A Bailey Pyrotron resistance type thermometer, labelled "RT," had three pens and recorded left and right wye pipe steam temperatures and spray water temperature. The wye pipe temperatures were taken near outlets from piston valve chambers and served to indicate balance between cylinders. These two temperatures were recorded by pens with a range of 100°to 500°F. The third pen showed spray water temperature near spray water controller, this pen recorded on a range of 0 to 400°F. The recording chart made one complete revolution in 8 hours.

Figure 7B shows the development of thermocouples to measure water-side sheet temperatures at firebox. Style "A" was the first type made. It had a copper disc in which thermocouple wires were imbedded, which could be forced against water-side of firebox sheet through existing wash out plug holes. The moulded bakelite in the cap served to protect thermocouple wires as well as act as a heat dam to prevent too rapid heat transfer through tube and thus reduce temperature at couple junction in disc. Some of this style lasted about one year which was considered a satisfactory service life, however, several disadvantages were found. With the equipment available it was difficult to satisfactorily mold the Bakelite in the cap. The stuffing box and the gasket at cap became incrusted with boiler water solids and prevented smooth operation in that it was difficult to keep copper disc against firebox sheet during expansion and contraction of boiler. It was also found that size and shape of cap and disc was critical and that hot spots would develop sometimes at point of contact with sheet if shape did not allow sufficient water passage past end.

The next modification "B" was similar to the final style "C" but in this arrangement the wires went through stuffing box composed a soft rubber cork in a special copper tube fitting at the end of a foot or more of copper tubing, through the tubing and a standard fitting and then into boiler water space. Stuffing box was tightened sufficiently to prevent leakage and the tubing was made long enough to be sure it would be cool and heat damage to the rubber was therefore avoided. The variously insulated thermocouple wires were also dipped in Bakelite Varnish to prevent attack from boiler water and to reduce heat conduction from the couple. This style gave very good results but it was difficult to protect wires under screw head and service life was from but three days to two weeks, because of boiler water attack. Bakelite varnish over fiber glass proved the best insulation, with uncoated glass and ceramic tubes being among the quickest to fail.

Style "C" shows the final design used. Wires were placed in a 3/16" copper tube with end closed by flattenning at contact with sheet. At the opposite end this small tubing was sweated inside of 3/8" copper tubing to make the connection steam tight. A regular fitting was used on the 3/8"pipe where couple protecting tube entered boiler. This arrangement gave satisfactory results and more than a year of service.

Washout-plug size holes were provided in outside wrapper sheet as necessary to permit access to water-side of firebox sheet for drilling and tapping the hole in sheet for holding screw and to allow application of couple. Outside wrapper sheet was also drilled and tapped in a nearby space between staybolts for application of the 3/8" IPS copper tube fitting where couple entered boiler. A picture of one application is included in photo section.

This style could be successfully applied at any time to firebox sheets reasonably close to outside sheet but the application of couples to the crown sheet for example, could only be done during renewal of the sheet, or portion thereof. Thermocouples of this style were also successfully applied in the crotch of each of six Security Circulators during their installation in the boiler.

Figure 8 - Pressure Measuring Arrangement

This covers the pressure recording and indicating equipment used on the standing test. The pressure gages at firing deck were the usual cab gages with the addition of an atomizer steam pressure gage.

The gages for steam pressure in the flow nozzle lines were used in determining meter correction factors to be applied to chart reading of auxiliary steam flow.

The boiler pressure at dome was transmitted to a gage at the auxiliary panel board and to the boiler pressure recorder-controller at main panel board. This controller regulated fuel oil flow to maintain desired boiler pressure.

The exhaust steam pressure was transmitted to a pressure gage at auxiliary panel and a pressure recorder at main panel. This pressure was used when determining proper exhaust steam temperature to maintain simulation of road service conditions.

Two four pen pressure recorders were located on main panel, recording pressures as noted on sketch.

The steam pressure in feedwater heater chamber was transmitted to auxiliary panel and used for calculating condensate recovered by the feedwater heater from the exhaust steam.

The steam pressure in wye pipe was transmitted to auxiliary panel and used in determining adjustable orifice settings.

The pressure gages at each cylinder for spray water pressure and steam pressure were used in balancing the steam flow and temperatures in the two cylinders.

The pressure in the cold water pipe to feedwater heater chamber was measured on right side of engine where pipe enters smokebox. This pressure was transmitted to main panel. The purpose of installing this gage was merely for the convenience of the operator to observe performance of feedwater system, in that the pressure gave an indication of flow rate and helped in diagnosing trouble in feedwater system. It was noted after installation that pressure loss between cold pump and heater became quite large at the higher rates of flow.

Figure 9 - Draft Measurement Arrangement.

This sketch shows the draft measuring arrangement used.

In order to conveniently read all the drafts at a central location a bank of manometer tubes was used, all connected to a large area water tank to reduce zero drift to a minimum. With highest drafts on all tubes, the lowering of the water level or zero point, was negligible.

A system of interconnected plug valves was used when reading the manometers. All the valves were connected to a shut-off handle and thus when tubes were to be read, all were shut-off together. This gave in effect the simulataneous reading of all drafts at a given time.

Although the scale for reading the drafts could be raised or lowered, it was found more practicable to adjust the zero by carefully adding or removing water from reservoir as required and leave scale fixed in position.

Sketch also shows relative position of draft tubes in smokebox.

Figure 10 - Smoke Measuring Arrangement.

This sketch covers the smoke density indicating and recording arrangement.

A photo electric cell and light source were located just above smoke stack, and registered density of gases emitting from the stack. Indication was given on a meter at firing deck in Ringelmann numbers, i.e. from 0 to 5 with 5 being complete opacity or no light received, by photo cell. In addition, indication was transmitted to a high speed, indicator-recorder at main panel where a record was made of smoke density on a strip chart.

The indicator at firing deck was provided with a red warning light adjustable to go on at a predetermined smoke density. This was usually set at #2 Ringelmann, merely for the information of the Stationary Engineer.

The 115 volt power source had a separate ground line between indicator at firing deck and recorder at panel to provide for better electrical characteristics and prevent false indication.

Figure 11 - Gas Analysis and Sampling Equipment.

The flue gas analysis was obtained by two means: "A" by automatic instruments consisting of the oxygen (O_2) and carbon dioxide (CO_2) analyzers and recorders with related equipment, and "B" by Orsat analysis at completion of run, of a continuously collected sample.

A. Automatic analysis and record.

The sample for the two recorders was taken from a five point sampler located approximately midway between the exhaust stand and the tube sheet inside the smokebox.

The sampler consisted of a cross of 18" lengths of 1/4" iron pipe. The end of each leg of the cross was fitted with a tee with the leg of the tee connected to the pipe. All tees were in the same plane as the legs of the sampler which was mounted in a vertical plane and at right angles to the longitudinal center line of the boiler with arms of the cross vertical and horizontal. The gas sample entered thru the runs of the four tees and also thru a 1/16" hole at the center of the cross on the down stream side. The copper tubing connecting the sampler to the panel board was attached at the center of the cross on the upstream side opposite the 1/16" hole.

From the sampler, 3/4" copper tubing conducted the sample to the panel board. The gas then passed thru an inductor and preliminary washer, a gas pump and scrubber, a separator, and then divided for each of the two analyzers by which time it was under positive pressure.

The gas sample for the CO_2 recorder, after leaving the separator went through a positive pressure indicator, which was also a safety device to prevent excessive pressure or vacuum in the CO_2 analyzer, and an SO_2 absorber before entering the analyzer.

The inductor-preliminary-washer cleaned the sample of sand and other particles and also cooled the gases. The gas-pump scrubber was of the water aspirator type which drew the gas from the smokebox through the inductor and delivered it under positive pressure to the subsequent apparatus. The arrangement had a motor driven centrifugal water pump to supply the pressure necessary for the aspirating action and the water was recirculated with make up water being added automatically. The separator was of the centrifugal type to remove any water remaining in the gas sample after it was pumped and scrubbed.

This aspirating equipment was furnished with the Bailey Oxygen Analyzer and provided a large sample supply. The CO_2 meter was equipped with a small mechanical vacuum pump whose volumetric capacity was felt to be inadequate because of the distance of the instrument from the gas source. In view of the relatively large sample available at the O_2 analyzer a portion was diverted to the CO_2 meter through the safety device devised to prevent dislodging the oil in the CO_2 meter pump, because of excess pressure or vacuum at times when only one of the pumps was turned on. With only the oxygen analyzer pump on, the gas sample positive pressure forced the colored water from the lower jar up into the top reservoir or trap and then the system vented itself. With only the CO_2 meter pump on, air was drawn through the liquid trap and tube and excessive vacuum could not be developed in the CO_2 pumping arrangement. During test operation, the diverting valve from the O_2 system was adjusted, with both pumps operating, so as to assure several inches of gas sample pressure in the safety device from which the CO_2 meter took its sample.

The CO_2 and O_2 analyzers were each equipped with indicator pointers and also recorded gas analysis on circular charts.

B. Manual Analysis of Flue Gases.

The sampling system for Orsat analysis had a sampler identical to that for the recorders, and it was located closely in front of the sampler used for the recorders. The gas sample was obtained by means of a vacuum developed by a steam jet exhauster.

A continuous sample was accumulated from the gas line through an appropriate arrangement, in a sampling bottle of two liters capacity containing an acidified salt solution. The collected sample was later transferred to the analyzing apparatus by proper manipulation of the valves and changes in relative elevation of the bottles.

The tubing connecting the sample bottle with the leveling bottle contained a pinch cock and plastic choke in parallel with each other. The diameter of the hole in the choke was such that it required 45 minutes for the liquid to drain from the sampling bottle into the levelling bottle. Thus with the pinch cock closed, a continuous sample was easily taken at a uniform rate to provide an average of the flue gases during the run, but the fluid could be quickly transferred from one bottle to the other by releasing the pinch cock.

Analysis of the gas sample was made on a Fisher Unitized, Technical Universal Model Gas Analyzer (Orsat Separators) with slow combustion unit for determination of methane and hydrogen.

Figure 12 - Firebox Survey Equipment

This sketch shows the firebox survey equipment and relative locations of probe holes, on top centerline, rear center and right side of firebox.

Firebox surveys were made by Battelle Memorial Institute representatives aided by members of test crew. These surveys were for the purpose of obtaining gas temperatures, velocities and samples for analysis of firebox conditions. The surveys were made at the usual test rates but during special runs of long duration because of the time required.

Probe holes, as shown on sketch, were for access to interior of firebox with the various probes. Staybolts were removed from the boiler sheets at these points and holes enlarged to allow 2" ID boiler tubes to be inserted and rolled and beaded over. Removable plugs with handles were made for each probe hole and all were plugged except when in use.

Three types of probes were used in the firebox survey; a gas sampling probe, a gas velocity probe and a thermocouple probe. All probes were water cooled during use and were constructed from thin wall non-ferrous tubing.

To obtain samples of firebox gases, sampling probe was connected with cooling water hoses and with rack of gas sampling bottles. Then, by manipulation of pinch cocks and transfer bottle, and by controlling the vacuum on the sample line, saline solution was displaced in desired sampling bottles to obtain gas samples at selected locations in the firebox. Flow indicator or bubbling bottle, was placed in gas sampling to facilitate adjusting gas flow and it also indicated that gas lines were clear. After samples were taken, racks of samples were removed to a convenient location for analysis by the Orsat method.

The gas velocity probes had two pressure connections to an inclined tube manometer filled with colored xylene. The probes were of the double pitot tube type such that one tube faced up stream and one downstream each being connected to one leg of the manometer. The use of a double tube had several advantages; namely the error is less than for a normal pitot tube if the opening is not pointed directly into the gas stream, the pressure difference is greater for a given gas velocity and also, the probe can be inserted into a smaller opening. These had been calibrated by Battelle Memorial Institute for the same range of Reynold's number as applies in the firebox. The pressure differential was converted to velocity in feet per second by means of suitable conversion formulae.

The temperature probes were of the shielded gas aspirating type. Platinum - platinum, 10% rhodium thermocuples were used. The cold junction was a Dewar flask filled with water and melting ice. The voltage of the thermocouple was measured by means of a potentiometer and later corrected to temperature in degrees F. The thermocouple was protected with ceramic tubing and was shielded with a single tube of fused quartz. The firebox gases were aspirated past the couple at high velocity by a vacuum system as shown on sketch. The quartz shield reduced radiation losses from thermocouple and proved very durable in this service. Multiple type ceramic shields were also tried but were too sensitive to the thermal shock of repeated entry and exit from the firebox. However, great care also had to be taken in controlling the aspiration when using the fused quartz tubing, to avoid drawing cold air through it while very hot.

Test Run:

The following covers a typical test run at the Standing Test Plant.

Prior to actual tests, trial runs were made when necessary to determine suitability and characteristics of the new device or arrangement. Optimum damper and air openings, proper atomizer pressures, and similar items of operation were then established before the actual tests. This was not always necessary but some of the major changes made, required considerable pretest operation to obtain best results.

On the day of a test, engine was fired up using house steam for blower and atomizer, and at some suitable pressure, such as 160 to 200lbs. pressure on boiler, change-over was made to the steam from locomotive boiler and firing-up continued until operating pressure was reached.

During the firing-up period, which required from one to two hours, depending on the initial temperature of the boiler water, valves in valve chamber were approximately positioned, new charts applied to recorders and panel board made ready for operation.

After boiler was up to pressure, throttle was opened slightly to warm up piping, cylinders, etc.

After a suitable warm-up period, throttle was opened slowly to wide open position and steam rate controlled by position of piston valves over diamond shaped ports in the valve chambers. Cylinder spray water was turned on and desired loading rate on boiler was obtained by final adjustment of piston valves.

As the spray water rate, the amount of steam bled off, and the segment height of the adjustable orifice was dependent on the wye pipe temperature and pressure, a slight amount of trial and error adjustment was required when setting the test steaming rates in order to obtain proper relationship between steam temperature and pressure at nozzle balance temperatures in both cylinders.

During the above trial and error period, feedwater and oil flows were changed over from hand control on locomotive to hand control at panel board and then to automatic control. Normally no further attention was required after oil and feedwater were placed on automatic control.

After the above trial and error period and after rates, temperatures and pressures had stabilized, the test run was started. Oil, cold water and hot water meters were read at running start, at end of run and at 15 minute intervals during the run.

Temperatures, pressures and drafts as indicated by instruments on the auxiliary panel board were read at start and at end of run and at each 5 minute interval.

Normally the runs were of 45 minutes duration but for special tests and firebox surveys, were as long as three hours.

After completion of a test run, piston valves were repositioned to obtain next wye pipe pressure desired, the exhaust steam temperature controller was set to the corresponding temperature and the temperatures in the two cylinders balanced by adjustments to the manually operated spray valves.

After conditions again stabalized, the test run was made in the same manner as before.

During and immediately after the change in rate any necessary firing adjustments were made such as to dampers, atomizer, etc., to obtain optimum performance and minimum color at stack. The remaining runs usually two more, were made in a similar manner.

Four runs of 45 minutes duration each could be obtained in one day under normal conditions with as many as five being done during tests of a repetitious nature. Wye pipe pressures were selected so as to produce firing rate increments of roughly 1000 pounds of oil per hour during a four run series of tests. Normally no runs were made at firing rates below 3000 pounds per hour. The high rates were limited to those within the capacity of the feedwater pump to maintain the water level.

The locomotive flues were well sanded before each test run and, when absolutely necessary, during the test runs at intervals sufficiently frequent to avoid excessive changes in steam and flue gas temperatures.

Atomizer steam pressure was adjusted for optimum fire and stack conditions.

A continuous sample of flue gas was taken throughout each test run as an average sample covering the duration of the test period, for Orsat analysis. Continuous fuel oil sample was also taken as an average for each day of testing, for determination of moisture, density, and heat value. Figure 13 shows sample results of these determinations.

Examples of the data manually recorded are shown in Figures 14 to 25 inclusive covering the oil and water meter readings, the temperatures, pressures, and other observations made during a series of tests at wye pipe pressures of 4, 7, 10 and 13 psig, as shown in heading on each sheet.

The results were calculated on prepared forms illustrated by sample sheets such as Figure 26, for the oil, air and water rates and Figure 27, for the boiler efficiencies. Sample calculation of air-fuel relations, Figure 28, from the flue gas analysis also is included to show method used by Battelle Memorial Institute representative.

<u>Measurement of Steam Consumption by Auxiliaries:</u>

When it was desired to measure the steam consumed by any one or a group of auxiliaries such as air compressors, blower, turbo generator etc., the necessary valves in the manifold were operated to cause the steam supply to flow through either the 1" or 3" orifice depending on the steam rate expected.

To determine the steam consumption, the auxiliary to be tested was operated in a manner simulating service as closely as possible.

Pressure and temperature readings were taken at orifice, to permit calculation of correction factor to be applied to steam flow as recorded. These correction factors were based upon specific volume of steam and the correction factors for the various steam conditions were obtained from manufacturer's data covering the orifice installed.

Figure 29, "Metering Orifice Correction Factors vs. Orifice Temperatures for Various Orifice Pressures, " was a chart for determination of these correction factors as used in metering the steam consumption of the various locomotive auxiliaries, and was used in connection with the 1" and 3" orifices. It was drawn from a chart furnished by the Bailey Meter Co., for this equipment. The maximum capacity of the 1" orifice was 1000 pounds of steam per hour, and for the 3" orifice, 12,000 pounds per hour, at design conditions of 250 psi gage steam pressure, temperature 650°F., with a maximum meter differential of 120 inches of water. Variation of steam condition from design conditions was compensated for by use of the correction factors. Entering the graph with the measured gage pressure and temperature, the correction factor for steam under those conditions was obtained. The chart reading when multiplied by this factor and the chart factor then gave the flow in pounds of steam per hour.

Calibration of Meters.

A. Oil Meter:

The oil meter was calibrated when occasion required without relocating, by weighing the amount of oil passing through the meter during a measured time interval. Oil was fed from the tender oil tank, under air pressure, through the oil meter and a branch line to a weighing tank of approximately 140 gallons capacity.

One valve in the line was used for setting the flow rate in advance of actual run and another valve was used for quickly starting and stopping the oil flow for calibration run. The oil was weighed in a tank held in suspension by a calibrated traction dynamometer. Readings were taken of oil meter and dynamometer dialometer before start, with weighing tank empty, and at finish of run after flow was stopped. Oil temperatures at meter were taken at regular, frequent intervals during the run.

The true weight of the oil through the meter was determined from the difference in the dynamometer dialometer readings. The apparent gallonage, from difference in oil meter readings, was adjusted to a temperature of 60°F. by using the average temperature from the readings during the run and the expansion co-efficient for group "O" petroleum oils. By means of an hydrometer, the density of the oil in lbs, per gallon at 60°F. was determined from a representative sample and the apparent or meter-indicated amount converted to pounds.

The actual weight, from the weighing tank divided by the apparent weight from meter readings established the meter correction factor for the particular rate of flow. The apparent flow rate used in plotting the meter correction curves was obtained by dividing the difference in actual meter readings by the time interval.

From these calculations, for the various flow rates used in the calibration, meter factors versus the apparent flow rate were plotted and a smooth curve drawn through the plotted points.

Figure 30, "Meter Correction Factors vs Flow Rate," is a typical calibration curve used in the test calculations for obtaining the factors by which the oil meter outages in gallons were multiplied to determine the correct metered volume of fuel oil, depending on the apparent flow rate in gallons per minute for the test period. The apparent flow rate is defined as the difference between meter register readings in gallons taken at start and finish of each test period, divided by the time interval involved, in minutes.

This factor curve covered the range of flow rates used at the Standing Test Plant.

B. Cold Water Meter:

The cold water meter was also calibrated while in its usual place, by the use of feedwater pump equipment and appropriate branch piping. The hot pump was blocked and the water from the meter diverted to the large calibrating tank.

Data was taken in a manner similar to the method used for calibrating the oil meter, using one valve to adjust flow rate and another for starting and stopping the calibrating run. Height of water in calibrating tank was measured and water meter readings taken before the start and following the finish of calibrating run.

The difference in gallonage in the calibrated tank divided by the difference in meter readings gave the correction factor, while the difference in meter readings divided by the time interval gave the apparent flow rate used for plotting the results.

In a manner similar to that for the oil meter, values of meter correction factor versus apparent flow rate was plotted and a smooth curve drawn through the plotted points.

C. Hot Water Meter:

To insure accuracy of calibration for service under the difficult conditions imposed by the use of a reciprocating hot water pump, the hot water meter was calibrated under the same conditions, with meter in place and using heated water supplied by the regular feedwater equipment. Effluent was, however, diverted to the calibrating tank where it was discharged at the bottom of the calibrating tank through a locomotive type safety valve set to open at 250 psig in order to duplicate the pressure conditions and the action of the boiler check in normal service.

To supply the hot water and the steam to operate the pump, the engine was manually fired during calibration period using the injector to supply the boiler. The locomotive throttle was opened enough to supply sufficient exhaust steam to feedwater heater chamber to raise outlet temperature of water to normal operating range.

Calibrating tank was filled about one third full with cold water prior to each calibration run so that flashing and evaporation of the high temperature water discharged during the calibrating run would be minimized.

Height, as measured in gage glass, and temperature of water in calibrating tank, together with meter readings, were taken before start and after finish of each run. Precautions were taken to assure that temperature of water in gage glass and tank were similar. Water temperatures at meter were read at regular, frequent intervals during the run.

The amount of water in calibrating tank at start and at end of run was converted into pounds by multiplying gauged gallonage by density factor for the measured temperature of the water in tank. The weight at finish less the weight at start was the weight of water through the meter.

The difference in meter readings multiplied by the density for the average temperature at meter gave the apparent weight through the meter.

The weight of water as determined by the calibrating tank divided by the apparent weight indicated by the meter gave the meter correction factor. The difference in meter readings divided by the time interval gave the apparent flow rate used for plotting the data.

Curve of meter correction factor versus apparent flow rate was drawn in the usual manner, and the curves for both hot and cold meters shown on one graph sheet, for convenience. Sample curves are shown in Figure 31, the lower being that for the hot water meter readings.

The upper curve is an example of the meter factors used for the cold water meter to determine the correct volume of cold water in gallons used by the boiler feedwater heater, and covered the apparent meter flow rates usually used.

Figure 32, "Density of Water vs Temperature," was made up for convenience of reference and is a plot of the variation in the weight of water, pounds per gallon, relative to temperature, degrees Fahrenheit, and was used in connection with the calculations made from the readings of the water meters.

Calculation and Control Graphs:

A. Exhaust Steam Pressure Temperature Relation.

The exhaust nozzle pressure temperature curve shown on Fig.33, was used as a control for establishing conditions of exhaust steam temperature and pressure at the exhaust nozzle during the first portion of the standing tests. This curve was developed by plotting curves of average exhaust nozzle steam pressure versus steam temperature from data obtained during preliminary dynamometer road tests of basic arrangements on engine 4401, and drawing a smooth lower limit curve through the temperatures indicated by these curves. The lower limit curve was used in order to have a margin of safety in duplicating road operation conditions. On this curve, the temperature for 15 psig exhaust nozzle pressure was found to be 379°F. and this was selected as a principal reference point because it represented a large percentage of locomotive operation on grades.

The same data from dynamometer tests were then plotted on a steam temperature- entropy chart together with the initial or inlet steam conditions and these points connected by straight lines. The slope of these lines was considerable, as might be expected from the conditions of road service, so a line was arbitrarily drawn through the point for 15 psig and 379°F, with an intermediate slope to represent as well as possible by a single condition, the many different ones of service.

Actually the deviations of service conditions from the pressure temperature relation selected, would be inconsequential to the applicability of the test results, particularly in view of the margin provided by the temperatures being in the lower range and the fact that for reductions in exhaust pressures effected through nozzle enlargement on the test engine, a closely similar change could be expected on an engine in service.

The curve thus developed was advantageous and while not technically correct for all combinations of nozzles tested it was a necessary compromise to avoid extensive pre-testing of the trial arrangements in road service.

The curve shown in Fig. 33, was used until July 1948 at which time the Type E superheater units had to be renewed in the test locomotive. The set of type "E" superheater units applied at that time conformed to a new standard in length, whereby the unit return bends at firebox end were located 48" from the boiler back tube sheet as compared with the units removed which were 24" longer having the return bends 24" from rear tube sheet. As the change to the shorter units resulted in a reduction in temperature of the superheated steam ranging from 40°F to 50°F, it was necessary to develop a new exhaust pressure-temperature curve lower than that used for the previous tests, in order to restore a suitable value to the heat drop of the steam passing through the desuperheating system so it would be comparable to that of the previous standing tests and road operation.

The latter curve is shown on Figure 34 and it may be noted that for the various pressures the temperatures are of the order of 40°F lower in the low range and 50°F lower in the high range.

These reductions to the temperatures shown on the new control curve were selected by consideration of data obtained through comparative tests at the Test Plant with the two lengths of units, results of which were shown in Report ST-4, figures 4-32 and 4-33 and of data obtained during certain road tests made with several lengths of units.

B. Surplus Steam Bleed-Off Flow Adjustment Graphs.

As covered elsewhere, it was necessary to adjust the segment height of the adjustable orifice to compensate for the difference in exhaust steam temperature and pressure at the various test rates from the primary or basic steam condition, to maintain the unity ratio between spray water and bleed-off steam quantities under automatic operation of the desuperheating system.

For use with the orifice and meter, the manufactuer supplied curves from which the maximum capacity of the orifice with the meter's maximum of 53" of water differential pressure could be found for any segment height, but for the basic steam condition only. Additional curves were furnished to permit ready determination of the meter correction factor for the other steam conditions encountered.

From the latter graphs, Figure 35 was constructed. Then from this graph and data from the maximum capacity curves, the additional curve Figure 36, entitled Segment Heights vs Correction Factors was drawn. This was done by dividing the maximum capacity of the meter and orifice, which was 25,000 lbs per hour of steam at basic condition of 10 psig and dry saturated, by the correction factors in the appropriate range of values to obtain an adjusted maximum. The segment heights corresponding to the adjusted maximum capacity figures were then plotted against the correction factors.

From these two figures, No's 35 and 36, the proper settings for the adjustable orifice could be determined. However, for this routine work, the multiple references required proved tedious and a simplified method was provided through the construction from the two previously used curves of the reference charts entitled Segment Height vs Wye Pipe Temperature for Various Wye Pressures, as shown in Figures 37 and 38. These figures are the same except for range covered, one having been used during tests made while the locomotive was equipped with the long supérheater units, and the other subsequent to the change in length of units.

Using values of the steam temperature and pressure, as measured at the junction of the wye pipe and the horizontal run to the orifice, the proper setting of the segment height of the adjustable orifice could be read directly opposite the intersection of the given temperature and pressure lines.

A complicating feature in the use and setting of the adjustable orifice, was the necessity of obtaining a specified temperature of steam at the locomotive exhaust nozzle for a given pressure at that point while the control equipment operated from the non-uniformity of dissimilar steam conditions existing in the wye pipe. This difficulty was slight and was overcome by a trial and error method of approximate control settings and the use of wye pipe pressures as the primary basis for actual establishment of the steaming rates desired. Initially, a curve of wye pipe pressure versus exhaust nozzle pressure was plotted in an endeavor to permit selection of the exhaust nozzle pressures as the basis for setting the test rates, however, it was found that this relation varied too much with the changes made. Thereafter the wye pipe pressures were used and values usually to the nearest pound of pressure, were specified from experience to produce the desired overall range of firing rate and a suitable spread between the individual test rates.

The wye pipe pressures were ofthe order of but one or two pounds above the pressure at the exhaust nozzle and within the range of temperatures involved it was found that the slight orifice re-adjustment necessary from the setting that could be estimated by experience, caused only a minor disturbance to conditions at the exhaust nozzle which were then readily corrected to the final ones desired.

Where feasible,automatic equipment was used for control and to record data, not only from the standpoint of reducing the number of personnel required as observers, but to reduce the possibility of errors, to eliminate variations common to manual control, and to provide a complete, continuous, and permanent record of performance.

Pressure Charts:

1. Exhaust Nozzle Pressure Chart No. 1304P, Fig. 39 was used to record the exhaust pressure (psig) at the nozzle. This record was supplemented during test period by data from gauge on auxiliary panel.

2. Steam Pressures recorded on Circular Chart No. 350PS, Fig. 40 were dry pipe pressure at dome end, pressure at the saturated side of the header, pressure at the superheated side of the header, and pressure at the left steam pipe just above steam chest.

3. Master Boiler Pressure Chart No. 400KP, Fig. 41 showed the boiler pressure during the runs. The automatic firing control was not used on the particular day represented by this chart because several fuel oil control valves were required for operation of the multiple Coen burners in the test installation. However, chart shows how closely a desired boiler pressure could be maintained with good burners even by manual firing control, under the steady operating conditions provided by the automatic feedwater and bleed off controls and with the firing control automatic, a finer degree of pressure maintenance was obtained. The dips in the pressure line shown occurred during changes in steaming rate. For convenience the boiler pressure was also recorded on data sheets from observations of gauge on auxiliary panel.

4. Miscellaneous steam pressures shown recorded on chart No. 400KP,

Fig 42 were left and right steam pipe pressures (with pen for left steam pipe pressures set 5lbs high so that the two lines for steam pipe pressures would not coincide), oil heater steam pressure, and steam pressure to feedwater pumps. With other burners, the pressure of the atomizing steam at burner was recorded instead of the pressure to oil heater as the heater was not used with other burners.

Flue Gas Composition.

1. Carbon dioxide (CO_2) content of flue gases was recorded in per cent, on circular chart 560-1, Fig. 43.

2. Oxygen (O_2) content of flue gases was recorded in per cent on chart No 10K2, Fig. 44.

Water Level:

1. Fig 45 shows a typical boiler water level chart No. 30L, on which was recorded the water level in the boiler. It illustrates the degree of precision obtainable with the automatic control.

Flow Rates:

1. Cylinder desuperheating water flow chart No. 250, Fig. 46 was used for record of the amount of water required to desuperheat the superheated steam in the cylinders to the desired temperature of exhaust steam. The chart is self explanatory, rate of flow in pounds per hour being 100 times the chart reading, for water at $70^{o}F$.

2. Surplus steam flow chart, also No. 250, but Fig. 47 was the record of the amount of steam bled off through wye pipe. The rate of flow in pounds of steam per hour was maintained equal to chart reading times 100 for the various exhaust steam temperatures and pressures by porper adjustments to the 8" adjustable orifice.

Temperature Charts:

1. Recorded on chart No. 500 KT2, Fig. 48 were the temperatures of

the desuperheating water, and bleed-off steam in left and right wye pipes. The bleedoff steam temperatures were used to balance the steam conditions in the two cylinders.

2. Bleed-off steam temperature chart No. 500 Kl, Fig.49 was used on the exhaust steam temperature controller and is illustrative of the degree with which desuperheating system maintained desired exhaust steam temperature. Bleedoff steam temperature was also recorded manually on data sheet from potentiometer readings made on an instrument at the auxiliary panel.

3. Temperature of smokebox flue gases are shown on strip chart No. 504, Fig. 50 and the relative locations at which the temperatures were taken in the smokebox are shown on Fig 7.

4. Boiler and firebox sheet temperatures are shown on strip chart No. 506, Fig. 51, and the relative locations at which the temperatures were taken are shown on Fig. 7.

Recording Instrument Charts.

Smoke Density:

1. Density of the smoke at stack was recorded on strip chart No. 5401-N, Fig. 52, a value of 20 corresponding to No.1. Ringelmann 40 to No.2 Ringelmann, etc.

