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Magnetohydrodynamics (MHD) Engineering Test Facility (ETF) 200 MWe Power Plant

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(MHD) ENGINEERING TEST FACILITY (ETF) 200
MWe POWER PLANT CONCEPTUAL DESIGN
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Conceptual Design Engineering Report (CDER)

Volume V — Supplementary Engineering Data (Cont'd)

Gilbert / Commonwealth
Engineers / Consultants

September 1981

Prepared for
National Aeronautics and Space Administration
Lewis Research Center
Under Contract DEN 3-224

for
U.S. DEPARTMENT OF ENERGY
Fossil Energy
Office of Magnetohydrodynamics



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MHD-ETF
CONCEPTUAL DESIGN
ENGINEERING REPORT

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	031	STEAM BYPASS & STARTUP

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SYSTEM DESIGN DESCRIPTION

SDD-231

CLOSED CYCLE COOLING WATER SYSTEM

FOR

MAGNETOHYDRODYNAMICS

ENGINEERING TEST FACILITY

CONCEPTUAL DESIGN - 200 MWe POWER PLANT

FLUID SYSTEM DIAGRAM NO. 8270-1-531-302-231

<u><i>C. J. Wall</i></u>	<u>3/6/81</u>
SYSTEM ENGINEER	DATE
<u><i>Louis L. Wagner</i></u>	<u>3/18/81</u>
REVIEWED	DATE
<u><i>Harry G. Glendon</i></u>	<u>3/18/81</u>
REVIEWED	DATE
<u><i>John P. Sullivan</i></u>	<u>3/18/81</u>
APPROVED	DATE

Revision: 1
Date: September 25, 1981
Approved: *John P. Sullivan*

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
CLOSED CYCLE COOLING WATER SYSTEM

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1.0 FUNCTION AND DESIGN REQUIREMENTS

This document presents a description of the Closed Cycle Cooling Water System (CCCWS) as depicted on Fluid System Diagram 8270-1-531-302-231, Closed Cycle Cooling Water-Turbine and Compressor Building, and Diagram 8270-1-531-302-232, Closed Cycle Cooling Water-HR/SR Area and MHD Bldg. The document includes descriptions of system functions, interfaces with other systems, equipment and piping requirements, design criteria, description of components, operating modes, and safety and maintenance requirements.

1.1 FUNCTIONAL REQUIREMENTS

The CCCWS is designed to circulate cooled, treated demineralized water through a closed loop system to all major equipment in the main turbine and compressor buildings, the HR/SR building and the MHD building.

Three 50 percent capacity closed cycle cooling water pumps, two operating and one standby, pump warm water through one 100 percent station heat exchanger for cooling. A redundant 100 percent capacity station heat exchanger is provided for backup. The cooled water is distributed through headers leading to the main turbine generator and auxiliary coolers; air separation and oxidant equipment auxiliary coolers; HR/SR, and coal processing equipment coolers and MHD magnet accessories. After passing through the equipment the cooling water is returned to the suction side of the closed cycle cooling water pumps.

1.2 SYSTEM INTERFACES

Major equipment components involved with the CCCWS include the Generator Hydrogen Coolers, Turbine Lube Oil Coolers, Pump and Fan Bearing Coolers, Station Service Heat Exchangers, Closed Cycle Cooling Water Pumps, and the Closed Cycle Water Head Tank. Major system interfaces with the CCCWS include the Circulating Water System, Condensate System, and Lube Oil Subsystem. The CCCWS also interfaces with other various systems, such as the MHD Magnet accessories, and the Plant Service and Instrument Air Supply System.

1.3 DESIGN CRITERIA

The closed cycle cooling water piping system is all welded construction in accordance with ANSI B31.1. Piping is carbon steel A106 Grade B seamless. Valves are in accordance with ANSI B16.5 and B16.34. All equipment is flanged for easy removal.

All pipe sizing is based upon economic considerations, and hydraulic analysis to ensure adequate cooling water flow to all coolers during all operating modes.

Heat exchangers and pumps are sized with reserve capacity to assure proper operation under any load or emergency condition.

Standby pumps and heat exchangers are provided for flexibility. This standby capacity allows for the removal of any one unit from service for maintenance during full load operation.

The closed cycle water head tank is vented to atmosphere and is fabricated from ASTM A-285 carbon steel plate.

1.3.1 Codes and Standards

System engineering design is in accordance with applicable codes, standards, and guides issued by the following organizations:

1. American National Standards Institute (ANSI)
2. American Society of Mechanical Engineers (ASME)
3. American Society for Testing and Materials (ASTM)
4. American Welding Society (AWS)
5. Manufacturers Standardization Society of the Valve and Fittings Industry (MSS)
6. Pipe Fabrication Institute (PFI)
7. Occupational Safety and Health Administration (OSHA)
8. Instrument Society of America (ISA)
9. National Fire Protection Association (NFPA)
10. Heat Exchange Institute (HEI)

1.3.2 Design Parameters

The design pressures, temperatures and pipe sizing flow rates are taken from the manufacturers' equipment recommendations, and tabulated on the fluid system diagrams 8270-1-531-302-231 and -232. Flow rates are those occurring with main turbine Valves Wide Open, and the Heat Recovery/Seed Recovery (HRSR) and MHD unit operating at Maximum Continuous Rating conditions. Closed Cooling Water pipe sizing is based on pressure drop, as a percent of normal (design) pressure, usually running around 1 to 2 psi drop per 100 ft. of pipe.

2.0 DESIGN DESCRIPTION

The major components of this system are the closed cycle cooling water pumps, station service water heat exchangers, all station auxiliary coolers, closed cycle water head tank, chemical fill tank, piping, instruments, and controls. The major equipment components are covered further in this section as well as other System Design Descriptions as noted in Section 1.2.

2.1 SUMMARY DESCRIPTION

The cooling water is chemically treated to prevent corrosion or scale of the carbon steel pipe and equipment. The cooled treated water will circulate through a closed loop system to all major equipment in the main turbine-generator area and HR/SR area. In addition, all equipment associated with the MHD topping cycle requiring closed cycle cooling water will also be included in this system.

There are three 50 percent capacity closed cycle cooling water pumps. Two pumps circulate the water through the system during normal plant operation. One 50 percent capacity pump is utilized for cooling auxiliary equipment during plant shutdown.

A closed cycle water head tank, vented to atmosphere, is the highest point in the system. The head tank is provided to maintain a reserve volume of created condensate and to maintain positive pressure on the pump suction piping. A level control valve with a manual bypass admits condensate makeup to replace system leakage. The signal is from a level controller mounted on the tank.

A chemical treatment tank is connected across the cooling water pumps to introduce chemicals into the suction header when required.

The water passes through the shell side of the two station service heat exchangers for cooling during normal plant operating conditions. The cooling water through the tubes of these heat exchangers is raw water as covered in the Circulating and Service Water System design description and fluid system diagram 8270-1-571-302-201. A condensate bypass around these heat exchangers is controlled automatically to limit the minimum cooling water temperature. The cooled condensate flows from the heat exchangers to all the station auxiliary coolers, and returns to the pump suction manifold.

The CCCWS serves station auxiliary equipment within the main-turbine generator area, compressor areas, HR/SR area, and MHD building. Auxiliaries in the turbine area (See Fluid System Diagram 8270-1-531-302-231) include the following:

Generator Hydrogen Coolers - Four 25 percent units in operation at all loads.

Alternator Coolers - Two 100 percent (one in service at all loads)

Bus Duct Cooler - One 100 percent (in service at all loads)

Main Turbine Lube Oil Cooler - Two 100 percent (one in service at all loads)

Main Turbine Hydraulic Oil Cooler - Two, A & B (one in service at all loads)

Condensate Pumps A, B, & C - Two in service at all times

Vacuum Pumps A & B - Two in service at all times

Boiler Feedwater Booster Pumps A & B

Main Boiler Feedwater Pumps A, B, & C - Two in service at all times

The auxiliaries in the compressor areas (See Fluid System Diagrams 8270-1-531-302-231, -232) including the following:

Air Separation Unit (ASU) Turbine Lube Oil Coolers - Two 100 percent (one in service at all loads)

Oxidant Compressor Turbines (2) Lube Oil Coolers - Two 100 percent per turbine (one per turbine in service at all loads)

Oxidant Compressor Motor Bearing Coolers - Two 100 percent (one in service at all loads)

Plant Service/Instrument Air Compressors Inter and Aftercoolers - Two 100 percent (one in service at all loads)

The auxiliaries in the boiler area (See Fluid System Diagram 8270-1-501-302-232) include the following:

Induced Draft Fans (3) Bearing Coolers - Two 100 percent per fan (one per fan in service at all loads)

Coal Pulverizer Mills (3) - Three maximum in service depending on load.

Flue Gas Recycle Fans (3) Bearing Coolers - Two 100 percent per fan (one per fan in service at all loads)

Secondary Air Fans (3) Bearing Coolers - Two 100 percent per fan (one per fan in service at all loads)

Sample Coolers - Intermittent

Boiler Access Doors - All in service

The auxiliaries in the MHD building (See Fluid System Diagram 8270-1-501-302-232) include the following:

Magnet Warm Bore Liner Cooler

Magnet Power Supply Coolers

Power Absorbing Resistors Coolers

Refrigerator Compressor Inter and Aftercoolers - One Each @ 100 percent (in service at all loads)

Refrigerator Liquifier Cooler

Vacuum Diffusion Pumps Cooling Circuits - Two 100 percent per pump (one per pump in service at all loads)

Vacuum Fore Pumps (2) Bearing Coolers - Two 100 percent per pump (one per pump in service at all loads)

All of the lubricating oil coolers include automatic temperature controls which modulate the water flow required to maintain correct oil temperature.

The generator hydrogen coolers are automatically temperature controlled to maintain proper temperature at various loads. All other equipment is manually adjusted to a fixed constant flow rate which is suitable for all load conditions.

The necessary temperature and pressure instruments and controls are included for each piece of equipment.

As noted by the list of auxiliaries being cooled, there are some spare units on standby service and others that vary in water flow requirements in accordance with the load. During plant shutdown, few units require cooling; therefore, a 50 percent capacity pump is utilized for operation under shutdown conditions.

An automatic recirculation flow control from the pump discharge header to the pump suction header is provided to maintain constant system pressure across the pumps during throttled conditions, as well as ensuring minimum flow.

Each pump may be operated locally or remote manual from the main control room.

2.2 DETAILED DESCRIPTION

2.2.1 Major Equipment

Major interface equipment components shown on the CCCWS diagram are the generator hydrogen coolers, turbine lube oil coolers and turbine hydraulic oil coolers, ASU turbine lube oil coolers, oxidant turbines lube oil coolers, boiler feed pumps and condensate pumps, MHD magnet accessories, and plant service and instrument air compressors. These items are described in the following system descriptions:

<u>ITEM</u>	<u>SYSTEM DESIGN DESCRIPTION</u>	<u>FLUID SYSTEM DIAGRAM</u>
1. Main turbine generator	Main & Reheat Steam	8270-1-501-302-011
2. Station service heat exchangers	Circulating & Service Water	8270-1-571-302-201
3. Boiler feed pumps	Boiler Feedwater	8270-1-521-302-081
4. Condensate pumps	Condensate	8270-1-511-302-101
5. Plant service and instrument air compressors	Industrial Gas	8270-1-652-302-241
6. Superconducting magnet and cryogenic equipment	Magnet	

Major design data of equipment components directly associated with the Closed Cycle Cooling Water System are:

1. Closed Cycle Cooling Water Pumps:

DESIGN & PERFORMANCE DATA

Type	Horiz. Centr.
Quantity	3
Capacity, GPM	1500
TDH at design conditions, ft.	
Shutoff head, ft. (assumed)	
Pump speed at design conditions, rpm	
Eff. at design conditions, % (assumed)	80
Driven brake horsepower required at design conditions, BHP	

MATERIALS OF CONSTRUCTION

Casing	ASTM A48, Cast iron
Impellers & casing rings	ASTM A296, Iron chromium
Shaft	ASTM A576, Hot rolled carbon steel
Shaft sleeves	ASTM A322, Hot rolled alloy steel

2. Closed Cycle Water Head Tank:

Type	Vertical cylindrical
Quantity	one
Size	72 in. OD by 9 ft. high
Tank material	ASTM A285, Carbon steel, C PVQ
Wall thickness	1/4 in.
Corrosion allowance	1/16 in.
Exterior coating	Inorganic Zinc Primer
Interior coating	Mobil 78-W-3
Design pressure	Atmos.
Design temperature	150 F
Code required	None
Test	5 psig hydro.

3. Chemical Fill Tank:

Type & Size	Vertical cylindrical
Quantity	One

2.2.2 Piping and Valves

All piping is seamless carbon steel ASTM A106 Grade B Schedule 40. All valves are carbon steel with bronze trim. Valves 2 inch and smaller are 600 lb. socket weld forged steel. Valves 2-1/2 inch and larger are 150 lb. butt weld. Valves 6 inch and larger are 150 lb. butterfly type, utilized for throttling as well as shut-off service

Expansion joints are rubber spool type.

2.2.3 Electrical

Electrical Supply

The closed cycle water pump motors are 460 volt, 3 phase, 60 Hz supplied from 480 volt motor control centers.

Electrical instruments, controls, and valve limit switches are supplied with power coordinated with instrument power sources.

2.2.4 Instruments, Controls and Alarms

Local Pressure Indicators

Direct-reading pressure indicators are provided at each pump discharge. Additional pressure indicators are provided as indicated on Fluid System Diagram 8270-1-531-302-231 and 8270-1-531-302-232.

Pressure Controller

A pressure controller is installed in the main header of the closed cycle system to signal the pump recirculation valve, for system pressure and pump minimum flow protection.

Local Temperature Indicators

Direct-reading temperature indicators are provided in the system as indicated by Fluid System Diagrams 8270-1-531-302-231 and 8270-1-531-302-232.

Temperature Test Wells

A thermowell for the installation of temperature test instruments is installed on the pump discharge header.

Temperature Controllers

1. A temperature controller is provided in the main header downstream of the station service heat exchangers. This modulates the temperature control valve, which bypasses the heat exchangers to control system temperature.
2. Temperature controllers are provided in all boiler feed pump lube oil systems in order to regulate the independent temperature control valves.
3. The generator hydrogen cooler temperature control valve is modulated by a temperature controller installed in the hydrogen system.
4. The turbine lube oil cooler temperature control valves are modulated by a temperature controller installed in the various turbine lube oil systems.

Tank Level Controls

The closed cycle head tank instrumentation is provided in the system as indicated by Fluid System Diagram 531-302-231. The level controller modulates the makeup valve located in the condensate supply line.

3.0 SYSTEM PROTECTION AND SAFETY PRECAUTIONS

3.1 PROTECTIVE DEVICES

The piping and valve limits are equal to or greater than those of the connecting equipment. Therefore, no additional protective devices are required.

3.2 HAZARDS

No special hazards exist other than unforeseen operating conditions due to malfunction of mechanical or electrical equipment. Most of the emergencies that could occur would not shut down the plant because of the standby flexibility and automatic control of the system.

3.3 PRECAUTIONS

There are no special precautions for the safe operation of the CCCWS. It is designed to ensure operating security through the use of automatic controls, and monitoring instruments. Startup, normal operation, and shutdown must be in accordance with equipment manufacturers' instructions.

Pumps can be operated locally or remotely. Pressure drop across station service heat exchangers should be periodically monitored to provide an indication of tube plugging. Makeup water to the head tank is automatically controlled with manual backup. All coolers are automatic with suitable temperature controls and monitoring.

Spare pumps and heat exchangers permit removing faulty units from service for repair or maintenance during normal plant operation without disrupting service.

An automatic temperature controlled bypass around the heat exchangers limits cooling water temperature to a safe minimum value.

4.0 MODES OF OPERATION

4.1 STARTUP

Initial fill of the system commences after piping flushing has been completed. The system is filled with treated condensate from the condensate pump header into the closed cycle cooling water head tank. When normal level is established in the head tank, all equipment valves must be opened. One 50 percent capacity pump is to be started and the total system vented. Water analysis should be made at this time and the necessary chemical treatment applied if required.

4.2 NORMAL OPERATION

Normal startup is with one 50 percent pump operating, and venting of all equipment to remove trapped air. After this has been done, and with cooling water flowing through the necessary station equipment coolers, plant startup may commence.

When sufficient load has been attained, startup of a second 50 percent capacity closed cycle cooling pump is mandatory.

The pumps should be started locally until normal operation has been confirmed. At this time, all pump suction and discharge valves should be opened. Pumps may then be started and shut down remotely from the control room.

All temperatures and control valves should be checked for proper operation before increasing load from startup.

4.3 SPECIAL OR INFREQUENT OPERATION

No special operations are anticipated with this system.

5.0 MAINTENANCE

5.1 SURVEILLANCE AND PERFORMANCE MONITORING

In the event that certain important parameters of the CCCWS fall outside of predetermined limits, an annunciator in the control room will be activated.

The following problems are indicated at the annunciators in the main control room:

1. Closed cycle cooling water pumps, stopped (as indicated by an auxiliary contact in the motor starter)
2. Closed cycle water head tank, low level and high level alarm.
3. Closed cycle cooling water loop temperature downstream of the station service heat exchangers (connected to control room computer to maintain pre-set cooling water temperature).

5.2 INSERVICE INSPECTION

Frequent inservice inspection includes the following:

1. Check condition and operation of all valves and temperature controls.
2. Check for leaks.
3. Check chemical analysis of water. A fill tank is included for adding treatment chemicals.

4. Manufacturers' detailed instructions must be adhered to.
5. The most likely problem to be encountered will be plugged tubes in the station service heat exchangers.
6. Check high and low level alarms on the head tank.

5.3 PREVENTATIVE MAINTENANCE

A routine preventive maintenance schedule must be adhered to. This includes inspection and calibration of all instruments, controls and valves to ensure that they are operating within their prescribed ranges. Provisions have been made to conduct this maintenance during normal plant operation.

Spare pumps and heat exchangers permit removing any faulty unit from service for maintenance during normal plant operation.

5.4 CORRECTIVE MAINTENANCE

5.4.1 Manufacturer's Instructions

A complete file of instruction books is available at the plant to guide the plant personnel in maintenance and overhaul of any piece of equipment. If necessary, a representative of the manufacturer can be present to supervise the overhaul or replacement of plant equipment.

5.4.2 Spare Parts Inventory

The CCCWS will require very nominal quantities of spare parts inventory for regular maintenance and common repairs. The following spare parts inventory are recommended:

1. Pumps - (one set for each type pump) - casing rings, impeller rings, packing/mechanical seals, shaft sleeves, bearings.
2. Seats and packing for hand valves.

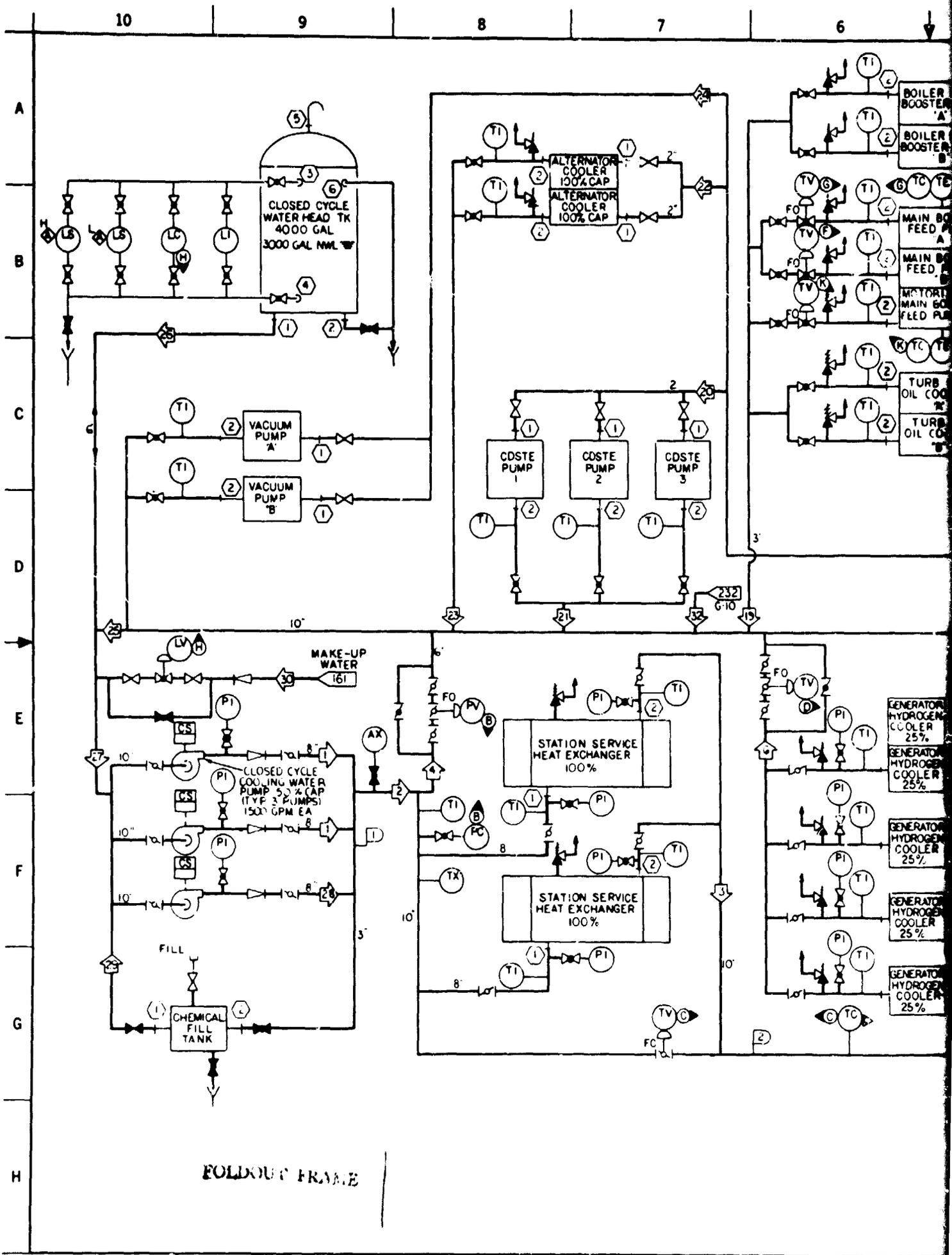
MHD-ETF PROJECT
 SYSTEM DESIGN DESCRIPTION
 CLOSED CYCLE COOLING WATER SYSTEM
 APPENDIX "A"
 REFERENCE DOCUMENTS

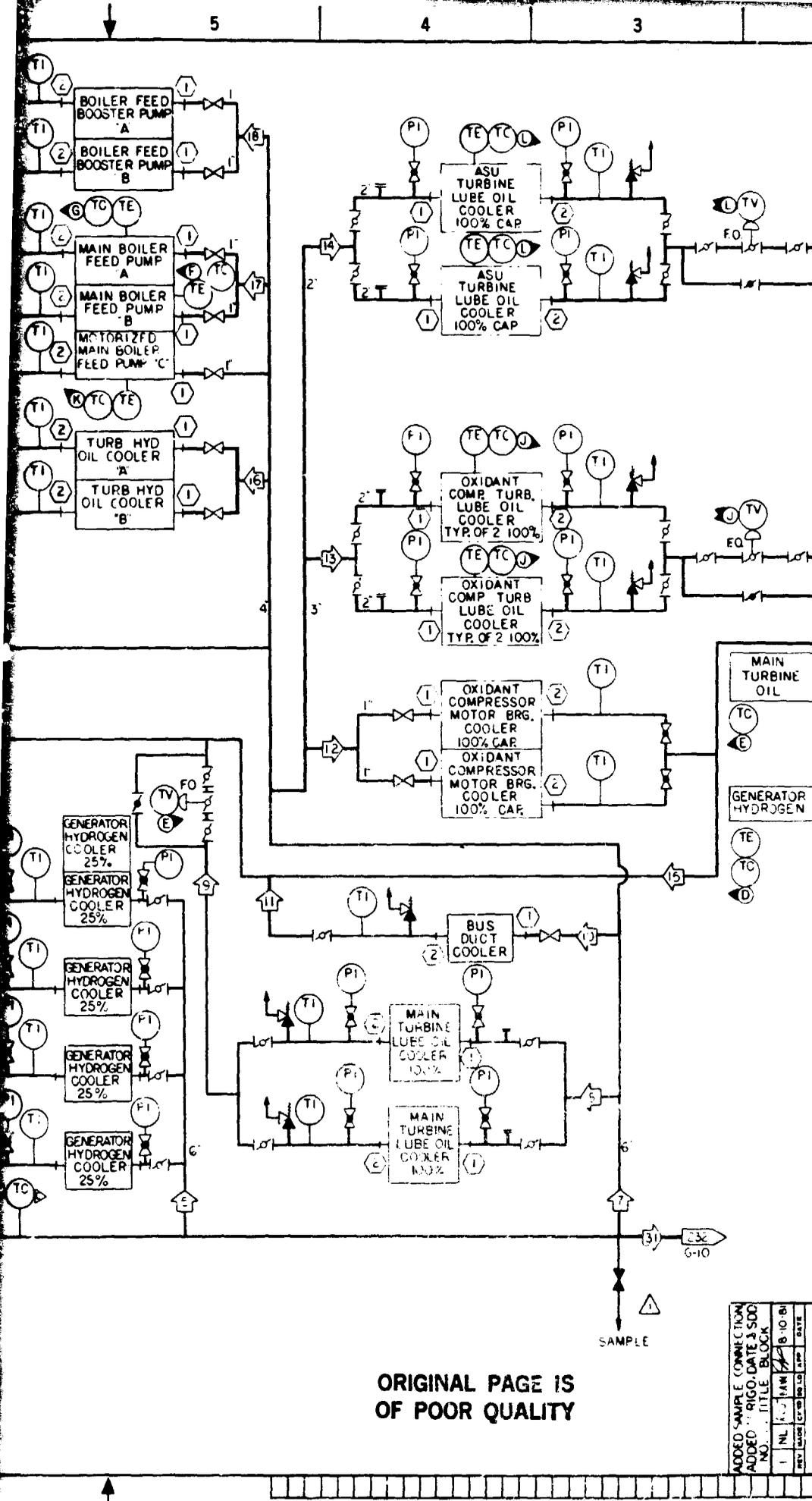
REFERENCE DOCUMENTS - ATTACHED

<u>Fluid System Diagram</u>	<u>Diagram No.</u>
Closed Cycle Cooling Water - Turbine and Compressor Building	8270-1-531-302-231
Closed Cycle Cooling Water - HR/SR Area and MHD Building	8270-1-531-302-232

REFERENCE DOCUMENTS - NOT ATTACHED

<u>System Design Description</u>	
Condensate	
Main & Reheat Steam	
Circulating & Service Water	
Boiler Feedwater	
Plant Service & Instrument Air Supply	
 <u>Plant Heat & Flow Balance Diagram</u>	
System Heat Balance	8270-1-540-314-001





OPERATING DATA						
#	FLOW GPM	PRESS PSIG	TEMP °F	BY	REMARKS	REV
1	1500	7	100		PUMP DISCHARGE	
2	2830	75	100		HEAT EXCH INLET	
3	2580	6	80		HEAT EXCH OUTLET	
4	1200	75	100		RECIRC	
5	900	6	80		GEN. H. COOLER	
6	900	5	100		RETURN	
7	1100	60	80		LOOP	
8	700	60	80		TURBINE LO COOLER	
9	700	50	100		RETURN	
10	40	6	80		BUS DUCT COOLER	
11	40	5	100		RETURN	
12	20	60	80		OXIDANT MOTOR	
13	80	60	80		OXIDANT TURBINE	
14	40	60	80		ASU TURBINE	
15	140	60	100		COMP AREA RETURN	
16	80	60	80		TURBINE HYD. CLR.	
17	30	60	80		BLR. FEED PUMPS	
18	20	60	80		BOOSTER PUMPS	
19	120	50	100		RETURN	
20	30	60	80		CONDENSATE PUMPS	
21	30	50	100		RETURN	
22	40	60	80		ALTERNATOR CLR.	
23	40	60	80		RETURN	
24	20	50	100		VACUUM PUMP	
25	2830	60	80		LOOP SYS. RETURN	
26	60	50	100		HEAD TANK	
27	2830	50	100		PUMP SUCTION	
28	1500	75	100		50% PUMP DISCH.	
29	170	75	100		CHEM. FILL RECIRC.	
30	60	75	100		MAKE-UP	
31	580	60	80		LOOP TO HR/5R	
32	580	60	80		LOOP RTN. HR/5R	

DESIGN DATA						
#	FLOW GPM	PRESS PSIG	TEMP °F	BY	REMARKS	REV
1	3500	150	125		ASTM A 53 GR. B SCH 40	
2	3500	150	125		ASTM A 53 GR. B SCH 40	

I.C. NO. C-373-842

3-27-81	CONCEPTUAL DESIGN ISSUE	
2-13-81	PRELIMINARY ISSUE	
DATE	RELEASED FOR	ENGR.

MAGNETOHYDRODYNAMICS ENGINEERING TEST FACILITY CONCEPTUAL DESIGN

FLUID SYSTEM DIAGRAM

CLOSED CYCLE COOLING WATER-TURB. & COMP. BLDG. SDC-231

200 MWe

DDE - NASA

MHD PROJECT OFFICE
LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

APPD. H. RIGO
DATE 9-25-81

GILBERT ASSOCIATES, INC.
ENGINEERS AND CONSULTANTS READING, PA

ENGINEERING INTERFACES

MADE	CHECKED	DATE
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1-3	1-3	1-3

SCALE NONE

8270-1-531-302-231

88270-601 DRAWING NUMBER

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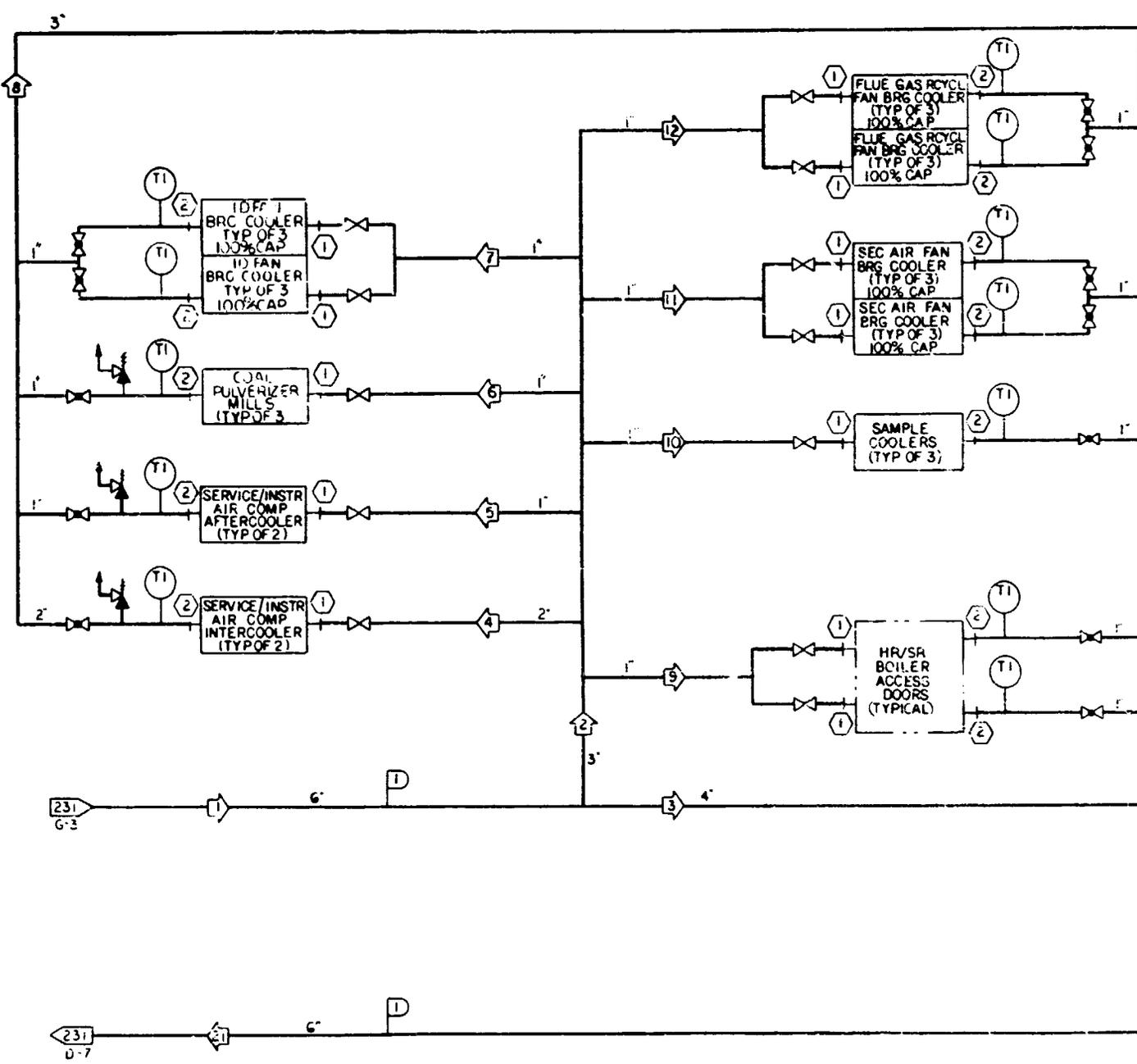
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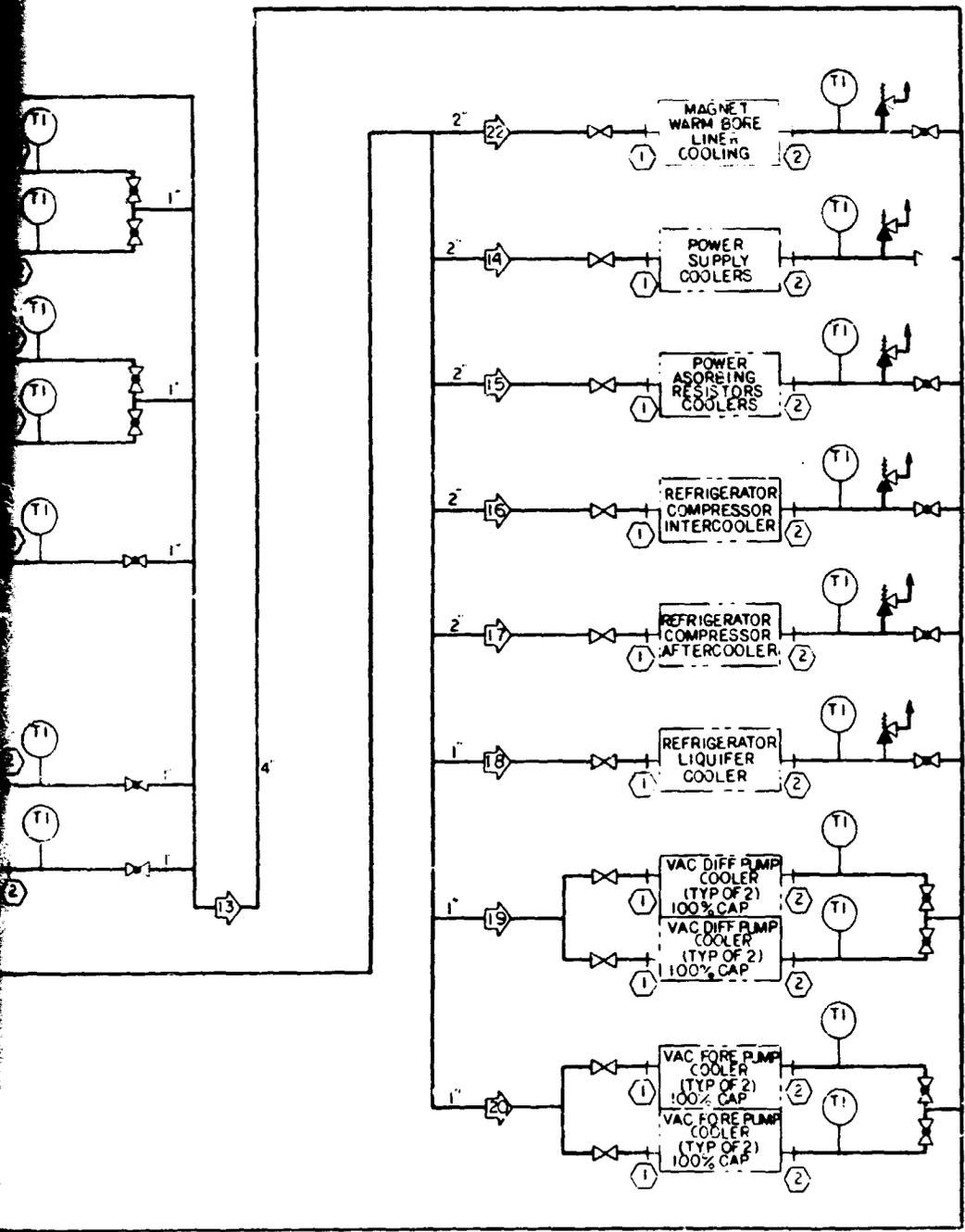
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FOLDOUT FRAME



OPERATING DATA

#	FLOW	PRESS	TEMP	BY	REMARKS	REV
	GPM	PSIG	F°			
1	580	55	80		LOOP	
2	240	55	80		HR/SR AREA	
3	360	55	80		MAGNET CRYOGEN	
4	40	55	80			
5	30	55	80			
6	30	55	80			
7	30	55	80			
8	130	55	80			
9	30	50	100			
10	20	55	80		INTERMITTENT	
11	30	55	80			
12	30	55	80			
13	240	55	80			
14	75	50	100			
15	50	55	80			
16	100	55	80			
17	100	55	80			
18	5	55	80			
19	5	55	80			
20	5	55	80			
21	580	55	80		LOOP	
22	40	55	80		200GPM IF LNR FAILS	

DESIGN DATA

#	FLOW	PRESS	TEMP	BY	REMARKS	REV
	GPM	PSIG	F°			
1	800	150	125		ASTM A53 GR. B SCH. 40	

I. D. NO. C-373-845

3-27-81	CONCEPTUAL DESIGN ISSUE	
2-13-81	PRELIMINARY ISSUE	
DATE	RELEASED FOR	ENGR

MAGNET HYDRODYNAMICS
ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN

FLUID SYSTEM DIAGRAM

CLOSED CYCLE COOLING WATER - HR/SR AREA - 9 LDs. 500-231
200 MW_e

DRE - NASA

MHO PROJECT OFFICE

LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

APPD. H. RIGO
DATE 9-25-81

GILBERT ASSOCIATES, INC.
ENGINEERS AND CONSULTANTS - BEADON, PA.

DRAFTING

DESIGNED BY: [Signature]

CHECKED BY: [Signature]

SCALE: NONE

8270-1-531-302-232

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ADDED H. RIGO. DATE 3-5-81
NO. IN TITLE BLOCK

REV	DATE	BY	DESCRIPTION
1	3-5-81	H. RIGO	ADDED H. RIGO. DATE 3-5-81

SYSTEM DESIGN DESCRIPTION

SDD-241

INDUSTRIAL GAS SYSTEMS

FOR

MAGNETOHYDRODYNAMICS

ENGINEERING TEST FACILITY

CONCEPTUAL DESIGN - 200 MWe POWER PLANT

FLUID SYSTEM DIAGRAMS NO. 8270-1-652-302-241, -242

eg. Hall / R. B. Jensen 3/6/81
SYSTEM ENGINEER DATE

Larry L. Wagner 3/17/81

Hang Hauke 3/17/81
REVIEWED DATE

John Phillips 3/18/81
APPROVED DATE

Revision: 1
Date: September 25, 1981

Approved: *John Phillips*

**MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
INDUSTRIAL GAS SYSTEMS**

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REFERENCE DOCUMENTS - NOT ATTACHED		

1.0 FUNCTION AND DESIGN REQUIREMENTS

This document presents a description of the Industrial Gas Systems as depicted on Fluid System Diagrams 8270-1-652-302-241, Plant Service and Instrument Air Supply and 8270-1-652-302-242, Miscellaneous Gases. The document includes descriptions of system functions, interfaces with other systems, equipment and piping requirements, design criteria, description of components, operating modes, and safety and maintenance requirements.

1.1 FUNCTIONAL REQUIREMENTS

The plant service air and instrument air supply is designed to provide clean, dry, oil-free, compressed air to all parts of the plant for use in instrumentation functions, and for providing air for service use. Air header distribution piping is run throughout the plant for this purpose. Most of this piping is contained indoors, although portions extend outdoors.

Two 100 percent capacity, 2 stage, oil free, electric motor driven, reciprocating air compressors are provided. One compressor serves as standby to start automatically in the event the first compressor becomes inoperative.

Each compressor has an inlet filter - silencer.

The discharge from compressors is piped through aftercoolers, moisture separators, prefilters, dryers and afterfilters to assure moisture free air at -44°F dewpoint feeding the plant main air receiver. The two parallel connected air dryers are each sized for 100 percent duty. The system air receiver supplies air to the plant main air header that distributes service and instrument air throughout the plant.

Extra receivers are furnished, together with check valves, in the critical MHD and turbine areas to provide instrument air for an extended period of time in the event of a loss of system pressure.

Flow limiters are installed at each hose station to prevent inadvertent, excessive use of air by operating personnel.

The Miscellaneous Gases System is a group of four separate sub-systems which is designed to supply industrial type gases for the steam turbine generator, backup supply for the MHD Magnet System, and inert gas for blanketing various pieces of equipment throughout the plant.

1.2 SYSTEM INTERFACES

The major equipment components involved with the Industrial Gas Systems include the air and gas compressors, intercoolers, aftercoolers, separators, receivers, filters, dryers storage tanks and gas bottle racks.

The compressor jacket cooling, the integrally mounted intercoolers and the inline piping aftercoolers interface with the Closed Cycle Cooling Water System, Fluid System Diagram 8270-1-531-302-231.

Drains from the aftercooler, separators, and receivers interface with the Plant Industrial Waste System, Fluid System Diagram 8270-1-641-302-371.

The miscellaneous gases hydrogen and carbon dioxide interface directly with the main ac generator hydrogen cooling system of the steam turbine generator. The helium supply interfaces with the MHD Magnet helium distribution system. The nitrogen supply interfaces with various coal handling and cycle equipment throughout the plant, and indirectly with the ASU.

The equipment for the four different gas sub-systems is located in an attached, small building called the Miscellaneous Gas Storage Building. Bottle racks of four bottles each are supplied for hydrogen, carbon dioxide, and helium. A nitrogen storage system which utilizes a source of product nitrogen from the Air Separation Unit (ASU) and a high pressure compressor to fill high pressure storage tanks are also included.

Hydrogen is normally used to make up for leakage from the main ac generator cooling system and as a batch supply to refill the system after the generator has been purged. Carbon dioxide is used to purge the main ac generator. Helium is used as a backup to the main supply to the MHD Magnet system. Nitrogen is used primarily as an inerting gas to prevent explosions and for the purpose of minimizing absorbing moisture in the pulverized coal system. Nitrogen is also used to fill systems to prevent corrosion in piping and equipment that is out of service.

1.3 DESIGN CRITERIA

A piping header system is used to distribute compressed air throughout the plant for use as either service air or instrument air. To avoid contamination of instruments and equipment at service terminal locations, this air is provided dry, clean and oil-free. A minimum dewpoint of -44°F is provided which avoids condensation in outdoor headers. The compressed air discharge is maintained at a nominal pressure of 125 psig.

The compressed air is delivered by one of two oil free, reciprocating compressors. Each compressor is sized for 100 percent capacity namely 1000 SCFM minimum. Each compressor is driven by a 250 hp electric motor, direct coupled to the compressor. Redundant filters, aftercoolers, separators and dryers are provided for the system.

A large air receiver is located in the proximity of the compressors to avoid short cycling of the operating compressor and to minimize the effects of air surges on the desiccant air dryers. Several smaller air receivers are located throughout the plant to accommodate local, momentary high use rates. Receivers are located in the MHD and turbine areas to provide reserve capacity in the event the system pressure would fall.

All piping is welded in carbon steel except that piping after the MHD and turbine receivers which will be either copper or stainless steel.

The miscellaneous gas sub-systems are individually manifolded and distributed throughout the plant as required. The hydrogen pressure inside the ac

generator is regulated between 1/2 psig to 30 psig. Hydrogen leakage (and makeup) is estimated to be 275 cubic feet per day. Estimated volume for refilling the generator at standstill to 1/2 psig is 3,950 cubic feet. Another two volumes are required to raise the generator cooling system pressure to 30 psig.

Carbon dioxide is used to purge the ac generator when it is shut down for unit outage or for maintenance. First the hydrogen is purged from the generator by substituting carbon dioxide. Then air is used to replace the carbon dioxide. When the generator is ready to be put back in service, carbon dioxide replaces the air and finally hydrogen replaces the carbon dioxide. The estimated volume of carbon dioxide to replace hydrogen is 3,160 cubic feet, and to replace air requires 2,370 cubic feet.

Nitrogen is used to replace air to eliminate potentially explosive or combustible mixtures such as pulverized coal and air, and coal dust and air. It is also used to replace water in steel vessels and piping to reduce the possibility of oxygen corrosion attack when the equipment is out of service. The quantities required are (TBD).

Helium is used in the MHD Magnet cryogenic system to aid in reducing temperatures to near absolute zero. The quantity required to back up the main helium supply is (TBD).

The air receivers and nitrogen storage tanks are designed in accordance with ASME Boiler and Pressure Vessel Code, Section VIII, Division 1, Unfired Pressure Vessels, latest edition.

Except where noted, the piping systems are constructed of carbon steel pipe in accordance with ANSI B31.1. The piping after the MHD and turbine area receiver are either copper or stainless steel.

The equipment for the installation is selected and installed to comply with sound level and other safety requirements of OSHA.

1.3.1 Codes and Standards

System engineering design is in accordance with applicable codes, standards, and guides issued by the following organizations:

1. American National Standards Institute (ANSI)
2. American Society of Mechanical Engineers (ASME)
3. American Society for Testing and Materials (ASTM)
4. American Welding Society (AWS)
5. Manufacturers Standardization Society of the Valve and Fittings Industry (MSS)
6. Pipe Fabrication Institute (PFI)
7. Occupational Safety and Health Administration (OSHA)
8. Instrument Society of America (ISA)
9. National Fire Protection Association (NFPA)
10. National Electric Code (NEC)

1.3.2 Design Parameters

The design pressures, temperatures and flow rates for sizing of the piping are shown on Fluid System Diagrams 8270-1-652-302-241, and -242. Pressure drops to the most remote user are estimated to be less than 5 psig.

Air receivers are strategically located to permit high surges of air for short durations as is required by:

1. Certain valves with large piston actuator, and
2. Certain service air requirements.

2.0 DESIGN DESCRIPTION

The Industrial Gas Systems consists of compressors, coolers, separators, filters, dryers, receivers, tanks and header piping. The major equipment components are covered in System Design Descriptions noted in Section 1.2.

2.1 SUMMARY DESCRIPTION

The compressed air piping header is distributed throughout the plant to conduct high pressure air to both service air and instrument air users. The pressure in this header is maintained at a nominal 125 psig. The air is filtered and dried to accommodate a variety of pneumatic valves, actuator motors and service air applications both at indoor and outdoor locations.

Two full capacity air compressors are furnished to provide complete redundancy. The compressors are of the oil-free, reciprocating type. These compressors use no oil for lubrication in the cylinder, thereby eliminating potential sources of oil vapor and droplets in the compressed air. By means of cylinder unloading, the compressors can be operated at maximum efficiency at any capacity up to 100 percent. Two stages of compression with intercooling are required. Each compressor has a direct coupled electric motor drive.

Use of the compressors is alternated to distribute the wear equally on each compressor. The running time for each compressor is indicated by means of a meter located at each compressor.

Cooling water is furnished for the intercoolers and the aftercoolers from the Closed Cycle Cooling Water System. Moisture condensed at the aftercooler is separated from the air stream at separators located after each aftercooler. This water is removed with traps and drained to waste. Two aftercoolers are furnished for the purpose of redundancy.

Two air dryers are provided. One will be operated while the other is maintained as a standby. The dryer will provide a dewpoint of approximately -44°F during normal full load operation. At light loads the dewpoint may be lower than -44°F. A prefilter is provided before each dryer, and an afterfilter is located after each dryer to absorb any desiccant dust which may become entrained in the air stream.

An air receiver is located downstream of the dryers. This receiver will prevent frequent loading and unloading of the compressor. In addition it will minimize the deleterious effects of system surges on the dryer beds. Several additional, smaller air receivers are located adjacent to users which require air in momentary, large surges, and to ensure instrument supply to critical users.

Each air compressor is furnished with an inlet filter-silencer which is located outside the building and slightly elevated. The filter-silencers minimize dust ingestion into the compressor cylinders, thereby prolonging compressor life. The sound dampening action of the filter-silencers ensure that the sound level is well within that dictated by OSHA.

A low pressure switch is located on each receiver to activate an alarm in the event that the system pressure falls to a predetermined value.

Each miscellaneous gas system has its own piping header system to deliver the gas to the user. The hydrogen system takes bottled hydrogen at approximately 2,000 psig and reduces it in several regulated steps to about 30 psig. For safety reasons there is a removable section of pipe in the line leading to the ac generator which must be removed when the unit is down for service.

The carbon dioxide system when in use is valved wide open to keep the supply tanks and piping from freezing. There is a safety valve on the manifold set at 100 psig which is the only pressure limitation.

The nitrogen system receives its supply from the ASU as product nitrogen at 50 psig. The nitrogen is compressed, cooled and stored in tanks at about 2,000 psig. The pressure is reduced by pressure regulators in steps and distributed in a low pressure header system throughout the plant at 5 psig.

2.2 DETAILED DESCRIPTION

2.2.1 Major Equipment

The major equipment components of the Industrial Gas Systems are the compressors, aftercoolers, separators, filters, dryers, receivers, tanks and header piping.

Air Compressors

Quantity	2
Type	reciprocating
Stages	2
Capacity	1,000 SCFM minimum
Pressure in	atmosphere
Pressure out	125 psig
Motor drive	250 hp
Aftercooler	1 each per compressor

Nitrogen Compressor

Quantity	1
Type	reciprocating
Stages	2
Capacity	50 SCFM
Pressure in	50 psig
Pressure out	2,000 psig
Motor drive	TBD
Aftercooler	1

Tanks and ReceiversNo./Capacity, cu. ft.

Nitrogen Storage Tank	1/(TBD)
Main Air Receiver	1/151
Secondary Air Receivers	3/16 ea.
Instrument Air Receivers	2/50 ea

2.2.2 Piping and Valves

The piping is all welded construction in accordance with ANSI B31.1. The pipe material shall comply with the following:

<u>Size</u>	<u>Material</u>
2" - 8"	Seamless Steel ASTM A53 Grade B
Instrument Piping	Copper tubing, ASTM B, or Type 316 stainless steel

Valves are in accordance with ANSI B16.5 and B16.34. All equipment is flanged for easy removal.

All valves other than the hydrogen system shall be bronze or stainless steel globe valves.

High pressure hydrogen valves must be packless, globe type. Medium pressure and low pressure valves must be bellows sealed types.

2.2.3 Electrical

The control panels for the compressors shall use current that is 120 volts, 1 phase, 60 hertz. The control panels shall be dust tight (NEMA 12) and shall comply with NEC.

Alarm switches shall provide isolated contact closure for the actuation of alarm points in the annunciator system.

Electrical heaters in the air dryers are rated 460 volts, 3 phase, 60 hertz.

Compressor motors are rated 4160 or 3 phase, 60 hertz and are supplied from a 4160 volt motor control center. Motor rated 200 HP and higher will be 4160 volt; motor under 200 HP will be 460 volt.

2.2.4 Instruments, Controls and Alarms

Each compressor is furnished with a local control panel on which is mounted pressure gauges to indicate oil pressure, interstage air pressure and discharge air pressure. The compressor also has mounted on it a low oil pressure switch, a high air temperature switch and a high vibration switch, all of which are wired into the motor control circuit to stop the compressor in the event of a condition which would be harmful to the compressor.

When the control switch for the motor of one of the compressors is in the "automatic" position, that motor will be started if the pressure at the receiver would fall low. This low pressure condition would be detected by a two stage pressure switch which is mounted on the system receiver. One of the stages would be wired in the control circuit for one of the compressors and the second stage would be wired in the motor control circuit for the second compressor. Typically one stage would be set at 115 psig and the second stage would be set at 110 psig. After a motor has been started, the pressure in the receiver is maintained within a narrow band by means of pneumatic loaders which cycle unloaders on the compressor cylinders. Each compressor is sized at 100% capacity and therefore there would be no need to operate both compressors at the same time. Normally one would be operated while the second compressor is maintained in stand-by. Should the compressor which is operating be stopped for some reason, the compressor which had been retained as standby would be started when the receiver pressure falls to the setting at the two stage pressure switch on the system receiver.

High pressure limit switches are located on the header of each compressor before the first valve. These high pressure limit switches will quickly stop the respective compressor motor in the event that a compressor is inadvertently started when a blockage exists between the compressor and the system receiver.

A very low pressure switch on the main air receiver actuates the "Low Air Pressure" alarm in the control room in the event of low pressure at the system receiver.

A pressure transmitter on the system receiver transmits the actual air receiver pressure to an indicator in the control room.

Pressure gauges are furnished at various locations throughout the Industrial Gas Systems. These gauges assist operating and maintenance personnel to verify that the systems are functioning satisfactorily.

The nitrogen compressor is started manually, but will be shut off automatically by a pressure switch when the storage tank reaches 2,000 psig.

Various temperature indicators are located near the compressors and coolers. These assist operating personnel in locating difficulties and in determining when coolers require maintenance.

Each air dryer is furnished with a separate control panel which cycles the service air and instrument air between the two towers which are mounted on

each dryer. One tower remains in service while the second is being reactivated. Timers within the control panels determine the cycle rate. At the proper intervals, automatic valves are energized to alternate the air stream from one tower to the second tower. These control panels are furnished with an alarm which activates an annunciator in the event that the switch-over valve would fail to completely stroke from one position to the alternate position.

3.0 SYSTEM PROTECTION AND SAFETY PRECAUTIONS

3.1 PROTECTIVE DEVICES

All of the piping, valves and receivers are designed according to the standards and codes referenced in Section 1.3.1.

Receivers and tanks are designed, constructed, inspected, tested and stamped in accordance with the ASME Unfired Pressure Vessel Code Section VIII and are protected with pressure relief valves which are sized and set in compliance with the ASME code. Properly sized relief valves are also provided on the intercoolers and on the discharge piping before the first valve.

The compressors, dryers, coolers, separators and receivers are used at pressures within their rated capacities.

3.2 HAZARDS

Gas cylinders and piping shall be labelled to clearly identify their contents and operators shall be trained to follow safe procedures required for hydrogen, carbon dioxide, nitrogen, pressure systems and vessel safety.

The motors for the compressors are classified as medium and high voltage. The switchgear, in accordance with common practice and the NEC code, will be locked. Access will be available to only qualified personnel. The control panels for the compressors and the dryers will be low voltage, and these will also be locked to restrict access to only qualified personnel.

Rotating parts on the compressors are protected in accordance with the applicable OSHA standards. The sound levels also comply with OSHA requirements.

3.3 PRECAUTIONS

There are no special precautions other than normal maintenance procedures.

4.0 MODES OF OPERATION

4.1 STARTUP

To startup a compressor, the operator verifies that the manual water valves to the compressor coolers are open, and that the air compressor isolation valves are open. The operator verifies that the appropriate isolation valves on the compressor and the dryer are opened so as to provide an unobstructed path for

the compressed air from the compressed air header to the receiver. To start a compressor motor, the control switch is moved to either "automatic" or "start." In the "automatic" position the compressor motor will be started if the detected pressure at the system receiver is low.

To startup one of the air dryers, the appropriate isolation valves on the dryer are opened. The control switch is moved to "on". The standby dryer remains in the "off" mode.

4.2 NORMAL OPERATION

Normal operation of the plant service air and instrument air supply involves the use of one air compressor and one air dryer. The usage of each compressor and dryer is alternated, as indicated by hour meters on the units, so as to distribute the wear equally on each unit. Each compressor, dryer and air filter is sized to provide 100 percent of the system capability. The piping of the compressors, dryers and filters is arranged to permit the service of any of these components while the system is providing 100 percent capacity.

The second air compressor and air dryer is maintained in standby for automatic startup in the event the system pressure falls to a predetermined value. Automatic valves on the cooling water piping are interlocked with the control circuit for the compressor starter so that these valves are opened whenever the compressor motor is operating and closed when the compressor motor is not operating.

Duplicate compressors, dryers, filters and aftercoolers are provided for 100 percent backup. It is possible to safely operate the service air and instrument air systems with both compressors running should a special high capacity condition occur.

Duplicate air dryers are provided for 100 percent backup. This permits one of the dryers to be temporarily deactivated for maintenance.

A service air and instrument air system receiver is provided in the system adjacent to the compressors in the HR/SR building basement. This receiver avoids rapid loading and unloading of the compressors. It also minimizes the deleterious effects of flow surges through the beds of the dryers.

A pipe header system is provided to distribute the service air and instrument air throughout the plant site. At various locations separate valves are provided for the purpose of permitting isolation of an area is required.

4.3 SHUTDOWN

In a normal shutdown, the control switch for any compressor would simply be moved to the "off" position. For added safety, the compressor disconnect switch can be locked in the "off" position. The normal cooling water valves may be closed to prevent the inadvertent flow of cooling water thru the compressor jacket.

4.4 SPECIAL OR INFREQUENT OPERATION

Any compressor or dryer which is used as a backup unit should be operated periodically to verify that these units are in good working condition.

To satisfy special high capacity requirements, the Plant Service Air and Instrument Air Supply System can be operated with both compressors running. The nitrogen compressor system is rated at 100 percent.

5.0 MAINTENANCE

5.1 SURVEILLANCE AND PERFORMANCE MONITORING

Annunciators provided in the main control room are activated when predetermined system limits are exceeded.

Problems applicable to the air compressors are indicated at these annunciators in the main control room (Fluid System Diagram 8270-1-652-302-241).

A control panel mounted on each air compressor contains pressure gauges which are used to monitor compressor performance.

Any problems applicable to the air dryers are indicated at a common annunciator in the main control room. A control panel mounted on each dryer contains panel alarm lights which will indicate the specific problem.

Each air dryer is fitted with pressure gauges to allow the operator to verify that each section is being properly pressurized and depressurized. A locally mounted moisture indicator changes color in the event of an undesirable rise in the air dewpoint. High dewpoint indication alerts the operator to correct the fault or change to the standby dryer.

In the event that the air pressure at the system receiver falls to too low a value, a pressure switch activates the annunciator to indicate "low air pressure".

5.2 INSERVICE INSPECTION

Frequent inservice inspection of the drain traps is required to verify that these are functioning correctly.

Periodic inspections of the compressors is required to verify that the seals on the pistons have not become worn excessively. Inspections of the compressors are required to ascertain that there is no excessive vibration or sounds which would be indicative of worn or inadequately lubricated parts. Oil samples should be taken periodically to verify that the levels of impurities have not risen excessively.

The filters must be inspected periodically to ascertain that the pressure differential across the filters, as indicated on a locally mounted differential pressure gauge, has not risen to an excessive level.

Infrequent inspections are also recommended to verify that there are no significant leaks from the header systems.

5.3 PREVENTATIVE MAINTENANCE

The compressors require oil changes to ensure maximum operating life.

The coolers must be cleaned periodically to remove scale and deposits.

Traps must be cleaned and tested at recommended intervals.

System low pressure control must be tested periodically to verify that it would operate correctly in the event of a low pressure condition.

In the air dryers, the switch-over valves must be periodically lubricated. Also, the desiccant in the towers of the dryers must be periodically replaced.

The cartridge elements in the air filters require replacement at regular intervals.

5.4 CORRECTIVE MAINTENANCE

5.4.1 Manufacturer's Instructions

A complete file of instruction books is available at the plant to guide the plant personnel in maintenance and overhaul of any piece of equipment. If necessary, a representative of the manufacturer can be present to supervise the overhaul or replacement of plant equipment.

5.4.2 Spare Parts Inventory

Certain critical spare parts should be maintained on hand for regular maintenance and common repairs.

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
INDUSTRIAL GAS SYSTEMS
APPENDIX "A"
REFERENCE DOCUMENTS

REFERENCE DOCUMENTS - ATTACHED

Fluid System Diagram

Diagram No.

Plant Service and Instrument Air Supply
Miscellaneous Gases

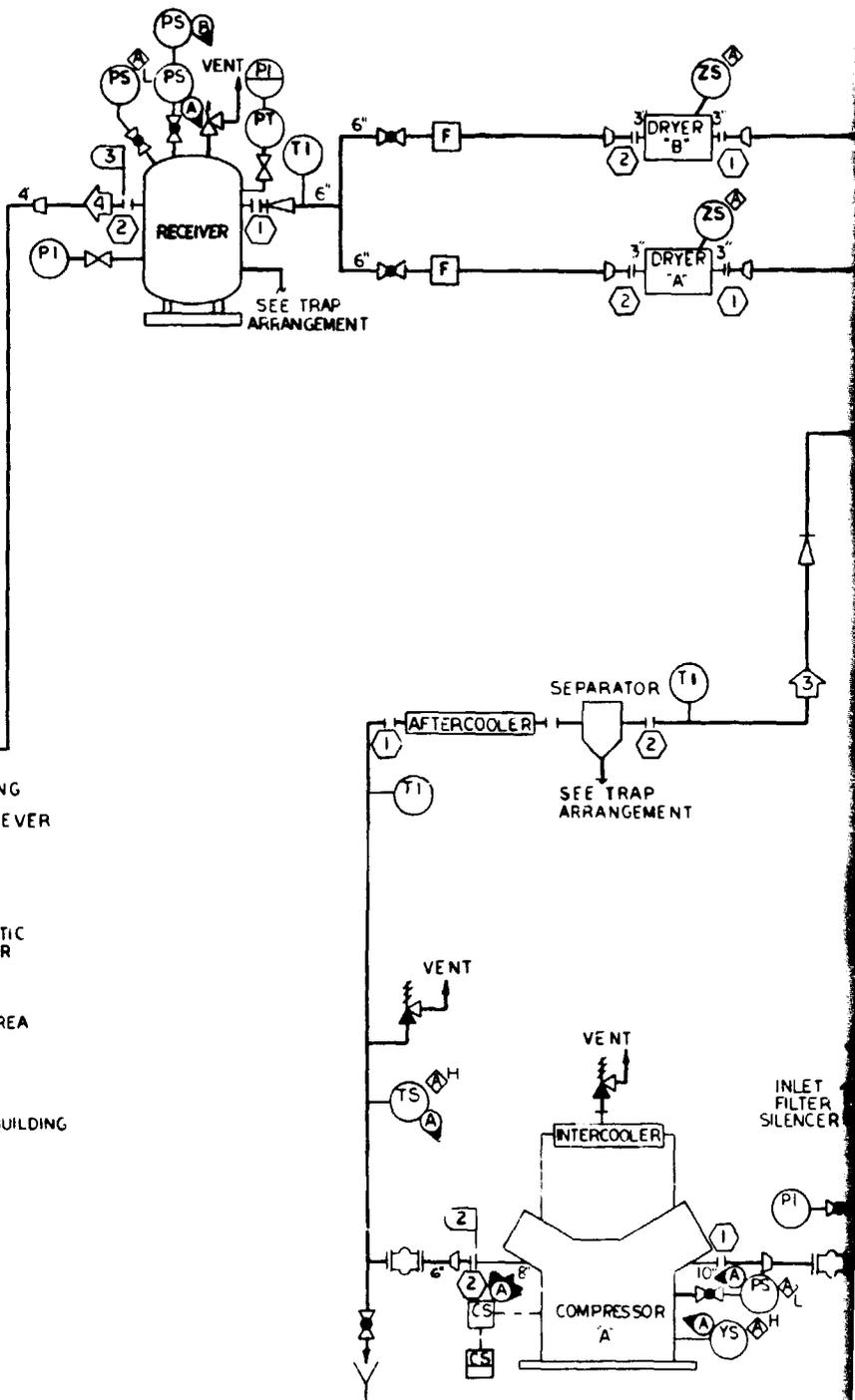
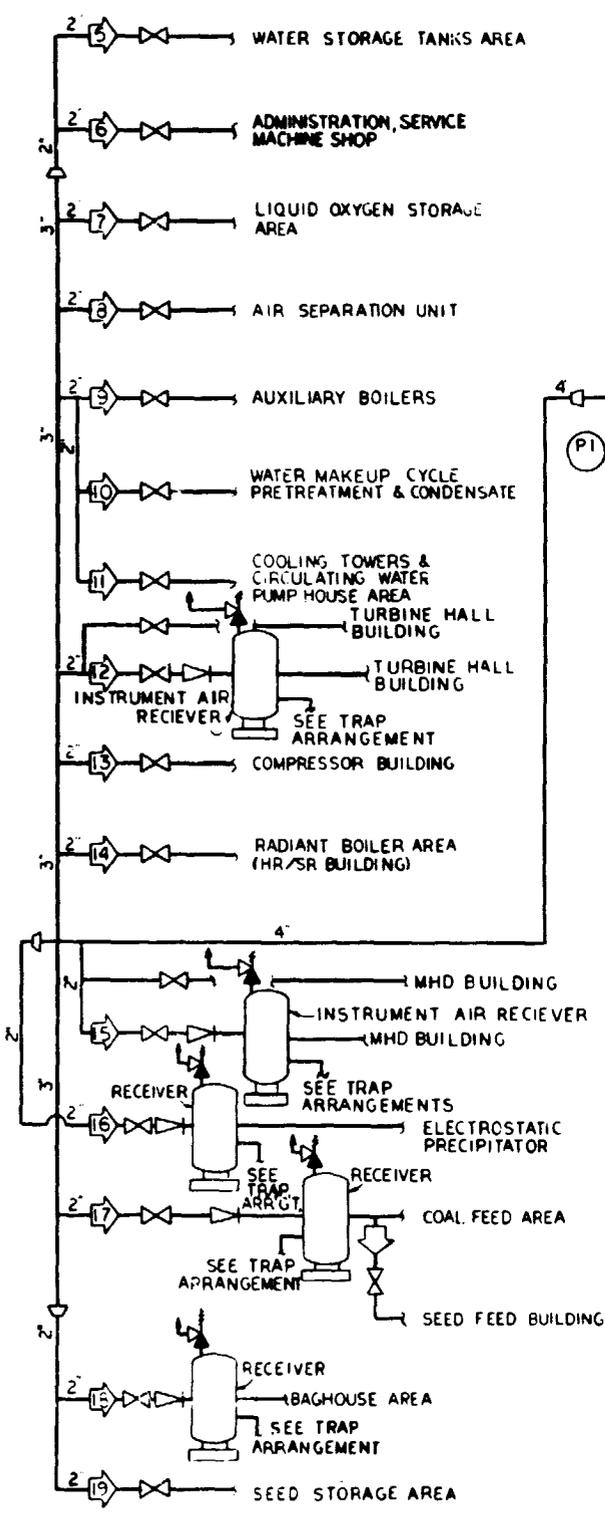
8270-1-652-302-241
8270-1-652-302-242

REFERENCE DOCUMENTS - NOT ATTACHED

System Design Description

Closed Cycle Cooling Water System
Plant Industrial Waste System

A
B
C
D
E
F
G
H



10

9

8

7

6

A

B

C

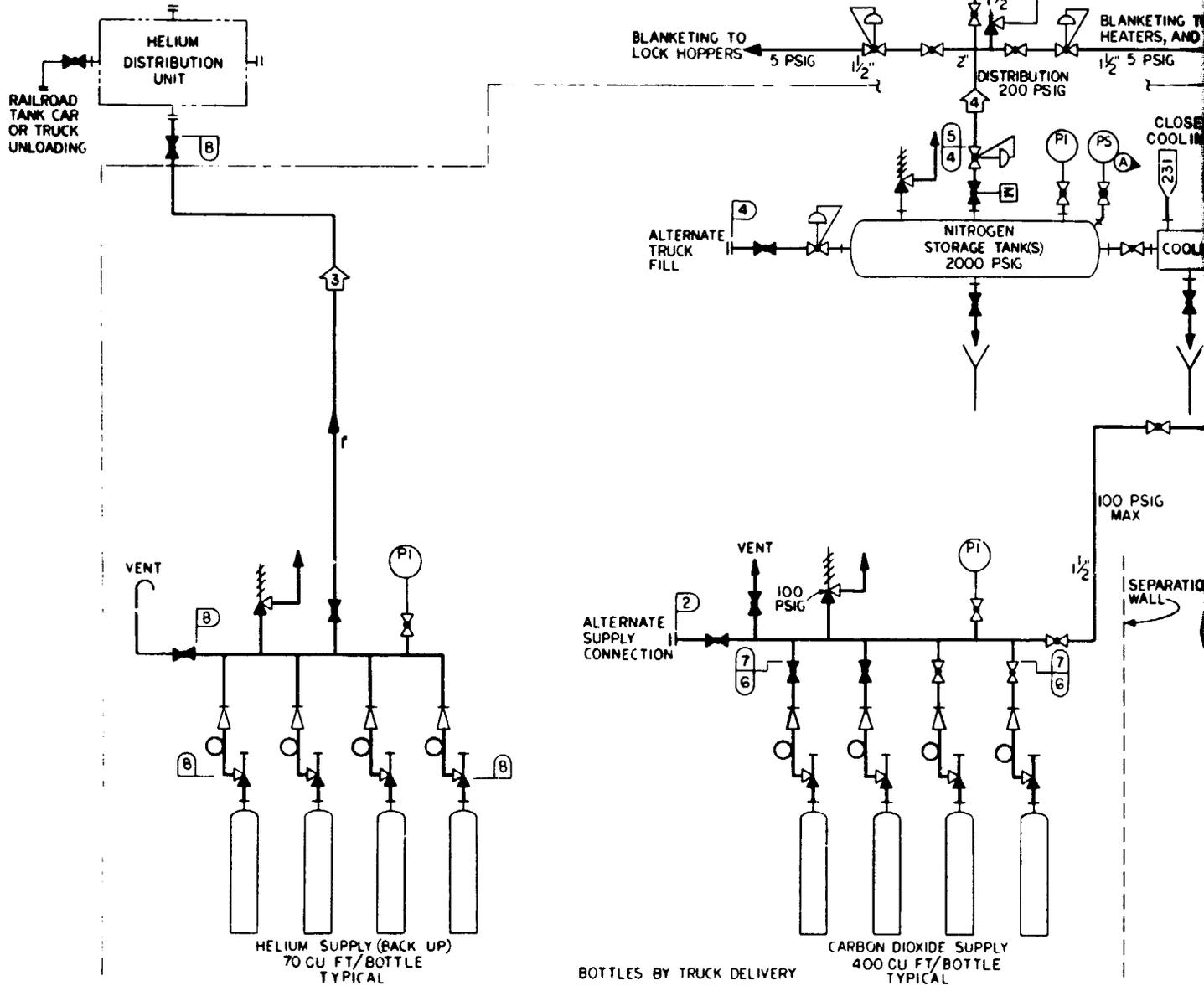
D

E

F

G

H



SYSTEM DESIGN DESCRIPTION

SDD-281

FUEL OIL SYSTEM

FOR

MAGNETOHYDRODYNAMICS

ENGINEERING TEST FACILITY

CONCEPTUAL DESIGN - 200 MWe POWER PLANT

FLUID SYSTEM DIAGRAM NO. 8270-1-413-302-281

[Handwritten Signature]

SYSTEM ENGINEER

DATE

[Handwritten Signature]

REVIEWED

[Handwritten Date]

DATE

APPROVED

DATE

Revision: 1

Date: September 25, 1981

Approved: *[Handwritten Signature]*

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
FUEL OIL SYSTEM

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REFERENCE DOCUMENTS - NOT ATTACHED		

1.0 FUNCTION AND DESIGN REQUIREMENTS

This document presents a description of the Fuel Oil System as depicted on Fluid System Diagram 8270-1-413-302-281, Fuel Oil System. The document includes descriptions of system functions, interfaces with other systems, equipment and piping requirements, design criteria, description of components, operating modes, and safety and maintenance requirements.

1.1 FUNCTIONAL REQUIREMENTS

The Fuel Oil System is designed to provide storage and transport of fuel oil from tanks to various users through piping and valves as follows:

From Rail/Truck Unloading Station to Main Oil Storage Tank; From Main Oil Storage Tank to various oil transfer tanks as follows:

Fuel Oil Transfer Tank for Coal System Control Building
 Heating Boiler Burner,
 Fuel Oil Transfer Tank for Warehouse Heating Boiler Burner,
 Fuel Oil Transfer Tank for Auxiliary Boiler Burner, Emergency Gas
 Turbine Generators, and Diesel Fire Pump
 Fuel Oil Transfer Tank for Vitiated Air Heater

1.2 SYSTEM INTERFACES

No direct system interfaces are associated with the Fuel Oil System.

1.3 DESIGN CRITERIA

Design criteria cover the fluid flow requirements, pressure-temperature ratings, and system limits to be used in the selection of the required components.

Engineering design criteria for all disciplines is in accordance with applicable codes, standards, regulations, and guides issued by governmental agencies, recognized standards organizations, and Gilbert Associates, Inc.

1.3.1 Codes and Standards

System engineering design is in accordance with applicable codes, standards, and guides issued by the following organizations:

1. American Petroleum Institute (API)
2. American National Standards Institute (ANSI)
3. American Society of Mechanical Engineers (ASME)
4. American Society for Testing and Materials (ASTM)
5. American Welding Society (AWS)
6. Manufacturers Standardization Society of the Valve and Fittings Industry (MSS)
7. Pipe Fabrication Institute (PFI)
8. Occupational Safety and Health Administration (OSHA)
9. Instrument Society of America (ISA)
10. National Fire Protection Association (NFPA)

1.3.2 Design Parameters

The design pressures, temperatures and "pipe sizing" flow rates are tabulated on the fluid system diagram 8270-1-413-302-281. Flow rates are those occurring with valves wide open during maximum operating conditions. Fuel oil line sizing is based on a pressure loss of approximately 1.5 psi per 100 feet of pipe, at minimum design fuel oil temperature.

2.0 DESIGN DESCRIPTION

The Fuel Oil System consists primarily of tanks, pumps, piping, valves, and controls. The components are discussed in detail later in this report.

2.1 SUMMARY DESCRIPTION

Fuel Oil unloading from rail tank cars is the primary delivery source. Provisions for truck shipment are provided as a fuel source backup. Two 300 GPM positive-displacement fuel oil unloading pumps are employed, capable of unloading three tankcars simultaneously with the use of a common piping manifold. The fuel is pumped for holding into the Main Oil Storage Tank, which is sized to store a one month supply at plant maximum operating fuel oil consumption rate.

Fuel oil is transferred to locally-installed user fuel oil transfer tanks by one, 100 percent capacity, centrifugal fuel oil transfer pump. Design redundancy is maintained by a duplicate standby transfer pump. Fuel oil is issued to the users in accordance with the following:

Critical Users - The emergency gas turbine generators and diesel fire pump fuel oil supply must be safeguarded against power outages and plant shut-downs. To ensure proper operation of these units, day tanks are installed to supply fuel for startup and short-term operation in the event of an emergency. The day tanks are located so as to deliver the required amount of fuel to the engines' integral fuel pump, while remaining independent of outside electrical or mechanical power requirements. The day tanks are sized for four hours of continuous operation, with additional capacity for fuel oil recirculation and heat dissipation purposes. The day tanks are supplied from the locally-installed fuel oil transfer tank by two submersible pumps, one for normal operation and one on standby. Fuel oil recirculation piping is provided from the engine manifold to the day tank, as well as between the day tank and fuel oil transfer tank. The pumps associated with critical users, i.e., the fuel oil transfer pumps, transfer tank submersible pumps, and auxiliary boiler equipment, are connected to the critical bus, so as to maintain fuel continuance in the event of a power outage.

Non-Critical Users - The remainder of the fuel oil users require no special safeguards to ensure uninterrupted fuel oil flow. Fuel oil is delivered from each fuel oil transfer tank by submersible pumps installed in the tank. Fuel oil recirculation from the user burner management system is provided to maintain proper flow and/or temperature control.

2.2 DETAILED DESCRIPTION

2.2.1 Major Equipment

The major equipment components shown on the fuel oil system diagram are described below:

Fuel Oil Unloading Pumps

Quantity	2
Type	Positive displacement
Capacity	300 gpm
Discharge pressure	50 psi

Main Oil Storage Tank - This tank is sized to accommodate a one month plant supply at maximum operating user flowrates. Two electric suction heaters are installed in the tank to warm the fuel oil on the inlet side of the fuel transfer pumps, when required. The main oil storage tank is equipped with level indicators, switches, alarms, and transmitters, to allow fuel oil unloading pump control and oil level monitoring at the rail/truck unloading station, pump house, and main control room.

Quantity	1
Type	Above ground, cylindrical welded
Code	API 650
Capacity	840,000 gallons
Diameter	60 ft.
Height	40 ft.

Fuel Oil Transfer Pumps -

Quantity	2 (100%)
Type	Horizontal, centrifugal
Capacity	200 gpm
Discharge pressure	50 psi

Fuel Oil Transfer Tanks - Four fuel oil transfer tanks provide local reservoirs of fuel oil for the individual users, and a method of temperature control where required utilizing tank heaters, temperature controllers, and recirculation lines.

All of the fuel oil transfer tanks are built to API 650 code specifications, located underground below frostline, and are furnished with manholes or handholes, external fill connections, tank heaters (where required), vents, level indicators, switches, alarms, and submersible fuel oil pumps. The fuel oil transfer tanks are each sized to accommodate the fuel oil supply durations as shown below. Tank capacities are listed as follows:

<u>Transfer Tank</u>	<u>Capacity</u>	<u>Supply Duration</u>
Coal System Control Building	3,800 Gal.	1 week
Warehouse Heating Boiler	1,700 Gal.	1 week
Emergency G-T Generator/ Auxiliary Boilers (2)/	55,000 Gal.	Generator: 36 hours
Diesel Fire Pump		Plant Heating Boiler: 24 hours
		Start-Up Boiler: 10 hours
		Fire Pump: 36 hours
Vitiated Air Heater	24,000 Gal.	40 hours

Transfer Tank Submersible Pumps - All pumps are of the submersible electric motor type which feed the user(s) and develop recirculation line flow. Two 100 percent capacity pumps are provided for each service, with capacities as follows:

<u>Pump Service</u>	<u>Capacity</u>
Coal System Boiler	30 gph
Warehouse Boiler	15 gph
Emergency G-T Generators/Diesel Fire Pump	400 gph
Auxiliary Boilers	600 gph
Vitiated Air Heater	600 gph

Day Tanks - Day tanks are provided to deliver fuel oil to the two critical oil-fired engines. In the event of a power outage, fuel will always be available by gravity flow to the engines. Tank construction will conform to API 650 code specifications. Day tanks will be furnished with handholes, external fill connections, drain plugs, vents, level indicators, controllers, switches, and alarms. Day tank capacities are listed as follows:

<u>Day Tank</u>	<u>Capacity</u>	<u>Supply Duration</u>
Emergency G-T Generators	350 Gal.	4 hours
Diesel Fire Pump	350 Gal.	4 hours

2.2.2 Piping and Valves

The fuel oil system piping is designed with welded joints in accordance with ANSI B31.1. Valves to be in accordance with ANSI 16.5.

Piping: 2" and smaller, ASTM A53, Grade B, seamless carbon steel, schedule 80.

2½" and larger, ASTM A53, Grade B, seamless or welded carbon steel, standard weight.

Shut-Off

Valves: 2" and smaller, ball type, one piece body, carbon steel, ASTM A105, double TFE seats, screwed ends.

2½" and larger, gate, carbon steel, ASTM A216, flexible disc type, bolted bonnet, OS&Y, 13% CrS.S. trim, flanged ends; or ball type, one piece body, carbon steel, ASTM A216, double TFE seats, flanged ends.

Check

Valves: 2" and smaller, forged carbon steel, ASTM A105, S.S. trim, bolted cap.

2½" and larger, carbon steel body, ASTM A216, Grade WCB, flanged ends.

2.2.3 Electrical

Motor-operated equipment and valves are 460 volt, 3 phase, 60 Hz, with power supplied from the 480 volt motor control centers. Electrical instruments, controls and valve limit switches will be coordinated with instrumentation power sources.

2.2.4 Instruments, Controls, and Alarms

All fuel oil tanks are equipped with level indicators, switches, alarms, and controllers, to allow proper flow control and monitoring of fuel oil, as described in Section 4.0. Pumping and valve controls are arranged such as to permit proper fuel oil regulation, as further discussed in Section 4.0. The tanks, piping, and pumps are provided with appropriate instrumentation for sensing flow, pressure, and temperature.

3.0 SYSTEM PROTECTION AND SAFETY PRECAUTIONS

3.1 PROTECTIVE DEVICES

Relief valves and recirculation lines are placed on the discharge side of all positive displacement pumps to prevent system overpressurization. The main oil storage tank is adequately diked to provide ample containment in the event of tank rupture. All vented entrances into the fuel oil system are equipped with flame arrestors.

The piping and valve design limits are equal to or greater than those of the connecting equipment. Therefore, no additional protective devices are required.

3.2 HAZARDS

Special hazards associated with fuel oil system operations are those concerning fire and oil spill contamination of soil and ground water.

3.3 PRECAUTIONS

Special precautionary measures shall be taken during tank car unloading aimed at preventing fuel oil spillage and accidental ignition. Hazardous areas shall be so marked with pertinent warning labels such as "No Smoking" signs, etc. Adequate equipment to combat fuel oil fires (carbon dioxide, foam, etc.) must be available at strategic locations throughout the plant site where hazardous areas such as fuel storage and handling facilities are located. Oil spill containing tanks, located at the rail/truck unloading station, and oil detectors in wastewater drains, will be installed to further protect and indicate against ground water contamination.

4.0 MODES OF OPERATION

4.1 STARTUP

Initial fill of the system commences after piping flushing has been completed. Filling of the main oil storage tank, the fuel oil transfer tanks, and the two day tanks is then performed in sequence. Rail tankcars are unloaded three at a time to hasten main oil tank filling. In normal operation, three of the four positive displacement pumps will be running at a capacity of 300 gpm each, developing a total filling rate of 600 gpm. Main oil storage tank filling time will be approximately one day.

Transfer tank filling can be accomplished normally by filling from the main oil storage tank via the fuel oil transfer pumps. However, if necessary, a tank truck may be used to accomplish filling through use of the external fill connections provided on each tank. This latter method can be used to expedite initial tank filling. The initial filling time for all transfer tanks will be approximately five hours.

Day tank filling will be accomplished from the designated transfer tanks via the submersible fuel pumps, at a flow rate of 20 gpm. Initial tank fill will require approximately 17 minutes.

Fuel oil will be recirculated within each transfer tank and heated to proper temperature and viscosity before discharge to user (when required).

Total system initial fill time will be approximately one and one-half days. The total rail tank car requirements for initial fill will be approximately 45-20,000 gallon tank cars, or 900,000 gallons of fuel oil.

