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BATTELLE NORTHWEST

THERMAL HYDRAULICS LABORATORY (C)

W. L. Thorne

Battelle Memorial Institute
Pacific Northwest Laboratory
Richland, Washington

I Establishment and Objectives

- A. Applied research in support of production
- B. Applied research in support of new reactor design
- C. Applied research to define basic variables for specific systems
- D. Research to advance the state of the art

II Organization

A. Analytical Unit

- 1. Definition of programs
- 2. Pretest analysis
- 3. Test design
- 4. Operation
- 5. Data analysis and report writing

B. Experimental Unit

- 1. Test design
- 2. Design of equipment
- 3. Fabrication and assembly of test sections
- 4. Installation and operation

(C)

This paper is based on work performed
under United States Atomic Energy
Commission Contract AT(45-1)-1830.

MASTER

III Facilities

- A. High Pressure Facility
 - 1. Steady state capabilities
 - 2. Transient capabilities
- B. Low Pressure Facility
 - 1. Steady state capabilities
 - 2. Transient capabilities
- C. Hydraulics laboratory
 - 1. Horizontal Flow System
 - 2. Vertical Flow System
 - 3. High Flow Facility
 - 4. Flowmeter Calibration
 - 5. Temperature Sensor Response
 - 6. Gas Cooling Facility

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AT HANFORD

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June 20, 1960

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AUTHOR

J. M. Batch and K. G. Toyoda

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DESCRIPTION OF THE THERMAL HYDRAULICS LABORATORY AT HANFORD

J. M. Batch and K. G. Toyoda

DESCRIPTION OF THE THERMAL HYDRAULICS LABORATORY AT HANFORD

J. M. Batch and K. G. Toyoda

PURPOSE

The purpose of this report is to provide a brief written description of the facilities existing at Hanford for research and development in the fields of heat transfer and hydraulics.

INTRODUCTION

Within the Hanford Laboratories Operation a large laboratory exists for research and development in the fields of heat transfer and hydraulics. The laboratory is operated by the Thermal Hydraulics Operation to supply experimental information in support of the programs concerned with the development of reactor engineering technology at Hanford.

The research and development programs in progress are concerned principally with the heat transfer from nuclear fuel elements to water as a coolant. Specific fields of study include heat transfer during boiling, boiling burnout, hydraulic stability, heat transfer during transient conditions of flow and heat generation, coolant mixing, two-phase pressure drop, and discharge rates under critical flow conditions.

Many of the experiments are performed at typical reactor conditions of pressure, flow, and temperature, and with test sections fabricated to actual fuel element dimensions. Where heat transfer is involved, heat generation within the test sections is provided by resistance heating with high amperage, direct current electricity.

Although most of the work performed in the laboratory is in direct support of the various Hanford reactors, many of the programs are of general interest, and the experimental results have wide applications. Since there is considerable interest in the laboratory and in the results of many of the programs, the following descriptions of the facilities for heat transfer and hydraulic experimentation are provided.

GENERAL DESCRIPTION OF THE LABORATORY

The Thermal Hydraulics Laboratory occupies a floor space of approximately 11,900 square feet. The layout is shown in Figure 1. The laboratory has three major apparatuses or divisions. These are:

1. High Pressure Heat Transfer Apparatus
2. Low Pressure Heat Transfer Apparatus
3. Hydraulics Laboratory

Additional facilities for experimentation or for support in the operation of the major apparatuses include a silicon rectifier, direct current power supply; a

motor generator, direct current power supply; an Organics Heat Transfer Apparatus, an electrical analog, a data reducing and calibration facility, and assembly and storage areas.

The High Pressure Heat Transfer Apparatus is an electrically heated facility designed for 2500 psig at 650°F. The maximum flow rate is 250 gpm. Experiments can be performed with test sections in either horizontal or vertical positions. To date, experimentation has been concerned mainly with subcooled and boiling burnout for fuel element models of solid rods (flow in annulus), for multi-rod configuration, and for externally and internally cooled configurations.

The Low Pressure Heat Transfer Apparatus is an electrically heated facility suitable for operation at 985 psig and 300°F at the inlet and 360 psig and 450°F at the outlet to the test section. Maximum circulating flow rate is approximately 100 gpm. The apparatus is used for support of existing reactors. Studies made on this apparatus include transient characteristics of pressure, flow, and temperature following sudden reductions of coolant; steady state pressure-flow characteristics of solid and internally and externally cooled fuel element assemblies; and flow mixing in cluster fuel element models.

A graphical illustration showing the major equipment, piping, and power connections of the two electrically-heated apparatuses is presented in Figure 2.

The Hydraulics Apparatus is designed to supply water to various test assemblies at 750 psig at 400°F. The Hydraulics Laboratory is confined to isothermal and/or adiabatic studies of pressure-flow characteristics. The test section includes actual Hanford flow configurations from front to rear header. Other test assemblies which comprise part of the Hydraulics Laboratory include a vertical test section and a critical discharge study test assembly.

The power supplies to provide direct current for simulation of nuclear heat generation in the heat transfer apparatuses are three motor generators and a silicon rectifier assembly. The nominal rating of the M-G set is 1125 KW (50 V at 22,500 amps) while the silicon rectifiers are capable of producing 2700 KW (85 V at 32,000 amps) continuously and 3840 KW (120 V at 32,000 amps) on a duty cycle. Either power supply may be connected to the bus system of either the High Pressure or the Low Pressure Heat Transfer Apparatus bus system, and both facilities may be operated simultaneously.

ORGANIZATION AND OPERATION

The Thermal Hydraulics Operation's principal responsibility is to provide heat transfer and fluid flow information of value for the design and operation of the Hanford reactors. The major group effort is concerned with obtaining experimental data from the several facilities, and with analyses leading to practical application of these data for reactor operation. In general the results are used to establish reactor operating limits and to provide information necessary for reactor hazards analysis.

The engineers in the group both run the laboratory apparatus and analyze the results. A working team is formed for each program to plan the experiments, design and fabricate appropriate test sections, prepare detailed test specifications, perform the experiments, analyze the results, and write the final

reports. Most of the engineers serve on more than one team. For example, since one man has prime responsibility for operation and maintenance of each major experimental apparatus, that man serves on all teams running programs involving that particular apparatus. Engineering technicians assist in operating and maintaining the laboratory equipment.

The laboratory operation is supported by a maintenance force assigned specifically to the Thermal Hydraulics Operation to assist in maintaining the various equipment. This force includes a foreman, fitters, electricians, instrument technicians, and a welder. Additionally, machinists, millwrights, and other craft personnel are readily available from the central maintenance organization.

The current experimental operation is such that all of the facilities may operate simultaneously. Each apparatus is operated on an individual basis with the intent of obtaining maximum operating efficiency on each equipment. The work schedule is normally on an eight hour day, five days a week basis, although double shift operating schedules are often utilized when running the High Pressure Heat Transfer Apparatus.

EQUIPMENT DETAILS

1. High Pressure Heat Transfer Apparatus

a. General

The High Pressure Heat Transfer Apparatus is a recirculating facility designed for steady state heat transfer experiments to investigate subcooled and boiling burnout, single and two-phase pressure drop, and other related studies. The primary circulating facility is rated for 2500 psig at 650°F. The deionized water coolant can be circulated at a maximum flow rate of 250 gpm. A simplified schematic flow diagram of the facility is shown in Figure 3.

b. Primary Pump, Piping, and Heat Exchangers

The facility piping is comprised of 2" to 4" Type 347 stainless steel pipes. The water circulation pump is a Byron Jackson mechanical seal pump, 2 x 4 - four stage special double case, rated for 250 gpm at 1450 TDH, and is driven by a 200 HP motor. The pump discharge flow is heated with four in-line electrical preheaters having a total capacity of 500 KW. The controls of the heaters consist of one 100 KW step, two 75 KW steps, three 33 1/3 KW steps, and one 150 KW variable and stepless control. The electrical preheaters are used to raise the loop water temperature to compensate for the cold system pressurizing injection water and to provide a control of the water temperature entering the test section.

The normal procedure for pumping is to provide 250 gpm of flow from the pump regardless of the test section flow rate requirements. Water in excess of that required for the test section is by-passed. This procedure is followed to establish a more stable operating system from flow and water temperature standpoints. Air operated flow control valves are provided in both the piping to the test section and in the by-pass line to control the respective flow rates.

The flow rate is measured with two types of meters - an electronic Cox turbine meter and a differential producing, venturi type meter. Several ranges of each type are available to assure the maximum accuracy.

Water from the test section and the by-pass line is combined and then water cooled in a Sentry Equipment Company shell-and-tube heat exchanger having a heat removal capacity of 15,000,000 Btu/hr. The heat exchanger is operated with constant cooling water flow rate; the primary fluid to the heat exchanger is regulated with a temperature-controlled, three-way valve so that a constant loop water temperature may be maintained during steady state operation.