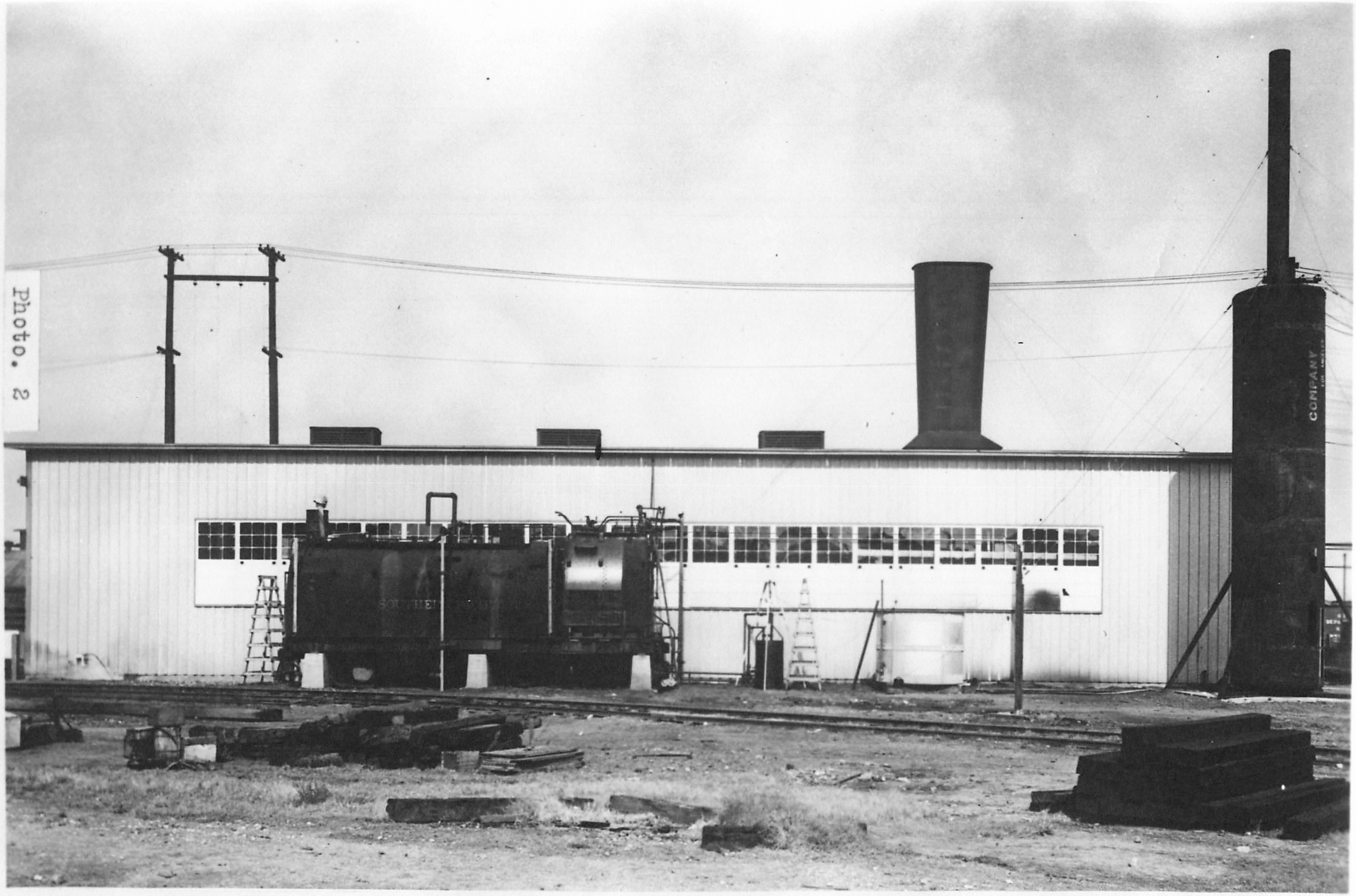
This typical record does not cover the same series of tests as the other sample charts. This example was selected as being better for reproduction because of the more legible recording of a ball type pen applied to the instrument subsequent to the date of the other test used for the illustrations.

The heavy overmarkings on the record are estimated averages used for establishing a single value for plotting on the graph of results.

Photo. 1

EXTERIOR OF STANDING TEST BUILDING - NORTH SIDE
Showing general view of building with surplus steam muffler at left.

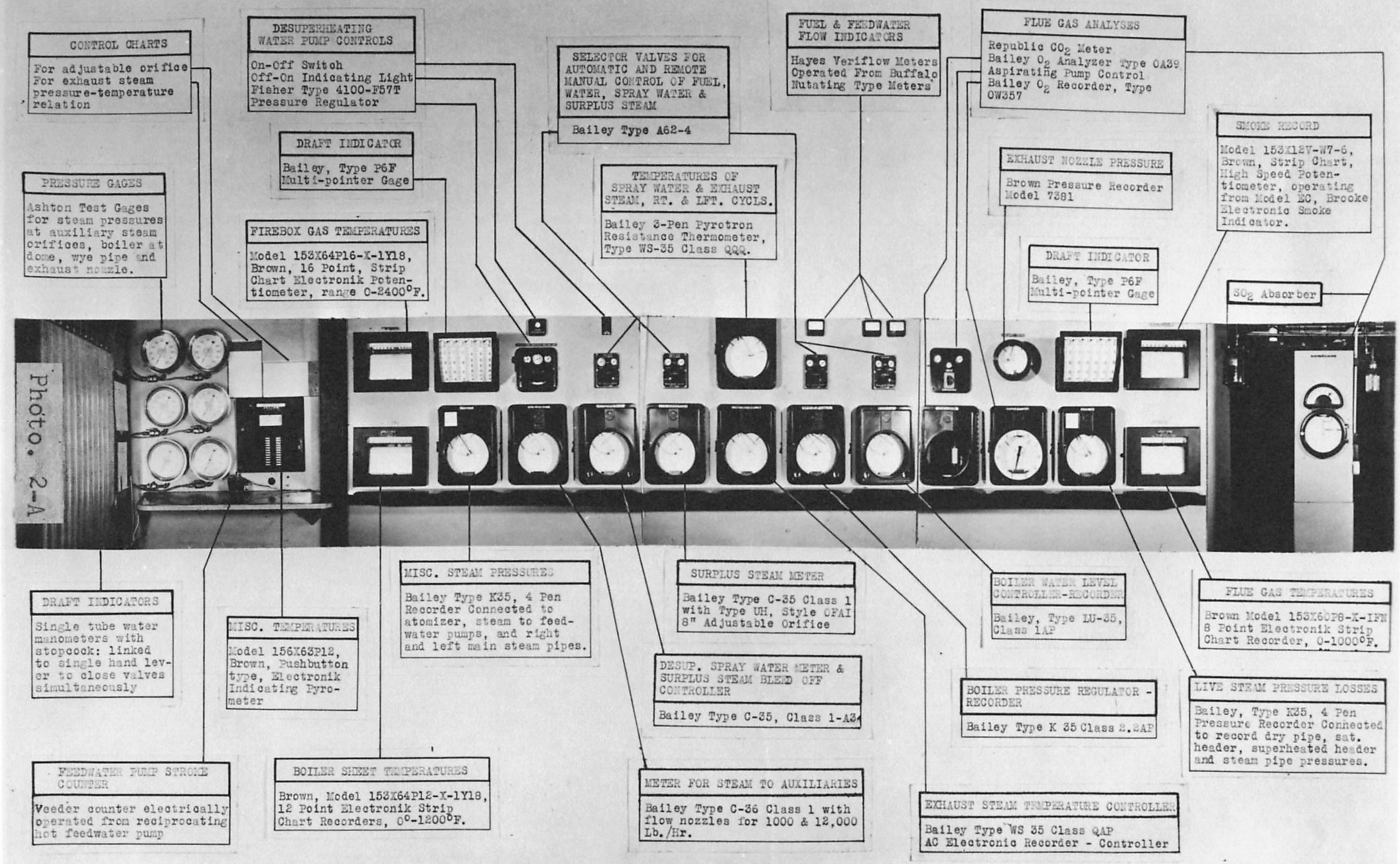
ST-38-1



EXTERIOR OF STANDING TEST BUIDLING - SOUTH SIDE

Showing from left to right, tender tanks for water and fuel oil, calibrating tank for oil meter, water meter calibrating tank, and surplus steam muffler.

ST-26-1



INSTRUMENT AND CONTROL PANELS

ST 82-1

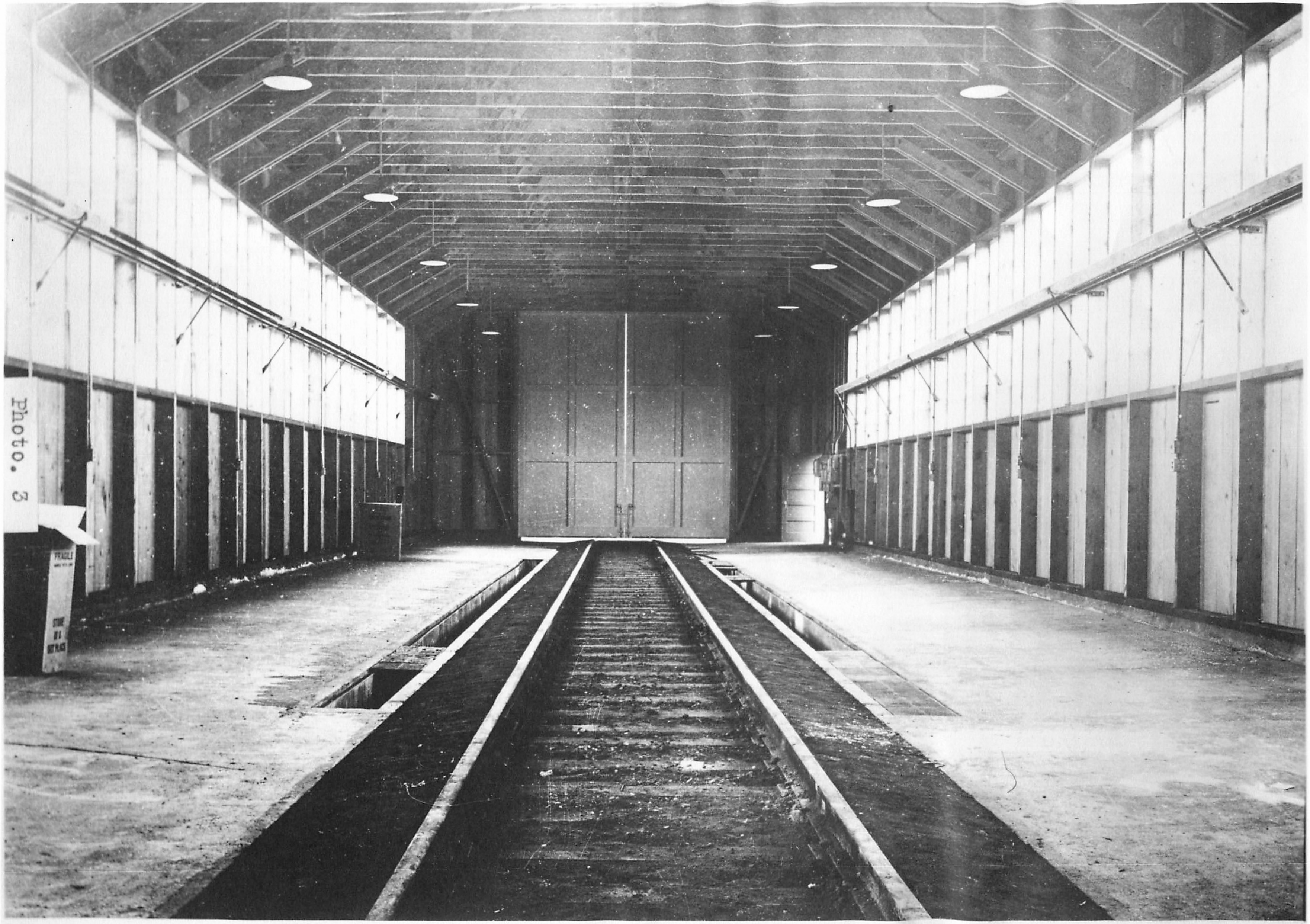


Photo. 3

INTERIOR OF TEST BUILDING - LOOKING WEST
Prior to installation of equipment and engine. ST-3

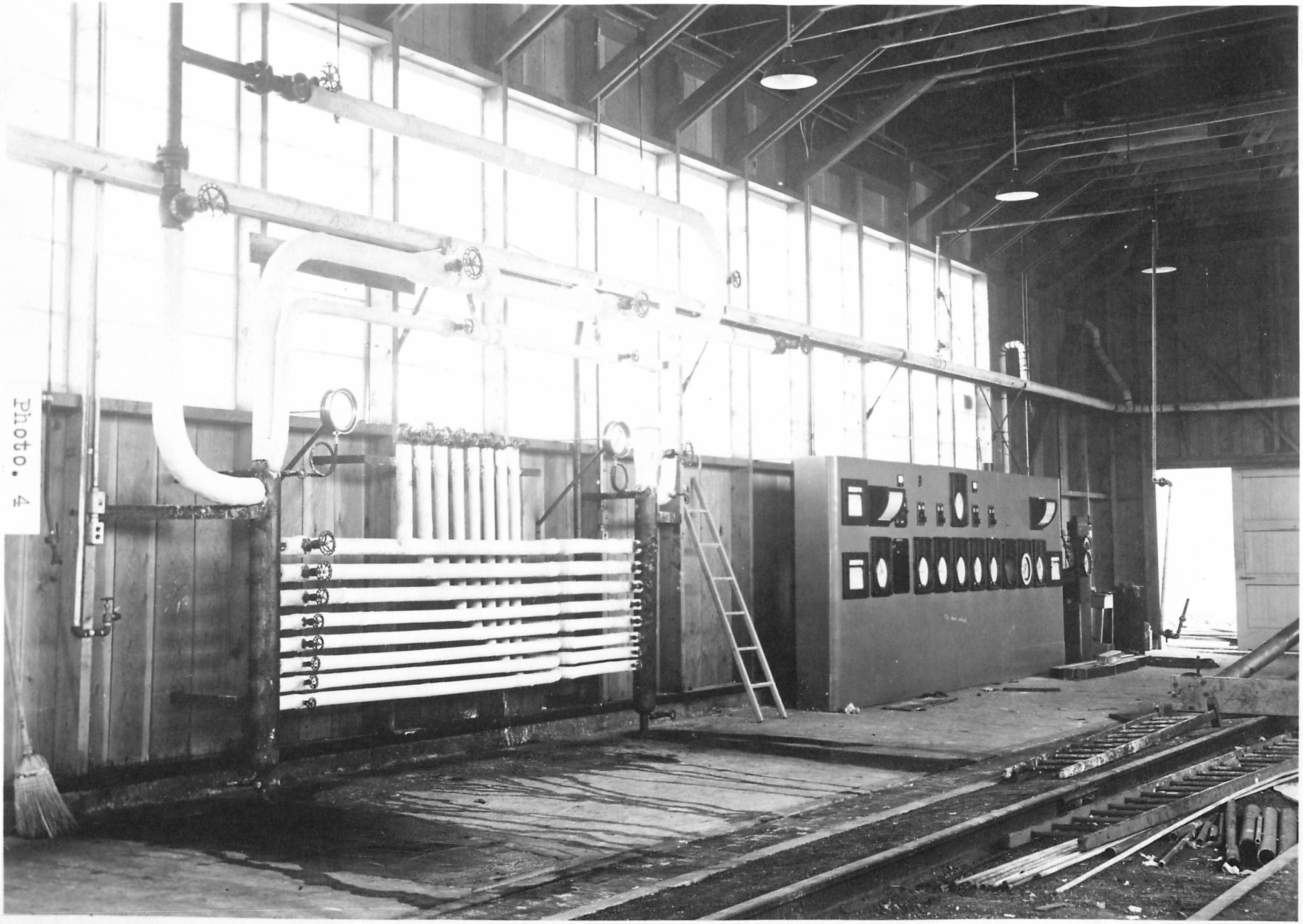
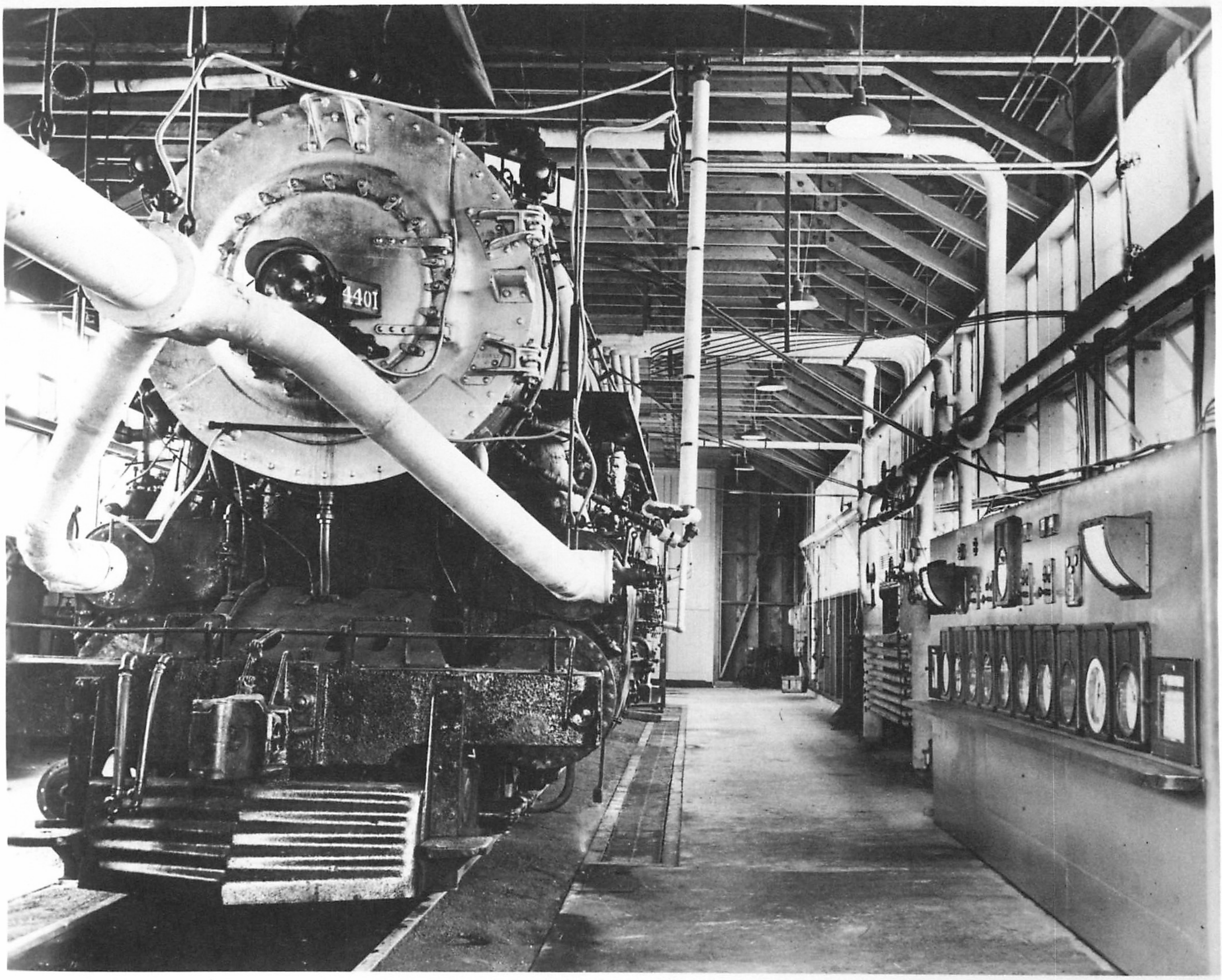


Photo. 4

INTERIOR VIEW, NORTH WALL OF TEST BUILDING
Showing east portion of north wall with metering manifold at center and main panel at right. Taken during installation of equipment.

ST-6



INTERIOR OF TEST PLANT, NORTH SIDE - LOOKING WEST

Showing main panel at right, and auxiliary manifold along wall in rear, and wye pipe at left for "surplus" steam from steam chests. Taken prior to installation of access platforms, auxiliary panel, and some other apparatus.

ST-16-2

Photo. 5

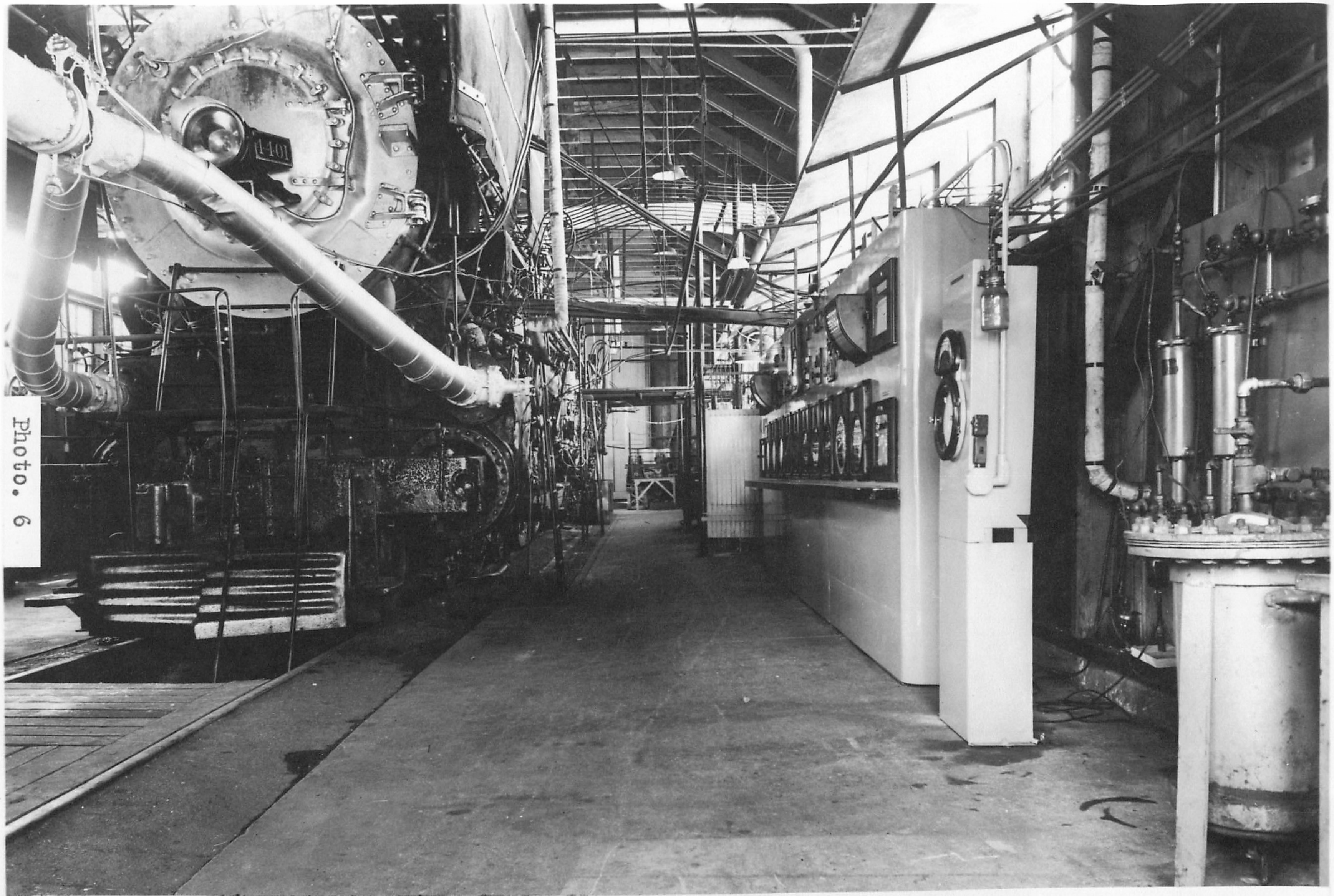


Photo. 6

INTERIOR OF TEST PLANT, NORTH SIDE - LOOKING WEST

Showing respectively, along wall at right from front to rear, separately mounted carbon dioxide recorder, main panel, and auxiliary panel. Access platform for left side of boiler shown. Wye pipe at left to remove "surplus" steam from steam chests. Front curtain raised to show smokebox.

ST-67-1

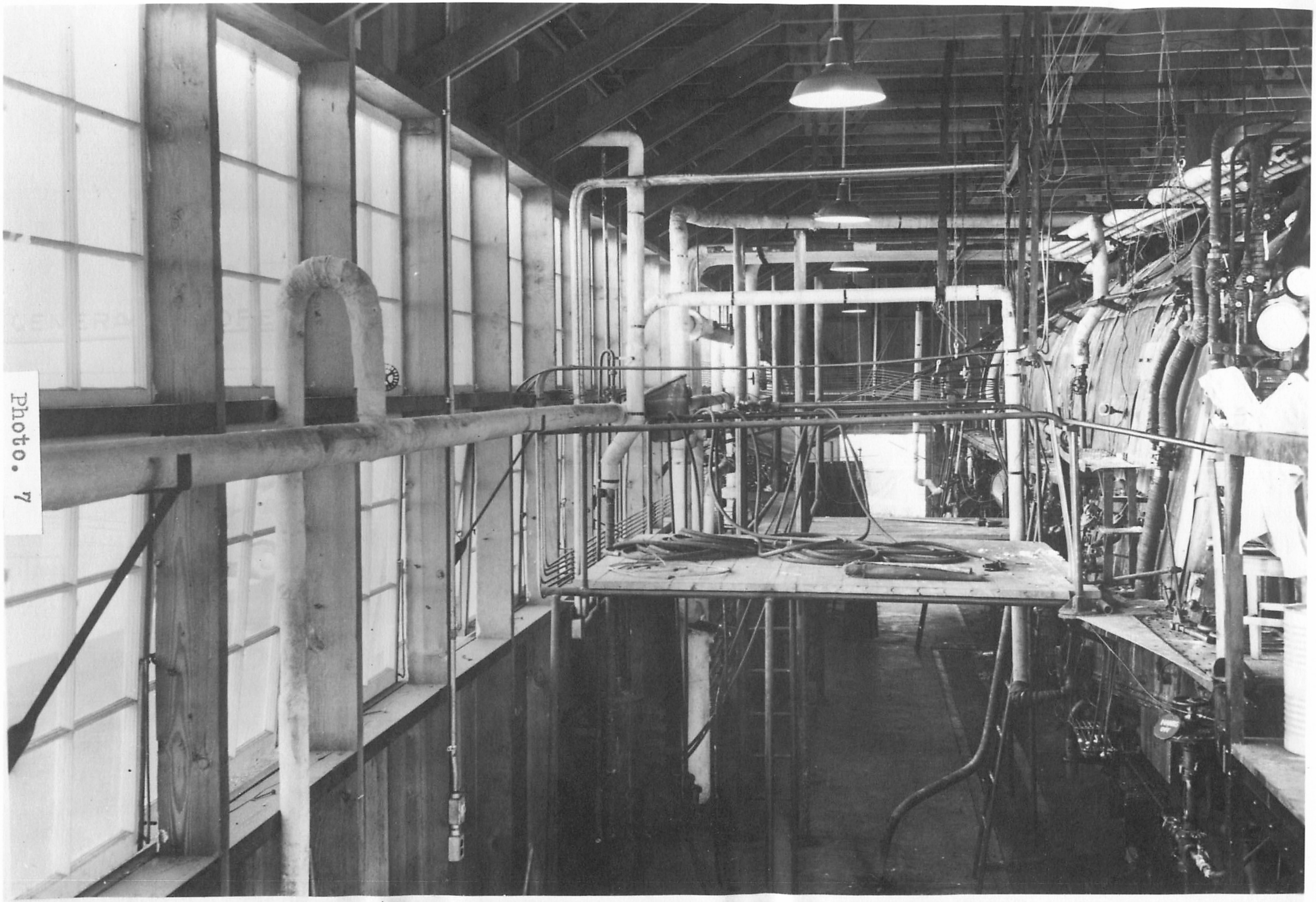


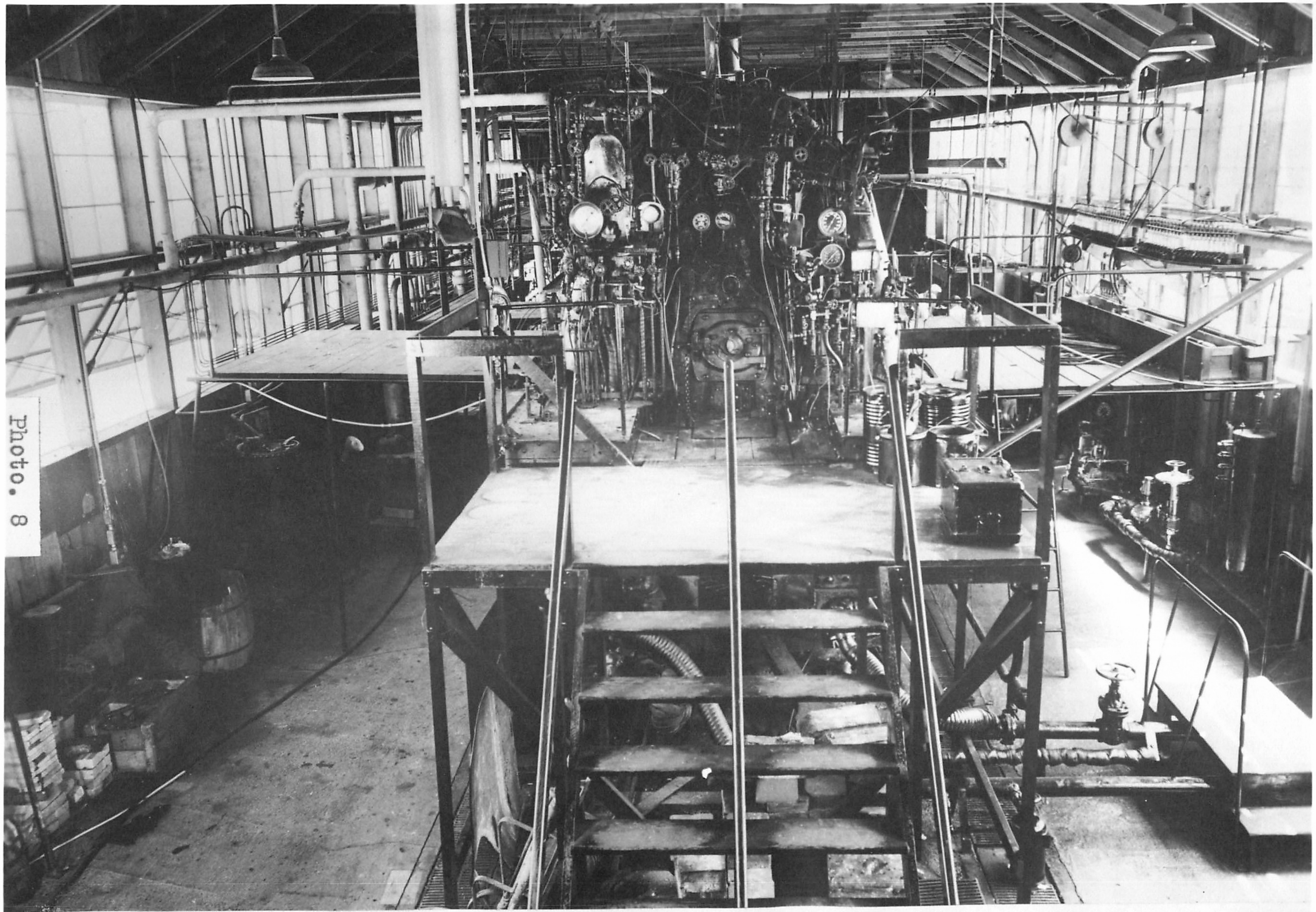
Photo. 7

INTERIOR OF TEST PLANT, NORTH SIDE-LOOKING EAST

Showing access platforms, piping and equipment on left side of engine. Stationary Engineer shown at manual firing controls.

ST-26-8

Photo. 8

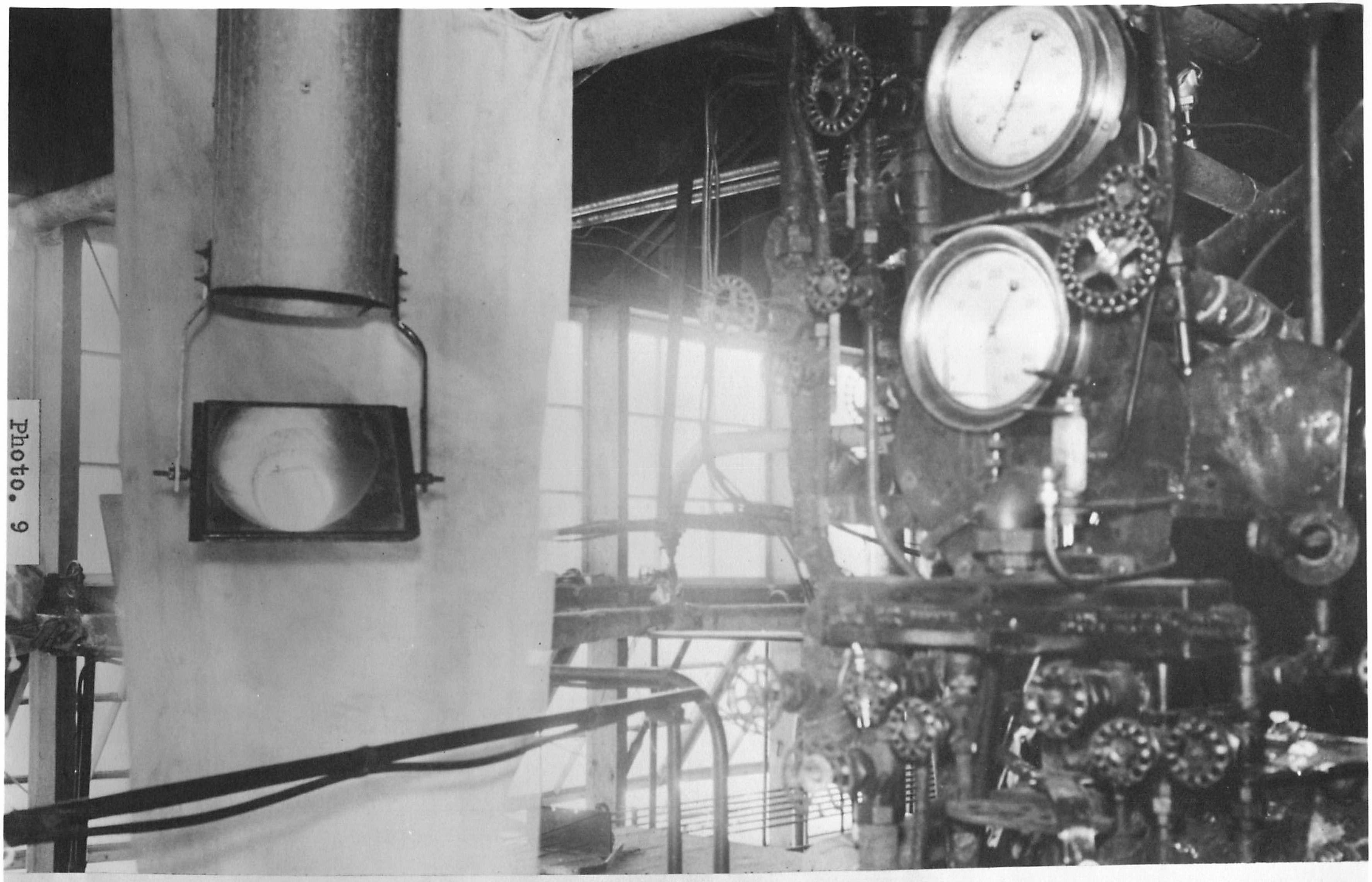


INTERIOR OF TEST PLANT - LOOKING EAST

Showing firing deck of locomotive with access platforms on left and right sides of firebox, and firing deck.