4.2 NORMAL OPERATION

During plant operation, the normal functions of the fuel oil system will be to keep the users supplied with a continuous flow of fuel oil at compatible pressure conditions, and regulate and maintain temperature of fuel oil to obtain acceptable viscosities where required.

The main oil storage tank is filled from rail tank cars by unloading pumps. Normal operation is to have two pumps running, unloading three rail tank cars. The fuel oil unloading pumps will be controlled locally and at the rail/truck unloading station, as well as being controlled and monitored at both the pump house and main control room.

The various transfer tank fuel oil levels are maintained by the main fuel oil transfer pumps. To ensure minimum flow protection, recirculation lines back to the main oil storage tank from the discharge of the pumps are provided.

For the fuel oil transfer tanks "C" and "D", the fuel oil level is regulated as follows:

When the fuel oil level reaches a "low" condition, the level valve controlling the fuel inlet to the tank opens, starting the fuel oil transfer pump. As the fuel level rises to tank capacity, the "high" level switch trips, shutting the level valve to the tank. This also initiates transfer pump shut-down, unless overridden by another transfer tank signal. At "low-low" condition, an alarm sounds in the pumphouse and central control room, signaling inadequate fuel capacity in the transfer tank. At the "high-high" condition, an alarm sounds in the pumphouse and central control room, signaling overcapacity in the transfer tank. This "high-high" condition also initiates transfer pump shut-down, overriding any other signal input into the control switch. Pump operation will be alternated to distribute the wear equally on each pump. The fuel oil transfer pumps will be controlled automatically by level switches on the individual fuel oil transfer tanks, as well as being controlled and monitored at both the pump house and main control room.

The fuel oil transfer tanks "A" and "B" are filled intermittantly by manually opening the fill valves serving these tanks. The fuel oil transfer pumps are operated at the fill valve site, using the locally-mounted control switches provided. When tank is filled, operator shuts-off pump and closes valve. Local transfer tank level indicators are used to observe fuel oil capacity.

The submersible pumps which feed the user normally run at a fixed capacity, regulating line pressure with a pressure control valve on the recirculation line to the tank. Flow control by burner management devices supplied with the user regulate the output flow conditions. Pump operation will be alternated to provide even wear on each pump.

The emergency G-T generators and diesel fire pump day tanks have separate level control systems consisting of level switches, indicators, and valves. The system operates in basically the same manner as the transfer tank control loop.

4.3 SHUTDOWN

If it becomes necessary to remove or replace any pumps, tanks, tank parts, or other pipeline equipment, adequate shut-off valving has been designed into the system. Drain connections have been incorporated into the day tanks to permit emptying when necessary. When necessary, the transfer tanks which are situated below grade may be emptied by pumping into a suitable tank truck.

4.4 SPECIAL OR INFREQUENT OPERATION

Special operational parameters are necessary to insure an adequate fuel supply for the Emergency G-T Generators, Plant Heating Auxiliary Boiler, and Diesel Fire Pump. To accomplish this, the pumps supplying these users are connected to the plant critical bus. To further protect the fuel oil supply, the "low" level switches on the two respective transfer tanks are set to allow no less than a three-day fuel oil supply for the G-T generators and fire pump, and a 24 hour supply for the plant heating auxiliary boiler.

5.0 MAINTENANCE

5.1 SURVEILLANCE AND PERFORMANCE MONITORING

Operating personnel will record all direct indicating instruments such as pressure indicators on pumps and strainers, and tank temperature indicators, and check equipment performance per shift. Level controls on all tanks and motor control switches are set to annunciate in both the pump house and main control room.

5.2 INSERVICE INSPECTION

All operating equipment shall be physically inspected while running to assure that it is functioning properly. Tank levels will be checked locally for comparison with monitor readings recorded at the pumphouse and main control room. Pump operation will be recorded to confirm alternation of standby and running modes per each usage. All valves and piping shall be routinely inspected for leakage.

5.3 PREVENTATIVE MAINTENANCE

Computerized record keeping will be instituted to alert the operating personnel when equipment needs overhaul, repacking, or cleaning, in accordance with the recommendations of the equipment manufacturer. In general, parts will be replaced during planned shutdowns when near the end of recommended life cycles.

5.4 CORRECTIVE MAINTENANCE

5.4.1 Manufacturer's Instructions

A complete file of instruction books is available at the plant to guide the plant personnel in maintenance of any piece of equipment. If necessary, a representative of the manufacturer can be present to supervise the overhaul or replacement of plant equipment.

5.4.2 Spare Parts Inventory

Manufacturers will supply lists of recommended spare parts. Critical parts and parts requiring long lead (delivery) times will be kept in inventory at the plant.

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
FUEL OIL
APPENDIX "A"
REFERENCE DOCUMENTS

REFERENCE DOCUMENTS - ATTACHED

Fluid System Diagram

Diagram No.

Fuel Oil

8270-1-413-302-281

REFERENCE DOCUMENTS - NOT ATTACHED

None

10

9

8

7

6

A

B

C

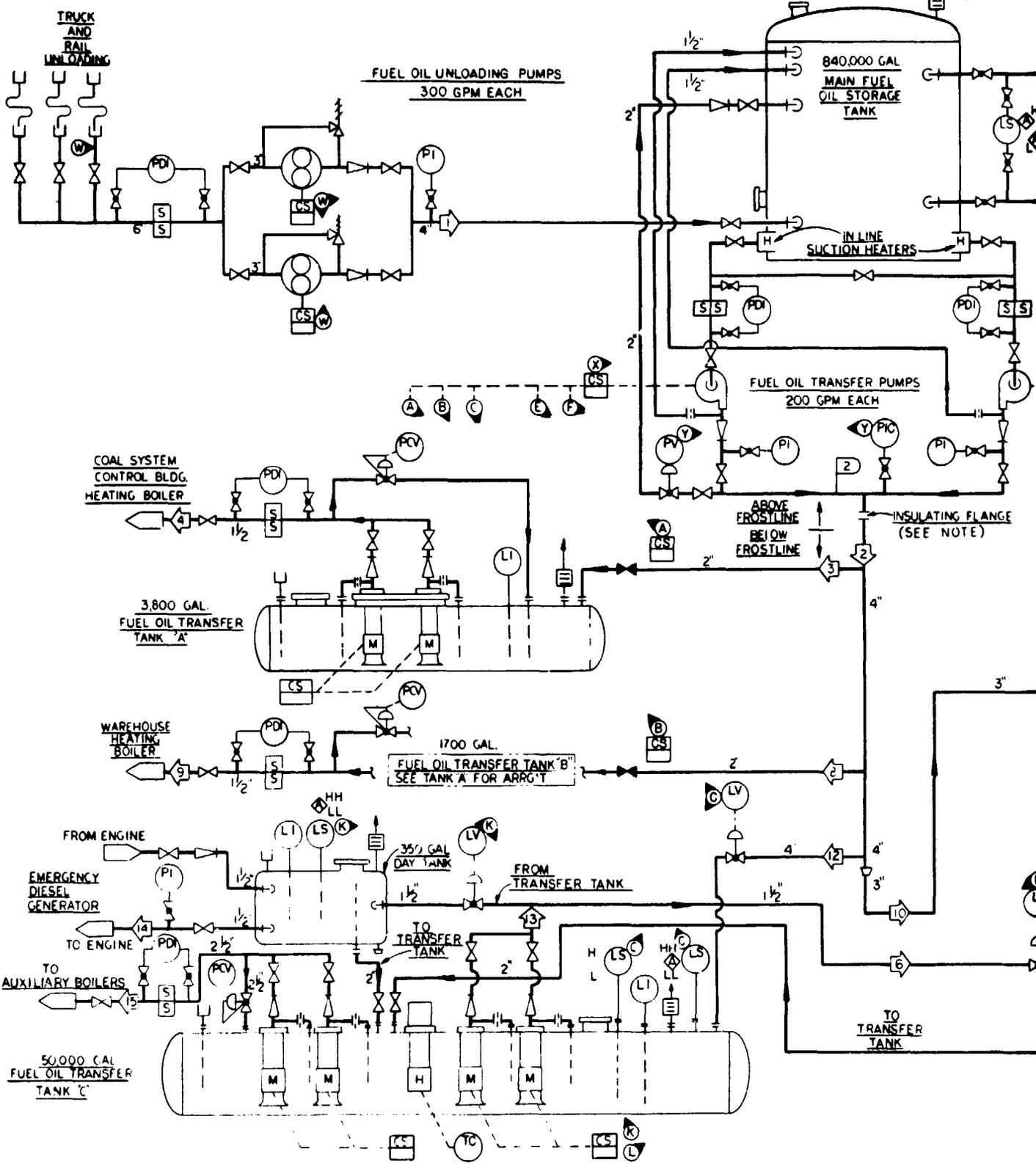
D

E

F

G

H



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5

4

3

2

1

OPERATING DATA

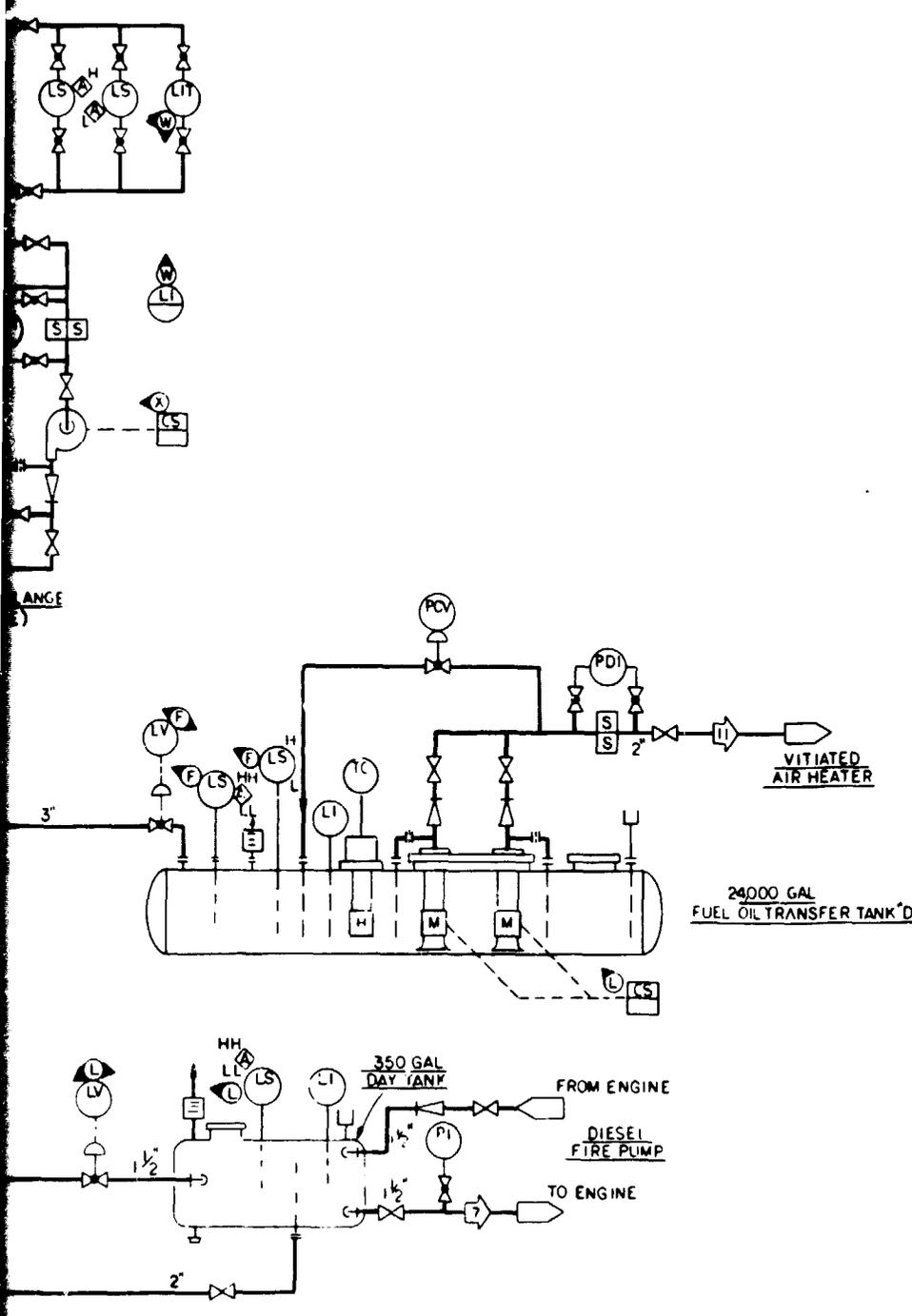
NO.	FLOW GPM	PRESS PSIG	TEMP °F	BY	REMARKS	REV
1	600	75	80		F.O. UNLOADING STM.	
2	480	75	80		F.O. TRANSFER LINE	
3						
4	0.38	25	100		COAL CTRL. BLDG.	
5						
6						
7	2	1	70		DIESEL FIRE PUMP	
8						
9	0.17	25	100		WAREHOUSE BLDG.	
10						
11		65	100		VITIATED AIR HTR.	
12						
13						
14	4	1	70		EMERGENCY GEN.	
15	20	25	80		AUXILIARY BOILERS	

DESIGN DATA

NO.	FLOW GPM	PRESS PSIG	TEMP °F	BY	REMARKS	REV
1	600	100	80		ASTM A-53 - GR B	
2	500	100	80		ASTM A-53 - GR B	

NOTE:

1 ALL UNDERGROUND PIPING AND TANKS TO BE PROVIDED WITH CATHODIC PROTECTION.



1.0. NO. C-373-841

3-27-81	CONCEPTUAL DESIGN ISSUE	
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	RELEASED FOR	ENGR.

MAGNETOHYDRODYNAMICS ENGINEERING TEST FACILITY CONCEPTUAL DESIGN

FLUID SYSTEM DIAGRAM	
FUEL OIL	SDD-281
200 MW _e	

DOE - NASA

MHD PROJECT OFFICE

APPR. H. RIGO

LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

DATE 9-25-81

GILBERT ASSOCIATES, INC. ENGINEERS AND CONSULTANTS READING, PA	
DRAFTING	ENGINEERING INTERFACES
DATE	BY
SCALE	DATE
8270-1-413-302-281	1
988278-281	DRAWING NUMBER

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REVISIONS	
NO.	DATE
1	1-5-80

SYSTEM DESIGN DESCRIPTION

SDD-321

BOILER FLUE GAS SYSTEM

FOR

MAGNETOHYDRODYNAMICS

ENGINEERING TEST FACILITY

CONCEPTUAL DESIGN - 200 MWe POWER PLANT

FLUID SYSTEM DIAGRAM NO. 8270-1-403-302-321/322/323

[Signature]

SYSTEM ENGINEER

DATE

Paul L. Laouette

REVIEWED

3/27/81

DATE

[Signature]

APPROVED

3/27/81

DATE

Revision: 1

Date: September 25, 1981

Approved: *[Signature]*

MHD-ETF PROJECT
 SYSTEM DESIGN DESCRIPTION
BOILER FLUE GAS SYSTEM

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1.0 FUNCTION AND DESIGN REQUIREMENTS

This document presents a description of the Boiler Flue Gas System represented on the following fluid systems diagrams:

- o Boiler Flue Gas (8270-1-403-302-321)
- o Afterburner Gas Supply (8270-1-403-302-322)
- o Coal Drying and Transport Gas (8270-1-403-302-323)

The document includes descriptions of system functions, interfaces with other systems, equipment and piping requirements, design criteria, description of components, operating modes, and safety and maintenance requirements.

1.1 FUNCTIONAL REQUIREMENTS

The Boiler Flue Gas System handles flue gas from the Heat Recovery/Seed Recovery System (HR/SR) outlet to the stack. After leaving the HR/SR, the flue gas passes first through a duct to the Electrostatic Precipitator (ESP). Downstream of the ESP, portions of the flue gas are drawn off for coal processing, gas recirculation, afterburner air heating and the balance of the gas flow passes through the low temperature economizer. Following the low temperature economizer, the flue gas lines returning from the afterburner air heater and coal processing rejoin the main stream and are passed through the Induced Draft (ID) fans to the stack. However, a portion of the gas leaving the afterburner air heater is used to pressurize the coal lock hopper system. At design load, 1,332,088 pounds per hour of flue gas at 12.75 psia and 480.9°F leave the HR/SR and 1,258,874 pounds per hour of flue gas at 13.00 psia and 228.2°F leave the stack.

1.2 SYSTEM INTERFACES

The Boiler Flue Gas System interfaces with Coal Management System, the secondary air supply and the secondary air heating sub-systems.

1.3 DESIGN CRITERIA

The maximum coal firing rate (for maximum ash content and maximum moisture content) with up to 25 percent excess air results in a total of 1,430,000 pounds per hour of flue gas at the stack. The minimum pressure at the inlet of the induced draft fans is designed to be 12.0 psia. Gas duct velocities are limited to a maximum of 3000 fpm, and duct layout is designed to achieve acceptable system pressure losses. The maximum permissible amount of particulate discharge at the stack based on EPA requirements is 55 pounds per hour. This produces a dust loading of 2.4×10^{-6} pounds of particulate per cubic foot of flue gas at the Induced Draft fans.

Flue gas recirculation is used to limit the flue gas inlet temperature to the secondary or finishing superheaters to approximately 2,500°F. Gas temperature monitoring instruments are used to automatically control the flow of recirculation flue gas to the afterburner section of the HR/SR. Recirculation flue gas flow is varied by controlling the number of recirculation fans in operation and by varying the position of the inlet control dampers for these

fans. For the baseload design point, 563,608 pounds per hour of 480°F flue gas are required for coal drying using as received coal with 22.7 percent moisture content. For the maximum moisture content of 27 percent for the incoming coal, the coal-drying flue gas flow would have to be increased to approximately 670,000 pounds per hour.

The Low Temperature Economizer is used for initial heating of boiler feedwater and is designed for a heat transfer rate of 5.5 million Btu per hour.

Engineering design criteria for all disciplines is in accordance with the applicable codes, standards, and guides issued by governmental agencies, recognized standards organizations, and Gilbert Associates, Inc.

1.3.1 Codes and Standards

System engineering design is in accordance with applicable codes, standards, and guides issued by the following organizations:

1. American National Standards Institute (ANSI)
2. American Society of Mechanical Engineers (ASME)
3. American Society for Testing and Materials (ASTM)
4. American Welding Society (AWS)
5. Manufacturers Standardization Society of the Valve and Fitting Industry (MSS)
6. Pipe Fabricators Institute (PFI)
7. Occupational Safety and Health Administration (OSHA)
8. Instrument Society of America (ISA)
9. National Fire Protection Association (NFPA)
10. Air Movement and Control Association (AMCA)

1.3.2 Design Parameters

The Boiler Flue Gas System is designed to handle 1,430,000 pounds per hour of flue gas leaving the HR/SR. The arrangement of equipment is shown on the Boiler Flue Gas drawing (8270-1-403-302-321), After Burner Gas Supply drawing (8270-1-403-302-322) and Coal Drying and Transport Gas drawing (8270-1-403-302-323). System design is based on the System Heat and Mass Balance diagram No. 8270-1-540-314-001.

2.0 DESIGN DESCRIPTION

The following describes the gas flow, pressure and temperature state points as it passes through ETF plant components downstream of the HR/SR. The major equipment components are covered in the detailed description Section 2.2.

2.1 SUMMARY DESCRIPTION

With normal operation at design capacity, about 1,346,737 pounds per hour of flue gas at 12.75 psia and 480.9°F enters the ESP. Following the ESP, the feedwater in the low temperature economizer absorbs some of the heat from the flue gas. Between the ESP and the low temperature economizer, flue gas is taken from the main flow for secondary air heating and coal processing. This

gas is returned to the suction of the ID fans. The ID fans discharge 1,258,874 pounds per hour to the stack at 13.00 psia and 228.20F.

2.2 DETAILED DESCRIPTION

From the high temperature economizer outlet (last component in the HR/SR system), a flue gas duct transfers 1,346,737 pounds per hour of flue gas at 12.75 psia/480.90F to the ESP. Approximately 14,649 pounds per hour of dry ash/seed mixture will be precipitated and removed in the ESP. The ash/seed collection from the ESP is described in the Seed Management System. Before entering the low temperature economizer, a total of 330,273 pounds per hour of flue gas is drawn off for gas recirculation, transport gas, and after burner air heating. An additional 563,608 pounds per hour of flue gas is drawn off for coal processing. The remaining gas flow of 438,208 pounds per hour enters the low temperature (LT) economizer. The flue gas temperature leaving the low temperature economizer is 315.50F.

Returning gas streams from the secondary air heater at 12.57 psia/232.90F/ 219,136 pounds per hour and from coal processing at 12.57 psia/1500F/ 601,531 pounds per hour mix with the gas leaving the low temperature economizer. The resulting gas mixture is at 12.57 psia/220.90F and has a flow of 1,258,874 pounds per hour. The gas flow splits and enters two of the three induced draft fans. Each fan is designed to handle 50 percent of the total flue gas flow that is directed to the stack. Flue gas ducts leaving the induced draft fans are joined into a single duct which discharges into the stack.

GAI Drawing 8270-1-403-302-322 titled "Afterburner Gas Supply" presents the flue gas recirculation fans and afterburner air heater sub-systems. From the main gas stream, 330,273 pounds per hour of flue gas is supplied for gas recirculation and secondary air heating. Of the 330,273 pounds of flue gas at 12.7 psia, 105,671 pounds per hour enters pneumatically controlled dampers into two of the three flue gas recirculation fans (50 percent capacity each). The flue gas at 13.08 psia flows through a check valve and manual damper prior to mixing with the heated secondary air. After the split for gas recirculation, the balance of 224,602 pounds per hour of flue gas enters the regenerative air heater at 480.90F and leaves at 232.90F.

A total of 205,286 pounds per hour of ambient air at 13 psia/42.00F enters through a steam coil air preheater, pneumatically operated dampers and into two of three afterburner gas fans (50 percent capacity each). At 13.18 psia/44.50F afterburner air leaves the fans and passes through check valves and dampers. The air flow mixes together, and flows to a regenerative air heater. At the exit of the air heater, the air condition is 13.1 psia/3310F. This air passes through a duct and blends with recirculated gas prior to entering the radiant boiler. The condensed steam from the steam coil air preheater is returned to the Auxiliary Steam System.

GAI Drawing 8270-1-403-302-323 titled "Coal Drying and Transport Gas" presents the Coal Processing System and the Transport Gas Compressor System for the coal lock hoppers. From the main gas stream, 563,608 pounds per hour of flue gas at 12.70 psia/480.00F are transferred by a duct into two of the three coal

drying fans. A pneumatically operated damper is installed upstream of these fans. Downstream, a check valve and damper are installed in the duct. These fans will be cooled by closed cycle cooling water flow. Outlets from the booster fans will combine before entering the mills. The gas flow will split into three ducts before entering two of the three mills. Pneumatically operated dampers are installed upstream and downstream of the mills. Pulverized coal along with flue gas will enter the baghouse. Pulverized coal, collected at the bottom of the baghouse, is transported to the coal lock hopper system by screw conveyors as described in the Coal Management System. Flue gas containing the moisture from coal drying is mixed with the main gas stream at the induced draft fan suction.

A flow of 5,466 pounds per hour of flue gas at 12.57 psia/232.90F is drawn from the return line from the air heater before the return is mixed with the main gas stream. This flow is used to pressurize the lock hoppers feeding coal to the combustor. The flow is split equally and supplied to two of the three gas compressors. Each compressor is rated at 50 percent of the total required capacity. Upstream lines to these gas compressors are equipped with diaphragm operated valves, and downstream lines are equipped with a check valve and a pneumatically operated valve. The discharges combine before the lock hoppers section. Circulating water lines equipped with diaphragm valves supply cooling water for the compressors.

2.2.1 Major Equipment

1. Electrostatic Precipitator (ESP)

This equipment is described with the HR/SR System

2. Flue Gas Recirculation Fans

Quantity	3-50%
Type	Centrifugal
Capacity @ 485°F	22,000 cfm
Developed Head	7 in. H ₂ O
Brake Horsepower @ 80% eff	31

3. Afterburner Gas Fans

Quantity	3-50%
Type	Centrifugal
Capacity @ 700°F	26,000 cfm
Developed Head	6 in. H ₂ O
Brake Horsepower @ 80% eff.	31

4. Air Heater

Quantity	1
Type	Ljungstrom, regenerative
Air flow	26,000 cfm
Gas temp, °F in/out	480/233
Air temp, °F in/out	72/130

5. Steam Coil Air Preheater

Quantity	1
Type	Fin-tube
Air flow	26,000 cfm
Air temp, °F in/out (design)	-20/70
Steam press./temp.	40 psi/350°F

6. Coal Drying Fans

Quantity	3-50%
Type	Centrifugal
Capacity @ 480°F	120,000
Developed Head	7 in. H ₂ O
Brake Horsepower @ 80% eff.	166

7. Coal Pulverizers and Baghouse

This equipment is described with the Coal Management System

8. Transport Gas Compressors

Quantity	3-50%
Type	Centrifugal
Capacity @ 233°F	875 cfm
Discharge pressure	100 psi
Brake Horsepower (est.)	450

9. Low Temperature Economizer

Quantity	1
Type	Fin-Tube
Gas temp, °F in/out	480/315
Feedwater temp, °F in/out	285/302

10. Induced Draft (ID) Fans

Quantity	3-50%
Type	Centrifugal
Capacity @ 221°F	195,000 cfm
Developed Head	7 in. H ₂ O
Brake Horsepower @ 80% eff.	270

11. Stack

Quantity	1
Type	Reinforced Concrete
Height	300 ft.

2.2.2 Piping, Valves, Ducts and Dampers

The ducts will be gunite lined carbon steel. Exposed surfaces of ducts or pipes will not exceed a temperature which is 50°F above ambient. Valves and dampers will be manufactured from carbon steel.

2.2.3 Electrical

Power for fan and compressor motors is from 4,160 volt buses and supplied from switch gear.

Motor-operated valves and dampers are typically 460 volt, 3 phase, 60 Hz, with power supplied from 480 volt motor control centers.

Power for instrumentation is taken from appropriate distribution centers.

2.2.4 Instruments, Controls, and Alarms

Instruments are placed at locations commensurate with good design practice to monitor system performance. These instruments will help protect against overloading any equipment with slag or loss of cooling water flow. The majority of the control switches and instrument readouts for each operation are located with their respective equipment. Only major instrument readouts are recorded at the Main Control Room Computer.

3.0 SYSTEM PROTECTION AND SAFETY PRECAUTIONS

3.1 PROTECTIVE DEVICES

The following parameters are measured, monitored, and controlled by appropriate instruments and controls:

1. Supply power to fan drivers.
2. Pressure, temperature and secondary air flow entering the regenerative afterburner air heater.
3. Pressure, temperature and flue gas flow to the coal processing plant.
4. Pressure, temperature and cooling water flow to all the fan and fan driver bearings.

3.2 HAZARDS

Boiler flue gas systems are hazardous due to high temperatures and toxic gases.

3.3 PRECAUTIONS

There are no special precautions, other than those associated with high temperature gas systems, required for the safe operation of the Boiler Flue Gas System. Maintenance records for all the instruments and controls shall be kept, and operations shall schedule maintenance for all the instruments.

4.0 MODES OF OPERATION

4.1 STARTUP

Prior to firing coal in the combustor, all the boiler flue gas handling equipment should be checked. Induced draft fans must be started prior to firing.

4.2 NORMAL OPERATION

During normal operation, the specific required components may be controlled and monitored from the main control room. Afterburner gas and gas recirculation fans are controlled by signals from the HR/SR control system.

4.3 SHUTDOWN

The equipment is shutdown manually as required.

4.4 SPECIAL OR INFREQUENT OPERATION

There is no special or infrequent operation anticipated.

5.0 MAINTENANCE

5.1 SURVEILLANCE AND PERFORMANCE MONITORING

Operating personnel will record direct indicating instruments at regular intervals per shift. The in-house computer will constantly monitor specified points on the Boiler Flue Gas handling system to give a running check on performance which can alarm or be viewed periodically as desired in the plant control room.

5.2 INSERVICE INSPECTION

Visual inspection of all equipment, ducts, piping, instruments, etc., shall be carried out periodically during operation to ascertain that the subject equipment is operating properly.

5.3 PREVENTATIVE MAINTENANCE

All equipment and motors are to be maintained and operated in accordance with the respective manufacturer's operating and maintenance instructions.

Computerized record keeping is used to alert the operating personnel that pieces of equipment need an overhaul, repacking, or cleaning, depending on the recommendations of the equipment manufacturer. In general, the part will be replaced during the planned shutdown if it is near the end of its recommended life cycle.

5.4 CORRECTIVE MAINTENANCE

5.4.1 Manufacturer's Instructions

A complete file of instruction books is available at the plant to guide the plant personnel in maintenance of any piece of equipment. If necessary, a representative of the manufacturer can be present to supervise the overhaul or replacement of plant equipment.

5.4.2 Spare Parts Inventory

Manufacturers supply lists of recommended spare parts. A certain percentage (TBD) of these parts will be kept in inventory at the plant. Complex parts requiring long lead time for delivery will be included in the plant inventory.

MHD-ETF PROJECT
 SYSTEM DESIGN DESCRIPTION
BOILER FLUE GAS MANAGEMENT

APPENDIX "A"

REFERENCE DOCUMENTS

REFERENCE DOCUMENTS - ATTACHED

Fluid System Diagrams

Diagram No.

Boiler Flue Gas	8270-1-403-302-321
Afterburner Gas Supply	8270-1-403-302-322
Coal Drying and Transport Gas	8270-1-403-302-323

REFERENCE DOCUMENTS - NOT ATTACHED

System Heat and Mass Balance	8270-1-540-314-001
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Layout

Plot Plan	8270-1-210-007-001
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System Design Descriptions

HR/SR
 Coal Management
 Seed Management
 Circulating Water
 Closed Cycle Cooling Water
 Auxiliary Steam

6

5

4

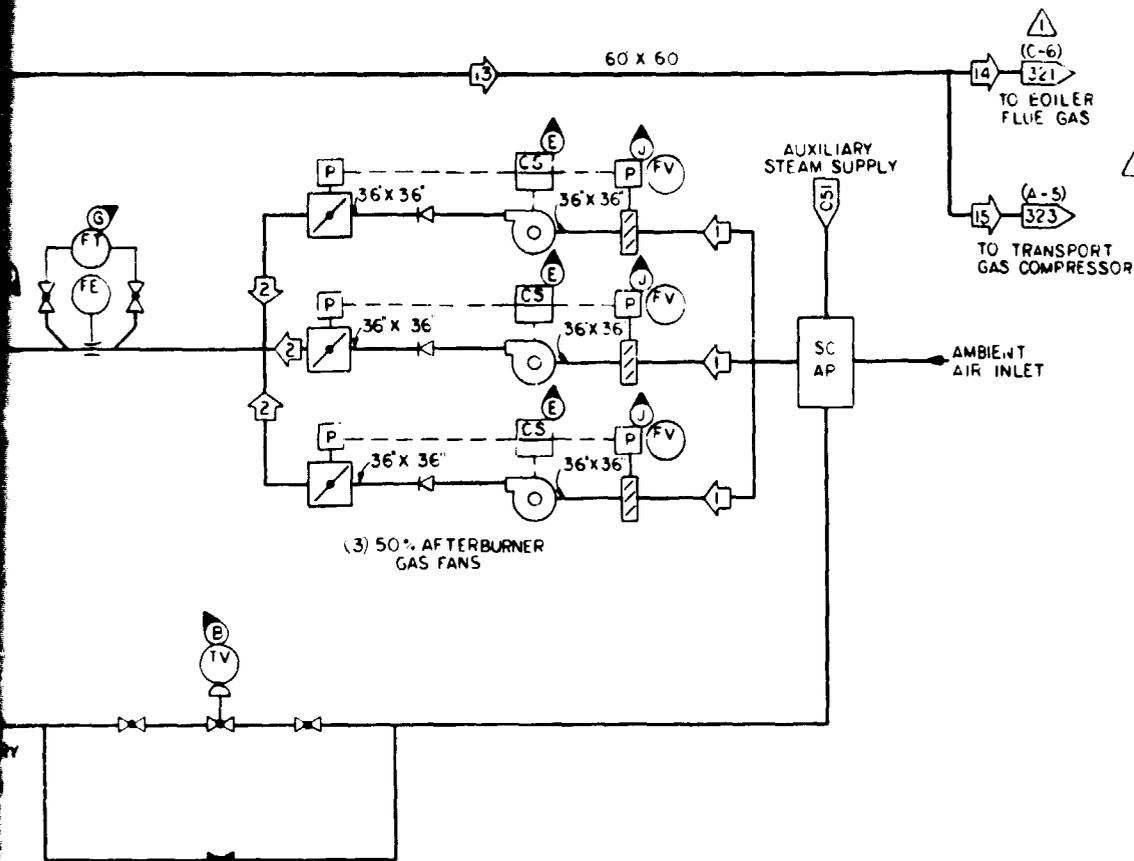
3

2

1

321 H
BOILER
FLUE GAS

AFTERBURNER
AIR CONTROLLER
H G E F J



OPERATING DATA

NO	FLOW CFM	PRESS PSIA	TEMP °F	BY	REMARKS	REV
1	25,520	13.0	70			
2	25,641	13.0	72.5			
3						
4	51,282	13.18	72.5			
5	136,400	12.75	481			
6	94,119	12.75	481			
7	44,281	12.75	481			
8	22,141	12.75	481			
9	21,842	13.0	486.5			
10	43,684	13.0	486.5			
11	77,594	13.0	331			
12						
13	70,192	12.57	232.9			
14	68,483	12.57	232.9			
15	1,708	12.57	232.9			

DESIGN DATA

NO	FLOW CFM	PRESS PSIA	TEMP °F	BY	REMARKS	REV

FOLDOUT FRAME

I. D. NO. C-373-027

3-27-81	CONCEPTUAL DESIGN ISSUE	
3-6-81	PRELIMINARY ISSUE	PLL
REV	RELEASED FOR	ENGR.

MAGNETOHYDRODYNAMICS
ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN

FLUID SYSTEM DIAGRAM

AFTERBURNER GAS SUPPLY SDD-321

200 MW_e

DDE - NASA

MHD PROJECT OFFICE
LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

APP. H. RIGO

DATE 9-25-81

GILBERT ASSOCIATES, INC. ENGINEERS AND CONSULTANTS READING, PA	
ENGINEERING INTERFACES	
DRAFTING	ENGINEERING INTERFACES
MADE	CHECKED
DATE	DATE
SCALE	SCALE
NONE	8270-1-403-302-322
NO. 000270-001	DRAWING NUMBER
	REV

NO.	DATE	BY	REVISIONS
1	9-25-81	H. R.	CHANGED OPERATING DATA C-6 WAS C-4 ADDED H. RIGO DATE # SDD NO. IN TITLE BLOCK

SYSTEM DESIGN DESCRIPTION

SDD-341

COAL MANAGEMENT SYSTEM

FOR

MAGNETOHYDRODYNAMICS

ENGINEERING TEST FACILITY

CONCEPTUAL DESIGN - 200 MWe POWER PLANT

FLUID SYSTEM DIAGRAM NO. 8270-1-410-302-341

SYSTEM ENGINEER

DATE

Paul L. Lavonette

3/27/81

REVIEWED

DATE

J. S. Sully

3/27/81

APPROVED

DATE

Revision: 1

Date: September 25, 1981

Approved: *J. S. Sully*

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
CCAT. MANGEMENT SYSTEM

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1.0 FUNCTION AND DESIGN REQUIREMENTS

This document presents a description of the Coal Management System that is represented on the following layout and fluid system drawings:

1. Plot Plan (8270-1-210-007-001)
2. Yard Coal Handling-Plan & Section (8270-1-240-002-001)
3. Yard Coal Handling-Sections (8270-1-240-002-002)
4. Coal Feed Lock Hoppers (8270-1-410-302-341)

The document includes descriptions of system functions, interfaces with other systems, equipment and piping requirements, design criteria, description of components, operating modes, and safety and maintenance requirements.

1.1 FUNCTIONAL REQUIREMENTS

The Coal Management System has the following coal processing functions: receiving, unloading, storing, screening, crushing, pulverizing, and conveying. The prepared pulverized coal is stored in the pressurized lock hoppers and supplied to the combustor as required.

In general, a loaded unit train proceeds through the thaw shed and the rotary car dumper where the run-of-mine coal is dumped. The physical and chemical properties of coal are tested at the sample house. Coal is transferred to and stored in two piles near the transfer house and reclaimed as required. Crushed coal is stored in bunkers prior to entering the pulverizer. Flue gas is used to dry coal in the pulverizers. Dried pulverized coal is conveyed to pressurized lock hoppers from which primary injectors supply coal to the first stage of the combustor.

1.2 SYSTEM INTERFACES

Major equipment associated with the Coal Management System includes an eight car length thawing shed, rotary car dumping system, sample house, transfer house, lowering wells, crushers, eight belt conveyors, pulverizers and pressurized lock hoppers.

The Coal Management System interfaces with other major systems such as Boiler Flue Gas, the Oxidant Supply System, MHD Power Train (combustor), Industrial Gas and the Slag Management System.

1.3 DESIGN CRITERIA

Design criteria such as minimum and maximum coal flow rates, as well as minimum dryness and fineness of coal are used in the selection of the components. Engineering design criteria for all disciplines are in accordance with the applicable codes, standards, regulations and guides issued by governmental agencies, recognized standards organizations, and Gilbert Associates, Inc.

1.3.1 Codes and Standards

System engineering design is in accordance with applicable codes, standards, and guides issued by the following organizations:

1. American National Standards Institute (ANSI)
2. American Society of Mechanical Engineers (ASME)
3. American Society for Testing and Materials (ASTM)
4. American Welding Society (AWS)
5. Manufacturers Standardization Society of the Valve and Fitting Industry (MSS)
6. Pipe Fabricators Institute (PFI)
7. Occupational Safety and Health Administration (OSHA)
8. Instrument Society of America (ISA)
9. National Fire Protection Association (NFPA)

1.3.2 Design Parameters

Maximum coal requirements of 108.0 tons per hour (based on 27 percent moisture and 12 percent ash), dried and pulverized to five percent moisture by weight and 70 percent-200 mesh fineness were used. An arrangement of equipment is shown on the System Heat and Mass Balance, Drawing No. E270-1-540-314-001. Coal/flue gas mixture velocities for line sizing are in the range of 50 to 80 feet per second, with maximum pressure drop limited to 0.43 psi.

2.0 DESIGN DESCRIPTION

The Coal Management System provides for the receiving, handling, processing, and storing of coal. Flue gas from the main gas stream between the Electrostatic Precipitator (ESP) and the low temperature economizer is tapped for coal drying in the pulverizers. Dried coal in the pressurized lock hoppers and the primary injectors is inerted with dry nitrogen or flue gas. Pulverized coal is supplied to the common header connected to the first stage sections of the combustor.

2.1 SUMMARY DESCRIPTION

At design capacity, the MHD-ETF plant consumes 101.8 tons per hour of coal (22.7 percent moisture by weight). During the first two years, wherein a 23 percent capacity factor is anticipated, the ETF plant will consume about 206,000 tons per year. Operating as a commercial power plant with 70 percent capacity factor, it will consume about 624,000 tons per year of coal. This latter consumption rate requires a minimum of 2 unit train deliveries (7,000 tons capacity each) per week.

The coal unloading and storing facility is located in the northwest corner of the plant site. A thawing process is essential for winter operation. The rotary dumping system and thawing requires a minimum of 3-1/2 to 4 hours for unloading a unit train with 100 cars. The 400 feet long (eight car-length) thawing shed is located at the coal unloading facility. Only four car lengths of the thawing shed is equipped with heaters.

The coal is dumped into a 300 ton capacity unloading hopper located 60 feet below the dumpers from which it flows into four reciprocating, plate type, vibrating feeders. Belt conveyors No. 1 and No. 2 transport coal from underground to the sample house, and to the transfer tower.

The transfer tower is equipped with a mechanical dust collector and coal sampling equipment. The transfer surge bin has two conical discharge chutes with the openings controlled by power actuated slide gates. From these two chutes, the coal can be diverted to two belt conveyors, No. 3A and No. 3B. These two conveyors deliver coal into the top of lowering wells which establish active coal piles. Excess coal is moved to long term storage and packed down by rubber tired dozers and dozer/scrapers. There is 30 days storage in each long term pile. Each coal pile is equipped with a lowering well.

Four vibrating feeders and four hoppers are located below grade in a concrete trench in line with each lowering well. The vibrating feeders dump the coal onto 42 inch wide belt conveyors No. 4A and No. 4B which deliver the coal to a 500 ton surge bin located in the control transfer house. The bin supplies two crushers rated at 500 tons per hour each and breaks the run-of-mine coal down to 1-1/2 inch size or less which is suitable for pulverizing. From the two crushers, coal is fed by gravity to belt conveyors No. 5A and No. 5B. These belt conveyors feed into a 2,000 ton storage capacity bunker via a coal tripper which is rated at 500 tons per hour. The bunker is suitable for 16 hours of active storage. From the storage bunker, the coal is fed by large diameter pipes to weigh-feeders which measure and distribute the coal to two of the three 55 tons per hour capacity pulverizers. The third pulverizer acts as a spare.

For coal drying in the pulverizer, approximately 563,000 pounds per hour of flue gas (2.75 pounds of gas per pound of as received coal) is tapped from the main gas stream between the ESP and the low temperature economizer. The gas pressure is boosted to atmospheric pressure prior to entering the pulverizers. In the pulverizer, coal is dried to five percent moisture by weight and pulverized to 70 percent-200 mesh size. At design capacity, the ETF plant consumes 83 tons per hour of dried coal. The pulverized coal is separated from the transport gas in the bag house and transported to the four 150 ton capacity (each) coal lock hoppers.

The dried pulverized coal is transferred to the depressurized 150 ton capacity (each) lock hoppers (A1 and A2), while the other pressurized lock hoppers (B1 and B2) are feeding coal to the continuously pressurized primary injector B. The coal feeding to the primary injector takes place without interrupting the continuous injection of coal from the primary injector to the combustor. All the lock hoppers and primary injectors have rupture discs with bag filters on the discharge to release overpressure to the atmosphere. Approximately one pound of high pressure gas is required to transport 30 pounds of coal from the primary injector to the coal feed header connected to first stages of the combustor. The Differential Pressure Controller (DPC) balances the air pressure between the primary injector outlet and the coal feed line. Signals from the combustor burner control system regulate the speed of the coal feeder and the flow of the high pressure transport gas to the combustor.

2.2 DETAILED DESCRIPTION

2.2.1 Major Equipment

An integrated coal unloading facility is composed of the following major components:

1. Rail Car Unloading
2. Storage Bunker
3. Coal Transport System

2.2.1.1 Rail Car Unloading

The coal unloading and storing facility, located in the northwest corner of the plant site, is 800 feet long and 500 feet wide (refer to GAI Drawing No. 8270-1-210-007-001). For seasonal handling of coal, a thawing process is essential. As an additional measure, a Freeze Control Agent (FCA) with glycol based compounds will be used to act as an antifreeze to weaken the crystalline structure of ice. The FCA will be sprayed on the coal at a cascade point on the coal belt conveyor at the mine and after the coal is loaded in the unit train.

A rotary dumping system considered most suitable for the coal thawing process, requires a minimum of 3-1/2 to 4 hours for thawing and unloading a unit train with 100 cars. Gondola type cars of random size (up to 100 ton capacity) can be accommodated without adjustment or loss of cycle time using the unit train and rotary dumping concept. This requires the use of cars with rotary couplers and approximately three miles of track around the perimeter of the site.

The 400 feet long (eight car-length) thawing shed is equipped with infra red electric heaters and located at the coal unloading facility (refer to GAI Drawing No. 8270-1-240-002-001). The average electrical power consumption for the thawing shed is estimated to be 7,000 kW at 480 volts per unit train. The thawing shed is divided into eight zones, 50 feet each. The first four zones from the approach end are utilized as thawing bays equipped with heaters, and the remaining four zones as soaking bays without heaters. Special care is required to avoid stress and damage to the cars due to overheating.

After a car has proceeded through the thaw shed, it enters a hydraulic car positioner unit. Locomotives are used only to spot the train for the initial stop in the thaw shed. After that, all train motion is controlled by the car positioner. The positioner unit consists of two hydraulic rams, one located on each side of the tracks. Each ram has two carriage arms, one for acceleration and one for deceleration.

Once the coal car has been positioned, it is ready for weighing and dumping. Scales located before and after the rotary car dumping device record the loaded car weight (gross) and the empty car weight (tare) for each car. Normally, a rotation of 160 degrees is used for dumping; however, 180 degrees maximum rotation can be utilized if required. Each car is furnished with

rotary couplers to enable dumping without disengagement. Two electric eyes detect any misaligned cars and prevent dumping in such an event. As car rotation begins, four hydraulic clamps engage the top of the car. Limit switches monitor the clamping and stop the rotation if secure clamping has not been obtained.

The coal is dumped into a 300 ton capacity unloading hopper located 60 feet below the dumper (refer to GAI Drawing No. 8270-1-240-002-002). Above the hopper a bar screen with 12 inch openings and runway space is provided for a small tractor-dozers to break up large or frozen chunks of coal, thus avoiding blockage or damage to the downstream coal handling equipment. The hopper is constructed of 1/4 inch thick steel plate with an 1/8 inch thick stainless steel liner. Four outlets, with slide gates, direct the coal into four reciprocating, plate type, vibrating feeders each rated at 1,000 tons per hour. These feeders discharge onto a short 54 inch wide belt conveyor which in turn discharges the coal through a chute onto the main 54 inch wide belt conveyor No. 2. Belt conveyor No. 2 is a long belt transporting coal from underground to the sample house, and to the transfer tower. Both belt conveyors No. 1 and No. 2 are rated at 1,750 tons per hour, 450 feet per minute.

2.2.1.2 Storage Bunker

The physical and the chemical properties of coal are tested at the sample house. The transfer tower is equipped with a mechanical dust collector and coal sampling equipment. The transfer surge bin has two conical discharge chutes with the openings controlled by power actuated slide gates. From these two chutes, the coal can be diverted to two 54 inch wide belt conveyors No. 3A and No. 3B. These conveyors are rated at 1,750 tons per hour, 450 feet per minute and deliver coal into the top of lowering wells which establish active coal piles. Excess coal is moved to long term storage and packed down by rubber tired dozers and dozer scrapers. There is 30 days storage in each of the two long term piles. Each coal pile is equipped with a lowering well.

Four vibrating feeders and four hoppers are located below grade in a concrete trench in line with each lowering well. The vibrating feeders dump the coal onto 42 inch wide belt conveyors No. 4A and No. 4B rated at 1,000 tons per hour, 450 feet per minute.

Belt conveyors No. 4A and No. 4B pass through weigh scales which monitor the tonnage of coal in transit and indicate the tonnage to the station control room. The station operator, upon advice from the chemist, can, by varying the feeder rates, obtain the required quality of coal by blending coals from each of the two piles. Belt conveyors No. 4A and No. 4B feed a 500 ton surge bin located in the control transfer house. At the top of each belt conveyor is a magnetic separator to remove tramp iron before the coal drops in the surge bin. The bin feeds two crushers rated at 500 tons per hour and takes the run-of-mine coal down to 1-1/2 inch size or less which is suitable for the pulverizers. From the two crushers, coal is fed by gravity to two 30 inch wide belt conveyors No. 5A and No. 5B, rated at 500 tons per hour, 450 fpm. The control transfer house is also equipped with mechanical dust collecting equipment.

2.2.1.3 Coal Transport System

Belt conveyors No. 5A and No. 5B feed into a 2,000 ton storage capacity bunker at an elevation of 150 feet via the coal tripper. This tripper is rated at 500 tons per hour, and can be fed by either belt conveyor No. 5A or No. 5B, each rated at 500 tons per hour. The bunker is suitable for 16 hours of storage and is equipped with a dust suppression system. From the storage bunker, the coal is fed by large diameter pipes to weigh-feeders which measure and distribute the coal to two of the three 55 tons per hour capacity pulverizers; one of the pulverizers acts as a spare. To reduce coal dust problems, a slight negative pressure is maintained in the coal preparation building by induced draft fans equipped with high efficiency bag type dust collectors.

2.2.1.4 Summary of Major Equipment Required, Capacities, and Power Consumption

The requirements for types of major equipment, and their capacities and power consumption, are shown in Table 1.

TABLE 1
REQUIREMENTS FOR TYPES OF MAJOR EQUIPMENT, CAPACITIES,
AND POWER CONSUMPTION

<u>Equipment</u>	<u>Number Required</u>	<u>Capacity</u>	<u>Power Consumption</u>
Pulverizers	3	55 tph/unit	500 HP/unit
Thawing Shed	1	8 car-length	7,000 kW
Rotary Car Dumper	1	100 ton/cars	(TBD)
Unloading Hopper	1	300 tons	-
Vibrating Feeders	4	1,000 tph/unit	(TBD)
Surge Bin	1	500 tons	-
Crushers	2	500 tph (1-1/2 inch size)	(TBD)
Storage Bunker	1	2,000 tons	-
Coal Tripper	1	500 tph	(TBD)

The capacity of the Coal Handling System is shown in Table 2.

TABLE 2

CAPACITY OF THE COAL HANDLING SYSTEM

<u>Feeder or Conveyor</u>	<u>Belt Size (Width) (Inches)</u>	<u>Belt Capacity tons/hour/each</u>	<u>Belt Speed fpm Power Consumption</u>	<u>Travel Distance (feet)</u>
1	54	1,750	450	<62
2	54	1,750	450	600
3A	54	1,750	450	150
3B	54	1,750	450	150
4A	42	1,000	450	600
4B	42	1,000	450	600
5A	30	500	450	530
5B	30	500	450	530

2.2.2 Piping and Valves

Coal transport from the unloading hopper up to the pulverizers is by rubber covered belt conveyors. Pulverized coal is transferred to the lock hoppers and to the combustor either by carbon steel pipes or pipe made from aluminum oxide (Al_2O_3), silicon carbide (SiC) and epoxy resin. The minimum Brinell Hardness Number of 500 is specified. The maximum velocity is limited to 70 feet per second. Where high abrasive wear is anticipated, the pipe and the fittings are lined with 95 percent pure rubber. This rubber should be cold cured, stabilized and should not contain any type of fillers, heat dissipating agents or sulfur.

Selected valves are specified in the drawings listed under Section 1.0. All the pipes and fittings are designed in accordance with ANSI 31.1 and the ASME Boiler and Pressure Vessel Code.

2.2.3 Electrical

The average electrical power consumption for the thawing shed is about 7,000 kW (480 volts, 3 phase, 60 Hz) per unit train. Power requirements for the electrical motors, pulverizers, and belt conveyors are listed under Section 2.2.1, Major Equipment.

2.2.4 Instruments, Controls, and Alarms

Instruments are placed at locations commensurate with good design practice to monitor system performance. These instruments monitor and control incoming coal flow, and help avoid overloading of belt conveyors, crusher, and pulverizers. In addition, this system is equipped with special instruments which will:

1. Activate infra red electric heaters.
2. Avoid stress and damage to the cars due to overheating in the thawing shed.
3. Prevent misalignment of cars at the rotary dumping area.
4. Stop rotation of the car dumper if secure clamping of the car has not been obtained.
5. Weigh and record gross and tare car weights.
6. Record pressure and temperature of the inert gas and level of oxygen in the pulverizers.

The majority of the control switches and instrument readouts for each operation are at the equipment location. Only major instrument readouts are recorded at the Main Control Room Computer.

3.0 SYSTEM PROTECTION AND SAFETY PRECAUTIONS

3.1 PROTECTIVE DEVICES

Of the instruments and controls discussed under Section 2.2.4, the following equipment is equipped with extensive, accurate protective devices:

1. Electric heaters in the thawing shed (to avoid stress and damage to the cars due to overheating).
2. The rotary car dumping equipment (to position car exactly on the rotary dumping device without misalignment).
3. The pressurized lock hoppers (to maintain pressure, temperature, and inert gas atmosphere to avoid explosion).

3.2 HAZARDS

Hazards associated with coal handling systems include spontaneous combustion of stored coal, explosive coal dust mixtures, and accumulation of methane gas in underground tunnels.

3.3 PRECAUTIONS

Fire detection/protection is included to handle any problems with items discussed in Section 3.2. Ventilation and dust suppression equipment is also provided where deemed necessary.

There are no special precautions for the safe operation of the Coal Management System except close monitoring of equipment, instruments, and controls for the lock hopper feed system and scheduled testing of all instruments and control systems.

4.0 MODES OF OPERATION

4.1 STARTUP

Upon arrival of a unit train at site, the train may pass through the thawing shed and unloading cycle, or be stored overnight on a side track. Other equipment described under Section 2.2.1 will be operated as required. Start up is in accordance with the manufacturers instructions.

4.2 NORMAL OPERATION

During normal operation, the key equipment components are controlled and monitored from the main control room.

4.3 SHUTDOWN

For scheduled shutdown or forced shutdown for an extensive period (days), the bunkers and lock hoppers are inerted with nitrogen from the Industrial Gas Systems to avoid fire.

4.4 SPECIAL OR INFREQUENT OPERATION

A complete loss of fire in the combustor will occur if the pulverized coal flow is interrupted. The loss of fire results in a forced shutdown unless restored within approximately (TBD) minutes.

5.0 MAINTENANCE

5.1 SURVEILLANCE AND PERFORMANCE MONITORING

Operating personnel record data shown on direct indicating instruments and coal analysis at regular intervals per shift. The in-house computer constantly monitors specified points to give a running check on performance which can initiate an alarm if performance is out of specification. Performance can be viewed periodically as desired in the plant control room.

5.2 INSERVICE INSPECTION

Visual inspection of all equipment, conveyors, instruments, etc., shall be carried out periodically during system operation to ascertain that the subject equipment is operating properly.

5.3 PREVENTATIVE MAINTENANCE

All equipment, conveyors and motors shall be maintained and operated in accordance with the respective manufacturer's operating and maintenance instructions.

Computerized record keeping will be used to alert the operating personnel that pieces of equipment need an overhaul, repacking, or cleaning, depending on the recommendations of the equipment manufacturer. In general, the part will be replaced during the planned shutdown if it is near the end of its recommended life cycle.

5.4 CORRECTIVE MAINTENANCE

5.4.1 Manufacturer's Instructions

A complete file of instruction books is available at the plant to guide the plant personnel in maintenance of any piece of equipment. If necessary, a representative of the manufacturer can be present to supervise the overhaul or replacement of plant equipment.

5.4.2 Spare Parts Inventory

Manufacturers will supply lists of recommended spare parts. A certain percentage (TBD) of these parts are to be kept in inventory at the plant. Complex parts requiring long lead time for delivery are to be included in the plant inventory.

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
COAL MANAGEMENT
APPENDIX "A"
REFERENCE DOCUMENTS

REFERENCE DOCUMENTS - ATTACHED

Diagram No.

Layout

Yard Coal Handling - Plan & Section	8270-1-240-002-001
Yard Coal Handling - Plan & Sections	8270-1-240-002-002

Fluid System Diagram

Coal Feed Lock Hoppers	8270-1-410-302-341
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REFERENCE DOCUMENTS - NOT ATTACHED

Plant Heat & Flow Balance Diagram

System Heat Balance	8270-1-540-314-001
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System Design Description

Boiler Flue Gas
 MHD Power Train
 Slag Management
 Industrial Gas Systems

A

B

C

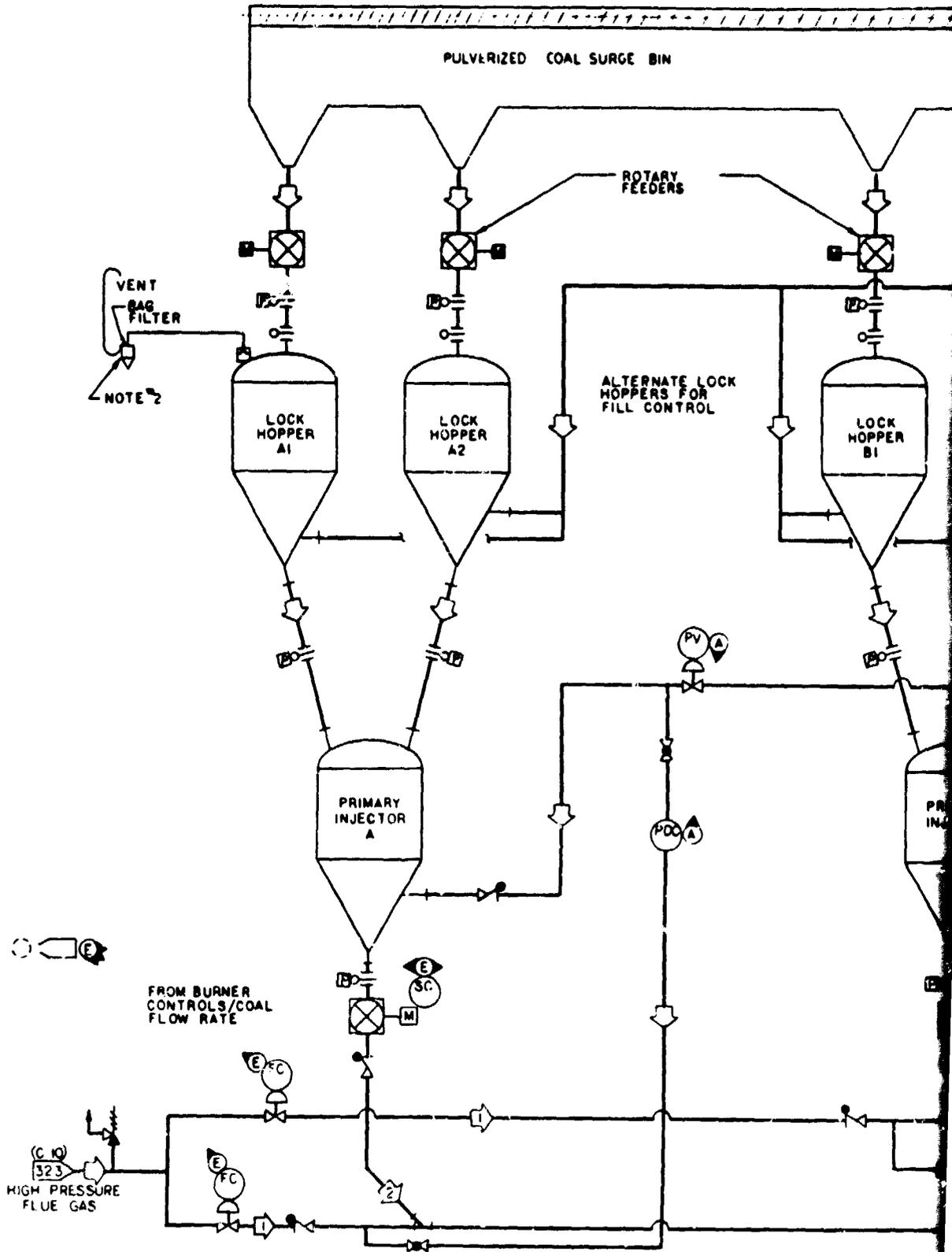
D

E

F

G

H



VENT
BAG
FILTER
NOTE 2

PULVERIZED COAL SURGE BIN

ROTARY FEEDERS

LOCK HOPPER A1

LOCK HOPPER A2

ALTERNATE LOCK HOPPERS FOR FILL CONTROL

LOCK HOPPER B1

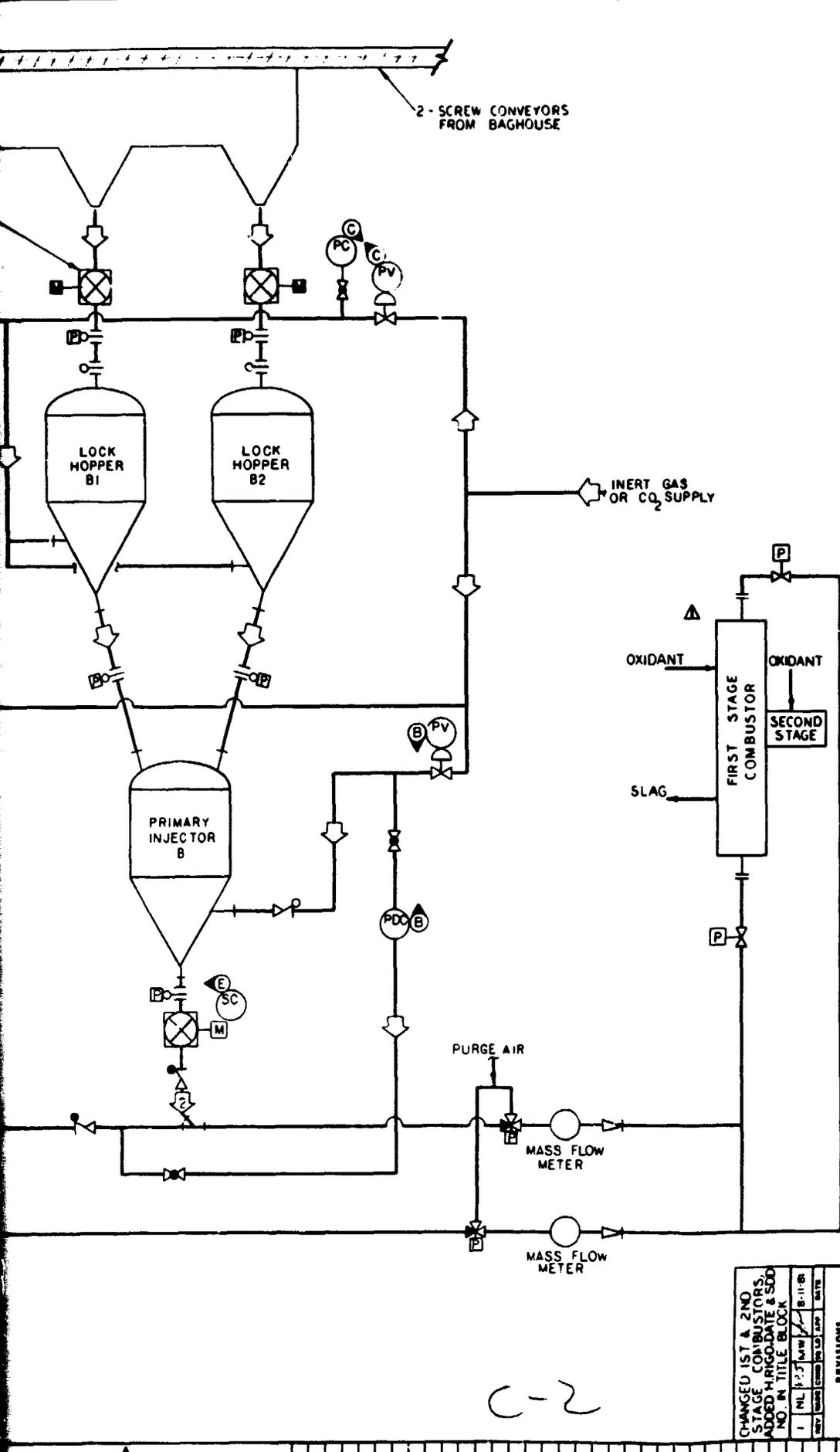
PRIMARY INJECTOR A

FROM BURNER CONTROLS/COAL FLOW RATE

(C.M.)
323
HIGH PRESSURE FLUE GAS

OLDOUT FRAME

6 5 4 3 2 1



OPERATING DATA

REV	FLOW THRU	PRESS PSIA	TEMP °F	REMARKS	REV
1	55	100	450		
2	165.6	150			

DESIGN DATA

REV	FLOW THRU	PRESS PSIG	TEMP °F	BY	REMARKS	REV

- NOTES:
 1. ALL SLIDE GATE VALVES WILL BE SUPPLIED WITH SEAL AIR.
 2. ALL LOCK HOPPERS & PRIMARY INJECTORS WILL HAVE RUPTURE DISC BAG FILTERS AND VENTS TO THE ATMOSPHERE.

I.O. NO. C-373-831

3-27-81	CONCEPTUAL DESIGN ISSUE	
2-13-81	PRELIMINARY ISSUE	
BY	RELEASED FOR	ENGR.

MAGNETOHYDRODYNAMICS ENGINEERING TEST FACILITY CONCEPTUAL DESIGN

FLUID SYSTEM DIAGRAM
 COAL FEED LOCK HOPPERS SDD-341
 200 Mw
 DOE - NASA

MHD PROJECT OFFICE
 LEWIS RESEARCH CENTER
 CLEVELAND, OHIO 44136

APPD. H. RIGO
 DATE 9-25-81

CHANGED 1ST & 2ND STAGE COMBUSTORS. ADDED HIRIGODATE & SDD NO. IN TITLE BLOCK

REV	DATE	BY	REASON
1	11-11-81	ML	1-3 M/W

GILBERT ASSOCIATES, INC.
 ENGINEERS AND CONSULTANTS

8270-1-410-302-341

8270-201

C-2

10

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6

A

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C

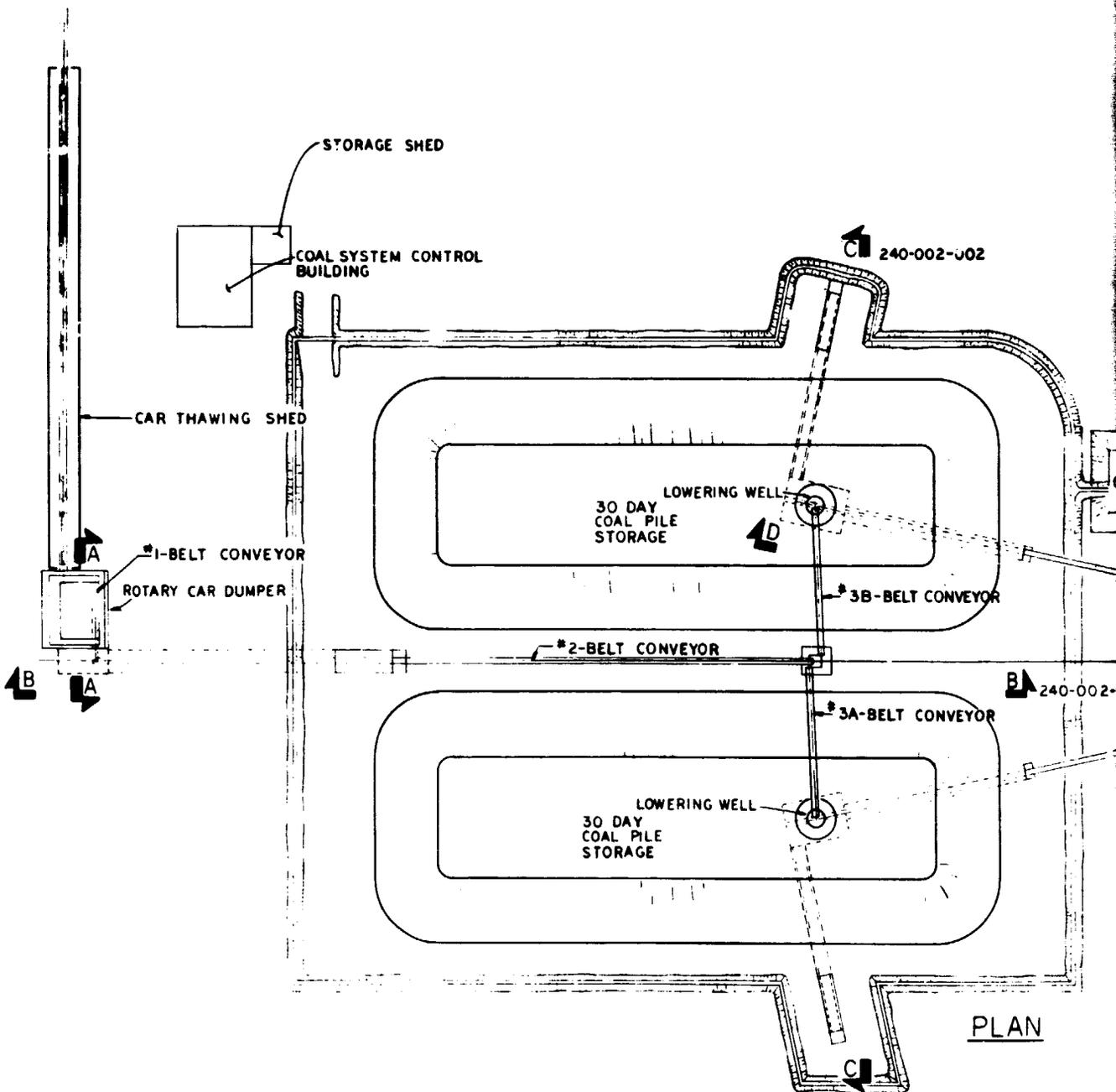
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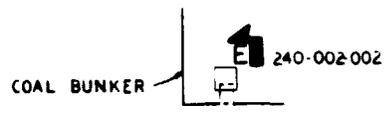


PLAN

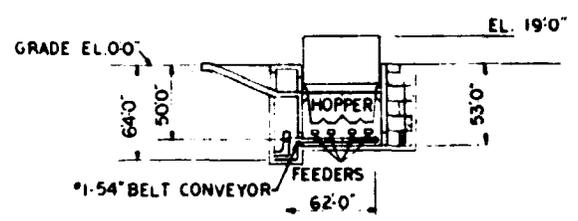
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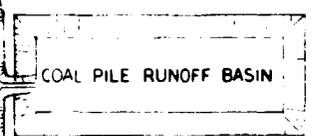
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SECTION A-A

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*5A BELT CONVEYOR

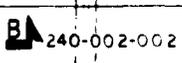


*4B BELT CONVEYOR

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CONVEYOR

CONVEYOR



CRUSHER HOUSE
240-002-002
SWITCHGEAR & DUST
SUPPRESSION BUILDING

*4A BELT CONVEYOR



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MAGNETOHYDRODYNAMICS
ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN

YARD COAL HANDLING

PLAN & SECTION SDD-341

200 MWe

DOE - NASA

MHD PROJECT OFFICE
LEVIN RESEARCH CENTER
CLEVELAND, OHIO 44135

APPD. H. RIGO
DATE 9-25-81

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ENGINEERS AND CONSULTANTS READING, PA.

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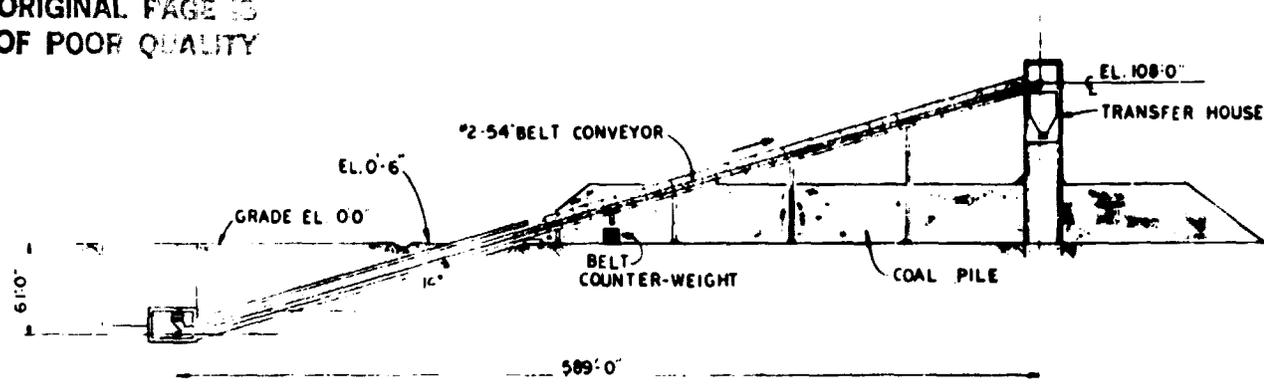
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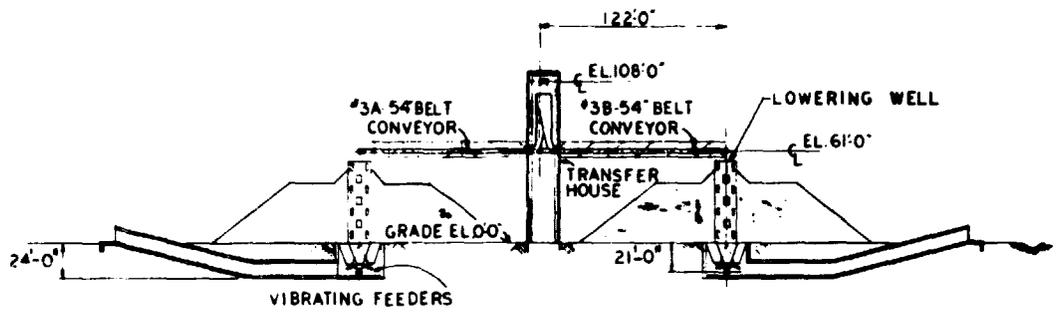
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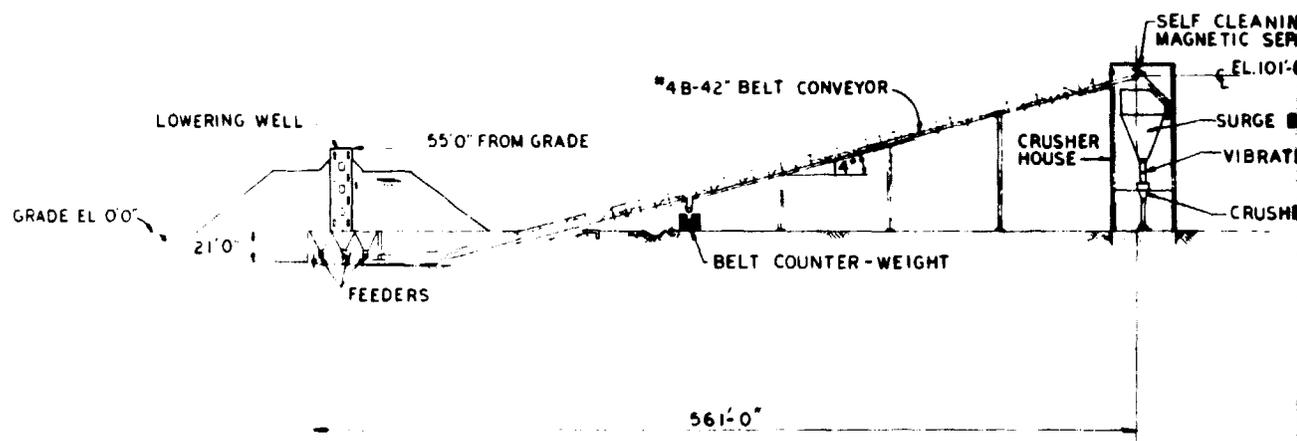
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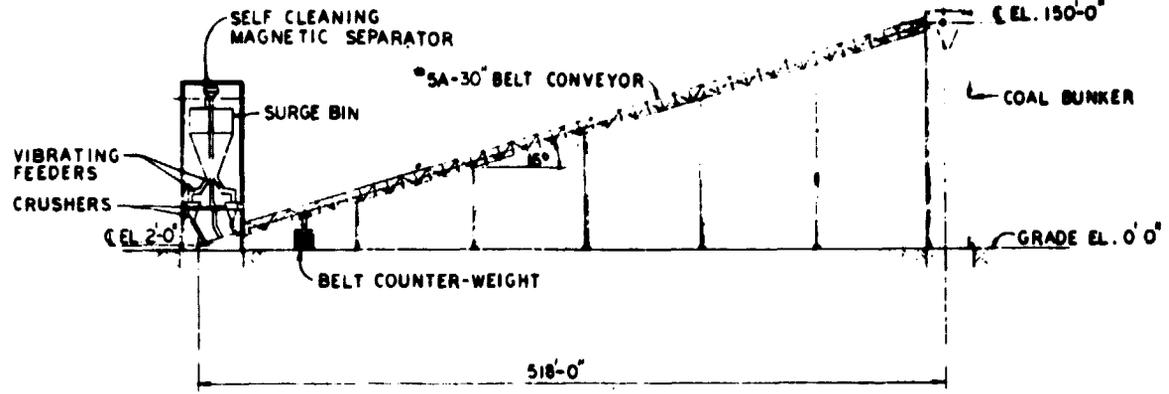
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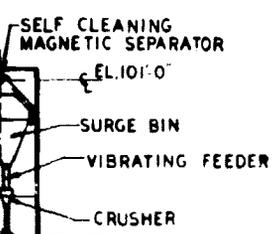
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TRANSFER HOUSE



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**MAGNETOHYDRODYNAMICS
ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN**

YARD COAL HANDLING

SECTIONS SDD-341

200 MW

DOE - NASA

MWD PROJECT OFFICE
LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

APPD. H. RIGO
DATE 9-25-81

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REVISIONS

E-3

SYSTEM DESIGN DESCRIPTION

SDD-342

SEED MANAGEMENT SYSTEM
FOR
MAGNETOHYDRODYNAMICS
ENGINEERING TEST FACILITY

CONCEPTUAL DESIGN - 200 MWe POWER PLANT

FLUID SYSTEM DIAGRAM NOs. 8270-1-410-302-342, 8270-1-451-302-352

LAYOUT DRAWING NOs. 8270-1-240-002-003, 8270-1-240-002-004

SYSTEM ENGINEER 9 DATE

Eric T. Nelson

REVIEWED 9/14/81 DATE

Eric T. Nelson

APPROVED 9/14/81 DATE

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Revision: 1

Date: September 25, 1981

Approved: *Eric T. Nelson*

**MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
SEED MANAGEMENT SYSTEM**

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1.0 FUNCTION AND DESIGN REQUIREMENTS

This document describes the Seed Management System as depicted on the Figures in and attached to this SDD, and on the following Fluid System Diagrams and Drawings:

<u>Drawing Number</u>	<u>Title</u>
8270-1-210-007-001	Plot Plan
8270-1-240-002-003	Seed Unloading & Storage Area, Plan
8270-1-240-002-004	Seed Unloading & Storage Area, Section
8270-1-410-302-342	Seed Feed System
8270-1-451-302-352	Spent Seed Removal from HR/SR Boiler and ESP
SDD-1101 (SDD-502)	MHD Power Train System, Assembly, Plan & Elevation
Figure 1 (SDD-504)	Heat Recovery/Seed Recovery System (HR/SR)

The document includes 1) descriptions of system functions, 2) interfaces with other systems, 3) equipment requirements, 4) design criteria, 5) description of components, 6) operating modes, and 7) safety and maintenance requirements.

1.1 FUNCTIONAL REQUIREMENTS

The Seed Management System 1) receives and unloads fresh seed, 2) recovers spent seed from the HR/SR Boiler and ESP, 3) conveys (and/or trucks), stores, pulverizes, mixes and injects prescribed fractions of fresh and spent seed into the MHD combustor, and 4) trucks spent seed to an off-site location for either reprocessing or sale.

1.2 SYSTEM INTERFACES

The Seed Management System receives fresh seed via rail and transports spent seed via truck to an off-site location for either seed reprocessing or sale. Within the ETF, this system injects seed into the MHD combustor, and recovers seed from the convective section of the HR/SR Boiler and from the ESP.

The physical equipment that makes up and interfaces with the Seed Management System is spread widely about the ETF Plot Plan, Drawing 8270-1-210-007-001. Therefore, tracing the physical flow of the seed is perhaps the best method of locating equipment and interfaces. In the Seed Management System, the flow of seed includes the following:

1. Delivery of fresh seed in sealed railroad cars to the Seed Unloading Facility, Item 37. (Design is for a fresh seed supply of potassium carbonate, although the system can handle a mixed seed consisting of potassium carbonate/potassium sulfate).
2. Storage of both fresh and spent seed in the silos of the Seed Unloading Facility, Item 37.
3. Conveying of seed from the silos of Item 37 to the Seed Feed Building, Building 35.

4. Pneumatic transport of pulverized seed from Building 35 to the MHD combustor located in the MHD Building, Building 34.
5. Recovery of spent seed from the convective pass of the HR/SR Boiler in Building 33, and from the ESP, Item 41.
6. Pneumatic transport of the spent seed from Building 33 and Item 41 to the Spent Seed and Fly Ash Silos, Item 19.
7. Truck delivery of spent seed from Item 19 to an off-site location for either seed reprocessing or sale.
8. Truck delivery of spent seed from Item 19 back to a silo in the Seed Unloading Facility, Item 37.

1.3 DESIGN CRITERIA

Design criteria include the seed/ash flow requirements, pressure-temperature ratings, and system limits specified in the ETF DRD. These are shown on the ETF System Heat and Mass Balance, Drawing 8270-1-540-314-001 and evolved from the detailed Chemical Equilibrium Calculations (CEC) described in Appendix B, "ETF SEED MANAGEMENT TASK - ESTIMATE OF CONDENSATE AND SOLIDS FLOW RATES".

The physical condition of the spent seed leaving the HR/SR has not been established. For the purpose of this System Design Description, it is assumed that the spent seed from both the HR/SR Boiler and the ESP can be handled by equipment available for handling fly ash. In addition, it is assumed that there are negligible differences in chemical composition between the spent seed leaving the HR/SR Boiler convective pass and the spent seed leaving the ESP.

Two Seed Management Systems were considered in the analysis of Appendix B, namely, 1) Once-Through Flow of Fresh Seed and 2) Partial Recycle of Recovered Seed. The criteria used to select a preferred process were as follows:

1. Fresh seed input flows and costs shall be minimal, and preferably of a single chemical.
2. Off-site shipping and reprocessing flows and costs shall be minimal.

The Partial Recycle of Recovered Seed system fulfilled all of the above criteria, and the Once-Through Flow of Fresh Seed fulfilled none. Hence, the Partial Recycle of Recovered Seed was selected for the reference design and is described in this System Design Description.

The once-through flow of fresh seed arrangement is desirable for initial ETF startup and initial ETF testing (runs of 10 hours duration or less). It can also be implemented using the exact equipment required for the reference Partial Recycle of Recovered Seed system. The Once-Through Flow variant is described briefly in Appendix B.

Engineering design criteria for all disciplines are in accordance with applicable codes, standards, regulations and guides by governmental agencies, recognized standards organizations, and Gilbert Associates, Inc.

1.3.1 Codes and Standards

System engineering design is in accordance with applicable codes, standards, and guides issued by the following organizations:

1. American National Standards Institute (ANSI)
2. American Society of Mechanical Engineers (ASME)
3. American Society for Testing and Materials (ASTM)
4. American Welding Society (AWS)
5. Manufacturers Standardization Society of the Valve and Fittings Industry (MSS)
6. Pipe Fabrication Institute (PFI)
7. Occupational Safety and Health Administration (OSHA)
8. Instrument Society of America (ISA)
9. National Fire Protection Association (NFPA)

1.3.2 Design Parameters

The design pressures and temperatures are taken from the ETF DRD, the ETF System Heat and Mass Balance, Drawing 8270-1-540-314-001, and from the results of Appendix B as shown in Figure 1. Solids conveying equipment is sized based on the flow rates determined from the above.

2.0 DESIGN DESCRIPTION

The Seed Management System consists of solids recovery, conveying, injection and storage equipment. The major equipment components are discussed in the Detailed Description of Section 2.2.