The present facility is designed for steady state operation. Additions of equipment to permit transient type experimentation will be completed during 1960. This facility includes a high pressure (5000psig) air storage system to maintain a controlled pressure up to 2000 psig in a 1000 gallon water storage tank. A quick acting valve assembly (less than 50 milliseconds full stroke) will change the source of water circulation through the test section from the recirculating pump to the water storage tank. This system is necessary to permit transient type experimentation on the existing tight recirculating facility to assure equipment integrity, and to provide an adequate supply of water during a transient period. The system further provides the flexibility of permitting water at any pressure and at any temperature to be introduced to the test section. A line diagram showing the basic piping and equipment for the transient system is shown in Figure 4.

c. Test Sections

The test sections may be either horizontal or vertical in orientation. The length of these test sections may vary from 3 feet to 35 feet in the horizontal assembly and from 3 feet to 20 feet in the vertical assembly. The configuration of the fuel element model may vary with typical models being a single rod, several rods in a cluster, and tube-and-tube type. The present maximum housing or process tube size is 3.25" ID. However, larger sizes may be accommodated by changes in the electrical power connections. Sizes and configurations of the test sections are limited only by the electrical resistivity characteristics of metals which must match the power supply output and by the design requirements of cooling water and electrical connections in complicated assemblies.

A typical test section of a cluster element is shown in Figure 5.

d. System Pressurization and Water Treatment

Water used as the coolant is demineralized water obtained from steam condensate and treated in an Illco-Way anion-cation water treating equipment. Water with a resistivity greater than 500,000 ohms is used to assure electrical insulation between the heat generating test section and other piping components. Approximately 2 per cent of the recirculating water is continually bled from the system and deionized to maintain the water quality.

The loop is pressurized to the required operating pressure by a bleed and inject method in conjunction with the water treatment procedure. The water to be treated is bled from the suction side piping of the recirculation pump and cooled to less than 100°F in a shell-and-tube heat exchanger. The rate of water bleed off is controlled through a high pressure drop valve. This water is then circulated to the storage tank.

Water from the tank is circulated to a vacuum de-aerator and to the water treatment towers at a maximum rate of 5 gpm. When required, chemical addition for pH control

is made at this point. The water is then injected into the loop through the seal of the primary loop circulating pump with an American-Marsh positive displacement pump.

e. Control Panel and Instrumentation

The control panel for the High Pressure Heat Transfer Apparatus is located in front of the test section (Figure 1). Instruments include recorders for the test section and system water temperatures, cooling water temperature recorder-controllers, system pressure recorder-controller, manometers, water treatment control, alarm system for high temperatures in the pump and heaters, low air pressure, etc.

Partial views of the control panel are shown in Figures 6 and 7. A listing of the more important instruments is given in Table I of the Appendix.

f. Temperature Monitoring

The basic thermocouples are chromel-alumel for the test rod temperature and iron-constantan for the water. A permanent extension lead wire system of 80 I/C couples and 120 C/A couples is installed between the test section areas and the panel board. Each end terminates in a quick-disconnect jack panel or console so that any pick up point can be connected to measure temperature on any appropriate recorder on the control panel by simple changes.

Temperatures are measured throughout the system for indications of potential troubles and for general control. These include the pump suction and discharge water, pump heat exchanger outlet water, preheater inlet and outlet water, preheater shell, flow control valve inlet and outlet water, flow meter inlet circulating loop, heat exchanger inlet and outlet. Since these temperatures are not critical to data analysis within the test section, readings are normally made on a 20-point recorder or on indicators. For such temperatures as preheater shell and pump heat exchangers which affect equipment safety, the readouts are also connected to the annunciator system.

Other water temperature readings critical for data analysis or for temperature control, such as inlet and outlet water temperatures of the test section, are monitored on single-pen recorders. The inlet water temperature is used to control the variable-and-continuous electric preheater; a separate inlet water temperature measurement and a pump suction temperature are used to regulate the heat exchanger three-way valve by a pneumatic controlling temperature recorder-controller and Indexit recorder. Where more accurate readings are required, a 48-point, push button, extended range potentiometer may be used during operation.

Techniques for measuring heater rod temperature vary with the configuration of the test assembly. Normally 1/16" or 3/64" OD sheathed thermocouples with magnesium oxide insulation are imbedded in or attached to the heater surface. Temperatures are recorded on two-pen, continuous record recorders, or on single-pen recorders having a 25-point manual and automatic stepping switch arrangement. All recorders have a full-scale response of less than one second so that sudden and rapid changes in heater temperatures can be detected before damage to the test section can occur.

g. Pressure Measurement

Several key pressure measurements in the system are continuously monitored with 0 to 2500 psi Heise or 0 to 3000 psi Helicoid gauges, or with a four-point extended range pressure recorder which uses SR4 Baldwin strain gauges as the sensing element. These pressures include inlets and outlets to the pump and to the test section. System pressure is automatically controlled by use of a strain gauge pressure transducer and an extended-range pressure recorder-controller sensing the tube outlet pressure, and which in turn controls the system bleed valve pressure drop.

Pressure drop data of test sections are obtained by indicators set up in a manifold of 60" mercury manometers and Barton torque tube differential indicators of 0 to 10, 0 to 25, and 0 to 50 psi ranges.

h. Flow Measurement

Flow measurements are made with calibrated venturi type elements or Cox turbine flowmeters. Differential pressures of the venturis are measured with a high pressure, 60 inch mercury manometer. For higher flows giving differential readings larger than 60" of mercury, four Barton Torque Tube pressure indicators having the ranges of 0 to 10, 0 to 25, 0 to 50, and 0 to 100 psi are used in a manifold system.

Four Cox turbine flowmeters having ranges from 2 to 75 and 5 to 300 gpm are used to supplement the flow measurements. The electrical signals from these flowmeters are visually displayed on digital indicators.

2. Low Pressure Heat Transfer Apparatus

a. General

The Low Pressure Heat Transfer Apparatus is a facility designed principally for the studies concerned with existing Hanford reactors. The operating characteristics of the facility permit certain transient-type as well as steady state experimentation to be performed.

The apparatus is normally a recirculating facility utilizing steam condensate to prevent scale deposit on the fuel element model in tests resulting in high heating surface temperature. The apparatus is designed for operation up to 985 psig at 300°F at the inlet side of the test section and for 360 psig at 450°F on the discharge side.

b. Circulating System

A simplified schematic flow diagram is shown in Figure 8. The piping is basically 2" and 4" type 304 stainless steel.

Flow is circulated by one of two Byron Jackson pumps. The pumps have the following characteristics:

No. 1 - 500 psig developed head at 35 gpm, 12-stage vertical 300 psig maximum suction pressure, 300°F maximum temperature

No. 2 - 700 psig developed head at 70 gpm, 14-stage vertical, 300 psig maximum suction pressure, 300°F maximum temperature

Water from the smaller B.J. pump No. 1 may be heated to 300°F by a Pfaudler shell and tube steam heater. The flow to the test section is manually controlled with several globe valves of different sizes in parallel. Each line contains a Potter turbine flowmeter in sizes from 3/4" to 2". Piping to the test section may be interchanged so that the supply will enter the test section as a single feed or as two feeds. The latter is to accommodate a fuel element model simulating an internally and externally cooled configuration. For this flow geometry, additional flow control valves and flowmeters are installed in each line to permit flow adjustment and flow monitor independently to each flow channel.

The heated coolant leaving the electrically heated test assembly, which may be all liquid or mostly steam, is cooled by two Schutte-Koerting steam condensers located immediately downstream of the test section. Cooling water for this purpose is provided by a by-pass around the test section of part of the water discharged from the recirculating pump. The pressure of the steam or water leaving the condenser is manually regulated to produce a desired pressure at the outlet of the test section. Water is then cooled in two shell-and-tube heat exchangers to a nominal 70°F.

The extent of pressurization required on the Low Pressure Heat Transfer Apparatus is to assure that the pump suction pressure is high enough to prevent cavitation in the pumps. The pressurization is accomplished by air loading of a pressure tank floating on line. Normal minimum pressure required is 5 psig.

c. Test Sections

The principal test section is a model of the fuel elements used in the existing Hanford reactors installed in a standard or actual process tube lined with electrical resisting phenolic resin. The lining is necessary to prevent electrical leakage from the resistance-heated test element to the housing tube. The electrical connection from bus to test section is shown in Figure 9.

Immediately downstream of the heated portion is a "dummy section", a reactor nozzle, outlet fittings, and header arrangement to simulate the reactor flow configuration as closely as possible.

An additional short test section is located parallel to the above reactor prototype. This test section is used for basic studies of heat transfer and boiling heat transfer mechanism, of flow mixing or channeling in cluster elements, stratification of vapor phase, etc. The housing tube may be metal or glass to permit visual observations or high speed filming. A typical glass tube assembly is shown in Figure 10.

d. Control Panel and Instrumentation

The control panel location is next to the process equipment and test section, and is indicated in Figure 1. Instrumentation includes Heise gauges, 6-point temperature recorders, single pen recorders, 2-pen pressure recorders, and steam preheater recorder-controller.

Partial views of the Low Pressure Heat Transfer Apparatus are shown in Figures 11 and 12. The latter shows also the high speed recording equipment used to obtain transient data. (The high speed recorders are described in Section 5C.) A listing of the more important instruments is given in Table II of the Appendix.

e. Temperature Measurement

The temperature measurement system is basically iron-constantan for both the water and test rod measurements. Quick disconnect plugs terminate either end of the permanent extension lead wire system to permit selection of any temperature recording on any one point on any recorder. Leads may be connected simultaneously to the recorders or to a circular 30-point selection temperature indicator during operation.

Basic heater rod thermocouples are 1/16" or 1/8" OD sheathed thermocouples imbedded in grooves slotted in the outer surface of the test rod. The hot junctions may be electrically insulated with cement.

f. Pressure Measurement

The pressure measurement is made by seven Heise gauges. The gauges range from 0 to 100 and 0 to 1200 psig. Any point to be measured may be directly indicated or be manifolded to any of the gauges. Provisions for recording up to six pressures on circular charts are also available.