ST-67-2

Photo. 9



CLOSE-UP OF MANUAL FIRING CONTROLS

Showing fireman's side at firing deck. Periscope for observing flue gases at top of smoke jack, shown at left.

ST-70-10

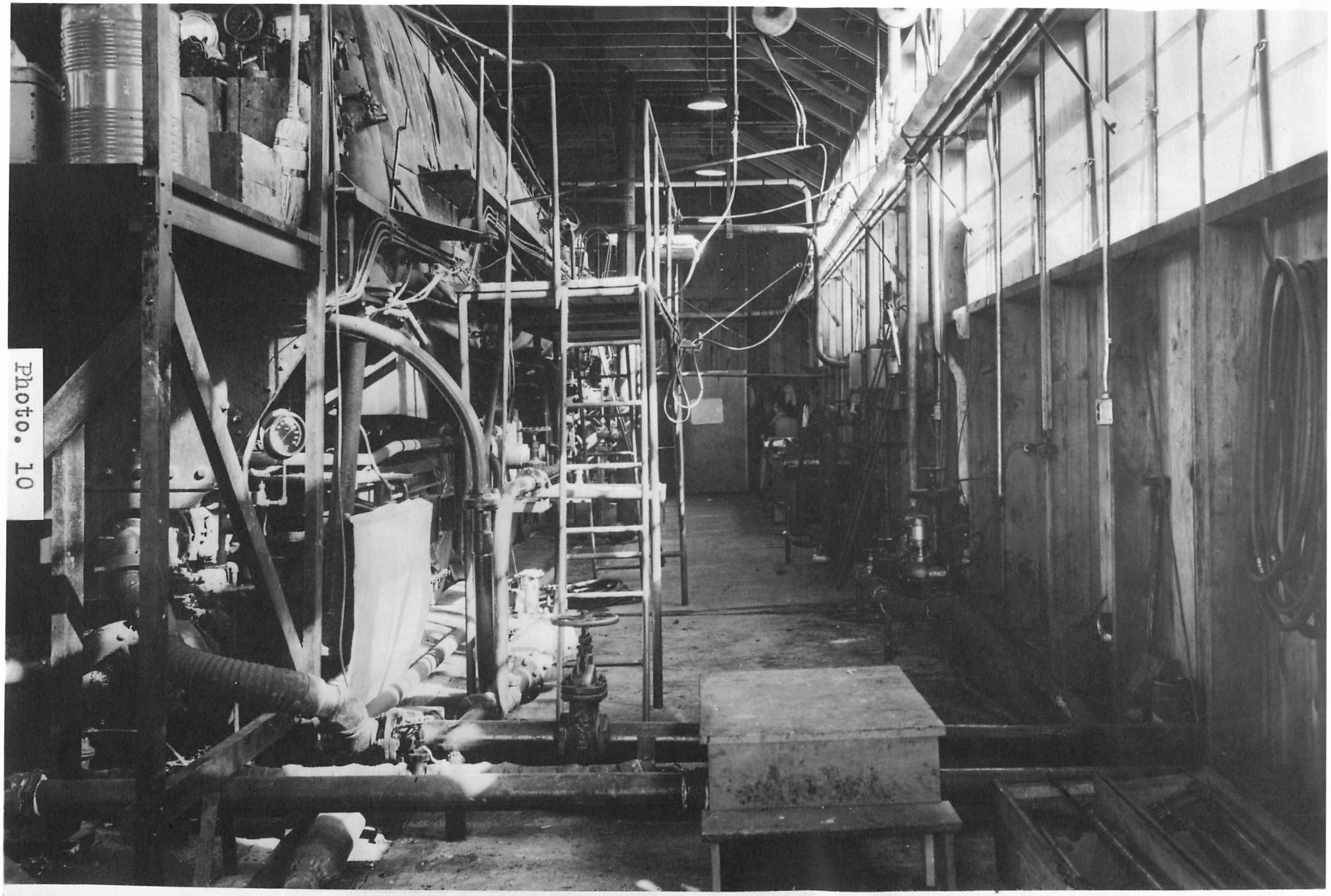


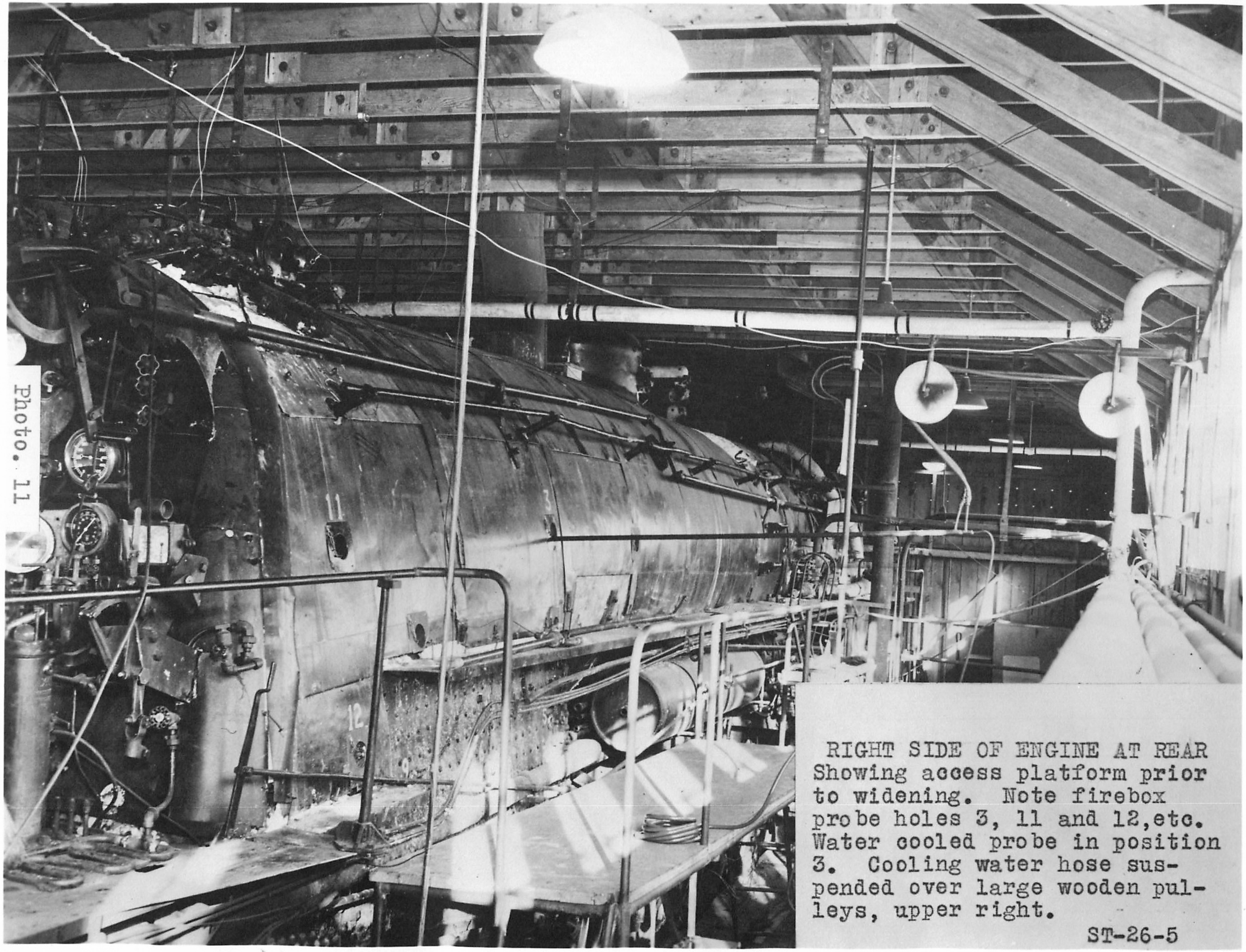
Photo. 10

INTERIOR OF TEST PLANT, SOUTH SIDE - LOOKING EAST

Showing firebox probe in No. 3 hole with cooling water hose over suspension pulleys Cold water pipes for feed pump and injector, and oil line in foreground. Oil meter and piping along wall at right.

ST-26-7

Photo. 11



RIGHT SIDE OF ENGINE AT REAR
Showing access platform prior to widening. Note firebox probe holes 3, 11 and 12, etc. Water cooled probe in position 3. Cooling water hose suspended over large wooden pulleys, upper right.

ST-26-5

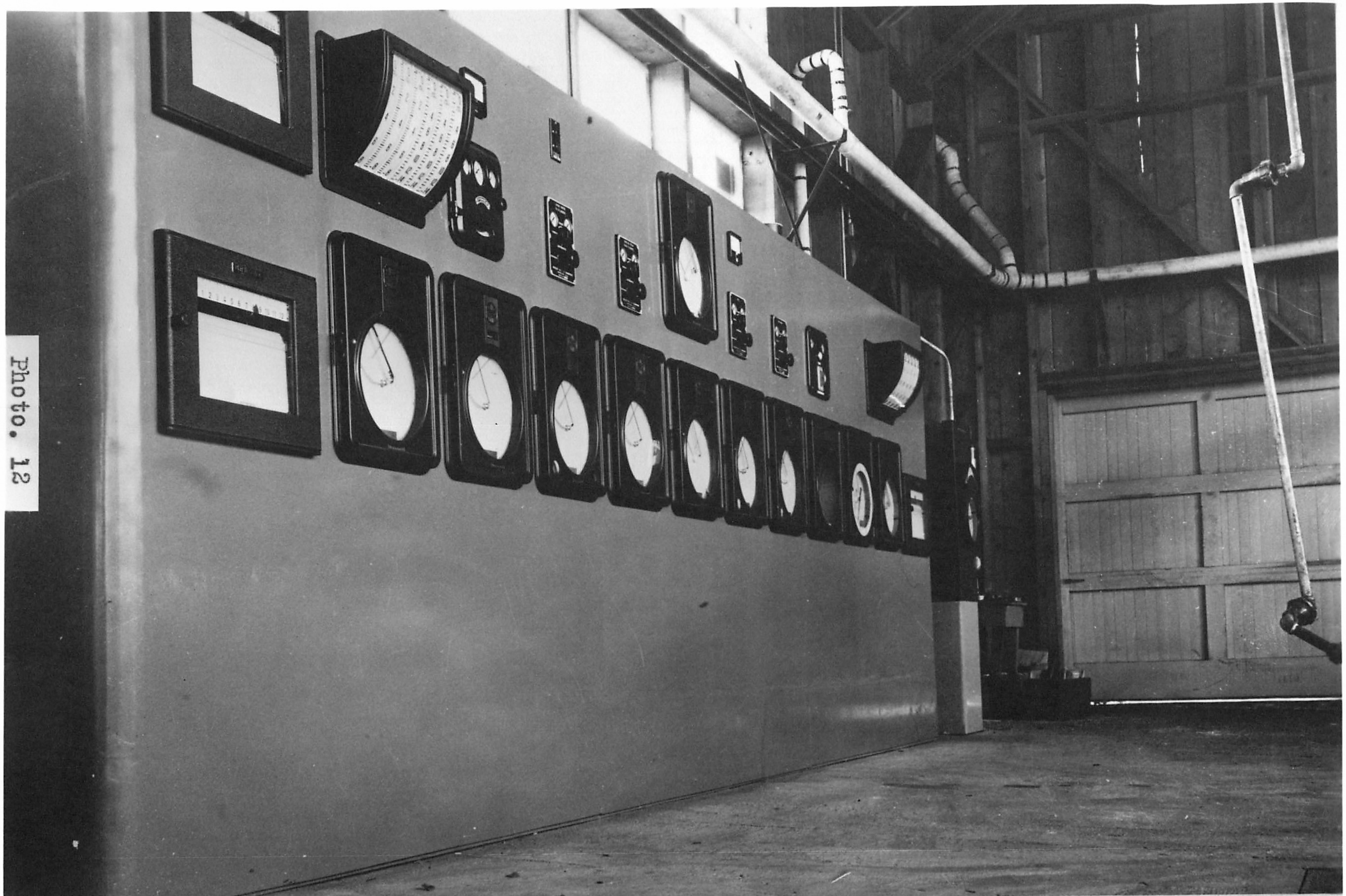
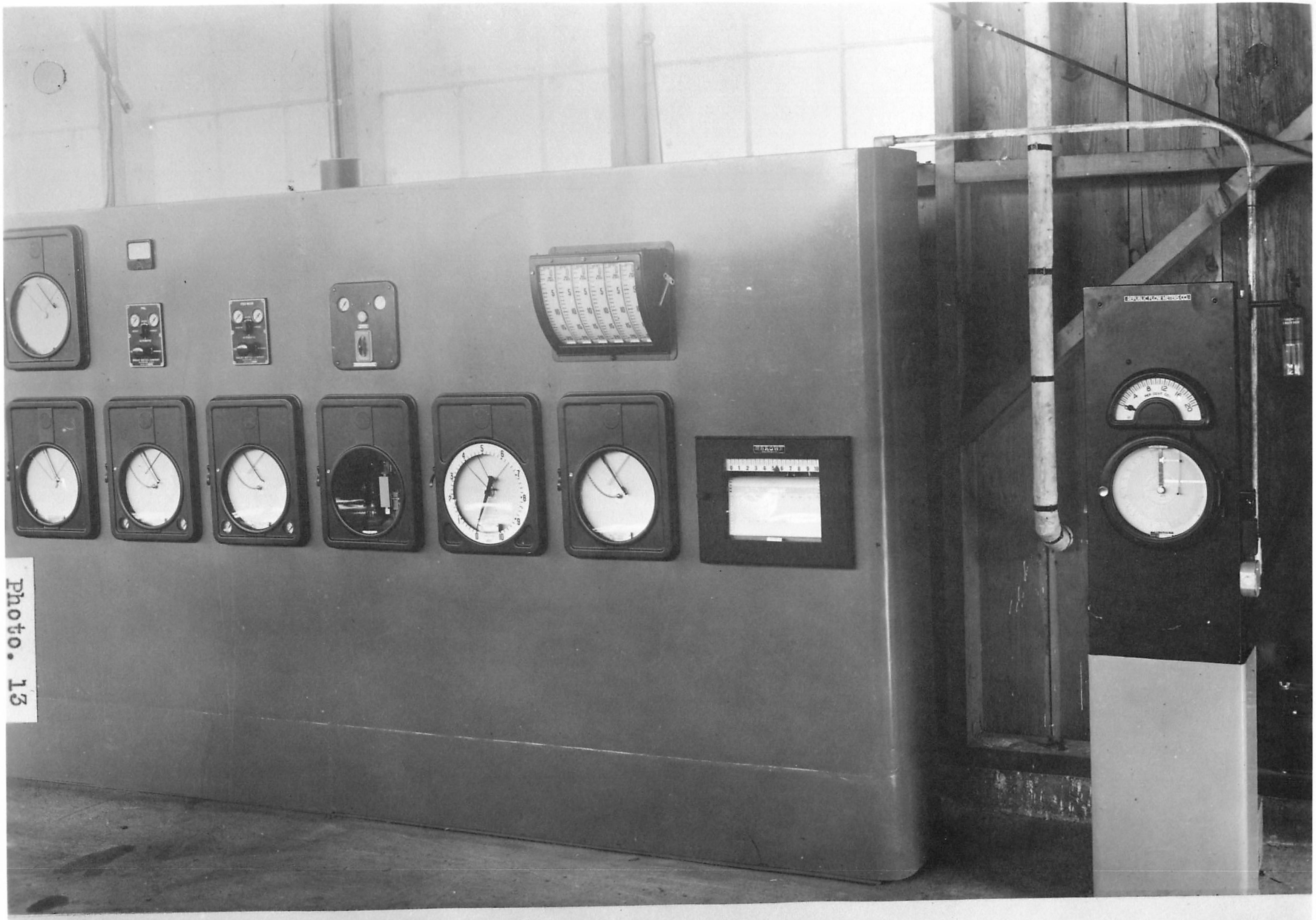


Photo. 12

FRONT VIEW OF MAIN PANEL

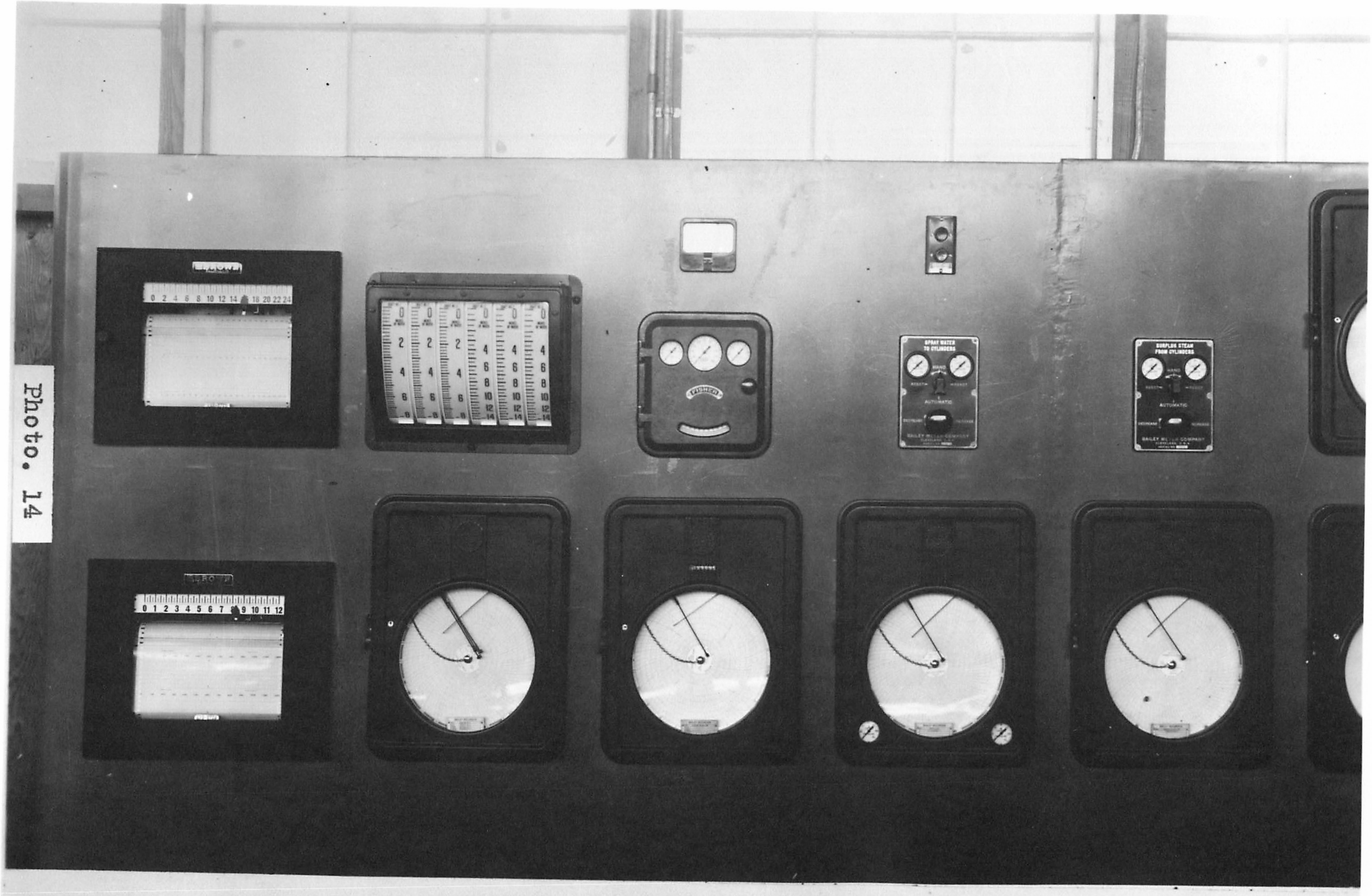
Taken from west of panel showing Carbon Dioxide Recorder separately mounted at right of panel.



RIGHT OR EAST END OF MAIN PANEL
With Carbon Dioxide recorder separately mounted at right. Taken prior to installation of smoke recorder at upper right corner of panel.

ST-8

Photo. 14



LEFT OR WEST END OF MAIN PANEL

Showing two Brown multipoint recording pyrometers at extreme left with Bailey pressure and fluid flow recorders and controllers extending to right.

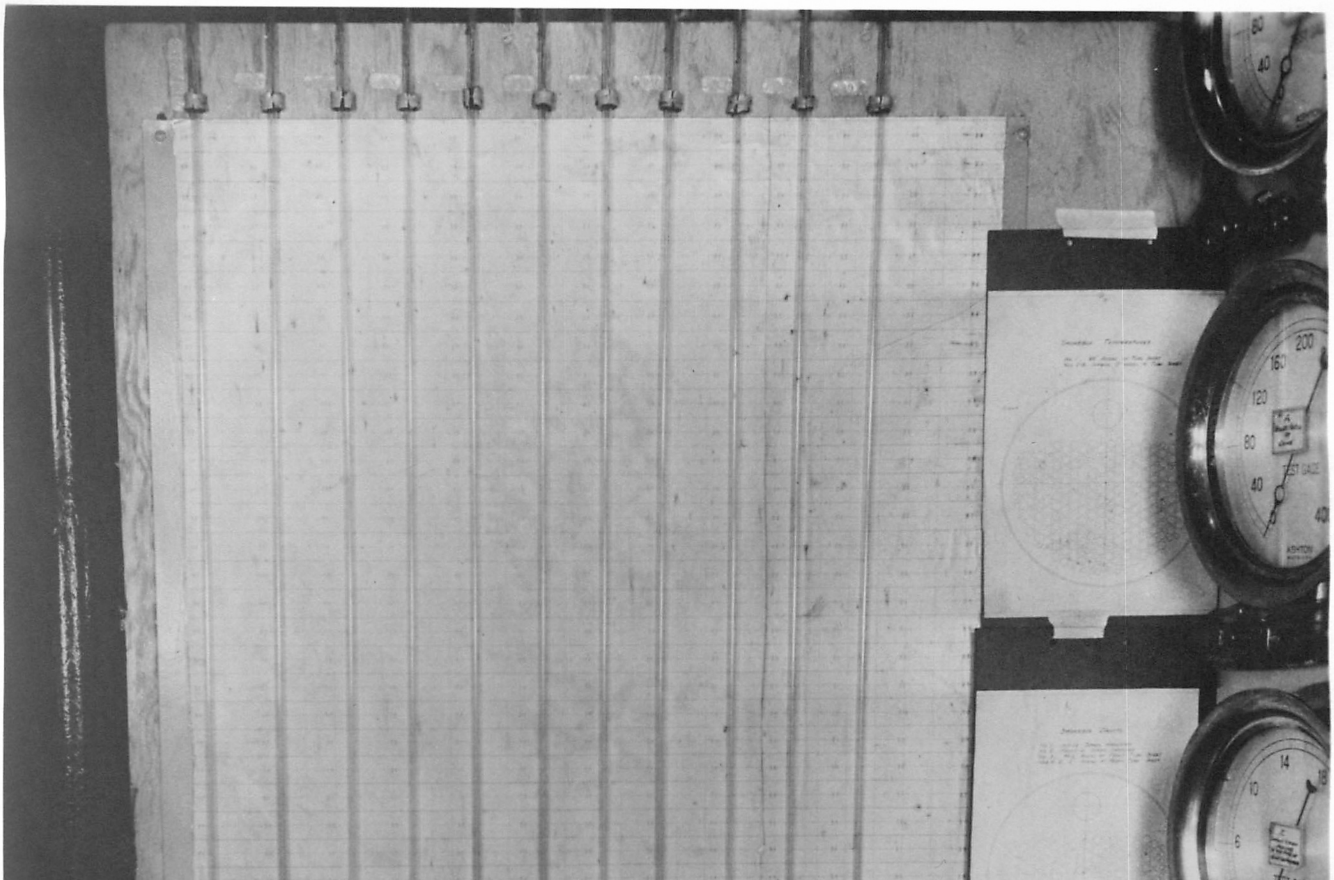
ST-9

Photo. 15

AUXILIARY PANEL

Supplementary data desk-panel showing (top pair) test gages for auxiliary-steam metering orifices; (middle pair) boiler pressure and feedwater heater chamber; and (lowest pair) wye pipe and exhaust nozzle pressures. On right, Brown electronic pyrometer with extra multipoint switch below. Single tube manometers for drafts, at left.

ST-26-6

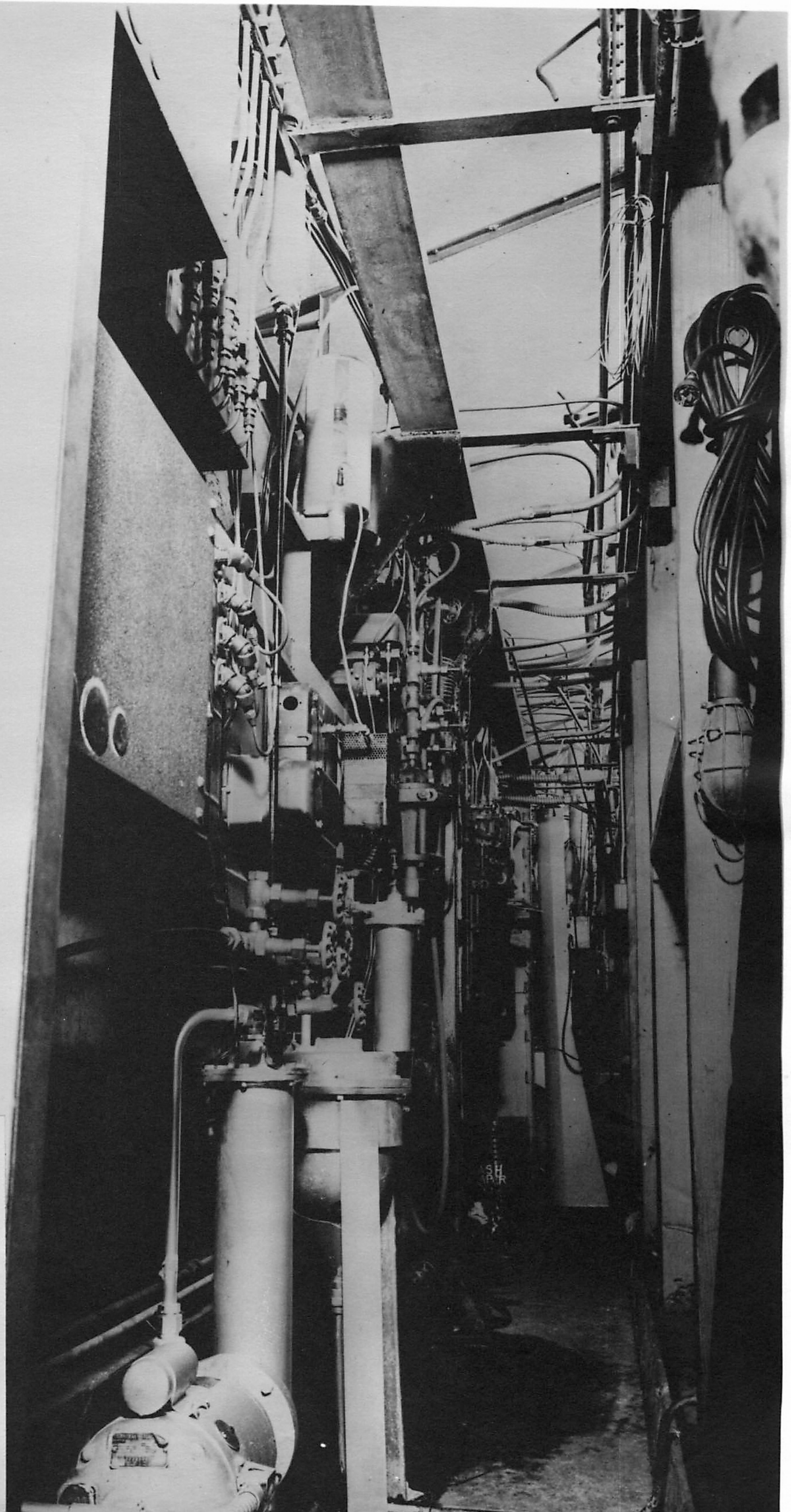


DRAFT MANOMETERS

Showing method of interconnecting shut-off valves in each tube for obtaining, in effect, simultaneous readings. Operating lever at right.

ST-70-1

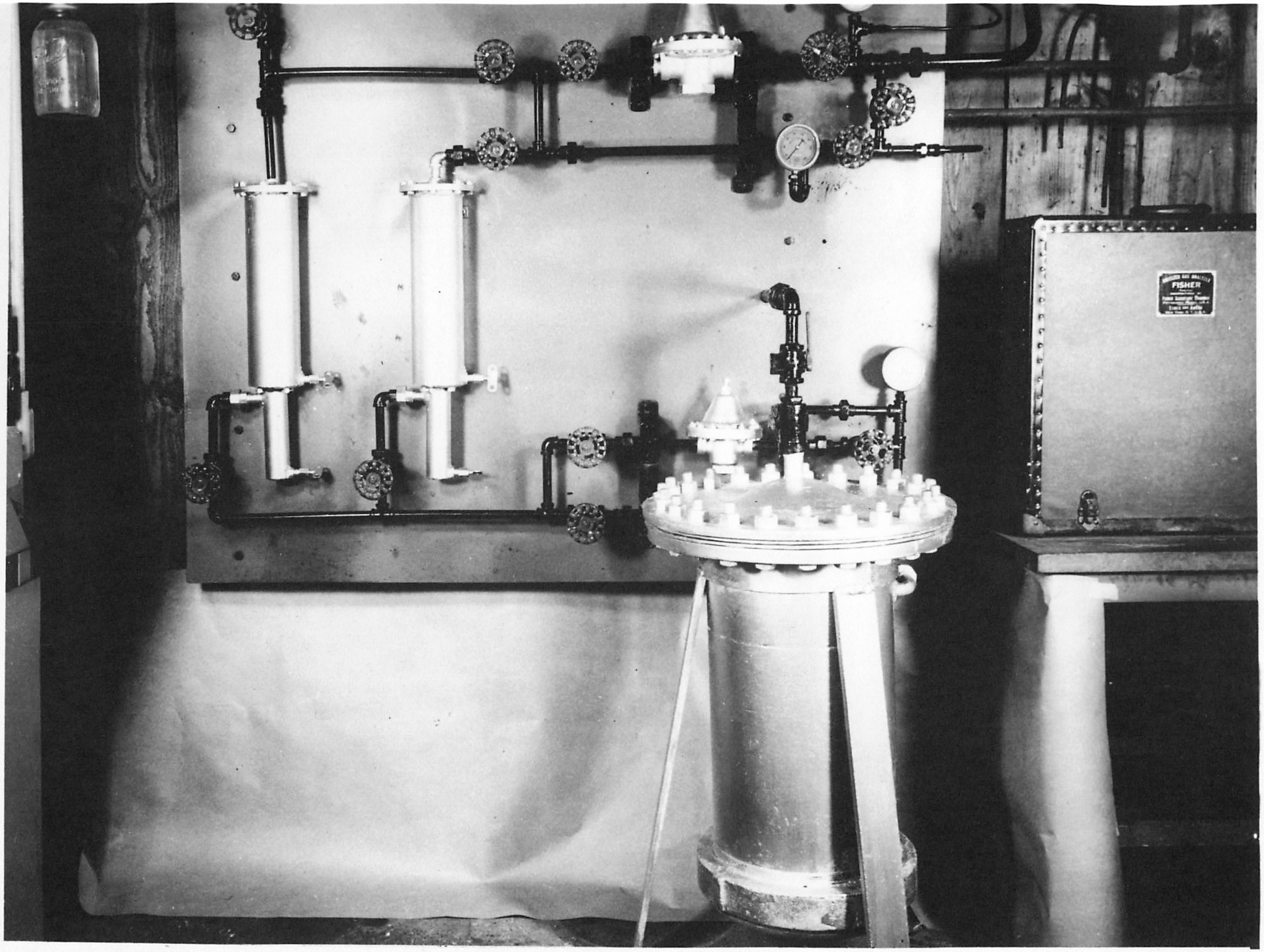
Photo. 16



REAR OF MAIN PANEL
View taken looking west with north wall of building at right. Flue gas sampler spray pump and washer in foreground.