2.1 SUMMARY DESCRIPTION

The Seed Management System is designed to inject seed into the MHD combustor and to recover spent seed from the convective section of the HR/SR Boiler and the ESP for off-site shipment and reprocessing. It is also designed for partial recycle of recovered seed for re-injection into the MHD combustor. Fresh seed is potassium carbonate (K_2CO_3) and has a dual role in the coal-fired MHD power system. The primary requirement for seed is to provide the necessary plasma electrical conductivity. The K_2CO_3 seed also chemically combines with SO_2 in the flue gas formed from the coal sulfur to form K_2SO_4 and thus eliminates SO_2 from the products of combustion.

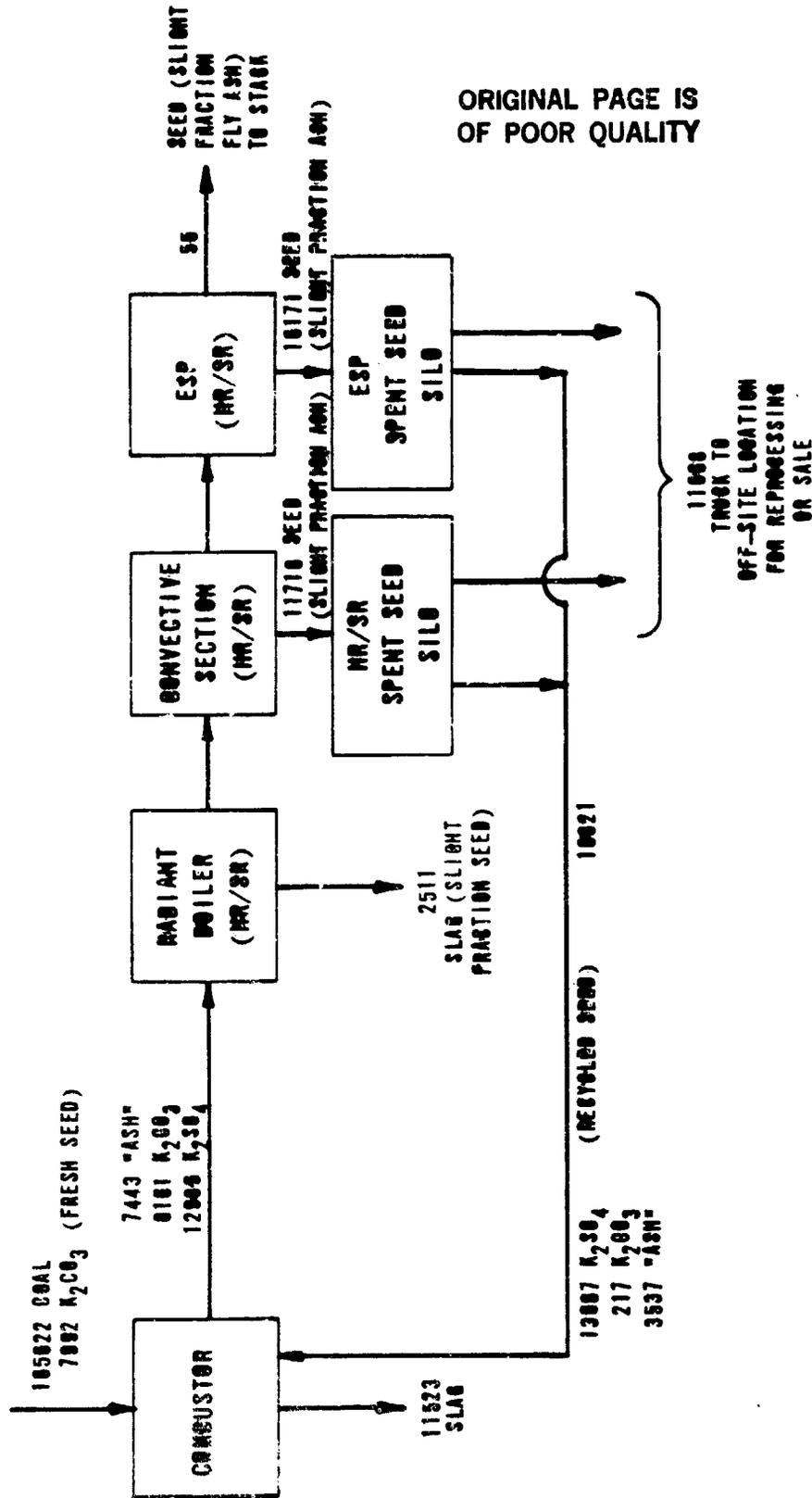


FIGURE 1
DOMINANT FLOWS (IN LB/MR) IN THE ETF REFERENCE SEED MANAGEMENT SYSTEM WHICH EMPLOYS PARTIAL RECYCLE OF RECOVERED SEED

Seed is considered spent after exiting the MHD Power Train. Figure 1 shows the mass flow diagram for the Partial Recycle of Recovered Seed. Slag is the primary constituent removed in the Combustor and Radiant Boiler. Very little seed condenses in these units. Some potassium is chemically bound to the Radiant Boiler slag (3.5 percent). This potassium cannot be economically recovered due to the formation of insoluble potassium aluminum silicates, and is therefore discarded with the slag.

Seed first condenses in the Afterburner Section of the Radiant Boiler (see Figure 1 of SDD-504) under oxidizing conditions (as liquid potassium sulfate at 2,400°F). In the Intermediate Temperature Oxidant Heater of the HR/SR at 1,593°F, the sulfate has solidified and solid potassium carbonate also appears. Seed deposition continues and is most critical in the Reheater Section of the HR/SR. Seed deposits in these areas will be carried through and incorporated with seed collected by the seed hoppers (see Drawing 8270-1-451-302-352) either in the HR/SR Boiler convective pass or the ESP. After passing through the HR/SR, the gas enters the ESP, where final seed collection and particulate removal occurs as shown on Figure 1 of SDD-504.

Particulate losses are kept at levels to meet EPA 1979 New Source Performance Standards. These Performance Standards for fossil fired steam generators limit particulate emissions to 0.03 pound per million Btu of heat input to the MHD Combustor. Since this requirement is more stringent than potassium recycle requirements, the design collection efficiency for the cleanup system is determined by EPA standards.

Should fresh seed be supplied by regeneration of ETF seed, this operation would be done off-site and the process equipment for this would not be part of ETF equipment and equipment costing. Sufficient fresh K_2CO_3 seed flow of 7,992 lb/hr is required to capture the sulfur.

For the fraction of the seed to be recycled, the seed is collected and stored in the Spent Seed and Fly Ash Silos for recycle (via truck) to the combustor without removing ash or impurities. The level of ash and impurities buildup in the seed is not severe enough to require ash separation or other on-site processing steps.

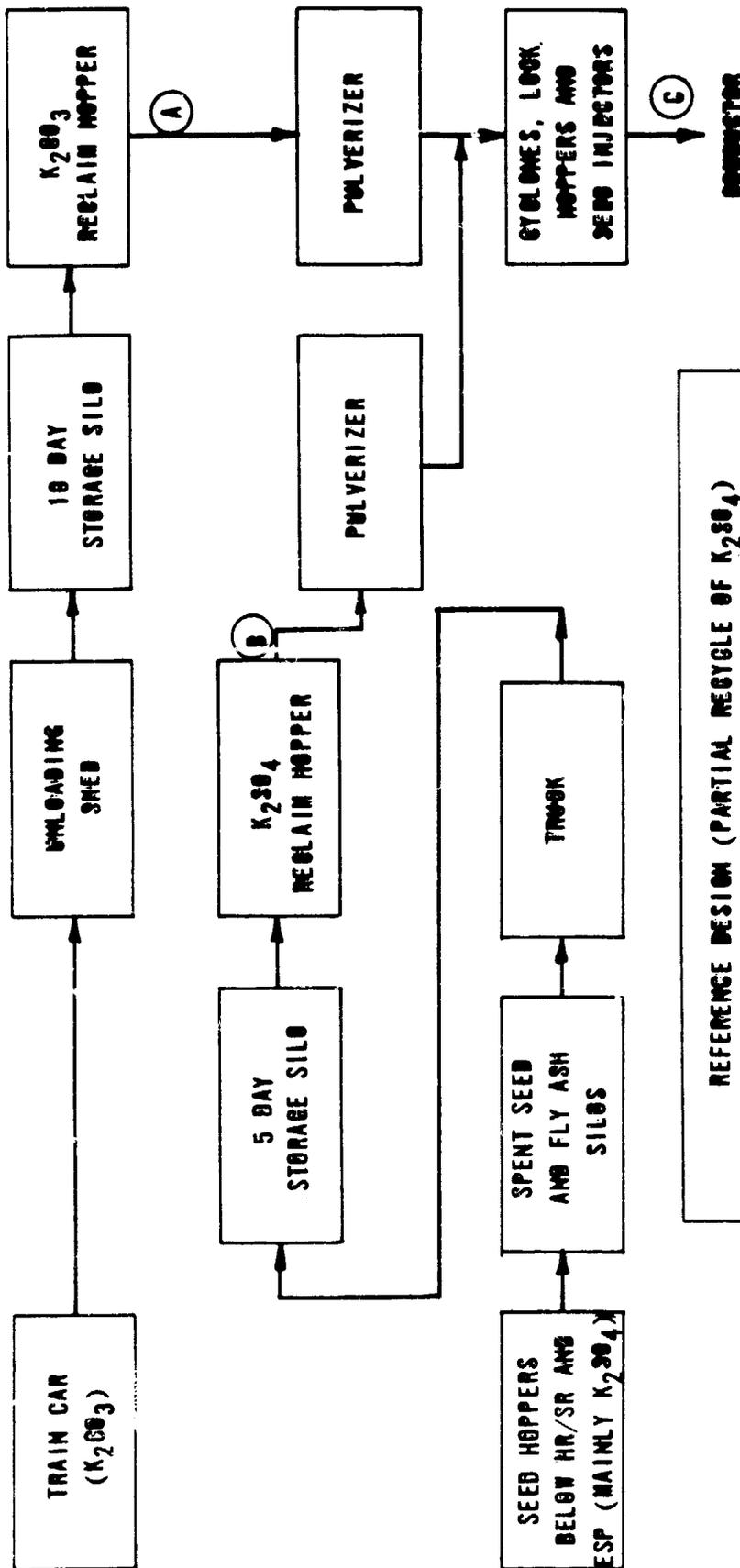
2.2 DETAILED DESCRIPTION

2.2.1 Major Equipment Sections

The following summarizes the major equipment sections included in the Seed Management System.

2.2.1.1 Fresh Seed Unloading And Storage

The location of the seed unloading and storage area is depicted as Item 37, Seed Unloading Facility, on the MHD Plant Plot Plan, Drawing 8270-1-210-007-001, Figure 2 shows the process flow diagram for fresh seed unloading, seed mixing, pulverizing, storage and injection for the reference system in which there is a Partial Recycle of Recovered Seed. Drawings 8270-1-240-002-003 and 8270-1-240-002-004 show plan/section views of



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REFERENCE DESIGN (PARTIAL RECYCLE OF K₂004)

A	K ₂ 003, LB/HR	7,902
B	RECOVERED K ₂ 004 (WITH ASH), LB/HR	16,821
C	TOTAL, LB/HR	24,813

FIGURE 2
BLOCK DIAGRAM SHOWING SEED UNLOADING AND STORAGE SYSTEM, AND SEED FEED SYSTEM

the fresh seed unloading and storage area. Potassium carbonate is delivered to the plant by sealed cars and is poured into fresh seed receiving pits. Potassium carbonate is hygroscopic and must be isolated from moisture during unloading and storage.

The Seed Unloading Facility (Item 37) is located on a rail line next to the Seed Feed Building, Building 35. The dumper track is provided with an unloading shed to prevent the K_2CO_3 from picking up moisture. Full redundancy is provided in the unloading and delivery system to keep up with maximum seed feed rate. Dust collection and suppression is provided at the unloading and transfer points.

Potassium carbonate is moved to a 10 day storage silo by screw conveyors.

The fresh K_2CO_3 seed passes through an "as received" sampling point in transit to the storage area. The K_2SO_4 spent seed is trucked from the Spent Seed and Fly Ash Silos through an "as-received" sampling point in transit to the storage area. The potassium carbonate and recycled potassium sulfate are stored in separate silos which are provided with screw conveyors. Each screw conveyor is designed for 75 tph delivery and 20 tph reclaim rate. The silos are sized for a minimum of 10 days of K_2CO_3 and 5 days of K_2SO_4 storage at full load as shown in Drawing 8270-1-240-002-004 and Figure 2.

2.2.1.2 Seed Feed System (Pulverizing, Mixing and Injection)

The equipment of the Seed Feed System processes seed from the storage silos for injection into the MHD combustor. This equipment is shown on Drawing 8270-1-410-302-342, and is located in the Seed Feed Building, Building 35, of Drawing 8270-1-210-007-001.

Fresh and recycled seed are reclaimed by screw conveyors from the K_2CO_3 and K_2SO_4 storage silos and conveyed to the K_2CO_3 and K_2SO_4 reclaim hoppers. The K_2CO_3 and K_2SO_4 flows are metered and pulverized separately and mixed at the outlet of the pulverizers.

Between the pulverizers and the combustor, all seed feeding equipment is in duplicate and interconnected for switchover. Hereafter, only one flow path is described. From the seed metering bunker, seed fed to the pulverizer is regulated by the feeders. The specially designed pulverizer grinds seed, along with a small fraction of slag, to a fineness passing at least 70 percent through a 200 mesh screen. The transport air from the air dryer (at about 18 psia in ratio of 5 lb. of seed to 1 lb. of air) transports pulverized seed to the cyclone collectors operating at atmospheric pressure. Piping returns the moist air to the air dryer.

The pulverized dried seed is transferred through pneumatic valves and feeders to the depressurized lock hopper (50 ton capacity), while the other pressurized lock hopper (50 ton capacity) is feeding seed to the continuously pressurized primary injector (50 ton capacity). The seed enters the primary injector without interrupting the continuous injection of seed from the primary injector to the combustor. The cyclone collector, lock hopper and primary injector are stacked vertically. Dry air is provided at the bottom of

the lock hoppers and primary injectors to avoid plugging the outlets. About 0.035 lb. of high pressure oxidant to 1 lb. of seed transports seed from the primary injector to the water cooled seed injector located near the combustor exit (see Drawing SDD-1101, of SDD-502). The oxidant is taken from the oxidant compressor outlet at a temperature of 433°F. The Differential Pressurized Cell (DPC) balances the air pressure between the primary injector outlet and the seed feed line. The signals from the combustor burner control regulate the speed of the seed feeder and the flow of the high pressure oxidant to the combustor (see Diagram 8270-1-410-302-342.)

The equipment required includes the following:

- Tandem Sealed Dump Car Site
- Unloading Shed
- Train Positioners
- Track Hopper
- Belt Feeders
- Sampling System "As Received"
- Storage Silos
- Screw Conveyors
- Hoppers and Bunkers
- Pulverizers
- Belt Scales
- Bag Filters and Exhausters
- Cyclone Collectors
- Lock Hoppers
- Primary Injectors
- Shutoff Gates and Slide Gates
- Chutes and Bins

2.2.1.3 Spent Seed Recovery

Seed is collected from the downstream end of the convective section of the HR/SR Boiler and from the ESP. A small fraction of ash is collected with the seed at these locations. No attempt is made to recover the small fraction of seed chemically combined with the Combustor and Radiant Boiler slag.

The seed leaving the HR/SR Boiler convective pass is assumed to be similar to fly-ash; therefore no size reduction equipment has been included. If this material is significantly coarser than fly-ash then it may be necessary to install size reduction equipment at the outlet of the HR/SR convective pass seed hoppers.

The equipment required includes the following:

- Bottom Seed Hoppers
- Pressurized Air Lock Feeders
- Piping and Valves

2.2.1.4 Spent-Seed Collection, Conveying, and Storage

Spent seed contaminated with fly ash is collected continuously from the HR/SR Boiler and ESP. The flow rates are shown in Figure 1. Detailed composition of

these flows is given in Table B2. The spent seed exit temperature is about 480°F. The maximum flow rate of the spent seed mixture is 27,889 lb/hr with 11,068 lb/hr being shipped off-site and 16,812 lb/hr being recycled.

Hot dry seed is collected from the HR/SR convective section and the ESP via a high temperature hopper/feeder system, and is conveyed to the Spent Seed and Fly Ash Silos (Item 19 of Drawing 8270-1-210-007-001). From these silos, the fraction of spent seed that is to be recycled is moved by truck to the Seed Unloading Facility (Item 37 of Drawing 8270-1-210-007-001). The remaining fraction is trucked off-site for either reprocessing or sale. Equipment for spent seed collection is shown on Drawing 8270-1-451-302-352, and on Figure 3.

The spent seed mixture is conveyed in a sequential pattern from these hoppers through one of the two air lock feeders into a positive pressure conveying air stream to the spent seed silos.

The conveying air is furnished by one of two 100 percent capacity positive displacement blowers. The air is vented from the silo through a bag filter to meet the EPA 1979 New Source Performance Standards (NSPS). The on-site spent seed silos located in the Spent Seed and Fly Ash Silo area (Item 19 of Plot Plan) are sized to contain 150 tons of spent seed mixture, which equals an 18 hour supply for recycle to the Seed Feed System/MHD Combustor and is intended to provide extra capacity for surge and emergency storage.

The following represent the major mechanical equipment for spent seed handling:

- Air Operated Handling Valves
- Conveying Air Blowers
- Air Heaters
- Storage Silos
- Bag Filters and Exhausters
- Dustless Unloader
- Dry Unloaders
- Piping

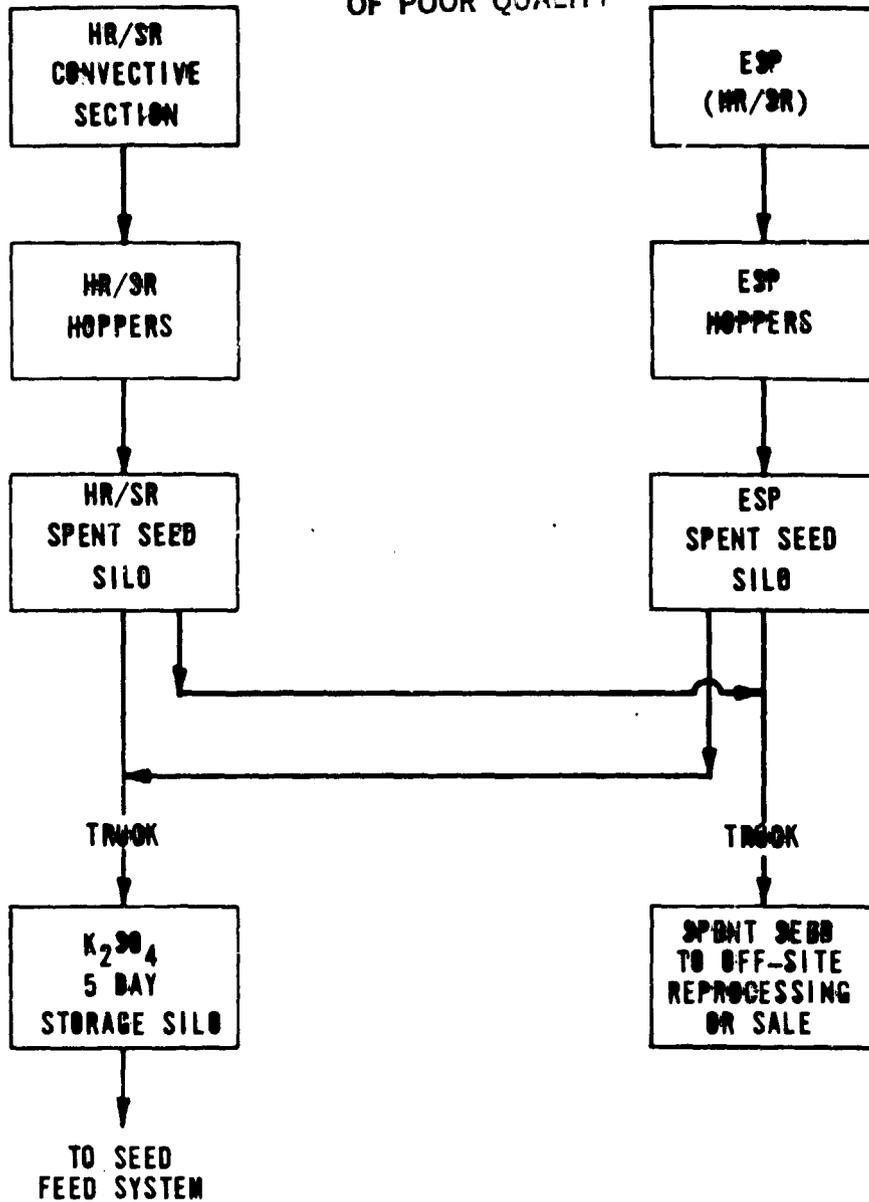
2.2.1.5 Spent Seed Shipment and Off-Site Reprocessing

The recoverables from the HR/SR Boiler and ESP are pneumatically conveyed to the spent seed silos, as shown in Drawing 8270-1-451-302-352. The recycled spent seed is conveyed through dry unloading flexible spouts to trucks for transfer to the K_2SO_4 Storage Silo. The spent seed that is to be sold or reprocessed off-site is transferred to trucks via the rotary dustless unloader shown on Drawing 8270-1-451-302-352.

2.3 INSTRUMENTS, CONTROLS, AND ALARMS

The Seed Management System is provided with instrumentation for sensing solids flow, pressure, and temperature at selected points to monitor system performance.

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REFERENCE DESIGN WITH K ₂ SO ₄ RECYCLE	
SPENT SEED, LB/HR	27,800
SPENT SEED TO OFF-SITE REPROCESSING OR SALE LB/HR	11,000
RECYCLE TO COMBUSTOR LB/HR	16,821

FIGURE 3
SPENT SEED RECOVERY

3.0 SYSTEM PROTECTION AND SAFETY PRECAUTIONS

3.1 PROTECTIVE DEVICES

The major equipment operating limits, equipment redundancy, and protective devices are described and included in Section 2.2.

The standard safeguards for enclosed moving screws and conveying systems are employed. An interlock system coupled with protective mechanical guard systems assures safe operation of screw conveyors and moving equipment.

The safety and health regulations presently governing the handling of potassium sulfate compounds and coal ash compounds will be followed.

3.2 HAZARDS

Special personnel hazards (biological - such as those affecting respiration, eyes, throat, etc.) are considered to exist in the Seed Management System beyond those normally associated with materials handling of solids in the 200°F to 600°F range. Standard conditions for handling fly ash and potassium sulfate and potassium carbonate will be followed.

3.3 PRECAUTIONS

Standard safeguards for employee protection used for conveyors and material transport systems will be followed. Recommended safeguards to minimize employee exposure will be followed. All equipment for handling K_2SO_4 , K_2CO_3 and fly ash will be selected to comply with Federal, state and local environmental regulations. Seed material trucked off-site is watered down in a rotary dustless unloading system to meet Federal, state and local regulations.

4.0 MODES OF OPERATION

4.1 STARTUP

4.1.1 Startup After Prolonged Downtime

System check-out and startup after a prolonged downtime requires a somewhat longer time than normal startup. Extra checks must be made to assure all maintenance and equipment assembly work is complete. The equipment and operating conditions that are to be checked are as follows:

- Dust Leakage
- Material Build-up in Filters and Receivers
- Low Compressed Air Pressure
- Rotating Equipment
- Accessory Equipment

Most of this check-out work is done while conveying rates are measured. Rates are determined by weighing all material entering the system. In addition, down times during facility testing are recorded during the testing period in order to obtain actual operating times for all feeders.

4.1.2 Normal Startup

The following startup procedure is followed for all pneumatic conveying systems:

1. Check that the low level alarms at each receiving bin indicate that material can be received.
2. Set the diverter gates for empty hoppers so that the material will flow to the correct hopper.
3. Start the blower to establish air flow through the conveying line.
4. Start the equipment that feeds the material into the conveying system.

Start the air flow first and stop it last to avoid trapping material in the lines. Avoid overfeeding or underfeeding screw feeders; overfeeding may be evidenced by blowing relief valves and by the backing up of material into the rotary feeder, whereas underfeeding may be signaled by the failure of the pneumatic conveying system to come up to the design vacuum or pressure.

4.2 NORMAL OPERATION

The normal load range of the Seed Management System follows the demands of the MHD combustor and HR/SR system with nominal flows as shown on Figure 1. The Seed Management System operates satisfactorily with minimum operator action in the event of load changes in the system.

4.3 SHUTDOWN

In a normal, controlled shutdown the conveying systems are emptied to solid storage locations followed by proper sealing of pressure locks. In an emergency shutdown, the pressure locks will be sealed after emptying the system to solid storage locations to the extent possible. Care is taken to stop the air flow last so that no material is trapped in any part of the conveying system. Both process control computer and operator attention are required to confirm proper functioning of the purging or clean-out systems.

4.4 SPECIAL OR INFREQUENT OPERATION

The Seed Management System is equipped with manual controls for special procedures requiring non-routine operation. Emergency overrides are included along with system isolation valves and lockout systems to permit emergency repair or inspection.

The equipment employed in the Seed Management System can readily be adjusted to a once-through flow of fresh seed (e.g., mixed potassium sulfate/potassium carbonate). Such operation may be desired for initial ETF "shake-down" and for ETF test runs of less than 10 hours duration. The dominant mass flows for such operation are shown in Figure B2 of Appendix B. Since ordinary recycle of seed in the Seed Management System is accomplished at the ETF by on-site trucks, once-through flow merely consists of deleting this truck transfer operation.

5.0 MAINTENANCE

5.1 SURVEILLANCE AND PERFORMANCE MONITORING

A process control computer monitors significant data points in the Seed Management System concurrent with the systems automatic controls. Alarms will alert plant operating personnel to any off-design performance or operation. Periodic calibration and maintenance are carried out on all analog and digital instrumentation to verify computer readout.

5.2 INSERVICE INSPECTION

Equipment, including conveyors, valves, controls, gauges, etc., shall be inspected periodically to verify that the equipment is operating properly.

5.3 PREVENTATIVE MAINTENANCE

Computerized record keeping will be used to alert the operators that certain pieces of apparatus need periodic overhaul, repacking, etc., in accordance with recommendations from the equipment manufacturer. In general, the part will be replaced or modified during a planned shutdown, if required.

5.4 CORRECTIVE MAINTENANCE

5.4.1 Manufacturer's Instructions

A complete file of instruction books is available at the plant to guide the plant personnel in maintenance and overhaul of any piece of equipment. If necessary, a representative of the manufacturer can be present to supervise the overhaul or replacement of plant equipment.

5.4.2 Spare Parts Inventory

The manufacturers supply lists of recommended spare parts. Critical parts will be kept in inventory at the plant. Complex parts requiring long lead time for delivery are included in the plant inventory.

**MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
SEED MANAGEMENT SYSTEM**

**APPENDIX "A"
REFERENCE DOCUMENTS**

REFERENCE DOCUMENTS - ATTACHED

<u>Fluid System Diagrams</u>	<u>Diagram No.</u>
Seed Feed System	8270-1-410-302-342
Spent Seed Removal from HR/SR and ESP	8270-1-451-302-352
<u>Layout Drawings</u>	
Seed Unloading & Storage Area, Plan	8270-1-240-002-003
Seed Unloading & Storage Area - Section	8270-1-240-002-004
<u>Other Documents</u>	
ETF Seed Management Task - Estimate of Condensate and Solids Flow Rates (Appendix B)	
MHD Power Train System, Assembly, Plan & Elevation	SDD-1101 (SDD-502)
Heat Recovery/Seed Recovery System	Figure 1 (SDD-504)

REFERENCE DOCUMENTS - NOT ATTACHED

<u>System Design Descriptions</u>	
Slag Management System	SDD-351
MHD Power Train System	SDD-502
Heat Recovery/Seed Recovery System	SDD-504
<u>Layout Drawings</u>	
Plot Plan	8270-1-210-007-001
<u>Plant Heat & Flow Balance Diagram</u>	
System Heat Balance	8270-1-540-314-001

A

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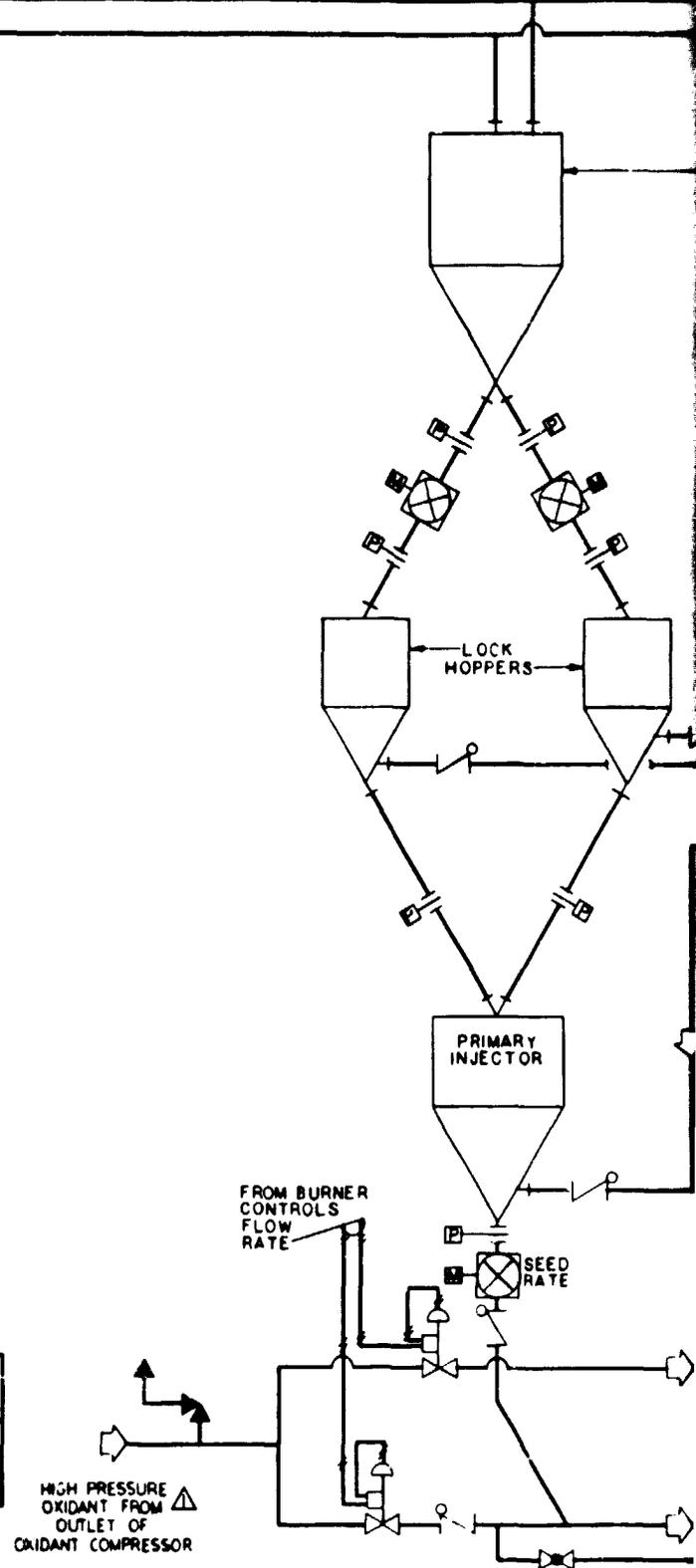
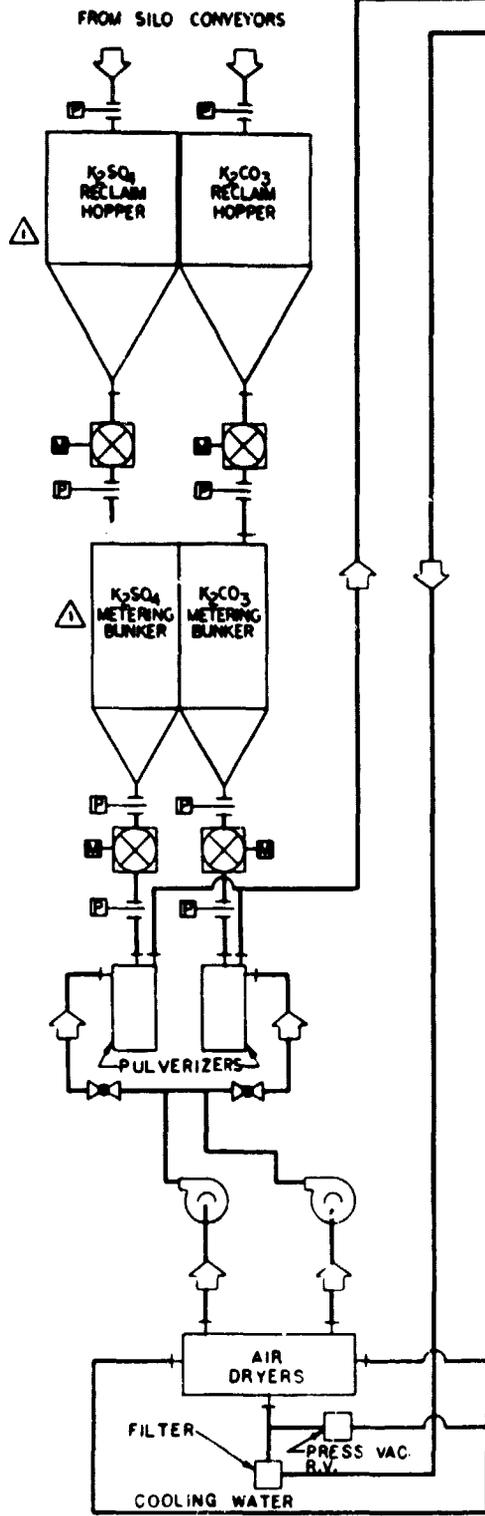
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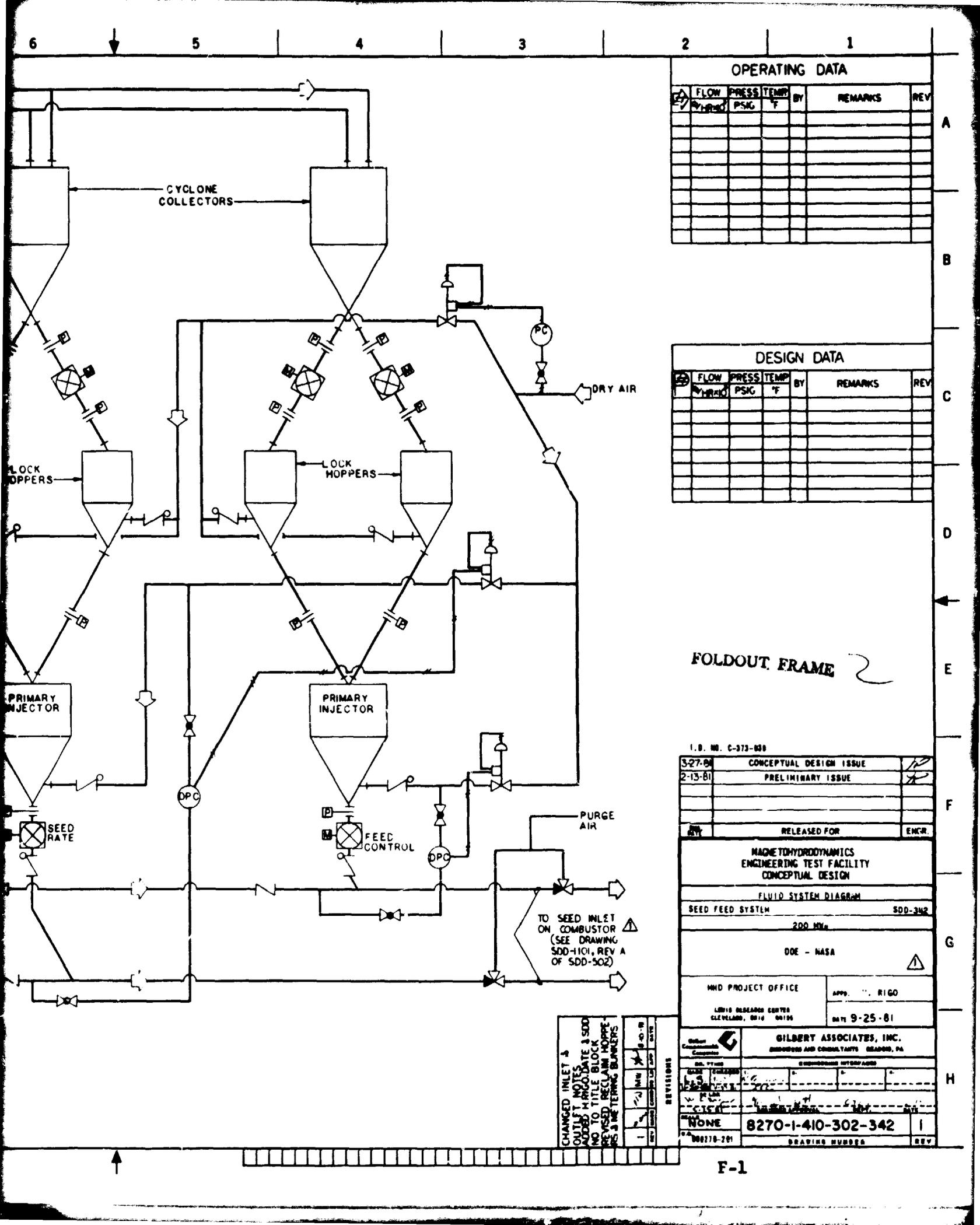
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HOLDOUT FRAME



OPERATING DATA

FLOW	PRESS	TEMP	BY	REMARKS	REV
PSIG	PSIG	F			

DESIGN DATA

FLOW	PRESS	TEMP	BY	REMARKS	REV
PSIG	PSIG	F			

FOLDOUT FRAME

I.D. NO. C-373-000

3-27-61	CONCEPTUAL DESIGN ISSUE	
2-13-61	PRELIMINARY ISSUE	

MACHETOHYDRODYNAMICS
ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN

FLUID SYSTEM DIAGRAM
SEED FEED SYSTEM SDD-342

200 MM
DOE - NASA

MND PROJECT OFFICE
LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

APP. RIGO
DATE 9-25-61

GILBERT ASSOCIATES, INC.
ENGINEERING AND CONSULTANTS
READING, PA.

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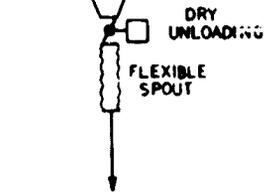
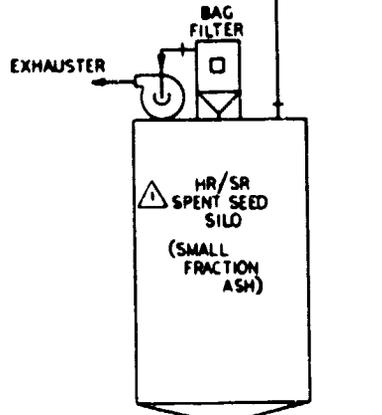
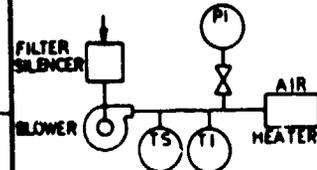
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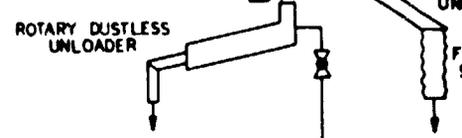
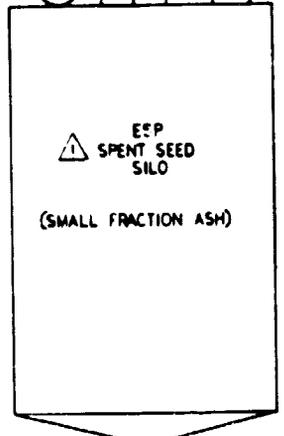
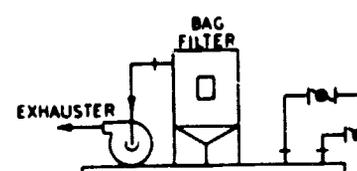
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TRUCK TO STORAGE SILO AT SEED UNLOADING FACILITY



TRUCK OFFSITE FOR SEED REPROCESSING OR SALE
MIX WATER
201
TRUCK TO STORAGE SILO AT SEED UNLOADING FACILITY

FOLDOUT FRAME

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SCREW CONVEYORS

SEED SILO
 K_2SO_4

SEED SILO
 K_2CO_3

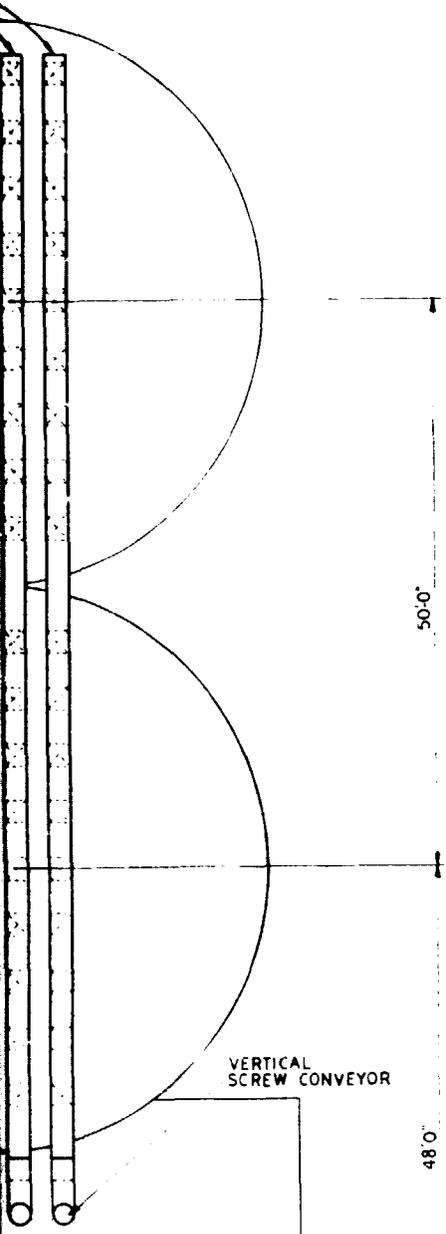
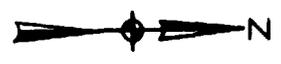
SEALED HOPPER CAR

HOPPER SHED

PLAN

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EOLDOUT FRAME



I. D. NO. 873-018

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**MAGNETOHYDRODYNAMICS
ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN**

SEED UNLOADING & STORAGE AREA

PLAN SDD-342

200 MWe

DOE - NASA ▲

MHD PROJECT OFFICE LEWIS RESEARCH CENTER CLEVELAND, OHIO 44135	APPD. H. RIGO DATE 9-25-81
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FOLDOUT FRAME

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SLIDE GATES

SEED SILO
 K_2CO_3

21'-6"

25'-0"

GRADE

33'-6"

VERTICAL
SCREW CONVEYOR

SCREW CONVEYOR

SECTION A-A
PLAN DWG. 240-002-003

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FOLDOUT FRAME 2

SLIDE GATES

SEED SILO
K₂SO₄

50'-0"

SCREW CONVEYOR TO LOCK HOPPERS



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MAGNETOHYDRODYNAMICS
ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN

SEED UNLOADING & STORAGE AREA

SECTION 200 MW SDD-302

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LEWIS RESEARCH CENTER CLEVELAND, OHIO 44135 DATE 9-25-81

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APPENDIX BETF SEED MANAGEMENT TASK - ESTIMATE OF CONDENSATE AND SOLIDS FLOW RATESINTRODUCTION

A Chemical Equilibrium Calculation (CEC) using the ETF design coal was made. The coal analysis used in the CEC study is given in Table B1. Pressures, temperatures, and material inputs were taken from the ETF Heat and Mass Balance, Drawing 8270-1-540-314-001.

Because of the chemical changes that occur along the MHD flow path, the amounts and compositions of the condensates present at any state point are different until the temperature drops below about 1,400°F. At this point, the system composition is essentially frozen. Therefore, although additional condensation may occur at lower temperatures, the composition of the condensate does not change.

In order to remove material from the system, it must be in a condensed phase, i.e., liquid or solid. At temperatures above 1,400°F some of the constituents normally considered as ash at room temperature are not condensed, but are in the vapor phase. Examples are the oxides of calcium, magnesium, or sodium. Some compounds of these elements may be present as condensates, such as magnesium silicate, but magnesium may still be present in the vapor phase.

In Figures B1 and B2 below, the term "ash" is used to designate only the condensed phases which may not contain all of the ash forming species fed into the system. Therefore, since only condensed phases are represented, and these are changing in composition and amount, a simple mass balance is not possible from the data in these Figures.

The CEC analysis showed that condensate and solids removed from the Primary Combustor and the Radiant Boiler are predominantly ash. At the Combustor, 65 percent of the incoming coal ash (88 percent of the condensed phase present) is removed. Another 11.8 percent of this incoming coal ash (86 percent of the condensed phase present) and, when present, 10 percent of the recycled ash are removed at the Radiant Boiler along with a slight fraction of "tied-up" seed.

A smaller proportion of the recycled ash is removed because more of this ash is in the vapor phase than is the fresh ash. Recycling concentrates the more volatile constituents of the fresh ash which are not removed from the Combustor into the recycled ash.

Removal of the seed dominated flow streams occurs in the convective section of the HR/SR and in the Electrostatic Precipitator (ESP). Two sets of calculations were performed to assess 1) the effect of using a sufficient amount of the recovered seed (contaminated with fly ash) to provide the potassium sulfate seed-fraction input required by the combustor and 2) the effect of using once-through flow of fresh seed with no on-site recycling. The partial recycle of recovered seed was selected as the mode of operation for design of the reference ETF Seed Management System.

TABLE B1
ETF DESIGN
COAL ANALYSIS USED IN CHEMICAL EQUILIBRIUM
CALCULATIONS OF THE
SEED MANAGEMENT SYSTEM

<u>Component</u>	<u>Weight %</u>
Carbon	59.45
Carbon Dioxide	18.04
Hydrogen	4.25
Nitrogen	0.97
Oxygen	2.46
Sulfur	1.05
Water	5.00
Aluminum Oxide	1.91
Calcium Oxide	1.21
Ferric Oxide	0.56
Potassium Oxide	0.06
Magnesium Oxide	0.44
Silicon Dioxide	4.22
Sodium Oxide	0.34
Phosphorous Pentoxide	0.04
Ash	10.70
HHV (Btu/lb)	10,960

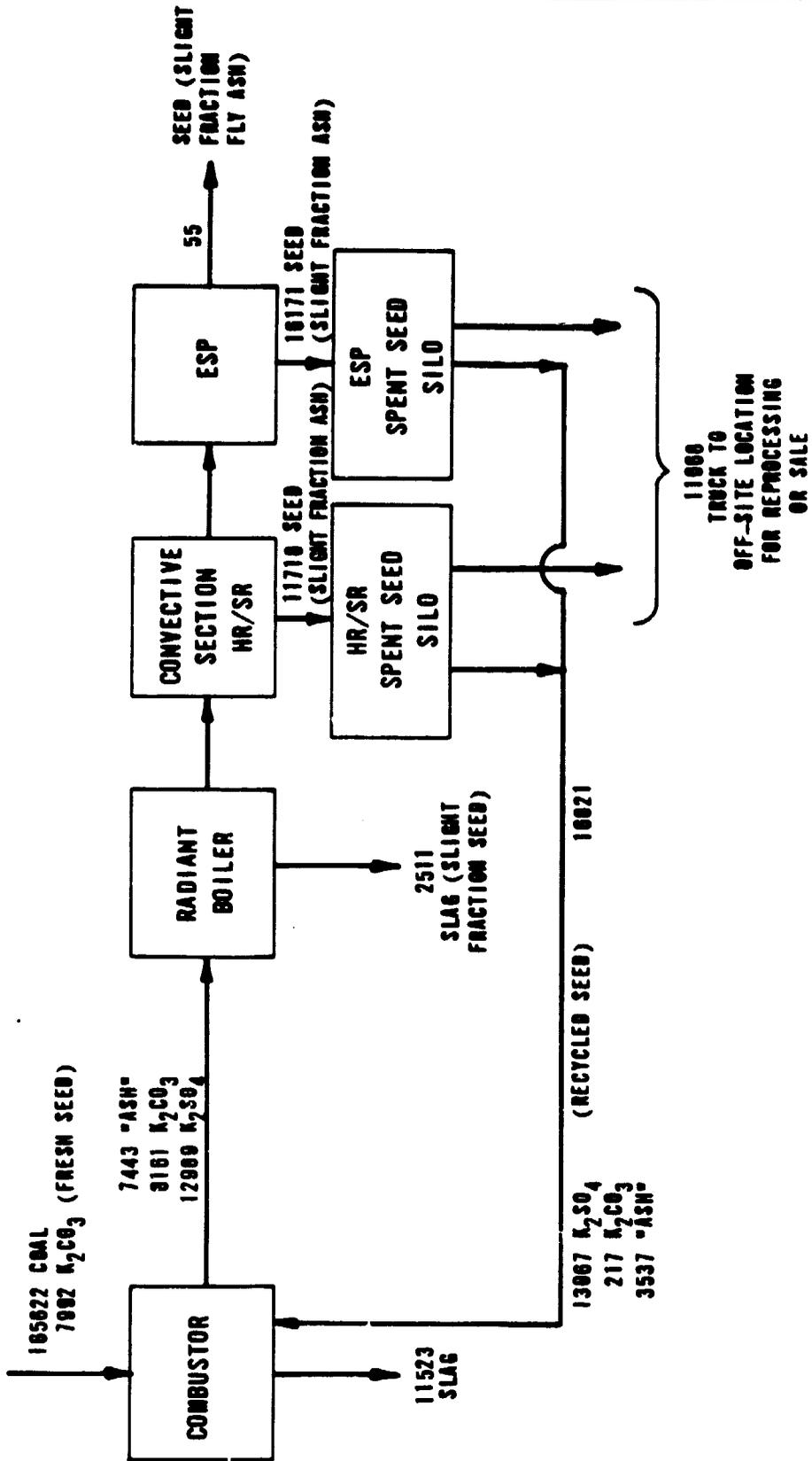
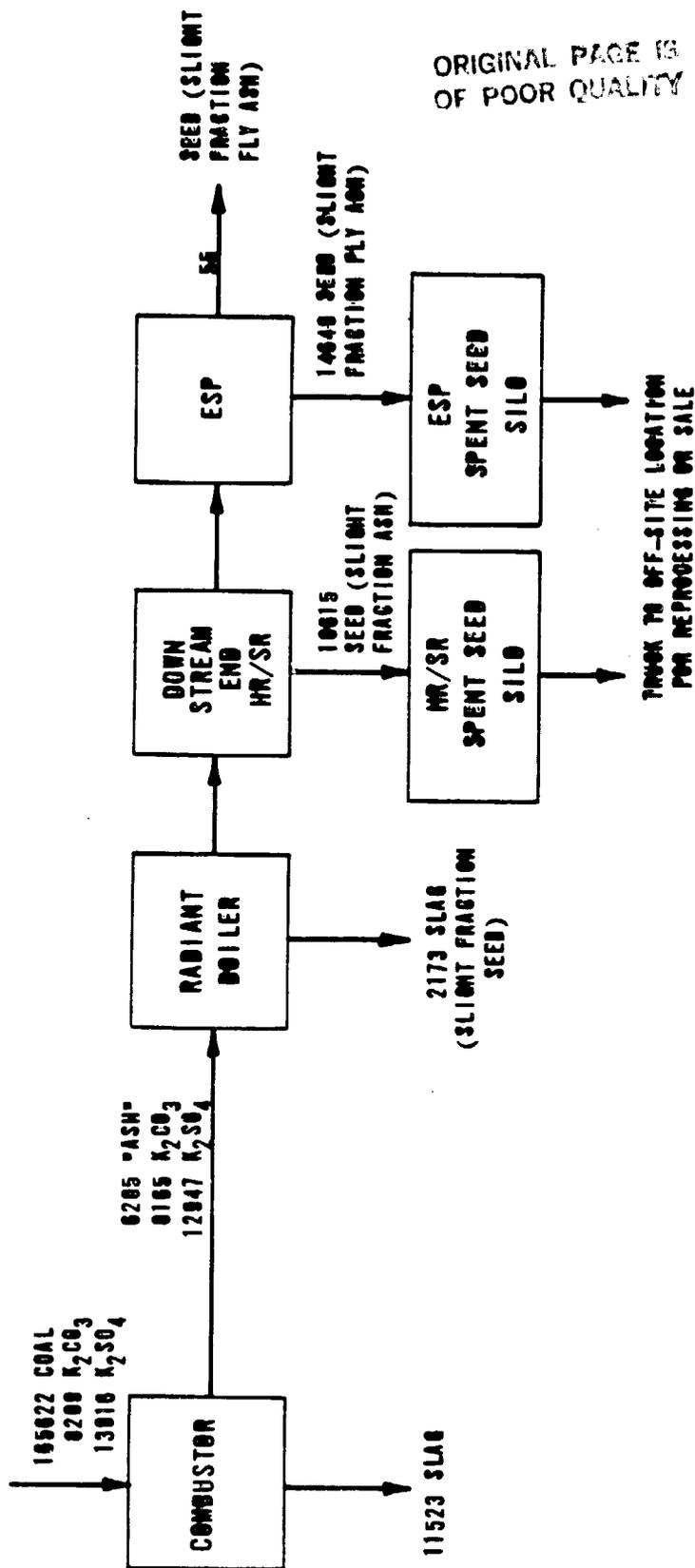


FIGURE B1
 DOMINANT FLOWS (IN LB/HR) IN THE ETF REFERENCE SEED MANAGEMENT
 SYSTEM WHICH EMPLOYS PARTIAL RECYCLE OF RECOVERED SEED



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FIGURE B2
DOMINANT FLOWS (IN LB/HR) IN THE ETF SEED MANAGEMENT SYSTEM WITH
ONCE-THROUGH FLOW OF FRESH SEED

PARTIAL RECYCLE OF RECOVERED SEED

Figure B1 shows the dominant seed and ash flow paths in the ETF when a sufficient fraction of recovered seed is recycled to the Combustor so as to require a fresh supply of only potassium carbonate. Steady state equilibrium is essentially obtained after five cycles of seed flow. Composition and states of the seed and ash are given in Table B2.

Since the recycle seed is introduced near the Combustor exit, the Combustor slag rejection is unaffected by the recycle ash in the recovered seed flow. Liquid potassium sulfate seed condenses first in the HR/SR, followed by solidification and the appearance of solid potassium carbonate in the Intermediate Temperature Oxidant Heater Section of the HR/SR. Only the seed at the downstream end of the HR/SR is recovered. A small fraction of seed is lost to the system as a result of being chemically combined with the slag rejected from the Radiant Boiler.

At the ESP, 78.82 percent of the solids in the flue gas are seed compounds. Of the 27,889 lb/hr of seed removed, 16,821 lb/hr, or 60 percent can be recycled to the Combustor. The make-up potassium carbonate is 7,992 lb/hr compared to 8,209 lb/hr for a once-through flow of seed. This results from the 217 lb/hr of K_2CO_3 in the recycle stream. The potassium in the aluminosilicate compounds is also available, since it will be vaporized at channel temperatures but its amount (65 lb/hr) is negligible compared to the total potassium requirement of 10,450 lb/hr. The recycle stream contains 3,537 lb/hr of "ash".

The fly ash disposed of (40 percent or 11,068 lb/hr), plus the ash removed from the Radiant Boiler, and the 55 lb/hr passing through the stack, equivalent to the EPA emission standard of 0.03 gr./scf, will contain 3.14 percent of the seed potassium tied up in the aluminosilicate, compared to the 2.68 percent for once-through flow of seed.

Partial recycling of the recovered seed has several effects. The recycled seed contains ash which has the effect of increasing the ash in the channel and downstream components to the equivalent of a coal with 12.8 percent ash instead of 10.7 percent ash. This reduces the plasma temperature by an insignificant 15°F and the conductivity by 4.6 percent. The recycled seed/ash increases mass flow in the channel. At steady state, about 50 additional pounds of recycled seed/ash is required because of the increased mass flow. No additional potassium carbonate is required since no additional new sulfur is added by the recycle stream.

This analysis of the partial recycle case was carried out in order to establish a preferred mode of operation with respect to the use of recycled seed within the seed management subsystem. It was beyond the scope of the seed management study to rebalance the entire ETF system assuming the injection of recycled seed. For this reason the once-through seed injection rate is shown on the system heat and mass balance diagram (Drawing 8270-1-540-314-001).

TABLE B2
COMPOSITION AND STATE OF FLOWS REMOVED AS SEED AND
ASH FOR THE PARTIAL RECYCLE OF SEED

State Point	(Weight %)				
	Primary Combustor (mainly ash)	Radiant Boiler (mainly ash)	Convective Section HR/SR (mainly seed)	ESP (mainly seed)	Stack
Temperature (°F)	3,462	2,190	481	481	228
Al ₂ O ₃	S* 23.58	S 2.15	S 0.47	S 0.47	S 0.47
CaCO ₃			S 1.08	S 1.08	S 1.08
CaO	S 15.09	S 10.47			
FeO	L 2.95	S 19.50			
Fe ₃ O ₄			S 1.13	S 1.13	S 1.13
MgCO ₃			S 0.43	S 0.43	S 0.43
MgO		S 3.74			
MgSiO ₃	L 13.75				
NaAlO ₂		S 1.22			
Na ₂ CO ₃			S 14.48	S 14.48	S 14.48
SiO ₂	L 4.46				
KAlSi ₃ O ₈	L 3.17	L 62.93	S 3.59	S 3.59	S 3.59
K ₂ CO ₃			S 1.29	S 1.29	S 1.29
K ₂ SO ₄			S 77.53	S 77.53	S 77.53
Weight (lb/hr)	11,523	2,511	11,718	16,171	55

*S = Solid

L = Liquid

ONCE-THROUGH FLOW OF FRESH SEED

In the once-through flow of fresh seed, the amounts and compositions of the materials removed from the system are given in Table B3. The flow diagram of this process is given in Figure B2. The slag rejected from the Combustor is mostly liquid containing some solids. Sixty-seven percent of the potassium in the coal is rejected here. Radiant Boiler slag is also a liquid-solid mixture. Despite the large percentage of potassium aluminosilicate present, only 1.83 percent of the total seed is lost here.

Seed first condenses in the Afterburner Section of the Radiant Boiler under oxidizing conditions (as liquid potassium sulfate at 2,400°F). In the Intermediate Temperature Oxidant Heater of the HR/SR (at 1,593°F), the sulfate has solidified and solid potassium carbonate also appears. Additional seed comes out along the HR/SR flow path. Seed is recovered from the HR/SR at the downstream end as shown in the ETF Heat/Mass Balance, 8270-1-540-314-001. In the ESP (at 481°F), 93.72 percent of the solids in the flue gas are seed compounds. An additional 0.85 percent of the seed potassium is tied up in the aluminosilicate. Thus, overall, 2.68 percent of the seed potassium is lost to the slag.

The allowable particulate emission, based on EPA 1979 New Source Performance Standard of 0.03 lb/MBtu, is 55 lb/hr. The ESP efficiency must be at least 99.6 percent to meet this limit. If compounds such as calcium phosphate are present, they would probably condense at sufficiently high temperatures to be removed by the ESP.

DISCUSSION

Figures B1 and B2 show the calculated equilibrium and steady state flows for both Partial Recycle of Recovered Seed and Once-Through Flow of Fresh Seed. Recycling of seed removes the need for fresh potassium sulfate seed, and reduces the shipped quantities of both fresh potassium carbonate seed and spent seed for either off-site sale or reprocessing. It also increases total mass flow slightly, lowers plasma temperature slightly, lowers conductivity slightly and increases potassium loss slightly. It also increases the waste holding volume for ash slightly, but reduces the waste holding volume for seed compounds containing fly ash by a significant 45 percent.

The Partial Recycle of Recovered Seed thus appears the preferable process and is used as the reference process for the ETF Seed Management System.

TABLE B3
COMPOSITION AND STATE OF FLOWS REMOVED AS SEED AND
ASH FOR ONCE-THROUGH FLOW OF FRESH SEED

<u>State Point</u>	(Weight %)				
	<u>Primary Combustor (mainly ash)</u>	<u>Radiant Boiler (mainly ash)</u>	<u>Convective Section HR/SR (mainly seed)</u>	<u>ESP (mainly seed)</u>	<u>Stack</u>
Temperature (°F)	3,462	2,190	481	481	228
Al ₂ O ₃	S* 23.58	S 2.08	S 0.14	S 0.14	S 0.14
CaCO ₃			S 0.32	S 0.32	S 0.32
CaO	S 15.09	S 10.42			
FeO	L 2.95	S 19.58			
Fe ₃ O ₄			S 0.34	S 0.34	S 0.34
MgCO ₃			S 0.11	S 0.11	S 0.11
MgO		S 3.75			
MgSiO ₃	L 13.75				
NaAlO ₂		S 1.25			
Na ₂ CO ₃			S 4.32	S 4.32	S 4.32
SiO ₂	L 41.46				
KAlSi ₃ O ₈	L 3.17	L 62.92	S 1.07	S 1.07	S 1.07
K ₂ CO ₃			S 1.34	S 1.34	S 1.34
K ₂ SO ₄			S 92.38	S 92.38	S 92.38
Weight (lb/hr)	11,523	2,173	10,615	14,649	55

*S = Solid
L = Liquid

SYSTEM DESIGN DESCRIPTION

SDD-351

SLAG MANAGEMENT SYSTEM

FOR

MAGNETOHYDRODYNAMICS

ENGINEERING TEST FACILITY

CONCEPTUAL DESIGN - 200 MWe POWER PLANT

FLUID SYSTEM DIAGRAM NO. 8270-1-451-302-351

[Signature] 2/27/81

SYSTEM ENGINEER DATE

Paul L. Lamotte 3/27/81

REVIEWED DATE

[Signature] 3/27/81

APPROVED DATE

Revision: 1
Date: September 25, 1981

Approved _____

MHD-ETF PROJECT
 SYSTEM DESIGN DESCRIPTION
SLAG MANAGEMENT SYSTEM

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REFERENCE DOCUMENTS - NOT ATTACHED		

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1.0 FUNCTION AND DESIGN REQUIREMENTS

This document presents a description of the Slag Management System as depicted on Flow Diagram 8270-1-451-302-351 and Plot Plan 8270-1-210-007-001.

The document includes a description of system functions, interfaces with other systems, equipment and piping requirements, design criteria, description of components, operating modes, and safety and maintenance requirements.

1.1 FUNCTIONAL REQUIREMENTS

Slag management consists of collecting, grinding, separating and transporting the condensed mineral fraction of the coal after combustion. The slag collected from the combustor and radiant boiler is ground and hydraulically transported to one of two dewatering bins. Dewatered slag is removed from the site by trucking or may be transported hydraulically to the slag disposal pond. Clear water from the dewatering bin is further allowed to settle in a recirculating and settling (R&S) tank, and is then returned to the pump inlet header for reuse by the makeup, recirculating and sluice pumps. The sludge water from the R&S tank is recycled to one of the two dewatering bins for further settling. The slag sluicing water also picks up pyrites collected at the coal pulverizers and dumps them into the radiant boiler slag hopper.

1.2 SYSTEM INTERFACES

Major equipment in the Slag Management System are: two dewatering bins, R&S tank, two makeup pumps, two recirculating pumps, two sluice pumps, two slag water recirculation pumps and one sump water pump. The Slag Management System interfaces with the MHD Power Train, Heat Recovery/Seed Recovery (HR/SR), and Circulating Water Systems. The Slag Management System also interfaces with the pyrite hoppers at the coal pulverizers.

1.3 DESIGN CRITERIA

The system continuously receives ground slag from the combustor slag subsystem and ground slag from the radiant boiler hopper at the combined rated capacity of 7 tons per hour as shown on the Heat and Mass Balance Diagram, 8270-1-540-314-001. The design is in accordance with the applicable codes, standards, and guides issued by governmental agencies, recognized standards organizations, and Gilbert Associates, Inc.

1.3.1 Codes and Standards

System engineering design is in accordance with applicable codes, standards, and guides issued by the following organizations:

1. American National Standards Institute (ANSI)
2. American Society of Mechanical Engineers (ASME)
3. American Society for Testing and Materials (ASTM)
4. American Welding Society (AWS)
5. Manufacturers Standardization Society of the Valve and Fitting Industry (MSS)

6. Pipe Fabricators Institute (PFI)
7. Occupational Safety and Health Administration (OSHA)
8. Instrument Society of America (ISA)
9. National Fire Protection Association (NFPA)

1.3.2 Design Parameters

The Slag Management System is designed to handle 10 tons per hour of combustor slag and 2-1/2 tons per hour of radiant boiler slag. The arrangement of equipment is shown on the slag handling flow diagram (8270-1-451-302-351). The water/slag slurry velocity in the piping is limited to 9 feet per second.

2.0 DESIGN DESCRIPTION

The Slag Management System provides for receiving, sluicing, and separation of ground slag from sluice water, and transporting slag off site by truck. The major components are described in the Summary Description, Section 2.1.

2.1 SUMMARY DESCRIPTION

At rated capacity, the ETF plant will consume 101.7 tons per hour of coal (22.7 percent moisture and 8.7 percent ash, by weight). However, with the worst coal analysis (27.0 percent moisture and 12.0 percent ash, by weight), the ETF plant will consume 108.0 tons per hour of coal. It has been calculated that a maximum of 9.75 tons per hour of slag (75 percent by weight of the incoming slag) may be collected by the combustor slag handling system; therefore, the equipment is designed to handle 10 tons per hour on a continuous basis.

Based on 50 percent by weight removal of the incoming slag, the radiant boiler slag handling system is designed for a capacity of 2-1/2 tons per hour. The slag has been ground to size 2 inches and smaller by the HR/SR equipment. Sluice pumps provide water to transport the ground slag, collected beneath the combustor final slag collection tank and the radiant boiler hopper (and the pyrites from the coal pulverizers) to one of the two dewatering bins. Settled slag from the dewatering bins is transported by truck to off-site disposal. Clear water from the dewatering bin is transferred to the R&S tank. Settled slag fines from the R&S tank are recycled to one of the two dewatering bins. If the dewatering bins cannot be used, the sluiced slag may be routed to a slag disposal pond.

EQUIPMENT CAPACITY REQUIREMENTS

Shifts (8 hr) Operating	3	2	1
	continuous	-	-
Combustor, ton/hr	5.8	8.6	17.3
Radiant Boiler, ton/hr	1.1	1.7	3.3

The above tabulation shows the operating time required at full load to remove the slag ash when firing specified coal. With the combustor ash removal

The above tabulation shows the operating time required at full load to remove the slag ash when firing specified coal. With the combustor ash removal equipment designed to handle 10 tons per hour and the radiant boiler designed for 2-1/2 tons per hour, all the equipment must be operating for more than one eight hour shift. If a run of poor coal (high ash) is burned, the equipment could still handle the slag in less than three shifts.

2.2 DETAILED DESCRIPTION

2.2.1 Major Equipment

The integrated Slag Management System is composed of the following major components:

1. Combustor Slag Tanks and Grinders (MHD Power Train)
2. Radiant Boiler Slag Hopper and Grinders (HR/SR System)
3. Recirculating and Settling Tank
4. Makeup, Recirculating and Sluice Pumps
5. Slag Water Recirculating Pumps
6. Dewatering Bins
7. Slag Disposal Pond
8. Sump Water Pump

As shown on the GA1 drawing 8270-1-451-302-351, two slag discharge openings are located on the HR/SR radiant boiler furnace bottom. A maximum of 2-1/2 tons per hour of disintegrated and ground slag from the radiant boiler hopper outlets is removed by ash jet pumps. Also, two slag discharge openings are located on the combustor final slag tank, from which a maximum of 10 tons per hour of ground slag is removed by ash jet pumps. Grinders reduce the size of the larger pieces of clinker and slag to 2 inches and smaller to permit handling by the ash jet pumps which convey the slag/water slurry to the dewatering bins. Makeup water for the system is provided from cooling tower blowdown.

A total of 1,800 gpm of water at 300 psig is required to transport the ground combustor slag via the ash jet pumps to one of the two dewatering bins. The dewatering bins, each 175 ton capacity, are equipped with an automatic cylinder operated discharge gate. Simultaneously, the slag which has settled in the other dewatering bin is drained, unloaded on to trucks, and transported off site. An air operated balancing valve is provided in the discharge line after each jet pump so it can be isolated from the rest of the system. An air operated balancing valve with limit switches is provided in each line at the dewatering bins so that ash (ground slag) can be discharged to either one of the two bins. Alternately, the water/slag slurry may be bypassed around the dewatering bins and routed to the slag disposal pond. Whenever the conveying operation is finished, the lines are flushed and drained to prevent slag accumulation and freezing during winter operation. Downstream of the ash jet pumps, a hand hole for clean out is provided for manual cleaning of plugged lines.

The water drained from the dewatering bins is allowed to settle in the R&S tank located beneath the dewatering bins. Conveying water overflows and also drains from the dewatering bins into this tank. Dewatering elements inside

the bin provide the final drainage necessary to obtain dewatered ash. High and low water levels are monitored in the R&S tank by a level switch (LS) and an emergency high level/overflow indicator. The settled fines are recirculated by jet pumps to a dewatering bin, thus completing a cycle in the system. The clear water from the R&S tank is returned to the inlet header to be reused by makeup, recirculating and sluice pumps.

Coal pulverizer rejects called "pyrites" are handled hydraulically as an adjunct to the Slag Management System. Pyrite storage hoppers are mounted below each coal pulverizer discharge spout to receive the rejects continuously. At the outlet of each pyrite hopper is a water jet pump. Circulated sluice water transfers the pyrites rejects to the radiant boiler slag hopper. A hand hole for clean out is provided to manually clean the plugged lines, if required.

The sluice pumps supply clear water to the grinders, to the agitating water nozzle supply ring located on the radiant boiler hopper, and to the ash jet pumps.

Recirculating pumps supply a total of 250 gpm of water for cooling the refractory lining, and to maintain the proper water level in the MHD Power Train combustor slag collection tanks and the HR/SR radiant boiler slag hopper.

Two makeup pumps supply a total of 500 gpm filtered water at 125 psig to the slag breakers and for flushing the slag during the unloading operations.

Two slag water recirculation pumps are provided at the slag disposal pond to reclaim water for use in the system. The pumps are sized to return 125 gpm to the R&S Tank.

A sump water pump provides water to a hydro-ejector to remove water and ash fines from the system area sump. The sump discharge is conveyed to the R&S Tank.

A slag disposal pond for alternate disposal of sluiced slag is located in the southwest area of the plant site as shown on GAI drawing 8270-1-210-007-001 "Plot Plan." The total area covered by the Slag Disposal Pond, item 47, is approximately 108,000 sq. ft.

TABLE 1

PUMP REQUIREMENTS

<u>Equipment</u>	<u>Number Required</u>	<u>Head/Capacity</u>
Makeup Pump	2	125 psig/250 gpm
Recirculating Pump	2	125 psig/125 gpm
Sluice Pump	2	300 psig/900 gpm
Slag Water Recirculation Pump	2	125 psig/125 gpm
Sump Water Pump	1	125 psig/50 gpm

2.2.2 Piping and Valves

The crushed slag slurry is transported through rubber lined carbon steel pipes, or pipe made of hard cast iron. The maximum velocity is 9 feet per second. Where high abrasive wear is anticipated, the pipe and fittings are made from heavy gauge metals.

Selected valves are shown on the drawings listed under Section 1.0. All the valves are designed in accordance with ANSI, MSS and the ASME Boiler and Pressure Vessel Codes.

2.2.3 Electrical

Electrical power is required at 480 volts, 3 phase at 60 Hz.

2.2.4 Instruments, Controls, and Alarms

Instruments are placed at locations commensurate with good design practice to monitor system performance. These instruments protect against overloading any equipment with slag or loss of circulating water flow. The majority of the control switches and instrument readouts for each operation are located with their respective equipment. Only major instrument readouts are monitored by the Main Control Room Computer.

3.0 SYSTEM PROTECTION AND SAFETY PRECAUTIONS

3.1 PROTECTIVE DEVICES

Of the instruments and controls discussed under Section 2.2.4, the following are equipped with protective devices:

1. Power supply for makeup pumps, recirculating pumps, and slag water recirculating pumps.
2. Power supply for the grinders located at the combustor slag tanks and the radiant boiler slag hopper.
3. Power supply for the sluice pumps.
4. Level control switches at the head tank, and at the R&S tank.

3.2 HAZARDS

Leaching of sluice water from the slag disposal pond must be avoided.

3.3 PRECAUTIONS

The Slag Management System takes part of its material (slag and water) from the grinders of the Combustor slag tanks. During operation, the Combustor is subject to very high Hall voltage, so the slag tanks must be resistively insulated to bring this Hall voltage down to ground potential at the interface to the Slag Management System. Special precautions must be taken to safeguard

the above interface against high voltage and ensure safe operation of the system. Monitoring by instruments and controls, and the scheduling of maintenance for all the safeguard equipment is required.

4.0 MODES OF OPERATION

4.1 STARTUP

Prior to operating the combustor, all the slag handling equipment will be checked and placed in operation.

4.2 NORMAL OPERATION

During normal operation, the specific required components will be controlled and monitored from the main control room.

4.3 SHUTDOWN

For scheduled shutdown or forced shutdown for an extended period, the combustor and radiant boiler slag handling equipment, dewatering bins, and recirculating and settling tank will be completely evacuated so that the slag does not clog the openings.

4.4 SPECIAL OR INFREQUENT OPERATION

Any problems with the dewatering bins or off-site trucking may require that the slag laden sluice water be diverted to the site slag disposal pond.

5.0 MAINTENANCE

5.1 SURVEILLANCE AND PERFORMANCE MONITORING

Operating personnel will record performance data shown on direct indicating instruments at regular intervals per shift. The in-house computer will constantly monitor specified points on the Slag Management System to give a running check on performance which can be viewed periodically as desired in the plant control room. Alarms will be initiated for off-normal operations.

5.2 INSERVICE INSPECTION

Visual inspection of all equipment, conveyors, instruments, etc., shall be carried out periodically during system operation to ascertain that the subject equipment is operating properly.

5.3 PREVENTATIVE MAINTENANCE

All equipment and motors are to be maintained and operated in accordance with the respective manufacturer's operating and maintenance instructions.

Computerized record keeping is to be used to alert the operating personnel that pieces of equipment need an overhaul, repacking, or cleaning, depending

will be replaced during the planned shutdown if it is near the end of its recommended life cycle.

5.4 CORRECTIVE MAINTENANCE

5.4.1 Manufacturer's Instructions

A complete file of instruction books will be available at the plant to guide the plant personnel in maintenance of any piece of equipment. If necessary, a representative of the manufacturer can be present to supervise the overhaul or replacement of plant equipment.

5.4.2 Spare Parts Inventory

Manufacturers will supply lists of recommended spare parts. Many of these parts will be kept in inventory at the plant. Complex parts requiring long lead time for delivery will be included in the plant inventory.

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
SLAG MANAGEMENT SYSTEM

APPENDIX "A"
REFERENCE DOCUMENTS

REFERENCE DOCUMENTS - ATTACHED

Diagram No.

Fluid System Diagram

Slag Handling

8270-1-451-302-351

REFERENCE DOCUMENTS - NOT ATTACHED

Layout

Plot Plan

8270-1-210-007-001

Plant Heat and Flow Balance Diagram

System Heat Balance

8270-1-540-314-001

SYSTEM DESIGN DESCRIPTION

SDD-371

PLANT INDUSTRIAL WASTE SYSTEM

FOR

MAGNETOHYDRODYNAMICS

ENGINEERING TEST FACILITY

CONCEPTUAL DESIGN - 200 MWe POWER PLANT

FLUID SYSTEM DIAGRAM NO. 8270-1-641-302-371

FLUID SYSTEM DIAGRAM NO. 8270-1-644-302-381

William D. Scott 3-27-81
SYSTEM ENGINEER DATE

Gilbert F. Hill 3-27-81
REVIEWED DATE

John D. Sullivan 3/27/81
APPROVED DATE

Revision: 1
Date: September 25, 1981

Approved: *John D. Sullivan*

**MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
PLANT INDUSTRIAL WASTE SYSTEM**

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1.0 FUNCTION AND DESIGN REQUIREMENTS

This document presents a description of the Plant Industrial Waste System as depicted on Fluid System Diagram 8270-1-641-302-371, Plant Industrial Waste, and 8270-1-644-302-381 Sanitary Waste. The document includes descriptions of system functions, interfaces with other systems, equipment and piping requirements, design criteria, description of components, operating modes, and safety and maintenance requirements.

1.1 FUNCTIONAL REQUIREMENTS

The Plant Industrial Waste System is designed to collect, store, transfer and treat, as necessary, all sources of liquid industrial wastes and sanitary wastes from the plant so that the resulting effluent is in compliance with all local, state and Federal environmental/regulatory agency discharge regulations, as further detailed in Section 1.3.2. Major anticipated or potential sources of plant industrial wastes are as follows:

1. Chimney wash
2. Air heater wash
3. Coal pile runoff
4. Coal shed and building drains
5. Demineralizer regeneration wastes
6. Turbine and compressor room drains
7. MHD power train and HR/SR area drains
8. Water pretreatment/treatment wastes
9. Flyash loading wastes/runoff
10. Slag handling waste overflow/runoff
11. Cooling tower blowdown (Partially reused for slag sluice water makeup)
12. Boiler blowdown (To be normally used as slag sluice water makeup)
13. Chemical cleaning wastes (To be handled by outside chemical cleaning contractor or held for incineration in the boiler)
14. Plant yard drainage
15. Fuel oil unloading/storage area runoff
16. Miscellaneous oil day tank and transformer pits
17. Sanitary wastes

1.2 SYSTEM INTERFACES

Major subsystems of the Plant Industrial Waste System with their major equipment components are as follows:

1.2.1 Coal Pile Runoff (CPR) Treatment

Consisting of the CPR Collection Basin, Dewatering Sump and Pumps, CPR Neutralization Tank, CPR Oxidation/Flocculation Tank, CPR Gravity Settler and related agitators, chemical feeds, controls and piping.

1.2.2 Demineralizer Regeneration Wastes Batch Treatment

Consisting of Batch Demineralizer Equalization/Neutralization Tank, Demineralizer Wastes Transfer Pumps, and related agitators, chemical feeds, controls and piping.

1.2.3 Plant Building Drainage/Sumps

For the Turbine and Compressor Room drains, MHD Power Train and HR/SR area drains and other building drains. Each subsystem consists of the building floor drain system, sump, sump pumps and related piping and controls. An Oil/Water Separator is provided for drains where the potential of oil contamination exists.

1.2.4 Main Wastewater Treatment

Consisting of the Waste Collection and Equalization Tank, Waste Transfer Pumps, Acid Neutralization Tank, Lime Neutralization Tank, Flocculation Tank, Gravity Settler/Thickener, Polishing Filter, Effluent Flow and Sampling Chamber and related agitators, chemical feeds, controls and piping.

1.2.5 Waste Sludge

Consisting of Sludge Pumps, Sludge Holding Tank, Sludge Filter Press and related controls and piping.

1.2.6 Fuel Oil Unloading/Storage Area Runoff Treatment

Consisting of containment facilities, collector pans, drainage collection piping, Oil/Water Separator, Oil Reclaim Tank and related controls and piping.

1.2.7 Plant Yard Runoff

Consisting of the yard drainage piping, Plant Yard Runoff Basin and Effluent Monitoring.

1.2.8 Chemical Feed

Consisting of two sulfuric acid feeds, one caustic feed, one lime slurry feed and polyelectrolyte feed equipment.

1.2.9 Plant Sanitary Wastes

Consisting of a package extended aeration, activated sludge, sewage treatment plant at the main MHD plant and an underground septic tank and pump station at the coal control building.

The Plant Industrial Waste System interfaces with other major systems which generate industrial wastes, such as:

- Boiler Feedwater
- Condensate
- Feedwater Heater & Miscellaneous Drains, Vents and Reliefs
- Plant Makeup Water
- Circulating Water
- Fuel Oil
- Slag Management
- Seed Management

1.3 DESIGN CRITERIA

Design criteria cover the fluid flow requirements, pressure-temperature ratings, and system limits to be used in the selection of the required components.

Engineering design criteria for all disciplines is in accordance with applicable codes, standards, regulations, and guidelines issued by governmental agencies, recognized standards organizations, and Gilbert Associates, Inc.

1.3.1 Codes and Standards

System engineering design is in accordance with applicable codes, standards, and guidelines issued by the following organizations:

1. American National Standards Institute (ANSI)
2. American Society of Mechanical Engineers (ASME)
3. American Society for Testing and Materials (ASTM)
4. American Welding Society (AWS)
5. Manufacturers Standardization Society of the Valve and Fittings Industry (MSS)
6. Pipe Fabrication Institute (PFI)
7. Occupational Safety and Health Administration (OSHA)
8. Instrument Society of America (ISA)
9. National Fire Protection Association (NFPA)
10. U.S. Environmental Protection Agency (EPA)
11. Hydraulics Institute Standards (HSI)
12. American Water Works Association (AWWA)

1.3.2 Design Parameters

The Industrial Wastewater Treatment System is designed to treat plant liquid wastes such that all discharges are in compliance with U.S. EPA, state and local discharge regulations. All plant components are constructed of corrosion resistant materials, suitable for the wastes being handled. Based on the Effluent Limitations, Guidelines, Pretreatment Standards and New Source Performance Standards Under Clean Water Act; Steam Electric Power Generating Point Source Category, EPA, Federal Register of October 14, 1980 for new sources, the limitations to be met are:

General (All Discharges)

- | | |
|--|-----------|
| 1. pH range | 6.0 - 9.0 |
| 2. No discharge of polychlorinated biphenyls | |

Low Volume Wastes (Includes Boiler Blowdown) 30-day avg. 1-day max.

Multiply low volume wastes flow by the following concentrations:

- | | | |
|---------------------------|---------|----------|
| 1. Total suspended solids | 30 mg/l | 100 mg/l |
| 2. Oil and grease | 15 mg/l | 20 mg/l |

Metal Cleaning Wastes 30-day avg. 1-day max.

Multiply metal cleaning wastes flow by the following concentrations:

1. Total suspended solids	30 mg/l	100 mg/l
2. Oil and grease	15 mg/l	20 mg/l
3. Total copper	1.0 mg/l	1.0 mg/l
4. Total iron	1.0 mg/l	1.0 mg/l

Sanitary Wastes

1. Biochemical oxygen demand 5-day	TBD	TBD
2. Total suspended solids	TBD	TBD

Cooling Tower Blowdown 30-day avg. 1-day max.

1. Total residual chlorine (TRC)	-	0.14 mg/l
2. No discharge of cooling tower maintenance chemicals which contain any of the 129 priority pollutants (Appendix B FR, Oct. 14, 1980).		
3. Discharge must be made from cold side of circulating water system.		