Four pressure indicators are also available for manifolding delta pressure readings. Ranges of these indicators are 0 to 50, 0 to 100, 0 to 250, and 0 to 400 psi.

g. Flow Measurement

Flow is measured with one of five Potter turbine flowmeters ranging in size from 3/4 to 2". Flow range is from 2 to 12 gpm for the smallest and 5 to 125 gpm for the largest Potter. Readout is obtained on milliammeters.

3. Hydraulics Laboratory

a. General

The Hydraulics Laboratory is a facility designed to study pressure-flow characteristics of existing Hanford reactor process tube flow geometries. Additions have been made to broaden the scope to include studies in vertical test sections and in equipment suitable for study of non-heating, two-phase pressure drop and critical discharge flow phenomena from orifices, nozzles, and pipes. All test apparatuses utilize the same pumping, water heater, and flow measuring equipment. Water employed is the standard Hanford reactor process water.

b. Process Piping

The Hydraulics equipment is a single-pass system, made up of basically 3" and 4" pipelines. Materials are Type 304 stainless steel at the inlet and carbon steel on the outlet system. Design rating is 750 psi at 400°F. A flow diagram is shown in Figure 13.

Process water is stored in a 3300 gallon head tank located on the mezzanine above the laboratory area and "floats" on the suction side of the pump. A level controller assures adequate supply of water in the tank at all times. The pumping station consists of three pumps. These are a Bingham 4-stage horizontal centrifugal pump, 500 gpm at 1387 feet head, 250 hp motor; and two Ingersoll Rand, five stage vertical pumps with 100 gpm at 1155 feet head, 60 hp motor. Water pumped by any of the three pumps is passed through a flow metering system of Potter and Fischer Porter turbine type primary elements. Flow control is performed by manual adjustment of remote loading stations. The water may be steam heated in a Ross U-tube heat exchanger up to a nominal temperature of 350°F. By proper valving the water can be supplied to one of the desired test sections.

After passing through the test section, all water is dumped to the sewer with quenching, if required.

c. Test Sections

Test assemblies, prototypical from front to rear header of the several different types of Hanford reactors, are used for determining pressure-flow characteristics. Actual reactor fuel elements are employed. All tests are made under isothermal or adiabatic conditions. Where test interest is directed at the fittings, the fuel elements may be omitted, and the process tube serves as the connecting pipe.

A vertical test section, with metal or plastic housing, is also available for hydraulic studies. Principal geometry simulates the Plutonium Recycle Test Reactor process tube although other configurations may be easily installed for testing.

The third test apparatus is designed for two-phase pressure drop measurements or for study of critical discharge rates from pipes, nozzles, and orifices. The latter is fitted with a momentum chamber to provide force data valuable for determining slip ratios in steam-water mixtures.

d. Control Panel and Instrumentation

The control panel location and general equipment layout is shown in Figure 1. The control panel is shown in Figure 14. Several Heise pressure gauges, U-tube manometers, Barton torque tube differential pressure indicators, a 12-point temperature recorder, and Potter electronic flow readout are used to obtain data. The pressure indicating instruments are manifolded so that pressure at any point or pressure drop between any two points may be readily obtained.

A list of the more important instruments is presented in Table III of the Appendix.

Temperature readings in the various test sections and pipings are obtained by use of iron-constantan thermocouples. Readout is obtained on the temperature recorder. Weston dial thermometers are also used in locations near the flow control valves to aid operators in setting test conditions.

Flow meters are calibrated by the weight method. The weigh tank capacity is 2000 lb. The timer used in connection with the weigh tank gives .1 second readings. At the present time, this assembly is used to calibrate the flow meters of all the major apparatuses.

4. Direct Current Power Supply

a. General

Two sources of power supply are available to provide the resistance heat direct current to the High Pressure Heat Transfer Apparatus and the Low Pressure Heat Transfer Apparatus fuel element models. These consist of three integrated motor-generator sets and a silicon rectifier system. The locations of this equipment are shown in Figure 1. Bus duct systems with eleven 1/2" x 6" copper bars in parallel supply the power from the sources to an intertie area located adjacent to both of the electrically-heated apparatuses. The intertie is such that either power supply may be connected to either the high or the low pressure test section, and both facilities may operate simultaneously. Figure 2 shows the general connection scheme.

b. Motor-Generators

The motor-generators consist of a double-ended machine and a single machine manufactured by Electric Products. Each is capable of producing 7500 amperes of direct current at 50 volts or a combined total of 22,500 amperes at 50 volts. The double-ended machine is driven by a 1250 hp, 512 rpm, 2300 volt synchronous motor. The single machine drive is a 700 hp, 512 rpm, 3200 volt synchronous motor. The generator controls are intertied such that one, two, or all three machines may be operated as a unit.

A portable control console may be located at either end of the motor-generator switchgear depending upon the test apparatus utilized. All control and power data indicators and recorders are mounted on this portable console. However, provisions for remote programmed power control and "stop" exist at each of the test apparatus control areas. Figures 15 and 16 show the generators and control equipment for this power supply.

c. Silicon Rectifiers

The silicon rectifier system was supplied by the General Electric Company. All equipment is designed for indoor use. The rating of this system is 2700 KW at 85 volts and 32,000 amps on a continuous basis. The equipment has overload capacities of 3840 KW at 120 volts and 32,000 amps on a one-half hour on, one hour off duty cycle or 48,000 amperes for one minute. The system consists of:

1. 13.8 kv AC circuit breaker
2. DC controlled saturable reactor
3. Two rectifier transformers for 13.8 kv, 3 phase, 60 cycle operation
4. Two 16,000 amp silicon rectifier cabinets
5. Amplidyne for DC control of the saturable reactor

The control panel is located between the High Pressure Heat Transfer Apparatus and the Low Pressure Heat Transfer Apparatus control areas. The panel is complete with controls, indicators, and power recorders. Remote programmed power changes can be performed. Emergency stop buttons are located at either control area. Figures 17, 18, 19, and 20 show the rectifier system and control panel.

5. Miscellaneous Support Equipment

a. Organic Heat Transfer Apparatus

The Organic Heat Transfer Apparatus is designed to obtain basic heat transfer and fouling data for organic coolants. Efforts on this apparatus have been limited to preliminary information on Monoisopropylbiphenyl. The resistance heating principle is employed using a single-phase A.C. power supply. Test section sizes are 1/4" to 3/8" OD tubing, approximately 12 inches long. Basic design rating is 100 psig at 800°F, with a maximum flow rate of 10 gpm.

b. Analog Computer

An analog computer having a grid net work of 12 by 24 points, supports analysis of steady state heat transfer problems. Resistance to heat flow is simulated by setting an appropriate electrical resistance between each grid point. Electrical current input to each grid point simulated heat generation, and temperatures are found from the voltages throughout the grid network. This computer is of special value for problems where the geometry is such that analytical solutions are not practical.

c. Calibration and Special Support Equipment

The support of the laboratory operation requires numerous specialized equipment to produce and obtain accurate data. Supporting devices include special equipment for calibrating, troubleshooting, recording, and analyzing data. Some of these items are:

1. Oscillographic recorder, Heiland Visicorder Model 1012, mirror galvanometer type, direct print, 36 channels. Chart speed may be varied in steps from .1 to 160 inches/sec. Recording width is 11 3/8". Carrier and DC amplifiers used with the recorder give frequency response capabilities of better than 1000 cycles per second.
2. Oscillographic recorders (2 units), Offner Type M Dynograph, six channels, chart speeds up to 250 mm/sec. Recording width 7 centimeters each channel, frequency response DC to $\pm 10\%$ at 70 cps. Input signal may be DC, reluctance type, strain gage, or carrier.
3. Pressure transducers, differential and absolute measurements, ranges ± 1 psid to ± 1000 psid, and 0 to 100 to 0 to 3000 psia.
4. X-Y recorders, Moseley Autograf Model 2S complete with curve follower attachment for programmed control of motor-generator and rectifier power supply systems, response one second full scale, range 0 to 7.5 mv to 0 to 150 volts.
5. Semi-automatic data reducer, Benson Lehner Oscar Model J, for analyzing and reading continuous strip chart and oscillographic records, complete with electrotypewriter and key punch adaptor.
6. High speed camera, Wollensak "Fastax" Model WF-2, 16 mm film, speeds up to 18,000 frames per second. Equipment complete with high intensity,

short duration stroboscopic light source capable of producing high intensity light flashes of less than 2×10^{-6} seconds duration up to 6000 flashes per second.

7. Mueller Bridge, Rubicon Model 1551, range 0 to 141.110 ohms, for use with National Bureau of Standards calibrated and certified platinum resistance temperature element.
8. Kelvin Bridge, Gray Instrument No. E-3272, range .5 microhms to 22.2 ohms, sensitivity one microampere.
9. High Precision potentiometer, Rubicon 2780, Type B with electrostatically shielded case, range 0 to 16 millivolts to 0 to 1.6 volts, limit of error at low range, 1 microvolt or .015%.
10. Oscilloscope, Textronic Model 545, cathode ray, wide range, fast rise unit.