ST-70-21

Photo. 17



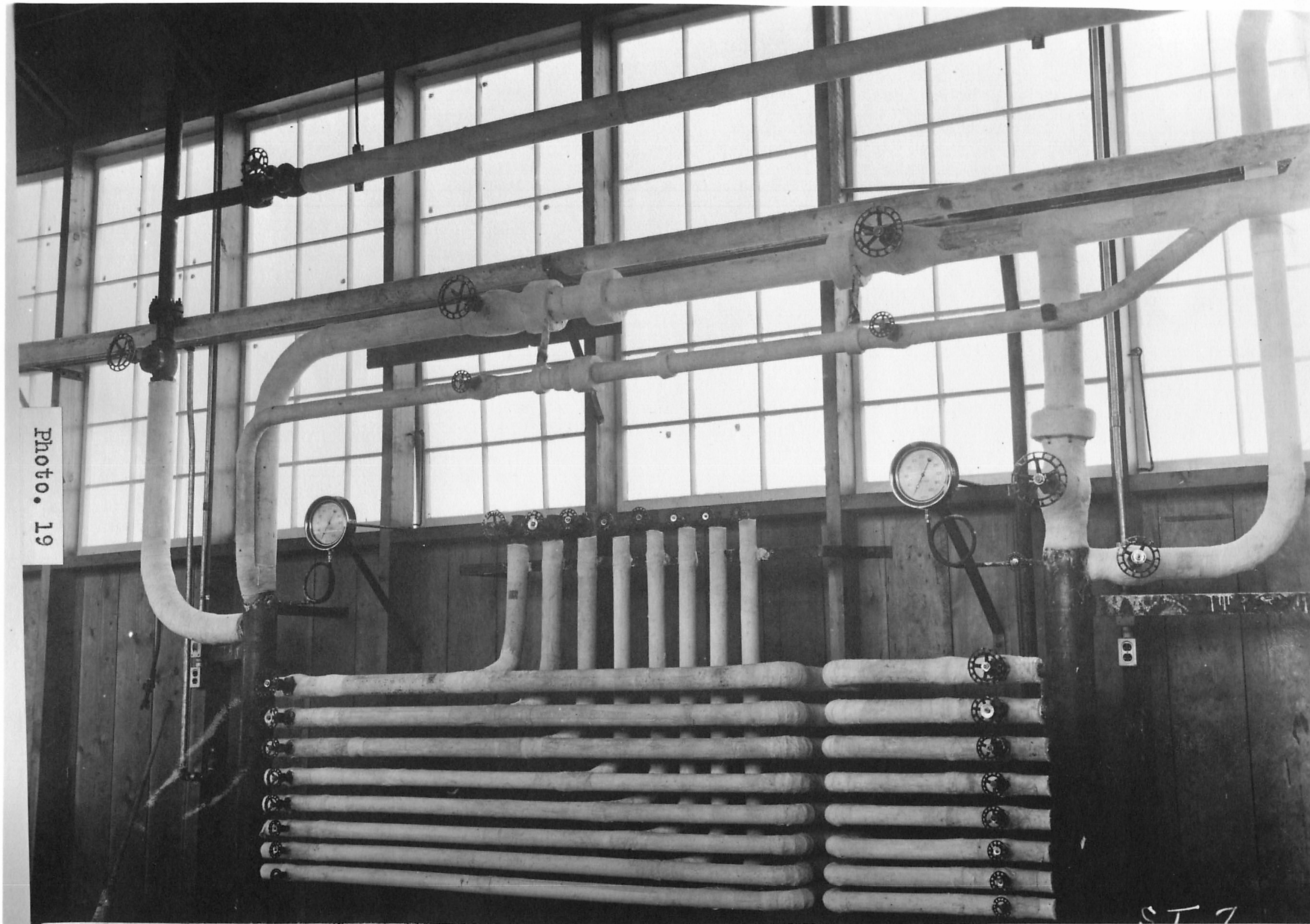
AIR SUPPLY PANEL FOR CONTROL INSTRUMENTS

Located near Carbon Dioxide Recorder along north wall of building, showing separator, filters, reducing valves and pressure gages. Fisher gas analyzing apparatus on table at right.

ST-70-11

Photo. 18

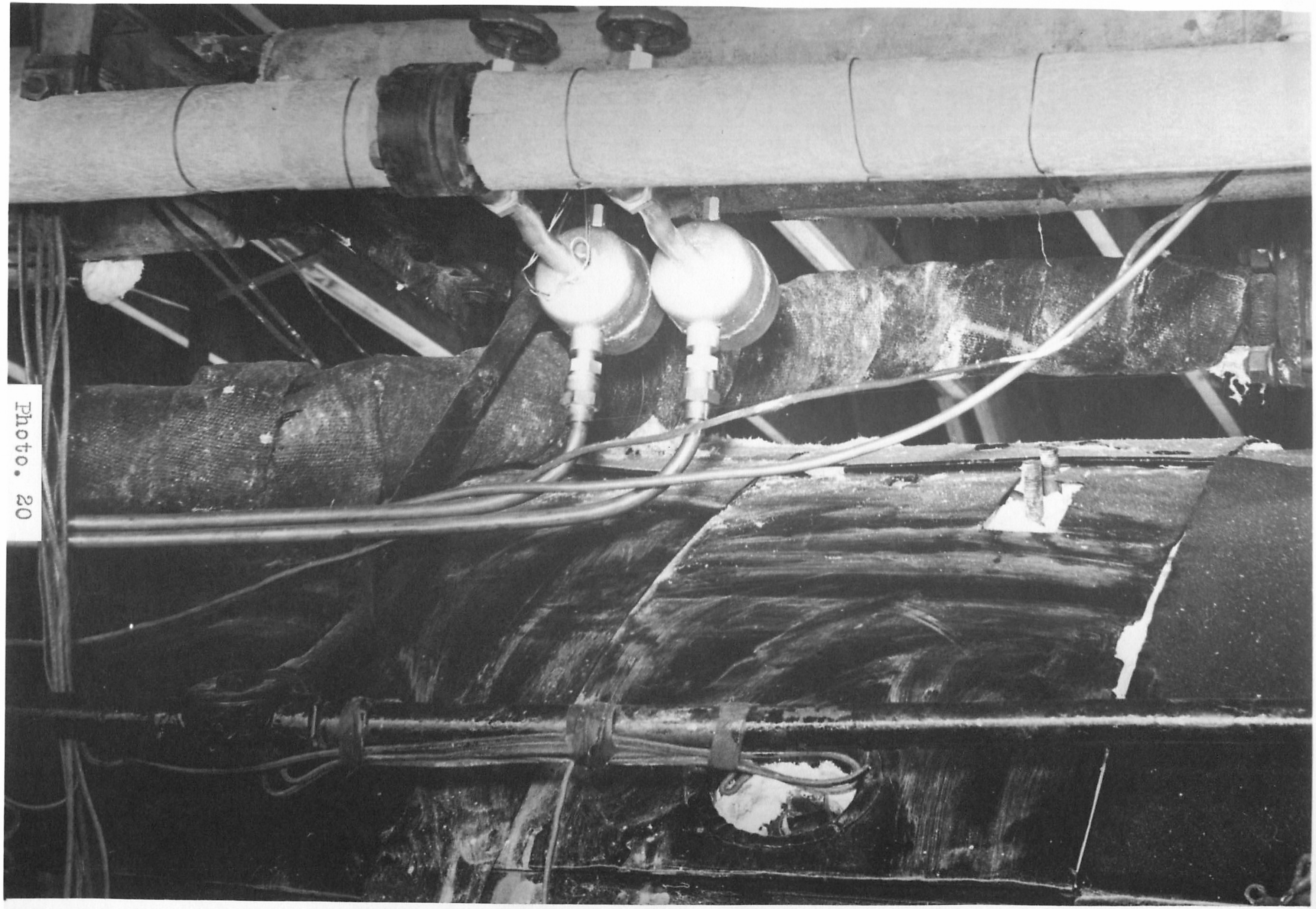
Photo. 19



AUXILIARY STEAM METERING MANIFOLD
Taken prior to completion of piping from manifold to auxiliaries.

ST-7

Photo. 20

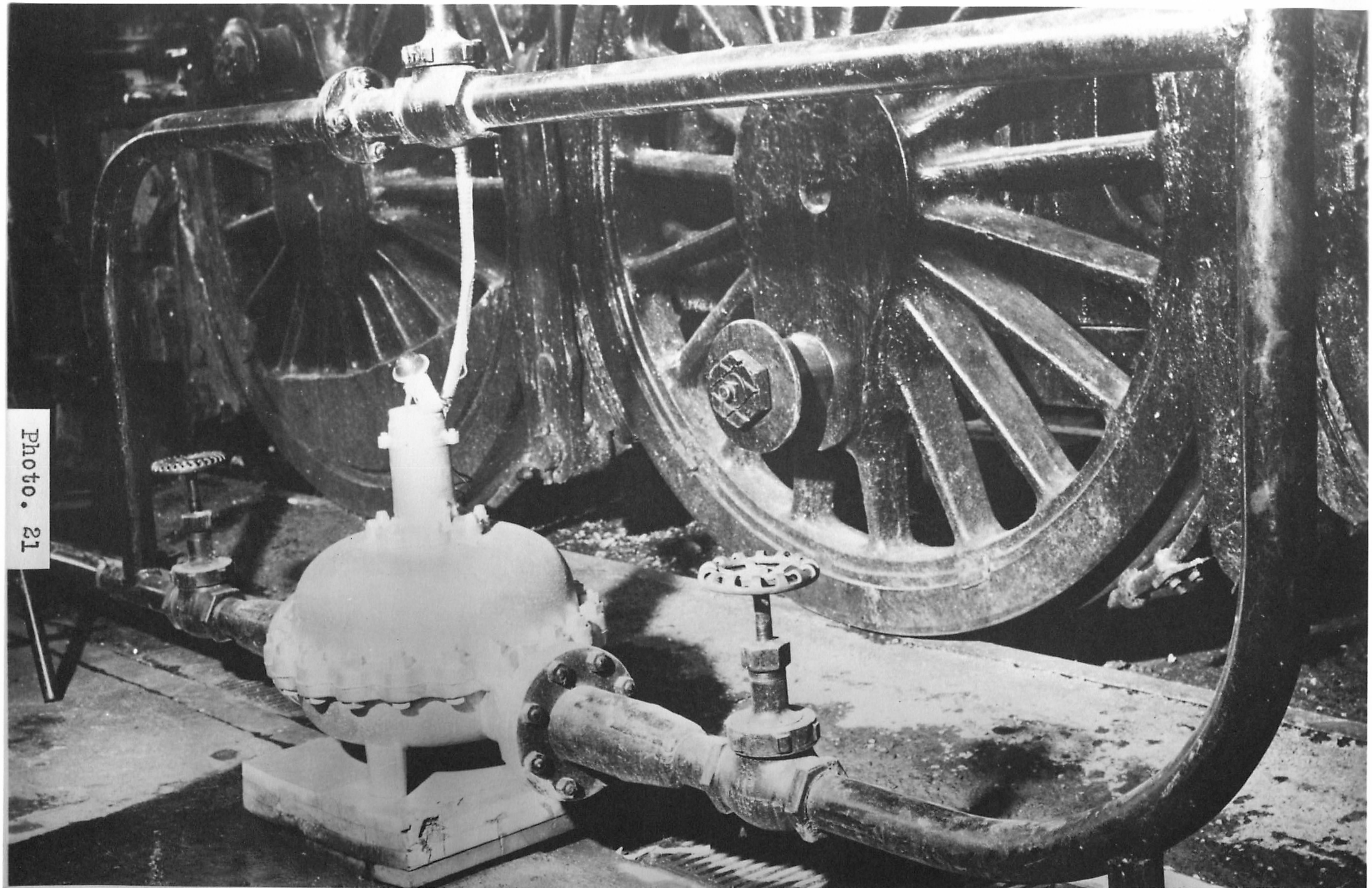


1" FLOW NOZZLE INSTALLATION ON ENGINE

This location, on left side of engine, was used when metering the small steam flow to burner atomizer.

ST-70-6

Photo. 21



COLD WATER METER FOR WATER TO HEATER
Showing nutating type meter with tachometer generator for remote indication of flow rate and by-pass piping, located at right of engine.

ST-70-18

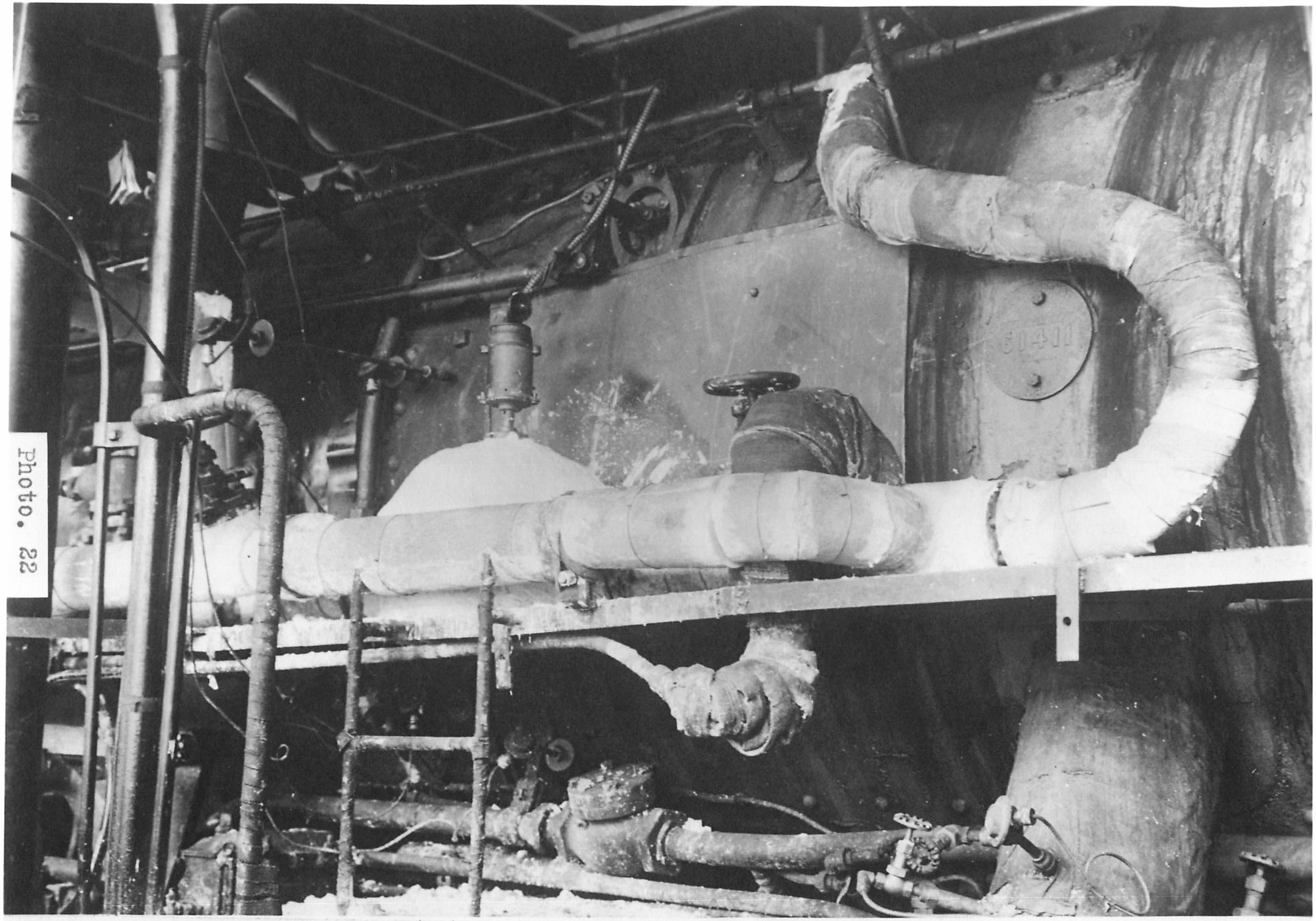


Photo. 22

HOT WATER METER FOR WATER TO BOILER
Showing nutating type meter with tachometer generator for remote indication of flow rate, meter located on right running board at smoke box.

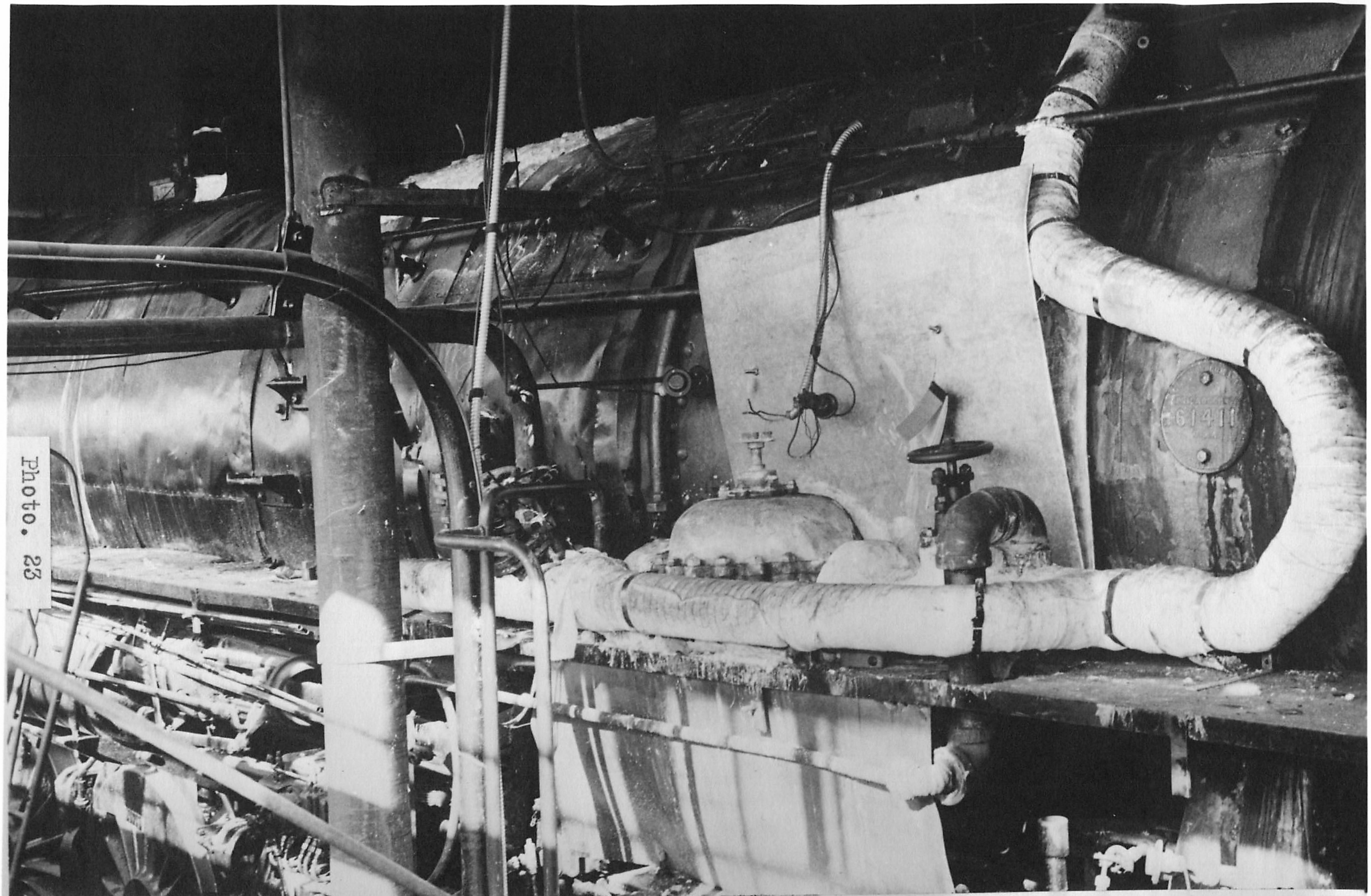


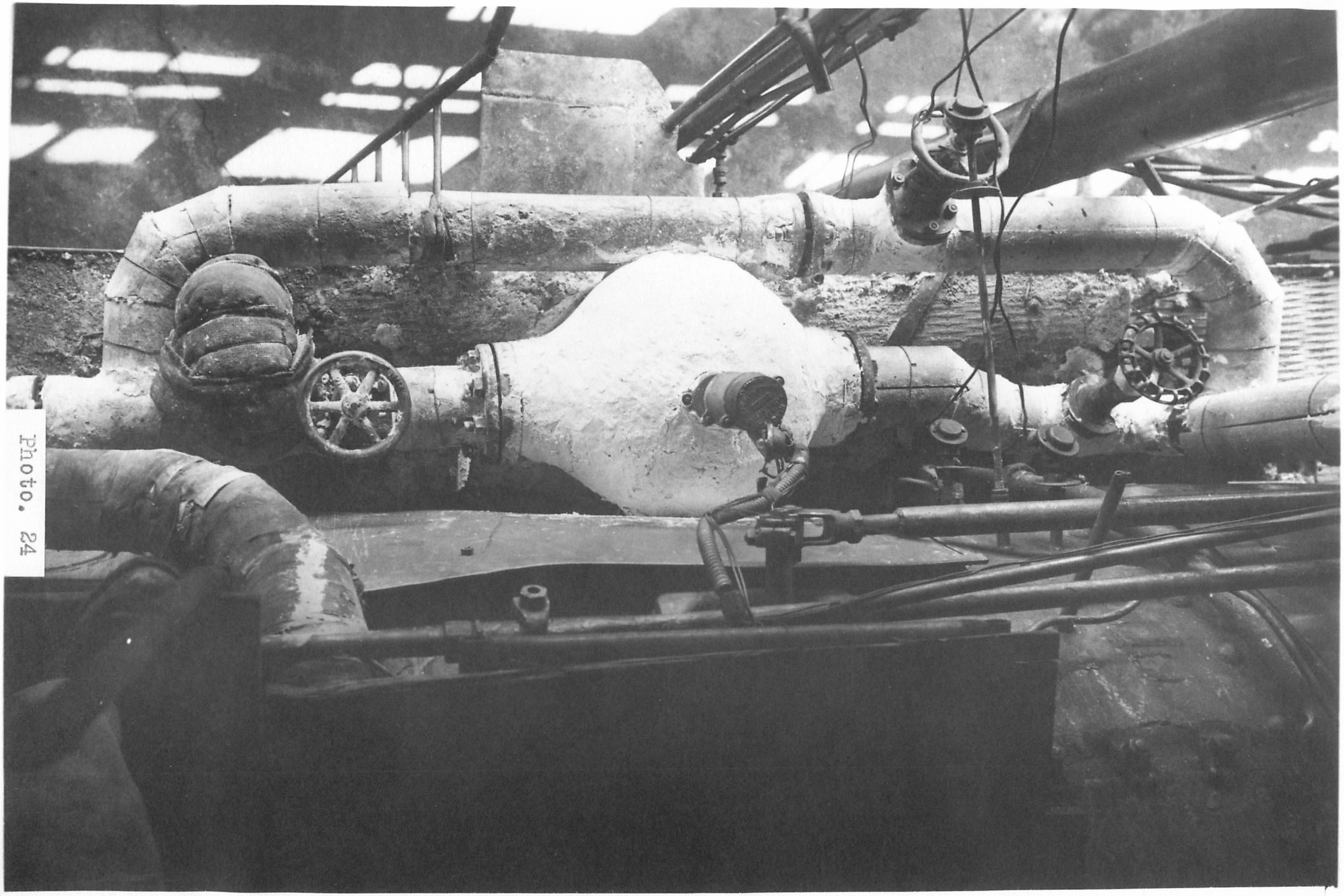
Photo. 23

RIGHT SIDE OF ENGINE AT SMOKEBOX

Showing hot water meter on running board and related piping. Large vertical pipe at left center is surge chamber which is connected to meter line at lower right by 1" copper pipe designed to maintain cool water in chamber.

ST-26-9

Photo. 24



HOT WATER METER FROM ABOVE

Showing by-pass piping around meter.

ST-70-4

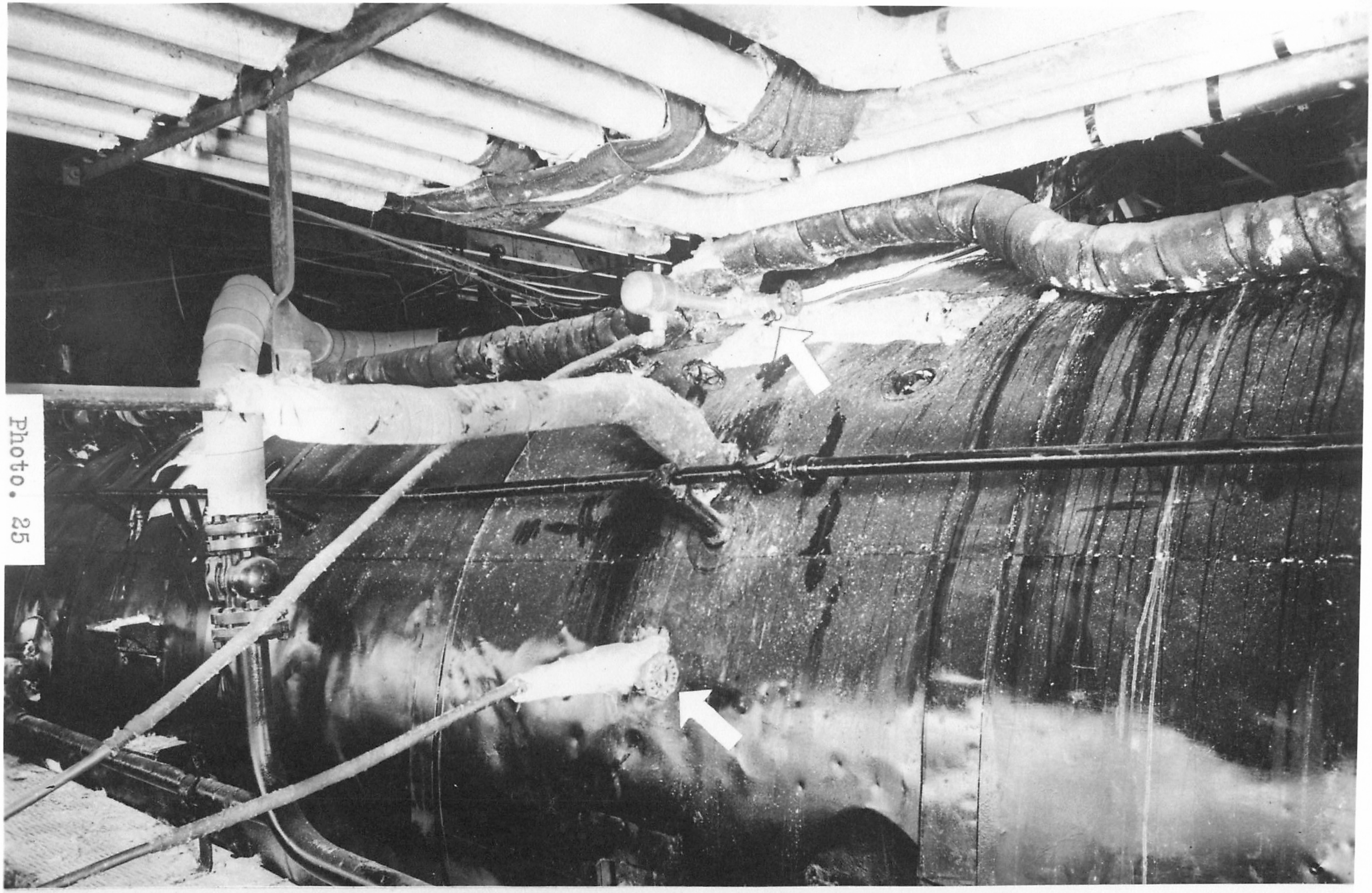


Photo. 25

LEFT SIDE OF ENGINE ABOVE RUNNING BOARD

Showing boiler connections, at arrows, to water level recorder controller. Injector line to boiler checks just above running board. At top are steam lines from auxiliary manifold to the various auxiliaries.

ST-70-20

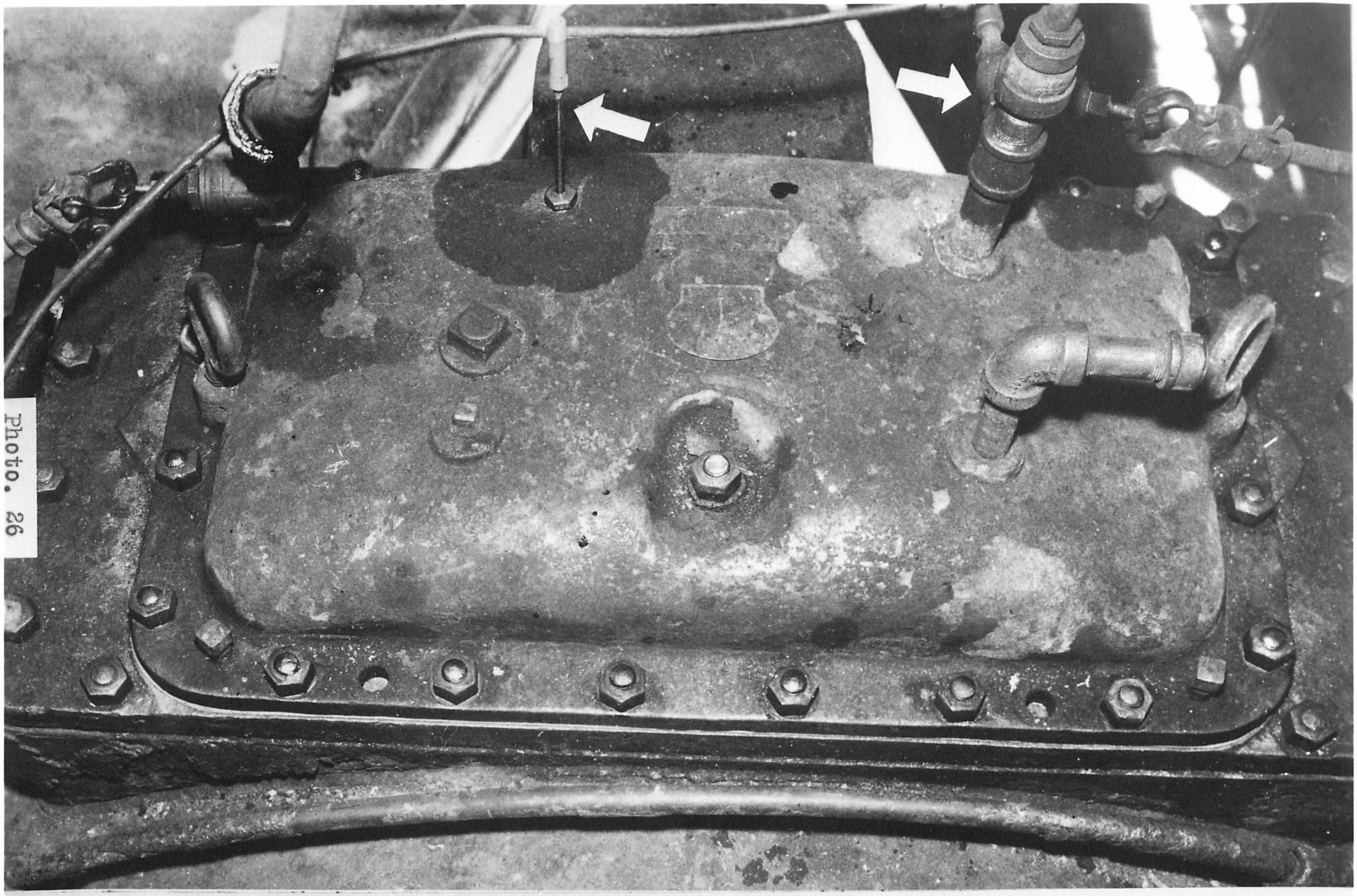
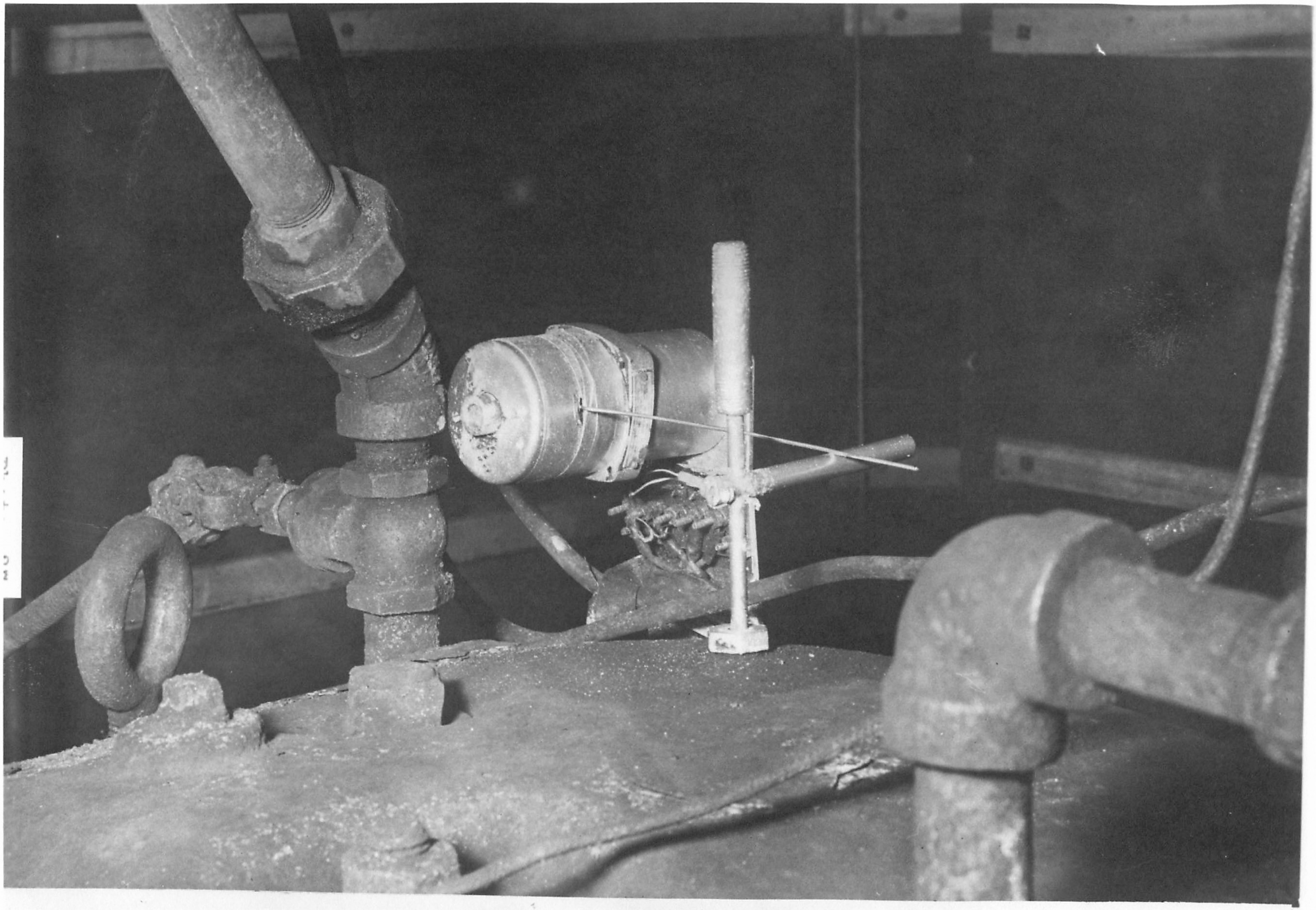


Photo. 26

FEEDWATER HEATER FROM ABOVE

With arrow left showing float level indicator rod at far edge of cover plate. Rod connection to float per Worthington Pump and Mach. Corp. Drawing DX91190. Arrow, right, indicates connection for temperature and pressure of steam in heater. ST-70-7



FEEDWATER HEATER FLOAT LEVEL INDICATOR
Showing Selsyn transmitter at feedwater heater chamber cover, used to indicate float level position on receiver at main panel.