Fly Ash Transport Water

1. No discharge of fly ash transport water; new sources shall utilize dry fly ash handling systems.

Bottom Ash Transport Water

Multiply transport water flow by following concentrations:

1. Total suspended solids	30 mg/l avg.	100 mg/l max.
2. Oil and grease	15 mg/l avg.	20 mg/l max.

Coal Pile Runoff

1. System shall be designed to handle the runoff from a once-in-10 year, 24 hour rainfall event; runoff in excess of this event is not subject to limitation 2 below.
2. Total suspended solids 50 mg/l

2.0 DESIGN DESCRIPTION

The Plant Industrial Waste System consists of sumps, pumps, tanks, basins, separators, piping, valves and controls. The major equipment components are covered in Section 1.2.

2.1 SUMMARY DESCRIPTION

The Plant Industrial Waste System is provided to collect and treat all plant industrial wastes or potential wastes, such that the resulting effluent is in compliance with all regulatory agency discharge regulations. Description of the major sub-systems comprising the Plant Industrial Waste System follows:

2.1.1 Coal File Runoff (CPR) Treatment

Diking and trenching are provided around coal storage piles to prevent extraneous surface runoff from entering the piles and to collect all contaminated runoff from the piles for subsequent treatment. Runoff is directed to a lined CPR collection basin. Runoff in excess of the once-in-10 year, 24 hour rainfall may overflow the sump directly to the storm sewer. Coal thaw shed and control building drains and water from the dust suppression system are directed to a sump and then pumped to the CPR collection basin. Large coal particles are settled and retained in the basin. These particles are periodically removed and reclaimed to the coal storage piles. The basin is provided with a dewatering structure which discharges to the basin dewatering sump. CPR dewatering pumps take suction from the sump and convey the runoff water to the CPR neutralization tank at a controlled rate.

In the CPR neutralization tank, runoff is completely mixed with a lime slurry solution by a mechanical agitator to raise the pH and precipitate heavy metals such as iron. A pH electrode mounted in the tank provides input to a controller to regulate addition of lime slurry through an air-operated pinch valve. Overflow from the CPR neutralization tank enters the CPR oxidation/flocculation tank. Tank contents are air-agitated to oxidize iron from the ferrous to ferric state. A polyelectrolyte solution is metered into the wastewater to aid in flocculation. Overflow from the CPR oxidation/flocculation tank enters a lamella type gravity settler to remove suspended solids as a waste sludge. Due to the wide variations in the raw coal pile runoff, clarified, neutralized effluent from the gravity settler may be directed to the waste collection and equalization tank for further treatment with other plant industrial wastes, or otherwise directed to the polishing filter system. Gravity settler sludge is pumped to the sludge holding tank where it combines with other waste sludges for final dewatering.

Chimney wash and air heater wash waters are likely to be acidic and contain fine ash particles. Therefore, these wash waters are to be directed to the CPR basin dewatering sump where they can be fed at a controlled rate through the CPR treatment system.

2.1.2 Demineralizer Regeneration Wastes Batch Treatment

Acid and alkaline wastes from the regeneration of makeup demineralizers and condensate demineralizers are directed to the batch demineralizer equalization/neutralization tank located near the demineralizers to combine and take advantage of self-neutralizing capacity. The combined wastes are agitated and analyzed for pH. Sulfuric acid or caustic are metered via chemical metering pumps from the respective bulk acid or caustic storage tanks as required to "rough" neutralize the wastes. Neutralized wastes are conveyed

via the demineralizer waste transfer pumps to the waste collection and equalization tank for further treatment with other in-plant wastes.

2.1.3 Plant Building Drainage/Sumps

The various buildings throughout the main plant have floor drain systems and sumps. Each building will be evaluated for potential oil contamination which may enter into the floor drainage system. For those buildings where little or no oil contamination is likely, the sumps are equipped with duplex sump pumps and an automatic level control system to direct floor drainage to the waste collection and equalization tank. For those buildings where oil contamination is possible, each sump is baffled to provide oil intercepting capacity. Oil may then be manually skimmed off the water surface into drums. Duplex sump pumps with an automatic level control system, convey wastewaters to the oil/water separator (coalescer) in the waste treatment building where any remaining oil is separated and removed to the waste oil holding tank for reclaim or disposal. Wastewater from the separator is directed to the waste collection and equalization tank for further treatment with other in-plant wastes.

2.1.4 Main Wastewater Treatment

All in-plant wastes are directed to the waste collection and equalization tank. In addition to the pretreated in-plant wastes discussed in Sections 2.1.1 through 2.1.3, the following wastes are directed to the waste collection and equalization tank:

1. Water pretreatment/treatment wastes such as sludges and filter backwash.
2. Flyash loading wastes/runoff. Flyash is dry conveyed from the HR/SR area into bulk silos, from which it is dumped into trucks for hauling to off-site recovery. Ash which spills on the ground under the silos will be contained and any water runoff from the area is directed to the slag disposal pond. Any pond overflow and excess water used for dust control will be directed to the waste collection and equalization tank.
3. Slag handling wastes overflow/runoff. Slag and pyrites are sluiced as a slurry to dewatering bins. From the bins thickened slag is loaded into trucks for offsite disposal. Slag which spills on the ground under the bins shall be contained and removed to the slag disposal pond. Any pond overflow or excess sluice water will be directed to the waste collection and equalization tank.

A mechanical agitator is provided in the waste collection and equalization tank. Wastewaters are allowed to equalize both hydraulically and chemically. Wastewaters are pumped via duplex wastewater transfer pumps at a flow-controlled rate to the acid neutralization tank. The tank is equipped with a mechanical agitator and pH controller which regulates feed of dilute sulfuric acid from the dilute sulfuric acid makeup tank to lower the pH and provide excess alkalinity reduction. Overflow from the acid neutralization tank enters the lime neutralization tank. The tank is equipped with a mechanical agitator and pH controller which regulates feed of lime slurry from

the lime slurry makeup tank to raise the pH and precipitate solids. Lime neutralization tank overflow enters the flocculation tank. The tank is equipped with a variable speed mechanical agitator and a polyelectrolyte feed system. Floc is formed at low speed agitation. The flocculation tank overflows into the gravity settler/thickener where suspended solids are separated and removed as a thickened sludge. A portion of the sludge is recirculated back to the flocculation tank to act as seed in floc formation. Waste sludge is pumped to the waste sludge holding tank for further dewatering.

Gravity settler overflow is directed to a packaged, automatic, final polishing filter system to remove small suspended matter to below the effluent limitations. A bypass is provided around the final polishing filter system should the gravity/settler effluent be satisfactory for discharge or reuse. Filter system backwash is directed back to the waste collection and equalization tank. Filtered wastewater is directed to the effluent flow and sampling chamber, which is equipped with an effluent flow recorder, effluent pH recorder, and effluent automatic sampler. Treated effluent may be discharged or reused for ash sluicing or chimney or air heater washwater.

2.1.5 Waste Sludge

Waste sludge is pumped from the CPR gravity settler and the main wastewater treatment gravity settler/thickener to the waste sludge holding tank. Sludge level controls provided at the settlers determine the waste sludge rate. When sufficient sludge has accumulated for sludge dewatering, sludge will be pumped to the filter press (or belt filter). Sludge is dewatered to a filter cake which can be dumped into a truck for hauling offsite. Press filtrate is directed back to the waste collection and equalization tank.

2.1.6 Fuel Oil Unloading/Storage Area Runoff Treatment

The fuel oil, rail unloading area is furnished with track collector pans and drainage pipes to direct all runoff through an oil/water separator prior to discharge to the storm sewers. Similarly, the fuel oil, tank truck unloading area is curbed and any runoff is directed through the oil/water separator. Fuel oil pumphouse drains and fuel oil storage tank diked area drains are also directed through the separator. Individual drains from the rail unloading, truck unloading, pumphouse and storage tank diked area are furnished with locked shut-off valves so that a major leak or rupture can be contained. Only controlled rainwater discharges are to be directed to the oil/water separator.

Skimmed oil from the separator will be pumped to the oil reclaim tank in the fuel oil pumphouse. Water can be bled back through the separator. Periodically, sediment which accumulates in the separator shall be removed via a portable pump to the plant yard runoff basin.

2.1.7 Plant Yard Runoff

Plant yard rainfall drainage from the main plant area will be directed via the storm sewer system to the plant yard runoff basin. The drainage will be continuously monitored. Should an accidental spill occur at the main plant,

an alarm will be initiated at a control panel in the main control room and the basin discharge valve closed to prevent an accidental discharge of polluttional materials. Appropriate treatment or cleanup action will be conducted in the basin to correct any problem. Periodically, sediment retained in the basin shall be removed and used as fill.

The miscellaneous oil day tanks and transformers are either diked or set above concrete pits such that accidental leaks or tank ruptures will be contained. Periodically, rainfall accumulations shall be checked for contamination and if none is present, the rainwater can be drained or pumped to the nearest floor drain or plant yard storm drain. Any contaminated rainfall shall be processed through the oil/water separator. Should a tank rupture, the oil shall be reclaimed if possible or removed by a licensed waste disposal firm.

2.1.8 Chemical Feed

2.1.8.1 Demineralizer Area

A bulk concentrated sulfuric acid storage tank and a 50 percent sodium hydroxide (caustic) storage tank are provided as part of the demineralizer equipment. Connections are provided on each tank for wastewater treatment chemical feed pump suctions.

A concentrated sulfuric acid metering pump and 50 percent caustic metering pump provide feeds as required to "rough" neutralize the equalized demineralizer regeneration wastes in the batch demineralizer equalization/neutralization tank.

2.1.8.2 Industrial Waste Treatment Building

Lime slurry feed equipment is provided for waste treatment, including the lime slurry makeup tank, lime slurry pump and bag lime feeder and filter. A 10 percent lime slurry solution is manually made up by dumping bags of lime in the feeder. The filter minimizes dusting problems. The lime slurry makeup tank is provided with an agitator and a low level alarm. Lime slurry is recirculated by the lime slurry pump in a loop to the CPR neutralization tank and to the lime neutralization tank and back to the lime slurry makeup tank.

Polyelectrolyte feed equipment is provided which consists of the polyelectrolyte makeup tank, a dry polyelectrolyte feeder/educto and two polyelectrolyte metering pumps. A 0.1 percent polyelectrolyte solution is manually made up in the makeup tank by educting a measured quantity of dry polymer into a known volume of water. An agitator is provided in the tank to mix the solution. Two polyelectrolyte metering pumps feed solution to the CPR oxidation/flocculation tank and the flocculation tank.

A dilute sulfuric acid feed system is provided which consists of the dilute sulfuric acid makeup tank and the dilute sulfuric acid metering pump. A 5-10 percent sulfuric acid solution of made up by diluting concentrated acid in a known volume of water. An agitator is provided for solution mixing. The dilute sulfuric acid metering pump feeds acid to the acid neutralization tank.

2.1.9 Plant Sanitary Wastes

2.1.9.1 Coal Control Building

Design is based on handling sanitary wastes for 20 people at the coal handling facilities. Sanitary wastes from toilets and showers are directed by gravity to an underground septic tank. The septic tank overflows into the pump station, which conveys the liquid to the surge tank at the main plant sewage treatment system.

2.1.9.2 Main Plant

Design is based on handling sanitary wastes for 200 people at the main plant. All sanitary wastes from the main plant flow by gravity through the comminutor into the surge tank. Pumped, coal control building, septic tank overflow is also directed to the surge tank. The sewage ejector conveys raw sewage at a controlled rate to the aeration tank. The aeration tank overflows into the clarifier where the activated sludge is settled. Clarifier overflow enters the effluent flow and sampling chamber and passes through the chlorinator and chlorine contact tank before being discharged.

Settled activated sludge is returned from the clarifier to the aeration basin. Periodically some activated sludge is wasted to the sludge holding tank.

All air required for sewage treatment is supplied by multiple duplex blowers included with the package equipment.

2.2 DETAILED DESCRIPTION

2.2.1 Major Equipment List

Coal Pile Runoff (CPR) Collection and Treatment

1. CPR Collection Basin
2. CPR Dewatering Pumps
3. CPR Neutralization Tank
4. CPR Neutralization Tank Agitator
5. CPR Oxidation/Flocculation Tank
6. CPR Gravity Settler
7. Coal Building Sump Pumps

Batch Demineralizer Wastes Treatment

1. Batch Demineralizer Equalization/Neutralization Tank
2. Demineralizer E/N Tank Agitator
3. Demineralizer Waste Transfer Pumps

Plant Building and Area Drainage/Sumps

1. MHD and HR/SR Area Sump Pumps
2. Turbine and Compressor Room Sump Pumps
3. Wastewater Oil/Water Separator
4. Waste Oil Holding Tank

Main Wastewater Treatment

1. Waste Collection and Equalization Tank
2. Waste C&E Tank Agitator
3. Wastewater Transfer Pumps
4. Acid Neutralization Tank
5. Acid Neutralization Tank Agitator
6. Lime Neutralization Tank
7. Lime Neutralization Tank Agitator
8. Flocculation Tank
9. Flocculation Tank Agitator
10. Gravity Settler/Thickener
11. Final Polishing Filter Equipment including the Filter Feed Tank, Filter Feed Pumps, Dual Media Filters, Backwash Water Storage Tank, Backwash Pumps, and Control Panel.
12. Effluent Flow and Sampling Chamber

Waste Sludge

1. Waste Sludge Holding Tank
2. CPR Sludge Pump
3. Wastewater Sludge Pump
4. Wastewater Sludge Recycle Pump
5. Filter Press Sludge Feed Pump
6. Filter Press

Fuel Oil Unloading/Storage Area Runoff

1. Oil Unloading Oil/Water Separator
2. Oil Reclaim Tank
3. Oil Reclaim Pump
4. Portable Dewatering Pump

Plant Yard Runoff

1. Plant Yard Runoff Basin

Chemical Feed

1. Concentrated Sulfuric Acid Metering Pump
2. 50 Percent Caustic Metering Pump
3. Lime Slurry Makeup Tank
4. Lime Slurry Makeup Tank Agitator
5. Lime Slurry Pump
6. Bag Lime Feeder
7. Bag Lime Feeder Filter
8. Polyelectrolyte Makeup Tank
9. Polyelectrolyte Makeup Tank Agitator
10. Dry Polyelectrolyte Feeder/Eductor
11. CPR Polyelectrolyte Metering Pump
12. Wastewater Polyelectrolyte Metering Pump
13. Dilute Sulfuric Acid Makeup Tank
14. Dilute Sulfuric Acid Makeup Tank Agitator
15. Dilute Sulfuric Acid Metering Pump

Plant Sanitary Wastes

1. Coal Control Building Septic Tank
2. Coal Control Building Sewage Pump Station

3. Surge Tank including the Communitor, Dual Blowers, and Sewage Ejector w/Dual Blowers
4. Package Sewage Treatment Plant including the Aeration Tank, Clarifier, Effluent Flow & Sampling Chamber, Chlorinator, Chlorine Contact Tank, Sludge Holding Tank, and Dual Blowers.

2.2.2 Piping and Valves

The piping and valves for the various plant industrial waste and related chemical feed services are provided to be suitable for each application as follows:

1. Acidic Wastewaters

(Such as chimney wash, air heater wash, coal pile runoff, coal shed and building drains, slag/ash overflow and loading drains)

Below Ground	Series 85 "Mono-Line" PE, ISO-DIN 8074 and ASTM D2239
Above Ground	Reinforced fiberglass pipe, ASTM D1763 or D2310

2. Strong Acid/Alkaline Wastewaters

(Such as demineralizer regeneration wastes)

Above and Below Ground	Reinforced fiberglass pipe, ASTM D1763 or D2310
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3. Neutral Wastewaters

(Such as water pretreatment wastes and filter backwash, building sump pump piping)

Above and Below Ground (Below Ground to be Mill Wrapped and Coated per AWWA C-203)	<2" Sch. 80 Seamless CS ASTM A106, Gr. B >2" Sch. 40 E.R. Welded CS ASTM A53, Gr. B
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4. Wastewater and CPR Treatment, Sludges, Polyelectrolyte, Dilute Sulfuric Acid

Above Ground	Reinforced fiberglass pipe, ASTM D1763 or D2310
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5. Lime Slurry

Above Ground	<2" Sch. 80 Seamless CS ASTM A106, Gr. B >2" Sch. 40 E.R. Welded CS ASTM A53, Gr. B
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6. Concentrated 93 Percent Sulfuric Acid
- Above Ground Sch. 80 Seamless CS
ASTM A106, Gr. B
7. Concentrated 50 Percent Caustic Soda
- Above Ground Sch. 10S 304L Welded SS,
ASTM A312, Gr. TP304L
8. Storm Drains
- (Such as plant yard drainage, fuel oil unloading runoff)
- Below Grade <15" 14GA. Galv. CSP
>15" 12GA. Galv. CSP
ASTM A444
Asphalt - coated with paved
invert.
9. Sewage
- Below Ground Extra heavy CISP ASTM A74
- Above Ground Sch. 40 Welded CS
ASTM A53, Gr. B, galvanized

2.2.3 Electrical

Pump, agitator, etc., motors 1/2 hp and larger are 3 phase, 60 Hz, 460 volt with power supplied from the 480 volt motor control centers; and less than 1/2 hp are 1 phase, 60 Hz, 115 volt supplied from local control panel transformers. Level controls, solenoid valves, pH controllers, and other controllers will be coordinated with instrumentation power sources.

2.2.4 Instruments, Controls, and Alarms

2.2.4.1 Level Controls

1. Level controls are provided where necessary to automatically control operation of pumps and locally alarm tank high and/or low level conditions.
2. For duplex pump installation at tanks and sumps such as the coal building sump, CPR basin dewatering sump, turbine and compressor room sump, MHD and HR/SR area sump and the waste collection and equalization tank the following level control sequences are provided:

LSL - both pumps shut off
 LSH1 - lead pump on
 LSH2 - 2nd pump on
 LAH - high level alarm
 Automatic pump alternation on pumpdown

3. For duplicate pumps at the batch demineralization equalization/neutralization tank level controls are provided as follows:

LSL - 1st pumps shut off
 LSH - 2nd pump on
 LAH - high level alarm

Lead pump to be manually started only (i.e., 2nd pump only comes on in the event of lead pump failure).

Interlock with pH controller

4. Miscellaneous tank level alarms:

- a. Waste Oil Holding Tank - LAH
- b. Sludge Holding Tank - LAH
- c. Lime Slurry Tank - LAL

2.2.4.2 Pressure Indicators

Discharge pressure indicators are provided at all centrifugal pumps. Discharge pressure indicators with snubbers are provided at positive displacement pumps.

2.2.4.3 Flow Control/Monitoring

1. Wastewater Transfer Pumps Discharge Flow

A magnetic flow meter/controller is provided to regulate flow from the waste collection and equalization tank to the flow-through treatment system via a flow control valve.

2. An ultrasonic effluent flow indicator/recorder/integrator is provided at the effluent flow and sampling chamber. The flow integrator is interlocked with the automatic composite sampler to provide a contact closure for sampling purposes on a flow interval basis.

2.2.4.4 pH Controls

- 1. pH indicator/controller/recorders are provided for the CPR neutralization tank, acid neutralization tank, lime neutralization tank and demineralizer neutralization tank with appropriate high or low alarms which alarm locally and in the main control room.
- 2. pH indicator/recorders are provided for the effluent flow and sampling chamber and the plant yard runoff basin with high and low alarms which alarm locally and in the main control room. pH readings from these two locations shall be on the computer printout for record.

2.2.4.5 Polishing Filter Equipment Controls

Automatic feed flow and backwash controls are provided as part of the filter equipment package.

2.2.4.6 Coal Pile Runoff Treatment Controls

Since only intermittent operation is required, equipment starts upon CPR dewatering sump LSH1 and has a time delay stop upon LSL.

2.2.4.7 Plant Sanitary Waste Controls

All necessary controls are furnished as part of the equipment package.

3.0 SYSTEM PROTECTION AND SAFETY PRECAUTIONS

3.1 PROTECTIVE DEVICES

- 3.1.1 Provisions are included to isolate city water and filtered water from any other plant system, to prevent contamination of these supplies. This will be accomplished by approved backflow preventers, or siphon break piping arrangements at chemical makeup tanks.
- 3.1.2 Level switches are provided at pump installations which on low level trip the pumps to prevent pumps from running dry.
- 3.1.3 Safety relief valves with discharge back to respective chemical storage tanks are provided for chemical metering pumps.
- 3.1.4 Tanks, piping, valves, etc., are designed for pressures which exceed maximum pump shut-off heads. Suitable corrosion resistant materials are selected.
- 3.1.5 An exhaust fan/filter unit is provided for the bag dry lime handling area to control dusting problems.
- 3.1.6 Safety shower and eye wash units are provided in areas where chemicals such as sulfuric acid, lime slurry, and caustic soda are handled.
- 3.1.7 Protective clothing and goggles are provided for workers in the chemical handling and chemical feed areas, and in the coal pile runoff area.

3.2 HAZARDS

- 3.2.1 A personnel hazard exists in the areas where chemical solutions are prepared or utilized. The equipment in these areas is designed to minimize leakage and exposure of personnel to the chemicals. These chemicals can cause severe burning where they come in contact with the body.
- 3.2.2 Coal pile runoff at times may be acidic and corrosive to the body.
- 3.2.3 Lime dust could be hazardous if inhaled in any great quantities. A respirator mask should be worn when handling lime in bags.

3.3 PRECAUTIONS

- 3.3.1 Personnel protective equipment and clothing are required when handling chemicals whether acid, or caustic solutions, or dry powders. Plant operators and maintenance workers shall wear full length rubber coats, rubber boots, rubber gauntlet gloves, face shields and respirators as appropriate for the chemical being handled. Suitable waterproof boots and clothing shall be worn when working in the coal pile runoff area.
- 3.3.2 Should any chemicals get in the eyes or on the skin, copious quantities of water shall be used to flush the contacted parts of the body via safety shower and eyewash units. Similarly, personnel should shower if wetted or in prolonged contact with coal pile runoff.
- 3.3.3 All safety shower and eyewash units shall be inspected during daily rounds for familiarity of location and for obvious problems. These units shall be tested at least weekly.

4.0 MODES OF OPERATION

4.1 STARTUP

4.1.1 General

Initial startup is considered to take place after the tanks have been cleaned, pumps aligned, packed, lubricated, and calibrated, piping and equipment hydrotested, pipe lines flushed, electrical wiring checked and instruments and controls adjusted and calibrated.

4.1.2 Coal Pile Runoff (CPR) Treatment

The CPR collection basin shall be cleaned of sludge and ready to receive runoff. The system electrical switching shall be placed in the "Auto" position so that when the LSH1 level is reached in the CPR dewatering sump all CPR treatment plant equipment will be energized and runoff will be pumped to the treatment system. Lime slurry solution and polyelectrolyte solution shall have been previously made up to full level in the respective tanks. The lime slurry agitator and lime slurry recirculation pump shall always remain on, since these are part of the main waste treatment system. Also, all tanks shall initially be filled with clean process water. All valves indicated as normally open shall be opened and normally closed shall be closed.

4.1.3 Demineralizer Regeneration Wastes Batch Treatment

The batch demineralizer equalization/neutralization tank shall be empty and the level control set prior to receiving wastes. The pH controller and chemical feed pumps shall be calibrated and set for standby operation. Valves shall be set in their normal open or closed positions.

4.1.4 Plant Building Drainage/Sump

Pump and level controls shall be set in the "Auto" position. Valves shall be set in their normal open or closed positions.

4.1.5 Main Wastewater Treatment

All pump and level controls shall be set in the "Auto" position. All other controls for pumps, agitators, drives, control equipment, etc., shall be placed in the "Start" position. Dilute sulfuric acid, lime slurry, polyelectrolyte and other solutions shall be made up to full level in their respective tanks. All tanks shall initially be filled with clean process water. Valves shall be set in their normal open or closed positions.

4.1.6 Waste Sludge

All pumps with level controls shall be set in the "Auto" position. All other equipment controls shall be placed in the "Start" position. Tanks shall be initially filled with clean process water. Valves shall be set in their normally open or closed positions.

4.1.7 Fuel Oil Unloading/Storage Area Runoff Treatment

All oil containment diking, curbing, collector pans, etc., shall be inspected for any defects. Valves in lines draining unloading or diked storage areas shall normally be closed and locked during unloading. After unloading without oil spill incident, unloading area drain valves may be open to allow rainfall runoff to drain to the oil/water separator. The diked storage area drain valve and oil pumphouse drain valves shall remain closed and locked when not draining water from these areas.

4.1.8 Plant Yard Runoff

The basin shall be cleaned of any sludge accumulations prior to being placed in service. The pH monitoring system shall be set to the "On" position.

4.1.9 Chemical Feed

All solutions shall be made up to the fill levels. All pump controls shall be placed in the "Auto" or "Start" position, as appropriate. All valves shall be set in their normally open or closed position. Lime slurry tank agitator and lime slurry recirculation pump shall be started and remain running.

4.1.10 Plant Sanitary Wastes

The coal handling facilities sewage pump station pump controls shall be set in the "Auto" position. Valves shall be set in their normally open or closed position. All pump and blower controls shall be set in the "Auto" position at the main plant sewage system control panel. All valves shall be set in their normally open or closed position. Hypochlorite tablets shall be loaded in the hypochlorinator. Sewage ejector air supply shall be throttled to provide a near constant sewage rate of 5.5 gallons per minute. The aeration tank and

clarifier shall be filled with service water, leaving room for about 2,000 gallons of waste activated sludge to be supplied from a local municipal sewage treatment plant via a tank truck. The waste activated sludge shall be added just prior to system startup.

4.2 NORMAL OPERATION

The Plant Industrial Waste System normally operates as described in Section 2.1 when set in the automatic mode as detailed in Section 4.1. Normal surveillance, routine testing, chemical solution makeup, instrument cleaning and calibration as previously described are required. Sampling of the effluent in accordance with National Pollution Discharge Elimination System (NPDES) permit requirements shall be conducted.

The equipment suppliers' operating instructions shall be followed for operation of the final polishing filter and plant sanitary waste treatment equipment and as a supplement to this System Design Description for all other equipment components.

4.3 SHUTDOWN

A subsystem may be shut down by placing equipment controls in the "Stop" or "Off" position at the control panels and closing the appropriate equipment isolating valves. All sludge lines and pumps shall be flushed with service water on extended shutdowns. The lime slurry system lines and pump shall be flushed before any shutdown and the slurry tank dumped and the contents treated when an extended shutdown is anticipated. Equipment suppliers' operating instructions shall be consulted for special procedures.

4.4 SPECIAL OR INFREQUENT OPERATION

Special operation occurs during the MHD plant shutdown. Scheduled outages require large quantities of water for various boiler circuit chemical cleaning and for cleaning and flushing of miscellaneous equipment and piping. Chemical cleaning and wastes will be handled by an outside contractor or held for incineration in the boiler.

Large quantities of raw water are required for washing fly ash and soot from the air heaters, low temperature economizer, precipitator, and from inside the chimney. This washing shall be coordinated when the CPR basin is at a low level so its storage capacity and treatment capability can be utilized. Reuse of treated effluent for washwater may be practiced.

Should a major oil spill occur it shall be contained at the spill area. If the spill is of a magnitude such that it can not be cleaned up or reclaimed by plant personnel, outside contractor services shall be utilized. If a major chemical spill reaches the yard drainage system, it shall be contained in the plant yard runoff basin for appropriate treatment. Outside contractor services shall be enlisted as required.

5.0 MAINTENANCE

5.1 SURVEILLANCE AND PERFORMANCE MONITORING

The Plant Industrial Waste System requires daily operator surveillance. Final pH conditions are monitored on the in-house computer. Operators should make periodic rounds to make sure pressure gauges are reading their normal ranges, treatment plants are producing acceptable quality effluent, pumps are lubricated and gland leakage adjusted properly, and air pressure is indicated at any controls where required. Unusual noises and vibrations should also be detected during the rounds. Chemical solution makeup tank levels shall be logged each shift, and solutions made up as necessary. pH readings at each treatment tank shall be noted and the settling characteristics of the solids visually evaluated at least twice per shift. All sumps, caked areas and separators shall be inspected for oil accumulations. Appropriate action shall be taken and logged.

5.2 INSERVICE INSPECTION

All pumps, tanks, piping, valves, controls, gauges, pipe supports, etc., shall be inspected periodically during system operation to ascertain that the system is operating properly. Any locations where excessive water or air leakage is detected should be noted and reported. Chemical makeup tank levels shall be recorded each shift and solutions made up as necessary.

5.3 PREVENTATIVE MAINTENANCE

pH electrodes shall be cleaned and calibrated at least weekly. Computerized record keeping will be instituted to alert the operators that certain pieces of apparatus need periodic overhaul, repacking, etc., depending on the recommendations of the equipment manufacturer. In general, parts will be replaced during planned shutdown if the parts are near the end of their recommended life cycle.

5.4 CORRECTIVE MAINTENANCE

5.4.1 Manufacturers' Instructions

A complete file of instruction books will be available at the plant to guide the plant personnel in maintenance and overhaul of any piece of equipment. If necessary, a representative of the manufacturer can be present to supervise the overhaul or replacement of plant equipment.

5.4.2 Spare Parts Inventory

The manufacturers supply lists of recommended spare parts. Critical parts will be kept in inventory at the plant. Complex parts requiring long lead time for delivery will be included in the plant inventory.

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
PLANT INDUSTRIAL WASTE SYSTEM
APPENDIX "A"
REFERENCE DOCUMENTS

REFERENCE DOCUMENTS - ATTACHED

Fluid System Diagrams

Diagram No.

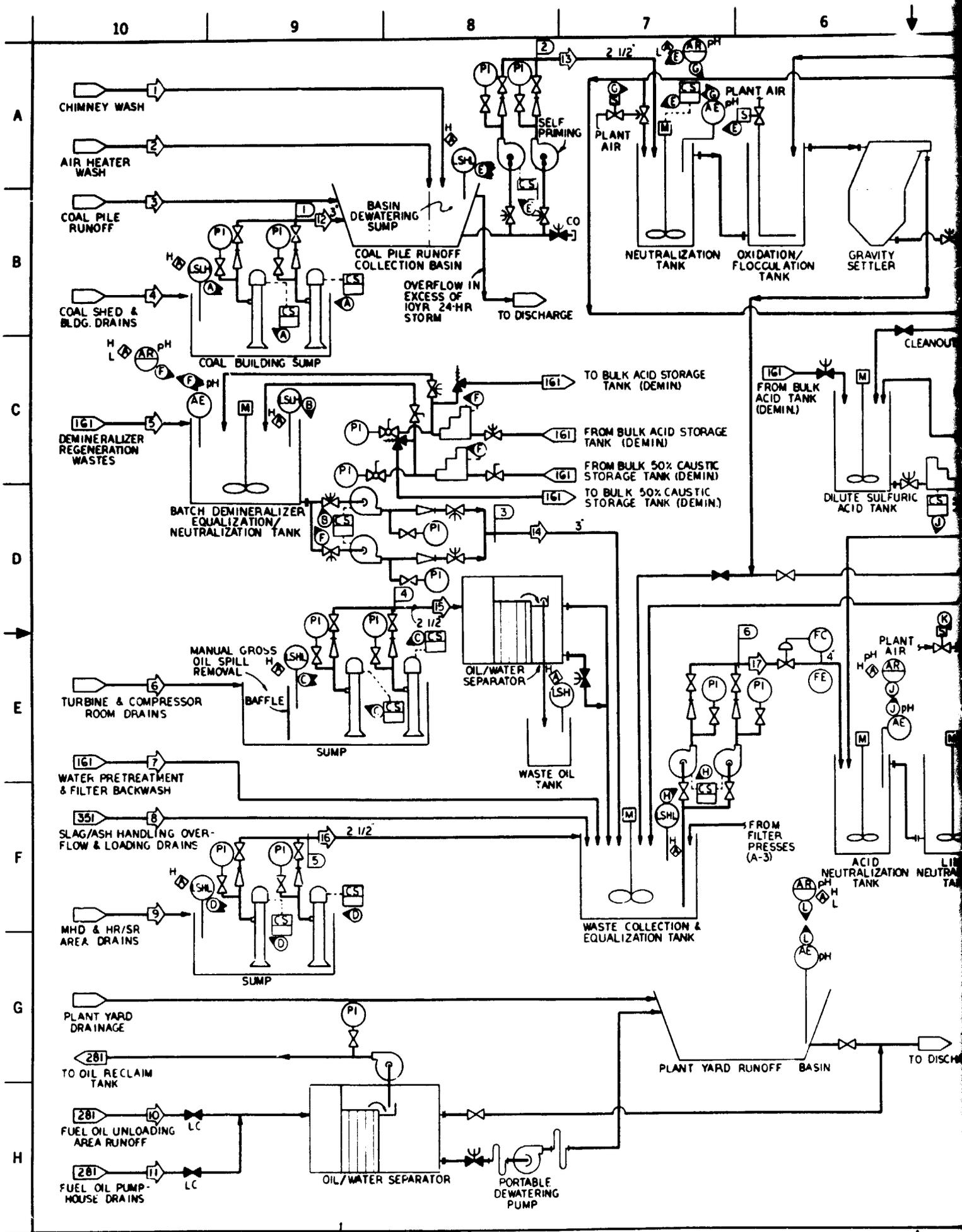
Plant Industrial Waste
Sanitary Waste

8270-1-641-302-371
8270-1-644-302-381

REFERENCE DOCUMENTS - NOT ATTACHED

System Design Descriptions

Condensate
 Circulating Water
 Boiler Feedwater
 Feedwater Heater and Miscellaneous Drains, Vents and Reliefs
 Plant Makeup Water
 Fuel Oil
 Slag Management
 Seed Management



FOLDOUT FRAME

**MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
FIRE SERVICE WATER SYSTEM**

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1.0 FUNCTION AND DESIGN REQUIREMENTS

This document presents a description of the Fire Service Water System. While the primary fire protection equipment is water supplied, this document also describes other equipment which is involved in overall plant fire protection. Included are descriptions of system functions, interfaces with other systems, equipment and piping requirements, design criteria, description of components, operating modes, and safety and maintenance requirements.

Fluid System Diagram 8270-1-781-902-401 is to be used in conjunction with the Fire Service Water System Description which describes the water supply and water extinguishing systems.

Fluid System Diagram 8270-1-652-302-242 is to be used in conjunction with that portion of the Fire Service Water System Description which describes the Nitrogen Inerting System.

1.1 FUNCTIONAL REQUIREMENTS

The Fire Service Water System provides the means to detect and extinguish fires throughout the MHD-ETF facility.

The major components of the system include the water supply, fire pumps, exterior underground distribution piping, interior distribution piping, fire hydrants, hose stations, fixed fire suppression systems, fire detection and alarm system, and portable fire extinguishers.

Fire pumps take suction from the water supply and provide flow to the exterior underground distribution piping. The water to the fire hydrants is supplied directly from the underground piping.

The interior distribution piping is supplied by the exterior distribution piping and in turn supplies water to the hose stations and the fixed water type fire suppression systems.

The foam fire suppression system requires a foam solution. This solution consists of foam liquid which will come from a foam liquid storage tank and a water supply which comes from the exterior distribution piping.

The Halon fire suppression systems are completely self contained and located in the vicinity of the hazard.

Nitrogen, used for inerting, comes from the plant's nitrogen storage supply.

1.2 SYSTEM INTERFACES

The main water supply for the Fire Service Water System is a water storage tank. This tank is described in the SDD for the Plant Makeup Water System.

There will also be interfaces with the following major systems:

1. Industrial Gas Systems, to provide supervisory air for dry pipe sprinkler and preaction water spray systems, and for nitrogen supply to spaces being inerted.
2. The HVAC System for isolation of the spaces protected with Halon 1301.
3. The Coal Management System for automatic conveyor shutdown upon fire detection on conveyor system.
4. The Fuel Oil distribution piping for the diesel fire pump's diesel engine driver.

1.3 DESIGN CRITERIA

Design criteria cover the fluid flow and storage requirements, pressure-temperature ratings and system limits to be used in the selection of the required components.

Engineering design criteria is in accordance with applicable codes, standards, regulations, and guides issued by governmental agencies, recognized standards organizations, and Gilbert Associates, Inc.

1.3.1 Codes and Standards

System engineering design is in accordance with the applicable standards issued by the National Fire Protection Association (NFPA).

National Fire Codes

- 10 - "Standard for Portable Fire Extinguishers, Installation"
- 11 - "Standard for Foam Extinguishing System "
- 12A - "Standard for Halon 1301 Systems"
- 13 - "Standard for Sprinkler Systems, Installation"
- 14 - "Standard for Standpipe and Hose Systems"
- 15 - "Standard for Water Spray Fixed Systems"
- 20 - "Standard for the Installation of Centrifugal Fire Pumps"
- 22 - "Standard for Water Tanks for Private Fire Protection"
- 24 - "Standard for Outside Protection"
- 72D - "Standard for Proprietary Signaling Systems"
- 72E - "Standard on Automatic Fire Detectors"

In addition to, and in compliance with the standards listed above, fire protection equipment, where possible, is listed by Underwriters' Laboratories, Inc. (UL) or approved by Factory Mutual Engineering Corp. (FM).

1.3.2 Design Parameters

The main water supply and the backup water supply are each sized to provide two hours flow at the design water flow rate. Water stored in tanks is treated, filtered water from a lake or river, clean well water, or potable city water. The lower portion of the main (filtered water) tank is reserved for fire protection and there are no non-fire service connections below the level of the quantity required for fire service. The backup supply tank is reserved for fire service use only.

The design water flow rate is determined by combining the maximum fixed extinguishing system demand, with the simultaneous demand of area related hose streams. The demand for the fixed extinguishing systems is determined by NFPA design parameters for each individual system.

The fire pumps are sized to provide the design water flow rate with consideration for one pump being out of service for maintenance or repair. Fire pumps are installed in accordance with NFPA Standard No. 20.

Fire hydrants and hose houses are spaced throughout the plant area to be utilized in accordance with NFPA Standard No. 24.

The Fire Service Water System water distribution piping is designed for a maximum operating water temperature of 150°F and a maximum pressure of 150 psig.

Fire Service Water System water is not to be used for any non-fire protection purposes.

The Halon 1301 fire protection equipment is designed and installed in accordance with NFPA Standard No. 12A.

The foam fire protection equipment is designed and installed in accordance with NFPA Standard No. 11.

2.0 DESIGN DESCRIPTION

The Fire Service Water System consists of equipment piping, valves, controls and fire sensing devices designed to provide fire protection and detection, and is further described in Sections 2.1 and 2.2. The Fire Service Water System main water supply is from the filtered (city) water storage tank which is part of the Plant Makeup Water System.

2.1 SUMMARY DESCRIPTION

2.1.1 Water Supply

Filtered water for fire protection service is stored in the filtered water tank. The lower portion of the filtered water tank is reserved for fire service water and there are no non-fire service connections below this level. The minimum required storage for fire protection (estimated to be 300,000 gallons) will provide two hours continuous flow at the design flow rate.

A separate storage tank, reserved for fire protection use, also having the minimum required storage capacity, is available if the main supply is not available.

The outdoor storage tanks are provided with heat for antifreeze protection in accordance with NFPA Standard No. 22.

Pumping capacity is provided by an electric-driven, 2500 gpm, centrifugal fire pump having a discharge pressure of 125 psig. As an emergency backup, a diesel driven fire pump of equal capacity and rating is provided. Both pumps are automatically started.

System water is maintained by an electric-driven jockey pump having a capacity of 20 gpm and a discharge head of 125 psig. When the system water demand exceeds the jockey pump capability, causing system pressure to drop below a preselected level, the electric-driven fire pump automatically starts. If the electric-driven fire pump fails to start, or if the water demand is so great that the system pressure continues to drop, the diesel driven fire pump will automatically start.

Each fire protection water storage tank supplies water to the fire pump suction header which serves both fire pumps and the jockey pump.

Each fire pump is connected to the external water distribution piping which consists of one or more closed loops. The external loop(s) feed the yard fire hydrants, the internal distribution piping, hose stations, and several fixed water type suppression systems.

Isolation valves are located strategically to limit the amount of fire hydrants, hose stations, or fixed fire protection equipment which would be out of service in the case of a pipe break or equipment repair.

2.1.2 Internal Distribution Piping and Hose Stations

The internal distribution piping supplies water to the interior fire hose valve stations and the fixed water type fire suppression equipment. Each hose valve station includes one 1-1/2 inch hose, one pin type hose rack, 75 feet of 1-1/2 inch fire hose and one adjustable water fog nozzle.

Gate valves are provided throughout the piping to limit the number of hose stations or fixed equipment affected when sections of the fire protection system must be isolated for maintenance or repair.

2.1.3 Fixed Fire Suppression Equipment

Several different types of fixed fire suppression equipment are utilized throughout the facility depending upon location (heated building or not), type of hazard, type and importance of equipment being protected, and size of area being protected. Different extinguishing agents and different modes of operation are employed.

These include the following:

1. Wet Pipe Sprinklers
2. Dry Pipe Sprinklers
3. Automatic Water Sprays
4. Halon Suppression
5. Preaction Sprinklers or Sprays
6. Fixed Foam Suppression

2.1.4 Nitrogen Inerting

Nitrogen inerting is provided for the following areas:

1. Coal Bunkers
2. Coal Storage Silos
3. Coal Feed Building Lock Hoppers

Each of the above includes a connection to the nitrogen gas supply, valves, piping and regulators as necessary (final design concept not yet determined).

Each of the above items is sealed and constantly flooded with nitrogen gas to eliminate the presence of oxygen which is necessary for spontaneous combustion of the coal.

2.1.5 Portable Fire Extinguishers

Portable fire extinguishers of various types are provided throughout the facility for first line fire fighting capability. These units are selected as to type, sized, and located in accordance with NFPA Standard No. 10 with respect to the particular hazards in the area.

2.1.6 Area Fire Detection

Fire Detection is provided in the following areas:

1. Inverter Building
2. Oxidant Compressors/Steam Turbine and Motor Drives Area
3. Switchgear Building

Each of these areas is provided with individual detection units and local fire detection panels.

This equipment is for detection and activation of local and remote fire alarm signals, and is not to be confused with the detection devices used in conjunction with the automatic operation of fixed fire extinguishing systems.

Approximately (TBD) ionization type fire detectors are located throughout the above areas.

2.1.7 Plant Fire Alarm Annunciation

A main fire service annunciator panel is located in the control room. This panel has audible fire and trouble alarms and visual fire and trouble alarms. Visual alarms on the face of the panel will indicate the location of the alarm and/or the equipment transmitting the alarm. All signaling circuits are constantly supervised and a trouble alarm signal is activated by a circuit failure or other trouble signal initiated with respect to the fire protection system.

The following are the general sources of the signals that will annunciate at the main fire service annunciator panel:

1. Valve closure (trouble signal initiated by position monitor switches from valves throughout the plant).
2. All sprinkler and water spray equipment (a signal from the pressure switch indicating fire).
3. Dry pipe sprinkler and preaction water spray equipment (trouble signal by low air pressure).
4. Fire detection instruments (fire or trouble signal from the local fire detection panel).
5. Foam protection equipment (fire or trouble signal from the local control panel).
6. Halon protected areas (fire or trouble signal from local control panel).
7. Fire pumps (pump running, off automatic start, or trouble signal from fire pump control panel).
8. Water supply tanks (low water level and low water temperature signals).

2.1.8 Outdoor Distribution Piping, Hydrants and Hose Houses

Underground distribution piping supplies water to fire hydrants each having a hose house, fire hose, and fog nozzle.

2.2 DETAILED DESCRIPTION

2.2.1 Major Equipment

2.2.1.1 Electric Motor Driven Fire Pump

Quantity	1
Type	horizontal, centrifugal
Capacity	2,500 gpm
Discharge pressure	125 psig

2.2.1.2 Diesel Driven Fire Pump

Quantity	1
Type	horizontal, centrifugal
Capacity	2,500 gpm
Discharge pressure	125 psig

2.2.1.3 Jockey Pump (Electric Motor Drive)

Quantity	1
Type	horizontal, centrifugal

Capacity	20 gpm
Discharge pressure	125 psig

2.2.1.4 Fire Service Water Storage Tank

Quantity	1
Capacity	300,000 gallons
Height	(TBD)
Diameter	(TBD)

2.2.1.5 Wet Pipe Sprinklers

A fire occurring in a room or area protected by wet pipe sprinkler equipment will cause one or more sprinklers to open because of the heat generated by the fire. Water will discharge only from the sprinklers that have had their fusible links melted by the fire.

Wet pipe sprinkler equipment is provided for the following areas:

- | | |
|---|----------------|
| 1. Auxiliary Boiler Building - | 3,000 sq. ft. |
| 2. Diesel Fire Pump Room - | (TBD) sq. ft. |
| 3. Warehouse - | 8,000 sq. ft. |
| 4. Below operating and mezzanine levels of the Turbine building - | 37,200 sq. ft. |
| 5. Administration, Service and Machine Shop Building - | 18,000 sq. ft. |
| 6. Coal Feed Building - | 1,800 sq. ft. |
| 7. Coal Preparation Building - | 3,600 sq. ft. |
| 8. Fuel Oil Pumphouse - | 200 sq. ft. |

Each wet pipe sprinkler area piping includes a shutoff gate valve with a position monitor switch, an alarm check valve or water flow alarm, and sprinklers. All equipment design is in accordance with NFPA Standard No. 13.

2.2.1.6 Dry Pipe Sprinklers

Dry pipe type sprinkler equipment is used in areas where freezing water would render a wet pipe system inoperable. All piping downstream of the dry pipe valve is filled with air under pressure from the service air system. The purpose of the air in the pipes is to hold the dry pipe valve in the closed position. The air is maintained in a specified pressure range. If the pressure falls below a minimum, a low air alarm is transmitted.

The heat generated by a fire occurring in one of the areas protected by the dry pipe sprinkler equipment will cause one or more sprinklers to open

allowing the air to escape. When the pressure on the downstream side of the dry pipe valve reduces to a preselected level (depending on the dry pipe valve design) the valve will open allowing water to discharge from the open sprinklers.

Dry pipe sprinkler equipment is provided for the following unheated areas:

- | | |
|---|----------------|
| 1. Rotary Car Dumper Building - | 3,000 sq. ft. |
| 2. Car Thawing Shed - | 12,000 sq. ft. |
| 3. Yard Coal Crusher House and Dust Collector | 5,000 sq. ft. |
| 4. Baghouse - | 3,000 sq. ft. |

Each dry pipe sprinkler piping includes a shutoff gate valve with position monitor switch, a dry pipe valve, sprinklers, air supply, and alarm pressure switches (one for low air and one for waterflow). All equipment design is in accordance with NFPA Standard No. 13.

2.2.1.7 Automatic Water Sprays

Spot type heat detectors are provided for all of the following hazards except the coal conveyors. These detectors will be spaced as necessary at each hazard. A fire or any overheating of the coal conveyors will be detected by the continuous line heat detectors. These detectors transmit an alarm to the local control panel which sends a signal to initiate operation of the respective deluge valve and shutdown the conveyor. Water spray protection is provided above and below the conveyor belt.

Automatic water spray equipment is provided for all of the following:

1. Turbine Lube Oil Storage Tank
2. Turbine Lube Oil Conditioner
3. Hydrogen Seal Oil Unit
4. Transformers
5. Coal Conveyors
6. Boiler Feedwater Pumps

A shutoff gate valve with position monitor switch, a deluge valve, piping, open water spray nozzles, a water flow pressure switch, fire detectors, and a control panel are provided for each of the above. All equipment design is in accordance with NFPA Standard No. 15.

2.2.1.8 Halon Suppression

Halon 1301 suppression equipment is provided for the main control room and relay room areas.

Each area includes a Halon supply, piping, discharge nozzles, control panel, smoke detectors, and local alarms. All equipment design is in accordance with NFPA Standard No. 12A.

Two zones of detection are provided in each area. These detection zones are connected to the control panel so that any one detector sensing a fire will initiate a fire alarm signal, and the system will automatically discharge upon receiving a signal from any detector in the second zone. A pre-discharge alarm sounds before system activation to allow time to evacuate the area.

Upon discharge, Halon 1301 completely floods the space within 10 seconds, providing a concentration of 5-7 percent by volume. This concentration is maintained for a minimum of at least 10 minutes by constructing the hazard area to be a tight enclosure. HVAC equipment and ducts which transfer air in or out of the protected space are automatically shut down.

There is a main supply of Halon 1301 and a backup supply ready for immediate use if needed because of failure of the primary supply or if needed before the main supply can be replaced after activation.

2.2.1.9 Preaction Sprinklers or Sprays

Preaction sprinkler or water spray equipment is provided with supervisory air by connections with the station air service system. The design is such that if one sprinkler or spray nozzle opened, either because of fire or by accident, a low air condition would be created and local and remote trouble alarms activated.

During normal operation conditions, water is prevented from entering the piping by a deluge valve. These deluge valves will only open if a fire condition were detected by the heat detectors in the respective area. Water would then be discharged from only the sprinklers or spray nozzles that had their fusible elements melted by the heat of the fire. Additional air would be prevented from entering the piping because of the higher pressure of the water supply.

Preaction protection requires that both a heat detector and a heat sensitive sprinkler or spray nozzle operate before any water is discharged. This prevents the accidental discharge of water in the event of mechanical damage to sprinklers or the sprinkler piping on the downstream side of the deluge valve. This would also prevent the accidental discharge of water in the event of false fire detector signals or inadvertent manual operation of the deluge valve.

Preaction sprinkler or preaction spray protection is provided for each of the following.

1. Diesel Generator Room (sprinkler)
2. Turbine Generator Bearings (water spray)

Each of the above includes a shutoff gate valve with position monitor switch, a deluge valve, a rubber seated check valve, piping, sprinklers or fusible element spray nozzles, heat detectors, supervisory air, local

alarms, pressure switches (water flow and supervisory air), and a control panel. All equipment design is in accordance with NFPA Standards No. 13 and No. 15.

2.2.1.10 Fixed Foam Suppression

Fixed foam suppression equipment is provided for the Main Fuel Oil Storage Tank and includes a foam tank, piping, valves, alarms, heat detectors, a proportioner, foam makers, and a local fire panel. All equipment design is in accordance with NFPA Standard No. 11. Foam will form a vapor tight blanket on the surface of the oil.

Fluoroprotein foam liquids are used to generate the foam. A cold foam with a minimum usable temperature not greater than -20°F will be used. Foam solution type, application rate, number of discharge outlets (TBD).

2.2.2 Piping and Valves

As noted on the flow diagram, piping nearby the MHD Building is stainless steel. All other interior distribution piping is carbon steel.

The underground piping is cement lined ductile iron with cast iron fittings.

Valves are U.L. listed and/or F.M. approved.

2.2.3 Electrical

The electric motor driven fire pump motor is 4,000 volt, 3 phase, 60 Hz supplied from a 4,160 volt motor control center.

The Jockey water pump motor is 460 volt, 3 phase, 60 Hz supplied from a 480 volt motor control center.

Electrical instruments, controls, and valve limit switches are supplied with power coordinated with instrument power sources.

2.2.4 Instruments, Controls and Alarms

2.2.4.1 Fire Pump Alarms

The motor driven fire pump and diesel driven fire pump have the following alarm signals sent to the main annunciator panel. One signal will indicate that the respective pump is "running" and another will indicate "trouble". In addition the diesel fire pump will transmit a signal if not kept on automatic start. There are no alarms associated with the jockey pump.

2.2.4.2 Water Tank Alarms

The water level of each fire service water supply is indicated locally, and a low water level alarm will be transmitted to the main annunciator panel. The water temperature is indicated locally and will be maintained at or above 42°F. If water temperature falls below 42°F, an alarm will be sent to the main annunciator panel.

2.2.4.3 Fixed Fire Extinguishing System Controls

Operation of any fixed fire extinguishing system will result in a local alarm and an alarm at the main annunciator panel.

All fixed extinguishing systems operate automatically as described in sections 2.2.1.5 through 2.2.1.10.

All fixed automatic extinguishing systems are electrically supervised.

2.2.4.4 Area Fire Detection Controls

Each fire detection system is designed so that a detector in the alarm mode will send a signal to its local detection panel. This panel will then transmit a fire signal to the main annunciator panel and activate a local alarm. The local detector panel also supervises the detector circuit and transmits a trouble signal to the main annunciator panel and sounds a local trouble alarm upon a failure in the detector circuit.

3.0 SYSTEM PROTECTION AND SAFETY PRECAUTIONS

3.1 PROTECTIVE DEVICES

A pressure relief valve is included on the discharge of each fire pump and another relief valve is included downstream of the jockey pump to protect the fire protection system from pressures in excess of 150 psig.

3.2 HAZARDS

There is a hazard associated with use of water hose streams on electrical equipment.

3.3 PRECAUTIONS

An extensive training program for plant employees should be instituted. This program should incorporate training in areas such as the hazards associated with coal, the proper use of fire protection equipment, and fire prevention measures.

4.0 MODES OF OPERATION

4.1 STARTUP

This system should be started before initiation of plant operation.

Prior to system start, the following should be verified:

1. The distribution system must be completely filled with water, and all air evacuated from the system.

2. Power must be supplied to all pump controllers and to all control panels.
3. All shutoff gate valves on the system must be in fully open position (except for drain valves which should be in the position shown on the fluid system diagrams).
4. All deluge valves must be in the normal set condition.

4.2 NORMAL OPERATION

During normal operation all systems are in a state of readiness.

Detection/sensing devices are constantly monitoring.

Automatic extinguishing systems function in the event of a fire.

Supervisory systems constantly monitor controls for all fixed automatic extinguishing systems.

Further description of operation is found in Section 2.0 of this document.

4.3 SHUTDOWN

This system should never be completely shut down. Maintenance may be performed on sections of the system by closing the appropriate valves and removing only that portion of the system from operating condition.

4.4 SPECIAL OR INFREQUENT OPERATION

If the normal source of water is eliminated by pipe break, etc., then the system water supply is drawn from the backup supply.

If the electric-driven fire pump does not function due to power failure, etc., then the diesel fire pump is automatically started.

5.0 MAINTENANCE

5.1 SURVEILLANCE AND PERFORMANCE MONITORING

All fire protection equipment and systems must be subjected to a complete inspection and acceptance test in accordance with the NFPA National Fire Codes after the installation is completed.

During operation the supervisory controls described earlier stand ready to activate a local trouble alarm and transmit a trouble alarm to the main annunciator panel to alert personnel of non-functional equipment.

5.2 INSERVICE INSPECTION

After the plant is in operation, periodic inspections and tests should also be conducted in accordance with the NFPA National Fire Codes, insurance requirements, and governmental regulations.

Fire alarm and detection systems should be subjected to operating tests and visual inspection on a regular basis.

Standard main drain flow tests should be conducted regularly on all fixed piping fire protection systems to ensure the water supply is available.

Wet pipe type sprinkler systems should be test operated by use of the inspectors test connections.

All fire extinguishers and hose stations should be inspected regularly to ensure that they are in operating condition.

The extinguishers should also be subjected to a hydrostatic test at regular intervals required by NFPA. Hose should be pressure tested on a regular basis.

5.3 PREVENTATIVE MAINTENANCE

Any fire protection devices found to be in need of maintenance should be promptly put into proper operating condition.

5.4 CORRECTIVE MAINTENANCE

5.4.1 Manufacturer's Instructions

A complete file of instruction books is available at the plant to guide the plant personnel in maintenance and overhaul of any piece of equipment. If necessary, a representative of the manufacturer can be present to supervise the overhaul or replacement of plant equipment.

5.4.2 Spare Parts Inventory

A supply of spare sprinkler heads, spray nozzles, and fire detectors are kept at the facility for replacing damaged items.

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION

FIRE PROTECTION SYSTEM

APPENDIX "A"

REFERENCE DOCUMENTS

REFERENCE DOCUMENTS - ATTACHED

Fluid System Diagrams

Diagram No.

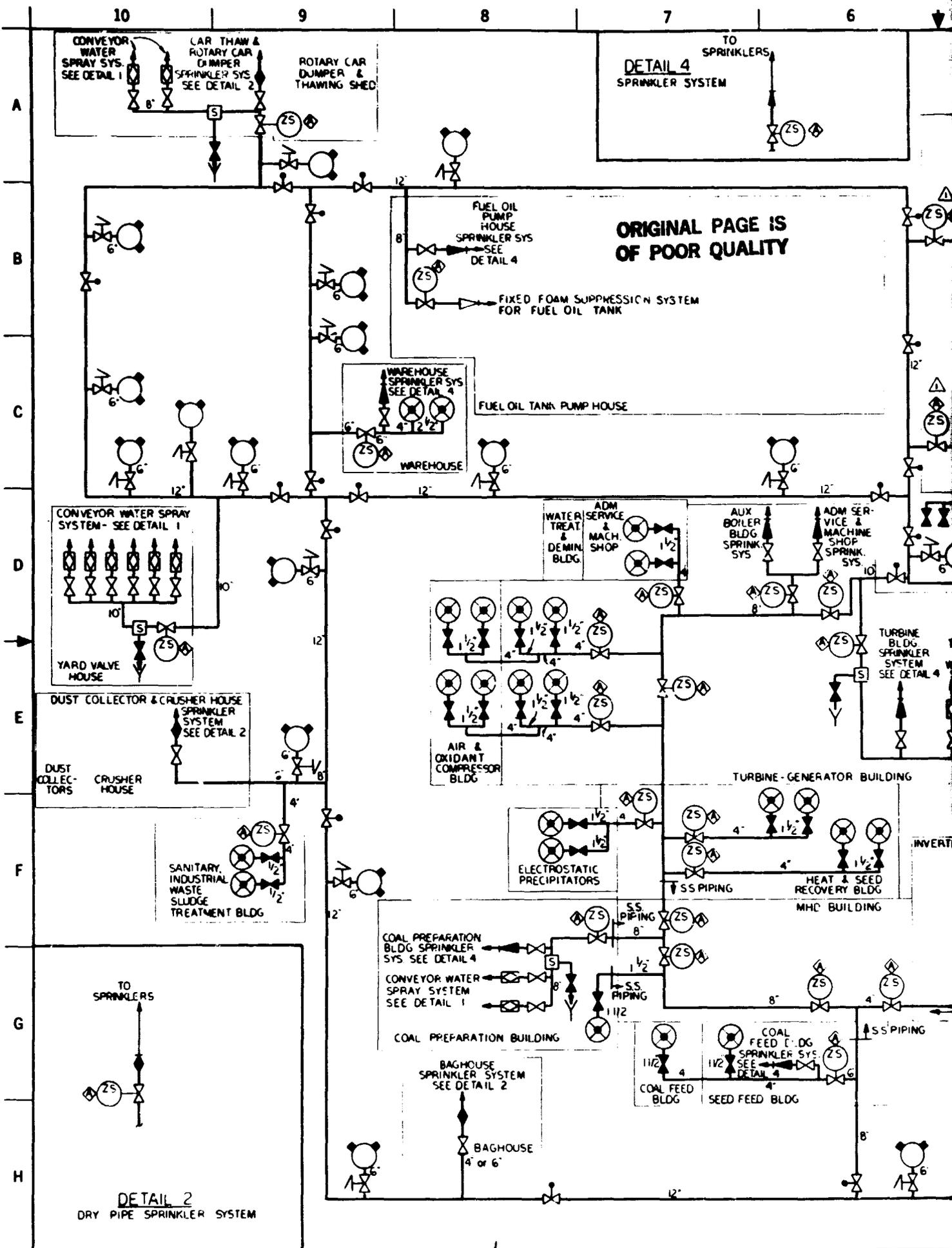
Fire Service Water

8270-1-781-902-401

REFERENCE DOCUMENTS - NOT ATTACHED

System Design Descriptions

Plant Makeup Water
Industrial Gas

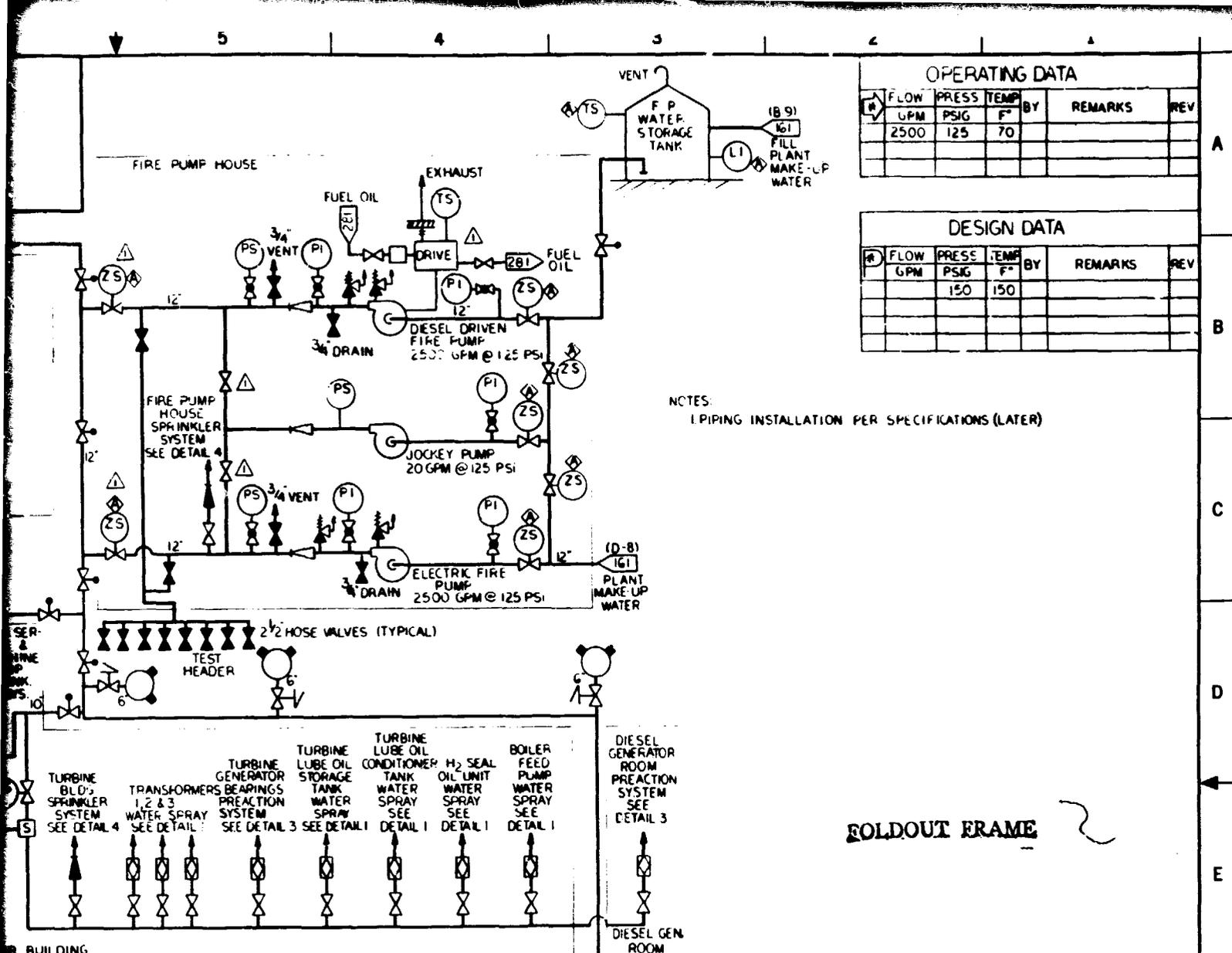


ORIGINAL PAGE IS
OF POOR QUALITY

DETAIL 2
DRY PIPE SPRINKLER SYSTEM

BOLDOUT FRAME

C-3

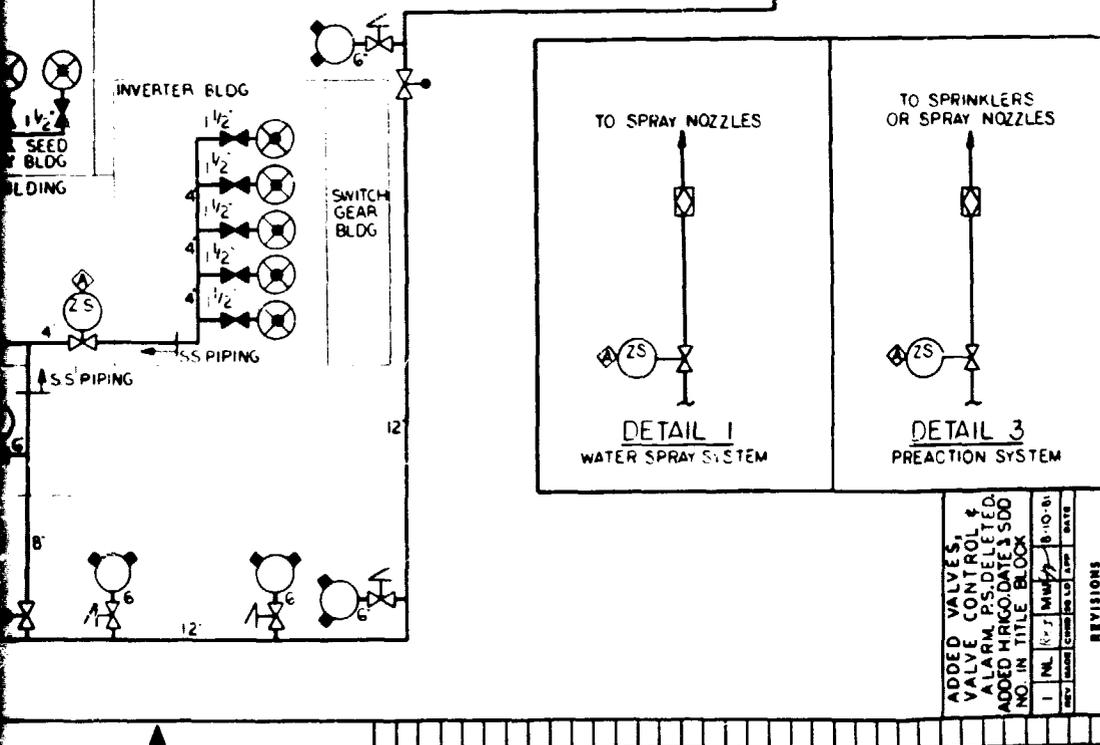


OPERATING DATA						
FLOW	PRESS	TEMP	BY	REMARKS	REV	
GPM	PSIG	F°				
2500	125	70				

DESIGN DATA						
FLOW	PRESS	TEMP	BY	REMARKS	REV	
GPM	PSIG	F°				
	150	150				

NOTES:
 1. PIPING INSTALLATION PER SPECIFICATIONS (LATER)

FOLDOUT FRAME



I.O. NO. C-373-852	
3-27-81	CONCEPTUAL DESIGN ISSUE
3-17-81	PRELIMINARY ISSUE
REV	RELEASED FOR
	ENGR.
MAGNETOHYDRODYNAMICS ENGINEERING TEST FACILITY CONCEPTUAL DESIGN	
FLUID SYSTEM DIAGRAM	
FIRE SERVICE WATER	SDD-NO1
200 MWe	
DOE - NASA	
MHD PROJECT OFFICE	APP. H. RIGO
LEWIS RESEARCH CENTER CLEVELAND, OHIO 44135	DATE 9-25-81
GILBERT ASSOCIATES, INC. ENGINEERS AND CONSULTANTS READING, PA	
DRAFTING: ALR CHECKED: [Signature] DATE: 9-25-81	
SCALE: NONE DRAWING NUMBER: 8270-1-781-902-401 REV: 1	

NO.	DATE	REVISIONS
1	9-25-81	ADDED VALVES, VALVE CONTROL & ALARM P.S. DELETED. ADDED HIRG DATE'S SDD NO. IN TITLE BLOCK.

SYSTEM DESIGN DESCRIPTION

SDD-501

OXIDANT SUPPLY SYSTEM

FOR

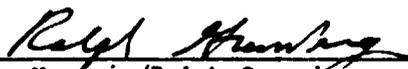
MAGNETOHYDRODYNAMICS

ENGINEERING TEST FACILITY

CONCEPTUAL DESIGN - 200 MWe POWER PLANT

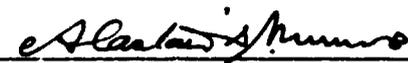
SYSTEM BLOCK DIAGRAM 1-FS-820

STUDY PREPARED BY:



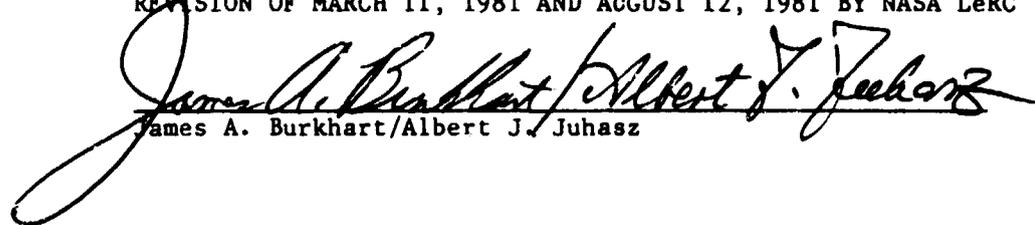
Dr. Wolfram Hartwig/Ralph Greenberg of Lotepro Corporation
March 11, 1981

APPROVED BY:



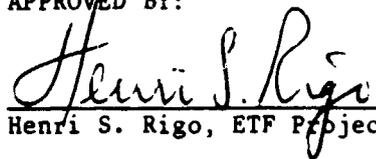
Alastair B. Munro, Vice President of Lotepro Corporation
March 11, 1981

REVISION OF MARCH 11, 1981 AND AUGUST 12, 1981 BY NASA LeRC



James A. Burkhart/Albert J. Juhasz

APPROVED BY:



Henri S. Rigo, ETF Project Manager, NASA LeRC

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
OXIDANT SUPPLY SYSTEM

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APPENDIX D - ALTERNATIVE ASU COMPRESSOR WITH ELECTRIC MOTOR DRIVE

DRAWINGS ATTACHED ARE AS FOLLOWS:

<u>DRAWINGS</u>	<u>Drawing No.</u>
Drawing Symbols and Drawing List	1-FS-822, Rev. 4
Block Diagram	1-FS-820, Rev. 2
Plan, Compressor Bldg	1-LO-1577-1, Rev. 3
Plan, Cold Box Area	1-LO-1577-2, Rev. 2
Plan, LOX Storage Area	1-LO-1577-3, Rev. 1
Plan, Air Filters, Aftercooler and and Oxidant Mixing Chamber	1-LO-1577-4, Rev. 3
Elevation "A"- "A", Turbines and Compressors	1-LO-1577-5, Rev. 2
Elevation "B"- "B", Turbines and Compressors	1-LO-1577-6, Rev. 2
Elevation "C"- "C", Cold Boxes and Equipment	1-LO-1577-7, Rev. 2
Oxidant Mixing Chamber, Plan, Elev. and Details	1-LO-1577-8, Rev. 2
Compressor Bldg., Plan, Utility Piping	1-LO-1577-9, Rev. 2
ASU (Air Separation Unit) Compressor, Steam Turbine Drive, Process and Instrumentation (P&I) #1	1-FS-813, Rev. 3
Air Separation Unit (ASU), P&I #3	1-FS-815, Rev. 1
Mixing Chamber, P&I #4	1-FS-816, Rev. 2
Liquid O ₂ & N ₂ Storage and Vaporization System, P&I #5	1-FS-817, Rev. 3
Oxidant Compressor, Steam Turbine Drive, P&I #6	1-FS-818, Rev. 3
Oxidant Compressor, Electric Motor Drive, P&I #7	1-FS-819, Rev. 3
Alternative ASU Compressor, Electric Motor Drive, P&I #2	1-FS-814, Rev. 3

MHD ETF PROJECT
SYSTEM DESIGN DESCRIPTION
OXIDANT SUPPLY SYSTEM

1.0 FUNCTION AND DESIGN REQUIREMENTS

This document presents a description of the Oxidant Supply System of the MHD Engineering Test Facility (ETF) as depicted in the block diagram of Drawing 1-FS-820, and as shown in the Drawings 1-LO-1577-1 to 1-LO-1577-9. "Equipment and Designation" lettering is given in Table 1. Instrument and control valve functional lettering variations are given in Table 2. The document includes descriptions of system functions, interfaces with other systems, equipment and piping requirements, design criteria, description of components, operating modes and safety and maintenance requirements. The term "Facility" is used in reference to other parts of the ETF not supplied as part of the Oxidant Supply System.

1.1 FUNCTIONAL REQUIREMENTS

The Oxidant Supply System provides pressurized oxidant to the Intermediate Temperature Oxidant Heater section of the Heat Recovery/Seed Recovery (HR/SR) System at the flow rate and pressure required for the operation of the MHD Power Train.

A medium purity gaseous oxygen stream is produced in a cryogenic air separation unit (ASU). This stream is blended with atmospheric air in a mixing chamber to provide a stream with the required oxygen fraction. The oxidant stream is compressed by two parallel high efficiency uncooled axial compressors driven by steam turbines.

The system provides liquid nitrogen (LIN) for cooling the superconducting magnet and gaseous nitrogen for auxiliary uses such as inert gas blanketing. Several features are incorporated in the design to facilitate plant start-up. These include provision for electrically driving one auxiliary compressor and storage of oxygen.

1.2 SYSTEM INTERFACES

The Oxidant Supply System interfaces are shown on Drawing 1-FS-820. All systems which interface with the oxidant supply are described in their respective "System Design Description". The Oxidant Supply System interfaces with the following subsystems:

Reheat Steam System
Auxiliary Steam System
Condensate System
Electrical Power System
Intermediate Temperature Oxidant Heater Section of HR/SR
Circulating Water System
Magnet System (LIN Supply)
Facility Central Control System
Facility Central Protection System

1.3 DESIGN CRITERIA

Design criteria for the Oxidant Supply System are the system outputs, derived inputs and accompanying process, mechanical and electrical requirements which are used to select size and design components and to determine performance.

The system configuration was selected on the basis of studies performed under NASA Contract DEN 3-165. In these studies, eighteen (18) cases incorporating variations of system configuration and component equipment were evaluated. All cases were designed to deliver the same oxidant stream (an air stream enriched to a total of 30.0% oxygen by volume) at the same delivery pressure (117.6 psia). Each case was optimized to minimize its power consumption.

The study was based on an MHD plant requiring three times the capacity needed for the ETF, but it used three parallel equipment trains to produce the capacity. The use of one equipment train is satisfactory for the ETF and is used herein.

The criteria used for final Oxidant Supply System selection and design are (not necessarily in the order of priority):

- a. Total power consumption of the Oxidant Supply System shall be at, or very near to, the minimum of all cases considered.
- b. Total capital cost of the Oxidant Supply System shall be at, or very near to, the minimum of all cases considered.
- c. Total operating and maintenance costs of the Oxidant Supply System shall be at, or very near to, the minimum of all cases considered.
- d. The Oxidant Supply System process design shall be based on technology currently in use and having a high level of reliability and availability.
- e. All components shall be available on the present day market.

The case selected for the ETF Oxidant Supply System is among the lowest in power consumption of the cases considered, with the possible exception of some advanced systems utilizing liquid pumping that might require some development. It is the lowest in capital cost, and in operating and maintenance costs.

It is nearly identical to the "The Blast Furnace Oxygen Plant System at Schwelgern" (see reference cited). This plant has been available to its customers at August Thyssen-Huette AG essentially around the clock since being commissioned in 1973. Shutdown has been yearly, or less frequent, and then for only a brief period of maintenance required by the entire Thyssen complex. The selected system has proprietary elements, but no development components, and could be procured on the present market.

1.3.1 Codes and Standards

Engineering design criteria for all disciplines is in accordance with applicable codes, standards, regulations, and guides issued by governmental agencies and recognized standards organizations.

Codes and Standards applicable to the design of the Oxidant Supply System including equipment specifications, layout, safety considerations, and mechanical, electrical and structural work and components are described in detail below. If no codes or standards are available or applicable, best industry practice and/or Linde AG/Lotepro standards are used. This also applies in those cases where Linde AG/Lotepro standards exceed industry norms.

1.3.1.1 Pressure Vessels

All pressure vessels are designed, fabricated, inspected and tested in accordance with the latest edition of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code for Unfired Pressure Vessels, Section VIII, Division 1.

Shell and tube heat exchangers are designed, fabricated, inspected and tested in accordance with the Tubular Exchangers Manufacturers Association (TEMA) Codes and with Heat Exchange Institute (HEI) Standards.

Heat exchangers of special design are designed, fabricated, inspected and tested in accordance with Linde AG specifications.

All threaded and flanged process and utility connections to pressure vessels have American National Standards Institute (ANSI) standard dimensions.

1.3.1.2 Piping

All cryogenic piping design, fabrication, inspection, and testing conform to:

ANSI B31.3, Petroleum Refining Piping and Compressed Gas Association (CGA)
"Safe Practices Guide for Air Separation Plant."

All piping in other services shall be designed, fabricated, tested and inspected as per ANSI B31.3.

All structural welds on process gas pipelines, whether shop or field fabricated, are to be subjected to radiographic analysis.

All threaded and flanged piping connections throughout the Oxidant Supply System have ANSI standard dimensions.

All equipment rated for oxygen service is designed, fabricated and installed in accordance with all applicable sections of the following standards:

CGA Pamphlet G-4.4, "Industrial Practices for Gaseous Oxygen Transmission and Distribution Piping Systems;"

NASA SP-3090, "ASRDI Oxygen Technology Survey Volume IX: Oxygen Systems Engineering Review; 1975";

NASA SP-3037, "ASRDI Oxygen Technology Survey Volume II: Cleaning Requirements, Procedures and Verification Techniques, 1972".

1.3.1.3 Electrical Equipment and Wiring

All electrical equipment and wiring shall be designed, fabricated and installed in accordance with the requirements of:

National Electrical Manufacturers Association (NEMA);

National Electrical Code (NEC);

Institute of Electronics and Electrical Engineers (IEEE);

Underwriters' Laboratories, Inc. (UL).

1.3.1.4 Foundations, Structural Steel, Buildings, and Miscellaneous Structures

Design and construction are in compliance with the following codes and standards:

Uniform Building Code, Latest Edition

American National Standards Institute (ANSI)
"American National Standard Building Code Requirements for

Minimum Design Loads in Building and Other Structures" (ANSI A58.1-1972).

Occupational Safety and Health Act (OSHA).

American Institute of Steel Construction (AISC)
"Specification for the Design, Fabrication and Erection of
Structural Steel for Buildings," February, 1969, and
Supplements.

The American Concrete Institute (ACI)
"Building Code Requirements for Reinforced Concrete"
(ACI-318-71), and "Manual of Standard Practice for Detailing
Reinforced Concrete Structures" (ACI-315)

American Society for Testing and Materials (ASTM)

American Welding Society (AWS)

Research Council on Riveted and Bolted Structural Joints of the
Engineering Foundation. "Specification for Structural Joints Using ASTM
A325 or A490 Bolts"

American Iron and Steel Institute (AISI). "Specification for the Design
of Cold-Formed Steel Structural Members"

Structural Engineers Association of California (SEAOC)
"Recommended Lateral Force Requirements," 1975

American Petroleum Institute - API 617 "Centrifugal Compressors for
General Refinery Services", 4th Edition 1979.

Foundation equipment bases and footings are designed and constructed as per
applicable requirements specified.

Structural steel used to support process units is designed and constructed as
per applicable requirements to be specified.

Personnel protection walls in the compressor building are designed and
constructed to conform to:

"European Working Panel (EWP) Code of Practice for Turbo
Compressors for Oxygen Service", Section 2.2.2, which
states:

"Precautions are to be taken to avoid danger and injuries to
personnel. The following solutions are good practice.

The hazard area is surrounded by an enclosure which shall be at least six feet and seven inches high (two meters high) and prevents line of sight between the compressor and operator areas within 100 feet (30 meters). The enclosure shall extend above the highest level of equipment within it.

The hazard area is totally enclosed. In this case explosion doors must be provided, above head height, to avoid overpressurizing in the event of an accident. Adequate ventilation should be provided.

The enclosure shall be of sturdy construction and of a material which is fire resistant in the presence of oxygen. A gap at floor level may be needed in the enclosure to provide adequate ventilation. Where openings are provided in the enclosure for the removal of machine components, e.g. cooler tube-bundles, then such openings must be covered with bolted panels when the machine is on oxygen service. All inspection ports in the enclosure must be covered with suitable transparent material, adequately reinforced."

1.3.2 Design Parameters

The nominal design case for the Oxidant Supply System consists of the expected normal operating conditions for the ETF plant. The oxidant supply system was designed for peak efficiency at the nominal design capacity. The design does not incorporate minor changes in design parameters due to later revision of the ETF heat and mass balance. Values quoted below may vary slightly from values used by GAI elsewhere in the ETF Conceptual Design Engineering Report (CDER).

The Oxidant Supply System design and operating parameters were selected by combining the plant performance optimization studies (described in Appendices B and C of the "System Design Description" (SDD-502) for the MHD Power Train System) with economic consideration (including those already described in Section 1.3). These dictate the use of the percentage of oxygen enrichment given below, the use of low pressure air in the ASU, the use of a high efficiency (low power consuming) ASU compressor with intercooling/ aftercooling, and the use of uncooled high-efficiency axial compressors to develop the oxidant pressure given below.

The primary design parameters are:

Percentage (by volume) of oxygen in the oxidant stream	30 %
Oxidant delivery pressure	73.5 psia
Oxidant delivery temperature	437°F
Oxidant mass flow rate	875,871 lbs/hr
Specific power consumption of the ASU compressor (when referenced to a standard 14.7 psia atmosphere)	196 kW-hr per ton of equivalent pure oxygen*
ASU product purity	70 % (by volume oxygen)
ASU capacity	1500 tons per day of contained oxygen
ASU product pressure	13.5 psia

NOTE: *The term "Equivalent Pure Oxygen" is used in normalizing the capacity and specific power consumption of air separation plants providing impure oxygen. If the plant product is considered to be a mixture of air and pure oxygen, the term "equivalent pure oxygen" refers to only the pure oxygen and excludes the oxygen contained in the admixed air.

1.3.2.1 Ambient Air Conditions

The ambient air conditions are based on the hypothetical Montana site selected for ETF. Table 3 gives the compositions of the ambient air, the ASU product (70 % by volume oxygen) and the oxidant stream for the Montana site.

1.3.2.2 Cooling Water Supply and Return Conditions

The cooling water required for the Oxidant Supply System is provided by the Circulating Water System of the ETF Facility. The cooling water conditions used to size equipment are:

Supply	74 °F	23.3 °C
Return, max. allowed	89 °F	31.7 °C

The cooling water is supplied at a pressure of approximately 50 psig.

1.3.2.3 Steam Conditions

Steam is available from the Facility Reheat Steam System (see SDD-011 and Fluid System Diagram No. 501-302-011) for the air and oxidant compressor steam turbine drives.

Inlet Conditions

Pressure	395.0 psia	27.23 bar
Temperature	1000 °F	537.8 °C
Enthalpy	1523.0 Btu/lb	3.542 MJ/kg

Outlet Conditions

Pressure	working into condenser set for 2.5 in (64 mm) Hg absolute.	
Temperature	108.7 °F	42.6 °C
Enthalpy	1102.3 Btu/lb	2.564 MJ/kg

Low Pressure Steam is available from the Facility Auxiliary Steam System (SDD-051 and Process Flow Diagram No. 507-302-051) for use in the liquid oxygen and liquid nitrogen vaporizers and for other system purposes such as deriming (moisture eliminating).