6. Supporting Services

a. Assembly Area

Machine, welding, instrument, electrical, and fitter shops are located within the laboratory building for joint usage with other experimental components. Additional to these shops, special areas are designated to perform specialized craft work in support of test section assembly. Adjacent to the High Pressure Heat Transfer Apparatus is a welding area with a special aligning lathe to assemble the test sections and pipe components. A hoist is available to transport the heavier test sections to the test apparatus. Thermocouple makeup and installation is performed in this area for heavier fuel element models. A separate thermocouple makeup area for smaller test sections is provided next to the rectifier power supply.

b. Storage Areas

Storage facilities for completed test sections are provided in either of two assembly areas. Components such as pipes, fittings, and valves which require long procurement time are maintained on hand in a separate storage building or in the plant warehouses. Total storage space retained by the Thermal Hydraulics Operation is approximately 4,000 square feet. Accurate inventories of all stored items are maintained to assure sufficient supply of critical items for operational continuity.

c. Water

Water requirements for equipment operation include raw and reactor process water. Both types of water are available in the laboratory area at pressures of up to 50 psig.

d. Steam

Steam is available in the building from the plant boiler at 225 psig in a 4" line. Steam is required to provide condensate in both of the electrically-heated apparatuses and for heating of process water in the Hydraulics Laboratory and the Low Pressure Heat Transfer Apparatus steam preheaters.

e. Air

Instrument and control air, which must be oil free and dry, is available at 100 psig from a 10 hp non-lubricated compressor and a dryer system. Air for general purposes is supplied from a larger building compressor at 100 psig.

f. AC Power

The primary electrical power is available at 13.8 KV. The rectifier power supply utilizes this supply directly. Transformers for 13.8 KV/2300 V, 13.8KV/440 V, 2300 V/440 V step downs to provide generator, pump, electric preheater, and other power requirements are located outside of the laboratory building.

LABORATORY OPERATION1. Personnela. High Pressure Heat Transfer Apparatus

The operation, maintenance, and routine modification of the High Pressure Heat Transfer Apparatus is delegated to a responsible engineer. No operation is conducted without his presence or authority. He is assisted by a technician to carry out the specified responsibilities. During operation, further assistance may be provided by other engineers interested in the test and by other technicians as required.

b. Low Pressure Heat Transfer Apparatus

The operation of the Low Pressure Heat Transfer Apparatus is conducted in the same manner as the High Pressure Heat Transfer Apparatus.

c. Hydraulics Laboratory

The responsibility for the operation, maintenance, and modification of the Hydraulics Laboratory is delegated to a specific engineer. The equipment may be operated by a technician but under supervision and direction of the responsible engineer.

d. Maintenance

The routine maintenance and minor modifications to existing facilities are performed by craft personnel. The craft personnel number ten plus a foreman and include a welder, fitters, instrument technicians, and electricians. These personnel are assigned to support the operation of the Thermal Hydraulics Laboratory specifically. Other craft personnel such as machinists and millwrights are assigned to other components in the laboratory building, but are available to the Thermal Hydraulics Operation for performing work.

Program priorities are established by the Supervisor, Thermal Hydraulics Operation. Based on these priorities, craft services are scheduled with the craft foreman by the Thermal Hydraulics Operation maintenance co-ordinator.

2. Operating Schedules

The prime responsibility of the Thermal Hydraulics Operation is to the support of Hanford reactor operation. All work concerned with continuity of reactor operation is therefore of the highest priority.

The normal schedule for equipment operation is based on a 40-hour, 5-day week. Because of the relatively long start up and shut down time required for the high pressure apparatus, double shifts may be used on occasion to increase operating time. Other facilities may also operate on a two-shift basis where the need for data warrants.

3. Safety

Safety is given a high degree of attention since many of the experiments involve water at high pressures and temperatures and in many cases, high electrical currents. Job hazard breakdowns are written and reviewed with personnel at intervals. All experiments which deviate from established practices are discussed thoroughly with operating personnel. Test section areas are barricaded during operation, while operating areas are chained off to prevent unauthorized entries. Safety glasses are required and furnished in the laboratory building.

Piping and vessels are designed, fabricated, tested, and inspected in conformance to applicable codes. All safety valves and pressure vessels are routinely inspected by procedures and at frequencies recommended by the Third Party Inspector.

J M Batch

SUPERVISOR

THERMAL HYDRAULICS OPERATION
HANFORD LABORATORIES OPERATION

K D Toyoda

ENGINEER

THERMAL HYDRAULICS OPERATION
HANFORD LABORATORIES OPERATION

JMBatch/KGToyoda:ag

Table I

PANEL INSTRUMENTATION
HIGH PRESSURE HEAT TRANSFER APPARATUS

<u>Measurement</u>	<u>Quantity</u>	<u>Description</u>
Temperature	3	Recorder, I&N Micromax, 0 to 1500°F C/A calibration, single pen record, heater temperature
Temperature	2	Recorder, Westronics D-11, 0 to 2500°F C/A calibration, 2 pen record, heater temperature
Temperature	2	Recorder, I&N Speedomax, Model G, 0 to 700°F I/C calibration, single pen record, water temperature
Temperature	1	Recorder, I&N Speedomax Model G, 0 to 600°F, I/C and 0 to 100°F delta, 2 pen record, water and water temperature rise
Temperature	1	Recorder-controller, General Electric Model HF, 0 to 700°F I/C calibration, electric preheater control
Temperature	2	Recorder-controller, Brown Model Y 152, 0 to 700°F, water temperature
Temperature	1	Recorder, Bristol 20 PG, 0 to 700°F, 20 point, water temperature
Temperature	1	Indicator, precision, Brown Model SC 156 X, 0 to 75 mv, water and heater temperature
Temperature	1	Recorder, Brown, SY 153, 2 pen record 0 to 2500°F, C/A calibration, heater temperature
Pressure	1	Recorder, Brown Y 153, 4 point, extended range to 2500 psig, for Baldwin SR 4 strain gauge transducers
Pressure	1	Recorder-controller, Brown Y 152, extended range to 2500 psig, for Baldwin SR 4 strain gauge transducers
Pressure	3	Indicator, Heise, 16" dial, 0 to 2500 psig
Pressure	3	Indicator, Helicoid, 8" dial, 0 to 3000 psig
Pressure	4	Indicator, differential, Barton 227, 0 to 10 psid
Pressure	4	Indicator, differential, Barton 227, 0 to 25 psid
Pressure	4	Indicator, differential, Barton 227, 0 to 50 psid
Pressure	1	Indicator, differential, Barton 227, 0 to 100 psid

Table I

Panel Instrumentation, High Pressure Heat Transfer Apparatus

<u>Measurement</u>	<u>Quantity</u>	<u>Description</u>
Pressure	4	Manometer, 0 to 60"
Flow	4	Indicator, Cox Type 6R, digital, up to 300 gpm, for use with Cox turbine flowmeters
Flow	1	Recorder-controller, Brown Y 152P, 0 to 150 gpm, for use with Potter turbine flowmeters
pH	1	Recorder-controller, Brown 152R
pH	1	Indicator, Beckman Model W, 2 to 12

Table II

PANEL INSTRUMENTATION
LOW PRESSURE HEAT TRANSFER APPARATUS

Measurement	Quantity	Description
Temperature	3	Recorder, Brown Y 153, 6 point, 0 to 600°F and 0 to 1200°F, I/C calibration
Temperature	1	Recorder, Brown Y 153, 6 point 0 to 800°F, I/C calibration
Temperature	1	Indicator, Brown Y 156, 0 to 600°F and 0 to 1200°F
Temperature	1	Recorder, Brown Y 153, two pen record, 0 to 1500°F, I/C calibration
Pressure	3	Recorder, Brown Y 702C, two pen, 0 to 500 psig
Pressure	2	Indicator, Heise, 16" dial, 0 to 1200 psig
Pressure	3	Indicator, Heise, 12" dial, 0 to 700 psig
Pressure	2	Indicator, Heise, 12" dial, 0 to 500 psig
Pressure	1	Indicator, Heise, 8" dial, 0 to 100 psig
Pressure	1	Indicator, differential, Barton 227, 0 to 50 psid
Pressure	1	Indicator, differential, Barton 227, 0 to 100 psid
Pressure	1	Indicator, differential, Barton 227, 0 to 250 psid
Pressure	1	Indicator, differential, Barton 227, 0 to 400 psid
Flow	2	Indicator and converter for Potter turbine meter, up to 125 gpm

Table III

PANEL INSTRUMENTATION
HYDRAULICS LABORATORY

<u>Measurement</u>	<u>Quantity</u>	<u>Description</u>
Temperature	1	Recorder, Bristol 12 PG, 12 point, 0 to 300°C I/C
Pressure	1	Indicator, Heise, 12", 0 to 100 psig
Pressure	1	Indicator, Heise, 12", 0 to 300 psig
Pressure	1	Indicator, Heise, 12", 0 to 500 psig
Pressure	1	Indicator, Heise, 12", 0 to 600 psig
Pressure	1	Indicator, Heise, 12", 0 to 700 psig
Pressure	2	Indicator, differential, Barton Model 227, 0 to 10 psid
Pressure	2	Indicator, differential, Barton Model 227, 0 to 500 psid
Pressure	2	Indicator, differential, Barton Model 227, 0 to 100 psid
Pressure	2	Indicator, differential, Barton Model 227, 0 to 150 psid
Pressure	2	Indicator, differential, Barton Model 227, 0 to 400 psid
Flow	1	Indicator and converter for turbine flowmeters, range to 200 gpm