SM-83-2

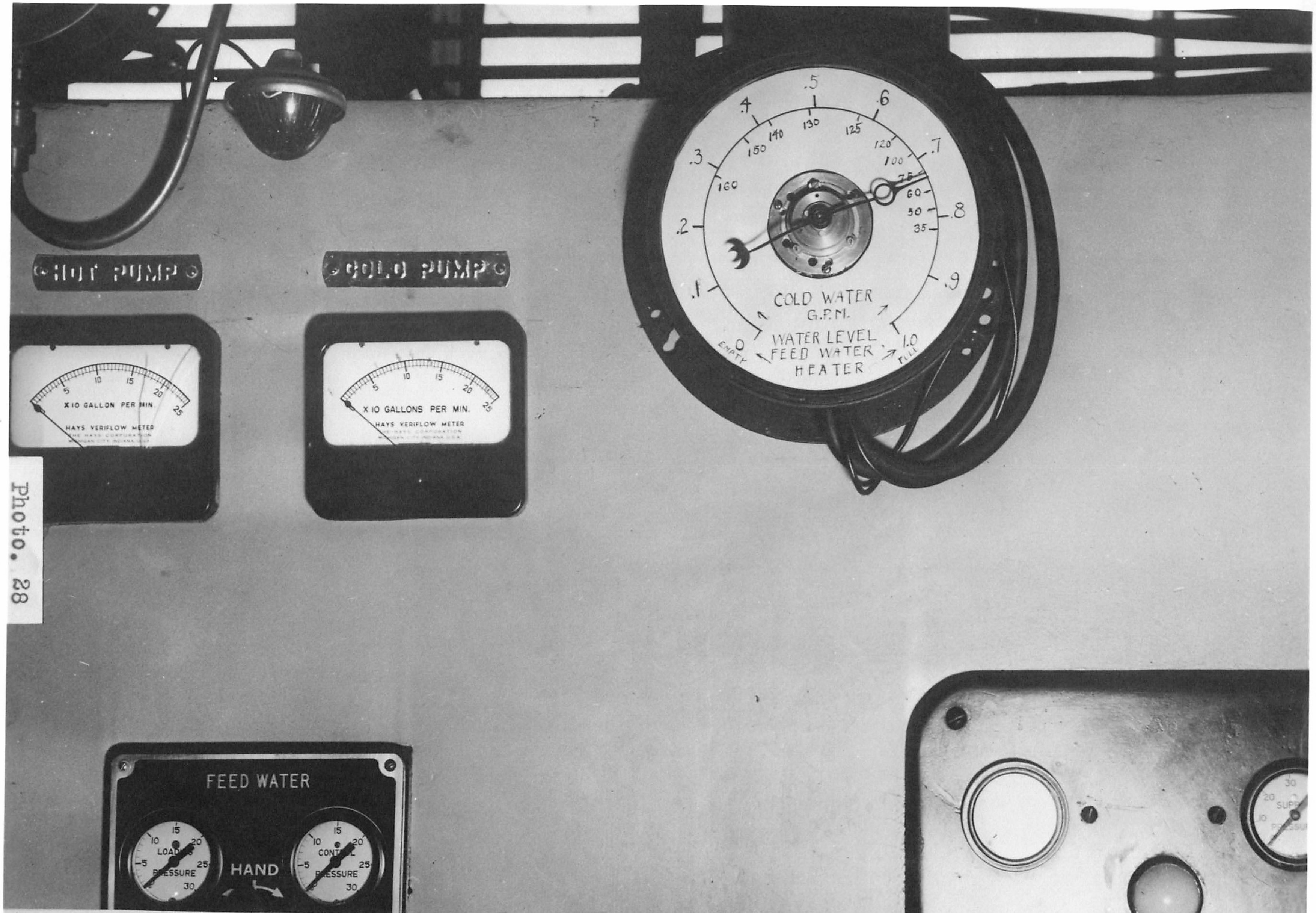


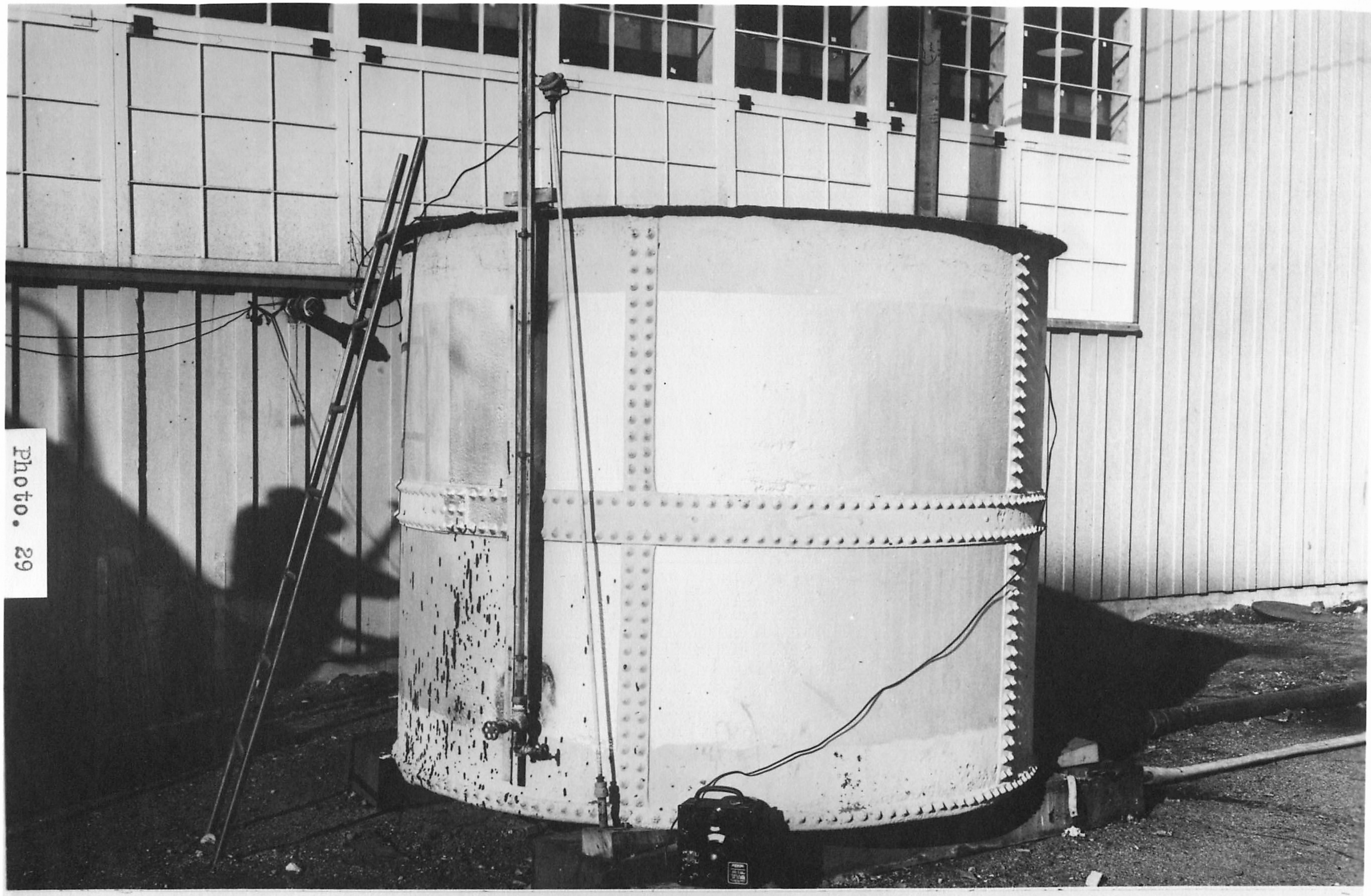
Photo. 28

FEEDWATER HEATER FLOAT LEVEL POSITION INDICATOR

Showing Selsyn repeater arranged to indicate feedwater heater chamber float level at main panel.

ST-83-3

Photo. 29



WATER METER CALIBRATING TANK- LOCATED ON SOUTH SIDE OF TEST BUILDING
Showing gage glass and potentiometer. This calibrated, 2,000 gallon tank was used for establishing correction factor curves for hot and cold water meters.

ST-26-3

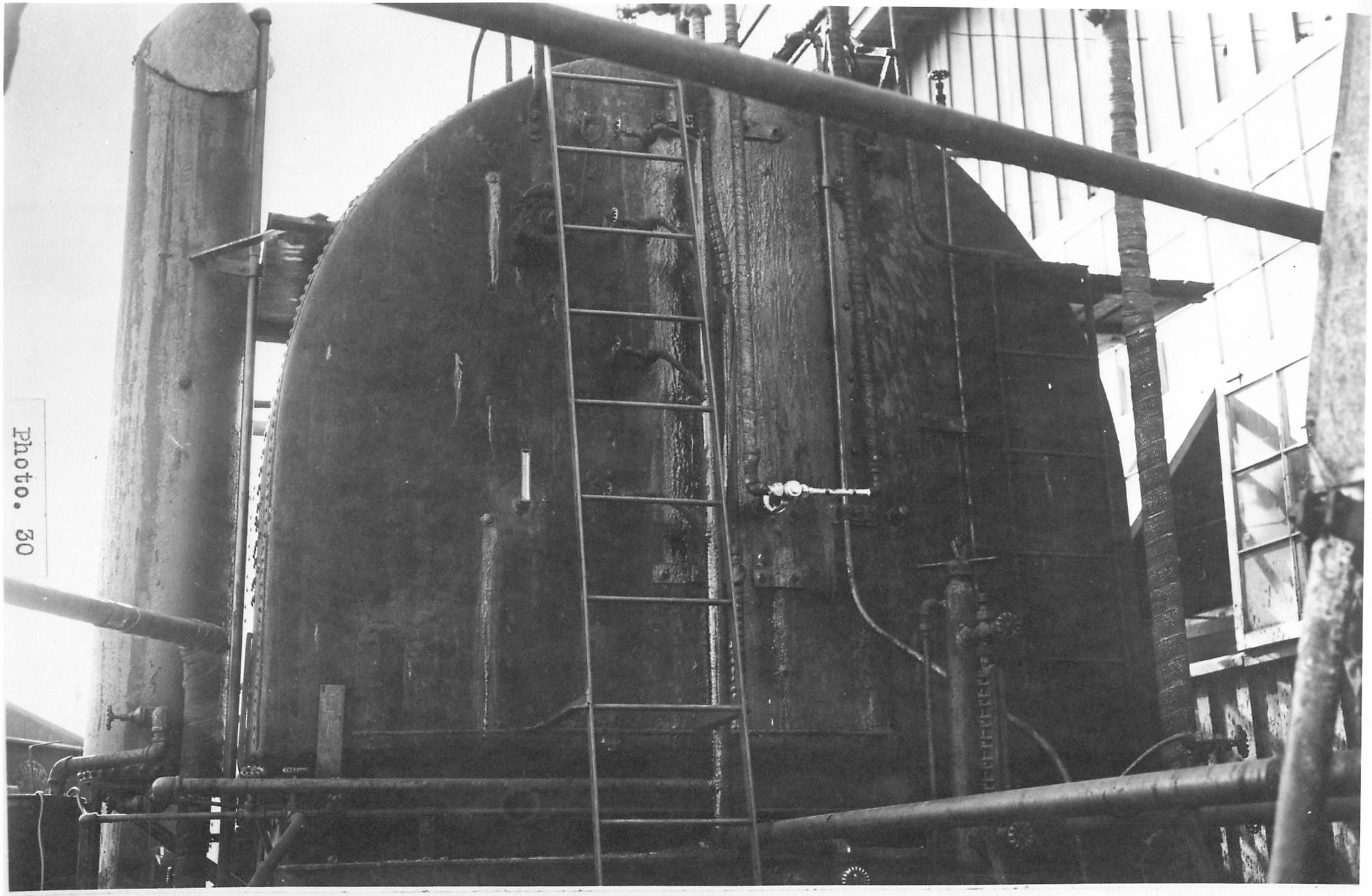


Photo. 30

FUEL OIL TANK

Located on South side of Test Building, showing thermometer, thermostat for regulating steam to oil heater, associated piping, and column with gage glass to feed oil additives to fuel supply. Vertical tank at left was used for investigating alleged effect of certain additives on fuel oil flow.

ST-70-17

Photo. 31

FUEL OIL METER AND GEAR PUMP

Located along South wall inside Test Building. Oil flow regulator in right foreground, then nutating oil meter with tachometer generator and gear pump with pressure regulator, to the rear along wall. Air pressure regulator for tender oil tank shown on wall above gear pump.

ST-67-3

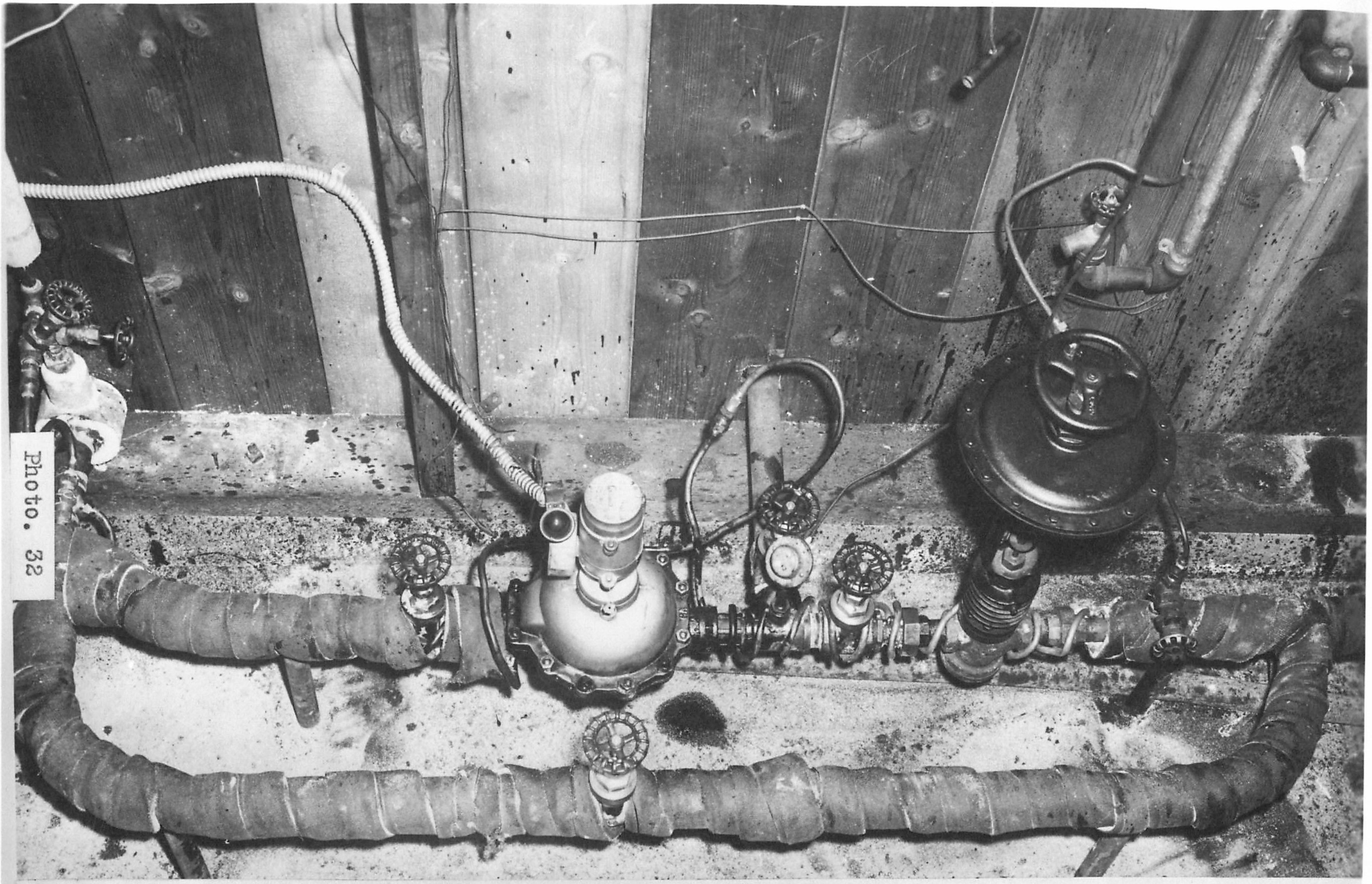
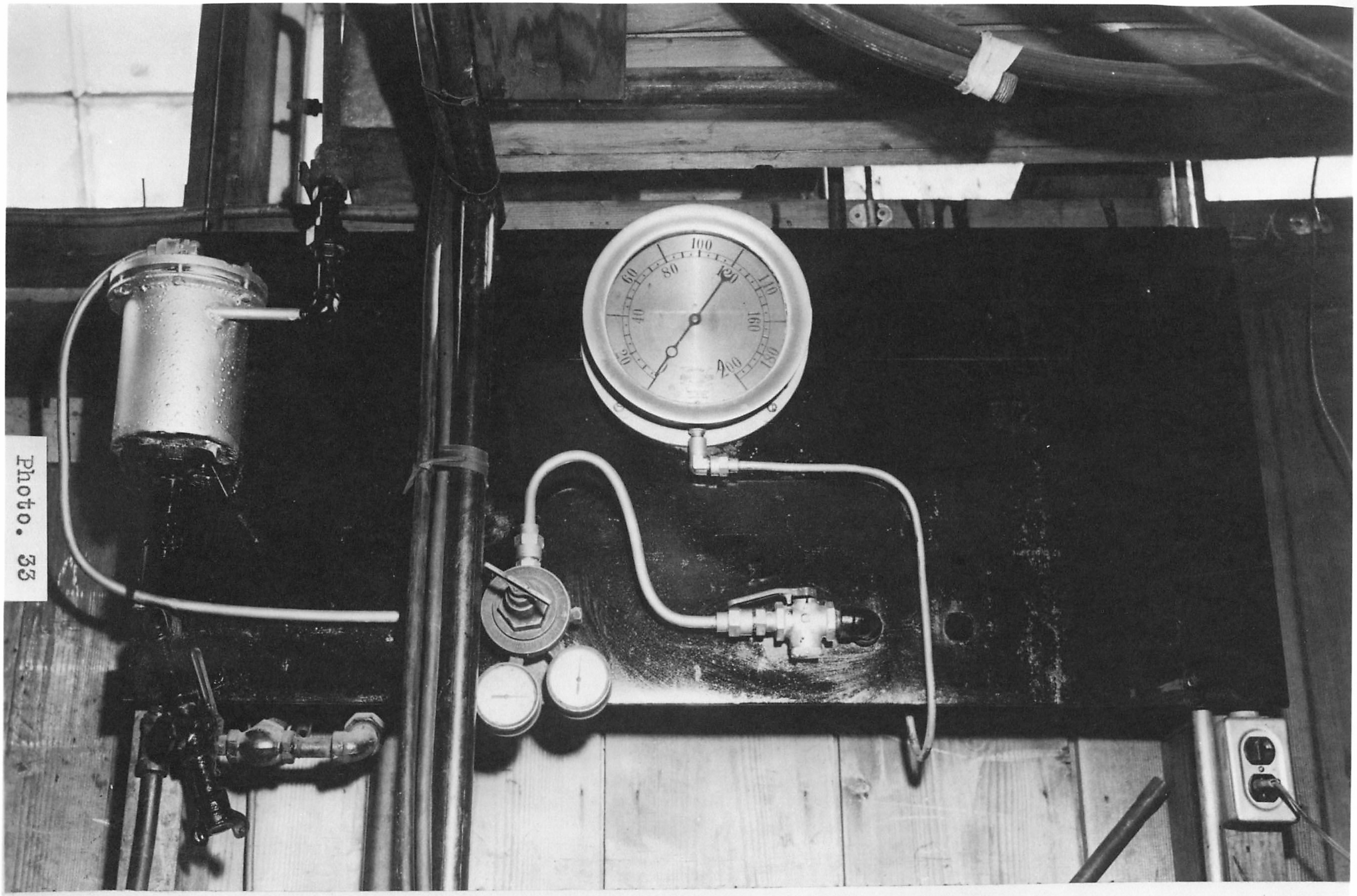


Photo. 32

FUEL OIL METER, FROM ABOVE

Showing fuel oil meter, by-pass, and controller, with portion of insulation removed to show heating coils. Thermocouple for temperature measurement and branch pipe to calibrating tank outside building, shown between meter and controller. ST-26-4



AIR SUPPLY REGULATOR FOR TENDER OIL TANK

Showing welding type pressure regulator set to maintain 10 psig in tank. Separator at left and pressure gage at right.

ST-70-19

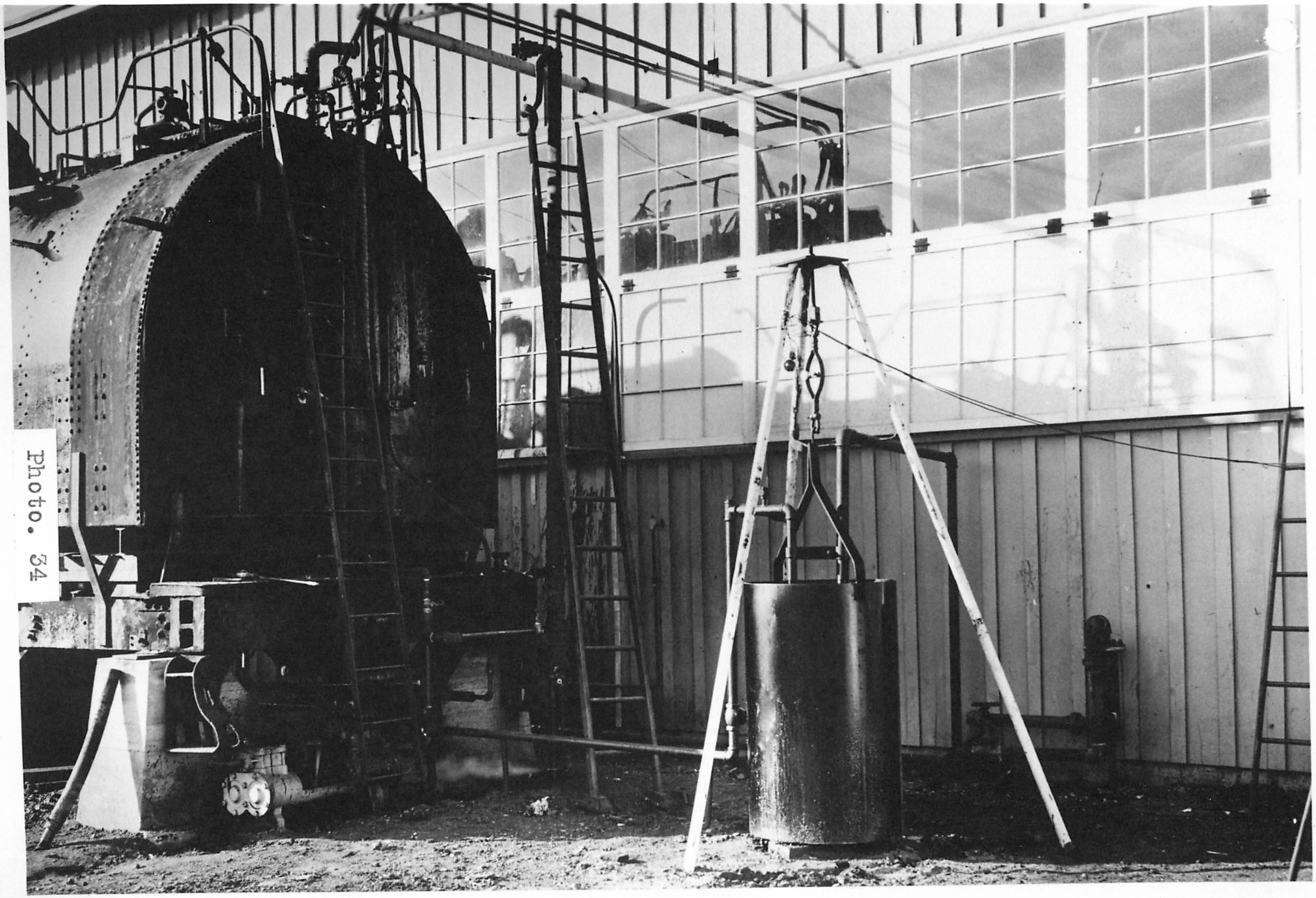


Photo. 34

FUEL OIL METER CALIBRATING ARRANGEMENT

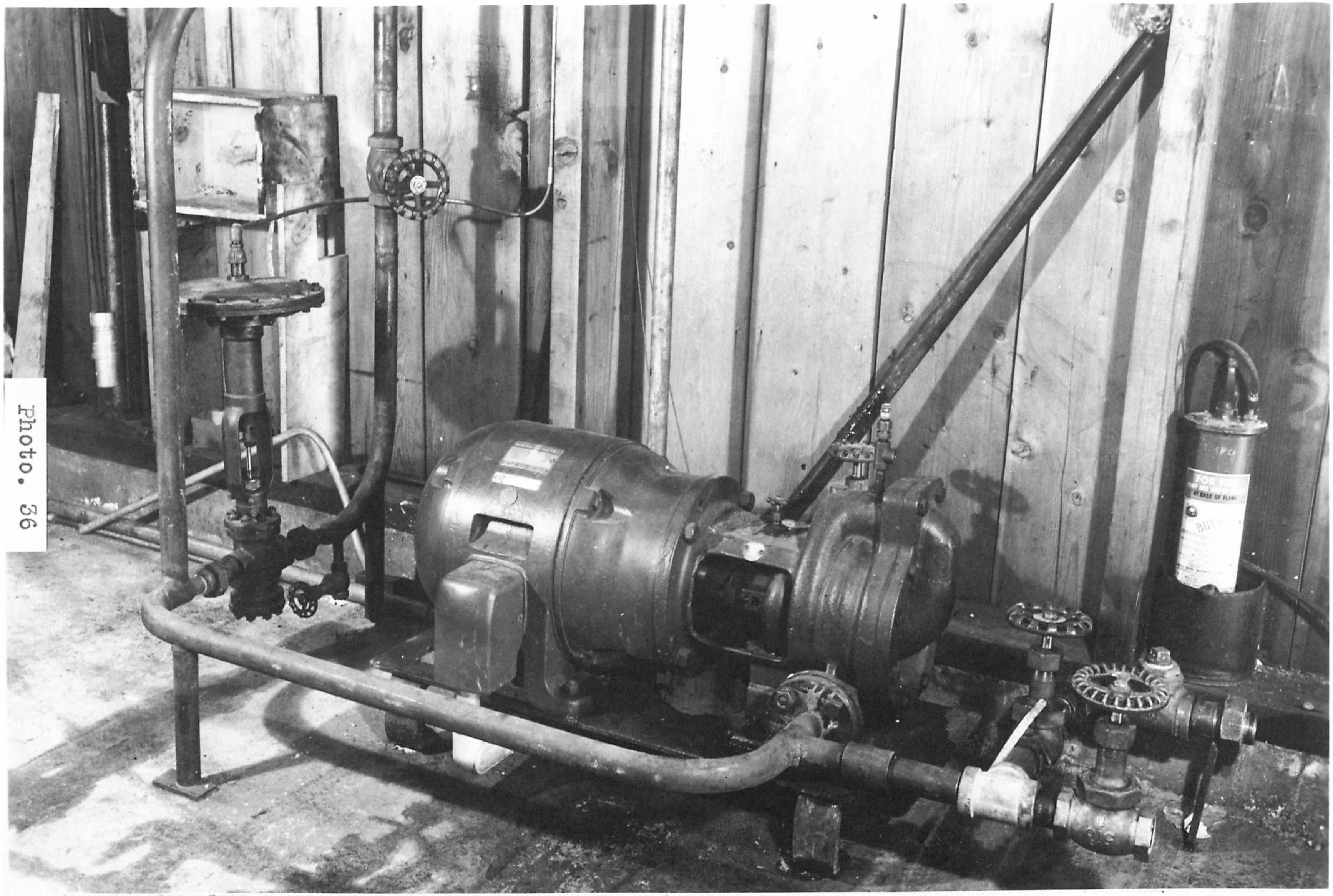
Showing calibrating tank suspended from traction dynamometer with coordinating-signal light adjacent to dialometer, and lower left, duplex pump for returning oil to tender tank. Oil meter is inside building, in normal operating position, no relocation being necessary for calibration.

ST-26-2

DESUPERHEATING WATER PUMP

With 25 HP motor to supply spray water for desuperheating the steam in cylinders. Adjacent to motor at left is diaphragm operated, initial pressure regulator, to maintain desired pressure at spray water control valve. View prior to completion of piping, and metering orifice visible at upper end of piping shown. ST-13

Photo. 35



DESUPERHEATING WATER PUMP AND MOTOR

Showing spray pump and motor with pressure regulator and by-pass piping around regulator. Piping at discharge of pump on right was used to facilitate filling boiler.