2.0 DESIGN DESCRIPTION

The Oxidant Supply System consists of the ASU, the ASU Compressor with its Auxiliaries, the Mixing Chamber, three Oxidant Compressors, and the Liquid Storage System.

2.1 SUMMARY DESCRIPTION

The Oxidant Supply System (Drawing 1-FS-820) provides pressurized oxygen-enriched air to the Intermediate Temperature Oxidant Heater section of the Heat Recovery/Seed Recovery (HR/SR) System at the flowrate and pressure required by the MHD power train. Medium purity oxygen, produced in a cryogenic Air Separation Unit (ASU), is mixed with ambient air in a mixing chamber. Two uncooled axial compressors raise the oxidant pressure to the value desired.

2.1.1 Air Separation Unit (ASU)

The ASU produces a medium purity oxygen stream by separating air into its oxygen and nitrogen components in a double distillation column. Compressed air from the ASU Compressor, cooled by the oxygen and nitrogen product streams to near liquefaction temperature, enters the lower column where the first stage of separation occurs. Liquified intermediate products are reduced in pressure and fed into the upper column where the separation is completed. The oxygen product is delivered as a gas at near ambient conditions. Some liquid oxygen and nitrogen products may be withdrawn for storage for use in plant startup, magnet cooling, etc.

Major elements of the ASU include:

Reversing heat exchanger (revex) and switching valves
Lower and upper distillation columns
Expansion turbines and valves
Impurity adsorbers

2.1.2 ASU Compressor and Auxiliaries

This system provides compressed air to the ASU at a temperature slightly above ambient.

Major elements include:

Filter and silencer
Compressor and steam turbine drive
Intercooler(s)
Aftercooler

2.1.3 Oxidant Mixing Chamber

The Oxidant Mixing Chamber blends incoming atmospheric air with oxygen product from the ASU to provide an oxygen-enriched stream suitable for operation of the MHD Power Train.

Major elements include:

Filter and silencer
Mixing chamber

2.1.4 Oxidant Compressors

The blended oxygen stream is compressed by uncooled axial compressors rated for enriched air service at up to 40 volume percent oxygen. The blended stream is delivered to the HR/SR system for heating and delivery to the MHD combustor.

Three 50 % oxidant flow compressors are used for redundancy. One compressor is driven by an electric motor to facilitate startup. The other two compressors are steam turbine driven.

Major elements include:

Oxidant compressor and electric motor drive
Oxidant compressor and steam turbine drive (2)

2.1.5 Liquid Storage System

Liquid oxygen storage is provided for plant startup and to improve plant availability by providing a supply of medium purity oxygen gas to the mixing chamber during maintenance or failure of the ASU or its air compressor. Liquid nitrogen storage is provided for magnet cryogenic supply and plant auxiliary uses, such as blanketing or accelerating ASU cooldown.

Major elements include:

Liquid oxygen and nitrogen storage tanks
Evaporators

2.1.6 Process Description of the Air Separation Unit (ASU) and ASU Compressor (Drawings 1-FS-813 & 1-FS-815, see Tables 1 and 2 for symbols)

The basic principle of the ASU process is to separate out various components of liquefied air at their respective boiling points. To achieve this, an air separation plant must contain equipment to perform the following functions:

- a. Air compression
- b. Cooling the air to its liquefaction temperature
- c. Removal of water vapor and carbon dioxide from the air
- d. Refrigeration

- e. Liquefaction
- f. Air separation
- g. Removal of dangerous impurities

A detailed description of the operation of the major equipment is given in Section 2.2.1 below.

2.1.6.1 Air Compression
(Drawing 1-FS-813)

The air to be separated is filtered through filter (F1), then passes through a silencer (SL) to be compressed by the ASU air compressor (C1) to the required pressure. The heat of compression is removed by the intercooler(s) (E1-A and E1-B) and an aftercooler (E2).

2.1.6.2 Cooling the Air to its Liquefaction Temperature
(Drawing 1-FS-815)

In the reversing heat exchangers ("revexes" E3 and E4) the air is cooled to its liquefaction temperature and then fed into the lower distillation column, or as it is more commonly called, the pressure column (T1). The heat removed from the air during the cooling process is transferred via the reversing heat exchangers to the product streams (medium purity oxygen, waste nitrogen and pressurized nitrogen), warming them to ambient temperature. Products which must be supplied dry and free of carbon dioxide are passed through non-reversing passages in the revexes (E3 and E4).

2.1.6.3 Removal of Water Vapor and Carbon Dioxide from the Air

Any water vapor and carbon dioxide present in the inlet air would lead to blockages in the low-temperature part of the ASU due to the formation of ice and dry ice. These two components are removed in the reversing heat exchangers (revexes E3 and E4) of this type of plant.

The water vapor and carbon dioxide present in the air solidifies on the walls of the revex passages as the air is cooled. By passing the inlet air and product waste nitrogen streams alternately through this equipment, the solid deposits are removed and leave with the waste nitrogen as it is warmed.

2.1.6.4 Refrigeration

Refrigeration, required to offset heat leakage through the insulation and to allow removal of cold liquids from the ASU, is obtained by expanding air in the expansion turbines (ET1 and ET2) and throttling valves.

2.1.6.5 Liquefaction

Liquefaction occurs in the liquefiers (E5 and E6) and in the main and auxiliary condensers (K1 and K2).

Air is condensed in the liquefiers by heat exchange with cold product gas streams. The liquid is then fed into the high pressure column (T1).

In the main condenser, located between the high and low pressure columns (T1 and T2), heat exchange takes place between gaseous nitrogen at the top of T1 and impure liquid oxygen at the bottom of T2. Due to the difference in pressure in the two streams, the nitrogen is liquefied and the liquid oxygen is partially vaporized. Both streams remain in their respective columns, so as to maintain the rectification efficiency. Additional liquefaction occurs in the auxiliary condenser.

2.1.6.6. Air Separation

The air is first separated in the high pressure column (T1) to give an oxygen-rich liquid and nitrogen gas. The oxygen-rich liquid is fed from the base of the high pressure column through a throttle valve to the low pressure column (T2). The feed point in T2 is chosen so that the composition of feed and the liquid at that point in the column are similar. Part of the liquid nitrogen is fed from the head of the high pressure column through a throttle valve to the head of the low pressure column. The liquid stream is first sub-cooled in a heat exchanger.

The final separation of the air takes place in the low pressure column (T2) as rising nitrogen gas causes oxygen to condense and flow downward to the main condenser (K1). The medium purity (70% by vol) oxygen from the base of T2 is taken as a liquid to auxiliary condenser (K2) where it is evaporated. The products, medium purity oxygen and nitrogen, are warmed to ambient temperature by passing through the various heat exchangers.

Producing medium purity oxygen in T2 lowers the temperature of the boiling oxygen in the main condenser K1 below that of pure oxygen. This in turn lowers nitrogen pressure in the pressure column T1 needed to maintain the

required differential between the boiling points in the two columns. Consequently, the incoming ASU air needs only to be compressed to a nominal 4 atm compared to the nominal 6 atm required for pure oxygen. This lowers the ASU compressor power consumption to 196 kW-hr per ton of "equivalent pure oxygen" for the design case.

2.1.6.7 Removal of Hazardous Impurities

Due to the continuous vaporization of liquid oxygen in the condenser (K1) there is the danger of fires resulting from hydrocarbon enrichment particularly acetylene. This enrichment can be avoided by periodic removal of liquid oxygen from the condenser. For this reason, a small fraction of the condenser liquid is removed via pumps (P1 and P2) and liquid adsorber (A3). The liquid is vaporized downstream of the adsorber which removes the hydrocarbon impurities. If high hydrocarbon concentrations are expected, one or more adsorbers may be placed in the product reflux line which transfers bottom column product to the top column.

The liquid product transferred to LOX storage is also cleaned using this system.

2.2. DETAILED DESCRIPTION

2.2.1 Major Equipment

2.2.1.1 ASU Compressor Systems (Drawing 1-FS-813)

This system takes ambient air and compresses it to the pressure required by the ASU. The compressor is driven by a steam turbine using steam from the Facility Reheat Steam System.

2.2.1.1.1 Air Filtration System (1 required) (Drawing 1-LO-1577-4 and 1-FS-813)

This system (F1) incorporates dual stage filtration with a resultant pressure drop of 0.2 psi. The first stage is designed for automatic surface renewal, the second stage is of semi-rigid replaceable design.

The air filter removes 99.5 % of all particles 10 micrometer (microns) or larger, 97 % of all particles 2 micrometer or larger and 95 % of all particles 1 micrometer or larger.

The filter housing is equipped with ladders and platforms for routine maintenance, doors to allow replacement and servicing of filter elements and surge doors to relieve back pressure should a compressor surge occur.

2.2.1.1.2 Silencer (1 required)
(Drawings 1-LO-1577-4 and 1-FS-813)

The silencer (SL) is designed to maintain noise levels in the vicinity of the ASU compressor to a "time weighted average" less than 85 decibels over an eight hour period. Pressure drop through the silencer is approximately 0.2 psi.

2.2.1.1.3 Air Flow Metering Line

As shown on Drawing 1-LO-1577-4, the pipe from the silencer to the inlet of the ASU compressor is quite long, so as to provide accurate flow measurement. The calibrated venturi, used for flow measurement in the automatic flow control of inlet air system, is located in this pipe.

2.2.1.1.4 ASU Air Compressor (1 required)
(Drawings 1-LO-1577-1, 1-LO-1577-5 and 1-FS-813)

The ASU air compressor (C1) is of axial-centrifugal design, coupled directly to a steam turbine driver. This compressor was selected to maintain low power consumption for the ASU.

For the nominal design case, the DEMAG AR 250/7/1F compressor has been selected. Detailed interconnections of fluid flows are shown on Drawing 1-FS-813. One intercooler (E1-A) is used for this particular compressor.

The compressor has a single horizontally split case with several axial stages and one radial stage. The intercooler (E1-A) is between the last axial stage and the radial stage.

A discharge blow-off valve, silencer and relief valve are provided for the compressor and are integrated into the surge control system.

A complete lubrication system is provided to supply the compressor and driver.

The compressor is surrounded by protective walls as described in Section 1.3.1.4.

2.2.1.1.5 Intercooler (1 required)
(Drawing 1-FS-813)

The ASU compressor intercooler (E1-A) is a recuperator which cools the air flow between the last axial stage and the radial stage. The Facility Circulating Water System (SDD-201 and Process Flow Diagram No. 571-302-201) supplies the cooling water.

The intercooler is an ASME-coded vessel with a carbon steel shell and stainless steel internals. The intercooler is supplied with atmospheric vents, drains, and moisture removal equipment.

2.2.1.1.6 Steam Turbine Drive (1 required)
(Drawings 1-LO-1577-1 and 1-LO-1577-5)

The ASU compressor drive is a full condensing steam turbine.

A surface condenser rated for 100 % condensing capacity with zero extraction at design speed and maximum air flow conditions is provided. The condensate is returned directly to the Facility Condensate System (SDD-101 and Process Flow Diagram 511-302-101).

Removal of non-condensibles from the surface condenser is provided by the Facility Condensate System.

The turbine drive is supplied from the common oil supply unit of the compressor (C1). Included are: a hydraulically operated stop valve, strainer in the stop valve, multi-valve automatic steam control valve gear, multi-valve non-throttling extraction control valve gear, automatic oil-operated non-return valve for extraction line (arranged for automatic closings by overspeed governor), shaft packing steam seal system, sentinel warning valve on turbine exhaust casing.

2.2.1.1.7 Direct Contact Aftercooler (1 required)
(Drawings 1-FS-813, 1-FS-820, and 1-LO-1577-4)

One aftercooler (E2) for the process air using cooling water from the Facility Plant Circulating Water System is provided. It also acts as a surge drum to protect the air compressor during heat exchanger reversals.

In addition, the aftercooler also serves as a wash tower to remove any possible corrosive contaminants from the air.

The aftercooler is of spray type design and includes a mist eliminator to remove entrained moisture from the gas discharge. It is an ASME-coded vessel with a carbon steel shell, lined with corrosion resistant, non-porous epoxy and fitted with 304 stainless steel internals. The aftercooler is supplied with atmospheric relief valves, drains, mist eliminator, and manholes for removal of column internals for maintenance and repair.

The air compressor aftercooler (spray cooler) requires a water pressure substantially above the aftercooler air pressure of 60 psia. Booster pumps are provided to raise the available water pressure to approximately 90 psig. The air compressor aftercooler is designed to have a water storage capacity of three minutes at maximum cooling water flow. Steam tracings of the bottom part of the vessel are provided to prevent freezing.

2.2.1.2 Air Separation Unit (1 required)
(Drawings 1-LO-1577-2 and 1-LO-1577-7)

The air separation unit consists of a coldbox subdivided into a number of coldbox subassemblies as described hereafter.

2.2.1.2.1 Coldbox Assembly (1 required)
(Drawings No. 1-LO-1577-2 and 1-LO-1577-7)

The assembly consists of several connected boxes, namely the column cold box, the adsorber cold box, the revex cold boxes, the valve cold box and the expander cold box. Drawing No. 1-FS-815 shows their placement in the flow schematic.

All coldbox equipment is designed for Pearlite insulation. All cryogenic equipment is installed in carbon steel casings, vapor proof and nitrogen purged. Material for the equipment inside the cold box is primarily aluminum, including the columns, trays, and piping. Flanged connections are minimized. Wherever they are used, they are insulated with mineral wool. All equipment is provided with stainless steel supports. Dump chutes are provided for removal of the Pearlite insulation.

The following equipment is installed inside the coldbox assemblies:

One (1) heat exchanger assembly (composed of reversing exchangers, E3 and E4) with reversing passes for air and waste nitrogen, and non-reversing passes for medium purity oxygen product, pressurized nitrogen product, and expansion turbine gas. Included are a timing device to actuate reversal of the passes, switch valves at the warm end, and butterfly valves at the cold end of the exchanger assembly.

One (1) Pressure Column (T1)

One (1) Upper Column (T2)

One (1) Intercolumn Condenser/Reboiler (K1)

One (1) Auxiliary Condenser/Reboiler (K2)

Two (2) Subcoolers (E7-A and E7-B)

Two (2) Air Liquefiers (E5 and E6)

Two (2) First-Stage Hydrocarbon Adsorbers (A1 and A2) for oxygen enriched sump liquid of the high pressure column. Supply includes initial adsorbent charge. Fill and discharge connections are provided. One adsorber is in operation while the other is reactivated/on standby.

One (1) Second-Stage Hydrocarbon Adsorber (A3) for the oxygen slipstream from reboiler (K1).

All interconnecting piping for the elements contained within the coldboxes from the feed inlet to the product outlets.

All process valves, operating valves and drains, deriming (moisture eliminating) and safety valves. Drains and safety valves discharge either to atmosphere or to a drain header.

All supports within the coldbox and all ladders and platforms required for the operation of the unit.

Coldbox piping is aluminum or stainless steel, with the exception of the deriming inlet-header and casing purge piping, which are made of carbon steel.

The coldbox carbon steel casing is designed in conformance with AISC specifications.

All structural members within the coldbox are suitable grade aluminum or steel for the individual application.

The coldboxes are supplied with support legs.

The coldboxes are supplied with a nitrogen purge system which will maintain a positive pressure inside the column box.

The external carbon steel surface is painted on completion of the plant construction phase. It is supplied with a zinc rich primer.

Approximate Dimensions

(Refer to Drawings 1-LO-1577-2 and 1-LO-1577-7 for more details).

	L	x	W	x	H
Column Cold Box	: 17'	x	18'	x	90'
Revex Exchanger Cold Boxes (2)	: 13'6"	x	13'6"	x	45'
Adsorber Cold Box	: 13'6"	x	11'	x	55'
Valve Cold Box	: 13'6"	x	13'6"	x	45'
Expander Cold Box	: 13'6"	x	10'	x	10'

The coldboxes are partially field assembled. (A cross section of 13'6" is generally the limit for transport by either truck or rail.)

2.2.1.2.2 Liquid Oxygen Pumps (2 required)
(See Drawing 1-FS-815)

Two liquid oxygen pumps (P1 and P2) are provided for recirculation of liquid oxygen through second stage hydrocarbon adsorber to reboiler/condensers. P2 is an installed spare.

2.2.1.2.3 Expansion Turbines with AC Generators (2 required)
(See 1-FS-815)

The expansion turbines (ET 1 and ET 2) provide the refrigeration required by the plant. One turbine serves as an installed spare and to provide additional refrigeration during start-up and maximum liquid production. The turbines are coupled through a gear reducer to an induction motor/generator for power recovery and speed control. Although the expansion turbine power is very small (0.1% of total power plant output) the generated power can be transferred to the grid or used for auxiliary purposes.

Included with the turbine is local instrument panel, adjustable inlet guide vanes, emergency shut-off valves, overspeed protection, complete lubrication system.

2.2.1.2.4 Liquid Disposal Ejector (1 required)

A liquid disposal ejector is supplied for the removing liquids from the cold box after shut-down of the plant. The liquids are evaporated by Facility supplied low pressure steam.

2.2.1.2.5 Exhaust Silencer (1 required)

An exhaust silencer (SL on 1-FS-815) is provided for the waste nitrogen stream to maintain a "time weighted average" noise level in the vicinity of the coldboxes less than 85 decibels over an eight hour period.

2.2.1.2.6 Regeneration Heater (1 required)

A steam heater is supplied to heat the nitrogen gas used for regenerating the hydrocarbon adsorbers.

2.2.1.2.7 Derime Heater (1 required)

One heater is supplied and powered from the Facility Auxiliary Steam System to heat derime air from the aftercooler (E2).

2.2.1.3 Oxidant Mixing Chamber
(see Drawings 1-FS-816, 1-LO-1577-4 and 1-LO-1577-8)

The mixing chamber is a rectangular cross-section box having round ducts at opposite ends of the box to introduce ambient air and exhaust the 30 % oxidant product. The 70 % oxygen from the ASU enters the mixing chamber in a duct which connects to an enclosed manifold at the top of the chamber. From this manifold are suspended three pipes, each having a number of holes about their perimeter and along their lengths. Holes are placed to promote turbulent mixing. Additional baffles inside the O₂ injection pipes also increase turbulent mixing.

The mixing chamber is constructed of sheet metal (with reinforcement to withstand slight variations in pressure) and has transition sections between the rectangular and round sections. It is airtight, with access through doors.

2.2.1.3.1 Mixing Chamber Air Filter (1 required)
(See Drawings 1-FS-816 and 1-LO-1577-4)

This system incorporates dual stage filtration with a resulting pressure drop of 0.2 psi. The first stage is designed for automatic surface renewal, the second stage is of semi-rigid replaceable design.

The air filter removes 99.5 % of all particles 10 microns or larger, 97 % of all particles 2 microns or larger and 95 % of all particles 1 micron or larger.

The filter housing is equipped with ladders and platforms for routine maintenance, doors to allow replacement and servicing of filter elements and surge doors to relieve back pressure during compressor surging.

2.2.1.3.2 Mixing Chamber Silencer (1 required)
(Drawings 1-FS-816 and 1-LO-1577-4)

The silencer is designed to maintain noise levels in the vicinity of the mixing chamber air inlet to a "time weighed average" not to exceed 85 decibels over an eight hour period. Pressure drop through the silencer is approximately 0.2 psi.

2.2.1.3.3 Air Flow Metering Line

As shown on Drawing 1-LO-1577-4, the pipe from the silencer to the mixing chamber is nominally 45 ft long so as to provide accurate flow measurement. A venturi is located in this pipe for use with the automatic flow controller shown schematically on Drawing 1-FS-816.

2.2.1.4 Oxidant Compression System
(Drawings 1-FS-818 to 1-FS-820, 1-LO-1577-1, 1-LO-1577-5 and 1-LO-1577-6)

The oxidant compression system consists of three equipment trains with identical compressors; two are steam turbine driven, and one is electric motor driven. Each compressor is rated to pass 50 % of total oxidant flow. Control and protection of the Oxidant Compression System is from the Facility Control/Protection System. Each compressor train is surrounded by protective walls as described in Section 1.3.1.4.

2.2.1.4.1 Oxidant Compressors (#1, #2, and #3) (3 required)
(Drawings 1-LO-1577-1, 1-LO-1577-5 and 1-LO-1577-6)

As discussed in Appendix B, a GHH compressor model AGR 7/14 was selected for use in all three units.

The oxidant compressors are designed as single horizontally split axial machines with a radial final stage for stabilization and reliability. The compressor housings have been made of a higher grade steel rather than cast iron used for the construction in an equivalent air compressor. This allows safe compression of a stream of up to 40 volume percent oxygen.

The assembled rotor is dynamically balanced and overspeed tested. Variable stators allow constant outlet pressure at various flows. The design speed of each compressor is between the first and second critical speed, conforming to API 617.

A pressurized lubrication system supplies the three oxidant compressors. A by-pass cooler (see Drawings 1-FS-818 and 819) for each compressor is provided. These exchangers cool gas that is recirculated back to the suction side of the compressors.

Oxidant compressor bearing seals are designed with a nitrogen buffer gas system to prevent lubricating oil vapors from entering the main flow path of the compressors.

2.2.1.4.2 Steam Turbine Drives (2 required)
(Drawing 1-FS-820)

The drives for Oxidant Compressor #2 and #3 are condensing steam turbines.

A surface condenser rated for 100 % condensing capacity with zero extraction at design speed and maximum oxidant flow conditions is provided. The condensate and non-condensibles are returned to the Facility Condensate System.

Each turbine drive is supplied from the common oil supply unit of the compressor.

The following are included for each of the turbines: hydraulically operated stop valve, strainer in stop valve, multi-valve automatic steam control valve gear, electro-hydraulic speed control governor, shaft packing steam seal system, sentinel warning valve on turbine casing.

2.2.1.4.3 Electric Motor Drive (1 required)

The driver for Oxidant Compressor #1 is a brushless synchronous motor with full voltage starting. The power system is resistance grounded, limiting

fault current to 400 amperes. The motor will be water-cooled with sleeve bearings insulated from the frame.

2.2.1.4.4 Protective Walls

Each compressor train is isolated by a protective wall in accordance with the safety recommendations of the EWP Code of Practice for Turbo Compressors for Oxygen Service, (see section 1.3.1.4). Sound attenuation to a "time weighted average" not to exceed 85 decibels, is combined with the protective walls. Visual inspection is provided through inspection ports in the wall.

2.2.1.5 Storage System (see Drawings 1-FS-820, 1-FS-817, 1-LO-1577-2, 1-LO-1577-3, and 1-LO-1577-7)

2.2.1.5.1 Liquid Oxygen (LOX) Storage and Vaporization

Liquid oxygen (LOX) is pumped (using internal ASU pumping) and stored at the same pressure (13.5 psia) normally used for delivery of the gaseous oxygen from the ASU. However, should the pressure of the product oxygen from the cold box drop, the liquid will automatically be fed to its steam vaporizer and from there to the oxidant mixing chamber.

The storage tank capacity of 50,000 gallons is more than adequate to permit operation for approximately four hours. The tanks are vacuum insulated for a low boil-off rate (0.3 % of the full tank or less). They are shop-fabricated and can be shipped to site without modification. The vaporizers are steam-heated from the Facility steam system.

2.2.1.5.2 Liquid Nitrogen (LIN) Storage and Vaporization

A 3000 gallon storage tank for liquid nitrogen (LIN) is provided. It is vacuum-insulated, resulting in a very low boil-off rate. It can be filled either by truck or from the ASU.

The liquid nitrogen contains a maximum of 100 ppm oxygen. It is piped to the superconducting magnet system for precooling helium refrigeration/liquefaction cycle and to the column coldbox for pre-cooling the ASU during ASU startup.

The pressure of the liquid nitrogen produced in the pressure column is adequate for supplying both the magnet system and ASU startup requirements. A vaporizer (using Facility steam) is provided to vaporize the LIN. This gas is produced at the same 47.9 psia (3.3. atm) as the pressurized nitrogen gas produced in the ASU. As shown on Drawing 1-FS-820, this line is connected to the line from the ASU that supplies pressurized nitrogen to the Facility compressor and blanketing systems.

2.2.2 Piping and Valves

This system includes piping material, pipe supports and valves for process air, liquid oxygen, liquid nitrogen, deriming air, instrument air, makeup water, cooling water and interconnecting of all equipment that is supplied.

Flexible connections are provided as applicable to the compressor, expander and product line.

Insulation is supplied for the deriming systems. Insulated lines have a moisture barrier and aluminum jacketing. Cathodic protection is provided where required. Underground piping is coated with bitumen and wrapped.

2.2.3 Electrical

2.2.3.1 General

The Facility supplies a complete high voltage (13.8 kV) and low voltage (480/277 V and 120/208 V) distribution system.

All electrical work is in accordance with the NEC and all other applicable codes.

Metal enclosed starters of the draw-out type are provided and installed by Facility with control principally by control stations or panels adjacent to the equipment being controlled.

13.8 kV and 480 V feeder lines for the ASU equipment are provided and connected to sources in the electric room which have been furnished and installed by the Facility.

A main control panel is furnished, installed and connected in the Facility control room.

Control and lighting feeders (480 V AC and 120 V AC) to the ASU equipment from panels and sources furnished and installed by the Facility in the control and electric rooms are provided.

2.2.3.2 Electrical System Design

Power Service

13.8 kV, 3 phase, 60 Hz source complete with disconnecting means and protective relaying in the motor starter is provided by the Facility. Feeders from the starter are provided and installed.

480 volt, 3 phase, 60 Hz sources complete with disconnecting means and protective devices in the 480 volt motor control centers is provided by the Facility. Feeders to the 480 volt equipment is provided.

High Voltage Electrical Distribtuion System

Metal-clad switchgear is provided for the 13.8 kV compressor motor of Oxidant Compressor #1.

This switchgear shall be provided and installed by the Facility in an electrical distribution room.

Protective relaying is specified by Lotepro for purchase and installation by the Facility.

Power distribution is by 15 kV shielded copper cable with filled cross-linked polyethylene insulation.

All power cable runs are in rigid steel conduit.

All power cable conduit are underground wherever possible.

Stress cones are used at 15 kV cable terminations.

Secondary (480 V/277 V) Electrical Distribution System

Feeders are provided and installed from the 480 volt motor control centers provided and installed by the Facility to all 480 volt equipment in the Oxidant Supply System.

The equipment is specified for purchase and installation by the Facility.

Power distribution is installed in rigid galvanized steel conduit.

480/277 volt lighting and power distribution is from panels provided and installed by the Facility in the electrical room.

Grounding

A complete ground grid system is installed by the Facility using insulated copper cable to provide a reliable equipotential system.

Provisions for connection of this grid to the main facility grid have been made.

All underground splices and connections are of the exothermic (cadweld) type and shall be water proofed by taping.

All exposed connections to equipment are double bolted for security.

A minimum of twenty-one (21) 3/4" diameter 10' long copper-weld rods are driven and connected to the ground grid to maintain the grid and equipment at ground potential.

All power circuits have a ground conductor installed with the power conductors to allow proper operation of ground relaying.

2.2.4 Instruments, Controls, and Alarms

2.2.4.1 Instrumentation (Refer to P&I Drawings 1-FS-813 to 1-FS-820)

Electronic instrumentation is used throughout, except for pneumatic valve operators, and local pneumatic instrumentation at the compressors.

Flow rates are measured across orifices, except for large-flow-rate low-pressure compressor inlets where venturis are used.

In addition to the instrumentation provided, all electronic signals are made available to and will be handled by the Facility's Data Handling System.

All instrumentation wiring is connected to terminal boards at the appropriate panels of the instrument room and/or the Facility Main Control Room.

Listed below are the major instrumentation components for the sub-systems of the Oxidant Supply System.

2.2.4.1.1. Air Separation Unit Instrumentation

Instrumentation for the ASU includes but is not limited to the following:

Local panels for the expansion turbines.

Automatic temperature control equipment for reversing exchanger groups.

Flow recording instrumentation for process air, gaseous and liquid oxygen, gaseous and liquid nitrogen products (two pen recording is specified) and gaseous oxidant.

Pressure gauges (without transmitters) for indication of important pressures. Transmitters are provided for all remote oxygen and oxidant pressures and all pressures above high pressure column pressure.

Pressure differential transmitters and pneumatic pressure gauges for indication of differential pressure of the columns and of the liquid levels of the pressure column, reboiler/condenser and auxiliary condenser. Resistance thermometers and multiple point indicator for all important temperatures.

Automatic analysis control equipment for oxygen and nitrogen products, oxidant O₂ content, reboiler hydrocarbon content, CO₂ content and oxygen in waste gas. A product totalizer is provided.

Automatic control equipment for the air and oxidant compressors.

Plant emergency trip system.

2.2.4.1.2 Air Compression System

Instrumentation for the air compression system includes but is not limited to the following:

Local panels.

Surge control--temperature and pressure compensated.

Vibration monitors.

Mass flow control.

Shaft position indicators.

Required gauges, thermometers, alarms and indicators.

Alarm and shutdown system with permissive start.

2.2.4.1.3 Oxidant Compression Systems

Instrumentation for the oxidant compression system includes but is not limited to the following:

Anti-surge and capacity control, temperature and pressure compensated.

Vibration monitors.

Shaft position indicator.

Required gauges and thermometers.

Local panel with alarm and shutdown systems, permissive start.

In addition, the recommendations of the European Working Panel on Oxygen Compression have been taken into account.

2.2.4.2 Controls (1-FS-816 through 1-FS-820)

Control systems are of fail-safe design.

The Mixing Chamber air and ASU product flows are regulated automatically (see Drawing 1-FS-816) as a function of the desired oxygen content in the product stream. Control of the Mixing Chamber flow (see Drawing 1-FS-816), of the LOX Storage System (Drawing 1-FS-817) and of the Oxidant Compressor System (see Drawings 1-FS-818 to 1-FS-820) are from the Facility Main Control Room, Main Control Panel. Control of the ASU, ASU Compressor and the LIN Storage System is from an auxiliary panel located in the Facility Control Room.

The liquid oxygen storage system shall be designed for automatic operation upon shutdown of the air separation unit.

Control power is obtained from panels provided and installed by the Facility in the electrical room.

All control cable is of 600 V rated multi-conductor copper with #14 as a minimum size for 120 V circuits. Cable for electronic or sensitive instrumentation use is a minimum 18 gauge and of shielded construction.

All cable is installed in conduits separate from 120 V and power circuits.

All control wiring is connected to terminal boards at the appropriate control panel in the Facility control room for access or service.

2.2.4.3 Alarms

Approximately 40 alarms, optical and acoustical, to signal potentially disadvantageous conditions are installed on the main control panel. An adequate number of sample points are brought outside the coldbox.

Alarms, optical and acoustical, to signal dangerous machinery conditions are provided. All compressor and expansion turbine alarms and shutdowns are annunciated, indicating at the control panels and locally to indicate the specific function which failed.

When the ASU cold box product flow ceases or decreases, an alarm sounds in the Facility Main Control Room to alert the operator. In response to this alarm, the LOX storage system transfers stored liquid product (70% O₂ by volume) through the Evaporator/Heater to the Mixing Chamber.

3.0 SYSTEM PROTECTION AND SAFETY PRECAUTIONS

3.1 PROTECTIVE DEVICES (Drawings 1-FS-813 to 1-FS-820)

The major equipment instrumentation for detecting dangerous conditions and protective devices have been described and/or included in Section 2.0, Design Description. These instruments and devices are given in greater detail on the Process and Instrumentation Drawings.

The piping and valve design limits are equal to or greater than those of the connecting equipment. Therefore, no additional protective devices are required. All major equipment have safety and relief valves, pressure burst discs, overspeed controllers and other devices appropriate to their function and operation.

3.2 HAZARDS

3.2.1 Air and Oxidant (30 Mole % Oxygen)

Constituents of air:	approx. 21 % oxygen
	approx. 78 % nitrogen
	balance: rare gases and impurities

Boiling point of air: -317.8°F (at 760 Torr)

CAUTION When allowed to come in contact with the skin, liquid air and liquid oxidant cause injuries very similar to burns.

When liquid air or liquid oxidant are left standing in an open container for some length of time, the oxygen content of the liquid will increase due to the evaporation of the more volatile nitrogen. The liquid will consequently assume, more and more, the properties of liquid oxygen.

3.2.2 Oxygen

Boiling point: -297.4 °F (at 760 Torr)

Oxygen is a colorless, odorless, non-toxic gas which is required for combustion. The higher the oxygen concentration, the more intense and rapid the combustion. Even an increase of 4 % in the oxygen content of air will result in a substantially intensified combustion. Many substances, including metals, which cannot be ignited in normal atmospheric air, are combustible in the presence of higher oxygen concentration or in pure oxygen. Combustible substances are, in the presence of higher oxygen concentrations, highly prone to self-ignition and to explosion. These phenomena are intensified in the presence of oxygen under pressure or of oxygen in liquid form.

Clothing impregnated with oxygen can easily ignite (e.g. by sparking from electrostatic charges) and will burn very rapidly. This danger exists not only during presence in an oxygen-rich atmosphere but also for some considerable time afterwards.

Oxygen in liquid state is an additional hazard. When allowed to come into direct contact with the skin it will, due to its coldness, cause injuries that are very similar to burns.

3.2.3. Nitrogen (Also applies for Argon and Neon)

	Nitrogen	Argon	Neon
Boiling points:	-320.4 °F	-302.6 °F	-410.8 °F

Nitrogen is a colorless, odorless and non-toxic gas. In high concentrations, however, it will cause suffocation when inhaled due to the lack of oxygen.

NOTE: Danger of Death by Nitrogen Suffocation

Breathing of nitrogen (or argon or neon), or of air enriched with these, is particularly dangerous since unconsciousness occurs very rapidly without any prior discomfort to the victim.

At room and low temperatures, nitrogen (also argon and neon) prevents processes of combustion. These gases are sometimes used for inerting.

As a result of its coldness, liquid nitrogen also causes injury when brought into direct contact with the skin.

Rare gases such as argon and neon possess essentially the same characteristics and hazards as nitrogen.

A dry nitrogen atmosphere is continuously maintained in the insulation spaces of the low-temperature sections in air separation plants so as to exclude humidity and to prevent oxygen condensing on the cold parts.

3.3 PRECAUTIONS

The following safety precautions must be strictly observed in areas near the air separation units, in the air and oxidant compressor building and in all facilities in which the product gases of the Oxidant Supply System are stored, handled and/or further treated.

3.3.1 Fire and Explosion Dangers

Smoking and all avoidable activity involving the use of open flames are prohibited.

All work involving open flame, such as welding, soldering, grinding, etc., is prohibited. However, when any such work is necessary, precautions must be observed to avoid increased concentrations of oxygen in the work location.

The enrichment of the air with oxygen is to be avoided. However, if any such enrichment has occurred, or may occur, the areas concerned must be clearly indicated and safety precautions correspondingly intensified. Care shall be taken that any such rooms or other confined spaces are sufficiently ventilated. Prior to personnel entering oxygen processing vessels and piping, such equipment must be very carefully purged with dry and oil-free air. It should be proved, by means of control analyses, that there are no increased concentrations of oxygen.

As an alternative to air, dry and oil-free nitrogen may be used for purging, provided the increased N_2 concentrations are removed before entering such spaces thus scavenged (see the Note in 3.3.2 "Danger of Death by Nitrogen Suffocation").

Personnel should avoid remaining in areas where there are increased concentrations of oxygen.

Work as described above shall be performed under the supervision of an authorized supervisor.

Special attention shall be given to possible sources of accidental ignition. Electrostatic charges shall largely be eliminated by the selection and use of clothing and shoes made of suitable materials. In order to prevent unintentional sparking, shoes studded with iron nails or having any other exposed iron or steel parts are prohibited.

All parts coming into contact with oxygen must be free from inflammable materials of any kind whatsoever. Particular care must be taken that all these parts are absolutely free from oil and grease.

Only perchloroethylene may be used for degreasing non-aluminum parts. Stabilized trichloroethane (methyl chloroform) may be used for degreasing aluminum parts.

CAUTION Trichloroethylene must not be used for cleaning parts made of aluminum or of aluminum alloys, since these substances react explosively with each other.

Trichloroethylene vapors may form explodable mixtures with air at temperatures around 20°C. Special attention must be given to the toxic nature of these cleansing agents (use of respirators, ventilation, protection of skin, etc.).

The personnel clothing must be free of any oil or grease. Even fatty cosmetics may constitute a source of danger.

The storage of combustible materials in the plant area is prohibited. An exception to this rule is storage of those lubricants and raw materials that are necessary for the operation of the plant.

Persons who have remained in an atmosphere rich in oxygen can be sure that their clothes have been impregnated with oxygen. Their clothes must, without delay, be aired very thoroughly.

Shutoff devices for oxygen shall be opened and closed slowly but smoothly. In the instance of oxygen under pressure, the application of this rule is absolutely imperative.

The concentration of acetylene in the liquid oxygen in the main condenser (K1) must be determined at least once a day and the results of these tests recorded in writing for purposes of determining when the plant must be shut down, the liquids drained, and the low temperature section derimed. (Refer to Section 2.1.6.7 "Removal of Hazardous Impurities".)

Too high an acetylene content in the liquid oxygen may cause an explosion. If the permissible values are exceeded, the following precautions must be taken to ensure that acceptable values are obtained:

1. Detect and/or eliminate the cause for the rise in acetylene content.
2. Immediate change-over or regeneration of the acetylene adsorbers.
3. Increase liquid production and flush.
4. If further acetylene increases cannot be prevented and when the acetylene content in the liquid oxygen reaches 1 ppm, the plant must be shut down, the liquids drained and the low temperature section derimed.

3.3.2 Danger of Death by Nitrogen Suffocation

The mixing of the air with nitrogen, or gases of similar characteristics, must be avoided. However, if any such mixture has occurred, or may occur, the areas concerned must be clearly designated and the personnel will be required to observe stricter safety precautions. Personnel are prohibited to enter such areas without respirators.

Care must be taken that all such areas are sufficiently ventilated.

It is prohibited to remain or to work in areas in which there are increased concentrations of nitrogen or in areas in which increased concentrations of that gas may occur.

If and when it is necessary to carry out work in such areas it must be ensured, before starting, that there are not increased concentrations of nitrogen, nor the possibility of such increases occurring.

Before entering any confined spaces which contain, or are presumed to contain, nitrogen, it must be ensured, by means of control analyses, that there is no danger from increased concentrations of nitrogen.

Any such work may only be carried out under the supervision of an authorized supervisor.

3.3.3 Danger Due to Effects of Coldness

When handling low-boiling temperature liquefied gases, personnel must wear the requisite protective clothing (gloves, safety goggles, tightly woven clothes), and avoid trouser legs tucked into boots as protection against contact with the liquid.

An enrichment of air results from the evaporation of the liquid. In this connection, see also Sections 3.3.1 (Fire and Explosions Dangers) and 3.3.2 (Danger of Death by Nitrogen Suffocation).

Before entering the low-temperature part of the air separation unit (ASU) that section must be heated. Concentrations of oxygen or of nitrogen must be determined to be a safe level for personnel inhalation.

3.3.4 Design of Buildings

Buildings and structures in the Oxidant Supply System must be provided with an adequate system of ventilation. Depending on requirements, fans or blowers are also necessary. The ventilation of cellars, pits, and channels is mandatory to avoid the danger of intensified concentrations of escaping gases in such locations.

In locations where liquid oxygen could escape, the floor must not be covered with any flammable material (e.g. asphalt). It must be free of joints and faults.

Sewers in the areas of Oxidant Supply System and its annexes must be provided with liquid seals.

Sufficient emergency exits from structures must be provided and clearly marked.

3.3.5 Fire Fighting Equipment

Suitable equipment is provided in sufficient numbers for the purpose of extinguishing clothing fires.

Water baths and showers, which can be operated by a single handle, are required.

Water hydrants are provided throughout the plant in sufficient quantity and in accessible locations. Nozzles and sufficient lengths of hose are kept ready for immediate use. In addition, portable fire extinguishers are provided

throughout the plant in sufficient numbers and at locations that are easily accessible.

The following types of fire extinguishers are required:

carbon dioxide fire extinguishers, for use in connection with electrical equipment.

powder-type fire extinguishers, for use in connection with all other type of equipment.

All safety equipment is maintained in perfect working order. Alarm systems are checked at regular intervals.

Warning signs are displayed throughout the Oxidant Supply System clearly and distinctly drawing attention to the fact that Smoking and Open Flames are prohibited within the limits of the Oxidant Supply System and in all confined spaces in which higher concentrations of oxygen may occur.

3.3.6 Safety Devices Against Excess Pressure

All vessels and pipes working under pressure, as well as vessels and pipes in which a build-up of pressure can occur, are equipped with safety devices and these shall always be kept in perfect working order. The blow-off pressure of the safety valves is periodically checked and readjusted, if necessary.

The alarm systems are checked periodically.

3.3.7 Cleansing of the Insulation

The insulated space of the low temperature section of the ASU is kept under pressure. The medium used for this purpose is dry nitrogen. The maintenance of such an overpressure must be controlled and dry nitrogen must be added, if necessary.

Through overpressurization, air humidity is prevented from penetrating the coldbox, possible oxygen concentrations in the coldbox are kept low, and cleansing of the insulation is rendered possible.

During any shutdown of the plant, purging of the insulation is not necessary, but recommended. During shutdown for maintenance inside the coldboxes, the boxes must be continuously purged and oxygen content monitored for sufficient breathing oxygen.

4.0 MODES OF OPERATION

The startup and operating procedures given in this section are for illustrative purposes only. Hence, they are cursory and lacking in detail. Since the Oxidant Supply System is a system in which it is possible to have flame enhancing substances (oxygen) and trapped combustible gases (hydrocarbons and oxygen) that could result in disastrous explosions, procedures must be carefully analyzed at the design stage to a level of detail far beyond the scope of this document.

4.1 STARTUP

The electric motor driven oxidant compressor #1 is used for ASU startup because electric power is available from the grid prior to the availability of steam from the HR/SR of the ETF. Since the ASU compressor, which is shut down during ASU startup, is not available for deriming and initial cooldown of the ASU, air flow is diverted (see Drawing 1-FS-820) from the outlet of this oxidant compressor through a by-pass line to the inlet of the aftercooler (E2). Sufficient cooling capacity exists in the aftercooler to reduce the air temperature to near ambient temperature as required by the ASU to complete deriming and cooldown.

After ASU cooldown, oxidant compressor #1 is valved off from the ASU. The ASU is valved off at "cold soak" condition and the oxidant compressor draws air into the mixing chamber through the ordinary flow path leading through the HR/SR to the combustor. The powerplant is started using this electric driven oxidant compressor #1. As steam becomes available, the ASU and one of the oxidant steam compressors are brought on line. Finally, the second steam driven oxidant compressor is brought on line and the electric one ceases operation. However, the electric driven oxidant compressor #1 remains as a standby unit.

Startup is described hereafter. The LIN storage tank is full at startup. Valve "line-up" is complete.

Refer to Drawing 1-FS-820. Note that shut-off valves, not explicitly shown, exist in all of the lines. The following shall be performed sequentially:

- a. Valve off ASU 70 % oxygen product line to Mixing Chamber.
- b. Open ASU 70 % oxygen product line to atmosphere.
- c. Valve off Steam Driven Oxidant Compressors #2 and #3.
- d. Open Air Inlet valves to the Mixing Chamber.
- e. Open valve between Mixing Chamber and Electric Motor Driven Oxidant Compressor.

- f. Valve off ASU compressor (C1) from aftercooler (E2).
- g. Open by-pass line connecting Electric Driven Oxidant Compressor with Aftercooler (E2).
- h. Purge the entire flow path from Mixing Chamber inlet to ASU product outlet line with discharge from oxidant compressor #1.
- i. Start derime (moisture removing) heater using this oxidant compressor air flow.
- j. Start aftercooler water flow.
- k. Open derime outlet on coldbox, open instrument valves.
- l. Start oxidant compressor #1 for deriming step.
- m. After the specified moisture level has been obtained, cease deriming by shutting off derime heater.
- n. Complete the cooldown process of ASU (See Drawing 1-FS-815) by completing the following:
 - (1) Set reversing exchanger program timer for the minimum time.
 - (2) Prepare expansion turbine for operation.
 - (3) Continue to flow air to ASU from the motor driven oxidant compressor.
 - (4) Cooldown the reversing chambers only. (This will be done at a controlled rate so as to minimize thermal stresses.) Do not allow air to enter the separation columns.
 - (5) After the reversing exchangers are properly cooled, begin to cool the separation apparatus. Both expansion turbines are used for this process. The cooldown period is shortened by adding liquid nitrogen from storage. This step is carried out after the separation apparatus reaches the appropriate temperature level.
 - (6) After liquid forms in the main condenser and liquefier heat exchangers, the rectification process can be established.
 - (7) At this time, only one expansion turbine is required. The outlet temperature should be reduced to a temperature as cold as possible without forming liquid in the discharge of the turbine.

- o. After operating liquid levels have been established, the ASU must be blocked off and remain in a Cold Condition for eight hours in order to allow time for startup of powerplant steam boilers.
- p. To provide airflow to the Facility MHD plant, close off oxidant compressor by-pass line to aftercooler (E2).
- q. Use oxidant compressor #1 to bring the MHD combustor on line and to raise steam in the HR/SR.
- r. Start steam driven oxidant compressor #2.
- s. Start ASU intercooler (E1-A) water.
- t. Start ASU compressor (C1) through atmospheric vent.
- u. Purge lines between ASU compressor (C1) and ASU.
- v. Open ASU product outlet to the atmosphere.
- w. Connect ASU compressor (C1) to ASU.
- x. Establish required product purges in ASU.
- y. Bring second Steam Driven Oxidant Compressor on line while simultaneously taking Electric Motor Driven one off line.
- z. Open ASU product line valve to the mixing chamber.
- aa. Shut off product flow vent to atmosphere.
- bb. Refill LIN storage tank, as liquid becomes available from ASU, until it is full.

4.2 NORMAL OPERATIONS

Normal operation is considered to be any operation between the 75% rated flow and 103.3% rated flow operating points specified in Appendix C. When the ASU reaches steady state for any point of operation, very little operator attention is required. The mode of operation can easily be changed from the main control room and/or compressor control panels.

4.3 SHUTDOWN

4.3.1 Planned Plant Shutdown

The following steps should be carried out quickly and in the order given:

- a. Shut valve between ASU product line and mixing chamber.
- b. Vent product lines to atmosphere.
- c. Switch control air system to replace compressor air.
- d. Vent air line from ASU compressor (C1) to atmosphere.
- e. Shut down expansion turbine, either ET1 or ET2.
- f. Shut down ASU compressor (C1).
- g. Shut down ASU intercooler (E1-A) and the aftercooler (E2).
- h. Shut down revex program timer.
- i. Close air and product lines.
- j. Open vapor discharge lines to atmosphere in the low temperature section of ASU.
- k. Shut down liquid pumps and close valves.
- l. For long duration shutdowns, discharge liquids from ASU to atmosphere.
- m. Close all valves -- with the exception of those mentioned above.
- n. The cold box may now be warmed up.

For short duration shutdowns of the plant, steps a to i are sufficient.

NOTE: Liquids must never be allowed to totally evaporate in the vessels! As soon as a liquid level has decreased to 20 %, the liquid must be completely discharged. This avoids possible contaminant build-up.

At every shut down of the plant, close the nitrogen butterfly valves by hand immediately and ventilate the cold-system. In this way pressure increases are avoided throughout the reversing exchangers. Also, thermal stress from flow of cold nitrogen can damage the warm end of the reversing exchangers.

4.3.2 Sudden Plant Shutdown Due to a Disturbance

Steps a to i should be carried out as in Section 4.3.1. Depending on whether the disturbance can be eliminated quickly or not, steps j, etc., should be carried out, either singly or together.

4.3.3. Plant Start-up from Cold Standby Condition

The plant is in Cold Standby when the columns and other cold parts are at operating temperature. The start-up sequence shall be performed as in Section 4.1. The purging of the cold part of the ASU cold boxes is unnecessary.

The temperatures in the low-temperature section determine at which point of the cooling procedure the start-up must be begun.

If the liquids have not been discharged, assure that prior to the start-up the liquid levels are not too high. (Otherwise trays of the rectification column or gas sockets could be flooded. A start-up in such case could entail mechanical damages to the trays of the rectification column and/or damages of the expansion turbine rotor.)

4.3.4 Warm-Up

Over a longer period deposits of ice, dry ice, and possibly hydrocarbons form in the low-temperature sections of the ASU. The flow resistances increase due to these deposits. Thus, in general after one year's operation, the low-temperature section should be shut down and warmed to remove these deposits.

The low-temperature section may have to be shut down before this, should the flow resistances in the heat exchangers and rectification columns increase so much that the design product quantities and purities can no longer be obtained.

This could only occur due to incorrect operation of the plant.

All parts of the low-temperature section can be warmed.

When a section is warmed all of its measuring and analysis lines must also be warmed and purged.

NOTE: Large temperature differences in the components can lead to damage due to thermal stress. For this reason, all warming is to be begun with cold gas. The warming path should be chosen so that components are warmed as evenly as possible.

The description of the warming processes in this section takes the above-mentioned criteria into consideration. For this reason, the warming processes must be strictly adhered to.

4.4 SPECIAL OR INFREQUENT OPERATION

4.4.1 Back-Up System Operation

When the supply of oxygen from the air separation unit fails, the backup system will go into operation automatically in order to provide an uninterrupted supply of oxygen. Plant failures will create a low pressure signal which allows pressurized stored liquid oxygen to enter the vaporizer. Oxygen is warmed to ambient in the vaporizer and enters the mixing chamber. Operation can continue for about four hours in this mode.

4.4.2 Acetylene Monitoring

Too high of an acetylene content in the impure liquid oxygen product of the main condenser (K1) may cause an explosion. Therefore, acetylene content is carefully monitored, and, if further acetylene increases cannot be prevented and, if the acetylene content in the (K1) liquid reaches 1 ppm, the plant must be shut down, the liquids drained, and the low temperature section derimed.

5.0 MAINTENANCE

5.1 SURVEILLANCE AND PERFORMANCE MONITORING

Operating personnel will record direct indicating instruments and may calculate performance per shift. The in-house computer will constantly monitor specified points to give a running check on performance which can be viewed as desired in the plant control room. The indicating measurements are useful as a check on the computer readings.

5.2 INSERVICE INSPECTION

All the equipment listed previously shall be inspected while operating to assure it is physically in service, compressor and turbine shafts are turning and pressures are indicated, product oxygen and air are moving, inter/aftercooler feel warm to the touch, and water level gages show condensate in

the condenser hotwells. Cold boxes should be monitored for excessive frost buildup. Indicating instruments will monitor the dynamics of each piece of equipment and the fact that it is operating properly.

5.3 PREVENTIVE MAINTENANCE

Computerized record keeping will be instituted to alert the operating personnel when equipment needs overhaul, repacking, or cleaning, in accord with the recommendations of the equipment manufacturer. In general, parts will be replaced during planned shutdown when they are near the end of their recommended life cycles.

5.4 CORRECTIVE MAINTENANCE

5.4.1 Manufacturer's Instructions

A complete file of instruction books will be available at the plant to guide the plant personnel in maintenance and overhaul of any piece of equipment. If necessary, a representative of the manufacturer can be present to supervise the overhaul or replacement of plant equipment.

5.4.2 Spare-Parts Inventory

The manufacturers of major equipment such as the compressors will supply lists of recommended spare parts. Critical parts will be kept in inventory at the ETF Facility. Complex parts requiring long lead time for delivery will be included in the plant inventory.

For the Oxidant Supply System, spare parts shall include:

1. Bearings, seals, gaskets and impellers for compressors and steam turbines.
2. Rotating assemblies, gaskets, bearings and nozzle rings for expanders.
3. Internal parts for automatic valves.
4. Analyzer cells, pressure switches, and various other instrumentation components.
5. Heater elements.
6. Relays and miscellaneous equipment for the electrical switchgear.

TABLE #1

"EQUIPMENT DESIGNATION" LETTERING USED THROUGHOUT

LOTEPRO DRAWINGS AND OXIDANT SUPPLY SYSTEM

DESIGN DESCRIPTION

A	Adsorber
C	Compressor/Booster
CT	Cooling Tower
D	Drum/Separator
E	Heat Exchanger or Liquefier depending on placement in system
ET	Expansion Turbine
F	Filter
G	Electrical Generator
H	Heater
K	Condenser/Reboiler
M	Electric Motor
P	Pump
S	Sieve
SL	Silencer
ST	Storage Tank
T	Rectification Column/Tower
V	Vaporizer

TABLE #2

INSTRUMENT AND CONTROL VALVE FUNCTIONAL LETTERING
DEFINITIONS USED THROUGHOUT LOTEPRO DRAWINGS AND
OXIDANT SUPPLY SYSTEM DESIGN DESCRIPTION

Instruments and control valves have their functions indicated according to the following logic:

<u>Letter Used</u>	<u>When placed in first position means</u>	<u>When placed in second position means</u>	<u>When placed in third position position means</u>	<u>When placed in fourth position means</u>
A:	Analysis	Alarm	Alarm	Alarm
C:		Controller	Controller	Controller
E:		Sample Connection		
F:	Flow rate			
H:	Hand (manually initiated)			
I:		Indicator	Indicator	
L:	Level	Level		
P:	Pressure			
R:		Record		
*S:	Speed	Switch	Switch	Switch
T:	Temperature	Transmitter	Transmitter	Transmitter
V:	Vibration	Valve	Valve	Valve
Y:		Relay	Relay	Relay
Z:	Shaft Position			

*NOTE: Where the lettering "SPIAS" is used (Drawings 1-FS-813, 1-FS-814, 1-FS-818 and 1-FS-819), the definition is "Speed Indicator Alarm Switch".

TABLE #2
(continued)

1. A "D" after one of the above specified letters indicate a "differential" (for example PDS -- differential pressure switch).
2. An "H" or a "L" to the right of an instrumentation oval indicates whether an alarm or shutdown switch will be actuated on a high or low condition.
3. The instrumentation symbols are in accordance with Instrumentation Society of America, ISA Standard S 5.1. (Refer to Drawing 1-FS-822 for Job P&I diagram symbols.)

TABLE #3
COMPOSITIONS OF AMBIENT AIR, ASU PRODUCT AND
OXIDANT STREAMS FOR THE MONTANA REFERENCE SITE

	<u>Mole Percent</u>			
	Dry Air	Ambient Air	70 % O ₂	30 % O ₂
Nitrogen, N ₂	78.084	77.626	26.88	68.160
Oxygen, O ₂	20.950	20.827	70.00	30.000
Argon, Ar	0.934	0.928	3.12	1.336
Water Vapor, H ₂ O	0	0.587	0	0.478
Carbon Dioxide	0.032	0.032	0	0.026
	<hr/>	<hr/>	<hr/>	<hr/>
	100.000	100.000	100.000	100.000

	<u>Weight Percent</u>			
Nitrogen, N ₂	75.519	75.238	24.152	65.111
Oxygen, O ₂	23.144	23.062	71.850	32.737
Argon, Ar	1.288	1.283	3.998	1.820
Water Vapor, H ₂ O	0	0.368	0	0.293
Carbon Dioxide	0.049	0.049	0	0.039
	<hr/>	<hr/>	<hr/>	<hr/>
	100.000	100.000	100.000	100.000

<u>Molecular Weight</u>	<u>Densities at 60°F and 14.7 PSIA</u> <u>(lbm/ft³)</u>	
Nitrogen, N ₂	28.013	Nitrogen .07378
Oxygen, O ₂	31.999	Oxygen .08428
Argon, Ar	39.948	Air .07630
Water Vapor, H ₂ O	18.016	Oxidant .07722
Carbon Dioxide, CO ₂	44.0101	(30 Mol % O ₂)

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION

OXIDANT SUPPLY SYSTEM

APPENDIX "A"

REFERENCE DOCUMENTS

REFERENCE DOCUMENTS - ATTACHED

APPENDIX B - SUMMARY OF COMPRESSOR STUDIES CONDUCTED BY LOTepro CORPORATION FOR THE ETF CONDITIONS

APPENDIX C - DATA TABLES GIVING STATE POINT CONDITIONS FOR THE HARDWARE OPERATING AT RATED FLOW, 103.3% RATED FLOW, 75% RATED FLOW, AND WITH THE ASU PRODUCING A MODERATE FLOW OF LOX

APPENDIX D - ALTERNATIVE ASU COMPRESSOR WITH ELECTRIC MOTOR DRIVE

<u>DRAWINGS</u>	<u>DRAWING NO.</u>
Drawing Symbols and Drawing List	1-FS-822, Rev. 4
Block Diagram	1-FS-820, Rev. 2
Plan, Compressor Bldg	1-LO-1577-1, Rev. 3
Plan, Cold Box Area	1-LO-1577-2, Rev. 2
Plan, LOX Storage Area	1-LO-1577-3, Rev. 1
Plan, Air Filters, Aftercooler and and Oxidant Mixing Chamber	1-LO-1577-4, Rev. 3
Elevation "A"- "A", Turbines and Compressors	1-LO-1577-5, Rev. 2
Elevation "B"- "B", Turbines and Compressors	1-LO-1577-6, Rev. 2

APPENDIX A
(continued)

Elevation "C"- "C", Cold Boxes and Equipment	1-LO-1577-7, Rev. 2
Oxidant Mixing Chamber, Plan, Elev. and Details	1-LO-1577-8, Rev. 2
Compressor Bldg., Plan Utility Piping	1-LO-1577-9, Rev. 2
ASU (Air Separation Unit) Compressor, Steam Turbine Drive, Process and Instrumentation (P&I) #1	1-FS-813, Rev. 3
Air Separation Unit (ASU), P&I #3	1-FS-815, Rev. 1
Mixing Chamber, P&I #4	1-FS-816, Rev. 2
Liquid O ₂ & N ₂ Storage and Vaporization System, P&I #5	1-FS-817, Rev. 3
Oxidant Compressor, Steam Turbine Drive, P&I #6	1-FS-818, Rev. 3
Oxidant Compressor, Electric Motor Drive, P&U #7	1-FS-819, Rev. 3
Alternatives ASU Compressor, Electric Motor Drive, P&I #2	1-FS-814, Rev. 3

REFERENCE DOCUMENTS - NOT ATTACHED

"The Blast Furnace Oxygen Plant at Schwelgern", E. Schoenpflug, Linde Reports on Science and Technology, 18/1973.

"Production and Use of 60 % Oxygen for Blast Furnaces", D. Tebbe, August Thyssen-Huette AG, October, 1975.

"The Optimization of Air Separation Plants for Combined Cycle MHD Power Plant Application", by H. Springmann, R. Greenberg, and A. J. Juhasz, Proceedings of 7th International Conference on MHD Electrical Power Generators, Vol I, pp 403-409, June 1980.

Final Report on Contract DEN 3-165 (1981).

Compressed Gas Association Pamphlet
G. 44.

Industrial Practices for Gaseous Oxygen Transmission and Distribution Systems.

"European Working Panel (EWP) Code of Practice for Turbo Compressors for Oxygen Service," Latest Edition.

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION

OXIDANT SUPPLY SYSTEM

APPENDIX "B"

SUMMARY OF COMPRESSOR STUDIES CONDUCTED

BY LOTEPRO CORPORATION FOR THE ETF CONDITIONS

In order to determine the optimum compressor selection for the ETF, all potential vendors of large rotating compression equipment in the USA and Europe were approached.

ASU Compressor

Vendors' proposals for the ASU compressor recommended the use of a combined axial-radial compressor with the radial stages (centrifugal) used at the high pressure end of the machine. There are numerous examples of this type currently in service at air separation plants.

Potential vendors for this application are tabulated below:

Company	Country of Manufacture	Type of Machine	Background
Dresser-Clark	USA	AR (axial/radial)	several machines in service
DeLeval	USA	AR	several machines in service
Sulzer Bros	Switzerland	AR	many applications in service
Demag	West Germany	AR	many applications in service
GHH	West Germany	AR	many applications in service
Ingersoll-Rand	USA	Axial	new designs being developed
Allis Chalmers	USA	Axial	new designs being developed
General Electric	USA	Axial	sold as part of gas turbine packages
Westinghouse	USA	Axial	sold as part of gas turbine packages
Elliot	USA	Axial ?	status uncertain

APPENDIX "B"
(continued)

In all cases the machine would be intercooled after the axial stages and possibly between radial stages, namely where more than one radial stage is required.

Oxidant Compressors

Selection of the oxidant compressors posed a problem, namely the uncooled compression of enriched air at up to 40 volume percent oxygen. It would be possible to use a traditional compressor rated for pure oxygen. This would be a horizontally split-casing centrifugal type machine. However, this proved to result in very expensive hardware due to the large oxidant flow rate and due to the many built-in safety features, most of which are not needed for this application.

The optimum solution was found to be the use of an axial-radial compressor almost identical to those used for uncooled air compression. It was determined that these compressors could be used safely with enriched air streams containing up to 40% (by volume) oxygen. In ETF, these compressors would be used for a nominal 30% oxygen enriched air service. Minor modifications to the compressor must be made to ensure safe operation. These modifications were studied by several manufacturers (Sulzer Bros., GHH, Demag, DeLeval and Dresser-Clark).

The summary findings of these studies are as follows:

1. Two operating axial/radial compressor units compressing enriched air at 30 and 40 volume per cent oxygen, respectively, were identified. Potential vendors for supply of these units would be the same as that given above for the ASU compressor.
2. High efficiency axial air compressor designs can be used at up to 40% O₂ by volume provided that:
 - a. The cast iron (containing graphite) housing is upgraded by material replacement with cast steel.
 - b. Bearing seals employ a nitrogen buffer gas system to prevent lubricating oil vapors from entering the suction side of the compressor.
3. Allowable vibration levels as specified in the international standards such as API 617 (Centrifugal Compressors for General Refinery Services, Fourth Edition, 1979) or European Working Panel on Turbocompressors for Oxygen Service (third printing 1978) can be used for compressors in oxygen enriched air service.

APPENDIX "B"
(continued)

4. It is quite important that the oxygen is distributed uniformly in the enriched air before entering the compressor because there is little mixing in the compressor. The degree of compressor reaction does not have significant influence in the mixing, distribution, or separation of oxygen in the gas stream.
5. The degree of reaction has an influence on the blade tip clearance needed to obtain maximum efficiencies. The blade tip clearance should be very small for a high reaction type blading (100% or 120%), but it is of less importance for a 50% reaction type blading. Since an increased blade tip clearance is required for oxygen enriched air compression, the drop in efficiency with 50 % reaction blading is smaller than it would be with the higher reaction blading.

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION

OXIDANT SUPPLY SYSTEM

APPENDIX "C"

DATA TABLES GIVING STATE POINT CONDITIONS

FOR THE HARDWARE OPERATING AT RATED FLOW,

103.3% RATED FLOW, 75% RATED FLOW, AND WITH THE ASU

PRODUCING A MODERATE FLOW OF LOX

State point operating conditions are given in Table 1C for the Oxidant Supply System operated at the nominal design Rated Flow. Small flows (0.6 tons/day) of liquid oxygen and liquid nitrogen (4.3 tons/day) are also produced to "top off" the liquid storage tanks and provide LIN flow to the magnet (see drawings 1-FS-815 and 1-FS-817 for flow path details). A pressurized gaseous nitrogen flow is also present (see Drawing 1-FS-815). This goes to the ETF Facility nitrogen gas compressor for use as inert gas blanketing throughout the Facility.

Table 2C shows the operating conditions achieved when the Oxidant Supply System is readjusted to produce 103.3% Rated Flow at the same 30% oxygen fraction as prescribed for design. This mode potentially allows increased coal flow and power production by the ETF plant.

Table 3C shows the operating conditions achieved when the ASU and Oxidant compressors are turned down (throttled back) to 75 % Rated Flow (at 30 vol % oxygen). This mode potentially allows operation of the ETF at the minimum power level prescribed in the "Design Requirements Document".

Table 4C shows the operating conditions achieved with the ASU adjusted for moderate production (50.2 tons/day) of LOX to accelerate refill of the LOX tanks. This operating mode corresponds to 75% of rated gaseous oxygen and oxidant flow.

Cooling water requirements for Rated Flow, 103.3% Rated Flow and 75% Rated Flow are given in Table 5C. Corresponding steam consumptions are given in Table 6C.

Electrical power consumptions for the #1 Oxidant Compressor (when in service) and for miscellaneous Oxidant Supply System items are given in Table 7C.

APPENDIX "C"
(continued)

Operating data for the ASU steam turbine driven compressor and for three oxidant compressors are given in Tables 8C to 10C. A Demag model AR 250/7/1F compressor was selected for the ASU compressor based on its low power consumption when compared to other manufacturers' compressors. GHH high performance axial compressors were selected for the oxidant compressors, again based on their high performance relative to other manufacturers.

APPENDIX C*
(continued)

TABLE 1C

STATE POINT CONDITIONS FOR THE NOMINAL DESIGN CASE
(RATED FLOW)

Note: scf are defined at 60°F and 14.7 psia

Air to ASU:

Flow	123,920 scfm
Pressure	56.6 psia
Temperature	84 °F

Gaseous Oxygen Product from ASU:

Contained Oxygen Flow	1500 ton/day (125,000 lbs/hr)
Discharge Pressure	13.5 psia
Temperature	75 °F
Composition (mol %):	
oxygen	70.00 %
nitrogen	26.88 %
argon	3.12 %
water vapor	0.00 %
CO ₂	0.00 %

*Discrepancies between the values given in this document and those used on the ETF Heat and Mass Balance Diagram are explained by the fact that the material was developed concurrently. Future ETF Heat and Mass Balance diagrams will utilize this data to update the ETF Heat and Mass Balance Diagram.

APPENDIX C
(continued)

TABLE 1C
(continued)

Liquid Oxygen Product from ASU:

Contained Oxygen Flow	0.6 ton/day
Discharge Pressure	26.1 psia
Temperature	-299 °F
Composition (mol %):	
oxygen	70.00 %
nitrogen	26.88 %
argon	3.12 %
water vapor	0.00 %
CO ₂	0.00 %

Gaseous Nitrogen Product from ASU:

Flow	198.6 ton/day
Discharge Pressure	47.9 psia
Temperature	75 °F
Composition (mol %):	
nitrogen	99.99 %
oxygen	less than 100 ppm

Liquid Nitrogen Product from ASU:

Flow	4.3 ton/day
Discharge Pressure	47.9 psia
Temperature	-304 °F
Composition (mol %):	
nitrogen	99.99 %
oxygen	less than 100 ppm

APPENDIX C
(continued)

TABLE 1C
(continued)

Oxidant Product from Oxidant Compressors:

Flow	875,871 lbs/hr
Suction Pressure	12.85 psia
Suction Temperature	50° F
Discharge Pressure	73.5 psia
Temperature Discharge	437 °F
Composition (mol %):	
nitrogen	68.16 %
oxygen	30.00 %
argon	1.34 %
water vapor	0.48 %
carbon dioxide	0.02 %

APPENDIX C
(continued)

TABLE 2C

STATE POINT CONDITIONS FOR 103.3% RATED FLOW

Note: scf are defined at 60°F and 14.7 psia

Air to ASU:

Flow	128,025 scfm
Pressure	57.3 psia
Temperature	84 °F

Gaseous Oxygen Product from ASU:

Contained Oxygen Flow	1550 ton/day (129,167 lbs/hr)
Discharge Pressure	13.5 psia
Temperature	75 °F
Composition (mol %):	
oxygen	70.00 %
nitrogen	26.88 %
argon	3.12 %
water vapor	0.00 %
CO ₂	0.00 %

APPENDIX C

TABLE 2C
(continued)

Liquid Oxygen Product from ASU:

Contained Oxygen Flow	0.6 ton/day
Discharge Pressure	26.1 psia
Temperature	-299 °F
Composition (mol %):	
oxygen	70.00 %
nitrogen	26.88 %
argon	3.12 %
water vapor	0.00 %
CO ₂	0.00 %

Gaseous Nitrogen Product from ASU:

Flow	198.6 ton/day
Discharge Pressure	47.9 psia
Temperature	75 °F
Composition (mol %):	
nitrogen	99.99 %
oxygen	less than 100 ppm

Liquid Nitrogen Product from ASU:

Flow	4.3 ton/day
Discharge Pressure	47.9 psia
Temperature	-304 °F
Composition (mol %):	
nitrogen	99.99 %
oxygen	less than 100 ppm

APPENDIX C

TABLE 2C
(continued)

Oxidant Product from Oxidant Compressors:

Flow	905,153 lbs/hr
Suction Pressure	12.85 psia
Suction Temperature	50° F
Discharge Pressure	76.0 psia
Temperature Discharge	448 °F
Composition (mol %):	
nitrogen	68.16 %
oxygen	30.00 %
argon	1.34 %
water vapor	0.48 %
carbon dioxide	0.02 %

APPENDIX C
(continued)

TABLE 3C

STATE POINT CONDITIONS FOR 75% RATED FLOW

Note: scf are defined at 60°F and 14.7 psia

Air to ASU:

Flow	96,740 scfm
Pressure	53.7 psia
Temperature	84 °F

Gaseous Oxygen Product from ASU:

Contained Oxygen Flow	1125 ton/day (93,750 lbs/hr)
Discharge Pressure	13.5 psia
Temperature	75 °F
Composition (mol %):	
oxygen	70.00 %
nitrogen	26.88 %
argon	3.12 %
water vapor	0.00 %
CO ₂	0.00 %

APPENDIX C

TABLE 3C
(continued)

Liquid Oxygen Product from ASU:

Contained Oxygen Flow	0.6 ton/day
Discharge Pressure	26.1 psia
Temperature	-299 °F
Composition (mol %):	
oxygen	70.00 %
nitrogen	26.88 %
argon	3.12 %
water vapor	0.00 %
CO ₂	0.00 %

Gaseous Nitrogen Product from ASU:

No product nitrogen for this case.

Liquid Nitrogen Product from ASU:

Flow	4.3 ton/day
Discharge Pressure	47.9 psia
Temperature	-304 °F
Composition (mol %):	
nitrogen	99.99 %
oxygen	less than 100 ppm

APPENDIX C

TABLE 3C
(continued)

Oxidant Product from Oxidant Compressors:

Flow	656,903 lbs/hr
Suction Pressure	12.85 psia
Suction Temperature	50° F
Discharge Pressure	55.0 psia
Temperature Discharge	352 °F
Composition (mol %):	
nitrogen	68.16 %
oxygen	30.00 %
argon	1.34 %
water vapor	0.48 %
carbon dioxide	0.02 %

APPENDIX C
(continued)

TABLE 4C

STATE POINT CONDITIONS WITH THE ASU PRODUCING
A MODERATE FLOW OF LOX*

Note: scf are defined at 60°F and 14.7 psia

Air to ASU:

Flow	123,920 scfm
Pressure	56.6 psia
Temperature	84 °F

Gaseous Oxygen Product from ASU:

Contained Oxygen Flow	1125 ton/day (93,750 lbs/hr)
Discharge Pressure	13.5 psia
Temperature	75 °F
Composition (mol %):	
oxygen	70.00 %
nitrogen	26.88 %
argon	3.12 %
water vapor	0.00 %
CO ₂	0.00 %

*This operating mode corresponds to 75% of rated oxidant and gaseous oxygen flow.

APPENDIX 3

TABLE 4C
(continued)

Liquid Oxygen Product from ASU:

Contained Oxygen Flow	50.2 ton/day
Discharge Pressure	26.1 psia
Temperature	-299 °F
Composition (mol %):	
oxygen	70.00 %
nitrogen	26.88 %
argon	3.12 %
water vapor	0.00 %
CO ₂	0.00 %

Gaseous Nitrogen Product from ASU:

No product nitrogen for this case.

Liquid Nitrogen Product from ASU:

Flow	4.3 ton/day
Discharge Pressure	47.9 psia
Temperature	-304 °F
Composition (mol %):	
nitrogen	99.99 %
oxygen	less than 100 ppm

APPENDIX C

TABLE 4C
(continued)

Oxidant Product from Oxidant Compressors:

Flow	656,903 lbs/hr
Suction Pressure	12.85 psia
Suction Temperature	50° F
Discharge Pressure	55.0 psia
Temperature Discharge	352 °F
Composition (mol %):	
nitrogen	68.16 %
oxygen	30.00 %
argon	1.34 %
water vapor	0.48 %
carbon dioxide	0.02 %

APPENDIX C
(continued)

TABLE 5C

COOLING WATER REQUIREMENTS FOR SYSTEM RATED FLOW,
103.3% RATED FLOW AND 75% RATED FLOW

(in GPM and resulting in a 15 °F rise)

ASU Compressor Steam Driven, One Motor Driven
Oxidant Compressor and One Steam Driven Oxidant Compressor

	<u>100% Rated Flow</u>	<u>103.3% Rated Flow</u>	<u>75% Rated Flow</u>
Air Compressor	5,470	5,800	4,160
Steam Condenser (27° F rise)	13,900	15,200	10,400
Expansion Turbine Lube System	100	100	100
Oxidant Compressors Lube System	300	300	300
Miscellaneous	100	100	100
Aftercooler	6,000	6,000	6,000

Steam Drives for ASU and Two Oxidant Compressors

Air Compressor	5,470	5,800	4,160
Steam Condenser (27° F rise)	20,200	21,900	14,300
Expansion Turbine Lube System	100	100	100
Oxidant Compressors Lube System	300	300	300
Miscellaneous	100	100	100
Aftercooler	6,000	6,000	6,000

APPENDIX C
(continued)

TABLE 6C

STEAM CONSUMPTION FOR SYSTEM RATED FLOW,
103.3% RATED FLOW AND 75% RATED FLOW
(in lbs/hr)

	<u>100% Rated Flow</u>	<u>103.3% Rated Flow</u>	<u>75% Rated Flow</u>
ASU Compressor	99,600	106,700	78,200
Oxidant Compressor* (1)	95,500	103,000	75,000
Oxidant Compressor (2)	191,000	206,000	150,000

*Assumes motor drive on the other compressor.

APPENDIX C
(continued)

TABLE 7C

ELECTRICAL POWER CONSUMPTIONS FOR SYSTEM RATED FLOW,
103.3% RATED FLOW, AND 75% RATED FLOW

	<u>100% Rated Flow</u>	<u>103.3% Rated Flow</u>	<u>75% Rated Flow</u>
With Electric Motor Driven Oxidant Compressor In Operation (kW at shaft)	12,150	12,860	7,840
<u>Miscellaneous items:</u>	<u>kW</u>	<u>Voltage</u> (volts)	<u>Phases</u>
Liquid oxygen pumps	80	480	3
Direct contact pumps for air compressor aftercooler	40	480	3
Condenser hot well pumps	10	480	3
Lighting	60	480	3
Instrumentation	20	480	3
Miscellaneous	20	480	3

APPENDIX C
(continued)

TABLE 8C

OPERATING DATA FOR ASU COMPRESSOR

WITH STEAM TURBINE DRIVE

(Demag Type AR 250/7/1F)

	<u>Units</u>	<u>100% Rated Flow</u>	<u>103.3% Rated Flow</u>	<u>75% Rated Flow</u>
<u>Flow Rate</u>	SCFM	123,920	128,030	96,740
<u>Inlet Conditions:</u>				
Pressure	PSIA	13	13	13
Temperature	°F	42	42	42
Relative Humidity	%	57	57	57
<u>Discharge Conditions</u> <u>(at Compressor Flange):</u>				
Pressure	PSIA	56.6	57.3	53.7
Temperature	°F	170	177	160
<u>Performance:</u>				
Power (required at drive coupling) in kW	kW +/- 4%	11,420	12,115	8,700
Compressor Speed	RPM	4,600	4,695	4,225

APPENDIX C
(continued)

TABLE 9C

OPERATING DATA FOR EITHER OF THE OXIDANT
COMPRESSORS WITH STEAM TURBINE DRIVE

(GHH Axial Compressor Type AGR 7/14)

	<u>Units</u>	<u>100% Rated Flow</u>	<u>103.3% Rated Flow</u>	<u>75% Rated Flow</u>
Oxidant		30 vol % O ₂	30 vol % O ₂	30 vol % O ₂
Flow Rate	SCFM	94,370	97,525	70,775
<u>Inlet Conditions:</u>				
Pressure	PSIA	12.85	12.85	12.85
Temperature	°F	50	50	50
Relative Humidity	%	9.6	9.6	9.6
<u>Discharge Conditions</u> <u>(at Compressor Flange):</u>				
Pressure	PSIA	73.5	76.0	55.0
Temperature	°F	437	448	352
<u>Performance:</u>				
Power (required at drive coupling) in kW	kW +/- 4	11,724	12,610	6,990
Compressor Speed	RPM	5700	5870	4930

APPENDIX C
(continued)

TABLE 10C

OPERATING DATA FOR ELECTRIC MOTOR DRIVEN

OXIDANT COMPRESSOR

(GHH Axial Compressor Type AGR 7/14L)

	<u>Units</u>	<u>100% Rated Flow</u>	<u>103.3% Rated Flow</u>	<u>75% Rated Flow</u>
Oxidant		30 vol % O ₂	30 vol % O ₂	30 vol % O ₂
Flow Rate	SCFM	94,370	97,525	70,775
<u>Inlet Conditions:</u>				
Pressure	PSIA	12.85	12.85	12.85
Temperature	°F	50	50	50
Relative Humidity	%	9.6	9.6	9.6
<u>Discharge Conditions</u> <u>(at Compressor Flange):</u>				
Pressure	PSIA	73.5	76.0	55.0
Temperature	°F	439	448	380
<u>Performance:</u>				
Power (required at drive coupl- ing including gear loss) in kW	kW +/- 4%	12,150	12,860	7,840
Compressor Speed	RPM	5700	5700	5700

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
OXIDANT SUPPLY SYSTEM

APPENDIX D

ALTERNATIVE ASU COMPRESSOR WITH ELECTRIC MOTOR DRIVE

The potential of driving the ASU compressor with an electric motor drive rather than a steam turbine was considered. Drawing 1-FS-814 identifies the flow process and instrumentation. In particular, use of this type of drive eliminates the need for a by-pass line from the electrically driven Oxidant Compressor connecting the aftercooler (E2) for ASU startup, and hence greatly simplifies the system and system startup.

Operating data for the electric motor driven ASU compressor is given in the attached Table D1.