FLOOR LAYOUT - THERMAL HYDRAULICS LABORATORY

Figure 2

THERMAL HYDRAULICS LABORATORY
HEAT TRANSFER FACILITIES

Figure 3

FLOW DIAGRAM OF
HIGH PRESSURE HEAT TRANSFER APPARATUS

Figure 4

FLOW DIAGRAM OF
HIGH PRESSURE HEAT TRANSFER APPARATUS TRANSIENT SYSTEM

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Figure 6

PANEL BOARD
HIGH PRESSURE HEAT TRANSFER APPARATUS

Figure 7
PANEL BOARD
HIGH PRESSURE HEAT TRANSFER APPARATUS

Figure 8

FLOW DIAGRAM OF
LOW PRESSURE HEAT TRANSFER APPARATUS

Figure 9

TYPICAL ELECTRICAL CONNECTION
END VIEW

Figure 10
GLASS TUBE ASSEMBLY

Figure 11

PANEL BOARD
LOW PRESSURE HEAT TRANSFER APPARATUS

Figure 12

PANEL BOARD AND HIGH SPEED RECORDING EQUIPMENT
LOW PRESSURE HEAT TRANSFER APPARATUS

Figure 13

FLOW DIAGRAM OF HYDRAULICS LABORATORY

Figure 14
PANEL BOARD
HYDRAULICS LABORATORY

Figure 15
MOTOR GENERATOR SET

Figure 16
MOTOR GENERATOR CONTROL
CONSOLE AND SWITCHGEAR

Figure 17

ONE LINE DIAGRAM
RECTIFIER POWER SUPPLY

Figure 18

RECTIFIER SYSTEM

Figure 20

RECTIFIER CONTROL PANEL AND
PROGRAM INPUT UNIT

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HIGH PRESSURE HEAT TRANSFER APPARATUS - 189D

K. G. Toyoda

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DESCRIPTION OF TRANSIENT SYSTEM
HIGH PRESSURE HEAT TRANSFER APPARATUS - 189D

I. INTRODUCTION

The knowledge of temperatures in a fuel element following piping failure or other abnormal occurrences is an important phase of nuclear reactor hazard analysis. Such temperatures are difficult to predict analytically because of the uncertainties in the thermal hydraulics conditions between the fuel element and the coolant during transient events. Project CGH 834 authorized the design and erection of a facility which will permit transient experiments to be conducted on the High Pressure Heat Transfer Apparatus in 189D. This report covers certain design considerations and operating procedures for the system.

II. BASIC DESIGN REQUIREMENTS AND CONSIDERATIONS

A. General System

The transient system for the High Pressure Heat Transfer Apparatus in 189D was to be designed for the following conditions:

1. The transient shall be at least one minute in duration.
2. The transient equipment shall permit operation at any system pressure from 500 to 2200 psi.
3. The system shall be capable of providing water during a run at any single temperature up to the saturation temperature of the operating system pressure.
4. The normally steady state equipment such as the recirculation pump, electric preheaters, heat exchangers, shall not be subjected to depressurization, flashing, or similar conditions which might damage the equipment.

It was apparent that any method selected for transient simulation could not utilize the steady state recirculating equipment in the transient flow system. First, the pressure and temperature flexibility could not be obtained, and second, each transient test could lead to conditions which would jeopardize the steady state equipment. It was also obvious that the transient equipment could not be completely separated from the steady state system, since the transient simulation must be imposed from an initially steady state system. The method selected was to utilize the existing High Pressure Heat Transfer Apparatus to circulate the coolant through the electrically heated test section under steady state conditions, then quickly isolate all equipment, except the test section, so that simultaneously the transient system could supply the coolant to the test section. During this changeover in the flow system, the steady state recirculating system must be reasonably undisturbed, and heat transfer and fluid flow characteristics in the test section must be unaffected as a result of the change.

Several methods for providing the transient water supply were considered. These included the following:

- a. A combination storage and pressurizing tank in which vapor-liquid equilibrium is established by boiling.
- b. A two tank unit in which one tank holds the water and the second tank is pressurized by boiling water.
- c. A water storage tank pressurized with gas.

Methods (a) and (b) had the disadvantage that a reduction in controlled pressure would occur since sufficient vaporization of the fluid to hold the pressure could not be maintained without significantly large instantaneous heat input. Method (a) also was restricted to maintaining the water at the saturation temperature. Method (c) was feasible and met all design requirements provided a sufficient gas supply was available. The procedure selected for detailed design was method (c) using air as the pressurizing medium. Air contained in a high pressure vessel would be regulated to the required water tank pressure through a valve.

B. Sizing

Analyses of flow requirements versus time following piping rupture simulation were made for several cases. A worse case study showed that upon failure of the inlet pipe to a fuel element, flow through the fuel element will stop, reverse and increase to about 1000 gpm in 0.1 second, then reduce rapidly to about 500 gpm. Thus, the transient water supply necessary to assure at least one minute of operation was selected as 1000 gallons. Calculations were then made to determine the quantity, pressure, and temperature of air which would be necessary to sustain the water flow rate. It was assumed that the air temperature could not be less than 100° at the water tank and that the air pressure in the storage tank would be 3000 psia at end of the test. The calculation showed that for 5000 psia initial air pressure, approximately 200 cubic feet of air at 325°F were required.

The pressure and volume were compromises of economic considerations (lower pressure, larger volumes) and maximum operating pressure (higher pressure, lesser volume).

C. Steady State-to-Transient Change Mechanism

To utilize the air-water system described above, a method for quickly changing from recirculating pumping to one pass pressurized system was necessary. It was mandatory that the switchover be made in a manner to assure that:

1. The main loop flow is maintained throughout the normal steady state system except through the test section.
2. Simultaneously, the coolant from the storage tank must be directed to the test section and exhausted to the atmosphere.
3. During the change in coolant supply source, fluid loss from the steady state recirculating system must be minimized and flow through the test section must be maintained.
4. The switch in flow supply must not introduce adverse conditions such as water hammer.

Several methods utilizing rupture discs and valves were investigated. Rupture discs could not be utilized for all functions since some closing functions were required. Where the function was open as in the case of atmospheric vent, it was decided that sufficient control of time and opening characteristics could not be designed into rupture discs. Thus, a total valve system was deemed the most desirable.

D. Steam Exhaust

Simulation of piping failure requires the fluid to exhaust to an atmospheric environment. Because of the location of the equipment, it was not feasible to discharge the exhaust steam directly to the atmosphere without a very large size and long "stack". A centrifugal separator to reduce the volume of vent was considered, but again the long stack requirement plus uncertainty in separation efficiency were causes for rejection. The method most feasible from the standpoint of location and simplicity was believed to be a direct contact heat exchanger. The final design called for the steam to be discharged into a horizontal flow tube located in a long pool. The steam creates a pumping action so that the cooling water and steam are circulated through the tube, and pumped back outside of the flow tube to the steam inlet - flow tube junction. The water circulation and the long flow tube run will allow effective steam condensation. A simple centrifugal separating unit is attached to the end of the flow-tube to allow air from the pressurizer to separate and vent.

E. Location

The addition of the transient equipment to the existing High Pressure Heat Transfer Apparatus required several compromises in location. Ideally, all transient components should be located as close as possible to the test section. This arrangement would permit simulation of accidents which occur adjacent to the test section without introducing errors for transporting fluid from a remote source. It would be relatively simple to add jumpers to simulate accidents which occur away from the test sections.

Existing space, however, did not allow locating of equipment near the test section. Only two locations were available for the air pressure tanks and the water storage tank. These were in the 185 Building between column lines 15 and 16 and outside, just north of the 189 Building. Both locations would require about the same length of pipe runs to tie in the vessels to the test section. The locating of pressure vessels within an occupied building added other problems of personnel hazards. A containment system for the pressure tanks if located in the 185 Building was considered too expensive. Thus, the vessels were located outside of 189D in reinforced concrete pressure cells.

The valve manifold assembly consisting of the high speed valves was also restricted in location. The proper location is at one end of the test section or at any point between the ends. Interference with the Low Pressure Heat Transfer Apparatus and the High Pressure Heat Transfer Apparatus panelboards precluded all suitable locations for the valve

assembly except near column 16 south of the test section. The valve assembly location was suitable for discharge of steam into the direct contact pool. The valve assembly is located above the building drain trench.

F. Safety

All equipment and systems were specified, designed and fabricated to the following principal codes:

1. ASME Boiler and Pressure Vessel Code, Section VIII.
2. Code for Pressure Piping, ASA B 31.1.
3. American Steel Flange Standard, ASA B 16.5.

The possible hazards associated with operation of the equipment were analyzed, and appropriate safeguards, where possible, were incorporated into the design.

However, it must be recognized that safety in operation can be assured only through proper practices of the operating personnel. It is mandatory that all personnel associated with the equipment operation or maintenance be fully cognizant of the requirements and limitations of all equipment comprising the system. Rigid adherence to operating and maintenance instructions must be enforced. It must be recognized further that the design was accomplished to achieve a specific purpose and that any deviations in operation from the design objectives must be thoroughly reviewed prior to utilizing the facility for other than designed purposes.

III. GENERAL DESCRIPTION

A. Transient System Operation

A simplified flow diagram illustrating the basic operating equipment of the transient system is shown in Figure 1. Prior to the start of the transient, steady state conditions are established in the flow system consisting of the recirculation pump, electric preheater, the test section, and the heat exchanger. The flow through the test section can be directed in either direction depending upon the proper positioning of Valves S and R. The flow system when valved to take the steady state flow path denoted by S1 permits the simulation of downstream failure, while the S and R valves positioned to allow flow path S2 is for simulating upstream failure. The transient flow, however, is unidirectional. That is, the coolant from the water storage tank enters at the same side of the test section regardless of the position of Valves S and R.