ST-18-5

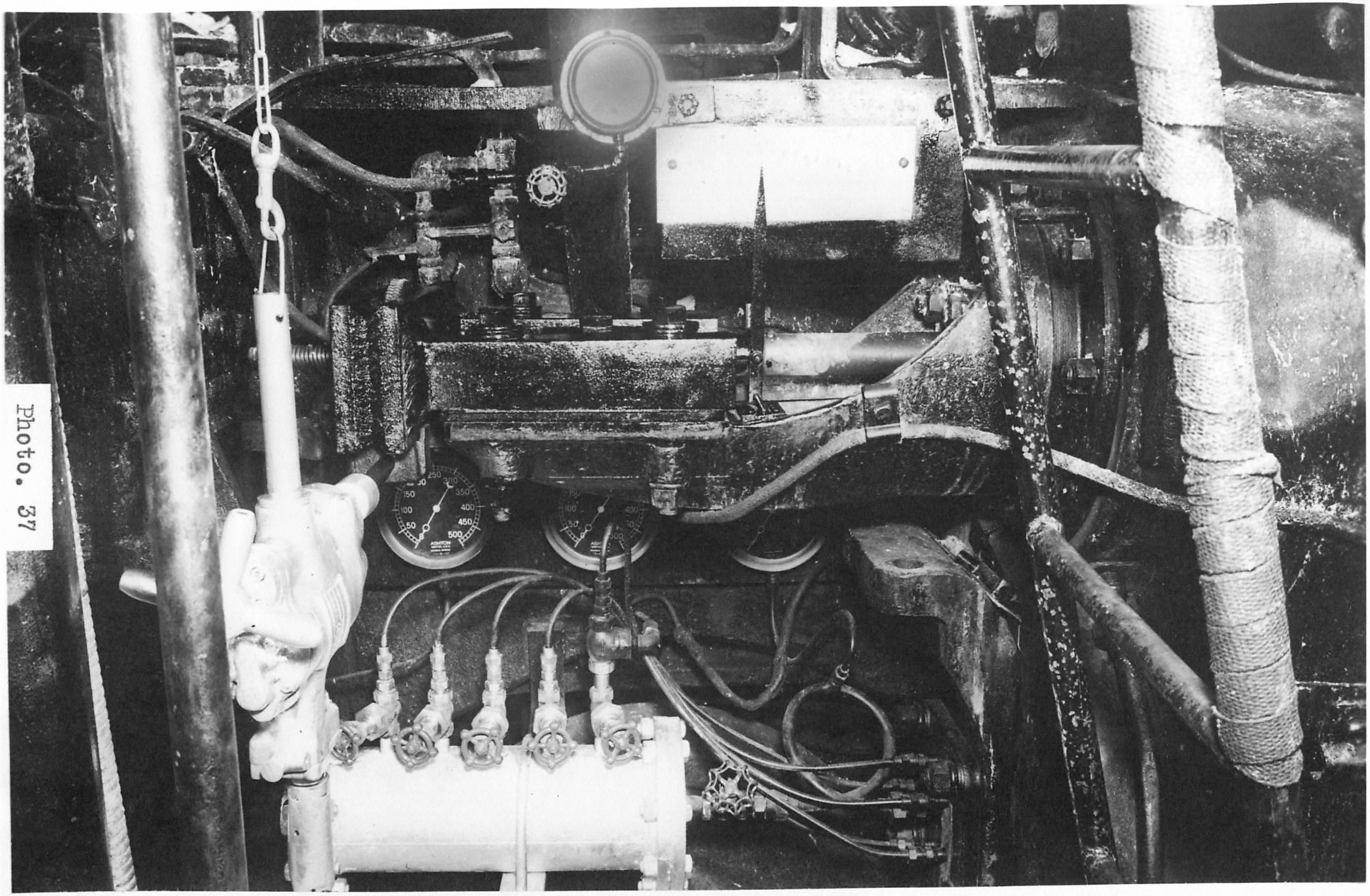


Photo. 37

RIGHT SIDE OF ENGINE AT CYLINDER

Showing general arrangement of valve positioning device, spray water manifold and filter, piping into cylinder spray tips, and air motor to operate worm gear. Below the positioning device are pressure gages mounted on engine frame to assist in proportioning spray water to the various nozzles.

ST-70-3

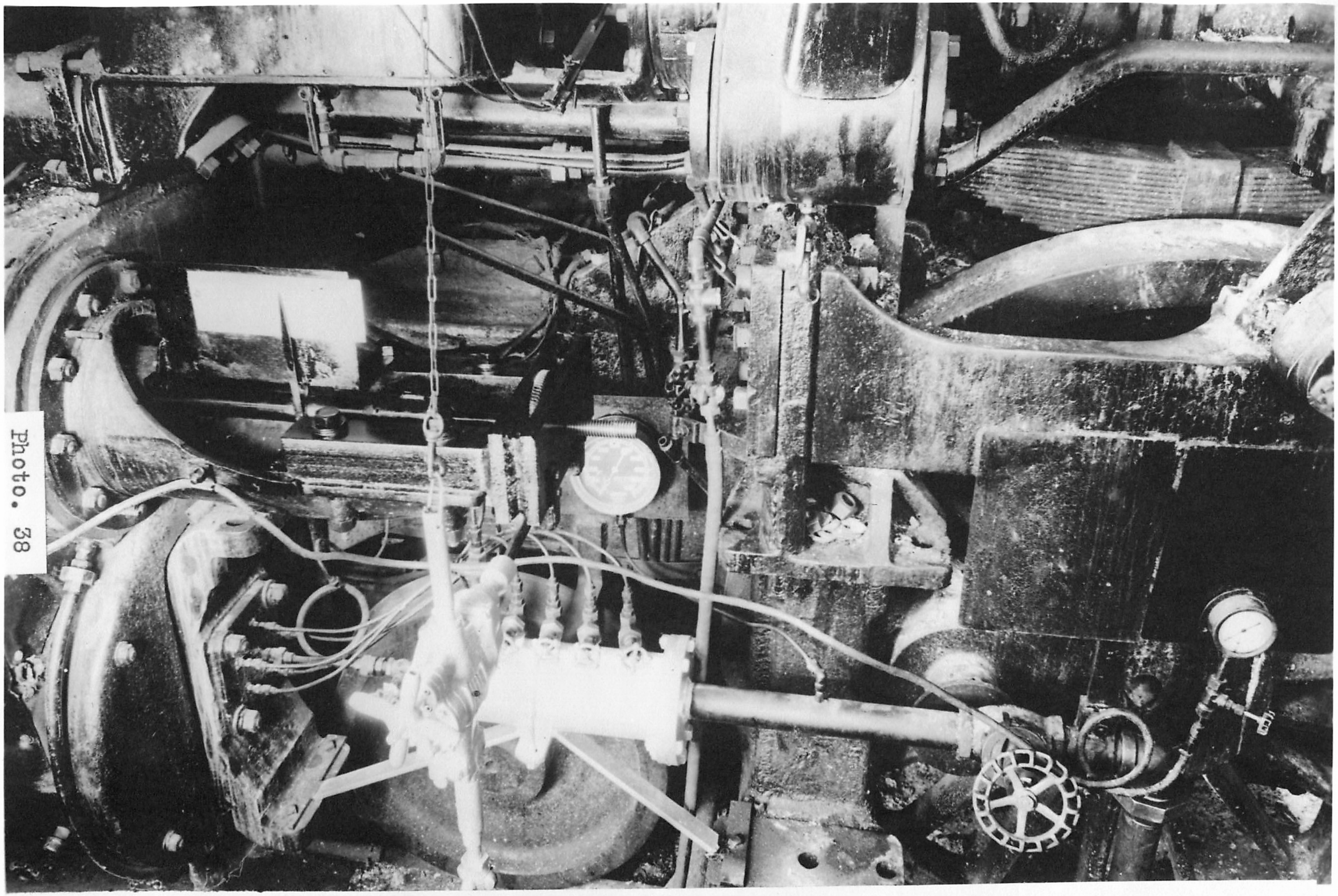


Photo. 38

LEFT SIDE OF ENGINE AT CYLINDER

Showing general arrangement of valve positioning device, spray water manifold and filter, piping to cylinder spray nozzles, and air motor to operate worm gear. Hot water pump at top of photo, with stroke counting contactor visible.

ST-70-15

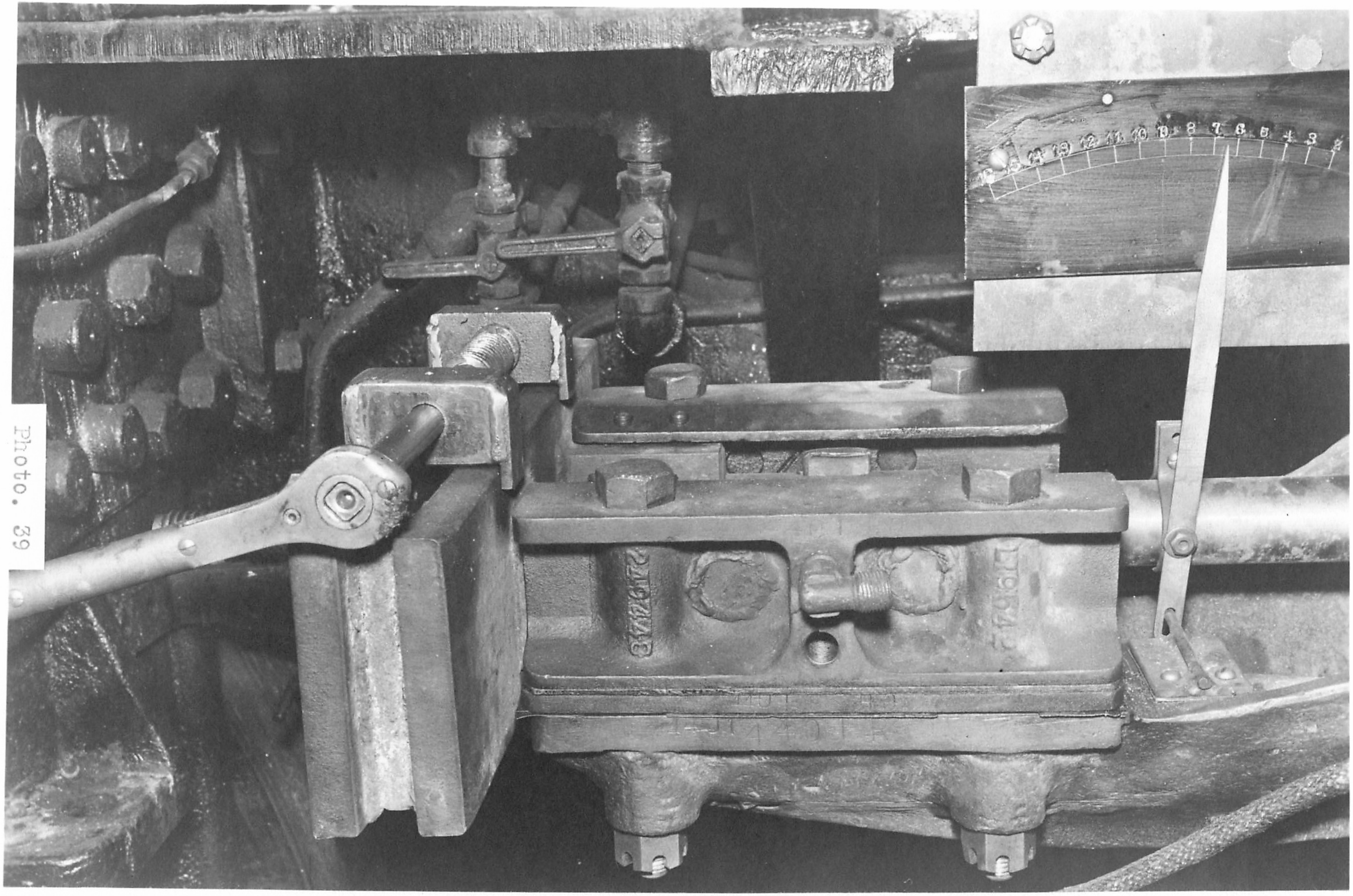


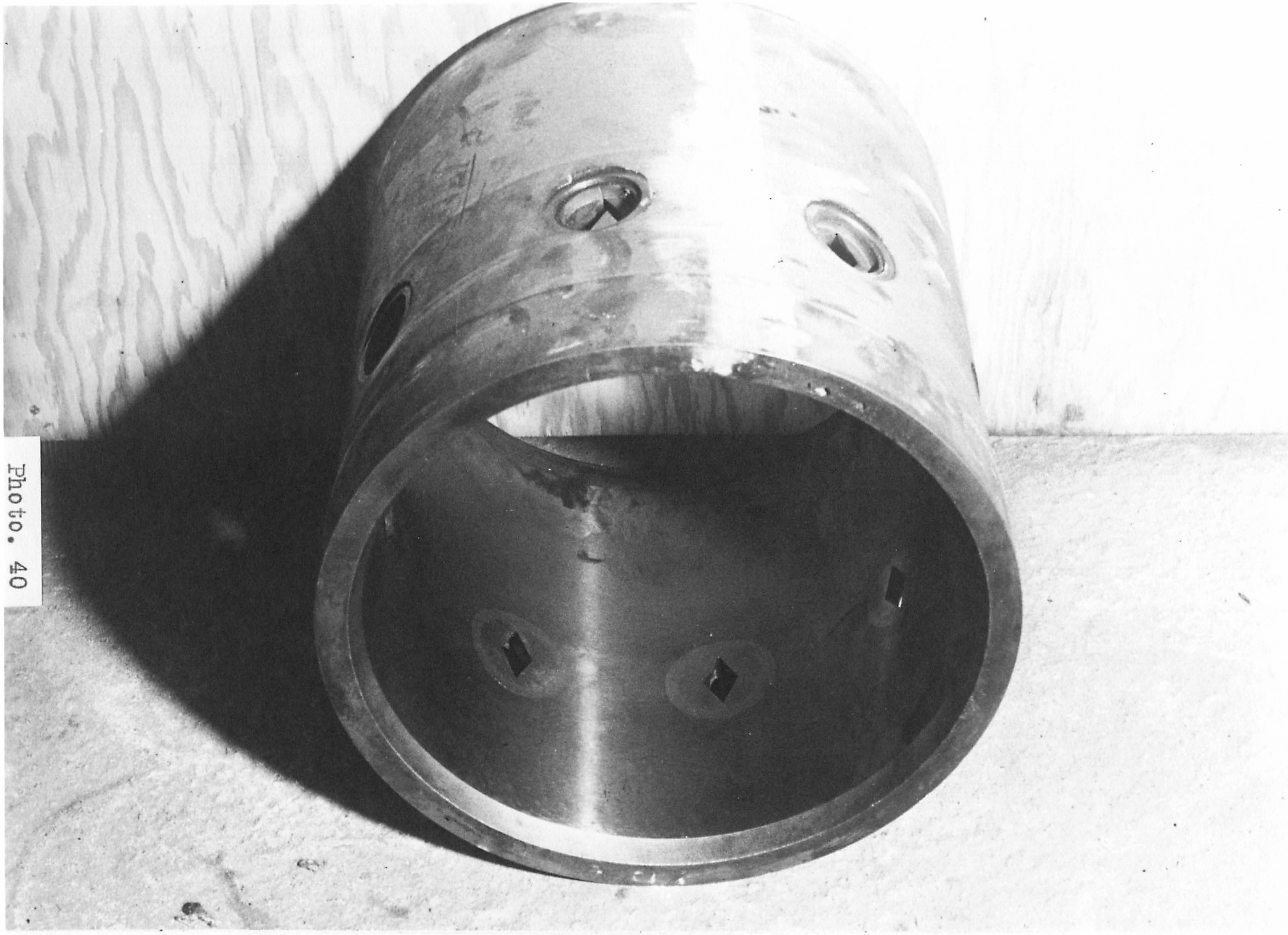
Photo. 39

VALVE POSITIONING ARRANGEMENT

Close-up of valve positioning arrangement with hand ratchet in place. Graduations on indicator are arbitrary but facilitated return to any previously established positions.

ST-18-7

Photo. 40



SPECIAL VALVE CHAMBER BUSHING FOR REAR OF STEAM CHEST
Showing diamond ported tool steel inserts. ST-41-1

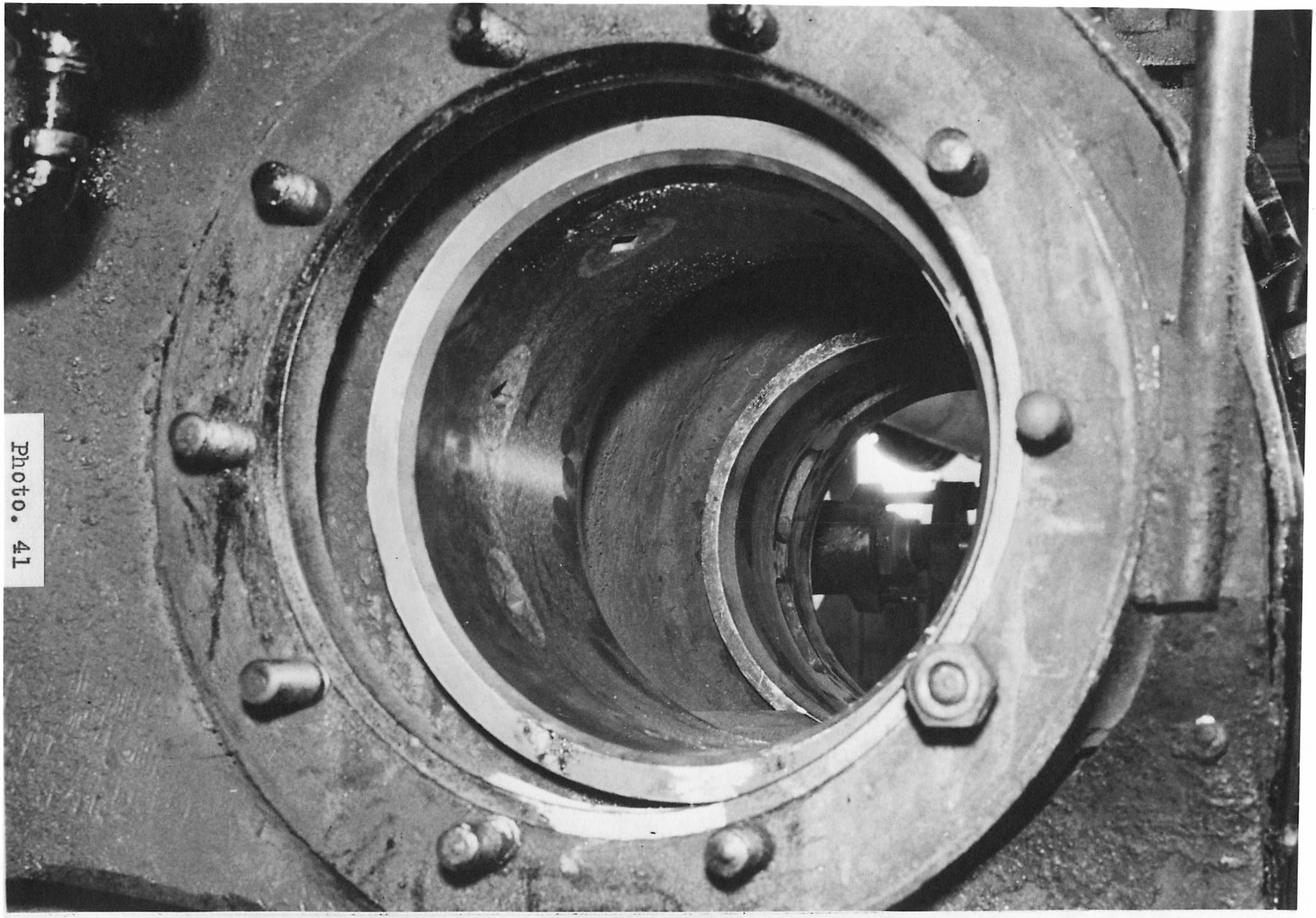
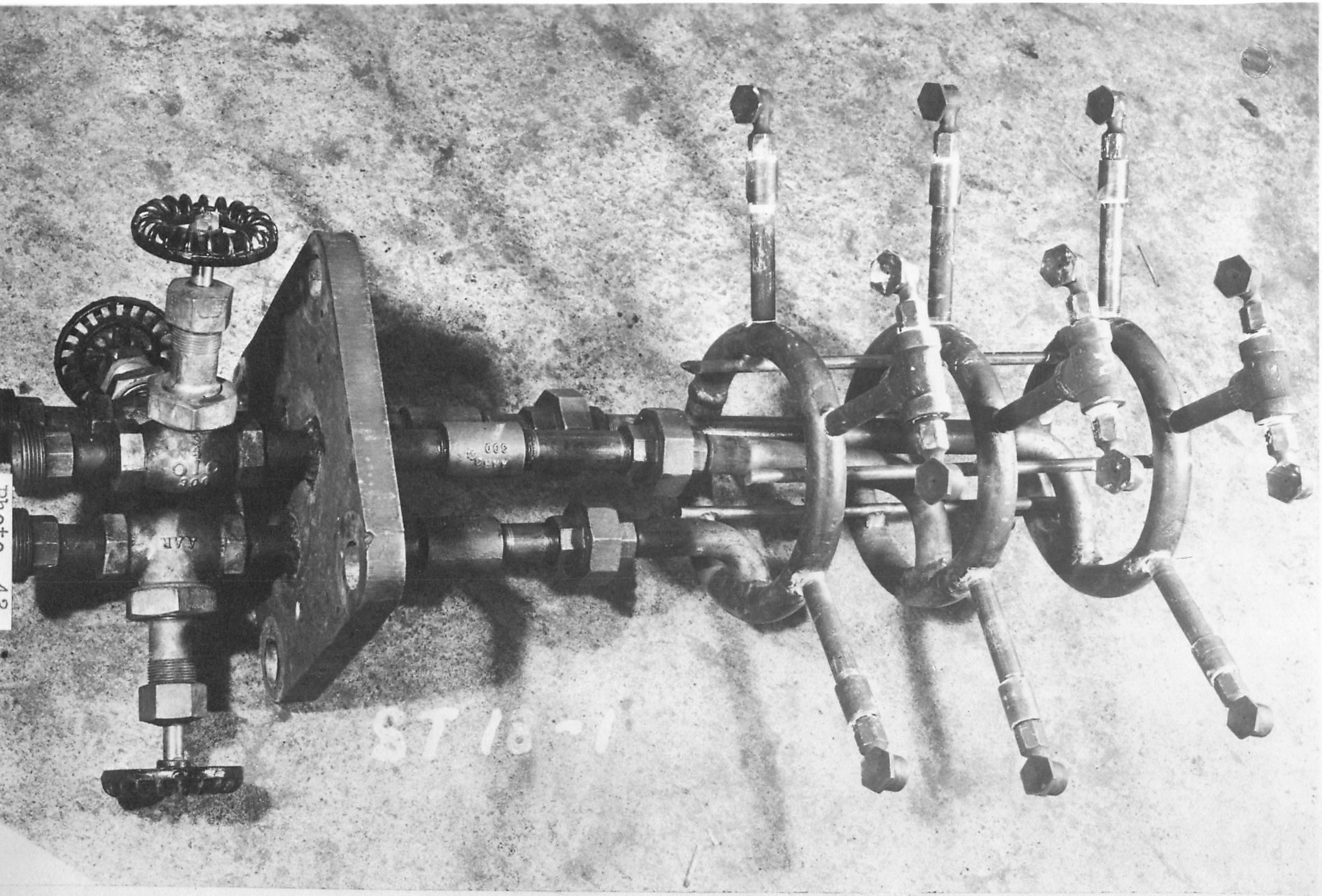


Photo. 41

SPECIAL BUSHING IN PLACE IN PISTON VALVE CHAMBER
Showing bushing in place on right side of engine at rear of steam chest.

Photo. 42



DESUPERHEATING WATER SPRAYS

Showing original grouping with which no baffles or other mixing devices were used initially. Plate at left is bolted over main piston rod opening in rear cylinder head, sprays being inside cylinder and control valves outside.

ST-18-1

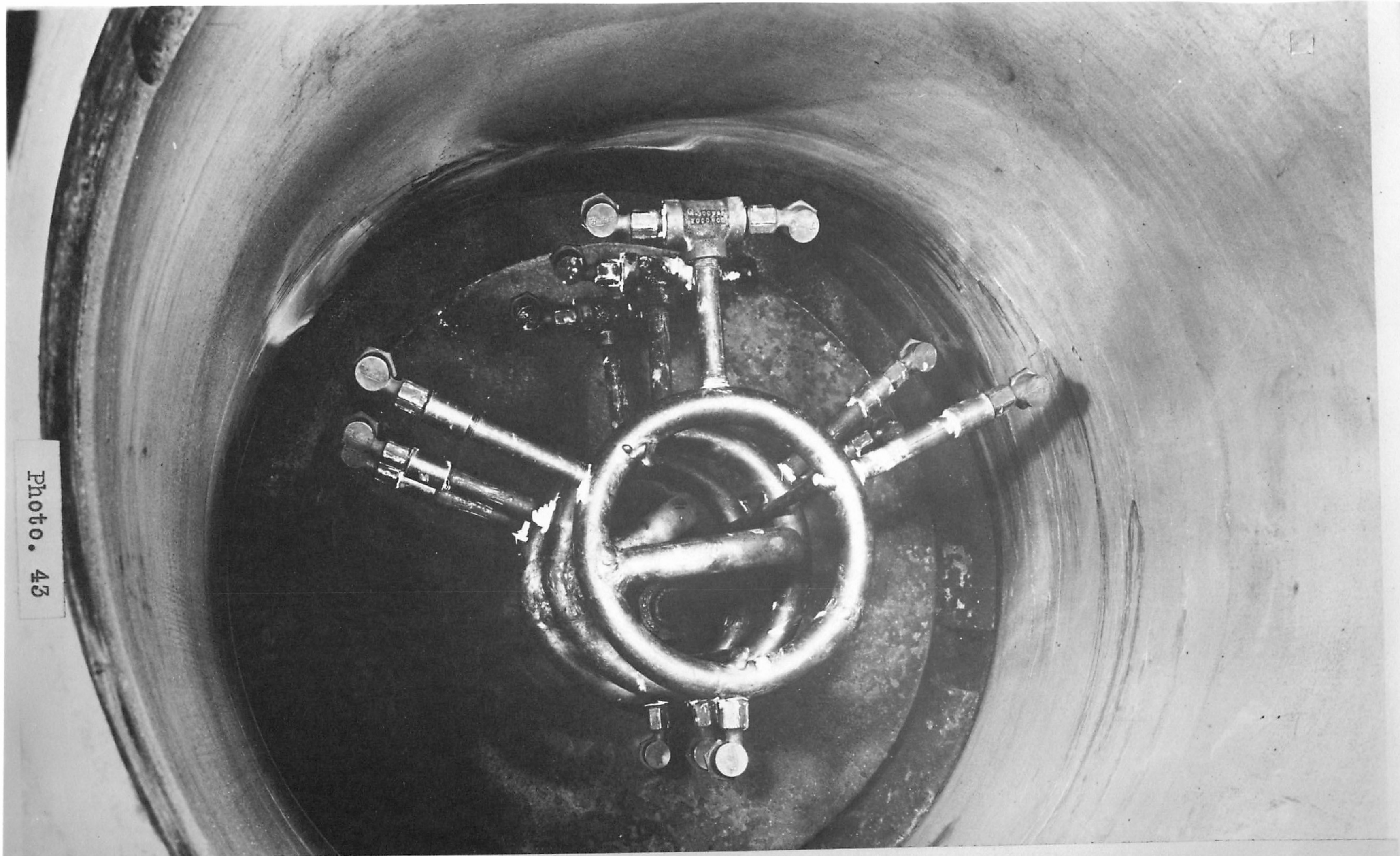
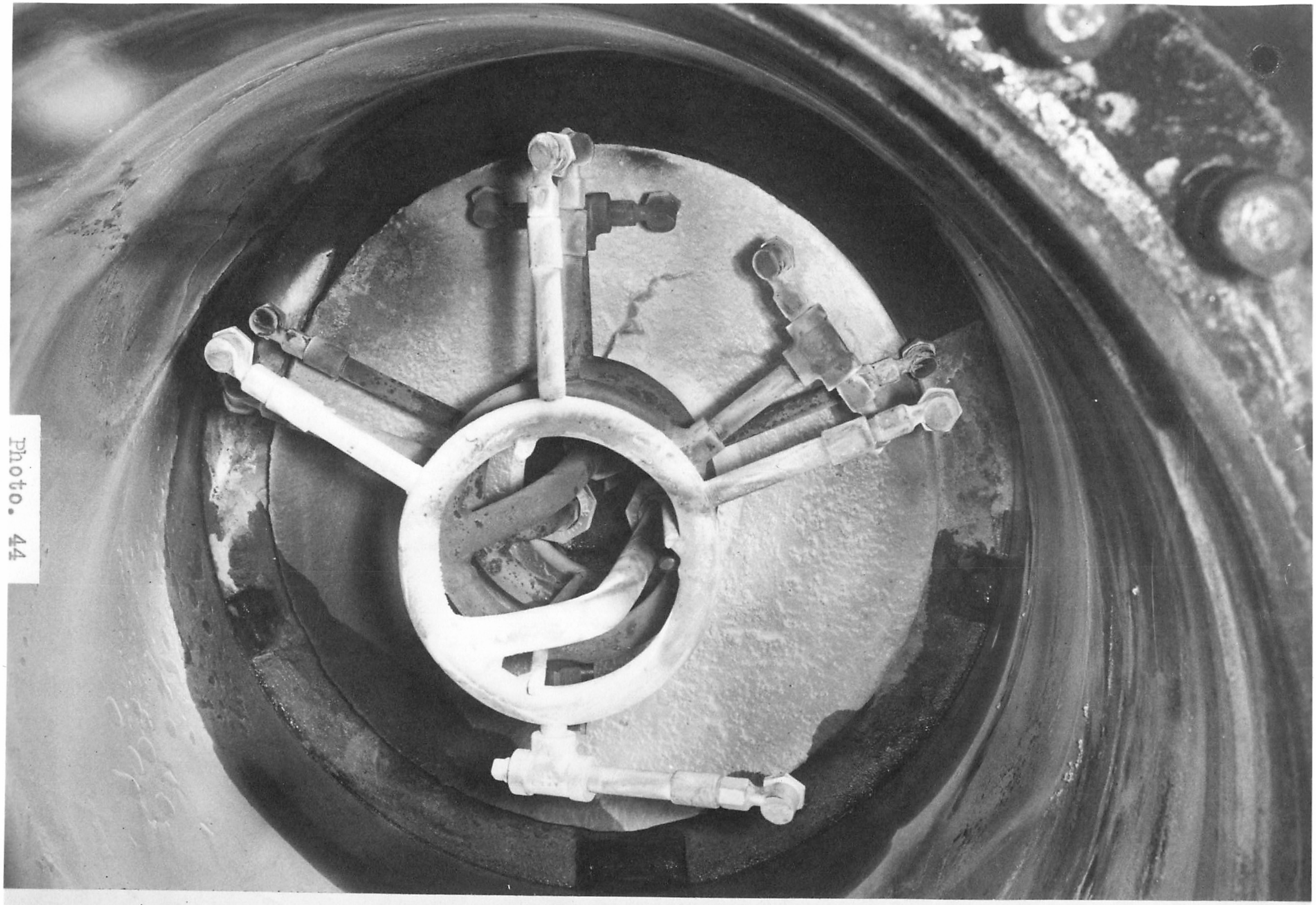


Photo. 43

DESUPERHEATING WATER SPRAYS

Showing original installation in cylinder. The sprays alone did not produce good desuperheating and a screen and baffles, as shown elsewhere, were added. ST-18-2

Photo. 44

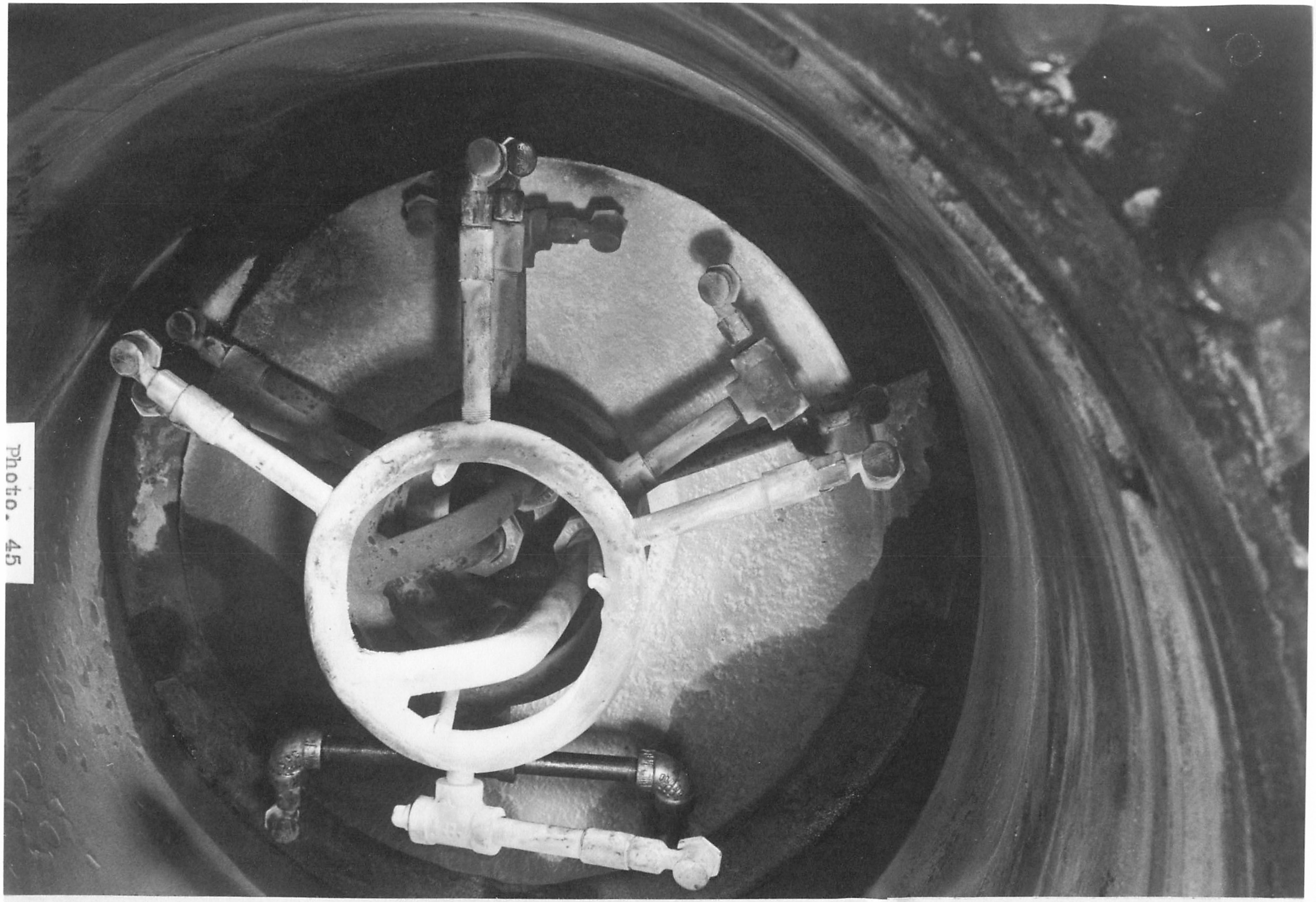


DESUPERHEATING WATER SPRAYS

Showing first modification made to nozzle grouping account unsatisfactory desuperheating.