APPENDIX D
(continued)

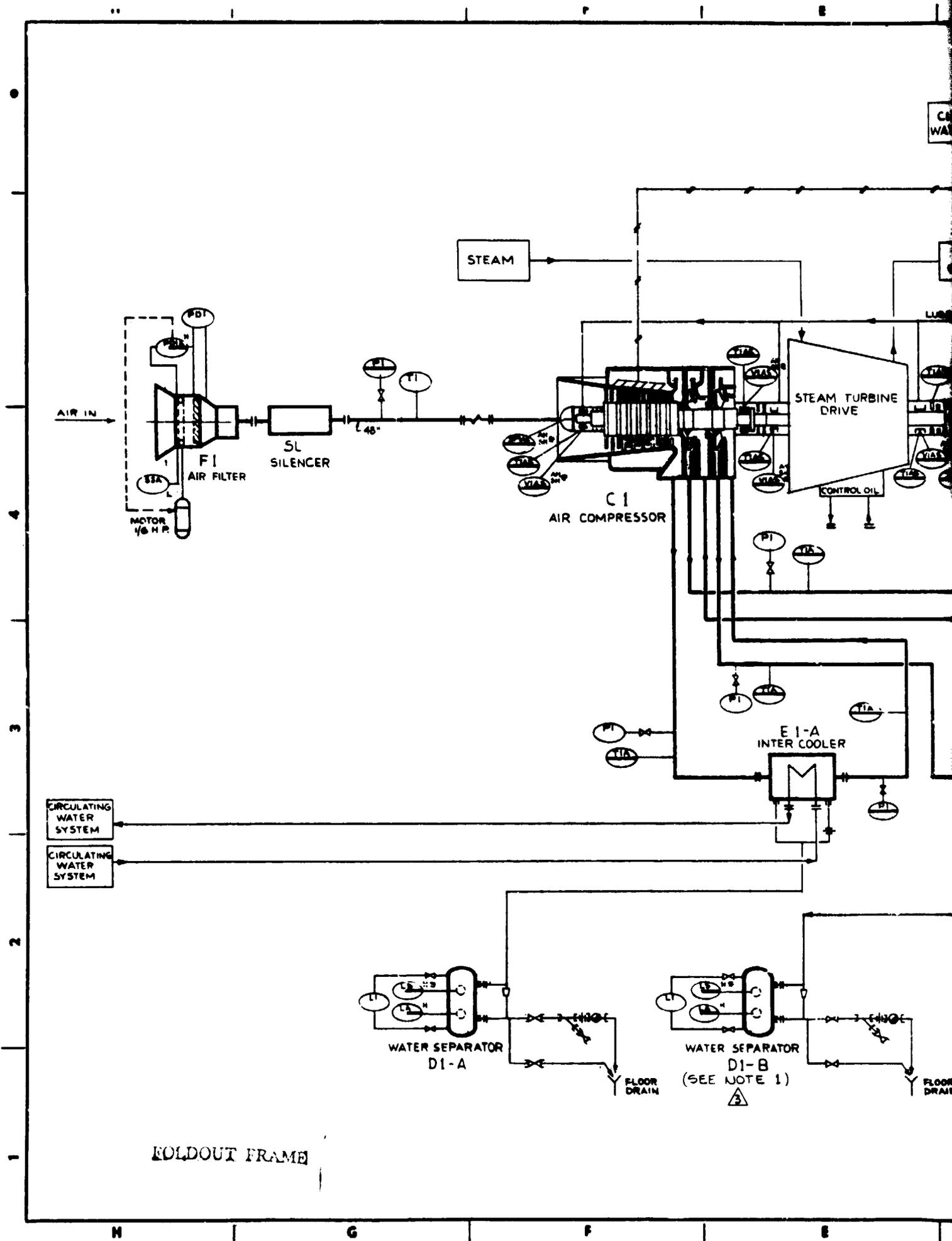
TABLE D1

OPERATING DATA FOR ALTERNATIVE ELECTRIC

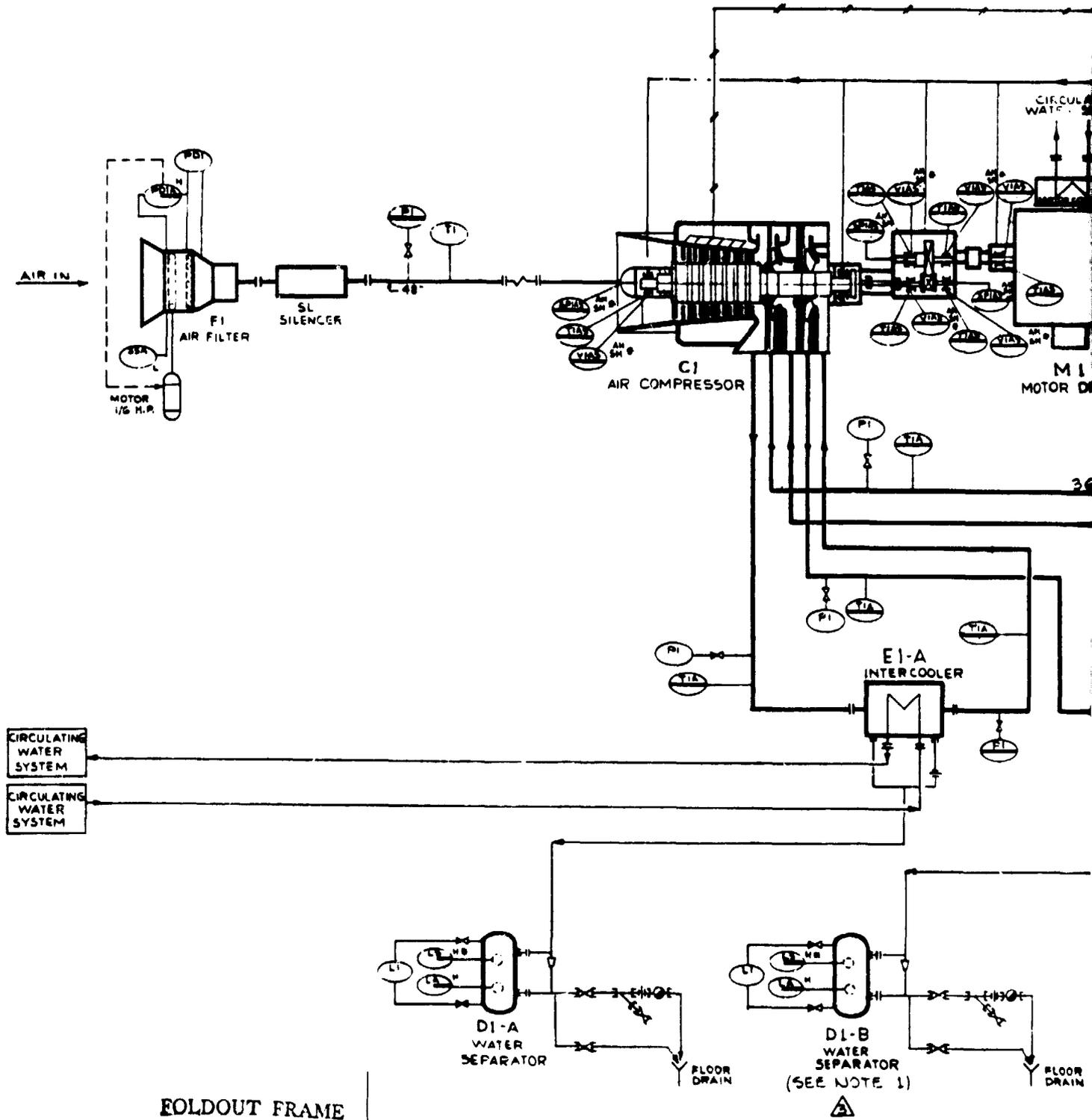
MOTOR DRIVEN ASU COMPRESSOR

(Demag Type AR 250-7-F)

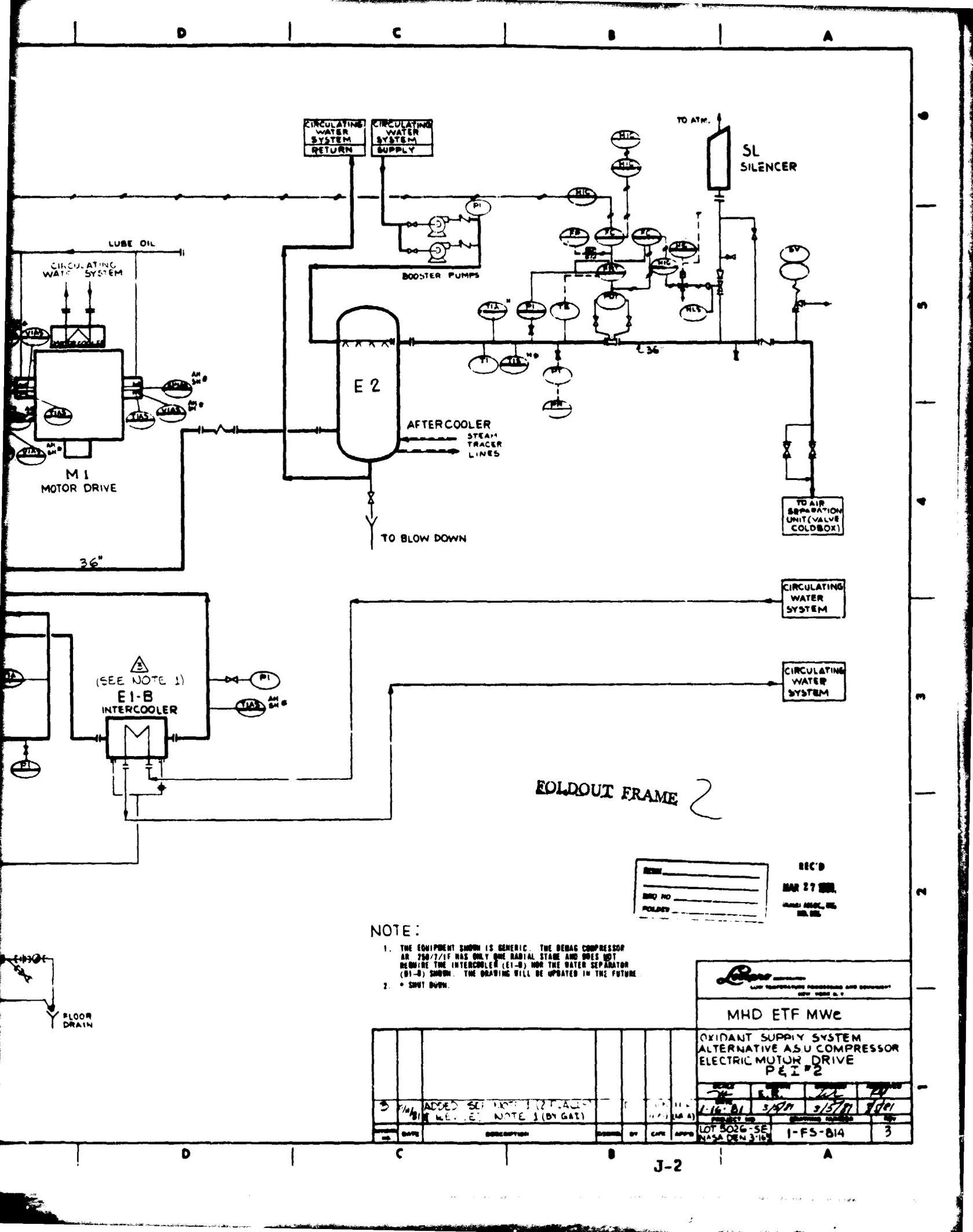
	<u>Units</u>	<u>100% Rated Flow</u>	<u>103.3% Rated Flow</u>	<u>75% Rated Flow</u>
Flow Rate	SCFM	123,920	128,030	96,740
<u>Inlet Conditions:</u>				
Pressure	PSIA	13	13	13
Temperature	°F	42	42	42
Relative Humidity	%	57	57	57
<u>Discharge Conditions</u> (at Compressor Flange):				
Pressure	PSIA	56.6	57.3	53.7
Temperature	°F	170	177	160
<u>Performance:</u>				
Power (required at drive coupl- ing including gear loss) in kW	kW +/- 4%	11,650	12,360	8,875
Compressor Speed	RPM	4600	4695	4225



ORIGINAL PAGE IS
OF FOUR QUALITY.



FOLDOUT FRAME



CIRCULATING WATER SYSTEM RETURN
CIRCULATING WATER SYSTEM SUPPLY

TO ATM.
SL SILENCER

LUBE OIL

CIRCULATING WATER SYSTEM

BOOSTER PUMPS

E 2

AFTER COOLER
STEAM TRACER LINES

TO BLOW DOWN

TO AIR SEPARATION UNIT (VALVE COOLBOX)

CIRCULATING WATER SYSTEM

CIRCULATING WATER SYSTEM

E2 OLDOUT FRAME

REV: _____
REV NO: _____
POLY: _____

REC'D
MAR 27 1964
NASA HQ, EL
WA, DC

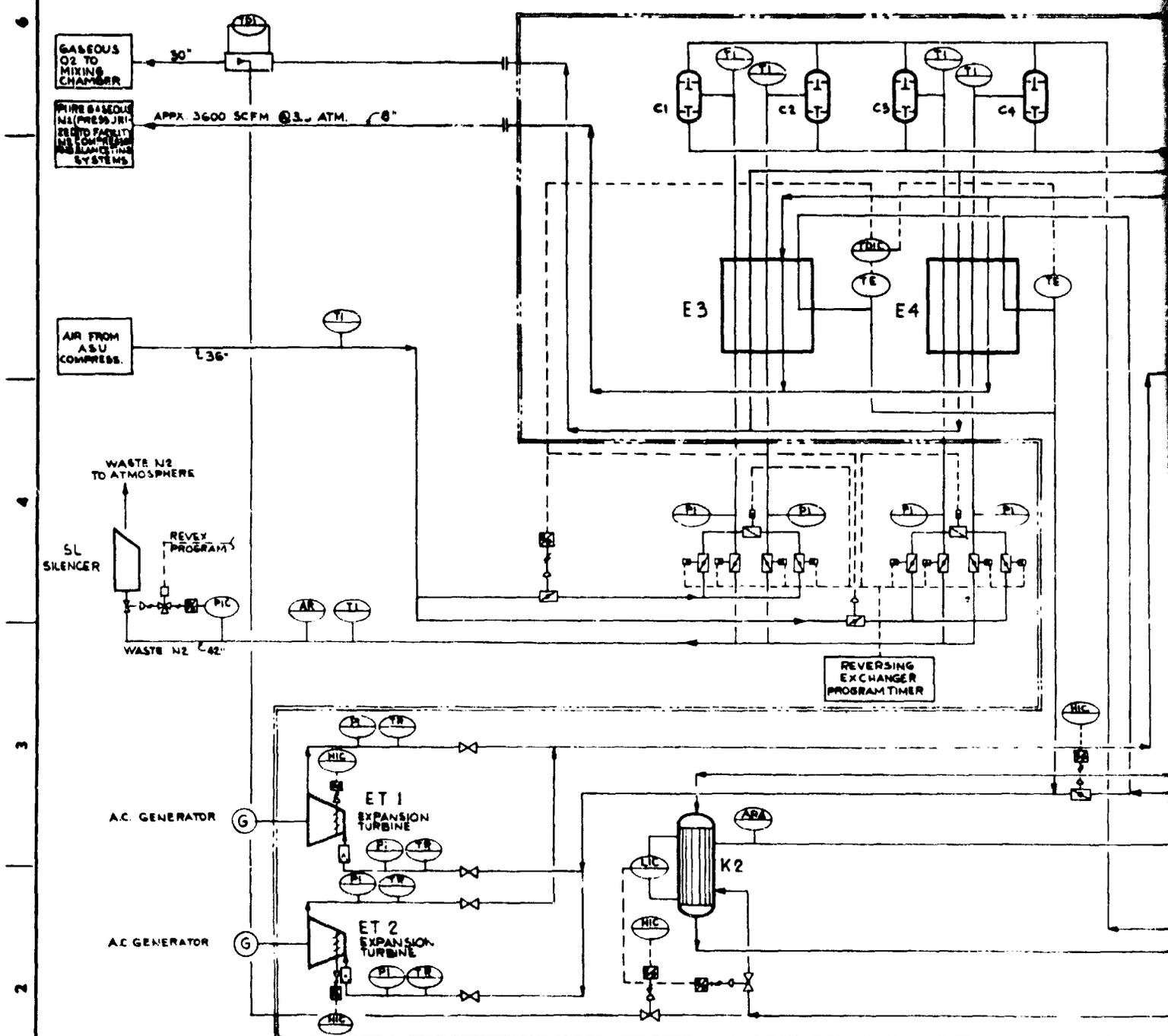
NOTE:

1. THE EQUIPMENT SHOWN IS GENERIC. THE DEBAG COMPRESSOR AN 250/7/1F HAS ONLY ONE RADIAL STAGE AND DOES NOT REQUIRE THE INTERCOOLER (E1-B) NOR THE WATER SEPARATOR (B1-B) SHOWN. THE DRAWING WILL BE UPDATED IN THE FUTURE.
2. * SHUT DOWN.

MHD ETF MWE	
OXIDANT SUPPLY SYSTEM ALTERNATIVE ASU COMPRESSOR ELECTRIC MOTOR DRIVE P E 2 # 2	
REV	DATE
1-16-61	3/27/61
2	8/1/61
3	9/15/61
4	8/1/61
5	8/1/61
6	8/1/61
7	8/1/61
8	8/1/61
9	8/1/61
10	8/1/61
11	8/1/61
12	8/1/61
13	8/1/61
14	8/1/61
15	8/1/61
16	8/1/61
17	8/1/61
18	8/1/61
19	8/1/61
20	8/1/61
21	8/1/61
22	8/1/61
23	8/1/61
24	8/1/61
25	8/1/61
26	8/1/61
27	8/1/61
28	8/1/61
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30	8/1/61
31	8/1/61
32	8/1/61
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38	8/1/61
39	8/1/61
40	8/1/61
41	8/1/61
42	8/1/61
43	8/1/61
44	8/1/61
45	8/1/61
46	8/1/61
47	8/1/61
48	8/1/61
49	8/1/61
50	8/1/61

REV	DATE	DESCRIPTION	APPROVED BY	DATE	APPROVED BY
5	8/1/61	ADDED SEE NOTE 1 (2 PLACES) & REV. E1 NOTE 1 (BY GAT)			

H G F E

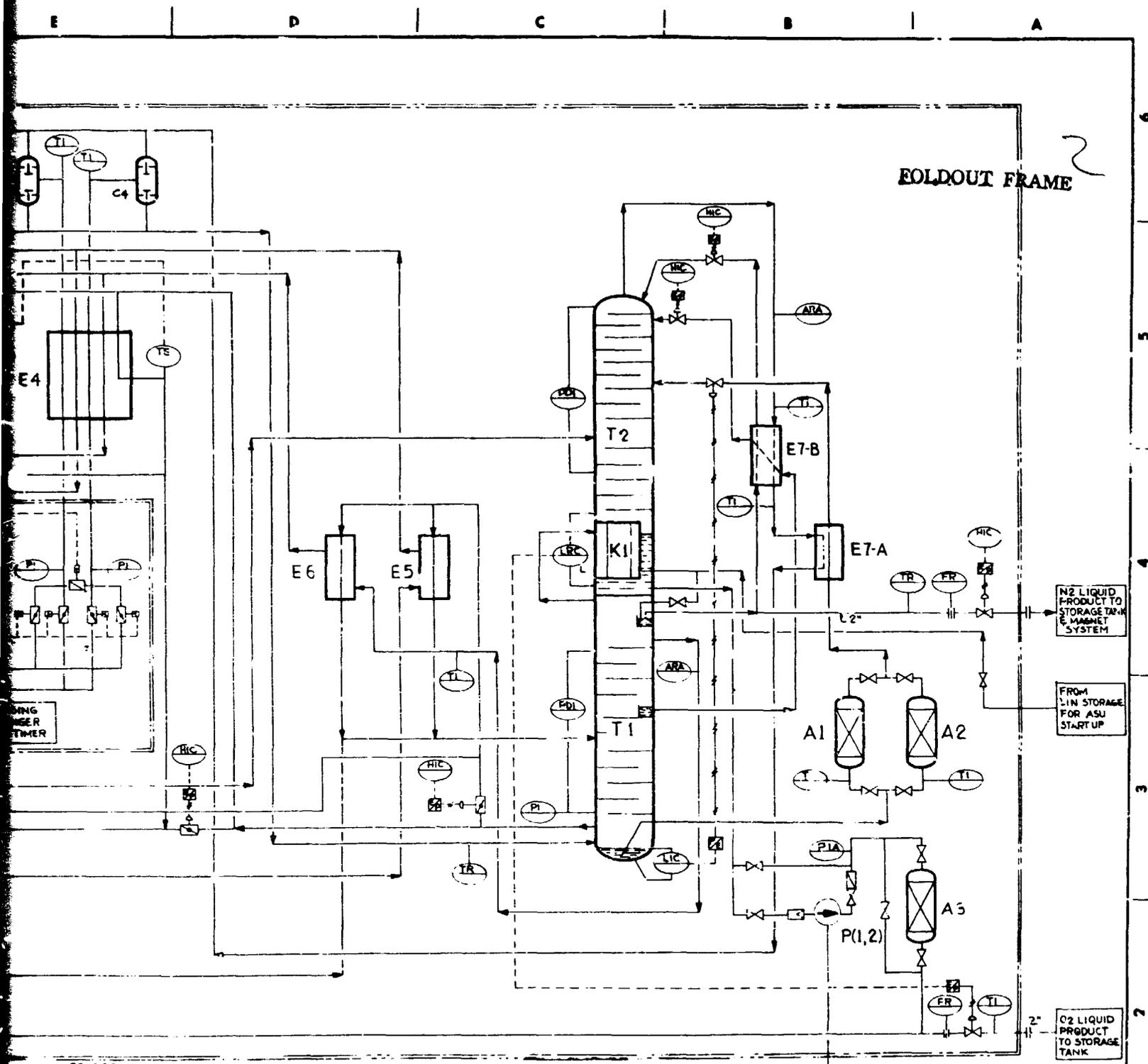


REVERSING EXCHANGER PROGRAM TIMER

COLDBOX

FOLDOUT FRAME

H G F E



E FOLDOUT FRAME

COLDBOX

LOW TEMPERATURE PROCESSING AND EQUIPMENT
REV. 1000 0-1

MHD ETF 260 MWe

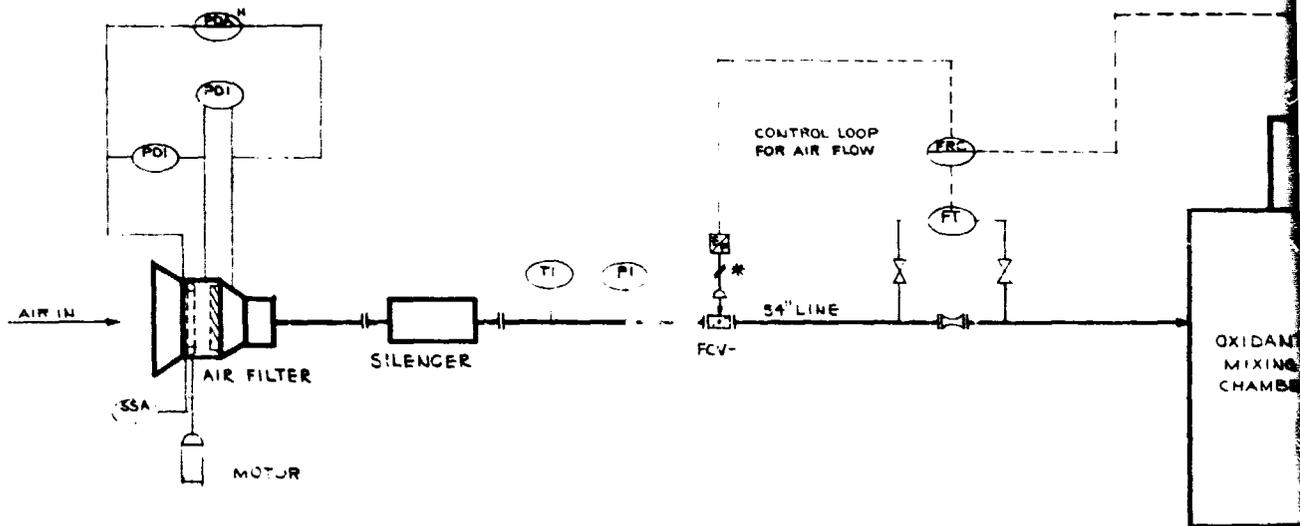
OXIDANT SUPPLY SYSTEM
AIR SEPARATION UNIT (ASU)
P&I #3

SCALE	DRAWN	CHECKED	APPROVED
H-16-81	12-15-80	8/5/81	3/1/81
PROJECT NO.	DRAWING NUMBER		REV
LOT 5026-36	1-FS-815		1

WASA DEN 3-102

NO.	0478	DESCRIPTION	COORD.	BY	CHK.	APPD.

J-3

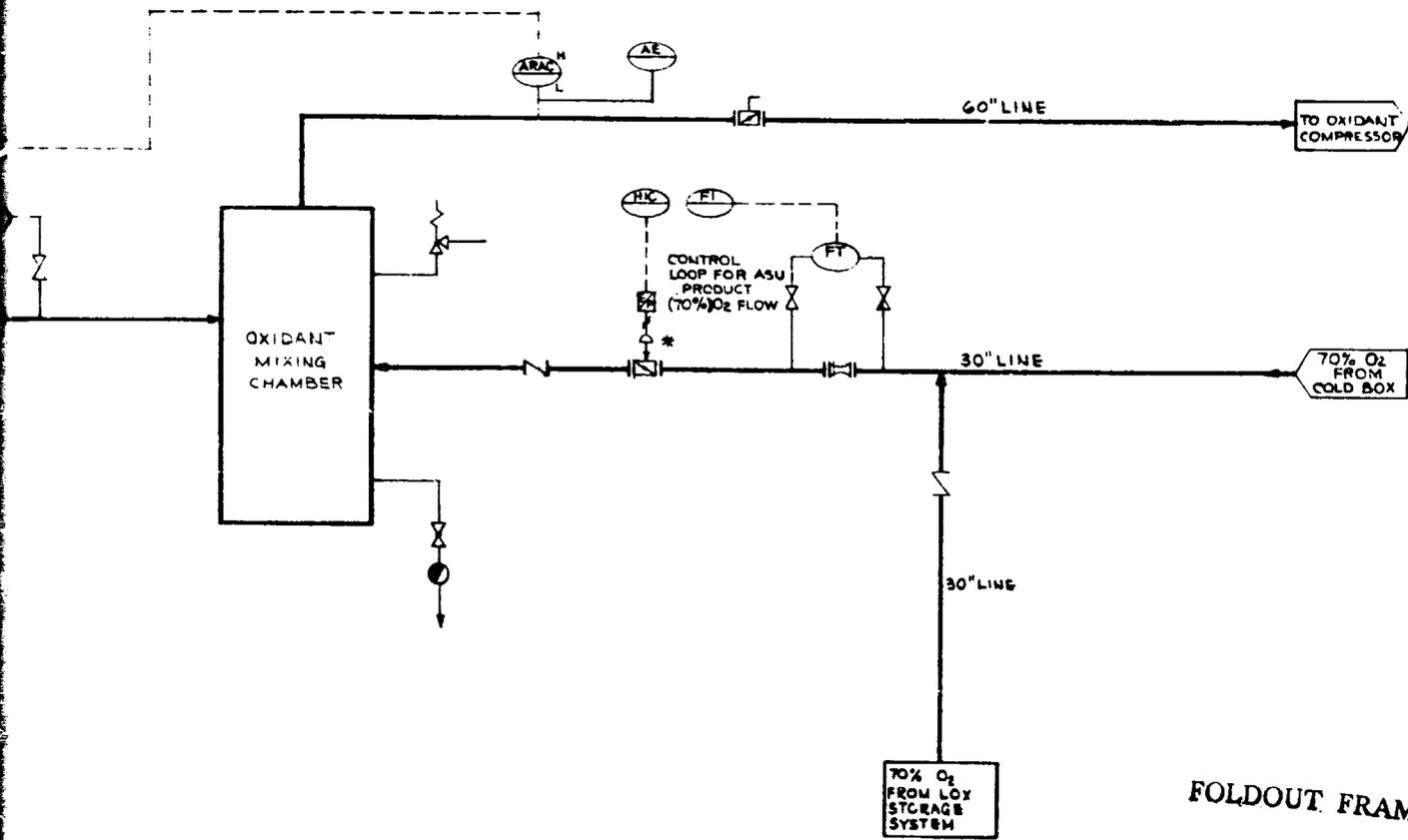


FOLDOUT FRAME

NOTE:

* CONTROL OF THE ASU PRODUCT FLOW/NOMINAL FLOW INTO THE MIXING CHAMBER ARE UNDER THE CENTRAL CONTROL/PROTECTION SYSTEM.

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OF POOR QUALITY



FOLDOUT FRAME 2

NOTE:
OF THE ASU PRODUCT FLOW (NOMINALLY 70% O₂) & AIR FLOW
MIXING CHAMBER ARE UNDER THE CONTROL OF THE FACILITY
CONTROL/PROTECTION SYSTEM.

<i>Linco</i> CORPORATION LOW TEMPERATURE PROCESSING AND EQUIPMENT NEW YORK, N. Y.			
MHD ETF 200 MWe			
OXIDANT SUPPLY SYSTEM MIXING CHAMBER PEI #4			
SCALE	DESIGN	CHECKED	APPROVED
DATE	1.16.81	3/17/81	3/9/81
PROJECT NO.	LOT 502G-SE NASA DEN 376	DRAWING NUMBER	REV
		1-FS-816	2

NO.	DATE	DESCRIPTION	COORD. BY	CHK	APPD

M

G

F

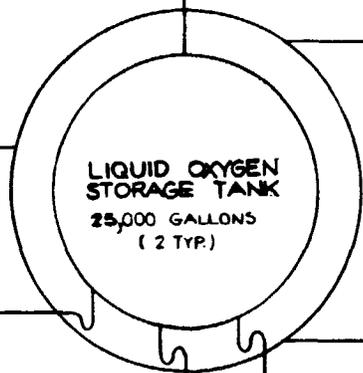
E

LIQUID NITROGEN FROM ASU

2" LINE

70% LIQUID OXYGEN FROM ASU

2" LINE



6" LINE

OXYGEN TO MIXING CHAMBER

30" LINE

PRESS N2 GAS TO FACILITY N2 COMPRESSOR BLANKETING SYSTEM

4" LINE

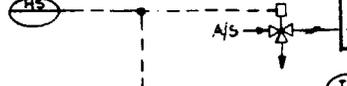
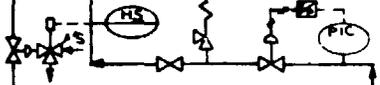
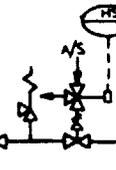
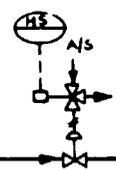
FOLDOUT FRAME

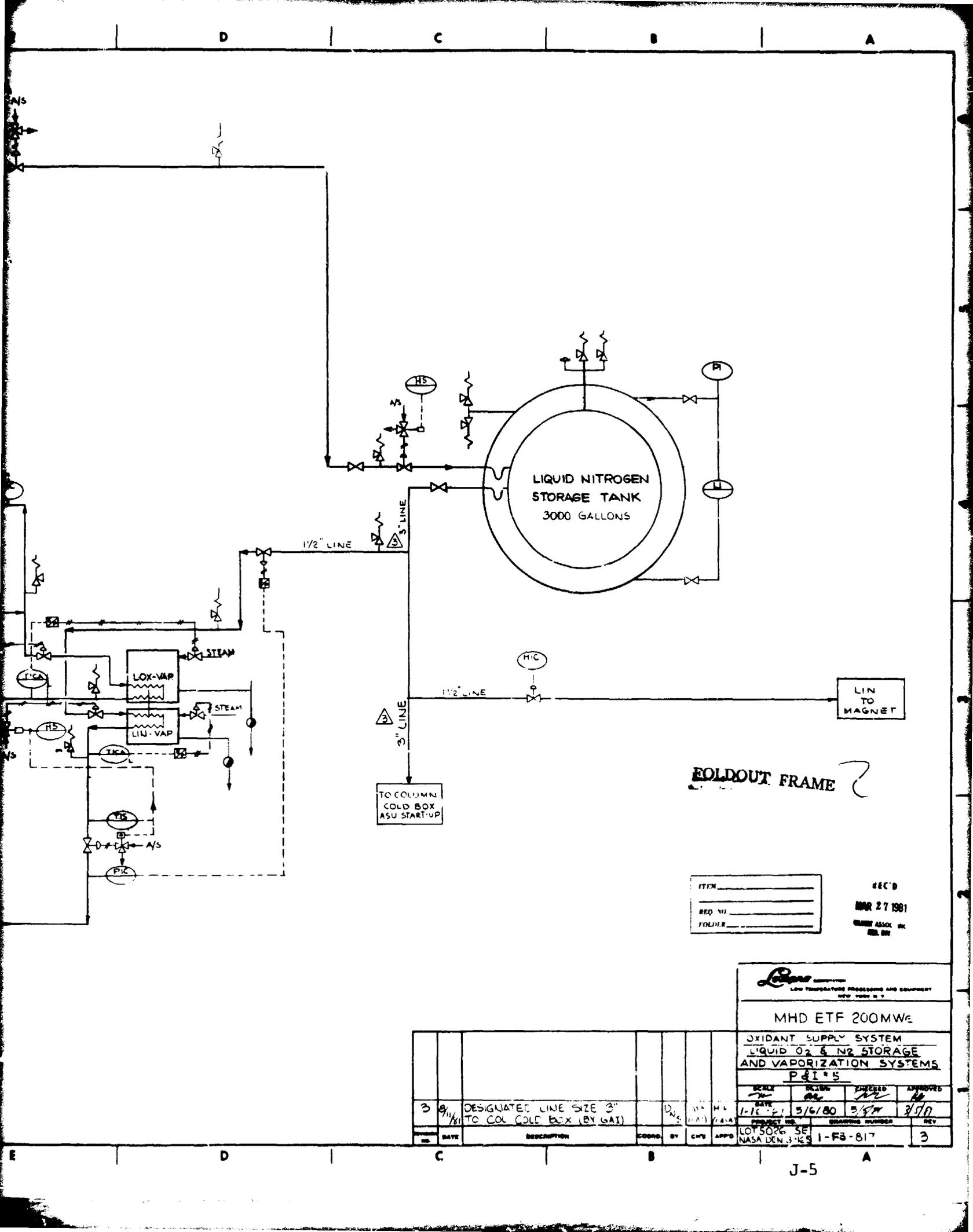
M

G

F

E





WELDOUT FRAME

ITEM _____
 REQ NO _____
 FOLDER _____

REC'D
 MAR 27 1981
 NASA ASAC INC
 BLD 011

 LOW TEMPERATURE PROCESSING AND EQUIPMENT NEW YORK, N.Y.			
MHD ETF 200MWe			
OXYDANT SUPPLY SYSTEM LIQUID O₂ & N₂ STORAGE AND VAPORIZATION SYSTEMS P&I'S			
DESIGN	DESIGN	DESIGN	APPROVED
DATE	DATE	DATE	DATE
1-16-81	5/6/80	3/87	3/70
PROJECT NO.		DRAWING NUMBER	
LOT 5026 SEI		1-F3-817	
NASA DEN 3-165			
REV			3

3	5/11/81	DESIGNATED LINE SIZE 3" TO COL COLD BOX (BY GAS)	COND.	BY	DATE	APP'D

OXIDANT FROM MIXING CHAMBER

TO ATM.

42" LINE

42" LINE

OXIDANT COMP. ELECTRIC MOTOR

OXIDANT COMP. STEAM TURBINE IDENTICAL TO C

ORIGINAL PAGE IS OF POOR QUALITY

T COMP SHUT DOWN

L.S. SELECTOR

BY PASS CO

SL SILENCER

CIRCULATING WATER SYSTEM

TO COMPRES. SHUT DOWN
TO STEAM TURBINE TRIP VALVE

42" LINE

EXP. JT

CONTROL OIL SYSTEM

STEAM TURBINE DRIVER

OXIDANT COMPRESSOR N°2

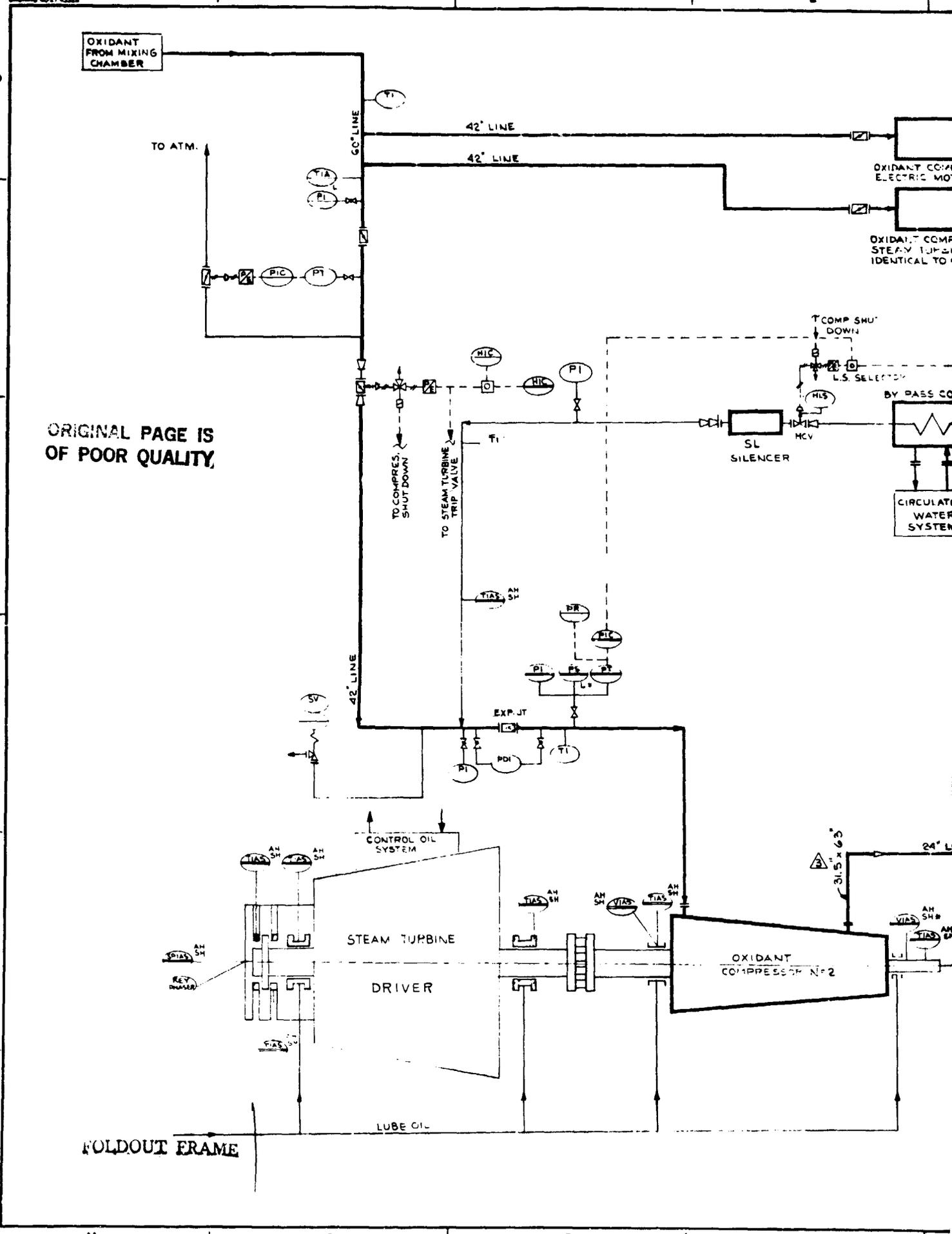
LUBE OIL

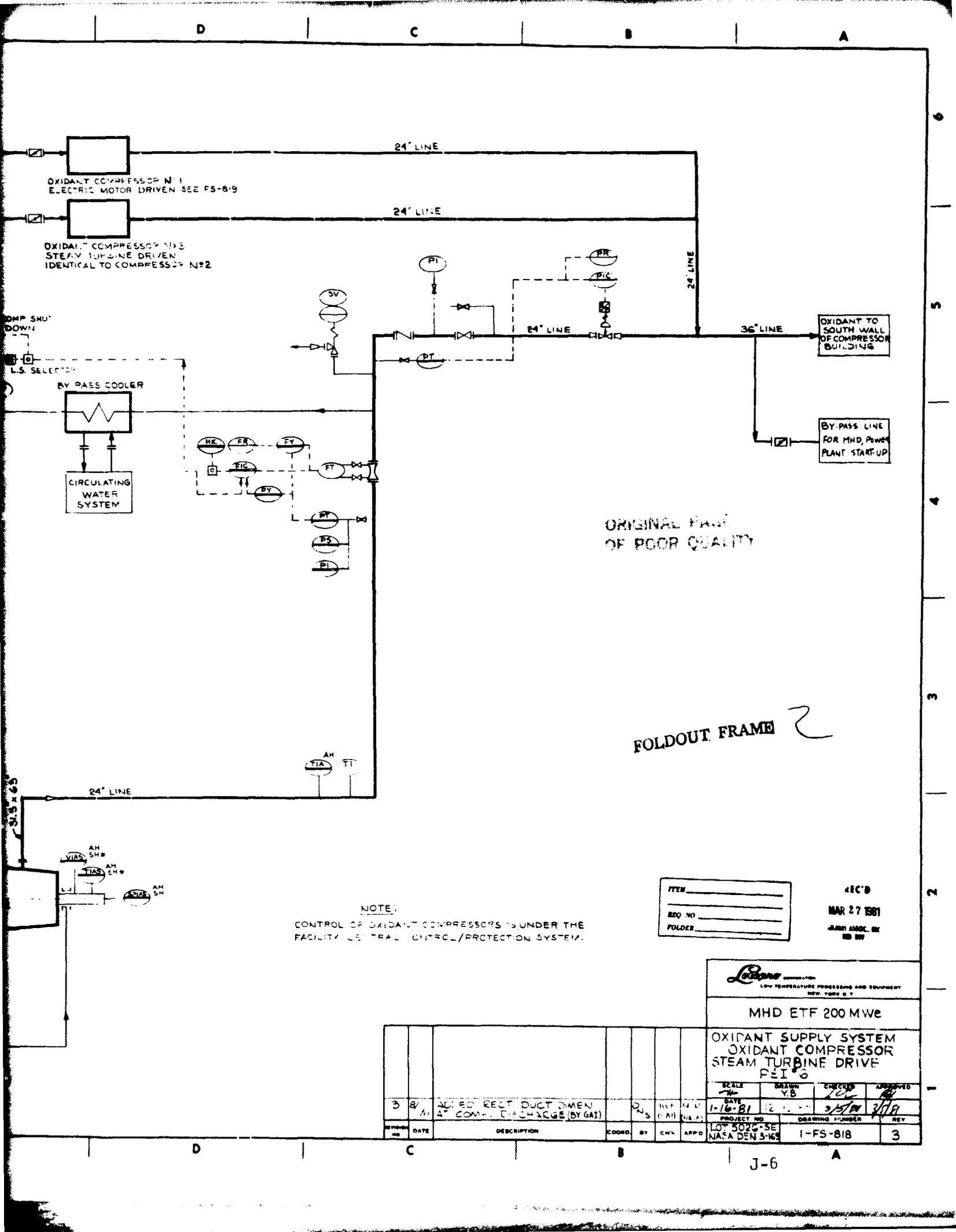
FOLDOUT FRAME

31.5 x 65°

24" LI

1
2
3
4





ORIGINAL PART
OF POOR QUALITY

FOLDOUT FRAME 2

NOTE:
CONTROL OF OXIDANT COMPRESSORS IS UNDER THE
FACILITY CENTRAL CONTROL/PROTECTION SYSTEM.

ITEM _____
REQ. NO. _____
FOLDER _____

REC'D
MAR 27 1981
JAN. ASST. IN
RD 07

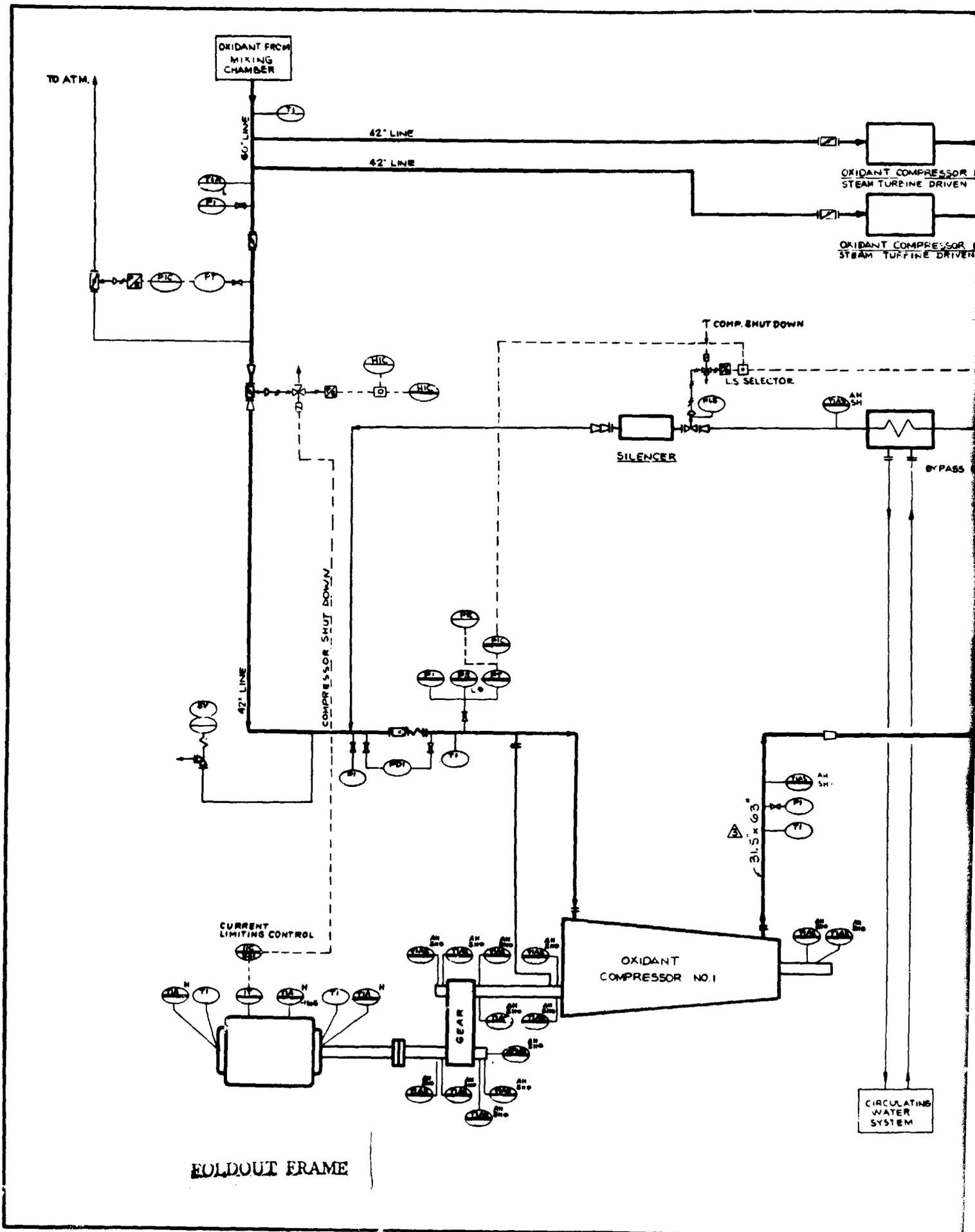
Lozano CORPORATION
LOW TEMPERATURE PROCESSING AND EQUIPMENT
NEW YORK, N.Y.

MHD ETF 200 MWe

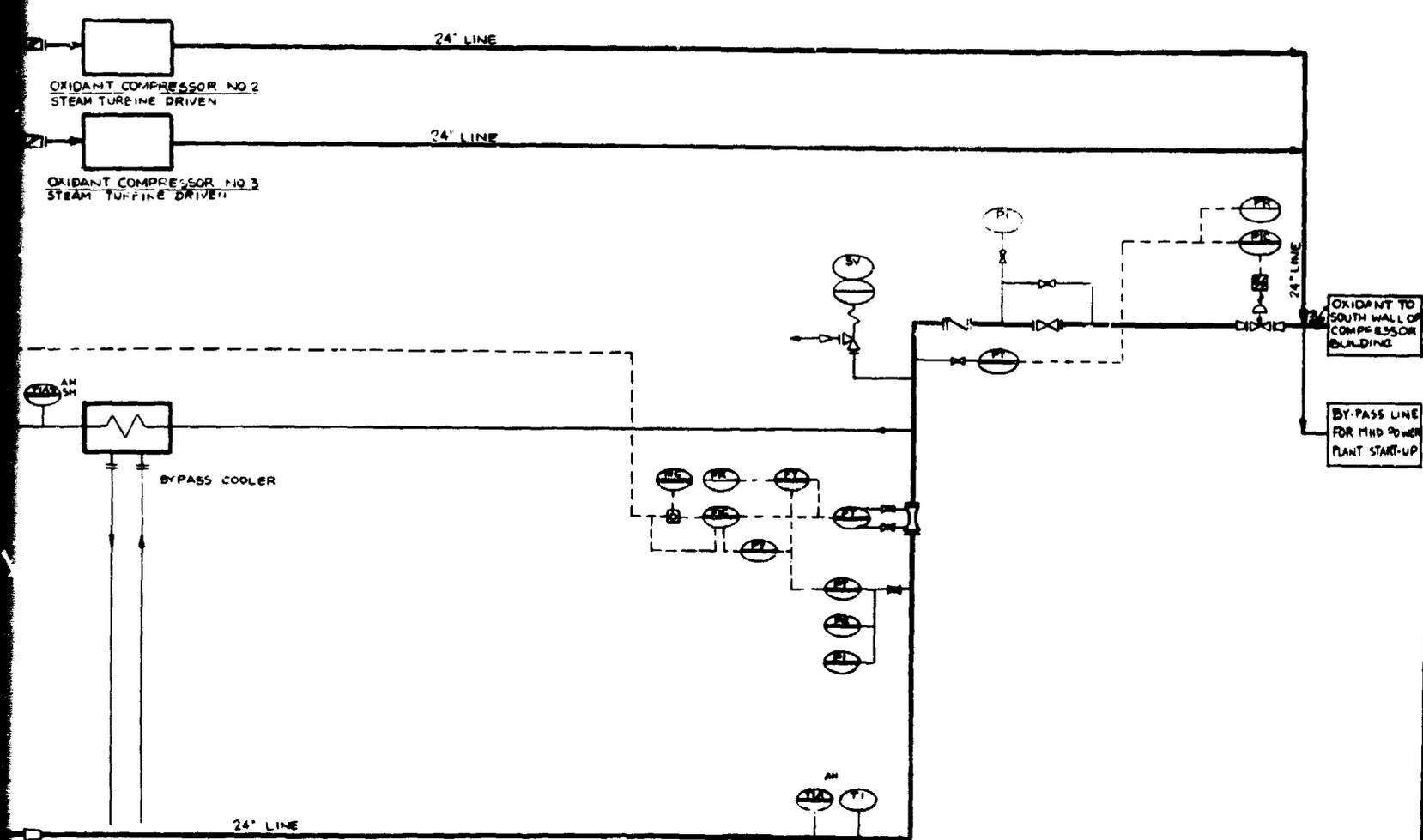
OXIDANT SUPPLY SYSTEM
OXIDANT COMPRESSOR
STEAM TURBINE DRIVE
P&ID

SCALE	DRAWN	CHECKED	APPROVED
	Y.B.	Y.B.	Y.B.
DATE	1-16-81	3/25/81	3/25/81
PROJECT NO.	LOT 5026-5E		
	NASA DEN 3-165		
DRAWING NUMBER	1-FS-818		
REV			3

REV	DATE	DESCRIPTION	COORD	BY	CHK	APPD
3	8/11	ADDED RECT DUCT DIMEN AT COMP. DISCHARGE (BY GAT)		NS	Y.B.	Y.B.



EOLDOUT FRAME



FOLDOUT FRAME 2

NOTE:
CONTROL OF OXIDANT COMPRESSORS IS UNDER
THE FACILITY CENTRAL CONTROL/PROTECTION SYSTEM.

ITER	_____
REQ NO	_____
FOLDER	_____

REV'D
MAR 27 1981
MHD ENCL. 28
REV. 10

Lozano
LOW TEMPERATURE PROCESSING AND EQUIPMENT
REV. 1980 0 1

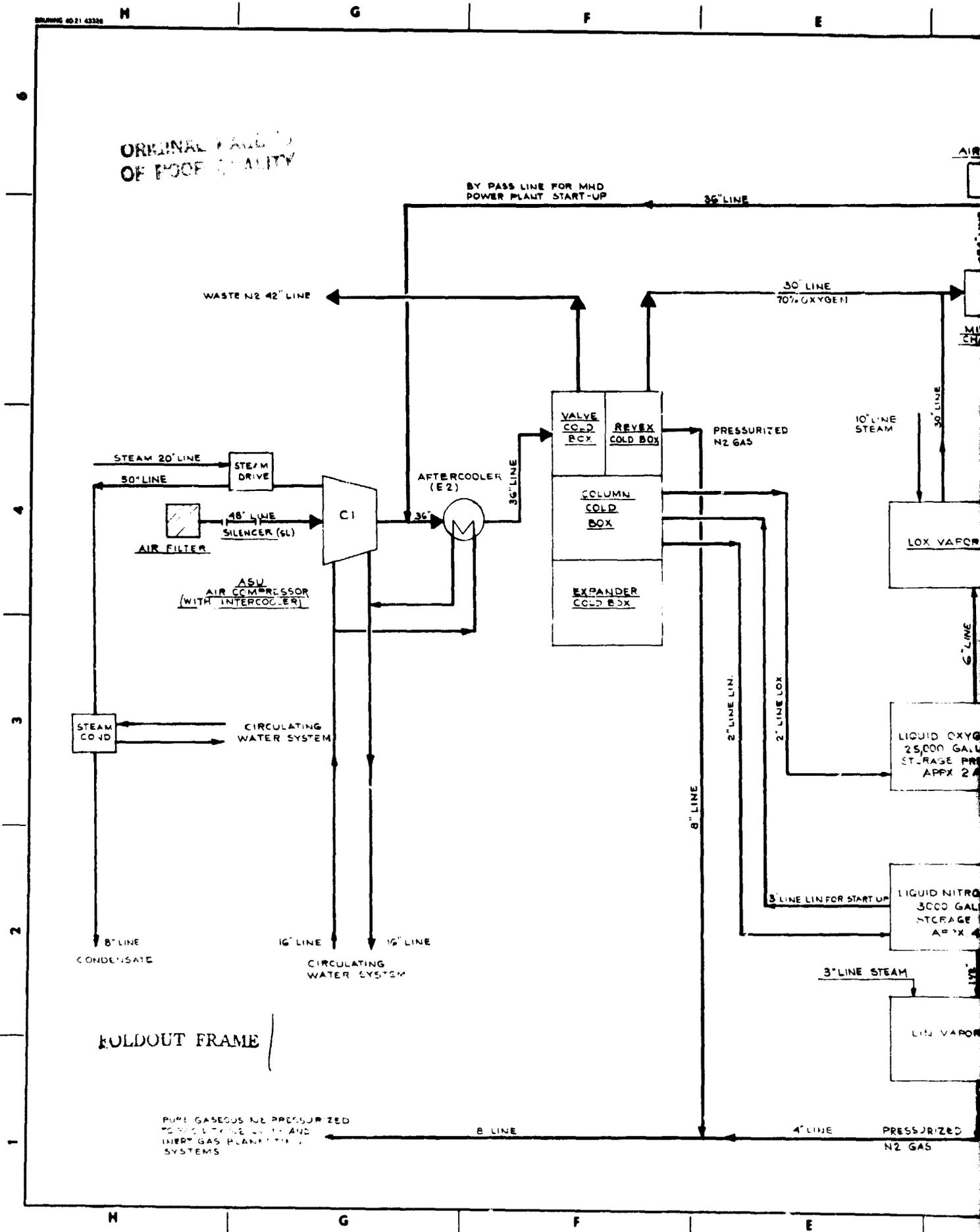
MHD ETF 200 MWe

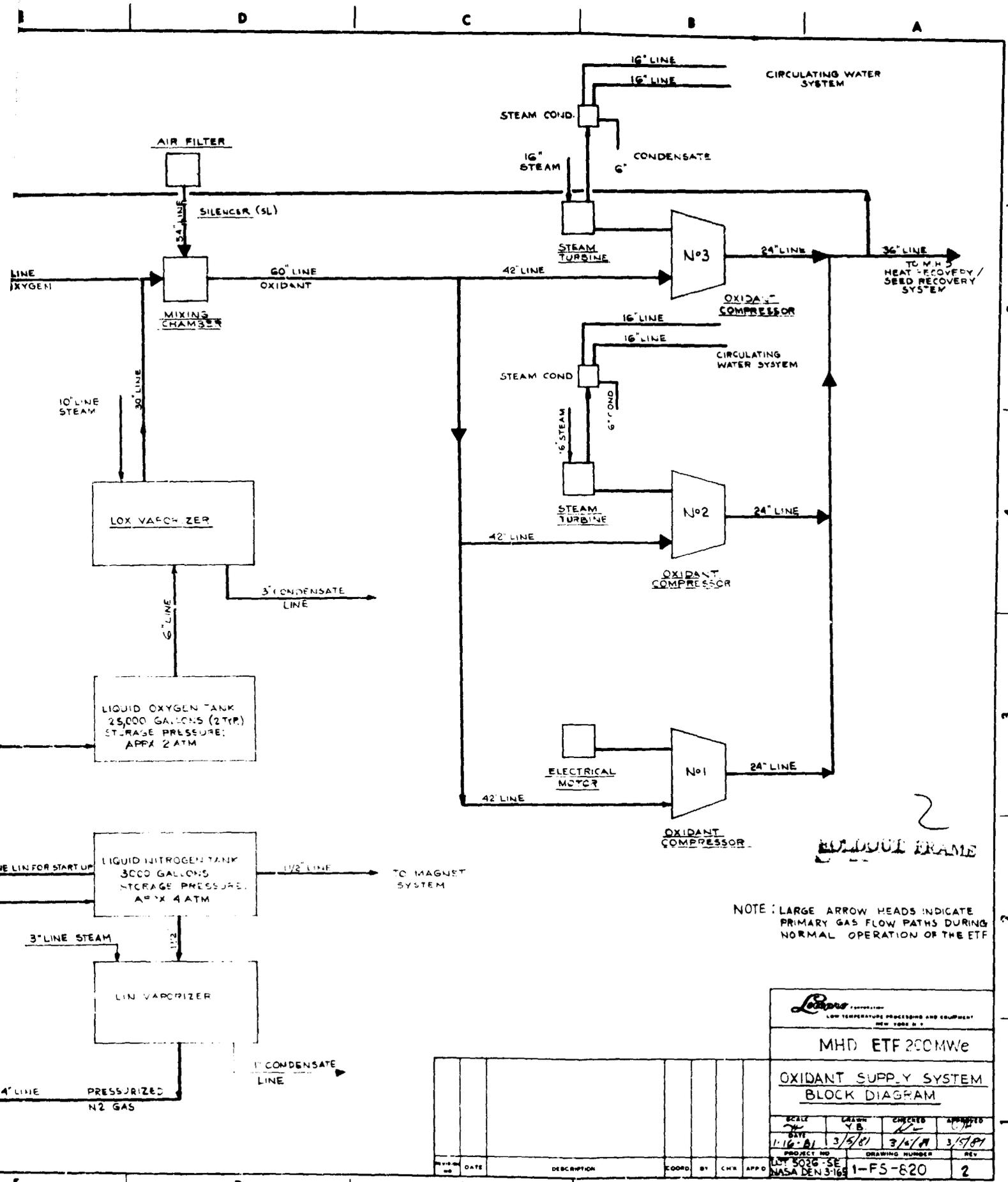
OXIDANT SUPPLY SYSTEM
OXIDANT COMPRESSOR
ELECTRIC MOTOR DRIVE
P 6107

NO.	DATE	DESCRIPTION	DESIGNED BY	CHECKED BY	APPROVED	SCALE	DATE	REVISED BY	REASON	DATE
1		ADDED RECT. DUCT DIMEN. OXIDANT COMPRESSOR DISCHARGE (BYGAT)	ONS	W.P. (A)	W.P. (A)					
						1:16 B1	5/80			3/80

PROJECT NO. LOT 3026-5E
NASA DEN 3-16
DRAWING NUMBER 1-FS-819
REV. 3

ORIGINAL LAYOUT
OF POOF QUALITY





 LOW TEMPERATURE PROCESSING AND EQUIPMENT NEW YORK, N.Y.			
MHD ETFCOR			
OXIDANT SUPPLY SYSTEM BLOCK DIAGRAM			
SCALE	DESIGN	CHECKED	APPROVED
DATE	3/5/81	3/4/81	3/5/81
PROJECT NO.	DRAWING NUMBER		REV.
157-5026-SE NASA DEN 3-163	1-FS-820		2

P&I DIAGRAM SYMBOLS

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OF POOR QUALITY

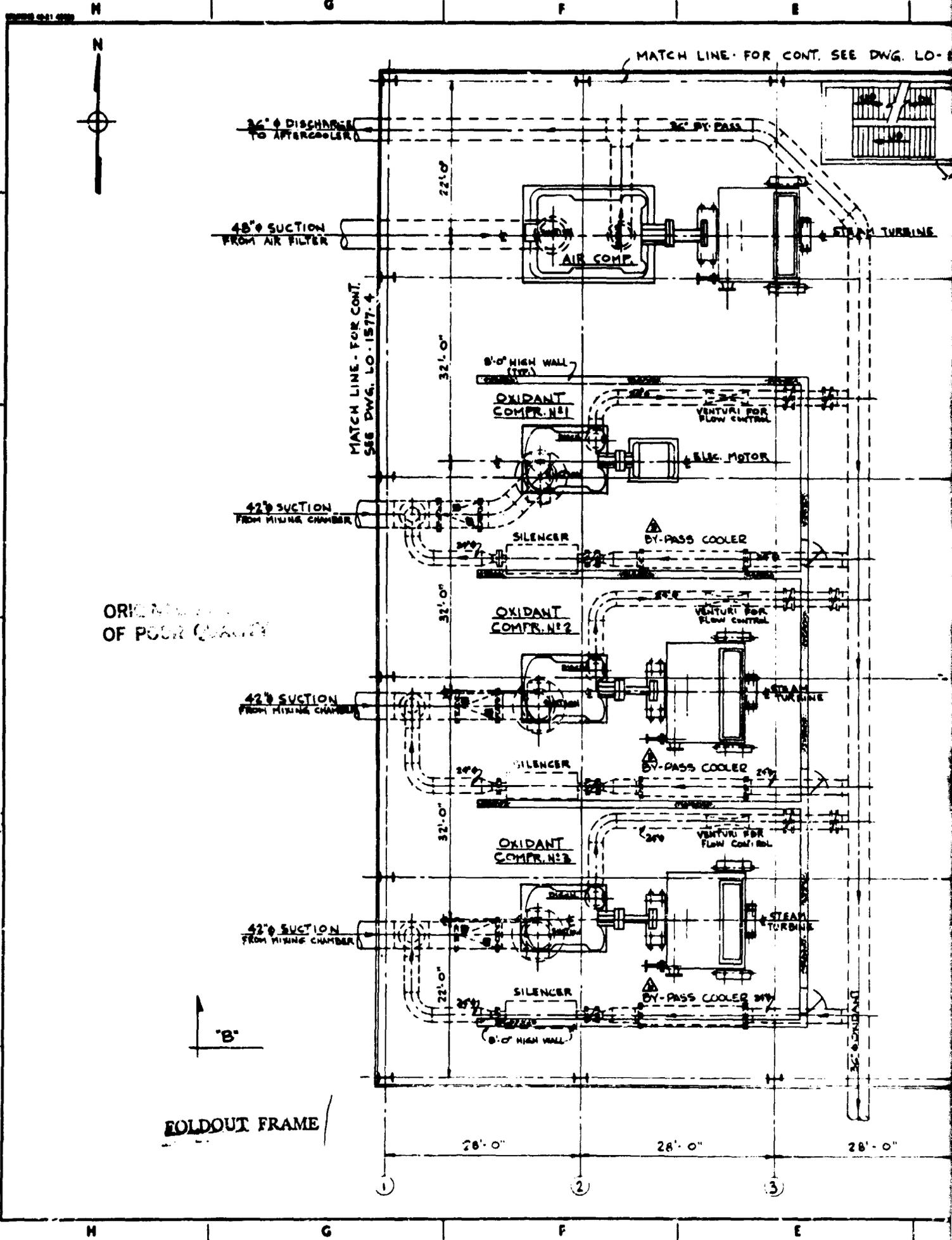
	<u>WELDED</u>	<u>FLANGED</u>	<u>SCREWED</u>
GATE VALVE			
GLOBE VALVE			
CHECK VALVE			
TAG NR			
SIZE SET PRESS.			
SAFETY VALVE			
BALL VALVE			
BUTTERFLY VALVE			

3 WAY VALVE

VALVE OPERATORS

SOLENOID		'Y' STRAINER	
PISTON		IN-LINE STRAINER	
MAN CONTROLLED	T	FLOOR DRAIN	Y
ORIFICE		STORM DRAIN	Ys
BLIND PLATE		TRAP	
EXPANSION JOINT		VENTURI TUBE	
SELEC. RELAY		REDUCER	
DIAPHRAGM		RUPTURE DISC	
INSTRUMENT LOCALLY MOUNTED		FLANGE	
INSTRUMENT MAIN PANEL MOUNTED		ELEC. INSTRUM. SIGNAL LINE	
INSTRUMENT LOCAL PANEL MOUNTED		INSTRUMENT CAPILLARY TUBING	
PROCESS LINE BY LOTEPRO		PNEUM. INSTRUM. SIGNAL LINE	
UNDERGROUND LINE		PUMP	
INSTRUMENT TELEMETERING		A.C. GENERATOR	
VACUUM JACKETED LINE		CLAPNET BOX C1, C2, C3, C4	
INSULATED LINE WITH HEAT TRACED LINE			
INSULATED & STEAM TRACED LINE			

ELIMINATE FRAME



MATCH LINE - FOR CONT. SEE DWG. LO-

36" DISCHARGE TO AFTERCOOLER

48" SUCTION FROM AIR FILTER

AIR COMP.

STEAM TURBINE

MATCH LINE - FOR CONT. SEE DWG. LO. 1577. 4

8'-0" HIGH WALL (TOP)

OXIDANT COMP. NO. 1

VENTURI FOR FLOW CONTROL

ELEC. MOTOR

42" SUCTION FROM MIXING CHAMBER

SILENCER

BY-PASS COOLER

OXIDANT COMP. NO. 2

VENTURI FOR FLOW CONTROL

42" SUCTION FROM MIXING CHAMBER

SILENCER

BY-PASS COOLER

OXIDANT COMP. NO. 3

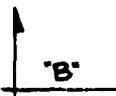
VENTURI FOR FLOW CONTROL

42" SUCTION FROM MIXING CHAMBER

SILENCER

BY-PASS COOLER

STEAM TURBINE



ORIGINAL OF POOR QUALITY

FOLDOUT FRAME

28'-0"

28'-0"

28'-0"

1

2

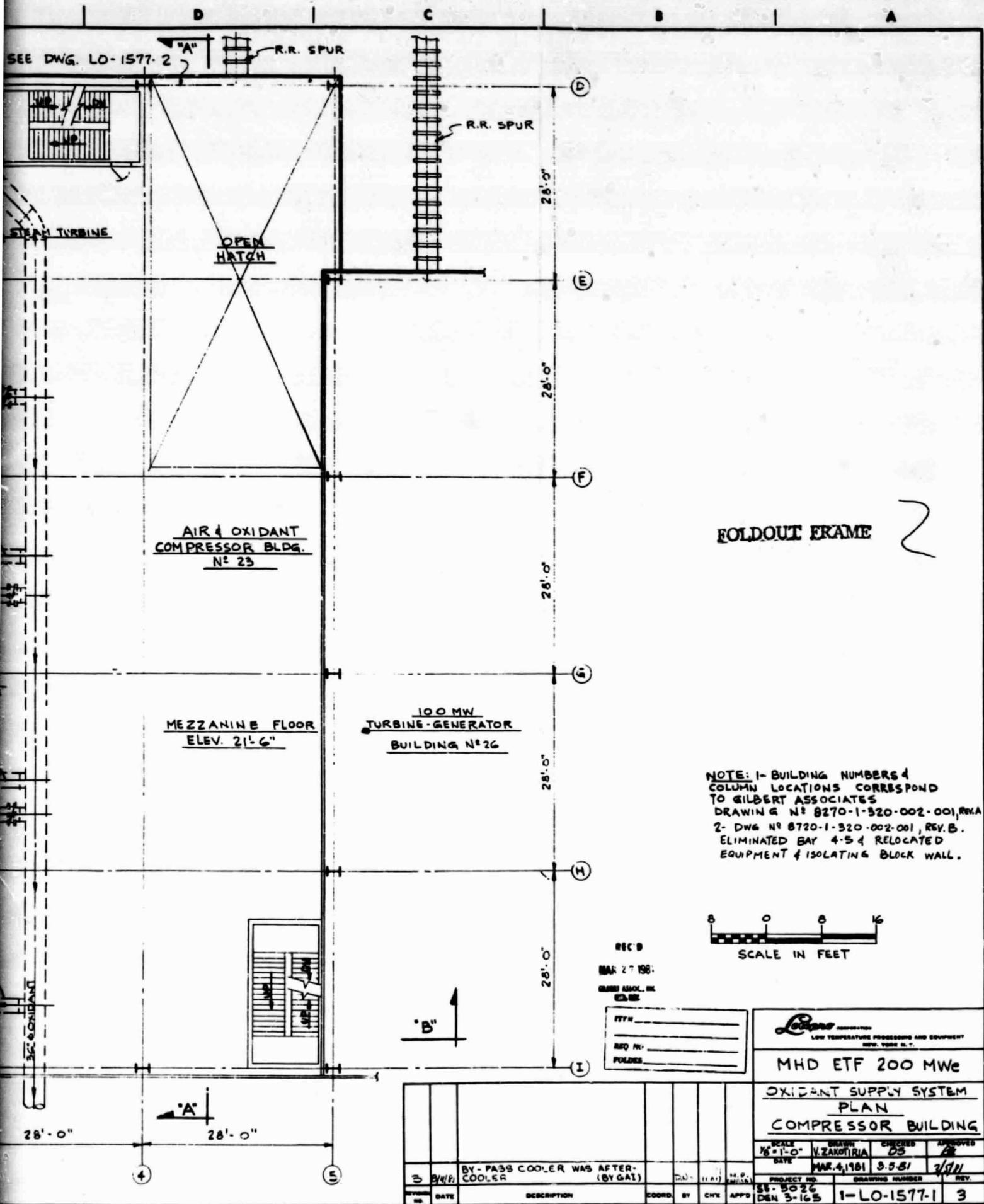
3

H

G

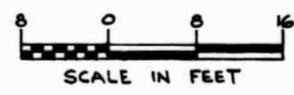
F

E



FOLDOUT FRAME

NOTE: 1- BUILDING NUMBERS & COLUMN LOCATIONS CORRESPOND TO GILBERT ASSOCIATES DRAWING N° 8270-1-320-002-001, REV. A
 2- DWG N° 8720-1-320-002-001, REV. B. ELIMINATED BAY 4-5 & RELOCATED EQUIPMENT & ISOLATING BLOCK WALL.



REC'D
 MAR 27 1981
 GIBERT ASSOC., INC.
 ENGINEERS

ITPM _____
 REQ. NO. _____
 FOLDER _____

Low CORPORATION
 LOW TEMPERATURE PROCESSING AND EQUIPMENT
 NEW YORK, N.Y.

MHD ETF 200 MWe

OXIDANT SUPPLY SYSTEM
 PLAN
 COMPRESSOR BUILDING

SCALE	DRAWN	CHECKED	APPROVED
1/8" = 1'-0"	V. ZAKOTIRIA	DS	DS
DATE	MAR. 4, 1981		3-5-81

NO.	DATE	DESCRIPTION	COORD.	BY	CHK.	APPRO.	PROJECT NO.	DRAWING NUMBER	REV.
3	3/4/81	BY-PASS COOLER WAS AFTER-COOLER (BY GAI)					88-5026	1-LO-1577-1	3
							DEN 3-165		

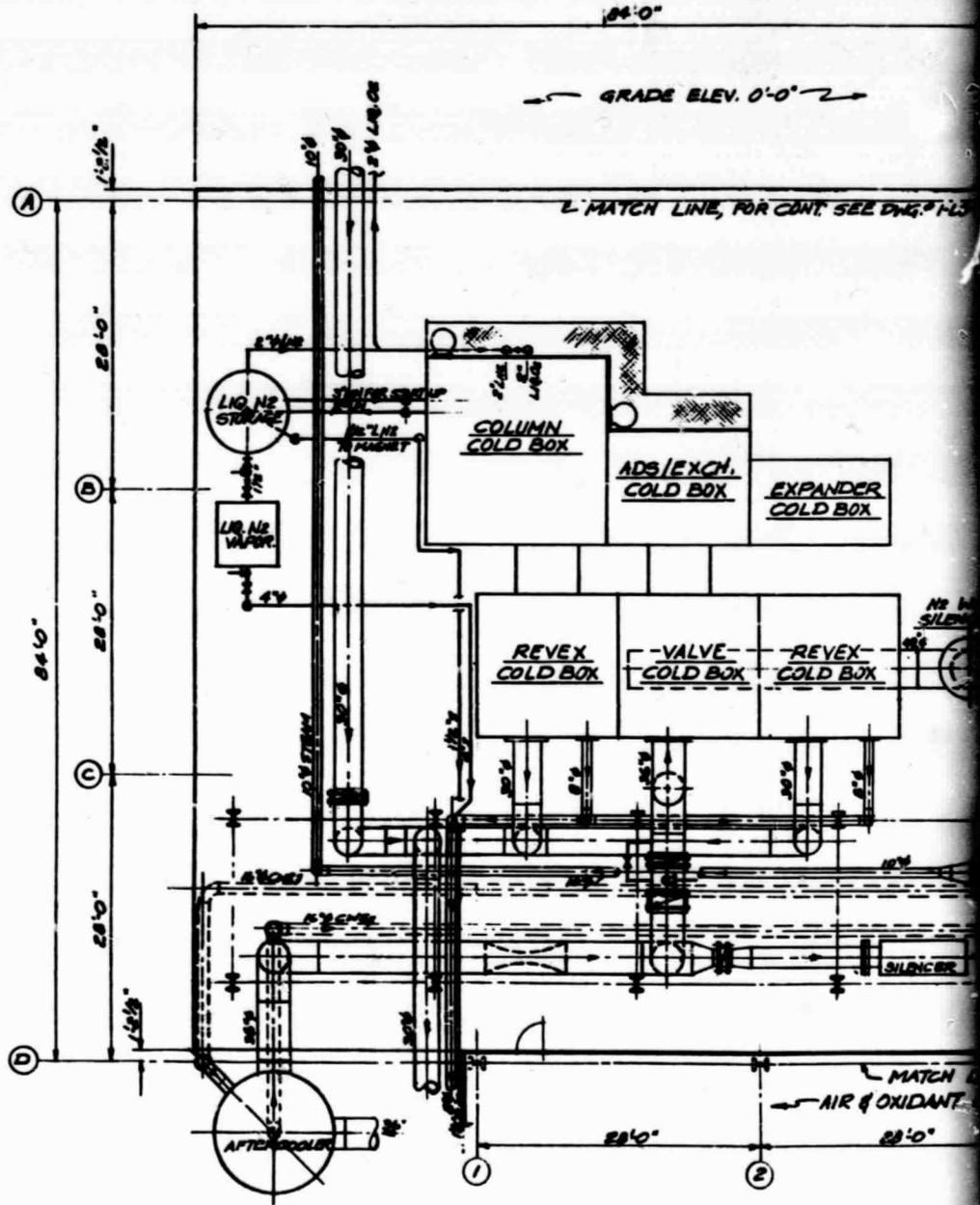
J-10

C-74

N G F E



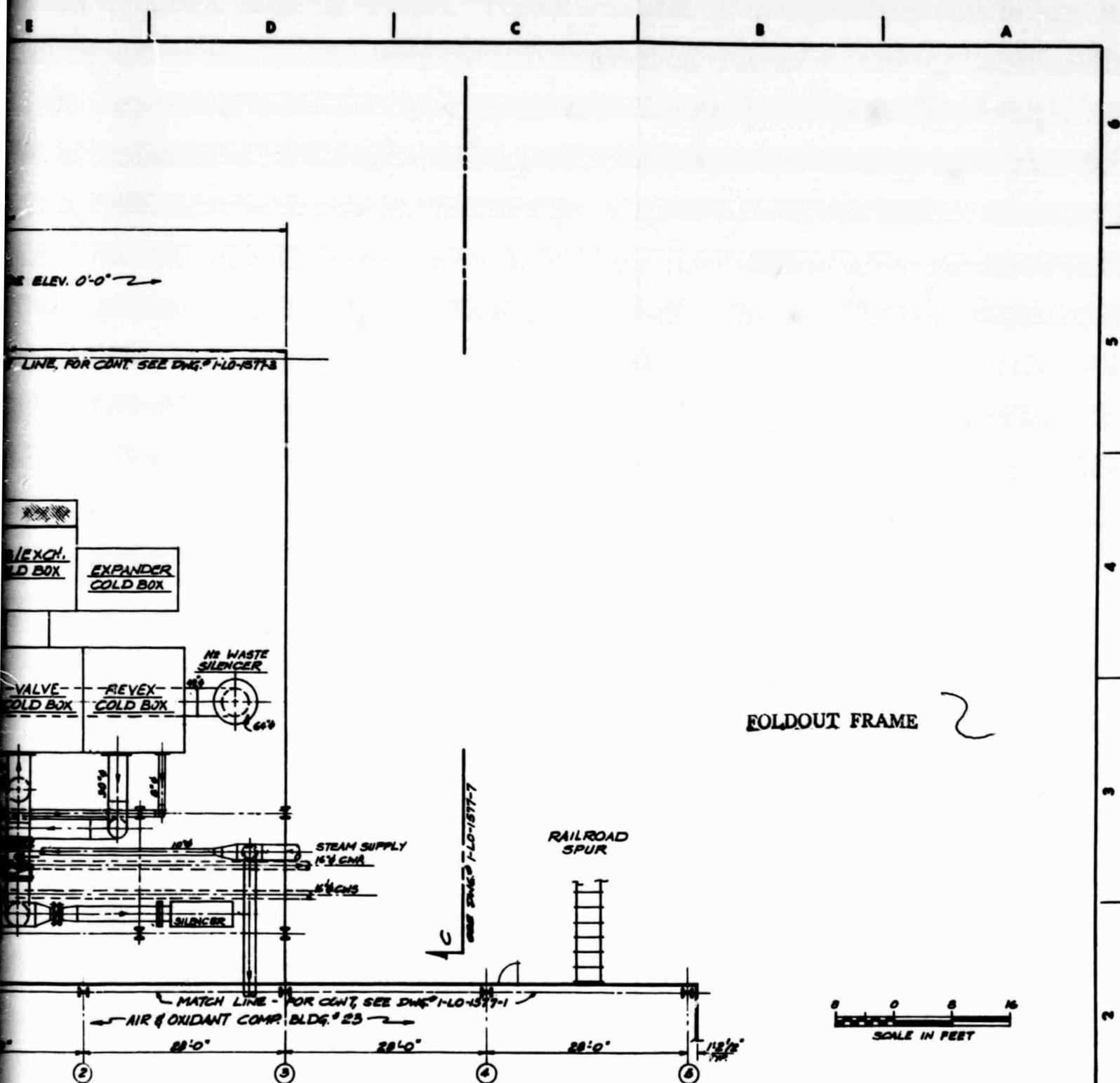
0
4
3
2
1



FOLDOUT PLANE

PLAN

N G F E



EOLDOUT FRAME 2

PLAN

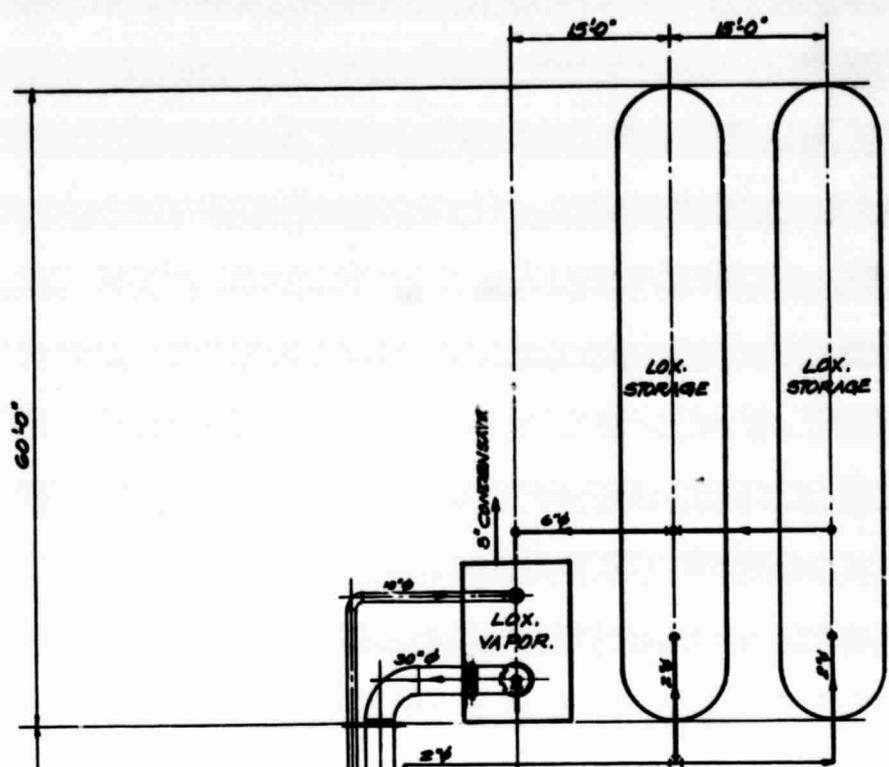


 <small>LOW TEMPERATURE PROCESSING AND EQUIPMENT INC. 1958 N.Y.</small>			
MHD ETF 200 MWe			
OXIDANT SUPPLY SYSTEM PLAN COLD BOXES & EQUIPMENT			
SCALE	DATE	BY	CHKD
1/8" = 1'-0"	2/26/61	WJ	WJ
REV.	DATE	BY	CHKD
1	3/6/61	WJ	WJ
2	2/9/61	WJ	WJ
PROJECT NO.	DRAWING NUMBER	REV.	
3E-8086 DRW 2-163	1-LO-1377-2	2	

NO.	DATE	DESCRIPTION	DRWN. BY	CHKD.	APPR.

PLUMBING SYMBOLS

H G F E



6
4
3
2
1

FOLDOUT FRAME

150'-0"
(NOT TO SCALE)

PL

GRADE ELEV. 0'-0"

1 1/2"

28'-0"
(TYP.)

1

MATCH LINE - FOR CONT. SEE DWG. NO. 1-LO-1577-2

H G F E



SEE DWG. 1-LO-1577-7

PLAN

EXPLODED FRAME

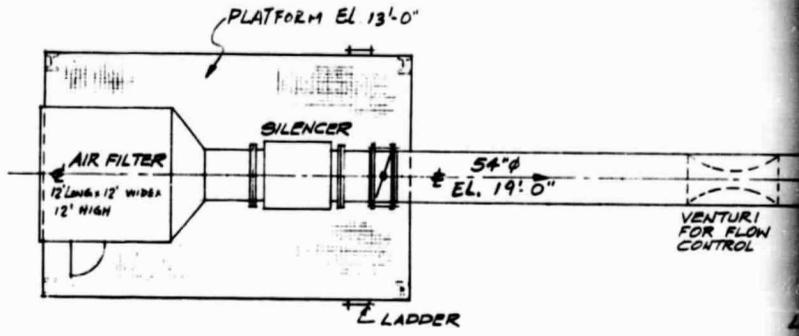
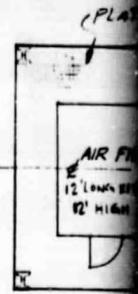


GRADE ELEV. 0'-0"

DWG. N11-LO-1577-2

MHD ETF 200 MWe						
OXIDANT SUPPLY SYSTEM						
PLAN						
LOX VAPORIZER & LOX STORAGE AREA						
DATE	BY	CHKD	APPD	REV		
2/17/71	WZ/ma	PL		2/17/71		
PROJECT NO.	DRAWING NUMBER		REV			
SE-5026	1-LO-1577-3		1			
DATE	DESCRIPTION		FORN	BY	CHK	APPD

J-12



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OF POOR QUALITY

FOLDOUT FRAME

PLAN

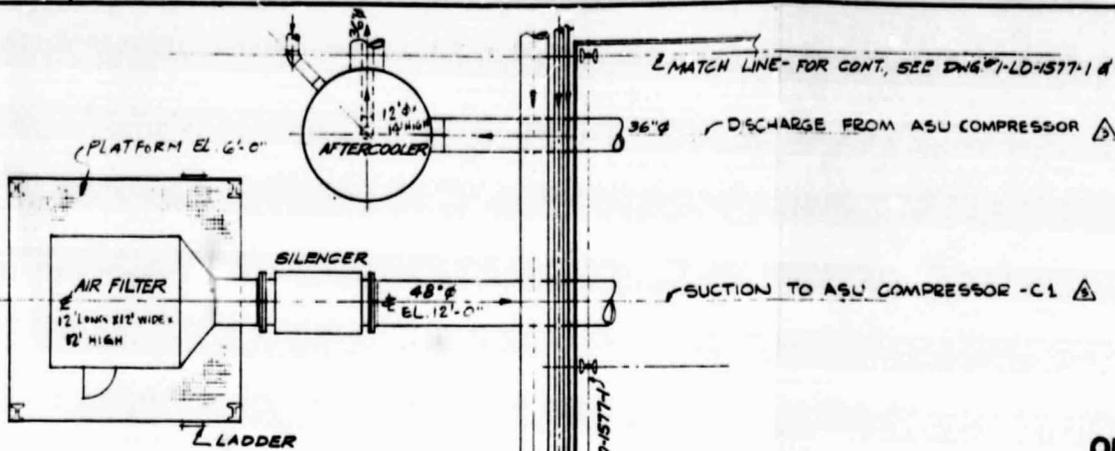
3

2

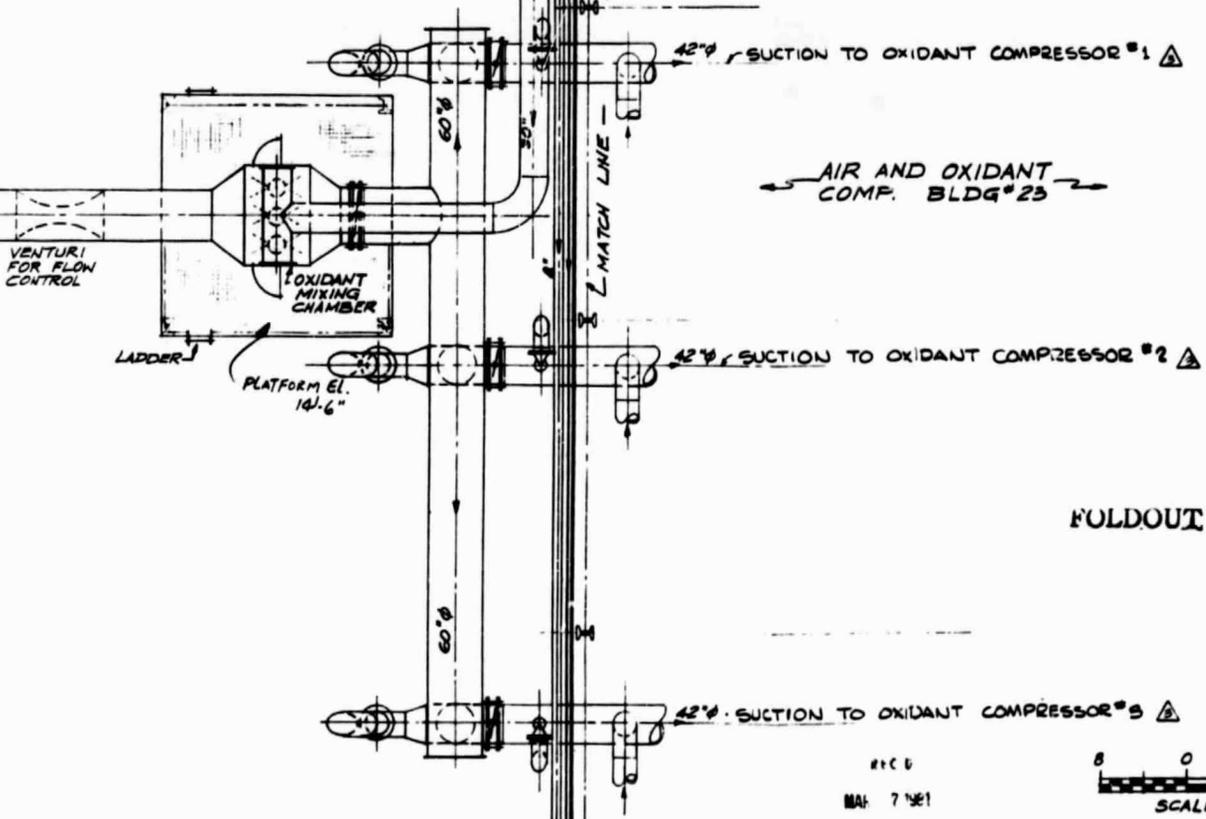
1

D C B A

2 MATCH LINE - FOR CONT, SEE DWG # 1-LO-1577-1 & 2



ORIGINAL PAGE IS OF POOR QUALITY



FOLDOUT FRAME

REC 6
 MAR 7 1961
 GROUP: A.S.M.A. IN
 RE. DR.