Upon establishing the steady state conditions prior to start of the transient test, the water storage tank is "floated" on the steady state system. The transient is initiated by simultaneous operation of Valves AB, C, and D. Specifically, the three-way valve, AB, closes to the test section and opens to the circuit TR; the two way valve, C, closes to stop flow from either S1 or S2 flow path; and the two-way valve, D, opens to the atmospheric, direct contact pool. The two flow systems in operation at this time are circuits TR and T.

The transient system can be separated into four principal functional categories for the purposes of discussion. These are:

1. Air pressurizing and regulating system.
2. Water storage and transport system.
3. Steady state-to-transient switching valve assembly.
4. Vapor condensation system.

The following discussions describe some of the basic operating features and characteristics of each of the above. It is not intended that the various equipment be described in detail in this report; operating personnel should consult the appropriate files for detailed information:

B. Air Pressurizing System

The air pressurizing system consists of the following equipment:

1. Non-lubricated air compressor, 125 psig discharge, 35 scfm capacity, dual control, complete with intake filter and aftercooler.
2. Air prefilter for oil vapor removal.
3. Air dryer, electrical, automatic cycle, 25 scfm capacity, final dewpoint minus 40°F, inlet pressure 100 psig.
4. Air receiver, 150 psig rated, 19 cubic feet capacity.
5. High pressure air compressor, 5000 psig discharge pressure, piston displacement 30 scfm.
6. High pressure oil vapor filter.
7. High pressure air storage tanks, two units, design pressure 5500 psig at 350°F, 100 cubic feet capacity each unit.
8. Pressure regulating valve, 2500# class, self actuating, pressure balancing.
9. Air surge vessel, 3000 psig at 650°F design, 20 cubic feet capacity.

The air fill to the storage tanks is made in the above sequence. The non-lubricated air compressor is also the primary instrument air supply to the high pressure heat transfer apparatus; thus, this unit is not limited to the transient operation. The operations of the non-lubricated air compressor, aftercooler, dryer, and air receiver (150 psig) are conventional and require no discussion.

Several important operational factors exist in the other units of the pressurizing system. These are as follows:

1. Although the high pressure air compressor is a continuous rated equipment, stringent maintenance and operating instructions must be followed to assure proper and safe operation. Thus, the equipment is to be operated only after complete understanding of limitations which exists.
2. Complete assurance that oil vapor carry-over does not occur is necessary because of oil-air mixture explosion potential. A high efficiency oil vapor filter has been installed on the discharge side of the compressor. (The intake air should be oil free since

a non-lubricated low pressure compressor and air prefilter have been provided).

The fact that a filter is installed is no guarantee that oil vapor carry-over will not occur. Frequent inspection of the filtering media and pipelines is required to assure maximum safety. From a safety standpoint, this possibility of vapor carry-over is probably the most significant item.

3. The air in the storage tanks must be preheated to 325° before air release for transient. This initial temperature is necessary to assure that the lowering of air temperature by expansion through the pressure regulator will not create temperature conditions which may reduce impact strength of the air vessels nor will cause a very severe thermal shock in the water storage vessel. The air temperature of 325° is attained by steam heating the ambient air of the air storage tank pressure cell, which in turn heats air in the vessels by conduction through the walls of the uninsulated tanks. The heating must occur before completion of air pressurization by the compressor so that later pressurization by air heating will not occur.
4. The air surge tank was provided as a result of a study to determine the initial pressure transient when the pressure regulator begins to control. The study indicated that a pressure drop will occur immediately following the opening of the atmospheric vent until such time that the air pressure regulator can begin to control. Where additional volume of air is provided downstream of the regulator, the drop is minimized by the expansion of the air in the surge tank.

C. Water Storage System

The water storage system consists of the following equipment:

1. Motor controlled valve, 2500 psi rating, complete with motor starter and control, stainless steel body and internals.
2. Water storage tank, 3000 psig design at 650°F, stainless steel cold, 1000 gallon capacity.
3. Tank-to-valve assembly transport line (4", Sch. 160).
4. Steady state recirculating facility to storage tank transport line (2 1/2" Sch. 80).
5. Flow tube meter.

The motor operated valve isolates the air system from the water system during the setup period. The valve is opened just prior to start of test after the water in the storage tank has been brought to the desired temperature.

The water storage tank is fitted with a thermal shield at the top. This shield is a feature incorporated to minimize the thermal shock at the nozzle and the head caused by the 100°F air which will suddenly enter the tank. The design rating of the tank is considerably above the expected operating pressure to assure integrity in event of a hydraulic shock dur-

ing the transient valving (Details of the shock consideration are discussed in the Valve Assembly Section). The tank itself does not have means for heating the water to the required test temperature. Thus, a circulation fill from the steady state facility is necessary. When the desired temperature is attained, the heat loss from the stored water is minimized by the steam trace coils around the tank.

D. Valve Assembly

The role of the valve assembly to switch from the steady state to the transient operation has been described previously. The valve assembly consists of two three-way manual valves (Valves S and R) to select the steady state flow direction through the test section, a two-way angle valve (Valve C) to stop flow from the test section to the steady state flow circuit, a three-way valve (Valve AB) to stop flow from the steady state flow circuit to the test section and simultaneously divert flow to the new recirculating circuit, and a two-way angle valve (Valve D) to open the end of the test section to the direct contact, steam condensing pool. Additional equipment to operate the quick acting valves include a hydraulic system, an electromagnetic hydraulic release valve, pressurizing handpump, valve interlock safety mechanism, and a control panel. The valves are mounted on a compact manifold system and arranged in such a manner to minimize hydraulic shock conditions, which may result from sudden closure of any flow path. This manifold minimizes the length of water column which can exist without a flow diverting path since the degree of shock depends on the water column length as well as the fluid velocity. Other means for relief of hydraulic shock exists. Valve AB has a diverting path in the second discharge port. Valve C can absorb reverberation shock against its seat by actuator spring compression. Although the basic design is expected to alleviate shock problems, additional safety is incorporated by high design pressure ratings of pipe and water tank. The rating permits a surge of 800 psi at the maximum test operating pressure. The valve manifold assembly is designed further to assure:

1. Simultaneous actuation and operation by using a single integrated hydraulic relieve actuating system.
2. Prevention of single valve misfire by the integrated hydraulic system and spring loading on each valve of sufficient force to operate the valve.
3. Prevention of premature valve actuation by safety tie rod arrangement in event of hydraulic system failure.

E. Vapor Condensation

During and immediately following the transient, a large quantity of steam is generated to some extent by the heat generation in the test section but principally by the depressurization or flashing of the initial high heat content of the fluid. Following exhaust of water from the water storage tank, air which was used to maintain the system pressure will follow. The direct contact pool must be capable of first condensing the steam and secondly, separating the air smoothly from the condensing pool.

Several model tests were performed to simulate the steam condensing and air removing mechanism. Based on these test results, the condensing system selected consisted of a 6 inch discharge line from Valve D placed horizontally in a 36 inch pipe for about 12 inch, a 20 feet length of totally submerged 36 inch pipe to permit steam to condense in a restrained flow area, and four short vertical pipes at the end of the 36 inch pipe to separate the air from condensing water. The system will create a pumping action on the cooling water during steam exhaust giving circulation of the condensed steam and condensing water through the 36 inch pipe, and back around to the inlet side outside of the pipe between the pool side walls. Effective and uniform mixing of steam and water is achieved therefore.

IV. EQUIPMENT CONTROLS AND REGULATIONS

A. Air System

The air system is designed for operation with initial air storage pressure of up to 5000 psig at a temperature of 325°F. Lesser initial pressure can be used where the controlled pressure in the water system permits. The pertinent operational features of the various components are as follows:

1. Non-lubricated air compressor
The 440 V power supply for the compressor is located in the main motor control center in starter 5A. Power supply is controlled through a 110 V system operating off a control transformer and has a pushbutton starter at the motor control center, an off-on selector switch at the compressor, and a dual control for constant speed or automatic start-stop operation.
2. Aftercooler, prefilter, dryer and air receiver
Air compressed in the oil-free compressor passes through an aftercooler, oil prefilter, and an electric dryer to the low pressure air receiver. Standard accessories and controls are supplied for the above. The aftercooler water supply valve and the power to the dryer are tied to the oil free compressor power control system so that operation of these auxiliary equipment occur only when the compressor is providing air to the receiver.
3. High pressure air compressor
The high pressure air compressor power supply is located in motor control center starter 3A. A 110 V system operating off a control transformer provides the control power. The following stop-start provisions are included in the system:
 - a. Starter at motor control center.
 - b. Off-on selector switch at the compressor.
 - c. Dual control pressure switch at the compressor. Only the high pressure (off) switch is connected. The compressor is not restarted when low pressure results during tests.
 - d. High temperature cut off switch set at 300°F and attached to the downstream piping providing automatic compressor stop and alarm actuation.

Additionally, downstream temperature is monitored and recorded on the 4 point Bristol located on Panel J. The compressor panelboard includes pressure indicators for the first three stages and the receiver pressures (compressor discharge), oil pressure gauge and oil level indicator.

During operation, the compressor suction pressure must be 2 psig or less. Higher suction pressure will cause motor overloading. To assure the suction pressure will not exceed this limit, the air from the receiver is throttled through a pressure regulating valve and a relief valve is located downstream of the regulating valve. Certain manually operated functions such as interstage cooler condensate draining are necessary during operation. These functions are discussed in the Instruction Manual which should be consulted.