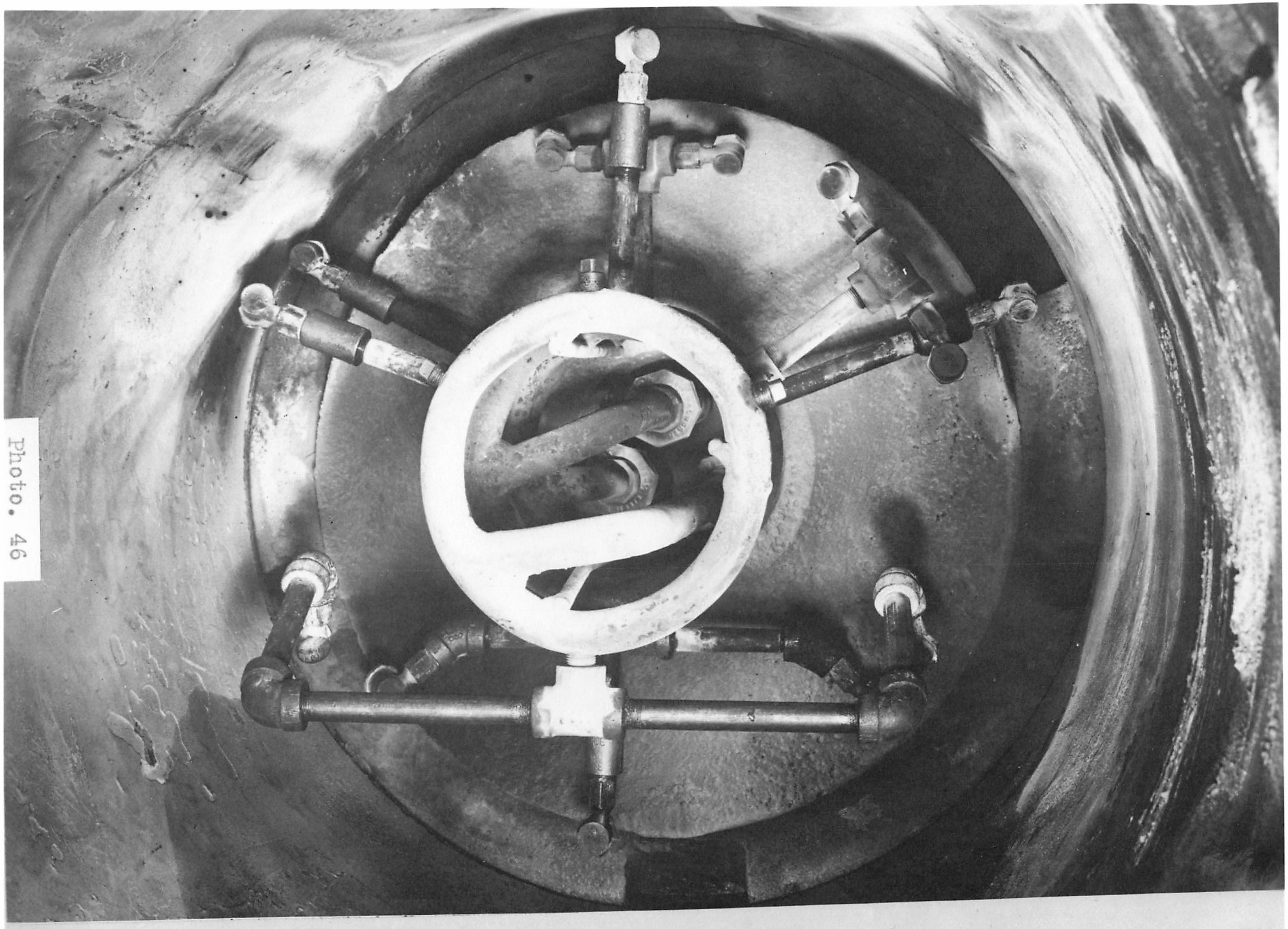
ST-24-1

Photo. 45



DESUPERHEATING WATER SPRAYS
Showing second modification made to nozzle grouping account unsatisfactory desuperheating.
ST-31-3

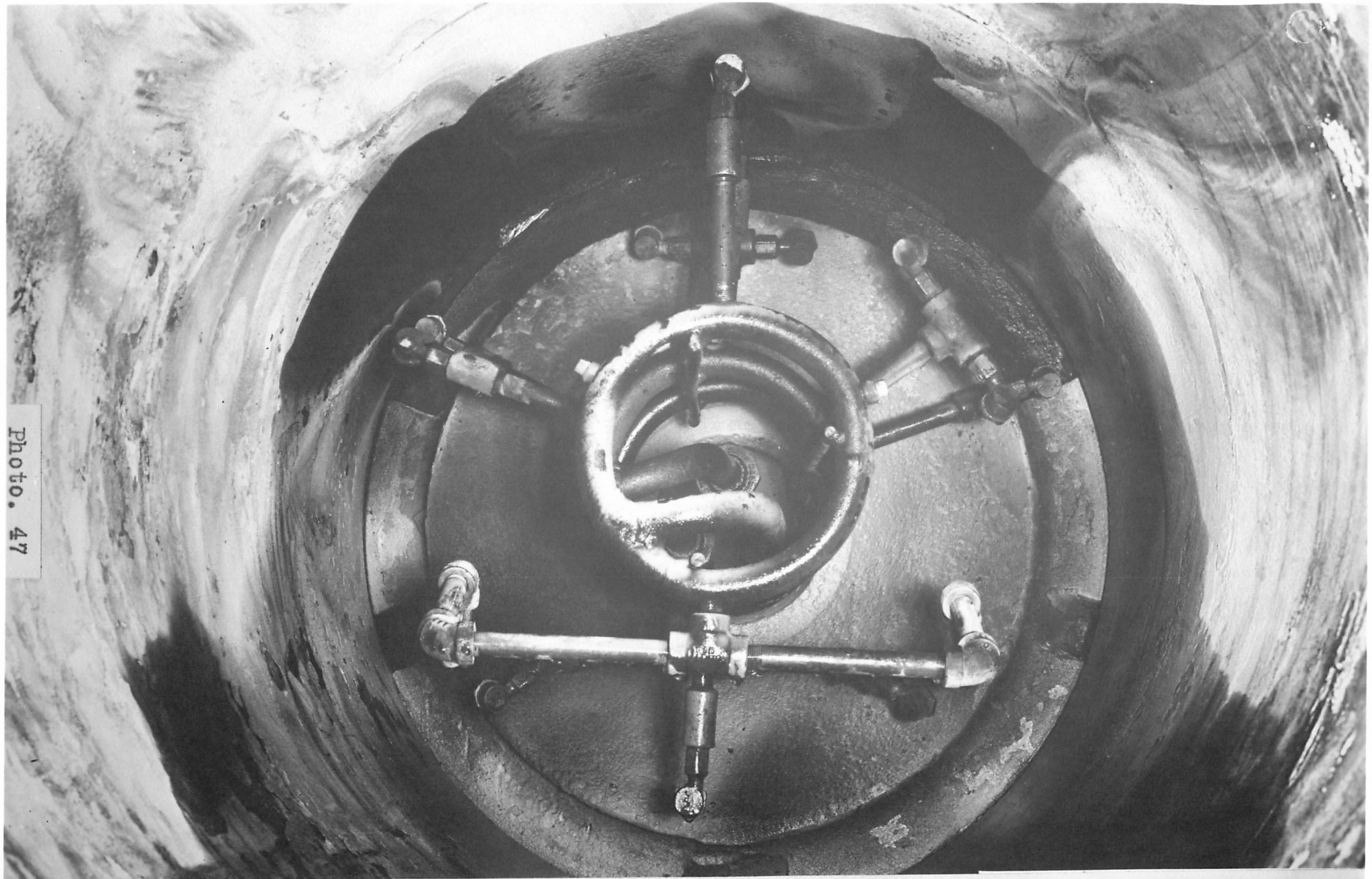
Photo. 46



DESUPERHEATING WATER SPRAYS
Showing third modification made to nozzle grouping account unsatisfactory desuperheating.

ST-32-0

Photo. 47



DESUPERHEATING WATER SPRAYS
Showing fourth modification made to nozzle grouping account unsatisfactory desuperheating.
ST-32-1

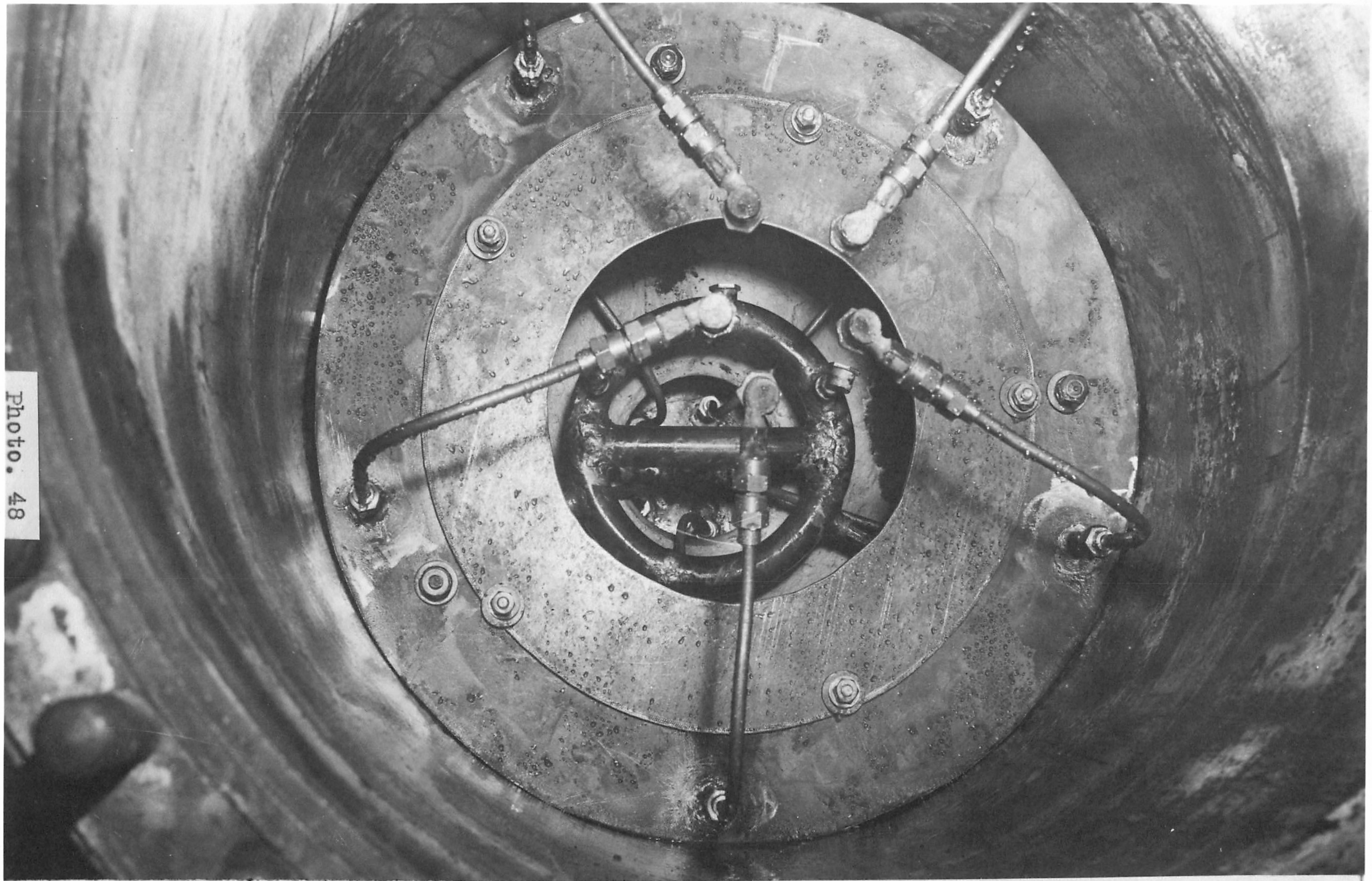


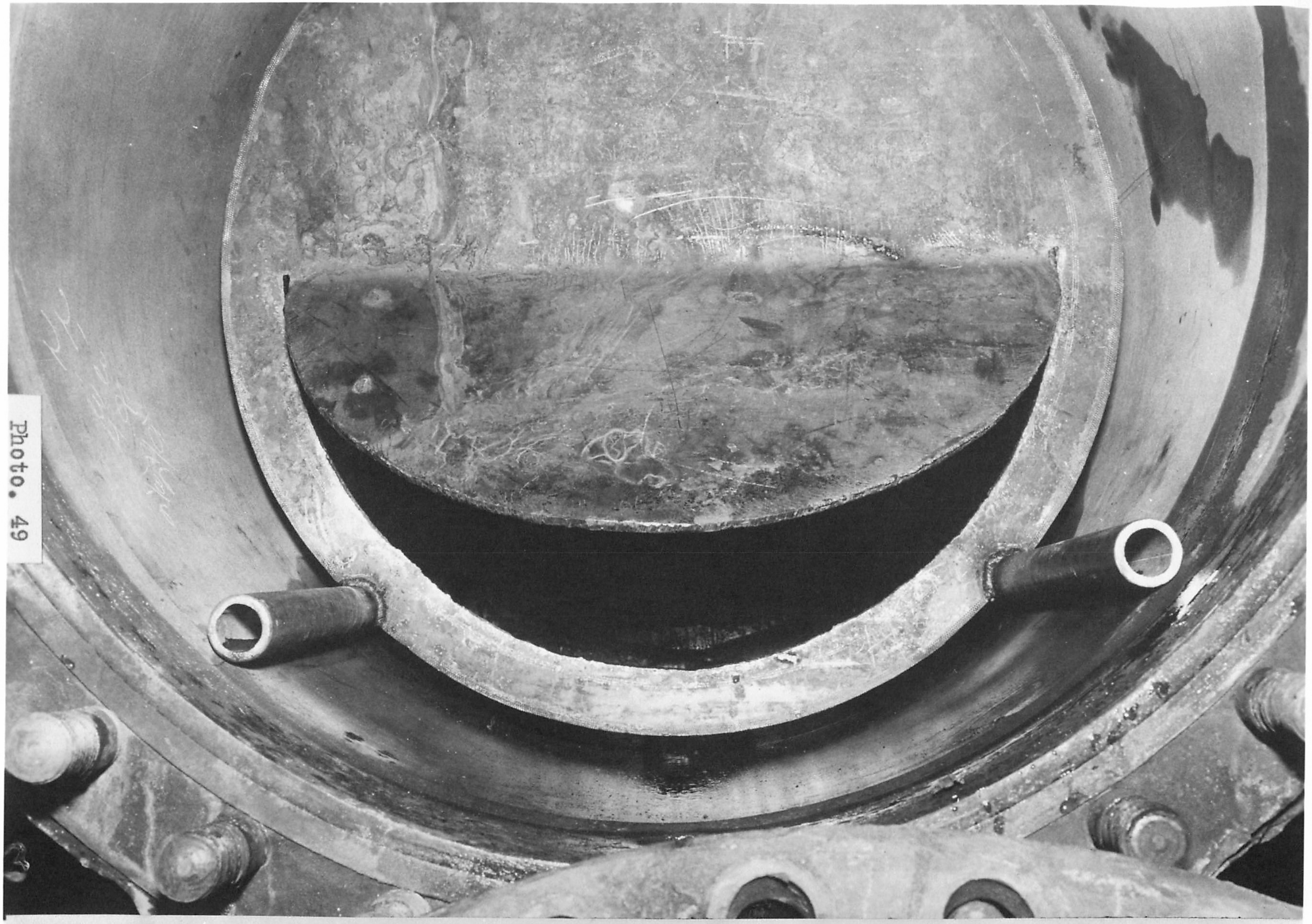
Photo. 48

INTERIOR OF CYLINDER

Showing final arrangement of desuperheating spray nozzles, with orifice plate added to centralize steam flow and reduce channeling. The five individually controlled sprays, directed into steam leaving orifice gave close control of final steam temperature. Mixture then passed through baffles shown elsewhere.

ST-52-1

Photo. 49



CYLINDER SPRAY BAFFLE ARRANGEMENT

Showing a trial baffle installed in cylinder to improve mixing of spray water and steam. An additional baffle and a screen were added later. ST-18-3

Photo. 50

FIRST CYLINDER SPRAY BAFFLE ARRANGEMENT

Steam enters through screen end after passing water spray. This arrangement added in cylinder account incomplete evaporation of desuperheating water with sprays only.

ST-20-1

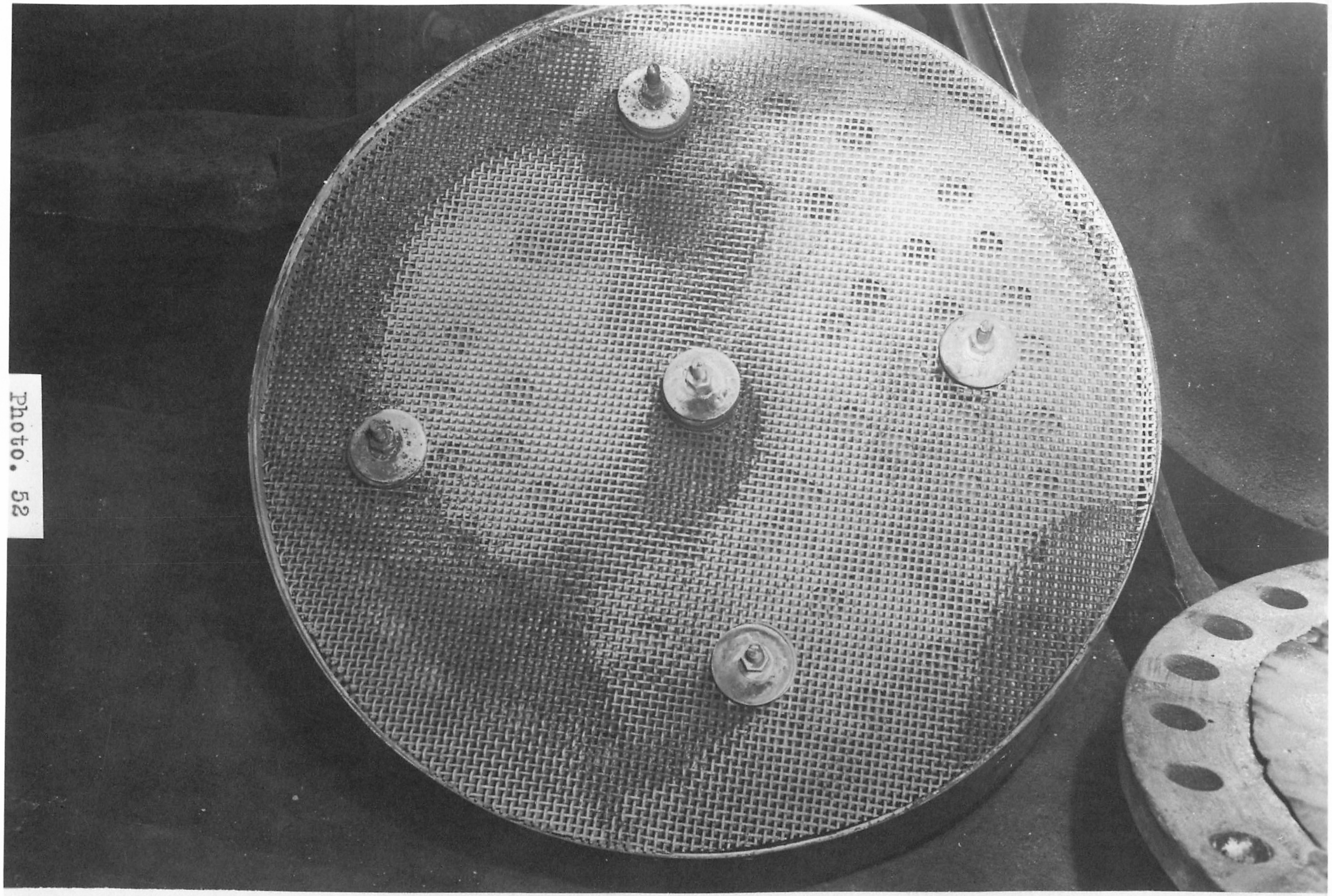
Photo. 51

TRIAL CYLINDER SPRAY BAFFLE ARRANGEMENT

Showing an intermediate arrangement of baffles and screens used in cylinders. Composed of numerous punched disks in series. Screen is shown along side prior to application.

ST-54-1

Photo. 52



TRIAL CYLINDER SPRAY BAFFLE ARRANGEMENT

Showing an intermediate arrangement of baffles and screens used in the cylinders. Composed of several punched disks in series. Outer screen shown in place.

ST-54-2

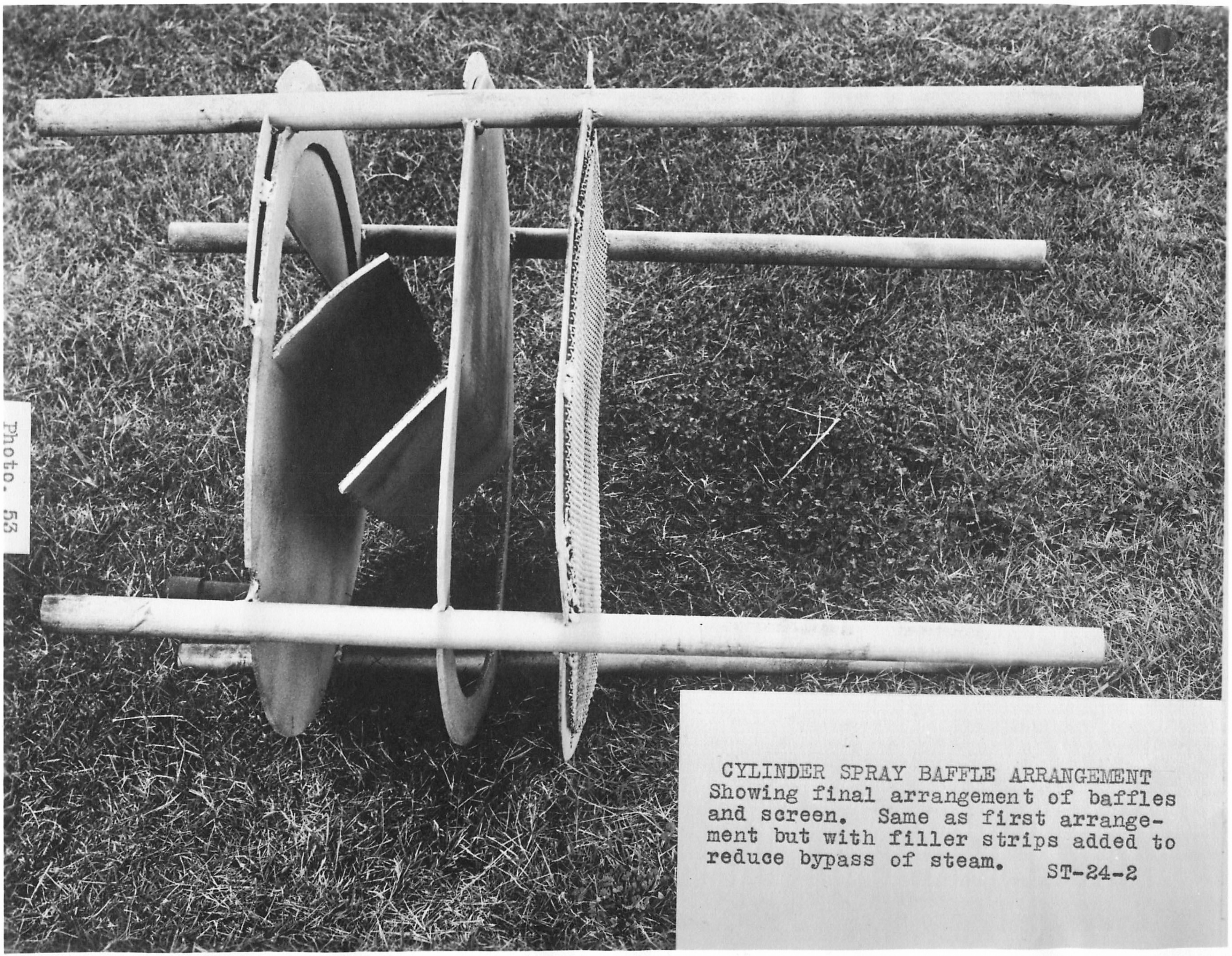
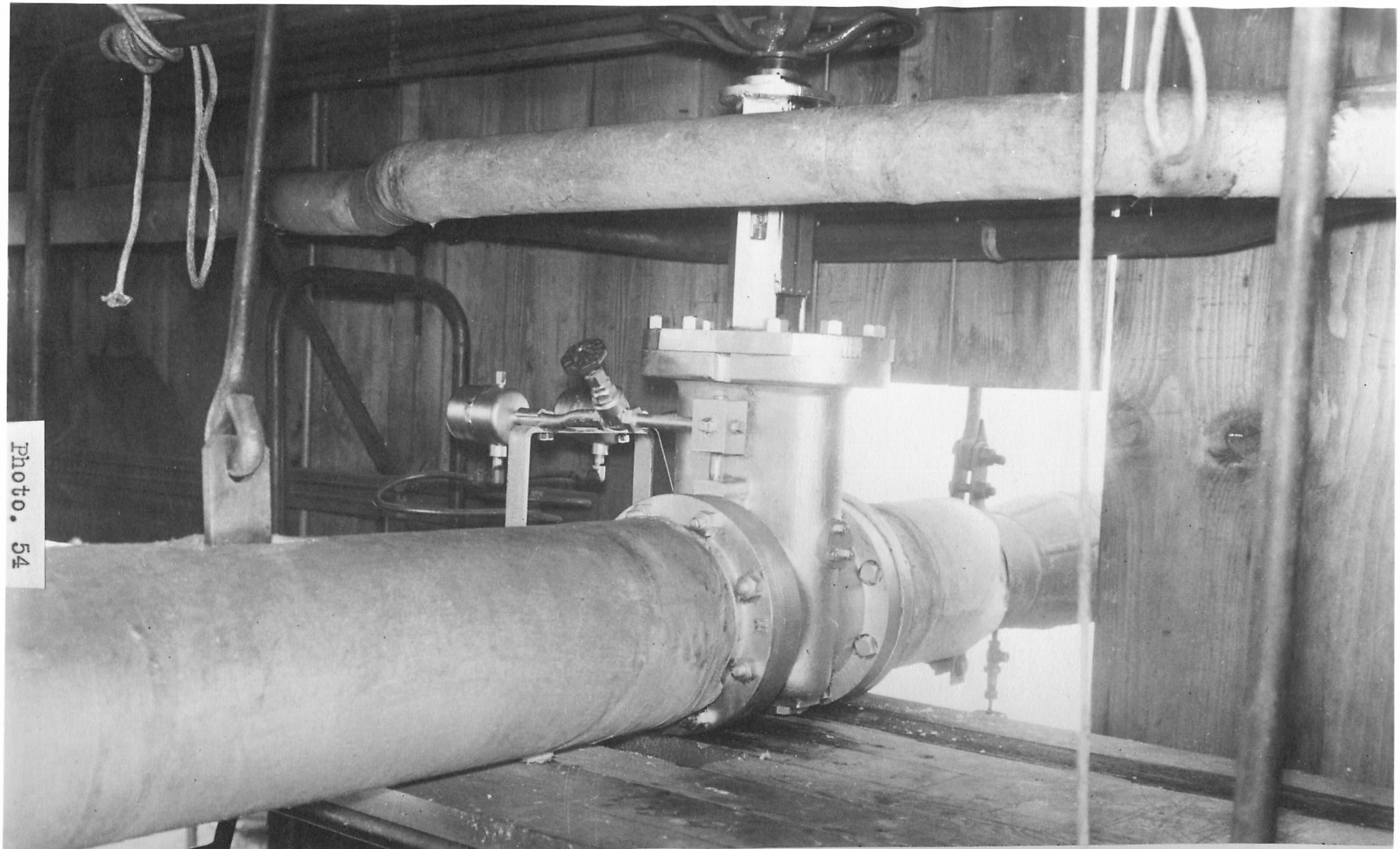


Photo. 53

CYLINDER SPRAY BAFFLE ARRANGEMENT
Showing final arrangement of baffles and screen. Same as first arrangement but with filler strips added to reduce bypass of steam. ST-24-2

Photo. 54



8" ADJUSTABLE ORIFICE

Adjustable orifice for metering bleed-off of "surplus" steam, showing hand wheel for adjusting segment height, and water level reservoirs for connections to recorder. Located in wye pipe at east wall of building. Orifice metered steam bled off, and through the recorder unity ratio beam linkage with spray water recorder-controller, influenced the position of bleed off control valve, located outside of building.

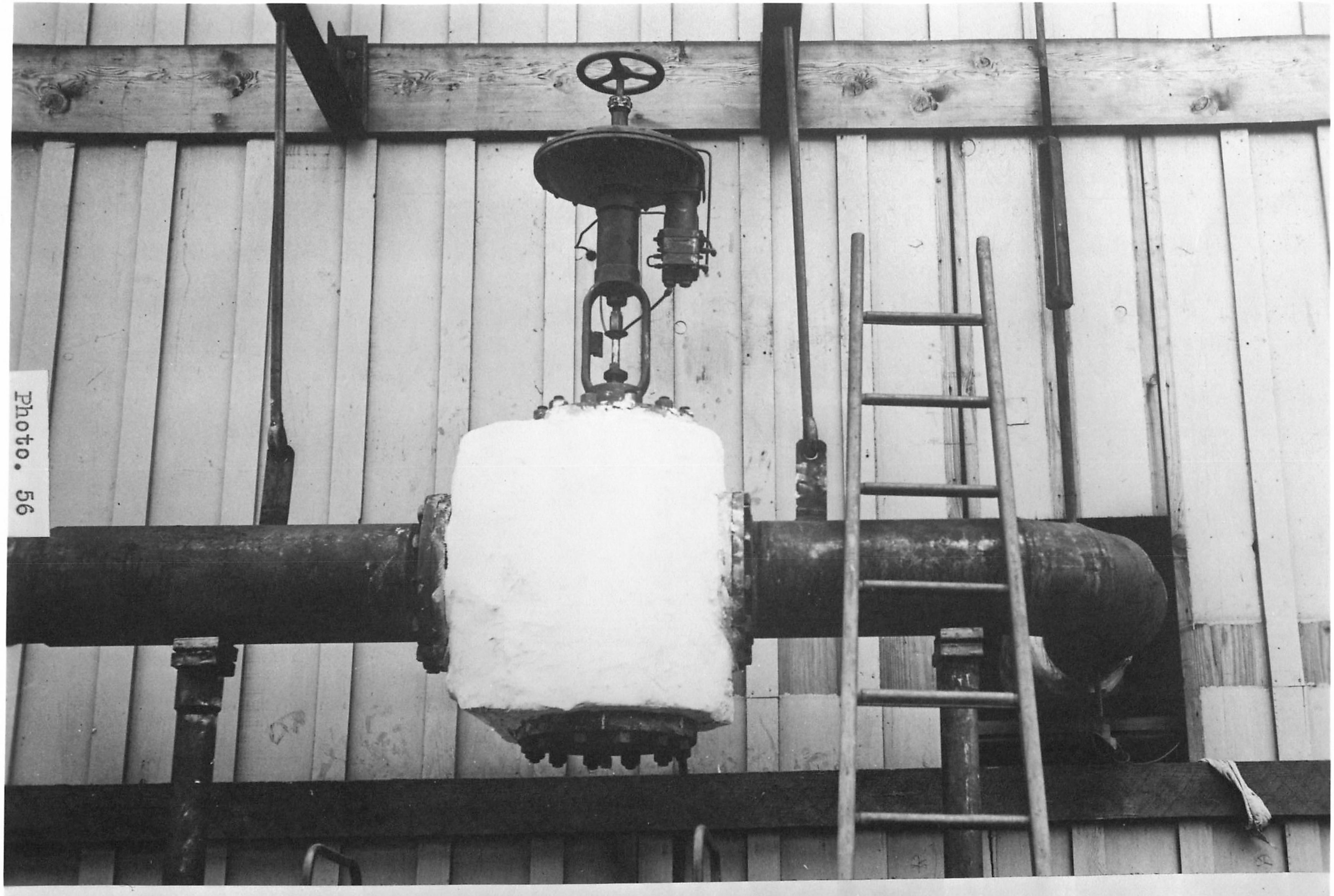
70-12

CLOSE-UP OF 8" ADJUSTABLE ORIFICE

Showing hand wheel and segment height indicator, with vernier scale just under hand wheel. ST-13-2

Photo. 55

Photo. 56

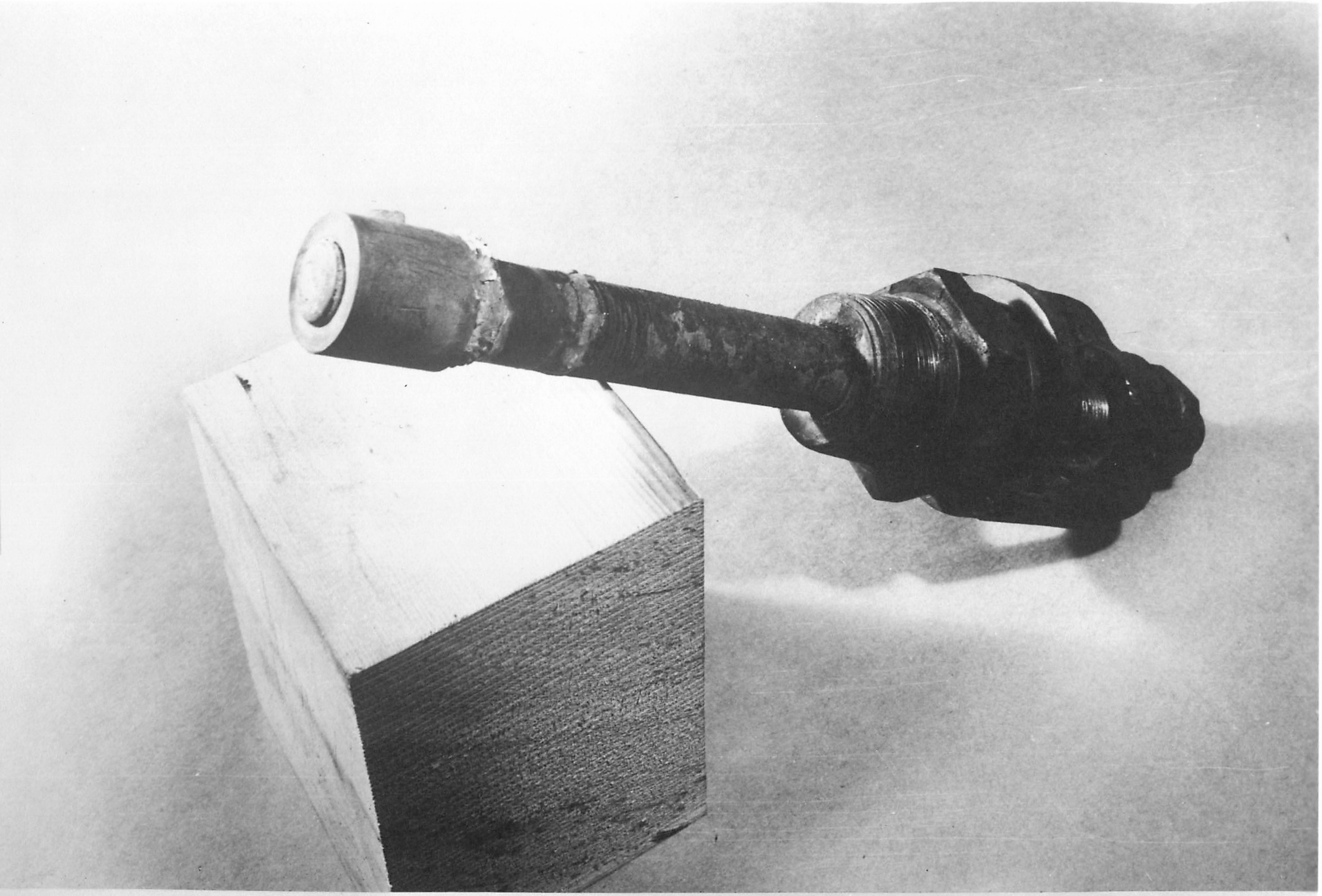


10" BLEED OFF CONTROL VALVE FOR SURPLUS STEAM

Showing diaphragm operated valve with positioner relay attached at diaphragm. Steam flows from metering orifice inside building through valve to muffler. Steam coils and lagging around valve, applied during period of cold weather, were subsequently removed.