ITEM	
REV. NO.	
DATE	

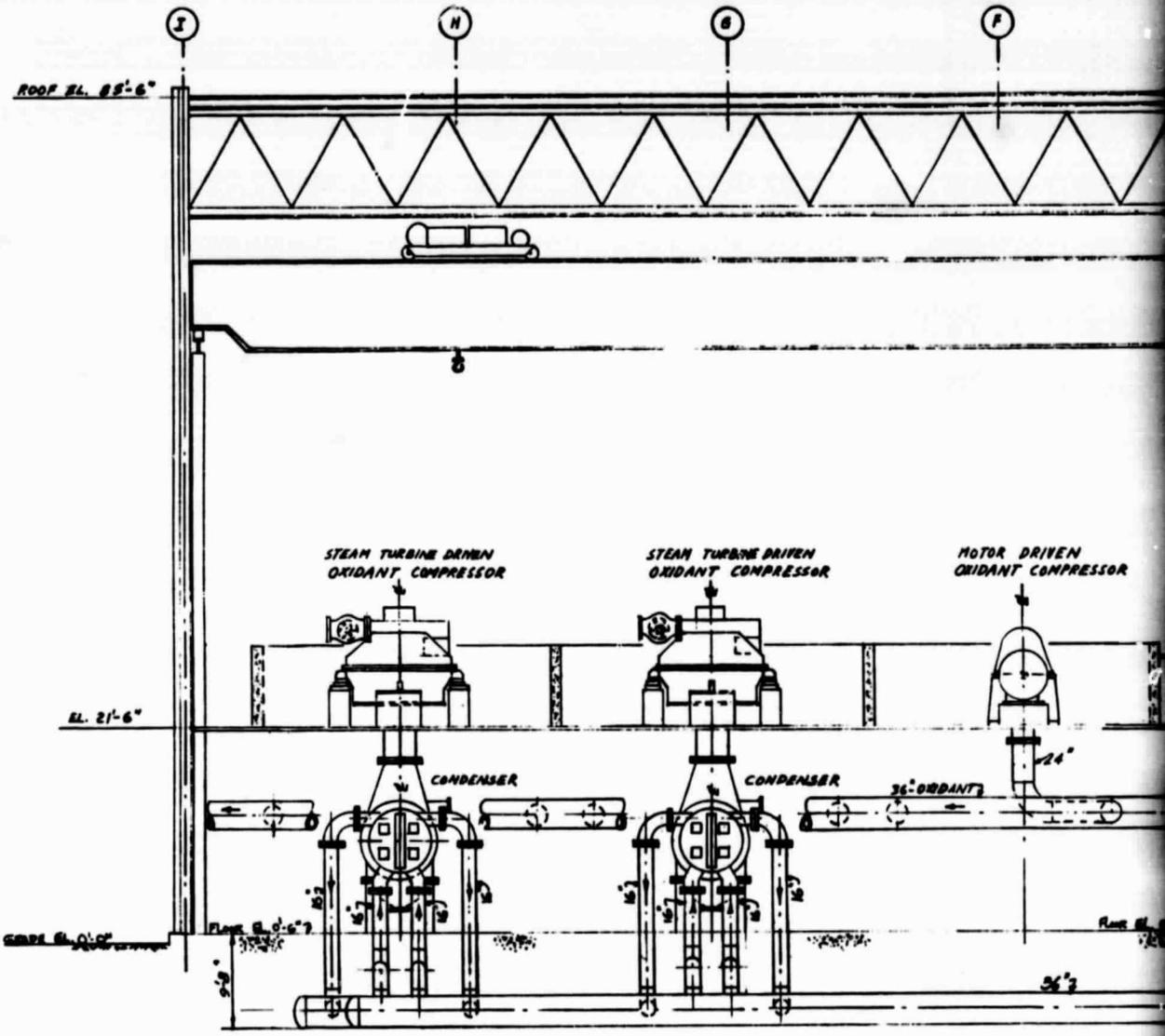
PURE GASEOUS N2 (PRESSURIZED)
 TO FACILITY N2 COMP. FOR
 INLET GAS BLANKETING
 SYSTEM
 1/2" TO MAGNET

MHD ETF 200 MWe			
OXIDANT SUPPLY SYSTEM PLAN			
AIR FILTERS, AFTERCOOLER & OXIDANT MIXING CHAMBER			
SCALE	DATE	BY	CHECKED
1/2" = 1'-0"	3/4/61	JZ	JZ
PROJECT NO.	DRAWING NUMBER		REV.
SE-6026	1-LO-1577-4		3

NO.	DATE	DESCRIPTION	COORD.	BY	CHK.	APPD.
3	3/11/61	ADDED SUCTON TO : ASU COMP. C1, OXID. COMPS. # 1, 2 & 3. ADDED DISCHARGE FROM ASU (BY GAS)		D.S.	JZ	JZ

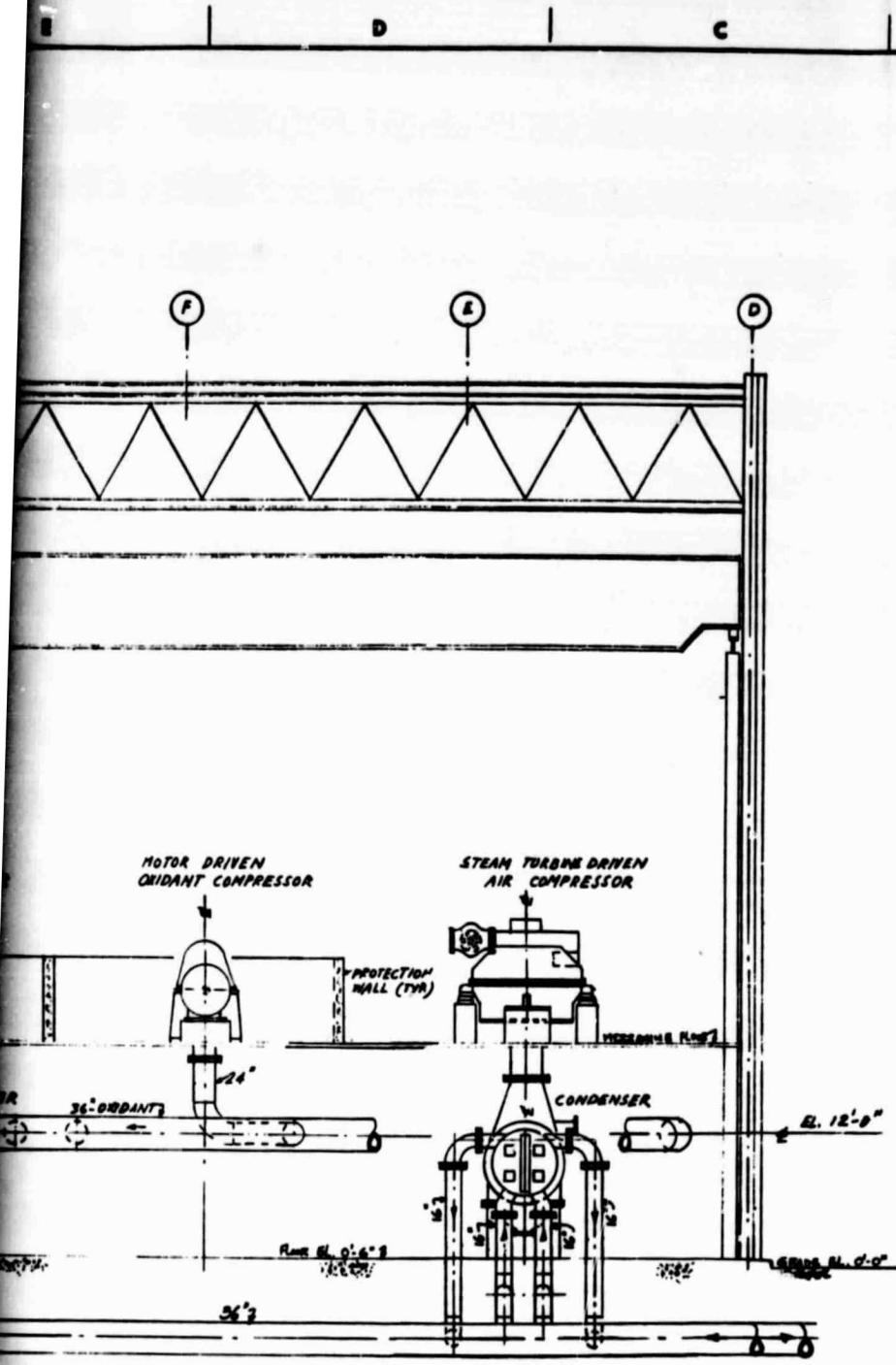
D C B A J-13

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ELEVATION "A"-"A"

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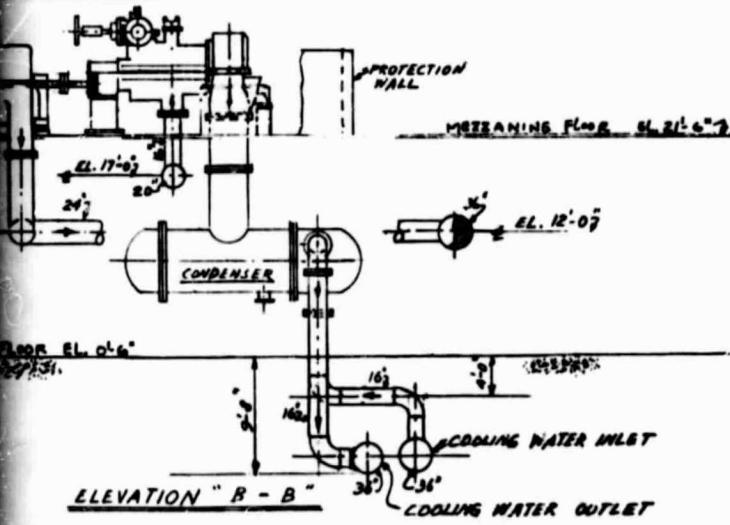
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		MHD ETZ 200MWc	
		OXIDANT SUPPLY SYSTEM	
		ELEVATION "A"-A"	
		TURBINES & COMPRESSORS	
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DATE	3-2-81	3-9-81	3/5/81
PROJECT NO.	31-5016	DRAWING NUMBER	1-10-1577-5
DATE	DEN 3-165	REV.	2

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3 4 5

TURBINE DRIVEN
PUMP COMPRESSOR



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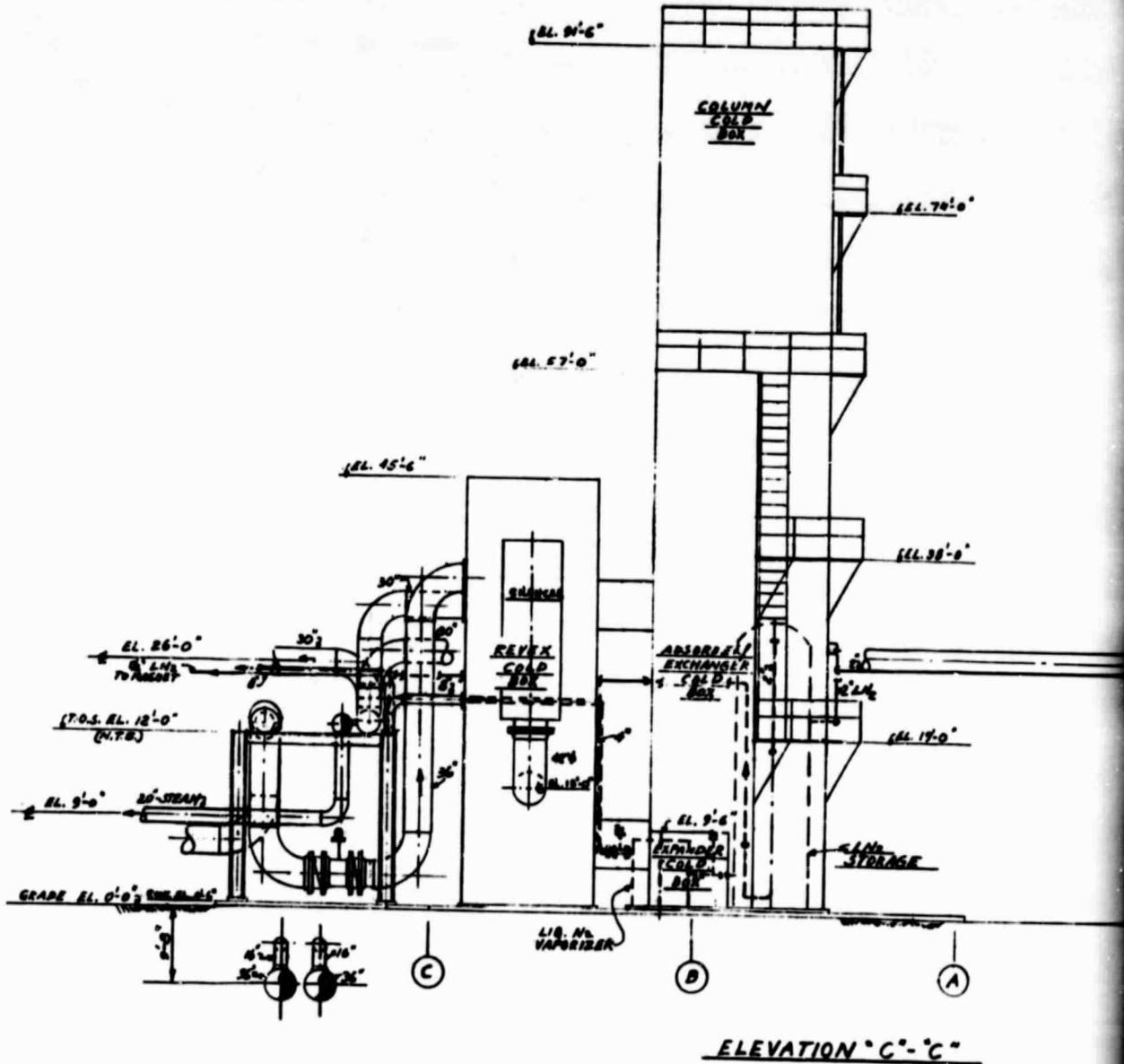
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LOW TEMPERATURE ENGINEERING & CONSULTANTS INC. YORK, N. Y.			
MHD ETF 200 MWe			
OXIDANT SUPPLY SYSTEM			
ELEVATION "B-B"			
TURBINES & COMPRESSORS			
DATE	BY	CHECKED	APPROVED
3-3-81	G.B.	RD	3/5/81
PROJECT NO.	DRAWING NUMBER	REV.	
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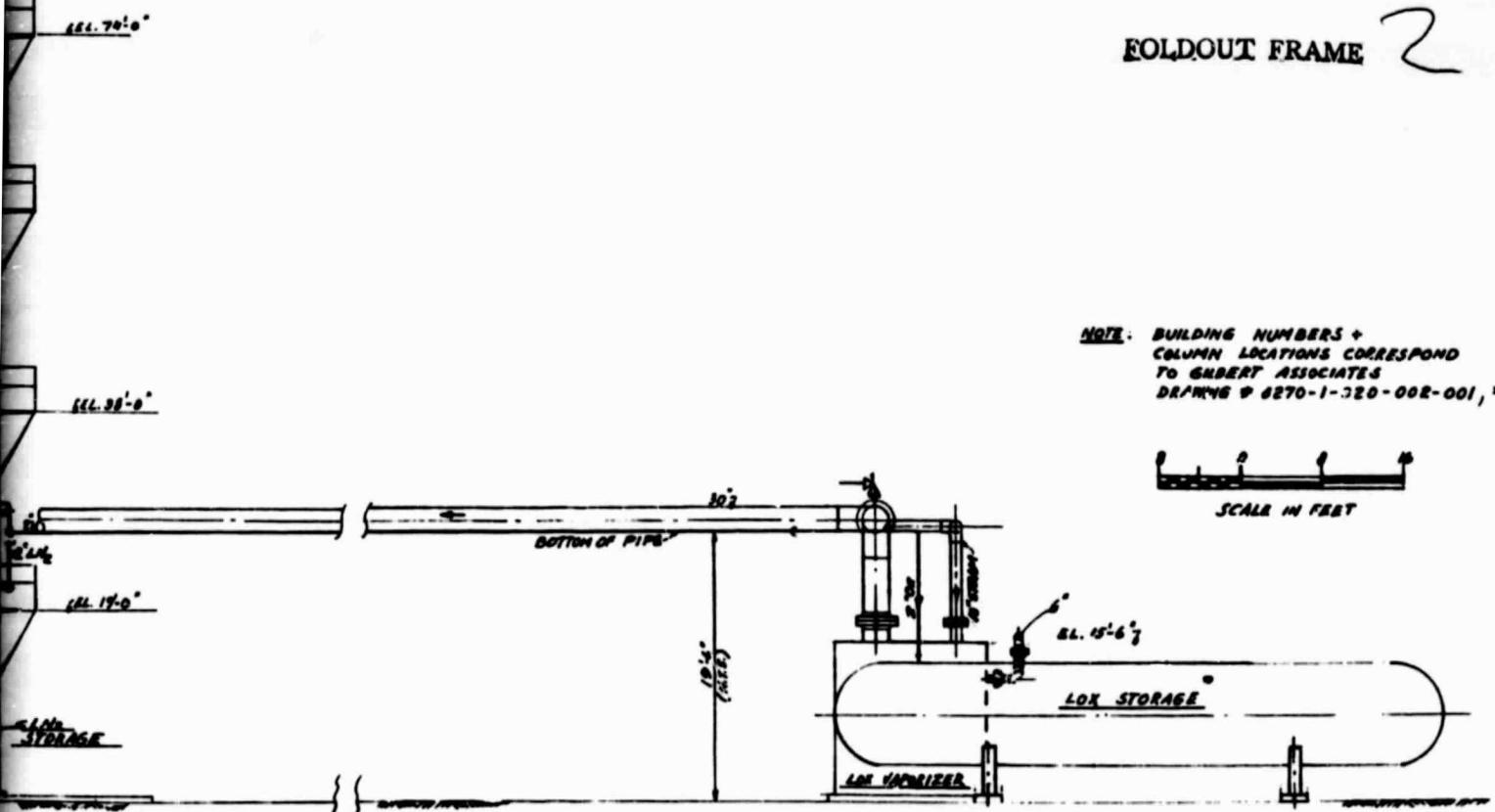


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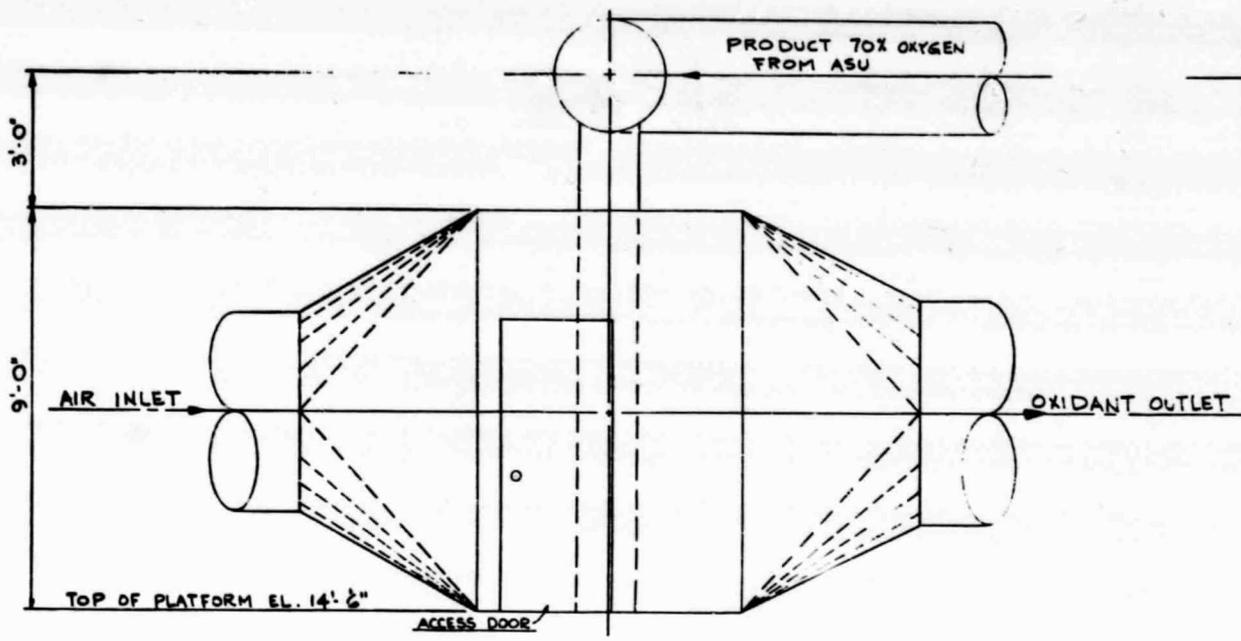
DN °C°-°C°

LOGAN LOW TEMPERATURE PROCESSING AND EQUIPMENT INC. 1952 S. C.			
MHD ETF 200 MWg			
OXIDANT SUPPLY SYSTEM ELEVATION °C°-°C° COLD BOXES & EQUIPMENT			
REV.	DATE	DESCRIPTION	BY
1	5-8-61		5/8/61
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3	1-10-62		1-10-62
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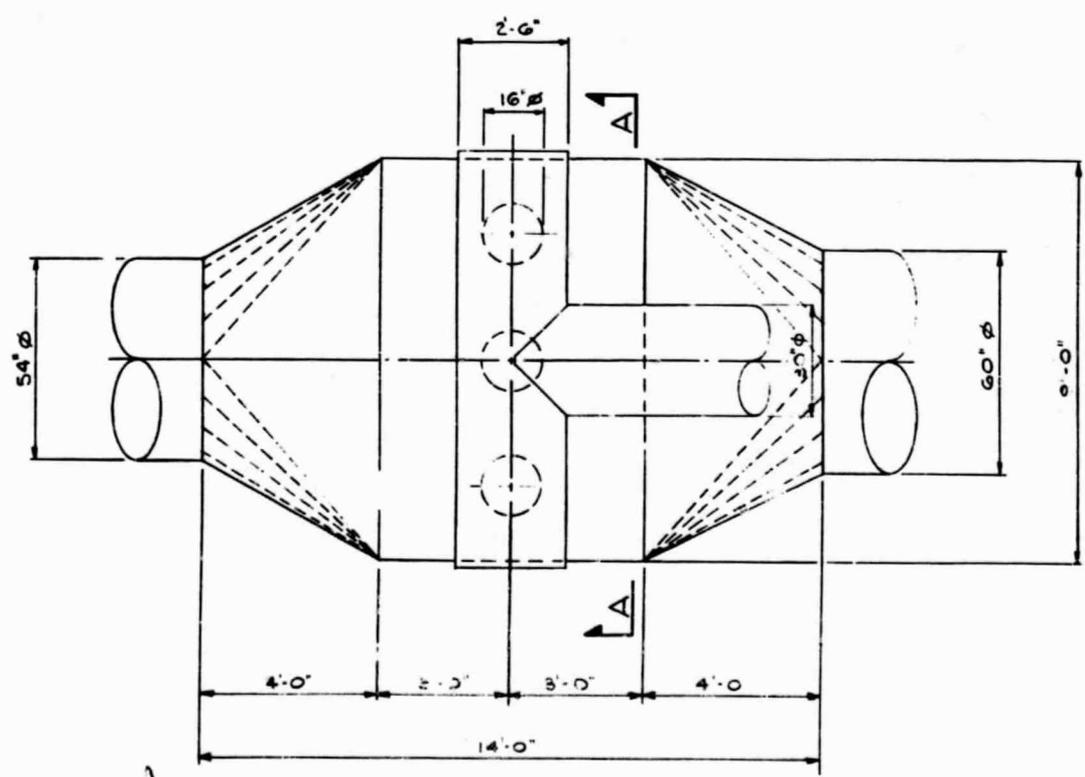
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FRONT VIEW

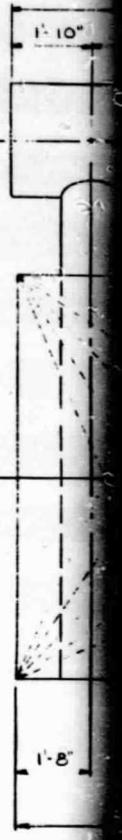


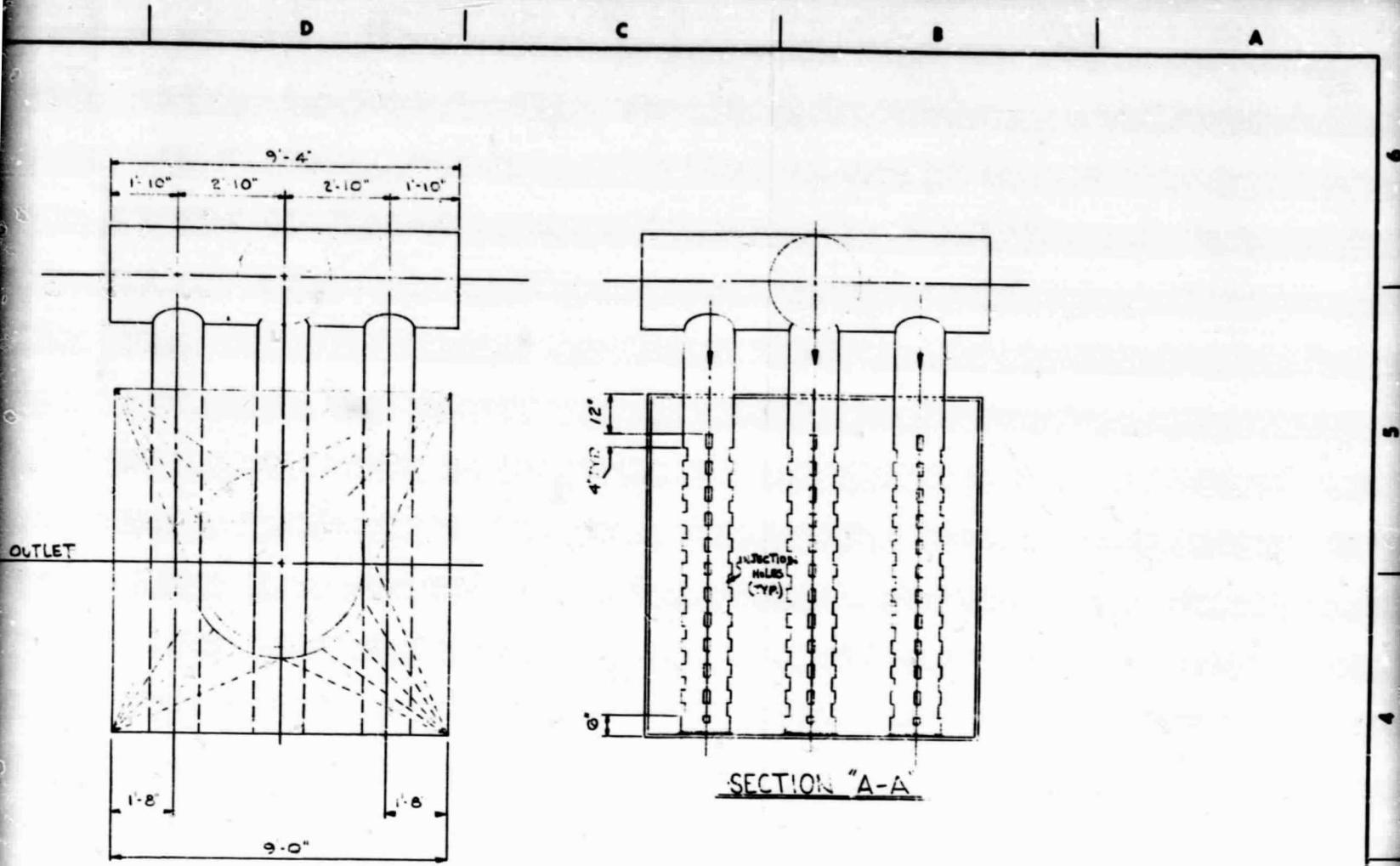
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TOP VIEW

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SIDE VIEW

SECTION "A-A"

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CIVIL ASSOC., INC.
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LePine CONSULTING
LOW TEMPERATURE PROCESSING AND EQUIPMENT
NEW YORK, N. Y.

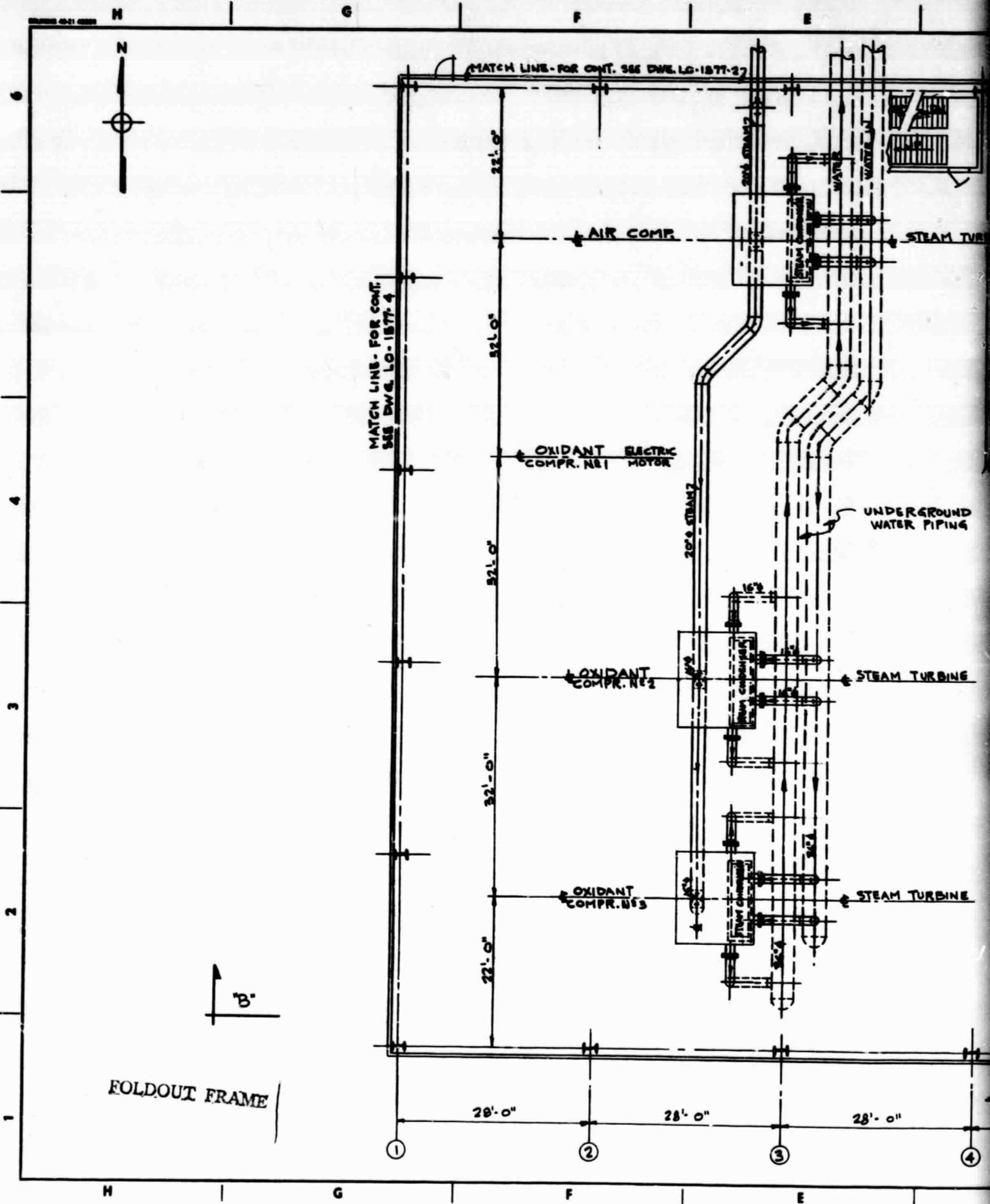
MHD ETF 200 MW_e

OXIDANT SUPPLY SYSTEM
OXIDANT MIXING CHAMBER
PLAN ELEV. & DETAILS

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DATE	3-5-81	3-5-81	3/5/81
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FORM 0-11 222



MATCH LINE - FOR CONT.
SEE DWG. LG-1877-4

MATCH LINE - FOR CONT. SEE DWG. LG-1877-27

AIR COMP.

STEAM TURBINE

OXIDANT ELECTRIC
COMPR. N#1 MOTOR

UNDERGROUND
WATER PIPING

OXIDANT
COMPR. N#2

STEAM TURBINE

OXIDANT
COMPR. N#3

STEAM TURBINE

FOLDOUT FRAME

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28'-0"

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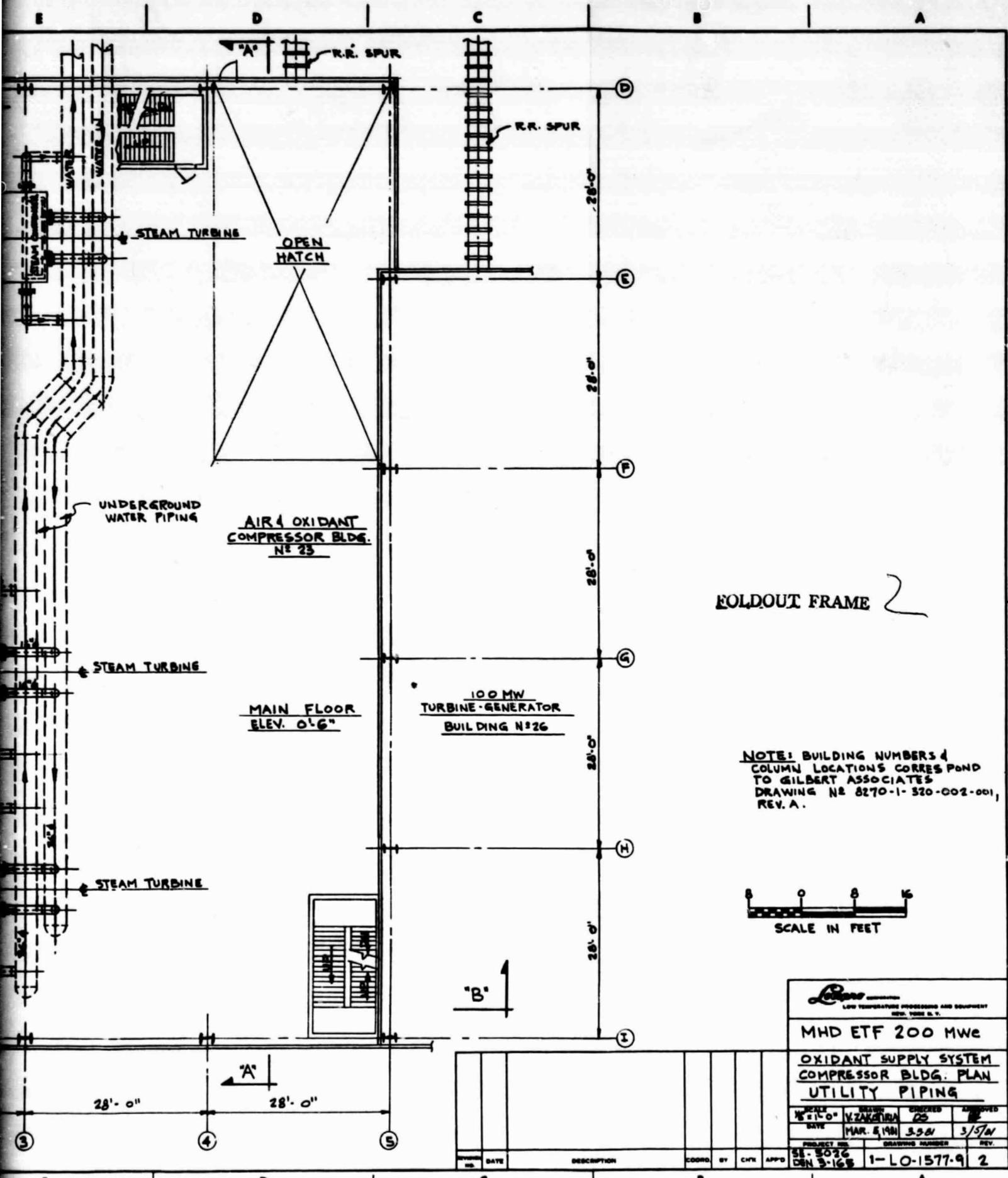
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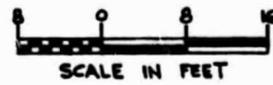
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LOW TEMPERATURE PROCESSING AND EQUIPMENT REV. 1988 U. S. A.			
MHD ETF 200 MWe			
OXIDANT SUPPLY SYSTEM			
COMPRESSOR BLDG. PLAN			
UTILITY PIPING			
SCALE 1/8" = 1'-0"	DRAWN K. ZAKHARA	CHECKED DS	APPROVED
DATE MAR. 5, 1981	3.5.81	3/5/81	
PROJECT NO. 58-5026	DRAWING NUMBER 1-LO-1577.9		REV. 2
DATE DEN 3-16-81			

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SYSTEM DESIGN DESCRIPTION

SDD-502

MHD POWER TRAIN SYSTEM

FOR

MAGNETOHYDRODYNAMICS

ENGINEERING TEST FACILITY

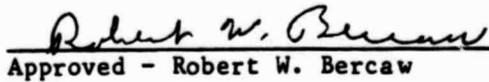
CONCEPTUAL DESIGN - 200 MWe MHD POWER PLANT


System Engineer - Thaddeus Mroz

8/11/1981
Date

Reviewed _____

Date


Approved - Robert W. Bercaw

8/20/1981
Date

Revision B

Date August 11, 1981

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
MHD POWER TRAIN SYSTEM

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reference No. 100-141-201		

August 11, 1981

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MHD ETF PROJECT
SYSTEM DESIGN DESCRIPTION
MHD POWER TRAIN SYSTEM

1.0 FUNCTION AND DESIGN REQUIREMENT

This document describes the ETF MHD Power Train System shown in Figure 1. The document includes descriptions of system functions, interfaces with other systems, equipment and piping requirements, design criteria, description of components, operating modes, and safety and maintenance requirements.

1.1 FUNCTIONAL REQUIREMENTS

The MHD Power Train System generates alternating current (AC) electrical power from the combustion of coal using the Magnetohydrodynamic process and provides the thermal input for electric power production in the steam bottoming cycle. It is the major portion of the ETF topping cycle and consists of the four subsystems schematically illustrated in Figure 1. They are:

1. The coal combustor, which produces the requisite high-velocity high-temperature plasma
2. The MHD generator which produces direct current (DC) electrical power
3. The inverter which converts the DC power to AC power compatible with the plant output requirements
4. The MHD control subsystem which maintains required conditions in the Power Train during operation.

Direct current (DC) electric power is generated in the MHD channel through the interaction of high velocity plasma with a magnetic field provided by a superconducting magnet which surrounds the channel. The electric current is collected by finely segmented electrodes in the channel walls and combined into a few current sources by consolidation circuitry. The currents from these DC sources are then inverted to alternating current for transmission by the Utility Grid.

The plasma required for power production is produced by combusting powdered coal with a pressurized oxidant and adding potassium seed to achieve adequate electrical conductivity. The high temperature needed to ionize the seed is obtained by enriching the combustion air with oxygen and preheating it to a temperature consistent with the state-of-the-art of metallic recuperators. Some excess coal is used in the combustion to limit the production of oxides of nitrogen (NO_x) by the high temperature and to provide the necessary

reducing condition in the Heat and Seed Recovery System (HR/SR) to reduce the NO_x concentration to environmentally acceptable levels prior to the release of the exhaust gas to the atmosphere.

Coal ash, released in the combustion process, flows through the Power Train with the plasma. A portion of this ash condenses as slag on the containment walls where it protects them from erosion and insulates them from the high temperature plasma. However, the ash also tends to reduce the plasma conductivity and combines with the seed, resulting in some loss of seed. Therefore, the combustor must be designed to reject a large fraction of the ash prior to the introduction of the seed.

The plasma enters the MHD channel from the combustor through a nozzle which accelerates it to the high velocity needed for power production. Its pressure, temperature and conductivity drop as it flows through the channel. The MHD energy conversion stops as the conductivity approaches zero, but the energy remaining in the gas is still satisfactory for powering the bottoming cycle. The gas is transferred for this purpose to the HR/SR System by the diffuser, which converts some of the kinetic energy of the gas into an increased static discharge pressure and meets the velocity requirements of the HR/SR.

The combustion gases lose large amounts of heat to the component pressure containment walls which must be recovered to improve plant performance. This is accomplished by cooling the components with boiler feedwater.

The design of the MHD Power Train is crucial to both the performance and cost of the entire ETF. The characteristics of the Power Train largely determine the design parameters of the Oxidant Supply System, Magnet, HR/SR, and Steam Power Train. This is a result of the close integration of the topping and bottoming cycles. Power Train design and operating parameters are established by maximizing the plant efficiency under conditions which minimize such cost drivers as compressor power, magnet length, and oxygen enrichment factor. Plant efficiency calculations include both the topping and bottoming cycle efficiencies. Established design parameters include:

1. Channel length and lofting
2. Peak magnetic field and profile
3. Channel load factor profile.

Established operating factors include:

1. Oxygen enrichment factor
2. Combustor pressure
3. Channel mach number

1.2 SYSTEM INTERFACES

Interfaces between subsystems of the MHD Power Train and plant systems are presented in Table 1 and are described in this document. Interfacing systems are described in the respective "System Design Descriptions".

1.3 DESIGN CRITERIA

Design criteria for the MHD Power Train are the system outputs, derived inputs and accompanying process, mechanical and electrical requirements which are used in the selection, sizing and design of components and to determine performance.

Engineering design criteria for all disciplines are in accordance with applicable codes, standards, regulations, and guides issued by governmental agencies and recognized standards organizations.

1.3.1 Codes and Standards

System engineering design is in accordance with applicable codes, standards, and guides issued by the following organizations:

- a. American National Standards Institute (ANSI)
- b. American Society of Mechanical Engineers (ASME)
- c. American Society for Testing and Materials (ASTM)
- d. American Welding Society (AWS)
- e. Manufacturers Standardization Society of the Valve and Fittings Industry (MSS)
- f. Pipe Fabrication Institute (PFI)
- g. Occupational Safety and Health Administration (OSHA)
- h. Instrument Society of America (ISA)
- i. National Fire Protection Association (NFPA)
- j. Combustion Institute

1.3.2 Design Parameters

1.3.2.1 Combustor Operating Parameters

The combustor operating parameters are listed in Table 2. The combustor stoichiometry was selected to provide an equilibrium NO_x value in the NO_x control furnace of the H₂/SR system which meets environmental constraints. High slag rejection is required in the combustor to reduce the loss of seed through combination with the slag and to improve plasma conductivity. The selected value is consistent with subscale experimental results. The heat and pressure loss parameters were scaled from subscale experimental results and the other parameters were calculated with the NASA Chemical Equilibrium Code using the reference coal listed in Table 3.

1.3.2.2 Generator Design and Operating Parameters

The generator design and operating parameters were selected by combining the plant performance optimization studies described in Appendix B with economic considerations which dictate the use of the minimum channel length and minimum oxygen enrichment factor consistent with good performance. The parameters given in Table 4 and Figures 2a and 2b were generated using the procedures and assumptions described in the Appendix B. The channel optimization was verified

by Gilbert Associates using their reference system model; their work is described in Appendix C.

2.0 DESIGN DESCRIPTION

2.1 Summary Description

The MHD Power Train System consists of four major subsystems and is designed as the ETF Topping Cycle producing AC electrical power and providing the thermal input for electric power production in the bottoming cycle. The system is sized for the total ETF thermal input and is designed for high temperature and high pressure operation with a specific electrical and thermal output.

Major subsystem components shown on Figure 1 are the combustor consisting of combustor and nozzle, MHD Generator subsystem consisting of channel and diffuser, the MHD control subsystem and the inverter subsystem.

Coal combustion occurs in two stages. In the first stage, coal is gasified by partial (fuel rich) combustion with a portion of the oxidant. In the second stage, the balance of the oxidant and the seed are injected to complete the required combustion at a fuel rich stoichiometric ratio and to produce the plasma required for MHD power production. The nozzle accelerates the plasma to the required velocity. The combustor is designed for maximum carbon utilization, minimum pressure drop, and minimum heat loss. All wall surfaces exposed to the combustion gases are designed to be slag coated to reduce heat loss and to protect them from erosion.

A large fraction of the ash content of the coal is continuously separated from the product gases and rejected in the first stage as liquid slag. The slag removal equipment consists of an assembly of tanks, crushers, valves and piping which are designed to maintain the combustor pressure and voltage isolation from ground. Slag drains from the combustor into water-filled tanks where it is shattered by rapid cooling. A crusher then reduces the slag to a slurry suitable for discharge to the Slag and Ash Management System.

The channel design is based on the CDIF 1A1 and 1B2 channels which are to be tested at CDIF. The channel is a diagonally connected Faraday type which incorporates segmented electrode walls and barwall insulator walls. Electrodes and barwall elements are of water cooled copper and are electrically insulated from each other. Anode electrodes are capped with platinum.

The channel design conforms to the following set of limiting operational constraints that represent existing technology for channel hardware evolved from limited endurance testing:

1. Axial electric field 2.5 kV/m
2. Transverse electrical field 4.0 kV/m
3. Transverse current density 10 kA/m² maximum
4. Hall parameter 4

Channel electrodes are segmented to limit the voltage difference between adjacent segments to less than 45 volts. Electrode segmentation length is to be set by fabrication economics and that required to limit maximum fault power to 1 kW.

The electrode consolidation circuitry matches the raw electric power from the channel to the input requirements of the inverters. This circuitry acts to control channel loading, regulate electrode currents and stabilize channel operation. This circuitry is designed to minimize electrical loss and to diagonally connect the channel while maintaining the design electrode voltage and current profiles.

The Diffuser size and divergence angle are selected to attain maximum pressure recovery needed for maximum enthalpy extraction in the channel. Diffuser cooling circuits are designed for steam generation and are integrated with the steam drum of the radiant boiler.

All surfaces of the channel and diffuser exposed to the combustion gases are designed to be slag coated to reduce heat loss and to protect them from erosion.

The inverter subsystem converts consolidated but unfiltered, DC electrical power from the MHD generator subsystem, to fixed voltage, 3 phase, constant frequency AC power and delivers it to the ETF switchyard. The subsystem regulates the DC electrical power input from the consolidation circuitry. It acts to control the DC input voltages and currents within the stated operational limits by varying the instantaneous rate at which power is converted and delivered to the output bus. It acts within its capacity to maintain operational conditions at the output bus within normal limits. It is designed to protect the power train from external electrical disturbances by disconnecting itself from the inverter bus whenever the normal limits are exceeded for an indefinite period of time, or whenever the bus emergency limits are exceeded. It protects the other electrical systems within the ETF from disturbances caused by the MHD Power train.

Cooling is required for the inverter subsystem to maintain inverter components within the design and allowable temperature operational limits. Type of coolant and degree of cooling will be determined by the component design. In the event of inverter malfunction the inverter will shut itself down and force both the DC bus current and the AC currents into the inverter bus to zero.

The MHD control subsystem controls the energy conversion processes within the MHD power train which are directly involved with producing regulated two-terminal DC power and the plasma flow rates required by power demand. This subsystem controls and regulates combustor operation and plasma conductivity by controlling coal, oxidant and seed input to the combustor for the required power level demand. The subsystem acts to control the MHD channel electrical load through sensing and measurement of the electrode power take-off currents and voltages, and the switching and modulation of active electrical control elements within the consolidation network. It also acts to regulate the flow of two terminal DC electrical power into the inverter and to connect or disconnect itself from the inverter as required.

This subsystem informs the supervisory control system (facility control system) of the status of the MHD power train and detects abnormal operation. It acts to stabilize the power train within its operational range through coordinated control of the combustor, generator, and electrical consolidation circuitry. The subsystem is designed to protect the MHD power train system. In event of abnormal operation, the control subsystem is designed to initiate corrective action within the required response time.

2.2 DETAILED DESCRIPTION

The MHD Power Train System is an open cycle, coal fired, close-coupled, single train electric power generating system.

The combustor and MHD generator subsystems are mounted in a mechanically close coupled, in-line horizontal configuration, shown on Drawing SDD-1101. The inverter and control subsystems are connected through electrical wiring and cabling.

2.2.1. Major Subsystems

2.2.1.1 Combustor Subsystem

The design of the coal combustor is based on the technology developed at 20 Mwt by the TRW Defense and Space Systems Group as part of the DOE MHD Combustor Development Program. Outline diagrams and scale-up parameters for this design were provided by TRW through the DOE Pittsburgh Energy Technology Center (PETC). The selection of this design concept was based on an evaluation by DOE of the relative merits of three alternative concepts. The DOE evaluation compared the test results at 20 Mwt, potential for scaling to large systems, and suitability for use in a commercial plant. This design provides the following advantages:

1. Relatively low heat loss and pressure drop
2. High carbon utilization
3. Effective slag rejection
4. Good operational characteristics including rapid startup and shutdown

The combustor subsystem assembly is shown on the Power Train Assembly Drawing SDD-1200. It consists of three major elements:

1. the combustor
2. the slag rejection equipment
3. the nozzle.

The combustor is a two stage unit combining two first stage combustor with one second stage combustor. Combustion gases from the first stage combustors flow toward each other, turn through 90° as they merge into one stream, pass through the second stage combustor, and discharge through the nozzle to the MHD generator. The first stage combustors gasify the coal and remove the coal ash as slag. The second stage combustor completes the combustion and produces the plasma. The plasma is accelerated by flow through the nozzle to the velocity required for electric power production.

The combustor is designed to operate at a pressure level of about 4.5 atm. The oxidiser, consisting of oxygen enriched air, is preheated to a nominal temperature of 1100° F. The fuel is Montana subbituminous coal pulverized to 70% through 200 mesh and dried to a moisture content of 5% before firing. An air/fuel overall stoichiometric ratio of 0.9 is employed for NO_x emission control.

The combustor subsystem is connected to the inlet end of the MHD generator which operates at a 30,000 volt potential above electrical ground. Therefore, it is necessary to provide electrical isolation for all combustor support members, the slag collection system, and the feed lines supplying oxidiser, fuel, seed, and cooling water.

Cooling of the combustor is required to maintain the temperature of wall materials and injectors within allowable operating temperature and stress levels at the heat load imposed on the walls and the injectors. Heat load is due to convective heat transfer from the gas to the wall, radiative heat transfer from the combination of the gas, seed and slag to the walls and the heat generated by or absorbed from coal combustion on the wall and from the slag deposited on the wall. The heat load is absorbed by high pressure boiler feedwater which is continuously circulated through cooling passages at a high velocity to provide a high coefficient of heat transfer.

Cooling water supply and discharge lines are electrically isolated from the combustor. Electrical insulator material is installed between connecting pipe flanges. A thin layer of insulating material is provided (e.g. flame spray) on the inner wall of the pipe for a short distance to minimize current conduction through the boiler feedwater.

2.2.1.1.1 First Stage Combustor

The first stage consists of a continuous cylinder containing two opposing combustor chambers mounted to discharge into a common mixing chamber. The oxidant is injected tangentially near the outer ends of each combustor to generate a vortex around the combustor axis. Pulverized coal is injected into the oxidant stream through a pintle-type assembly located on the axis of the combustor and near the inlet end. The combustor arrangement is selected for an optimum oxidant injection angle and velocity and for uniform radial mixing of the coal particles with the oxidant flow.

2.2.1.1.2 Second Stage Combustor

Fuel rich gases from the first stage are combusted with additional oxidant in second stage combustor. This raises the gases to their final temperature and establishes the final stoichiometric ratio at 0.9. The second stage combustor also serves as a plasma duct to transport the plasma to a location in the warm bore of the magnet where the magnetic field is sufficiently high for MHD power production. This process arrangement minimizes heat loss from the gases.

The length of the second stage plasma duct is determined by the residence time needed to complete the combustion and produce a straight flow having homogeneous temperature and conductivity.

The interior surface of the plasma duct is insulated with a slag layer condensed from the slag carryover from the first stage.

2.2.1.1.3 Nozzle

A flanged convergent nozzle connects the second stage combustor plasma duct and the channel inlet. The nozzle is designed for subsonic Mach Number discharge. Its length is determined to minimize pressure drop and heat loss, and the design includes the insulating effect of a layer of slag on its walls (slagging operation). The flow path cross-section is square and the discharge flow dimensions conform to those of the channel inlet. Cooling is provided by circulating high pressure boiler feedwater through internal cooling passages.

2.2.1.1.4 Slag Rejection Equipment

The conceptual design of the slag rejection equipment was prepared by the NASA MHD-ETF Office.

The slag rejection equipment assembly receives molten slag at combustor pressure from the combustor slag taps, cools it, reduces it to a slurry consistency and transfers it to the slag and ash management system. These functions are performed without perturbing combustor operation. They are accomplished through use of a sequential valve operation. The assembly consists of three quench tanks, three first stage slag collection tanks, a single second stage slag collection tank, slag crushers, valving, and electrical isolators.

Electric isolation is provided between the first and second stage collection tanks, at the discharge of the second stage collection tank, and in the service air and water lines. Fiberglass epoxy electrical insulation with sufficient dielectric strength is installed between flanges in the air supply lines; flexible insulating hose, is installed in the water lines. Electric isolation is also provided at the interface of the second stage slag collection tank legs and pit floor.

All equipment is designed for operation at combustor pressure. The tank sizes, integration with the combustor, and configuration are shown on Drawing SDD-1200. The structural support is shown on Drawing SDD-1102.

During operation, the first stage collection and quench tanks are filled with water to the over-flow outlets of the quench tanks and the second stage tank is empty. Cooled and filtered water is continuously circulated through the quench tank. The quench water temperature is maintained in the range of 160-180° F to limit the water vapor pressure and thus avoid the entry of water vapor into the combustor.

Slag is collected with the isolation valves between the quench tanks and first stage collection tanks in the open position, and the discharge valve on the first and second stage collection tanks closed. The second stage tank is at atmospheric pressure and at combustor Hall voltage potential. Hot slag falls into the quench tank and is shattered into small pieces by the stresses induced by thermal shock. The slag pieces fall into the crusher and are reduced in size to a slurry consistency. The slag pieces fall into and accumulate in the first stage slag collection tank. At a predetermined slag content, the first stage tanks are isolated from the quench tanks and discharged into the second stage tank raising its pressure to about two atmospheres. The valves between the first and second stages are then closed, and the valves between the quench and first stage tanks are reopened to permit the further collection of slag. The intertank insulator is rinsed and heated by spraying it with clean water at about 240° F. The residual moisture on the insulator evaporates upon venting the second stage tank allowing the insulator to stand off the full Hall voltage. The second stage tank is then electrically grounded and the slag slurry is discharged to the Slag Management System. The discharge valve is closed when the tank is empty and the insulator on the discharge line is cleaned with a hot water spray. This restores the equipment to its initial state. Controls, valves and crushers are pneumatically operated.

2.2.1.1.5 Structural Support

The combustor and slag rejection equipment are supported by a structure which stands on the pit floor. Details are shown on Drawing SDD-1102. The support structure is electrically isolated from ground by installation of dielectric material such as fiberglass epoxy between flanges in the structure support columns as shown on Drawing SDD-1102. This material has high compressive strength and a dielectric strength rating of approximately 400 V/mil. A few inches thickness of insulation has a standoff capability several times the anticipated potential.

2.2.1.2 MHD Generator Subsystem

The system consists of the channel, the power takeoffs, the consolidation circuitry, and the diffuser. The MHD generator is shown on Drawings SDD-1300 and 1301. The mechanical and electrical design of the MHD generator is based on the design contained in the Avco "ETF Conceptual Design" report, Reference FE-2614-2. It also incorporates the following modifications recommended by the Avco technical staff:

1. Extend the electrode structure to regions of magnetic fields of less than 0.5 Tesla to prevent electrical shorting of the Hall potential.
2. Reduce electrode segmentation from 100 electrodes/meter to 58 electrodes/meter.
3. Reinforce the primary structure of the channel with external trusses.
4. Provide current consolidation of transverse anode segments to limit fault power dissipation to approximately 1 kW.
5. Utilize the diffuser for steam generation

2.2.1.2.1 Channel Structure and Assembly

The active channel section is defined as that portion lying between the magnetic field values of 4 Tesla at the entrance and 3.5 Tesla at the exit. Within the active section, the channel is of the diagonally-connected Faraday type which incorporates segmented electrode walls and bar-wall insulator walls. Channel inlet and outlet flanges are located in a magnetic field of less than 0.5 Tesla to minimize power loss and potential damage to the nozzle and diffuser from axial circulating currents induced by the Hall potential. Inlet and outlet sections lie between the active section and the end flanges. These sections are fabricated window frame elements which are insulated from each other.

The channel active section is constructed of four 10-foot long modules to simplify fabrication and assembly. The modules are joined by tie bolts and joints are sealed with RTV Silicon rubber. Each module consists of a four-wall assembly. The top and bottom walls consist of water cooled electrode assemblies mounted on electrically insulating backboards fabricated of epoxy impregnated, continuous-filament glass cloth laminations. The side walls are constructed of water cooled bars mounted on similar backboards. Details of the electrodes and insulator bars are presented in the next section.

The backboards are structural elements and their assembly provides the pressure containment for the plasma as it flows through the channel. The assembly is reinforced and supported over its entire length by a truss type structural sections as indicated in Drawing SDD- 1300. The sections are mounted on all four sides of the channel and are bolted to each other to maintain the walls in compression. The truss assemblies also provide a means of supporting the coolant lines and electric cabling and a means of handling the channel and supporting in magnet warm bore.

The active section of the channel is bolted to the inlet and outlet channel sections which are flanged for attachment of the nozzle and the diffuser. Each of these sections are approximately five feet long and assembled from copper window frames which have diagonal angles corresponding to the local equipotential lines. Each window frame is insulated from its neighbors to avoid shorting the Hall potential.

The channel/structure assembly fits within the warm bore of the magnet and is designed for efficient packaging to minimize the warm bore cross section and for rapid installation and removal of the channel. The channel coolant water manifolding and electrical power take-off cables are mounted and supported within the open trusswork of the channel support structure. Electric cables are bundled to minimize space requirements. The channel/support structure assembly is supported by rails mounted in the rectangular magnet warm bore. Rollers are provided for removal and installation of the channel/support structure assembly.

2.2.1.2.2 Electrode and Insulator Walls

The electrode design concept was developed in the Avco Mk VI and Mk VII Component Development Program. It is characterized by low anodic oxidation rates, high interelectrode-gap breakdown strengths, and low thermal stresses. It effectively quenches anode interelectrode arcs and minimizes arc damage.

The channel is of the diagonally-connected Faraday type. The electrodes are segmented to limit the voltage difference between adjacent segments to less than 45 volts. The insulator walls are of the bar-wall type with short electrically-conducting bars approximately aligned along the diagonal equipotential lines and insulated from each other. The electrodes and bar-wall elements operate with a surface temperature of only a few hundred degrees

Fahrenheit and have a high thermal conductivity to help control arcs. The walls are designed to retain a continuous slag layer which covers them to a depth of approximately 2 or 3 mm. The slag layer acts as a renewable barrier between the plasma and the wall elements and reduces the heat loss from the plasma. Its surface temperature is approximately 2800° F.

The electrodes and the method used for their assembly are shown in Figure 3. Electrodes are fabricated from suitable lengths of OFHC copper bars, 1.0 inches thick, 0.602 inches wide. Each electrode consists of four transverse segments. This segmentation is selected to limit the maximum power of any interanode short to approximately one kilowatt and limits the longest segment to 14 inches (at the channel exit). The cathode electrodes are protected with a full-width, 0.125 inch thick copper-tungsten cap brazed onto the copper substrate. The anodes are protected by a 0.010 inch thick platinum cap that also covers the upstream edge. The anode upstream corner is reinforced by an 0.080 inch square platinum strip. Each electrode incorporates a water cooling passage along its axis. The passage is plugged at the ends, and the coolant enters and exits through connectors brazed to back of the electrode.

The electrode walls are assembled by bolting the electrodes to the insulating backboard with the coolant connectors projecting from the back of the backboard. A mica thermal barrier is placed between the electrodes and the backboard. All holes are sealed with RTV silicone rubber. Electrodes are insulated from each other by 0.075 inch thick boron nitride sheet. The sheet is recessed slightly below the surface of the electrodes and the resulting groove is filled with castable alumina. This provides effective slag attachment to enhance the formation of a stable slag layer. The alumina also protects the boron nitride from thermal shock resulting from any arcing and reduces the heat loading to the insulator.

The sidewalls consist of assemblies of segmented diagonal copper bars separated by boron nitride or alumina insulators mounted on backboards. The construction of the bars is similar to that of the electrodes. However, the bar life is considerably longer than the life of electrodes and elaborate surface protection is not required. Figure 4 illustrates the design of bars for the CDIF 1A1 channel.

2.2.1.2.3 Channel Cooling

All electrodes and bar walls elements are water cooled. A parallel-series manifold system, with flow regulating orifices on the supply side, provides a coolant flow to each element approximately proportional to the heat transport to it and prevents local flow starvation. Flexible hoses are used to connect the elements to the manifolds to provide voltage isolation. The material limitations of these hoses limits the coolant temperature to 280° F and the pressure to 250 psia. The channel is cooled by low temperature boiler feedwater in order to recover the heat lost to the channel walls. Feedwater is

taken directly from the deaerator and is discharged to the low-pressure economizer. All copper cooling passages are nickel plated to provide compatibility with the materials used in the turbines and the balance of the steam and boiler water systems.

2.2.1.2.4 Generator Power Takeoffs

The generator power takeoffs are a collection of electrical cables and connectors that transfer electrical current between the channel electrodes and the consolidation network located adjacent to the MHD generator.

The active channel section contains 704 anode and cathode electrode pairs. Each electrode consists of four (4) segments of equal current rating. Individual segments are either connected directly together within the warm bore, or insulated from each other through first and second stages of consolidation as required to meet the fault power-dissipation limit. In the high current region of the generator, individual power takeoffs are provided for each segment of every anode. In the low current region, anode segments are paired and a power takeoff is provided for each pair. A single power takeoff is provided for each cathode electrode since it is segmented only for mechanical purposes and the segments are internally connected.

Each power takeoff consists of a single high-voltage insulated cable with electrical connectors at each end. A spade lug is provided for each electrode termination and one mating connector is provided per cable bundle at the consolidation network interface. Individual power takeoff cables and their terminations have a maximum two volt drop at rated current and are designed for continuous operation at 280° F.

Power takeoff cables are bundled in groups corresponding to generator electrode consolidation groups. Each bundle contains the power takeoffs from one anode consolidation group and from its corresponding cathode consolidation group. Because the currents from each group are nominally equal and in opposite direction, the net magnetic force on each bundle is small. Eighty-eight (88) cable bundles are provided. Twenty-four (24) of these bundles lead out of the magnet warm bore from the combustor end and the remaining sixty-four (64) bundles exit from the diffuser end. Table 5 provides the details of organization of the generator power takeoffs. Each bundle is bound so that it will not separate in the magnetic field at current up to twice the design rating. Each bundle in its sheath is sufficiently flexible to be bent into curves of four foot (4 ft) radius or less, by one man. The voltage difference between cables within each bundle is less than 5 kV.

2.2.1.2.5 Consolidation Network

The 704 anodes and 704 cathodes along the channel length are characterized by unique voltages and currents. The function of the consolidation network is to organize and combine the currents into a high voltage DC current source requiring only one common positive terminal and six negative power terminals for connection to the inverter. The network is designed to provide Faraday loading of the channel electrodes while diagonally connecting them to take advantage of the Hall potential and thus provide power at the highest possible voltage. The circuit design is based upon consolidation networks developed by Avco-Everett Research Laboratory, Inc.

The consolidation network allows the inverter to load the generator. It acts to maintain the electrode voltage and current profiles established by the generator design. It regulates the current distribution among the power takeoffs within established limits. It stabilizes the generator by damping, reducing or otherwise suppressing electrically excited upsets to the process conditions within the channel. It protects the generator by preventing electrode voltages and currents from exceeding safe limits and by dissipating excessive power concentrations within the generator arising from faults, upsets or overloads. It acts to present a stable direct current source to the inverter under all conditions. It senses the power takeoff voltages and currents, and relays this information to the power train control system.

The 704 anodes and 704 cathodes are consolidated by groups of eight each into two sets of 88 groups as indicated on Drawing SDD-1501. A cathode group is consolidated by cascading three consolidation stages. Each stage combines two current sources into a single one having a current equal to their arithmetic sum and a voltage equal to the current weighted average of their voltages. This relationship also holds when several stages are cascaded to combine a larger number of sources. Thus, each group represents a source providing the current from eight electrodes at a voltage equal to their current weighted average.

The consolidation circuitry is designed to prevent excess current concentrations due to interelectrode faults by maintaining the current ratios between the source electrodes. The problem is the most severe for the anodes because anode faults tend to persist. Therefore, each anode electrode is electrically subdivided into either two or four segments and the current from the segments are combined by one or two additional stages of consolidation.

The interconnection of the eight-electrode consolidation groups is shown on Drawing SDD-1501. The generator is diagonally connected by connecting the anode and cathode consolidation groups as shown (i.e. an anode group is connected to the cathode group having the same number). Power terminals are created by further consolidating sets of 8 or 16 groups. The current and voltage values of the terminals are adjusted to match the channel design profiles for current and voltage.

Drawings SDD-1502 and SDD-1503 illustrate respectively the five and three stage consolidation networks for groups of eight anodes (for the high voltage portion of the channel) and cathodes. Each stage of consolidation consists of two separate sets of autotransformer coils and four blocking diodes. The coil sets are wound opposite hand on the same core to utilize their mutual inductance properties. The diodes prevent current backflow from one coil set to another. The stage combines two different voltages and currents by admitting them into opposite legs of each of the coils. The windings of the legs are proportional to the inverse ratio of the currents which are desired. Since the source with higher voltage would increase its current with time and cause the current from the other source to decrease, the currents are switched from one coil set to the other periodically so that, because of the flux linkages, the current which decreases during one conducting phase is restored during the next phase. Switching frequencies range from 200 Hz to 1 kHz. For each phase the current that emerges from the common tap is the arithmetic sum of the currents from each coil leg. The voltage is the average of the two sources, weighted by their current distribution. This relationship also holds when several stages of consolidation are used to combined larger numbers of sources. Switching from one phase of current flow to the other is performed by a thyristor network at the end of the final consolidation stage.

The interface between the consolidation network and the power train control system is presented in Drawing SDD-1500. The network is mounted on racks. Patch panel connectors are provided to mate with connectors on the power takeoff cables and busbar connections are provided for the output. The equipment will occupy approximately 5000 square feet of floor space adjacent to the powertrain and magnet.

The consolidation network has a low conversion loss and is suitable for operation within fixed magnetic fields of up to 0.25 Tesla in an environment equivalent to NEC Class 2, Division 1 (Group F). The autotransformers are air cooled and dissipate on their aggregate approximately 500 kW. Their maximum service temperature is 185° F (85° C). The semiconductor components dissipate up to 2000 kW and are cooled by a forced air system. 240 v AC electric service is also required. Equipment uniform floor loading will not exceed 250 pounds per square foot. Fencing or other personnel protection must be provided commensurate with the voltage hazard.

2.2.1.2.6 Diffuser

The function of the diffuser is to contain and efficiently decelerate the high velocity gas exiting from the MHD generator channel, and provide acceptable gas entry conditions to the HR/SR system. This requires that the gas be decelerated to a velocity of 300 fps and 1 atm pressure as it enters the radiant furnace of the HR/SR.

The geometry selected for the diffuser is based upon the limited data available for diffuser performance with nonsymmetric flows having relatively thick boundary layers. The design consists of a square two-dimensional diverging duct with plane walls having a wall half-angle of two and one half (2 1/2) degrees. Diffuser length and divergence angle are selected for maximum pressure recovery factor. The diffuser is constructed in three longitudinal sections and consists of an outer pressure vessel fabricated from 1/4 in. steel plate with cooling tubes welded to its inside surface. Structural stiffener beams, welded to the outer surface of the diffuser, provide rigidity and support. The upstream section of the diffuser is located in a region of relatively high magnetic field. This section is made from non-magnetic materials. The outer wall is stainless steel and the cooling tubes are Inconel 600. For channel removal this section is disconnected from the channel and remainder of the diffuser. The remaining downstream sections of the diffuser are fabricated from conventional carbon steel. The cooling tubes are designed to be coated with a slag layer and are designed for steam generation. The diffuser cooling water circuit is integrated with the steam generating circuitry of the HR/SR boiler.

The diffuser incorporates a transition section between it at the HR/SR to accommodate thermal expansion and other relative motions of the two systems in all three directions. The transition section is of the same construction as the diffuser.

The transition section is bolted to expansion joints at the diffuser outlet flange and at the inlet to the HR/SR.

The diffuser is mounted on a support structure which incorporates rollers to accommodate horizontal/axial movement and hydraulic actuators to maintain vertical alignment.

2.2.1.3 Inverter Subsystem

The inverter design is described in System Design Description 505.

2.2.2 Piping and Valves

Piping and valves are required for:

1. Coal, oxidant and seed supply lines
2. Water coolant lines for Combustor and MHD Generator Subsystems
3. Gas sampling lines

Piping and valves conform to applicable ANSI and ASME code standards.

2.2.3 Electrical

Motor-operated valves are 460 volt, 3 phase, 60 Hz, with power supplied from the 480 volt motor control centers. Solenoid valves will be coordinated with instrumentation power sources.

2.2.4 Instruments, Controls and Alarms

Drawing SDD-1500 shows the relationship of the MHD control subsystem to the Facility Supervisory Control System, the Inverter and its controller, components of the MHD Power Train, and the coal, oxidant and seed feeds.

The function of the control subsystem is to regulate the energy conversion processes within the power train that are directly involved with producing regulated DC electrical power from the pulverized coal, oxidizer, seed, and magnetic field inputs. It performs this function by modulating the flow of pulverized coal, oxidant and seed, and by controlling the DC bus voltages through the inverter subsystem.

The MHD control subsystem does not include inverter control functions, except to provide DC bus voltage reference signals. It does not include control of coolant flow to the components. This is performed by controls in the supervisory control system associated with the bottoming plant. It does not initiate power train startup or normal shutdown sequencing, although it has emergency shutdown sequencing. It responds to the presence or absence of flame in the combustor but does not control ignition.

The MHD control subsystem maintains the combustor firing rate at the value commanded by the supervisory (facility) control system. It maintains combustor stoichiometry at a setpoint determined by the supervisory control system. This is accomplished through open loop modulation of the oxidant inlet based on firing rate command, and closed loop oxidant inlet trim signals from the supervisory control system, which are based upon measurements of flue gas composition in the boiler. The control subsystem controls the rate of seed input to maintain plasma conductivity within predetermined limits by measuring the static pressure profile within the plasma duct, and the MHD channel electrode voltage and current profiles. The control subsystem regulates generator loading by setting the DC bus voltage reference maintained by the inverter and the switching and modulation of active electrical elements within the consolidation network.

The control subsystem stabilizes the power train within its operational range through coordinated control of the combustor, seed injection, consolidation network, and DC bus voltage.

It informs the supervisory control system of the operational status of the power train and provides data concerning the process conditions. It allows the operator, through the supervisory control system, to control the thermal and electrical output power levels of the powertrain. It allows the power train to be operated under all design modes of operation, but does not initiate these modes.

It issues alarms and shuts down those portions of the powertrain within its control to protect the powertrain and facility from damage, and the operators from injury.

The control subsystem performs corrective actions and issues alarms if the pre-determined limits of conductivity are not met or are exceeded.

The control subsystem is an assembly of electronic control circuits instruments and alarms mounted in a control cabinet and connected by signal cables to input sensors, output actuators and the supervisory control system. It is located adjacent to the consolidation network, and requires a clean environment whose temperature does not exceed 120° F. Required floor space will not exceed 100 square feet and the floor loading is nominal.

3.0 SYSTEM PROTECTION AND SAFETY PREVENTIONS

3.1 PROTECTIVE DEVICES

Protective devices are installed to protect the system from operation beyond the limits prescribed by the manufacturer.

3.2 HAZARDS

Installation of the MHD Power Train presents a hazard to personnel. Not only does a serious hazard exist from the magnetic field of the magnet but the power train high operational voltage requires isolation from personnel. Additionally very high temperatures exist within the equipment and in event of equipment failure personnel in the area could be affected.

3.3 PRECAUTIONS

The manufacturers operating and maintenance instructions must be followed for this high technology system.

4.0 MODES OF OPERATION

4.1 STARTUP

The MHD power train system shall be designed for startup from the following plant conditions:

1. Cold standby
2. Warm standby
3. Hot standby

Startup sequence and procedures from cold standby to normal plant operation, progress through and encompass the plant conditions identified for the warm, hot standby and hold conditions. The startup sequence of the MHD power train system from the cold standby condition to normal operation will take place in three phases:

1. Preheat
2. Transition to coal firing at minimum stable power level
3. Ramping to part/full load steady state normal operation.

The following plant conditions are assumed at the initiations of startup:

1. Magnet de-energized in superconducting state (4.5 K)
2. Air separation unit in cold standby condition. Liquid oxygen storage tanks full
3. Bottoming cycle at cold standby conditions
4. Auxiliary steam system operating
5. All facility systems in operational status per plant startup sequence
6. Coolant water circulating through the plant (including the power train system)
7. Walls of the power train system components are slag coated from previous operation
8. Oil-fired vitiated air preheater in operational readiness.

Preheat

1. Using the motor driven oxidant compressor, the power train system and HR/SR is purged with cold airflow at 10% of rated flow.
2. Operation of the vitiation oxidant preheater is initiated, with continuing air flow through the power train system. The firing rate and diluent air flow to the preheater is adjusted to the designated preheat temperature, determined by the allowable limits of the HR/SR components such as the heating rate of the steam drum and temperature limits on the oxidant heater and the superheater/reheater.
3. Preheat rate increases to 10% of rated plant heat input until steam is being generated and the steam turbine is rolling and synchronized. The firing rate of the vitiation oxidant preheater is reduced as the intermediate temperature oxidant heater brings the oxidant temperature to the design value. The oxidant enrichment is adjusted during this time to maintain the desired oxygen levels at the outlet of the preheater.

Transition to Coal Firing

1. Coal firing may be initiated when steam conditions are established in the HR/SR for startup and operation of a steam driven air compressor, and the following systems are in operational standby condition:

Coal management system
Seed management system
Slag rejection equipment
Air separation unit

2. Air flow to the combustor is increased gradually to 25% of the design flow while maintaining preheat temperature. The preheater firing rate is increased to raise the discharge preheat temperature to 1500° F (or as required by the combustor designer for coal startup). Coolant water circulation is initiated to the slag rejection quench tanks. Oxygen is added to the air and is adjusted to the level required for initial startup.
3. Coal injection is initiated in the combustor. Ignition is verified and combustion temperatures are monitored until stable combustion and required preheat of combustor walls is established. Operation of the vitiated air preheater continues until design oxidant temperature and oxygen concentration is available from the oxidant supply system.
4. The firing rate is adjusted to establish the second stage exhaust gas temperature to that required for seed vaporization. Seed injection is initiated and adjusted to the level required for the coal flow rate. Conductivity of the plasma is verified.

Ramping to Normal Operation

The magnet is energized and inverter system is placed into operation. All operational conditions are monitored. When the design magnetic field level is established and system is operating steady state at 25%, the combustor firing and seed injection rates are increased per the plant startup schedule to the required operational level.

After startup, the MHD power train system will be operated in an automated mode. Its operation will be controlled and will be sequenced to the overall ETF established operational requirements and procedures.

4.2 NORMAL OPERATION

The normal load range of the MHD Power Train System is categorized as baseload with very little part load operation below 75 percent. The system operates in a fully automated mode and is capable of operating satisfactorily in event of load change. During normal operation the system is controlled and monitored from the plant control room.

4.3 SHUTDOWN

In a normal controlled shutdown the combustor firing demand and output power will be reduced at a rate consistent with the shutdown requirements established for the ETF. During the shutdown procedure, system operational parameters are closely monitored. Water coolant is continuously circulated through the components.

At conclusion of power production, and/or at the limit of stable combustor operation fuel input is terminated, and oxygen enrichment is terminated in that order. The system is purged with air to remove unburned gaseous fuel.

4.4 SPECIAL OR INFREQUENT OPERATION

No special or infrequent operational modes have been identified.

5.0 MAINTENANCE

The system is designed to accommodate in-place inspection, maintenance, repair and parts replacement without removal of major components to the greatest possible extent, commensurate with the complexity and packaging restraints of the installation. Although convenient access is provided to the combustor and diffuser, limited access is available to those parts within the warm bore because of its small size and the space needed for the large number of pipes and cables which connect the channel to the other elements of the plant.

Maintenance documentation is provided for each subsystem and its components. The documentation contains recommended maintenance schedules, lists of recommended spare parts, detailed maintenance, replacement and check-out procedures, pictorial illustrations, a listing of special tools, handling requirements and personnel safety requirements for each operation. These instructions also indicate the requirements imposed upon each operation by other components, subsystems or systems.

The documentation is coordinated with mean-time to failure and mean-time to repair data, and manhours required for each procedure to assist plant management in planning for specific operations during scheduled and unscheduled plant outages.

5.1 SURVEILLANCE AND PERFORMANCE MONITORING SYSTEM

A computer system monitors significant data points in the MHD Power Train System in parallel with the automatic controls. This will alert plant operating personnel to any off-design performance or operation. Periodic calibration and maintenance will be carried out on all analog and digital instrumentation to verify computer readout.

5.2 IN-SERVICE/IN-SITU INSPECTIONS

All components piping, valves, controls gauges, etc., will be inspected on a scheduled basis to ascertain that the equipment is not damaged and is functioning properly.

5.3 PREVENTATIVE MAINTENANCE

Computerized record keeping will be maintained to inform the operators that certain components and component parts require periodic overhaul, replacement, adjustment, etc., in accordance with the recommendations of the component manufacturer. In general, the preventative maintenance will be conducted during planned shutdowns. Parts will be replaced at these times if they are near the end of their recommended operational life cycle.

5.4 CORRECTIVE MAINTENANCE

5.4.1 Manufacturers' Instructions

A design and operation manual for the system and specific component manuals will be available at the plant for maintenance and overhaul of any piece of equipment. If necessary, a representative of the manufacturer shall be present to supervise the overhaul or replacement of plant equipment.

5.4.2 Spare Parts Inventory

An inventory of spare parts shall be maintained. The inventory shall be based upon criticality, expected life of the parts, and the time to acquire spare parts from suppliers.

Table #1

MHD POWER TRAIN SYSTEM/FACILITY SYSTEMS INTERFACE

<u>MHD Subsystem</u>	<u>Facility Systems</u>	<u>Function of Facility Systems</u>
Combustor Subsystem	Coal Management System	Provides inerted, dried and sized coal to the combustor subsystem inlet at a regulated pressure and mass flow rate for the required operating power level and equivalence ratio. (Includes flow isolation valves and pressure and flow regulating equipment.)
Combustor Subsystem	Heat & Seed Recovery Systems	Provides oxidant to specifications to the combustor subsystem inlet at a regulated pressure, temperature and mass flow rate for the operating power level and equivalence ratio. (Includes isolation valves and pressure, temperature and flow regulating equipment.)
Combustor Subsystem	Seed Management System	Provides potassium seed per specifications to the combustor subsystem at a regulated pressure and mass flow for the required power level. (Includes flow isolation valves and pressure and flow regulating equipment.)
Combustor Subsystem	Slag Management System	Accepts processed (quenched and crushed) slag from the combustor subsystem for disposal and/or further processing.
Combustor Subsystem	Boiler Feedwater System	Provides coolant water to combustor subsystem per specifications at regulated pressure, temperature and mass flow rate for required power level. (Includes flow isolation valves and pressure, temperature and flow regulating equipment.)
MHD Generator Subsystem	Condensate System	Provides coolant water to channel per specifications at regulated pressure, temperature and mass flow rates for required power level. (Includes flow isolation valves and pressure, temperature and flow regulating equipment.)