4. High Pressure Air Filter

Immediately downstream of the high pressure compressor is located a pipeline filter with removable cartridge. This filter and adjacent pipeline should be inspected for oil film before and after each operation of the air system.

5. High Pressure Air Storage Tanks

Although two air tanks have been provided, these tanks operate as a single unit having common inlet and outlet connections. Control equipment include the following:

- a. Air temperature measurement consisting of a thermocouple in a thermowell in each tank is indicated on the four point Bristol recorder on Panel J.
- b. Storage tank pressure as measured at the inlet of the storage tanks is indicated at three locations. These locations are:
 - (1) Air compressor panel
 - (2) On the compressor room wall with a pneumatic transmitter (PT-T2).
 - (3) At Panel J on air receiver gauge (PI-T2).
- c. Low pressure air receiver trip and alarm set at predetermined air storage pressure at which test is to cease is actuated by a Meletron pressure switch (PS-T2-1). The pressure switch is part of the main air supply control valve system. Upon low pressure trip, the main control valve (PRV-T3-1) closes and simultaneously provides alarm signal at the main control panel panelarm to signify closing of the air supply. (Details of PRV-T3-1 operation are discussed in a later section).

Both tanks have a common drain system manually operated with two valves in series. Two valves are provided for safety shutoff reasons and to minimize pressure drop across any one valve if it becomes necessary to relieve air at high pressure from the tank. The operation of the valves are normally at low pressures to inspect the air tanks for contaminants and for bleed of such contaminants.

6. Pressure Regulating Valve PRV-T3-1

The main air pressure regulating valve to provide a constant pressure air supply to the storage tank is a dome loaded, self-actuated type valve. The dome is "loaded" with air to a pressure value equal to the required controlled downstream pressure. The valve opening is controlled by pressure balance of the downstream pressure with the reference dome pressure. The supply line to the dome is taken from the high pressure air compressor discharge. Two manual pressure regulators in series are provided in this line. A pressure gauge is located downstream of each valve for adjustments. The upstream valve (PRV-T3-2) reduces the 5000 psig air pressure to 4000 psig or less. The second valve (PRV-T3-3) having a maximum inlet pressure rating of 4500 psig, is capable of controlling the downstream pressure to any valve from 3000 down to 400 psig. The two valve system for the dome supply of the main PRV is necessary to maintain a reasonably constant regulated pressure in the dome. A single manual regulator results in a 4 to 5 psi reduction in the regulated downstream pressure for every 100 psi drop in the upstream supply pressure since this regulator is not pressure balanced. Thus, if the initial supply pressure were 5000 psig, and 2000 psig was the required regulated pressure to the dome, reduction in the air storage tank pressure to 3000 psig during a test could reduce the regulated pressure to 1900 psig. If a second valve is added, so that the upstream regulator is set for a 2500 psig controlled pressure and the second regulator set for a 2000 psig controlled pressure, a decrease in the storage tank pressure to 3000 psig will cause the downstream pressure of the first regulator to reduce 100 psi to 2400 psig, while the reduction of 100 psig in the upstream or supply pressure of the second regulator will result in only a 5 psi change in the final regulated pressure at the dome. In effect a resolution of 20 results.

The PRV air supply is opened or closed to the dome by a solenoid valve (EV-T3-2) located downstream of the second manual regulator discussed above. Between EV-T3-2 and the dome is located a second solenoid valve (EV-T3-3) which vents the dome to the atmosphere. Valve EV-T3-3 is orificed to assure slow bleed, hence, slow PRV-T3-1 valve closure to minimize hazards of shock in the air tanks. Prior to and during tests, EV-T3-2 is opened and EV-T3-3 is closed. When the main control valve is to be closed following completion of a test or during a test for some reason, the valves are reversed as to open and close positions. The operation of these valves are controlled by the following.

- a. Start of test, operate PBS-T3-1 at Panel J to open EV-T3-2 and to close EV-T3-3.
- b. At end of test, Meletron pressure switch PS-T2-1 automatically closes EV-T3-2 and opens EV-T3-3 to relieve the dome pressure, hence closes the main control valve (PRV-T3-1).
- c. In event tests are to be stopped prior to the automatic

stop operation, pushbutton PBS-T3-4 is actuated which will close EV-T3-2 and open EV-T3-3.

7. Surge Tank

As previously discussed, the surge tank is used principally for providing air during initial operation of the air storage system to minimize pressure drops incurred before the air control valve PRV-T3-1 begins to function. To allow PRV-T3-1 to begin control prior to start of test, air is bled from the surge tank. This bleed is controlled by a solenoid valve EV-T3-1 and opened by actuation of pushbutton PBS-T3-2 on Panel J. A manual valve is also provided for this function and is located in the compressor shed.

Pressure at the surge tank is measured at the pressure transmitter PT-T3-2 in the compressor shed and at Panel J on air receiver gauge Pl-T3-2.

8. Air Storage Tank Cell Heating

To attain 325°F air in the storage tanks, the ambient air in the cell containing the tanks is heated by steam. Two solenoid operated steam supply PRV's set at 100 psig and the draft inducer motor are provided electrical power from a 110 V, 20 amp circuit breaker distribution center in the main motor control center.

The motor may be manually stopped at the compressor shed with a pushbutton start-stop switch.

9. Relief Valve

An ASA 2500 lb. class relief valve set at 2500 psi is provided downstream of the surge tank, but upstream of the water system. This relief valve provides sufficient capacity to prevent high pressure buildup in the water system in event of failure of the air control valve as well as to relieve water hammer shock from operation of the high speed valve assembly, should such develop.

B. Water System

The equipment in the water system is designed for 3000 psig at 650°F. The design criteria called for operation up to 2200 psig; however, over-pressure design was incorporated because of the possibility for hydraulic shocks during testing. The pertinent control and regulating features of the water system components include the following:

1. Motor-operated air-water systems isolation valve (EMV-T3-1).

This valve is used to isolate the air system from the water system during the initial fill. The valve is opened just prior to start of transient test. Valve operator and pushbutton controls (PBS-T3-3) are located on Panel J. Open and close valve positions are identified by a light system. The pushbutton and lights are enclosed in keylock glass covered housing.

2. Water Storage Tank

The water storage tank has the following control accessories:

- a. Thermocouple inside a thermowell with readout on the four point Bristol on Panel J.
- b. Tank pressure indication on air receiver gauge (PI-T3-1) at Panel J.
- c. Tank pressure indication on the pneumatic transmitter (PT-T3-1) in the compressor shed.
- d. Transducer (PT-T3-3) at the tank with electrical leads to the Panel area for oscillographic recorder use.
- e. Water level indication at Panel J on indicator (LI-T3) with signal transmitted by pneumatic transmitter (DPT-T3).
- f. A differential pressure transmitter (IAS-T3) for alarm actuation on low water level.

The storage tank does not have provisions for internal heating. Therefore, it is necessary to fill the tank by recirculating heated water through the tank from the main recirculating facility. The tank has steam trace coils to minimize heat loss from the water vessel when the recirculation fill has been completed. The steam supply valve is solenoid controlled with the actuation switch located at the motor control center distribution panel. This supply source operates in conjunction with the air storage tank pressure cell heating system.

3. Flow tube

The rate of water flow from the storage tank is measured in a flow tube. Flow readout can be obtained by the pneumatic transmitter (FT-T3) located near Col. 18 or on the air receiver gage (FI-T3) at Panel J. The response of this system will in general be slow; hence, these are used merely for giving the operator some general control information. For high speed recording, three differential pressure transducers are available at the flow tube. These transducers consist of one each of 0 to 15 psi differential (PT-T-16), 0 to 25 psi differential (PT-T-15), and 0 to 50 psi differential (PT-T-14). The choice of range, of course, depends upon the expected flow range during the test. Shielded leads for connection to an oscillographic recorder are located at Col. 17 in the Panel area.

4. Water Pressure and Temperature Recordings

Pressure transducers and thermocouple assemblies have been procured. However, they are not installed during construction so that operating personnel may later determine the most appropriate and suitable locations. A shielded cable system with pickup and terminating in junction boxes at several convenient locations and the opposite ends in a junction box on Col. 17 for oscillographic recorder connection has been provided for the pressure transducer system. The thermocouple system will in general utilize the existing lead wire system to the thermocouple jack panel console with several leads from the console terminating at the junction box on Col. 17 for oscillographic recorder tie.

C. Vapor Condensation

The vapor condensation system has been described previously. Because of simplicity of operation, no special control or regulating equipment is provided.

D. Steady State Transient Switch Valve Assembly

The high speed valve manifold assembly consists of two manual valves for establishing steady state flow direction through the test section and three quick acting valves to isolate the steady state system and direct the transient flow system discharge to the direct contact, steam condensing pool. The assembly additionally consists of a electromagnet, hydraulic system release valve; hydraulic system pressurizing hand pump and pressure indicator; and mechanical safety latch for positive holding of the three quick acting valves. A panel board with lights for quick acting valve position indication, air supply and vent valve for cocking the electromagnet valve tri-cylinder, magnet, power supply rectifier, and actuation push button comprise the assembly.

Details of the operation are covered in the Valve Assembly Operating Manual. Thus, the operating procedure will not be covered here.