ST-13-3

Photo. 57



THERMOCOUPLE FOR TEMPERATURES OF WATER SIDE OF FIREBOX SHEETS

Showing original style with couple in copper button, left end, and packing gland and adjusting nuts, right end, for forcing and holding button against water face of firebox sheet. Successful injection molding of Bakelite insulation at couple button proved difficult with equipment available and a different style was eventually developed.

ST-45-1

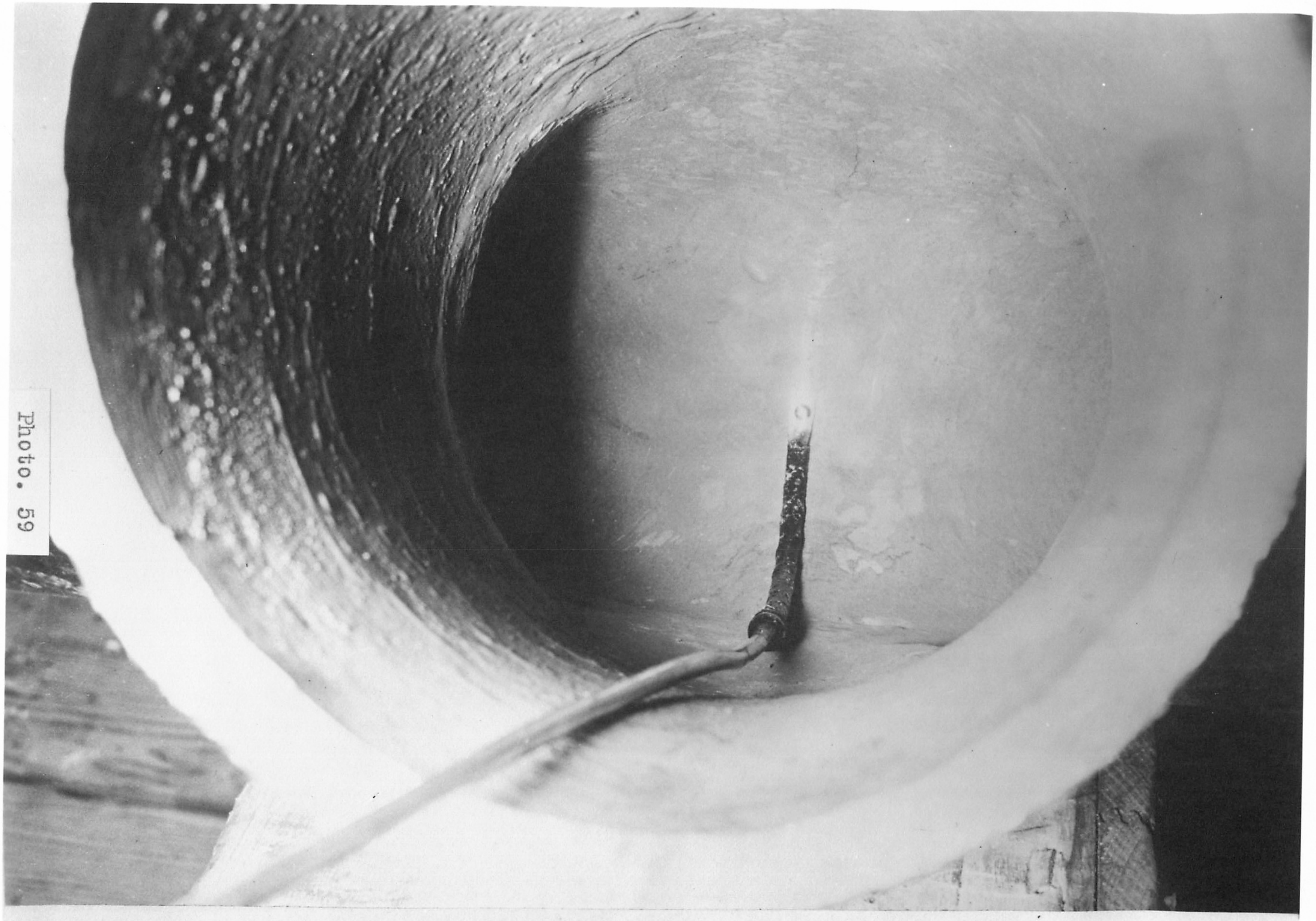
Photo 58

THERMOCOUPLE FOR TEMPERATURE OF WATER SIDE OF FIREBOX SHEET

Showing couple end of final design, with couple in peened flat portion of copper tube and an adjacent section insulated from boiler water with Bakelite varnish over glass tape wrapping. Couple held tight to sheet by small self tapping type machine screw.

ST-84-1

Photo. 59



THERMOCOUPLE APPLICATION IN SECURITY CIRCULATOR

View looking down into circulator riser, showing installation of tubing protected style of thermocouple to measure water side temperature.

ST-84-2

Photo. 60

THERMOCOUPLE FITTINGS ON BOILER EXTERIOR

Showing method of bringing tubing of final style of water side thermocouple through sheet. Visible through washout plug hole, is thermocouple end of the small size tubing which is held tight to firebox sheet by small machine screw. ST-90-1

				SMOKEBOX						
				12 Inches from Tube Sheet						
FIREBOX	Inside Netting	Front of Netting	Back of Diaphragm	Top Center	Left Top	Right Top	Left, 1/2 Up	Right, 1/2 Up	Bottom Center	Center 1/2 Up

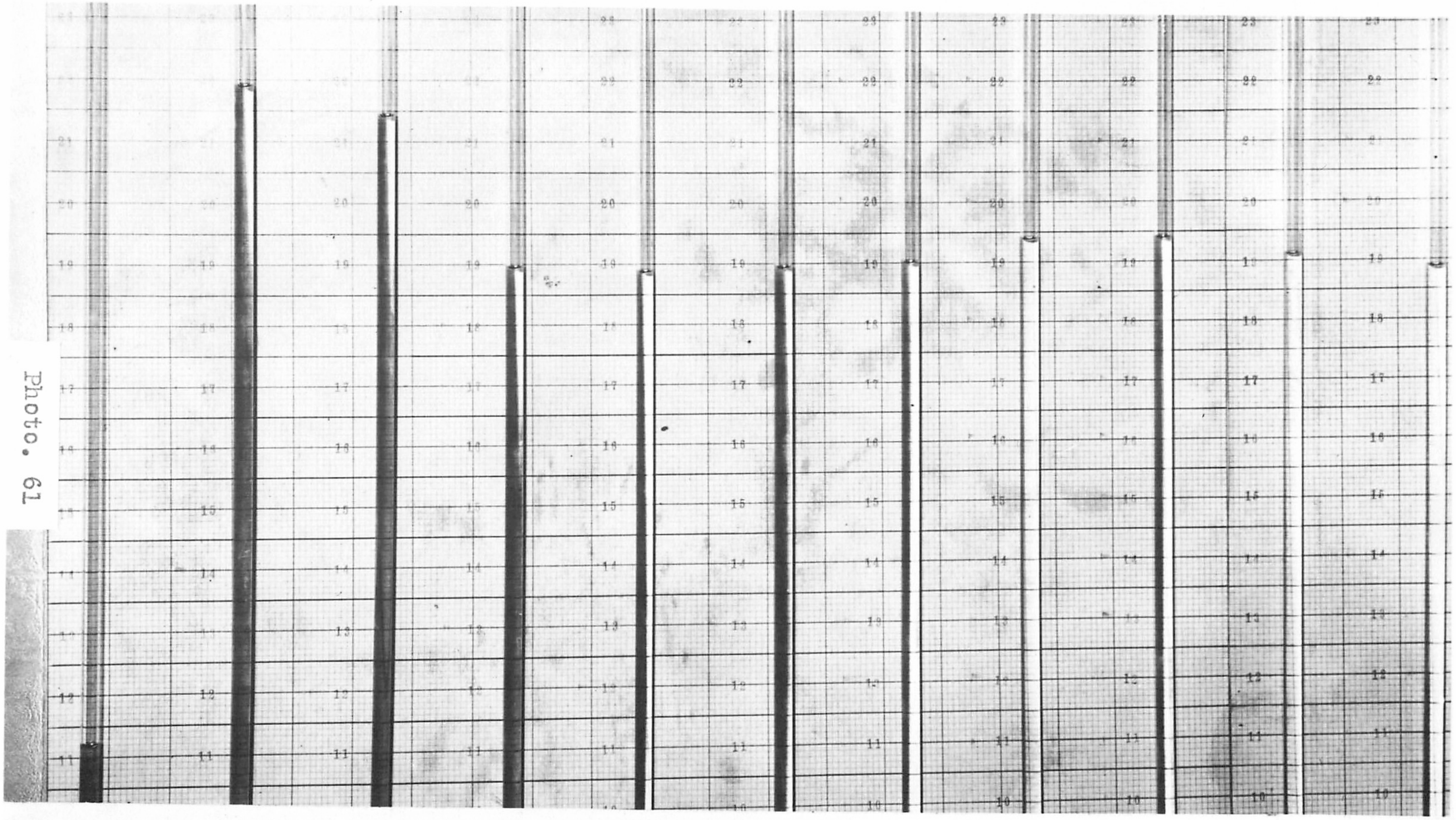


Photo. 61

DRAFT MANOMETERS

Illustrating a method of obtaining, in effect, simultaneous readings of the draft at numerous points by means of flash photography. Location of draft indicated, is shown by headings above. Later, plug valves were installed at bottom of each tube and interconnected to permit shutting all the tubes off at the same time, which gave the same effect.

ST-21-2A

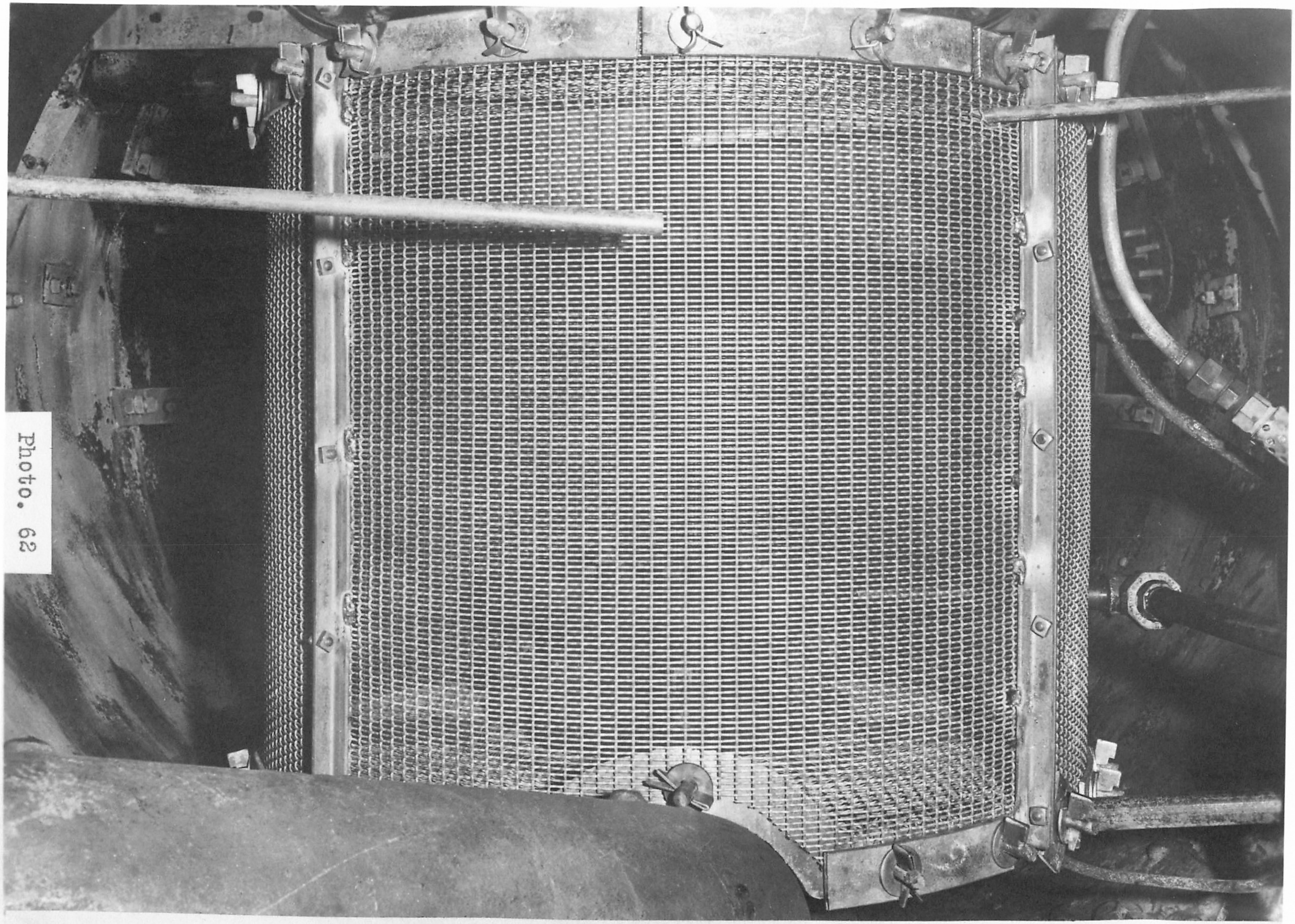


Photo. 62

INTERIOR VIEW OF SMOKEBOX
Showing the basket type spark arrester and near top, two of the tubes for measuring draft, one extending into arrester from right. ST-28-3

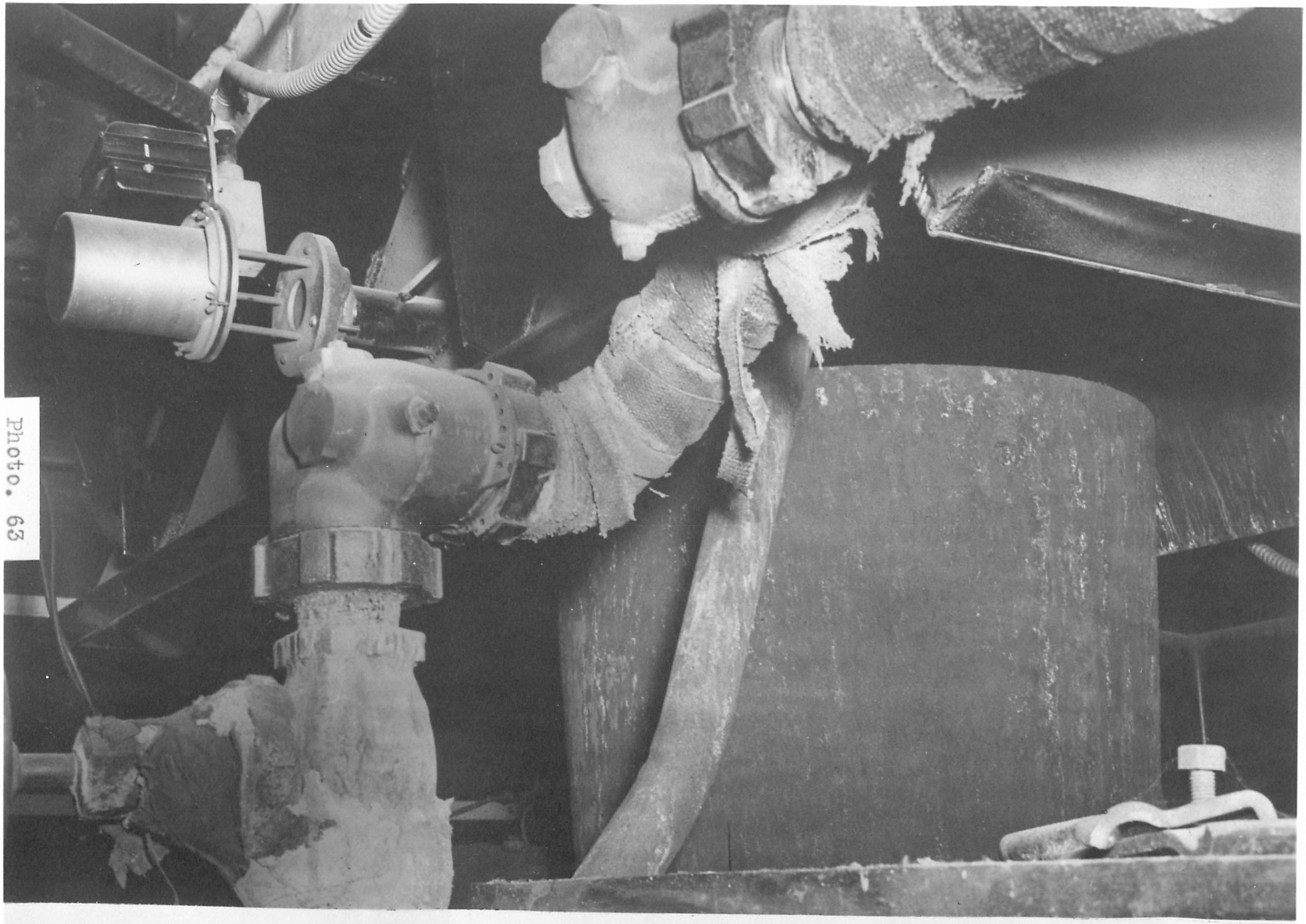


Photo. 63

SMOKE INDICATOR LIGHT SOURCE
Showing mounting on smoke jack. ST-89-3

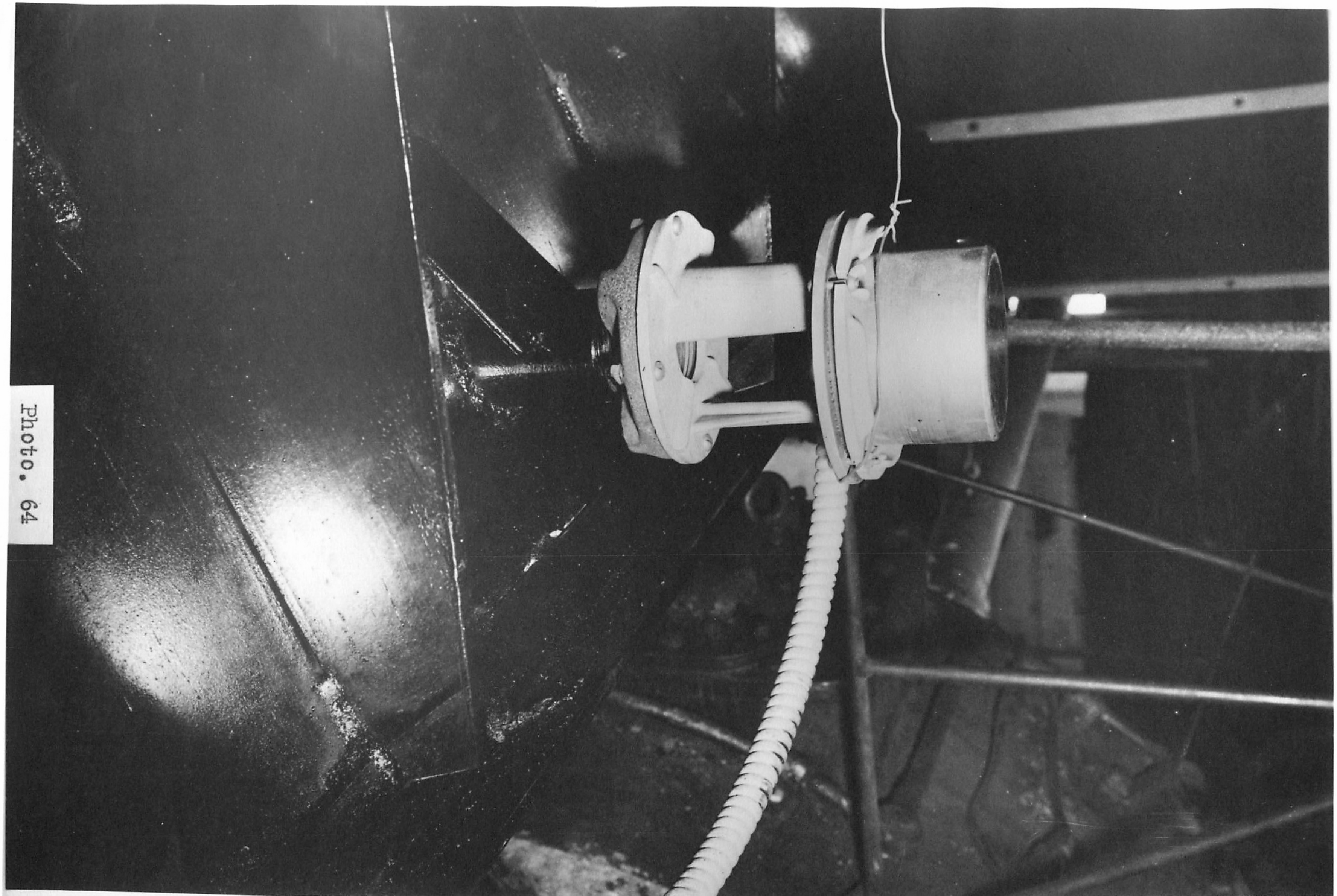


Photo. 64

SMOKE INDICATOR PHOTO CELL
Showing mounting on smoke jack, close to top of engine stack.

ST-70-13

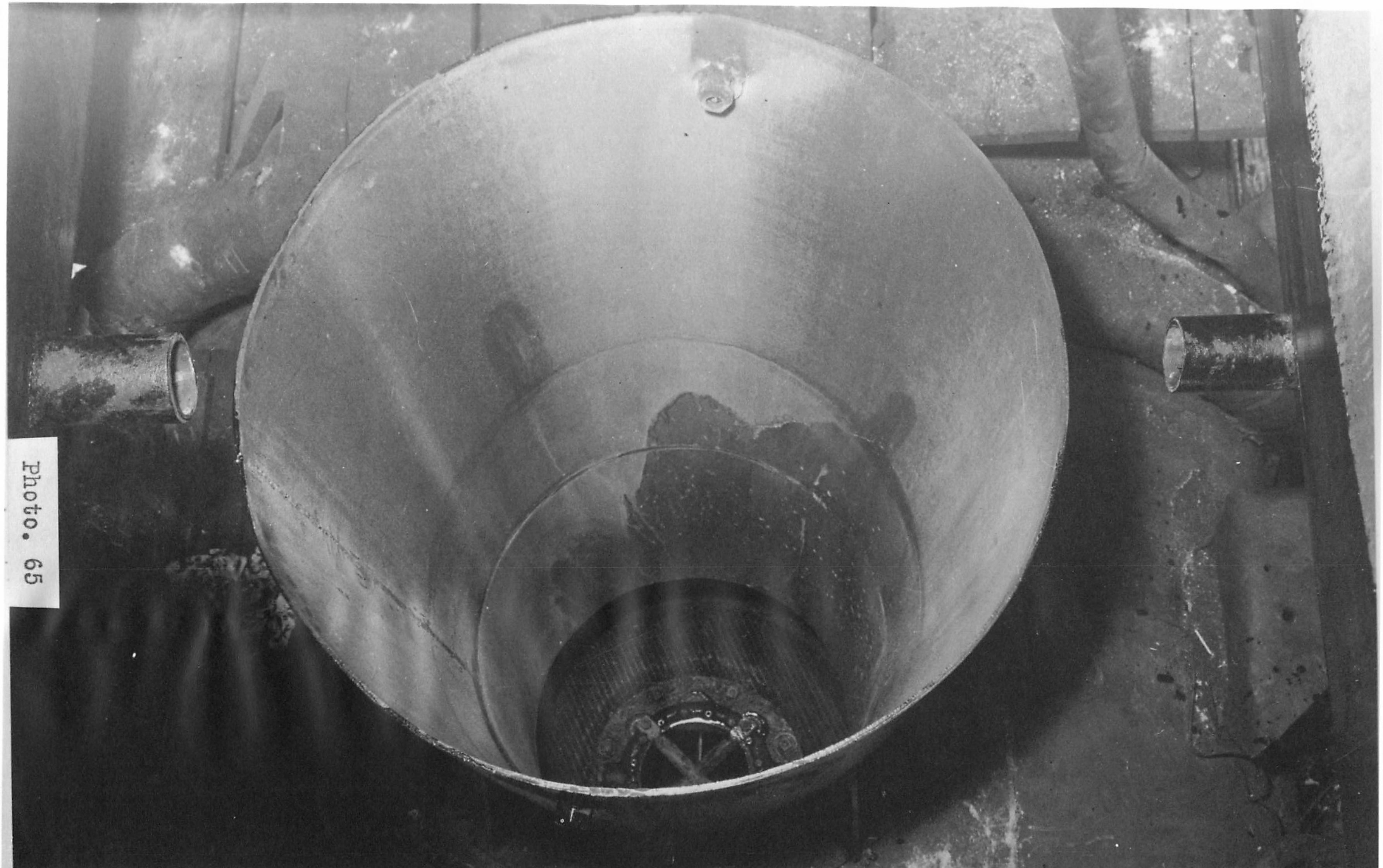


Photo. 65

SMOKE INDICATOR MOUNTING AT STACK

Showing view from inside smoke jack. Portions of an initially continuous, mounting tube, used to assure alignment during installation, are visible protruding from sides of jack and were left to protect lenses of light source and photo cell from sand and moisture in exhaust.

ST-70-8

SMOKE INDICATOR METER AND WARNING LIGHT
Showing meter, calibrated in Ringelmann numbers, with red warning light above, adjustable to desired limiting smoke density. Located at firing deck.

ST-70-9

Photo. 66

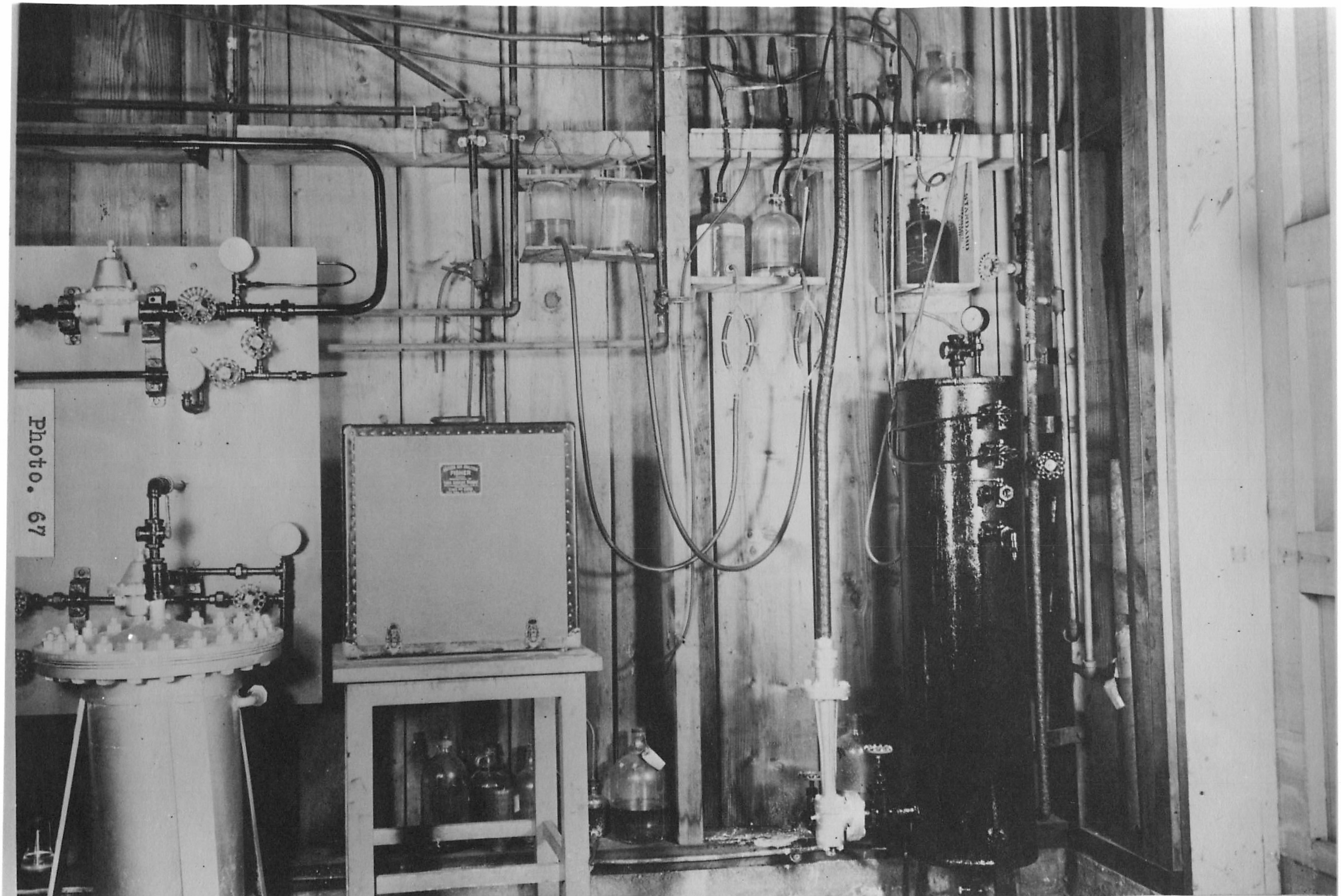


Photo. 67

FLUE GAS SAMPLING ARRANGEMENT FOR MANUAL ANALYSES
Showing vacuum tank with steam aspirator and sampling line connections to leveling bottles for extracting continuous sample during period of the test.

ST-70-16

FIREBOX SURVEY APPARATUS

On access platform right side, showing gas sample being obtained during firebox survey. Sample bottles in racks on left. Cooling water hoses, and tubing for gas sample attached to probe.

ST-83-1