V. OPERATIONAL PROCEDURE

It is expected that the setup work for performing a single test will require some 24 to 36 hours. The air system is rated to pressurize from 3000 psig to 5000 psig in 15 hours. If the test to be conducted is the first in the series, additional pressurizing time is required for fill from 0 to 3000 psig. Test preparations for the water system are expected to take about 6 to 10 hours with the operating temperature in the tank largely dictating the time required. The valve assembly and vapor condensation systems will require two to three hours for complete preparation. The following procedure is provided as a guide for the initial operations. Modifications may be required or desired to suit operating practices or for operating convenience; however, such changes shall be made after safety aspects have been reviewed carefully and found to be wholly satisfactory. It is assumed herein that all equipment are in good operating condition and routinely maintained.

A. Air Pressurization

1. Check high pressure filter and pipe line for oil traces. Proceed if oil vapor traces are not found and if carry-over to the receiver is not indicated.
2. Close valve EMV-T3-1 by actuating "close" button of PBS-T3-3 at Panel J. Lock door of pushbutton unit and remove key.
3. Close air supply manual regulators PRV-T3-2 and PRV-T3-3 to dome of PRV-T3-1.
4. Close manual drain valves of the high pressure air storage tank.

5. Turn on non-lubricated air compressor if not operating. After-cooler and dryer should automatically operate with the compressor.
6. Start high pressure air compressor at motor control center starter 3A when normal operating pressure in the low pressure air receiver is attained. Follow Instruction Manual Procedures for inter-and-after cooler draining, etc. Maintain checks at intervals on thermocouple readout of discharge air temperature. Air temperature should not exceed 125°F. Check all pressure gauges and temperature indicators frequently comparing one against the others to assure satisfactory operation. Continue checks throughout the entire air fill process and during any holding time which may be necessary after fill.
- 7.. When the receiver pressure reaches 300 psig, stop the high pressure compressor. Using two manual drain valves at the bottom of the tank, and balancing the pressure drop across each valve, bleed air from the storage tank to determine if contaminants are present and to remove them if other than oil. Any evidence of oil mixture or substances will require stopping of test preparation.
8. If air is clean, close manual valves and restart high pressure air compressor.
9. Turn on steam PRV and draft inducer motor for pressure cell heating. Heating should proceed so that the maximum temperature of approximately 325 F is reached in the air tank before completion of pressurization. Air at 60 F and about 3300 psig will rise to 5000 psig when heated to 325 F.
10. Pressurize to 3000 psig (or to any desired pressure which is pre-selected as "end of test" pressure). Check PS-T2-1 (Meletron switch) setting and alarm system operation.
11. Increase pressure to 3500 psig (or slightly above the trip setting in preceding step). PRV-T3-1 dome vent valve EV-T3-3 can now be closed and supply line valve EV-T3-2 can be opened by actuation of momentary contact PBS-T3-1.
12. Slowly open dome supply regulator PRV-T3-2 (upstream) to obtain controlled downstream pressure of 2500 psig. Slowly open PRV-T3-3 to controlled downstream pressure of 300 psig. The above operation will cause the main PRV-T3-1 to open until the surge tank pressure is at 300 psig.
13. Bleed air from surge tank by opening the manual bleed valve or by operation of EV-T3-1 through actuation of PBS-T3-2 on Panel J.
14. Pressurize tank to 5000 psig (or to lesser required pressure) for start of test. Air temperature in tank should be 325 F before or upon reaching the required supply pressure. If pressurized to

5000 psig, the compressor will automatically stop. Cut off power supply to compressor. Reset dome regulators PRV-T3-2 and PRV-T3-3 for required control pressures.

B. Water Fill and Heating

Water fill and heating is performed simultaneously with the air pressurization. However, the water fill process will require a shorter period of time, and should commence subsequent to start of air pressurization.

1. Steady state system pressure must be controlled at a point which will remain in the recirculating facility after high speed valve actuation. Check and change control point, if necessary.
2. Fill water system including water storage tank in normal manner. Remove trapped air. Overflow line from tank is the high leg of the level indicator. During fill, check 0 and 100% indication of level indicator for operation. Cap overflow line when tank is filled.
3. Position valves S and R of high speed valve assembly for steady state test section flow direction.
4. Cock high speed valves as per valve manifold instructions.
5. Close 2-1/2 inch manual valve between storage tank and valve manifold. Open 2 inch valve between top of storage tank and "Z" header. Partially open main steady state flow control valve.
6. Pressurize and begin recirculation in steady state loop.
7. Slowly open 2-1/2 inch manual block valve between tank and manifold. Flow through tank is from bottom to top or reverse of transient flow direction from tank.
8. Determine from total flow recorder and flow through tube as calculated from pressure drop data across test section the approximate flow distribution. Flow in test section should be sufficient to permit adequate heat input to the test section for heatup, if necessary. Note: flow through the tank will be relatively small when S and R valves are arranged for flow through the test section in the direction opposite to the "normal" flow. Thus, heating in the tank will lag.
9. Turn on preheaters for normal heating of circulating water. Provide additional heating in test section, if required.
10. When tank water has reached required test supply temperature, close the 2 inch valve between top of the tank and the "Z" header slowly. Adjust flow to test conditions. Supply power to tube.
11. Open motor-operated valve between air and water systems when the

transient test is ready to commence.

12. Check valve manifold for proper holding, Detach safety mechanism on valves.

C. Vapor Condensation Pool

1. Close the two 8 inch drain valves.
2. Fill pool with raw water to top of 36 inch flow tube.

D. Actuation

1. Actuate and hold PBS-T3-2 for 5 seconds to allow PRV-T3-1 to "control". Release after step 2 completed.
2. Actuate valve manifold pushbutton.
3. When air pressure reaches preset valve on the Meletron (PS-T2-1), air regulator valve will close. If test requires stopping before trip is reached, actuate PBS-T3-4 which also closes regulator valve.

E. Air System Unloading

Air should be unloaded through the main PRV through normal piping or through the surge tank drain valves. This is necessary to bleed air from a "low" pressure source. In event it becomes necessary to unload using the storage tank drain valves, precaution should be taken to distribute the pressure drop through both drain valves. Regardless of procedure, precaution must be taken to prevent extremely low air temperature during the expansion process.

VI. COMPRESSED AIR SYSTEM HAZARDS

Fires and explosions from oil in air are potential hazards of any compressed air systems. Mechanisms and phenomena which result in these hazards are reported to be from the following:⁽¹⁾

1. Entrained oil deposited in piping, air coolers, and receivers resulting in oxidation under given temperatures and pressures. Oxidation may be accelerated by rapid air flow and/or high temperatures and the air flow is suddenly cut off.
2. Following formation of flammable gaseous mixture in a pipe, deflagration may lead to explosion fueled by oil deposits.
3. The formation of a carbon-oxygen complex which is an exothermic reaction.
4. Chemical decomposition of oils to form peroxides or the

(1) "Explosions and Fires in Compressed Air Systems", Nuclear Safety, September, 1960, Volume 2, No. 1.

formation of flammable sulfur gases from sulfur sometimes present in lubricating oils.

In general, high temperature conditions must accompany the formation of explosive air-oil mixtures. These high temperature conditions may result from high air flow friction over oil impregnated rust and carbonaceous deposits, shock waves caused by rapid valve operation or from a combustion process, or from loss of cooling to the compressor or to the aftercooler.

In the design of the air pressurizing system, special attention was given to assure that air to the high pressure compressor would be cool and free of oil vapor. Piping runs, bends, and turns were minimized to reduce the locations where substances may accumulate. The discharge line from the compressor is provided with a filter to prevent oil carry-over to the storage tanks. Air discharge temperature is monitored with a thermoswitch for automatic compressor stop on high discharge air temperature, as well as with a continuous indicating thermocouple-recorder unit. The compressor is air-cooled and each stage is provided with a separator condensate trap to remove moisture and oil vapors.

Consideration was given to the possible use of synthetic lubricant in the compressor to minimize fires and explosions. Vendor's experience, however, indicated that compressor operation was often unsatisfactory when synthetic lubricant was used. Vendor suggested that petroleum lubricant with an efficient pipeline filter would provide the most reliable system. Since malfunction of the compressor could itself lead to hazards, the design followed the suggestion of the vendor.

There is only one valve which can be closed during transient operation from the air storage tank to exhaust. To prevent a sudden closure which can lead to shock wave conditions, the valve (main pressure reducing valve) dome vent is orificed so that the dome pressure will reduce slowly and hence, the valve will close slowly.

The pipeline in the water system consists of long runs and a large number of bends. If oil carry-over from the compressor to the air storage tank occurs, the oil may be carried further into the water system piping and components. Release of high velocity air through the piping in subsequent runs could cause heat up, vaporization, and ignition of oil which may have been deposited. To assure such incidence will not arise, it is necessary that oil carry-over from the compressor to the receiver be eliminated or be virtually impossible. Special precaution has been taken to assure that the air which is compressed to 5000 psig is free of oil vapor. However, since the compressor is petroleum oil lubricated, oil entrainment in the compressor discharge air remains a possibility particularly when the internals of the compressor become worn. The compressor discharge line is provided with a pipeline filter as one measure of safety precaution to minimize the carry-over of this oil to the storage tank.

These design considerations together with the proper maintenance and operating procedures should result in a safe system. However, a safe

system can be assured only by continuing efforts and surveillances. Additional to adhering to the compressor maintenance schedule in the Vendor Instruction Manual, the operating procedure discussed in Section V has included pipeline, filter, and air storage tank check-outs. In event that oil or other substances which may lead to hazards is found, it is necessary to inspect the compressor internals or to clean the air tank and pipeline with appropriate solvent, or both. Under no circumstance should pressurization and air release be permitted where oil carry-over to the storage tank is suspected until a complete system checkout is made and found free of oil.

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Special Studies