Table #1 (continued)

<u>MHD Subsystem</u>	<u>Facility Systems</u>	<u>Function of Facility Systems</u>
MHD Generator Subsystem	Magnet System	Provides operational magnetic field profile and 6 Tesla magnetic field strength to MHD generator requirements. Provides a mounting platform for the MHD channel within the warm bore.
Inverter Subsystem	Coolant Supply Systems	Provides coolant (liquid or air) to required components at regulated pressure, temperature and mass flow rate for required power level. (Includes required flow isolation valves and pressure, temperature and flow regulating equipment.)
Inverter Subsystem	Plant Switchyard	Transmits regulated AC electric power from the inverter subsystem to the utility power grid.
Control Subsystem	Facility Control System	Integrates the output from MHD control subsystem with regulated overall power plant operational control and protection.

Table #2

COMBUSTOR SUBSYSTEM OPERATING PARAMETERS

A. Thermal input	531.9 MW _t
B. Fuel	Coal, Montana Rosebud, 5% moisture as fired
1. Flowrate	165,622 #/hr
2. Inlet pressure	71 psia (nominal)
3. Inlet temperature	150° F
C. Oxidant	Air enriched with oxygen to a total of 30% by volume
1. Flowrate	867,852 #/hr
2. Inlet pressure	71 psia nominal
3. Inlet temperature	1100° F
D. Seed	Potassium, 1% nominal of channel flow
1. Flowrate	21,230 #/hr
2. Inlet pressure	71 psia nominal
3. Inlet temperature	150° F
E. Slag Rejection	65%
1. Flowrate	11,523 #/hr
F. Nozzle Outlet	
1. Stagnation temperature	4380 F (nominal)
2. Static temperature	4140° F (nominal)
3. Stagnation pressure	58 psia (nominal)
4. Static pressure	37 psia (nominal)
5. Mach number	0.9
6. Plasma velocity	2650 ft/sec (nominal)
G. Operating Life	
1. Combustor	8000 hours
2. Slag rejection equipment	31 years
H. Heat Loss (combustor plus nozzle)	25 MW _t (nominal)
I. Coolant	Treated high pressure boiler feed water
1. Flowrate	1,070,992 lb/hr
2. Inlet temperature	530° F (to combustor)
3. Outlet temperature	592° F (outlet from nozzle)
4. Inlet pressure	2100 psia (nominal)

Table 3

ETF COAL PROPERTIES

COAL RANK: Subbituminous B

	Weight Percent <u>as Received</u>
<u>Proximate Analysis:</u>	
Moisture	22.7
Volatile Matter	29.4
Fixed Carbon	39.2
Ash	8.7
	<u>100.0</u>

	Weight* Percent <u>as Received</u> (base)	Weight Percent <u>as Fired</u> (derived)	Weight Percent <u>Dry</u> (derived)
<u>Ultimate Analysis:</u>			
Carbon	52.13	64.0666	67.4385
Hydrogen	3.46	4.2523	4.4761
Oxygen	11.36	13.9612	14.6960
Nitrogen	0.79	0.9709	1.0220
Sulfur	0.85	1.0446	1.0996
Ash	8.71	10.7044	11.2678
Moisture	22.70	5.0000	0.
	<u>100.00</u>	<u>100.0000</u>	<u>100.0000</u>
Higher Heating Value, Btu/lb	8,920	10,962.5	11,539.5

	Weight Percent
<u>Ash Analysis:</u>	
SiO ₂	38.68
Al ₂ O ₃	17.80
Fe ₂ O ₃	5.25
TiO ₂	0.72
P ₂ O ₅	0.41
CaO	11.32
MgO	4.12
Na ₂ O	3.19
K ₂ O	0.51
SO ₃	18.00
	<u>100.00</u>

Initial Deformation Temperature, °F	2,190 + 230
Softening Temperature, °F	2,230 + 240
Fluid Temperature, °F	2,280 + 240

Table #4

MHD GENERATOR DESIGN AND OPERATING PARAMETERS

A. Channel Inlet

1. Stagnation temperature	4380° F (nominal)
2. Static temperature	4140° F (nominal)
3. Stagnation pressure	58 psia (nominal)
4. Static pressure	37 psia (nominal)
5. Mach number	0.9
6. Plasma velocity	2650 ft/sec (nominal)
7. Mass flow	1,048,569 #/hr
8. Heat rejection from MHD Channel	23 MW _t (nominal)

B. Channel Outlet/Diffuser Inlet

1. Stagnation pressure	14.0 psia (nominal)
2. Static pressure	9.0 psia (nominal)
3. Mach number	0.88
4. Velocity	2440 ft/sec (nominal)
5. Stagnation temperature	3760° F (nominal)
6. Static temperature	3500° F (nominal)

C. Channel active length 40.0 ft (nominal)

D. Channel overall length, flange to flange 50.0 ft (nominal)

E. Channel cross section
square
entrance - 2.04 ft
exit - 4.66 ft

F. Channel operational life, minimum 2000 hours

G. Magnetic field, peak 6 Tesla

H. Diffuser outlet

1. Flowrate	1,048,569 #/hr
2. Pressure	13.0 psia
3. Temperature	3500° F (nominal)

I. Diffuser pressure recovery coefficient 0.46

J. Diffuser operational life 30 years

K. Heat rejected from diffuser walls
and transition section 26 MW_t (nominal)

L. Diffuser length 40 ft (nominal)

M. Gas dynamic cross-section

inlet	22 ft ² nominal
outlet	64 ft ² nominal

Table 5

GENERATOR POWER TAKEOFF CABLING AND HARNESS ORGANIZATION

<u>Cable Bundle</u>	<u>Electrode Assemblies Served</u>	* <u>Warm Bore Exit End</u>	<u>Number and Gage of Anode Cables</u>	<u>Number and Gage of Cathode Cables</u>	<u>Number of Receptacle Pins</u>
1	1 - 8	c	32 - # 14	8 - # 6	40
2	9 - 16	c	32 - # 14	8 - # 6	40
3	17 - 24	c	32 - # 14	8 - # 6	40
4	25 - 32	c	32 - # 14	8 - # 6	40
5	33 - 40	c	32 - # 12	8 - # 4	40
6	41 - 48	c	32 - # 12	8 - # 4	40
.					
24	185 - 192	c	32 - # 12	8 - # 4	40
25	193 - 200	d	32 - # 12	8 - # 4	40
26	201 - 208	d	32 - # 12	8 - # 4	40
.					
44	313 - 320	d	32 - # 12	8 - # 4	40
45	321 - 328	d	16 - # 10	8 - # 6	24
46	329 - 336	d	16 - # 10	8 - # 6	24
.					
58	457 - 464	d	16 - # 10	8 - # 6	24
59	465 - 472	d	16 - # 12	8 - # 8	24
60	473 - 480	d	16 - # 12	8 - # 8	24
.					
88	697 - 704	d	16 - # 12	8 - # 8	24

*Key: c = combustor

d = diffuser

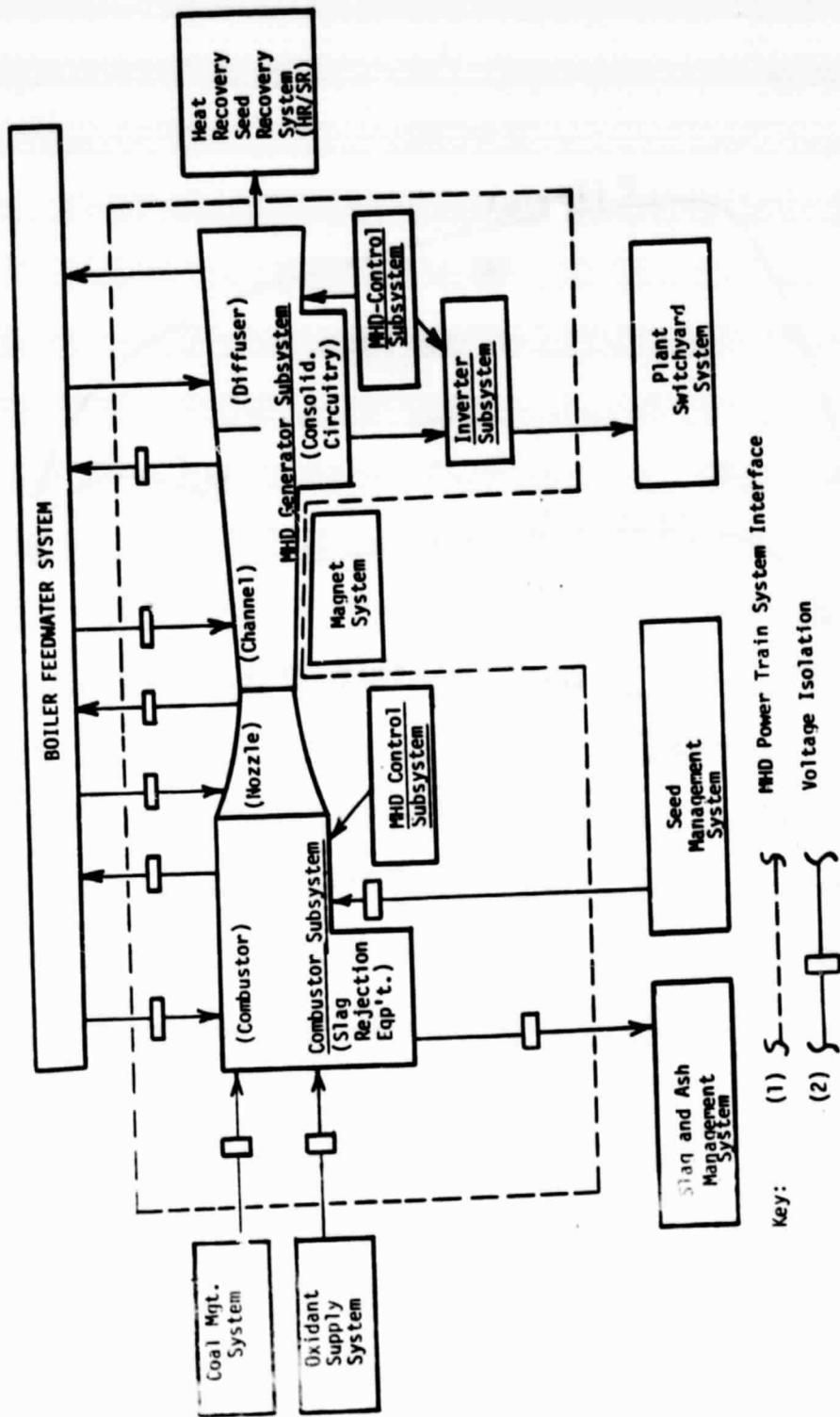
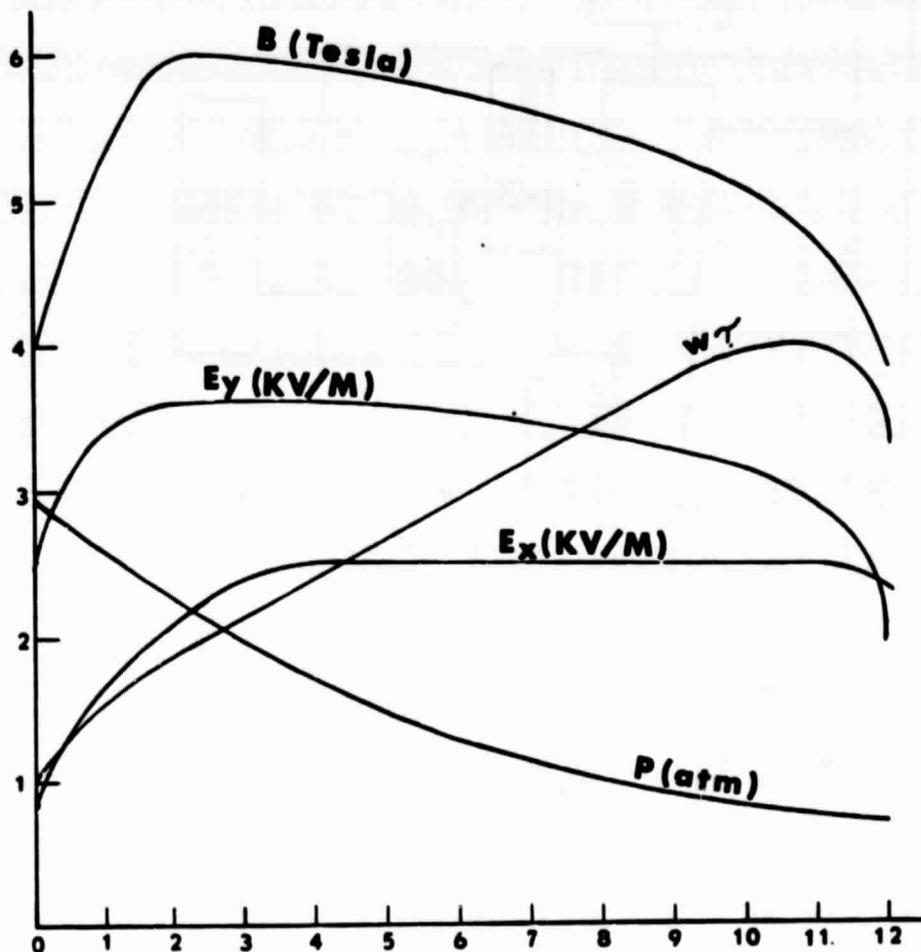


Figure 10.1 - Power Train Schematic And Interfaces
SDD-502

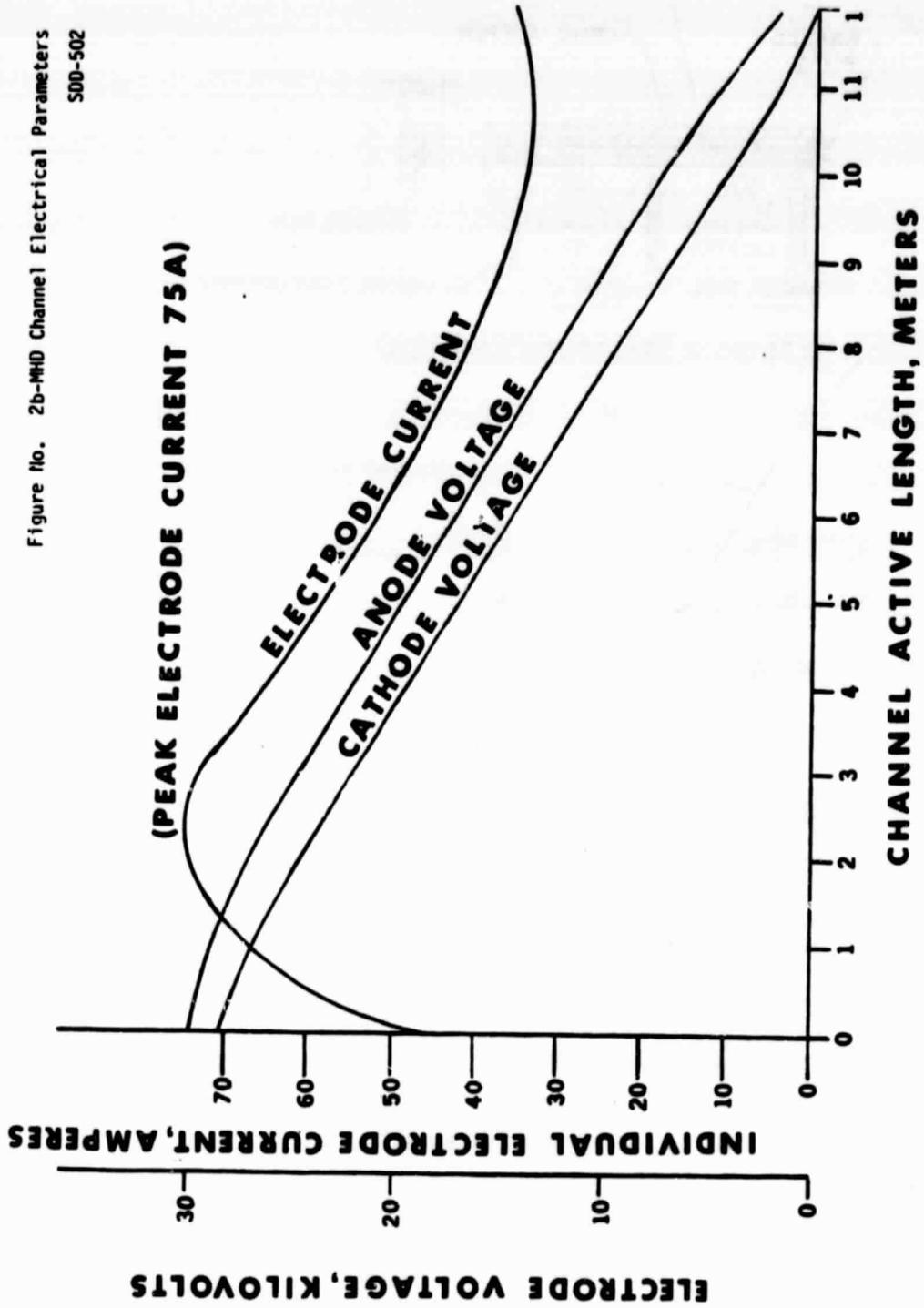


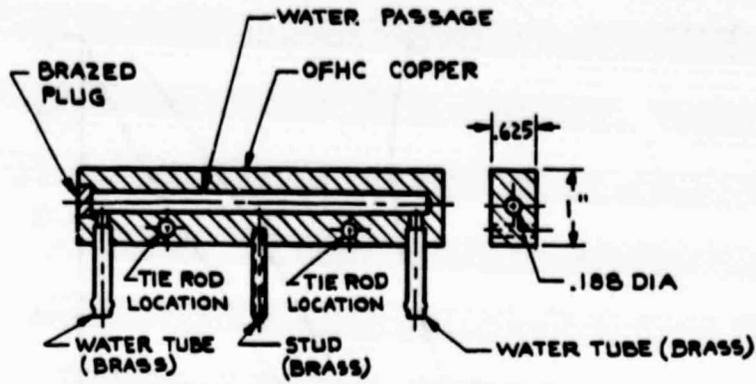
CHANNEL ACTIVE LENGTH, METERS

Figure No. 2a-MHD Channel Operating Parameters

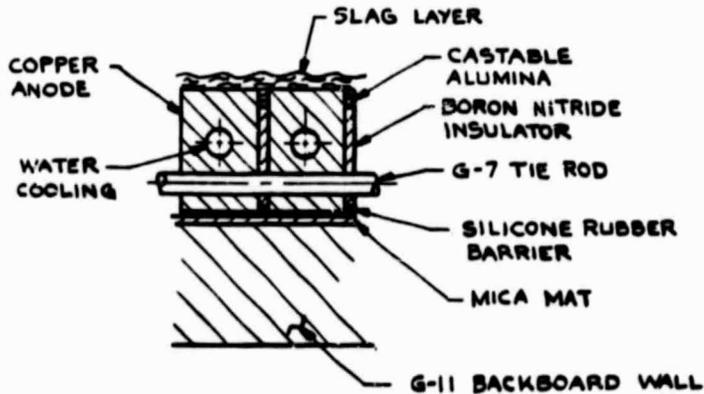
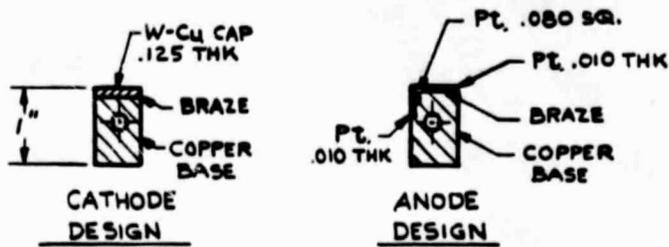
SDD-502

Figure No. 2b-MHD Channel Electrical Parameters
 S00-502





ELECTRODE STRUCTURE (SCHEMATIC)



ELECTRODE ASSEMBLY (SCHEMATIC)

Figure No. 3 - Electrode Design and Assembly

SDD-502

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION

MHD POWER TRAIN

APPENDIX "A"

REFERENCE DOCUMENTS

REFERENCE DOCUMENTS - ATTACHED

System Drawings

Drawing Index	SDD-1100
MHD Power Train System Assembly	SDD-1101
MHD Power Train System Facility and Support Structures Plan and Elevation	SDD-1102
MHD Combustor Plan and Elevation	SDD-1200
MHD Channel Support Structure Assembly Plan and Elevation	SDD-1300
MHD Channel Support Structure Plan and Elevation	SDD-1301
MHD Diffuser Plan and Elevation	SDD-1400
MHD Diffuser Cross Section	SDD-1401
MHD Diffuser and Transition Section Support Structure Plan and Elevation	SDD-1402
MHD Control Subsystem and Interface Block Diagram	SDD-1500
Consolidation Network Connection Diagram	SDD-1501
Consolidation Network Detail - 5 Stage Anode Consolidation	SDD-1502
Consolidation Network Detail - 3 Stage Cathode Consolidation	SDD-1503
Consolidation Network Detail - Make Up Current Distribution	SDD-1504

REFERENCE DOCUMENTS - NOT ATTACHED

System Design Description

Oxidant Supply System	SDD-501
Magnet System	SDD-503
Inverter System	SDD-505

Plant Heat and Flow Balance Diagram

System Heat Balance	8270-1-540-314-001
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Reports

Engineering Test Facility Conceptual Design, Final Report, FE-2614-2, Prepared by AVCO Everett Research Laboratory, Inc.

MHD POWER TRAIN SYSTEM DRAWING INDEX

DRAWING NO.	REV.	DRAWING TITLE		DRAWING NO.	REV.	DRAWING TITLE		DRAWING NO.	REV.	DRAWING TITLE
SDD-1100	A	CONCEPTUAL DESIGN - 200MWE MHD POWER TRAIN SYSTEM MHD POWER TRAIN SYSTEM DRAWING INDEX								
SDD-1101	A	CONCEPTUAL DESIGN - 200MWE MHD POWER TRAIN SYSTEM ASSEMBLY - PLAN AND ELEVATION		SDD-1300		CONCEPTUAL DESIGN - 200 MWE MHD POWER TRAIN SYSTEM MHD CHANNEL SUPPORT STRUCTURE ASSEMBLY - PLAN AND ELEVATION				
SDD-1102		CONCEPTUAL DESIGN - 200MWE MHD POWER TRAIN SYSTEM FACILITY AND SUPPORT STRUCTURES PLAN AND ELEVATION		SDD-1301		CONCEPTUAL DESIGN - 200MWE MHD POWER TRAIN SYSTEM MHD CHANNEL SUPPORT STRUCTURE PLAN AND ELEVATION		SDD-1500		CONC MHD MHD AND
								SDD-1501		CONC MHD CON CON
								SDD-1502		CONC MHD CON 5 ST
								SDD-1503		CONC MHD CON 3 ST
SDD-1200	A	CONCEPTUAL DESIGN - 200MWE MHD POWER TRAIN SYSTEM MHD COMBUSTOR PLAN AND ELEVATION		SDD-1400		CONCEPTUAL DESIGN - 200 MWE MHD POWER TRAIN SYSTEM MHD DIFFUSER PLAN AND ELEVATION		SDD-1504		CONC MHD CON MAKE
				SDD-1401		CONCEPTUAL DESIGN - 200 MWE MHD POWER TRAIN SYSTEM MHD DIFFUSER CROSS SECTION				
				SDD-1402		CONCEPTUAL DESIGN - 200MWE MHD POWER TRAIN SYSTEM MHD DIFFUSER AND TRANSITION SECTION SUPPORT STRUCTURE PLAN AND ELEVATION				

EOLDOUT FRAME

GENERAL NOTES

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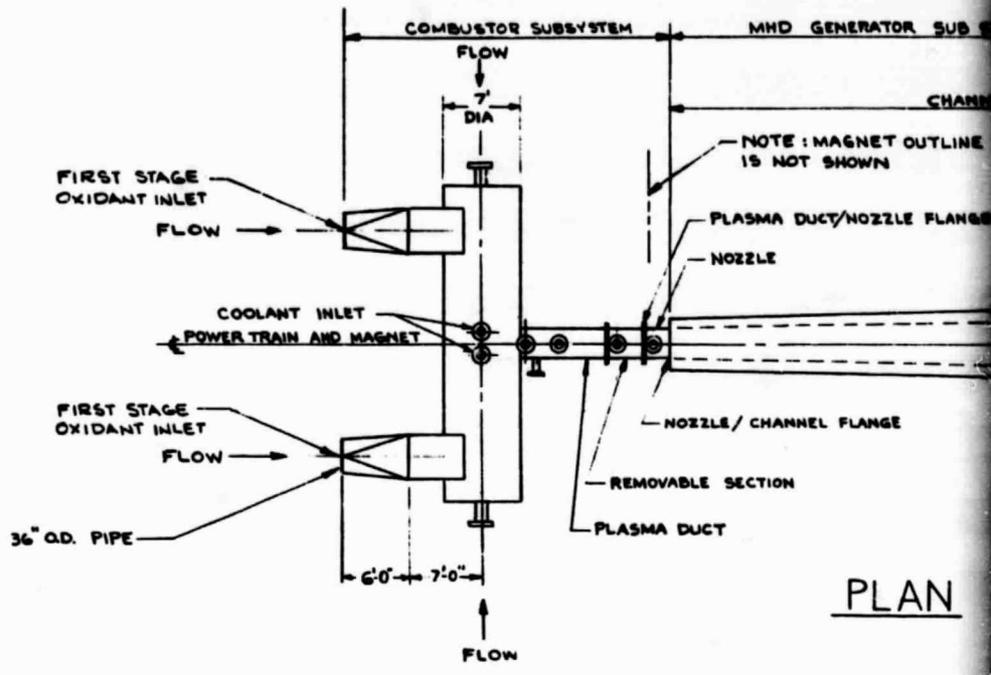
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SDD-1501		CONCEPTUAL DESIGN - 200MWE MHD POWER TRAIN SYSTEM CONSOLIDATION NETWORK CONNECTION DIAGRAM
SDD-1502		CONCEPTUAL DESIGN - 200MWE MHD POWER TRAIN SYSTEM CONSOLIDATION NETWORK DETAIL-- 5 STAGE ANODE CONSOLIDATION
SDD-1503		CONCEPTUAL DESIGN - 200 MWE MHD POWER TRAIN SYSTEM CONSOLIDATION NETWORK DETAIL-- 3 STAGE CATHODE CONSOLIDATION
SDD-1504		CONCEPTUAL DESIGN - 200 MWE MHD POWER TRAIN SYSTEM CONSOLIDATION NETWORK DETAIL-- MAKE UP CURRENT DISTRIBUTION

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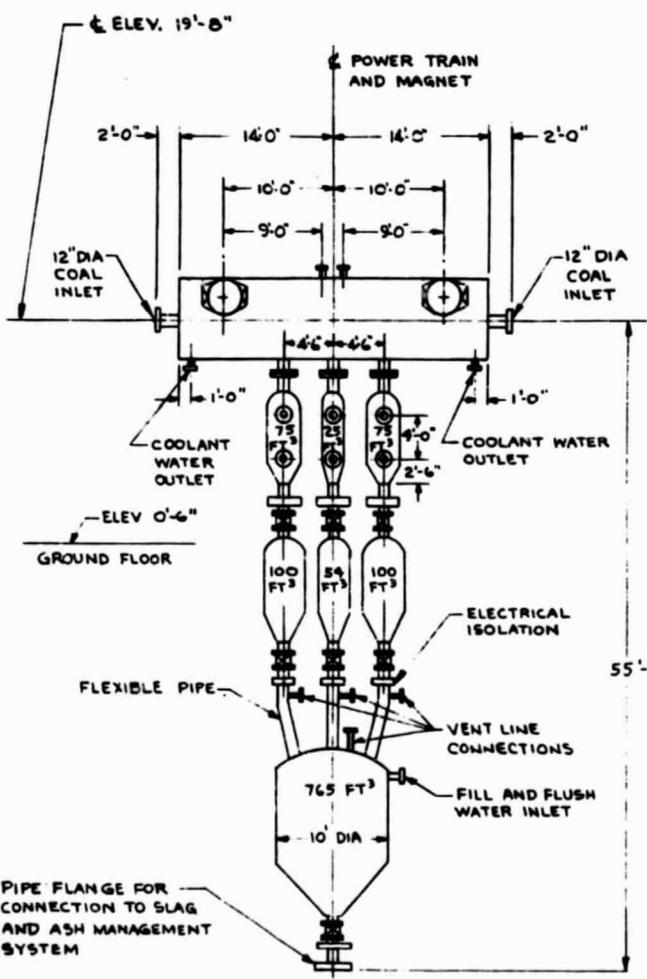
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 JAMES ALLEN, JR.
 MR. SW.

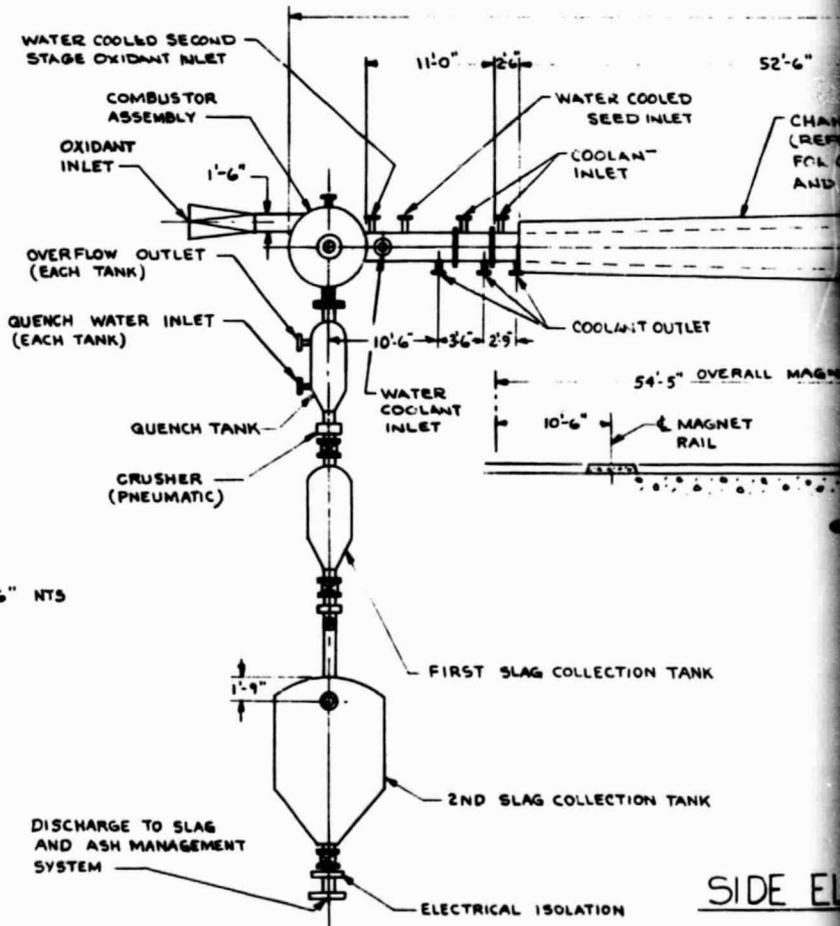
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PROJECT: MAGNETOHYDRODYNAMICS ENGINEERING TEST FACILITY		
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APPD. MROZ / BERCAW		DATE 2-23-81
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PLAN

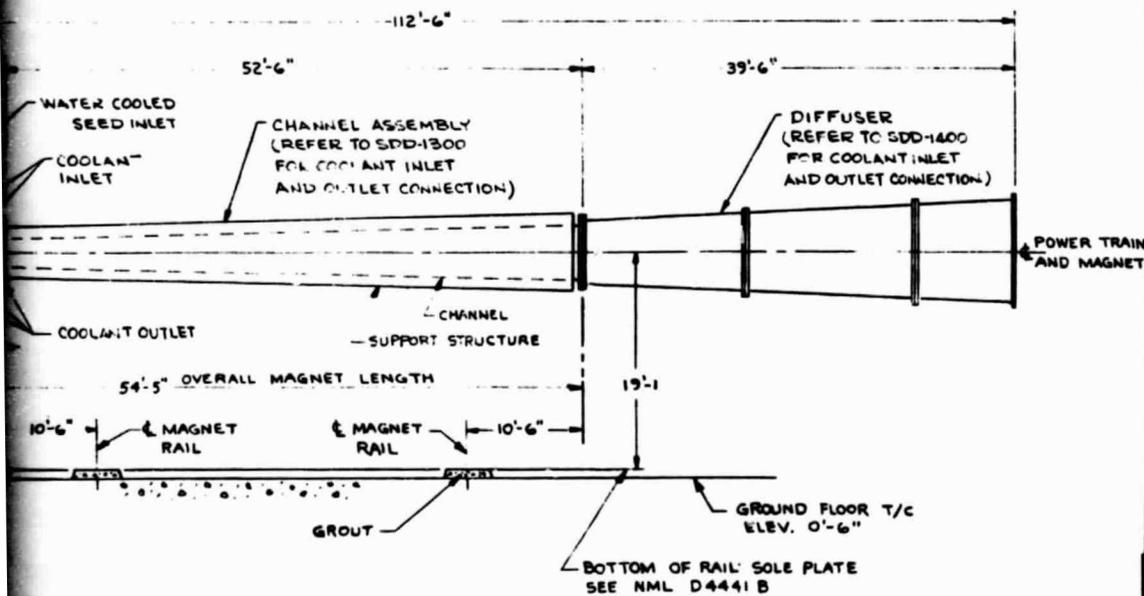
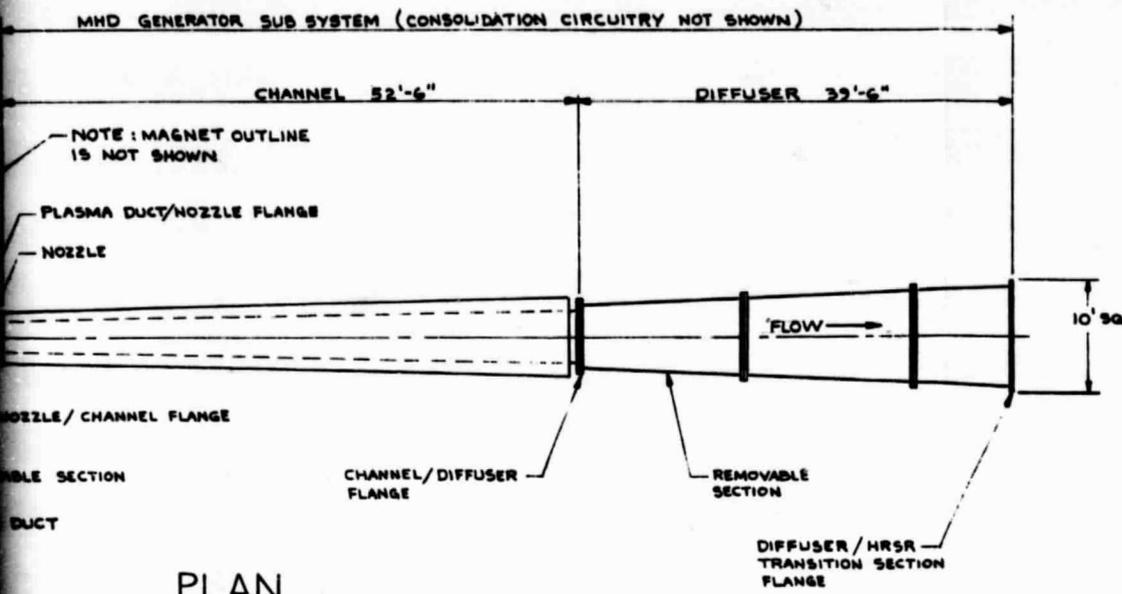


END VIEW



SIDE ELEVATION

FOLDOUT FRAME



GENERAL NOTES

1. GENERAL NOTES APPLY TO ALL DRAWINGS.
2. FOR ORIENTATION AND LOCATION SEE GAI DRAWING 8270-1-310-010-001.
3. CRUSHERS AND ALL VALVES ARE PNEUMATICALLY OPERATED.
4. FUEL, OXIDANT, WATER, SEED AND AIR SUPPLY LINES ARE ELECTRICALLY ISOLATED.
5. SEE DRAWING SDD-1100 FOR POWER TRAIN SYSTEM DRAWING INDEX.
6. REFER TO COMPONENT DWG. FOR ADDITIONAL DETAILS.

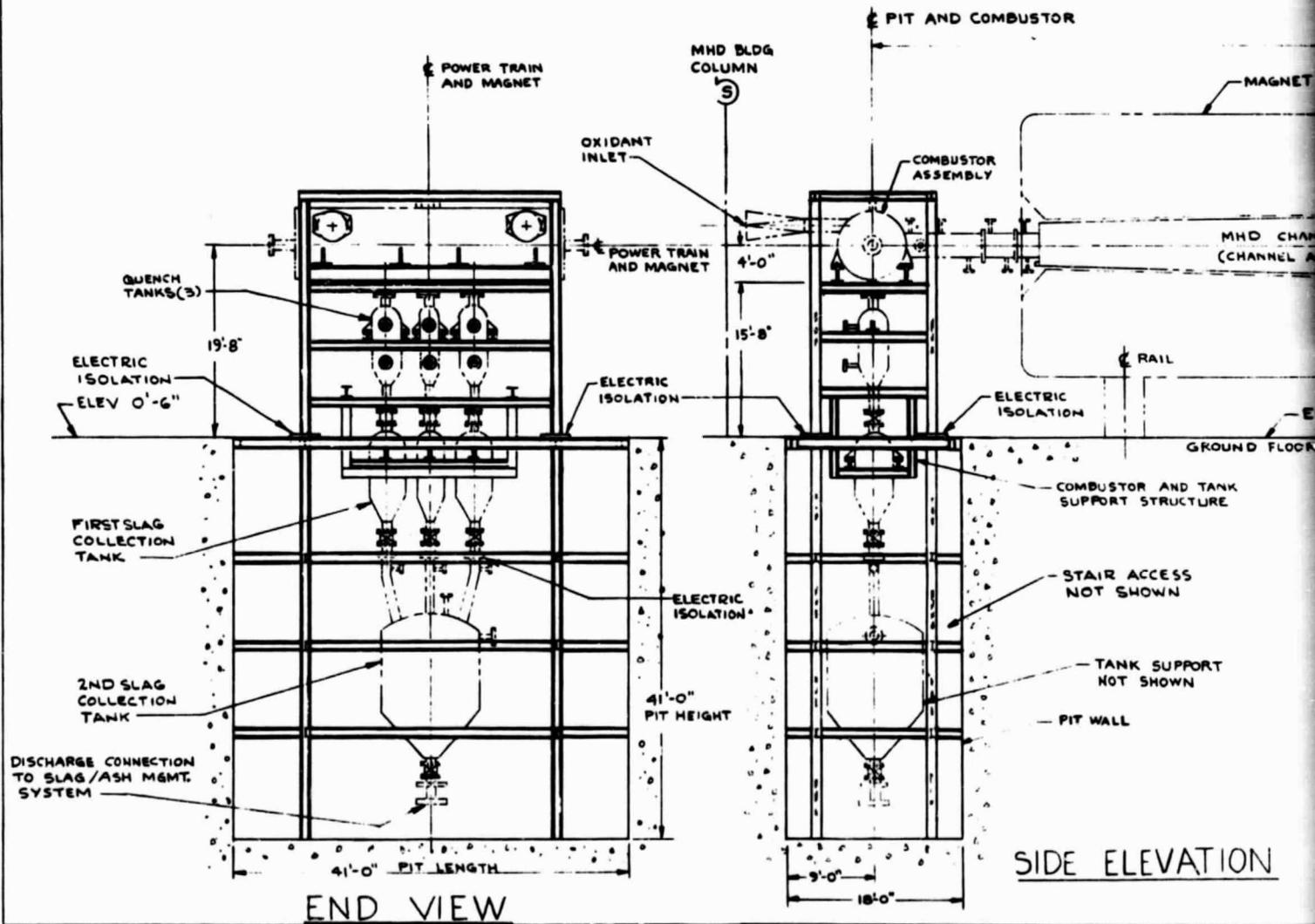
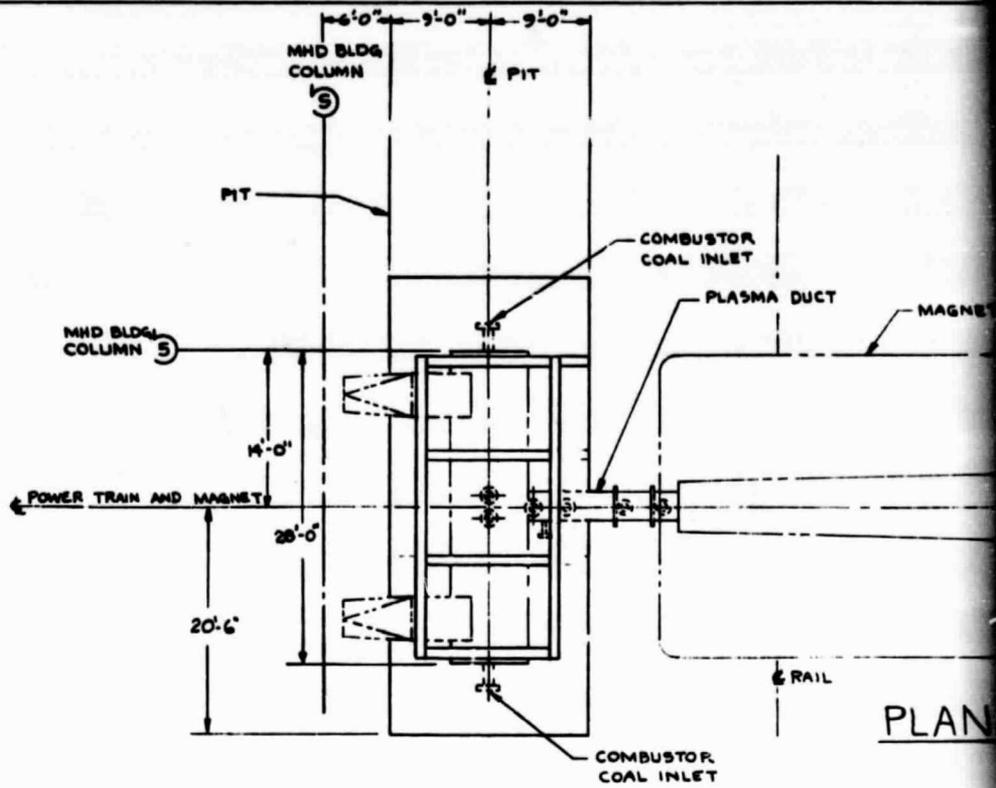
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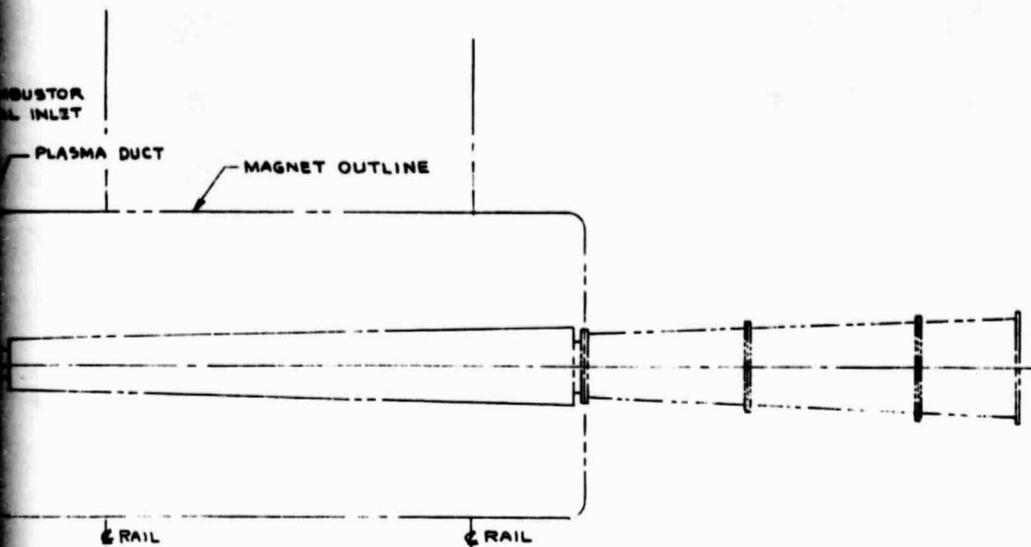
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- SDD-1200 MHD POWER TRAIN SYSTEM MHD COMBUSTOR
- SDD-1300 MHD POWER TRAIN SYSTEM MHD CHANNEL SUPPORT STRUCTURE ASSEMBLY

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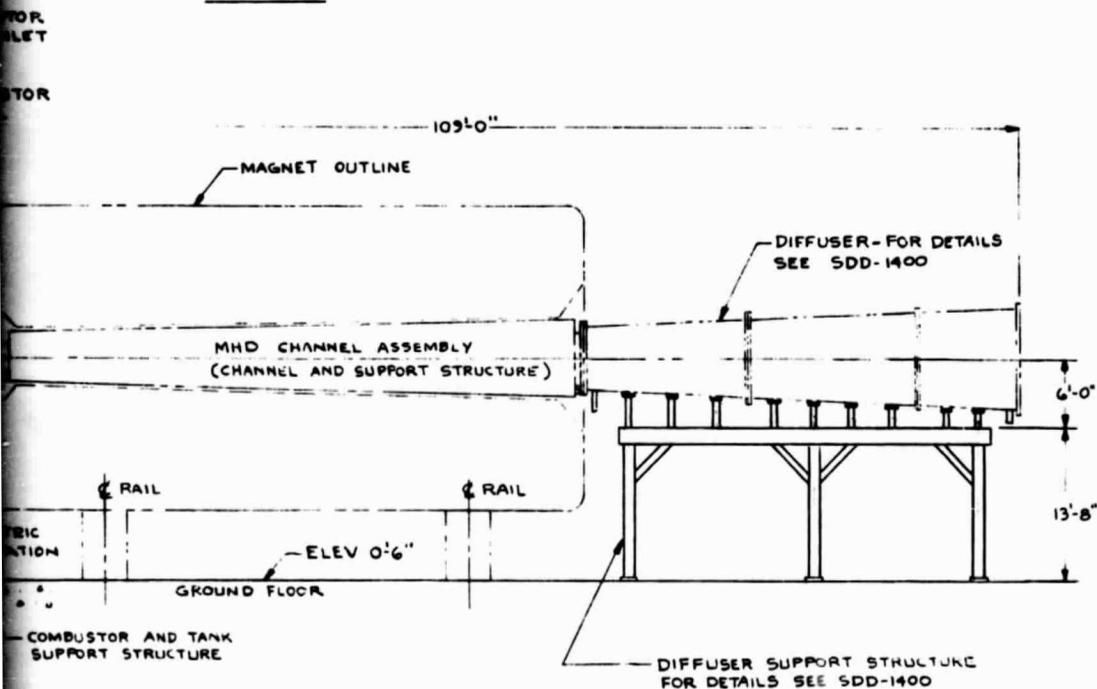
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APPD. MROZ / DERCAW		DATE 2-23-81	
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PLAN

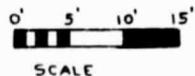


STAIR ACCESS NOT SHOWN

TANK SUPPORT NOT SHOWN

PIT WALL

SIDE ELEVATION



GENERAL NOTES

1. GENERAL NOTES APPLY TO ALL DRAWINGS.
2. SEE DRAWING SDD-1100 FOR POWER TRAIN SYSTEM DRAWING LIST.

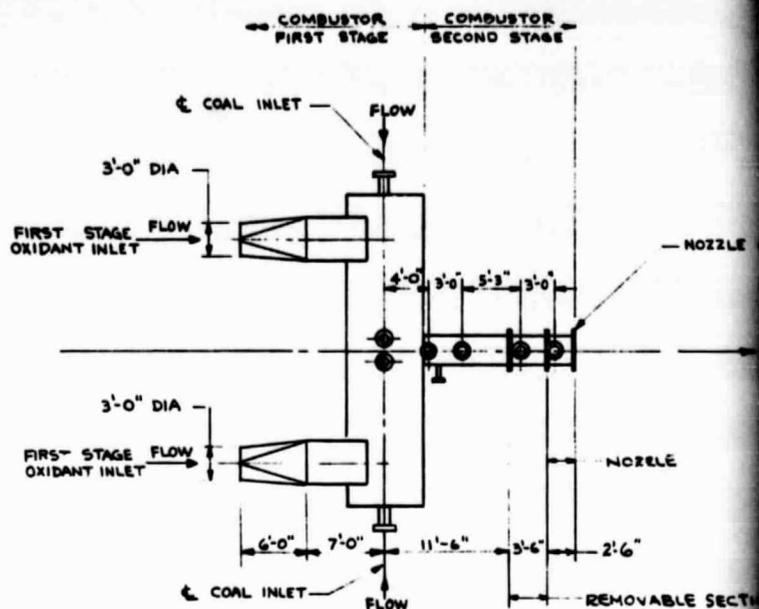
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- SDD-1200 MHD COMBUSTOR, PLAN AND ELEVATION
- SDD-1400 MHD DIFFUSER, PLAN AND ELEVATION

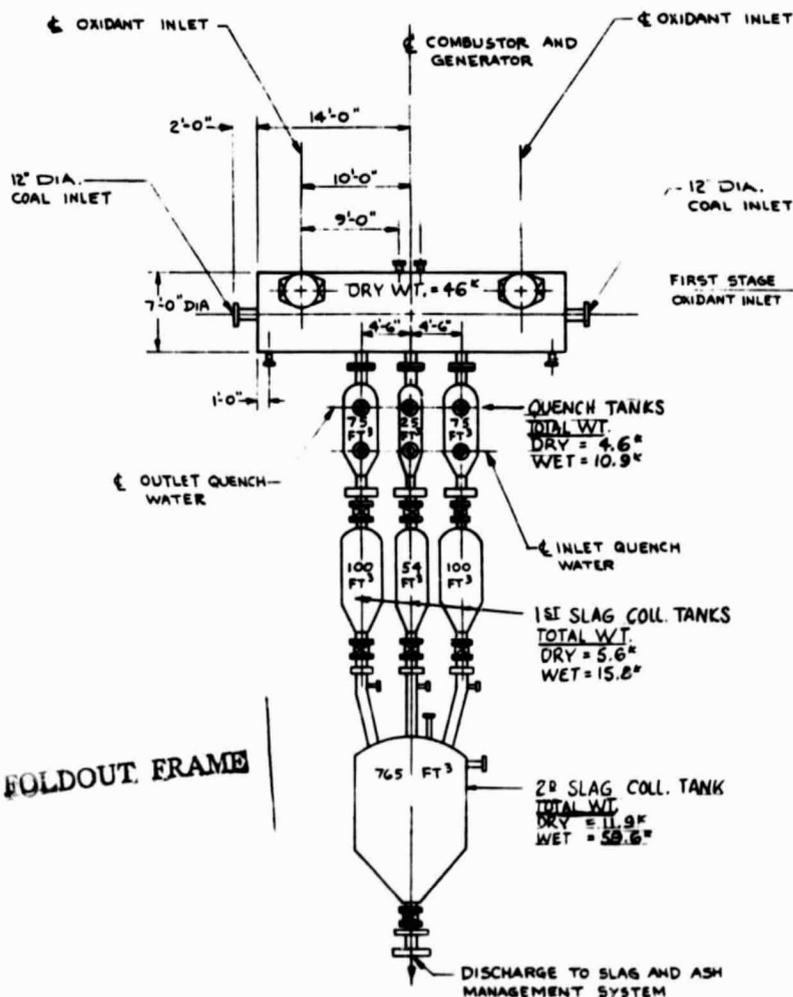
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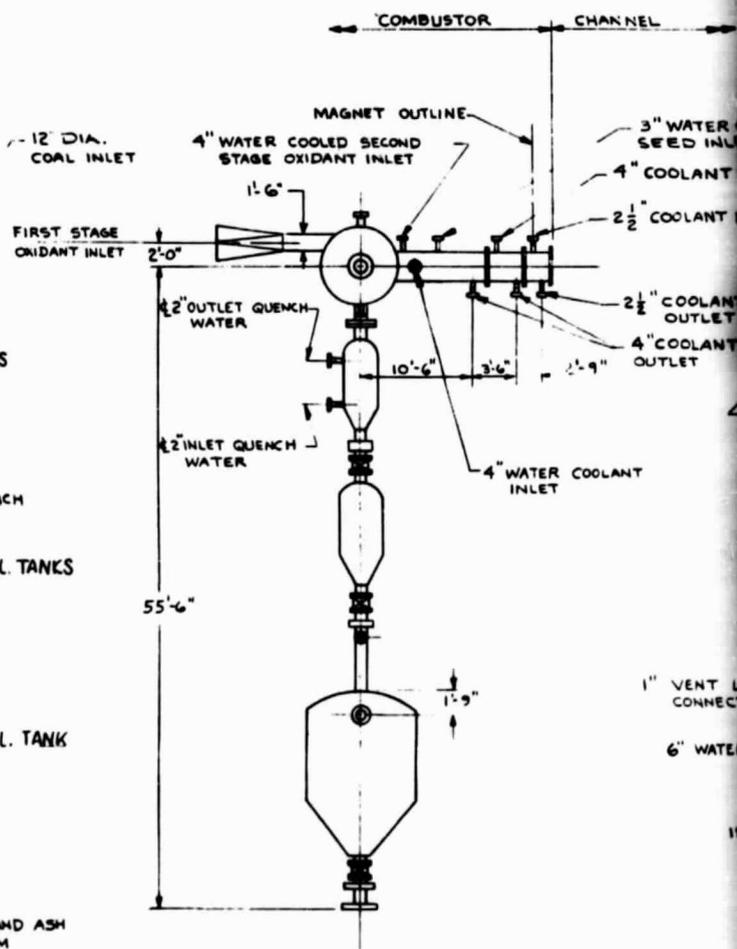
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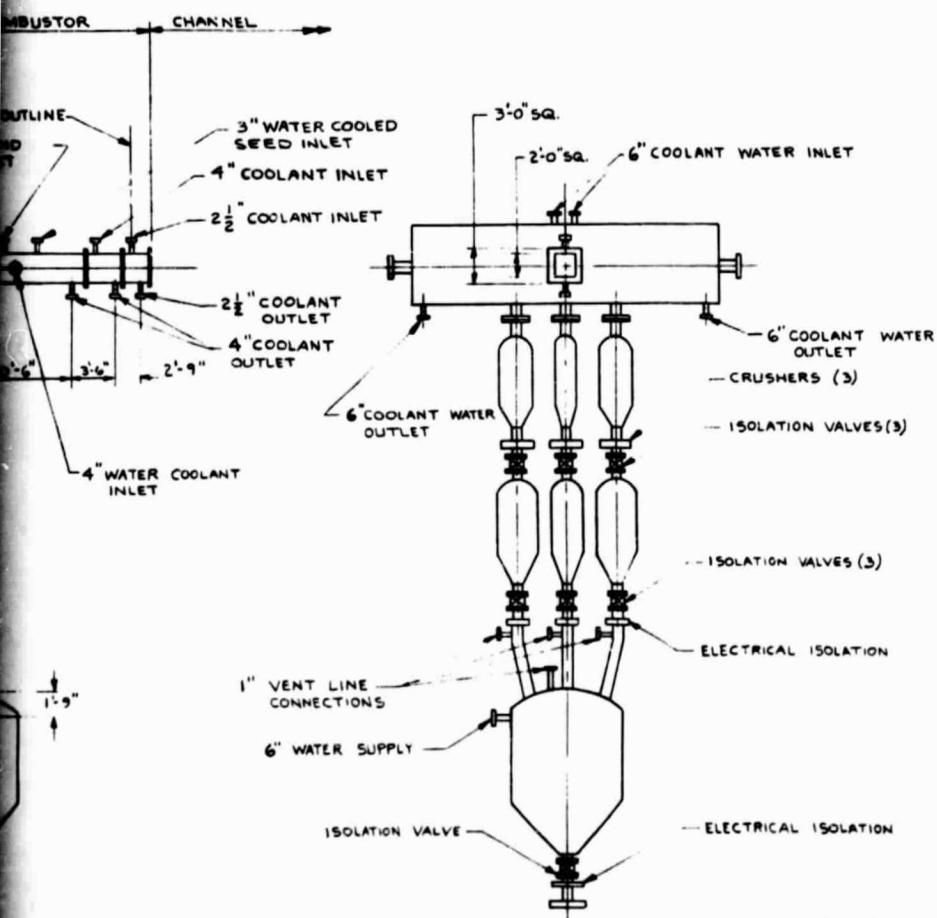
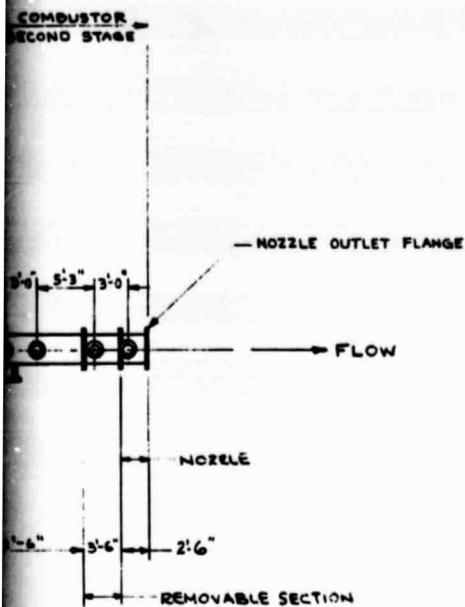


FRONT VIEW



SIDE ELEVATION

FOLDOUT FRAME



END VIEW



GENERAL NOTES

1. GENERAL NOTES APPLY TO ALL DRAWINGS.
2. CRUSHERS AND VALVES ARE PNEUMATICALLY OPERATED.
3. FUEL, OXIDANT, WATER, SEED AND AIR SUPPLY LINES ARE ELECTRICALLY ISOLATED.
4. SEPARATE COOLANT WATER SHALL BE SUPPLIED FROM COMMON MANIFOLD TO COMBUSTOR FIRST STAGE, SECOND STAGE, AND THE NOZZLE. DISCHARGES SHALL BE COMBINED INTO A COMMON MANIFOLD TO BE DELIVERED TO DIFFUSER COOLANT INLET.

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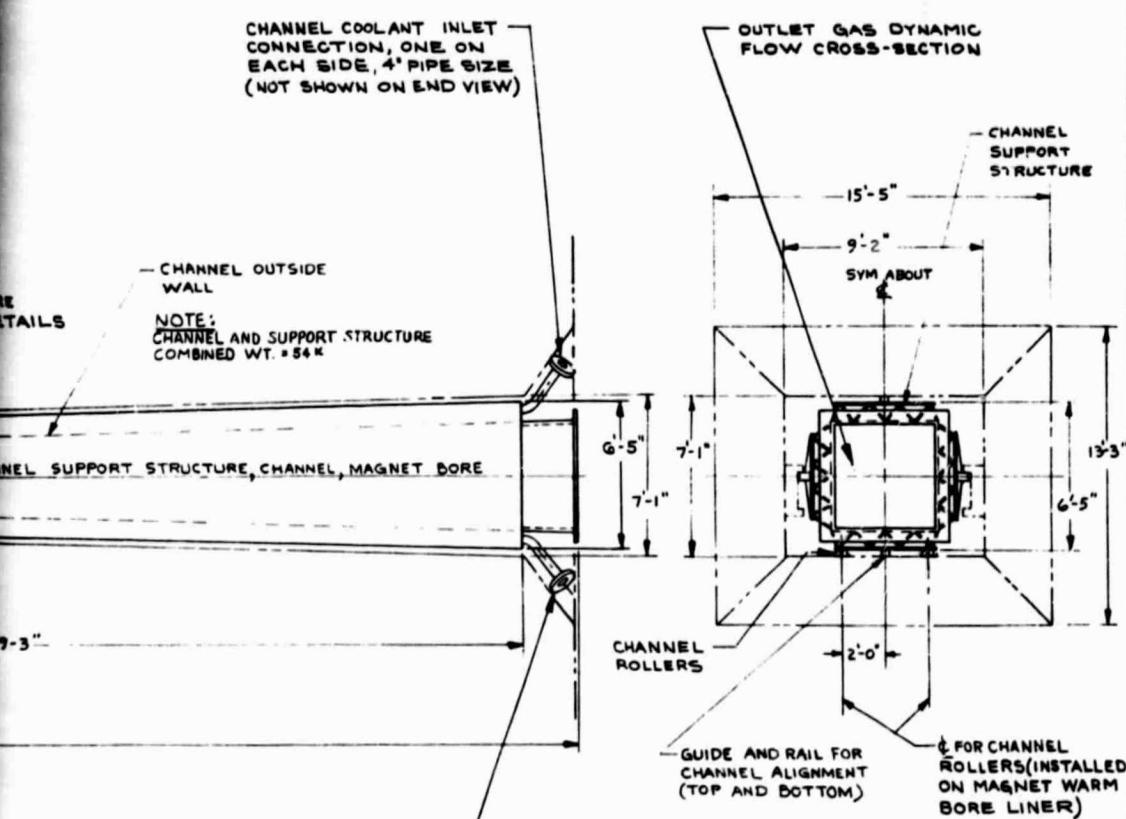
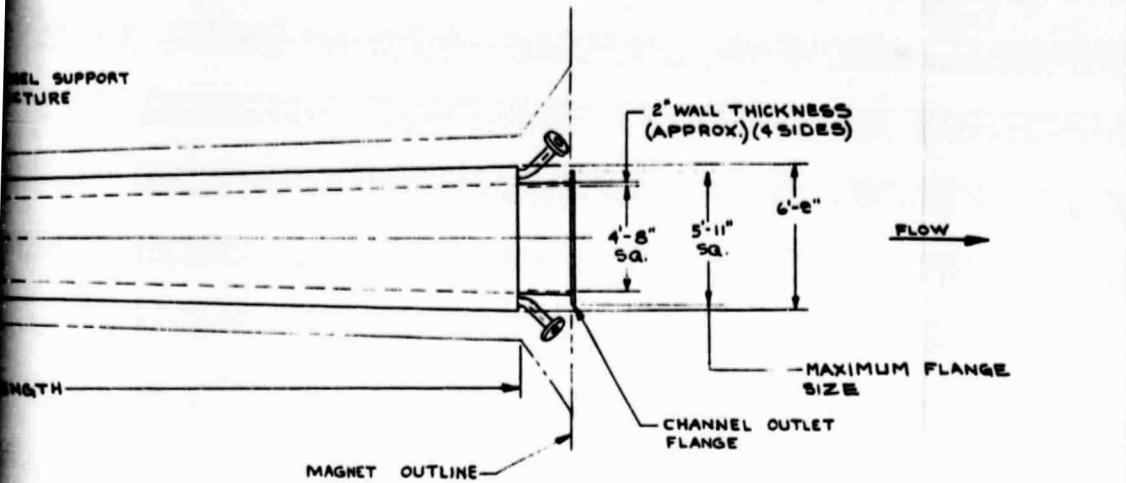
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- SDD-1102 MHD POWER TRAIN SYSTEM FACILITY AND SUPPORT STRUCTURES

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			REV

GENERAL NOTES

1. GENERAL NOTES APPLY TO ALL DRAWINGS.
2. CHANNEL ELECTRIC CABLES NOT SHOWN.



OUTLET END VIEW

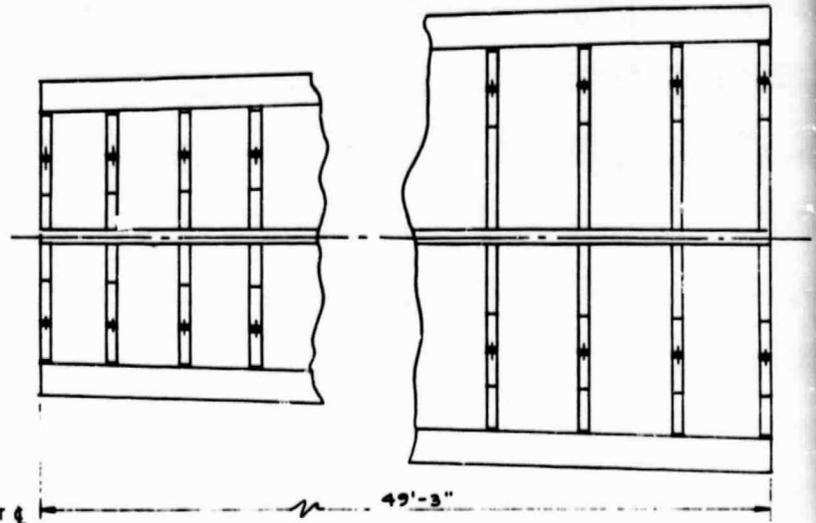


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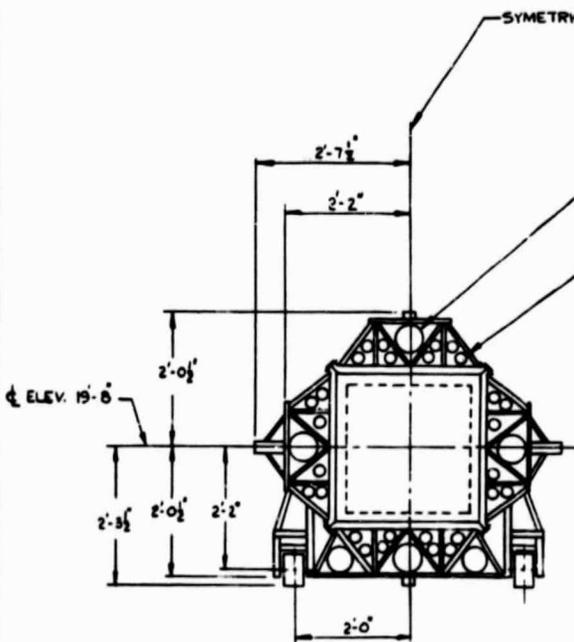
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- SDD-1301 MHD CHANNEL SUPPORT STRUCTURE PLAN AND ELEVATION

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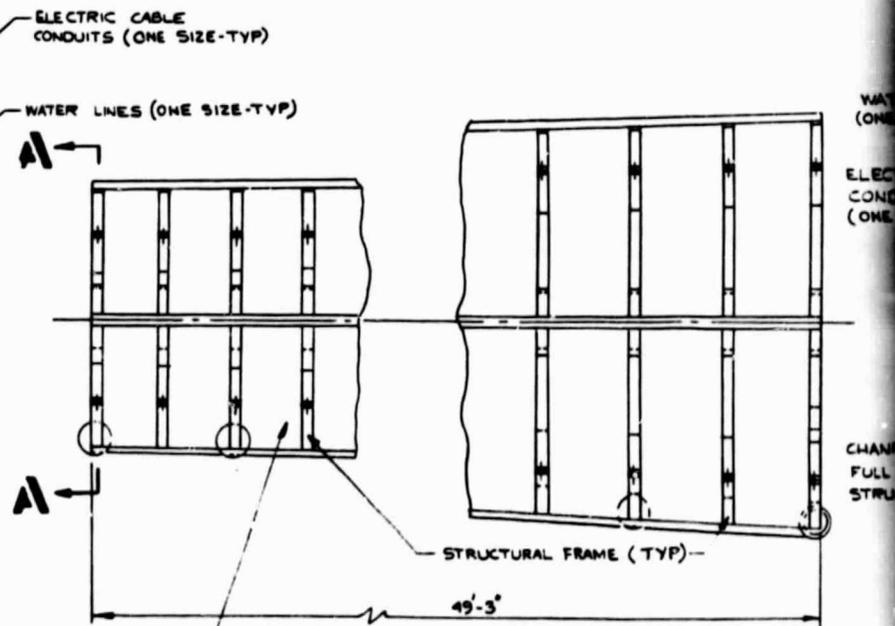
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APPD. MROZ/BERCAW		DATE 2-23-81	
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PLAN



SECTION A-A



SIDE ELEVATION

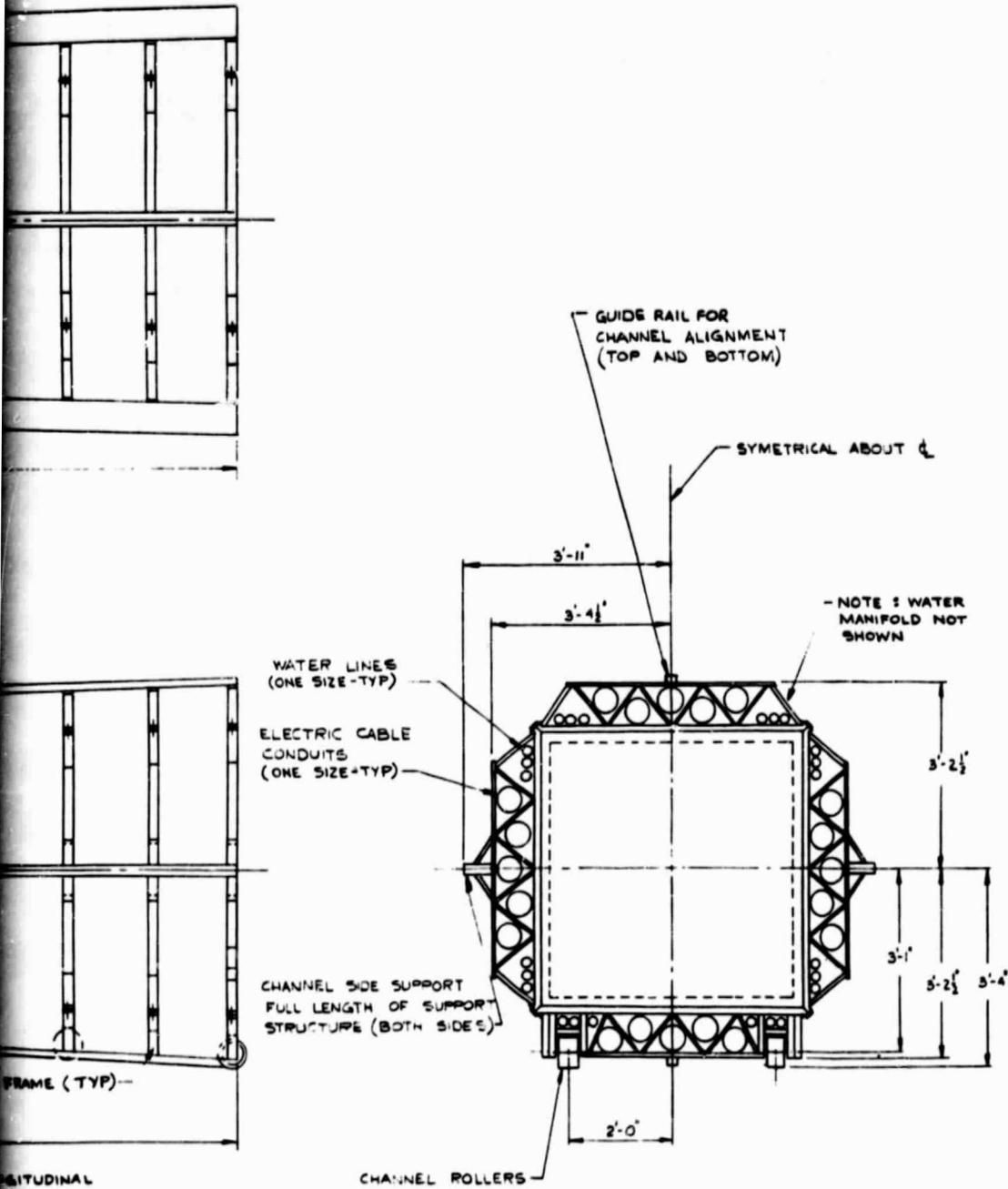
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FOLDOUT FRAME

GENERAL NOTES

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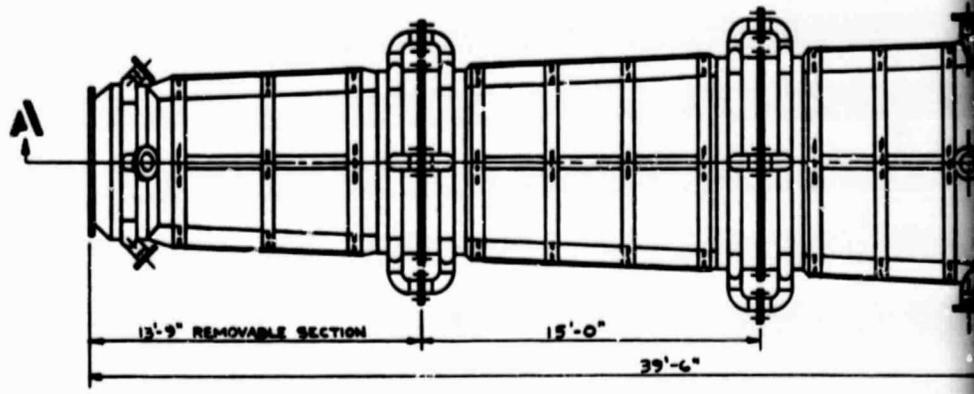
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ASSEMBLY - PLAN AND ELEVATION



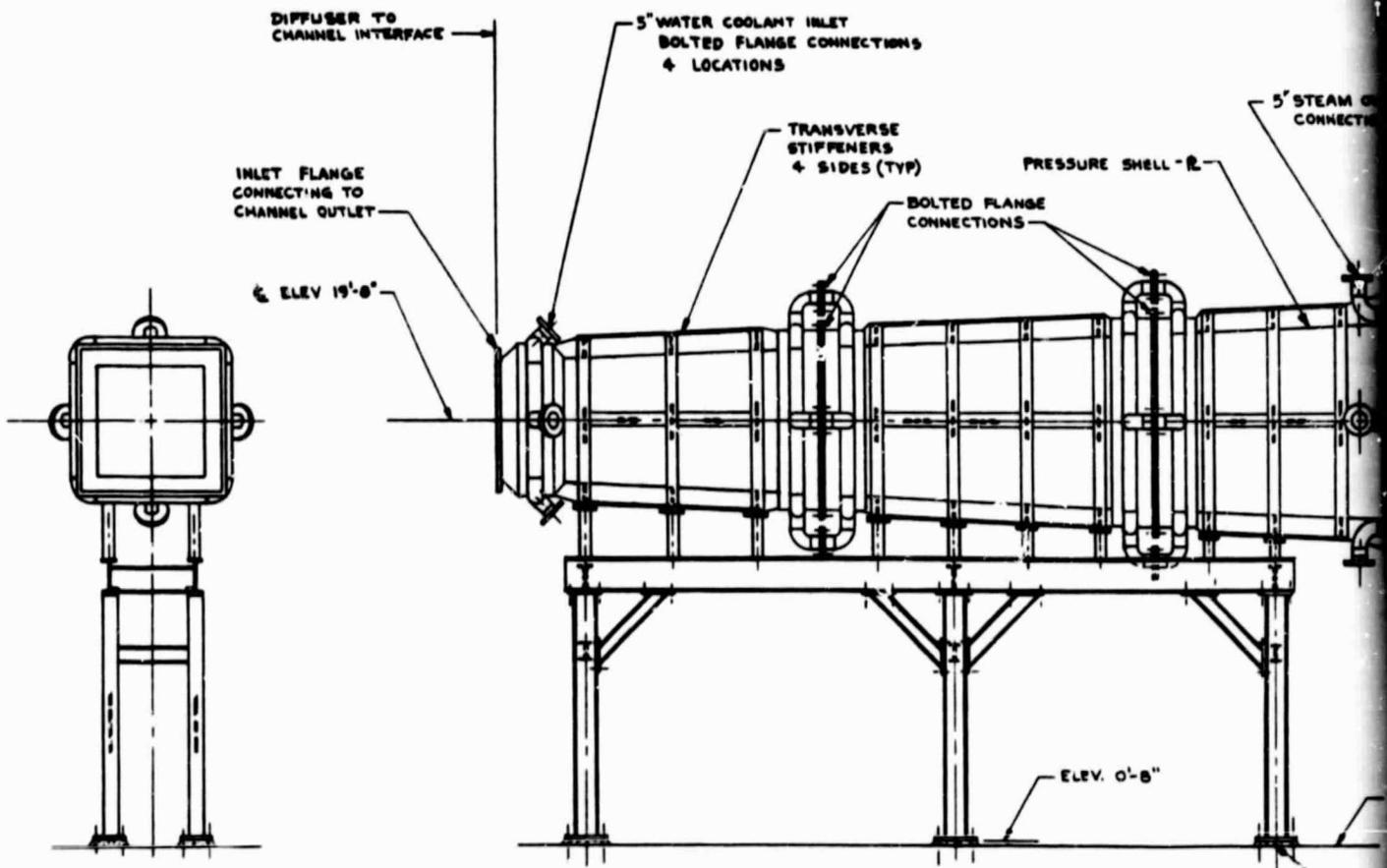
OUTLET END VIEW

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PROJECT: MAGNETOHYDRODYNAMICS ENGINEERING TEST FACILITY			
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PLAN



INLET END VIEW

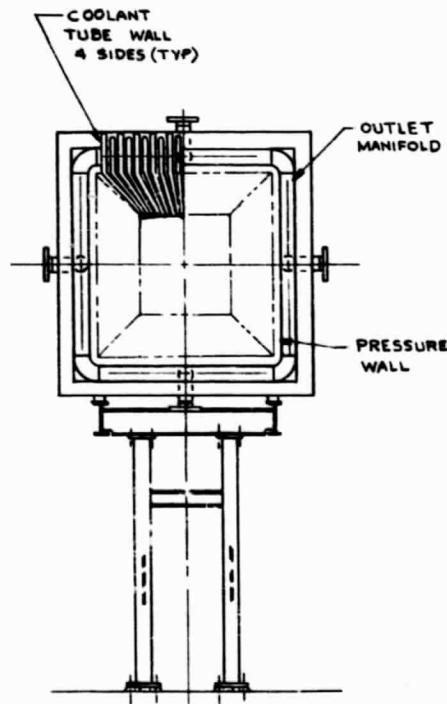
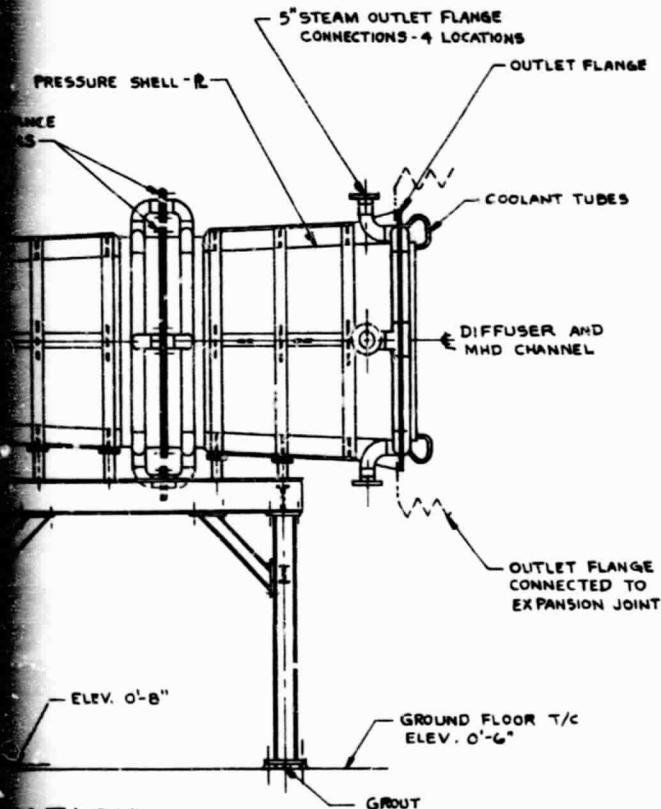
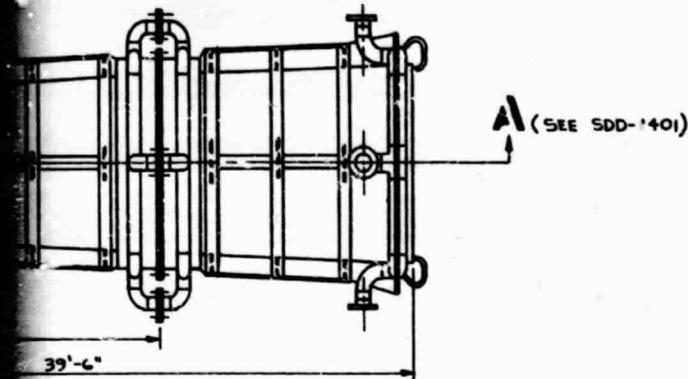
SIDE ELEVATION

FOLDOUT FRAME

GENERAL NOTES

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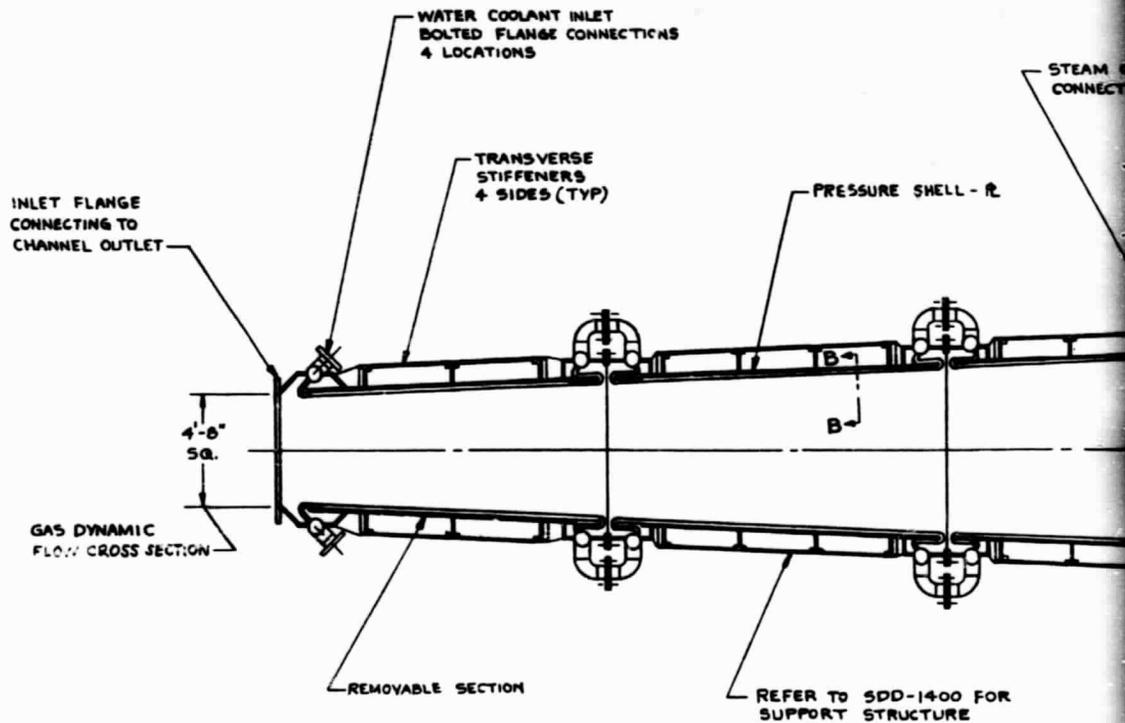
SDD 1401 MHD DIFFUSER CROSS SECTION
 SDD 1402 MHD DIFFUSER AND TRANSITION
 SECTION SUPPORT STRUCTURE
 PLAN AND ELEVATION



OUTLET END VIEW

FOLDOUT FRAME

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PROJECT: MAGNETOHYDRODYNAMICS ENGINEERING TEST FACILITY			
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APPD. MROZ/BERCAW		DATE 2-23-81	
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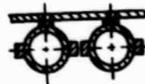
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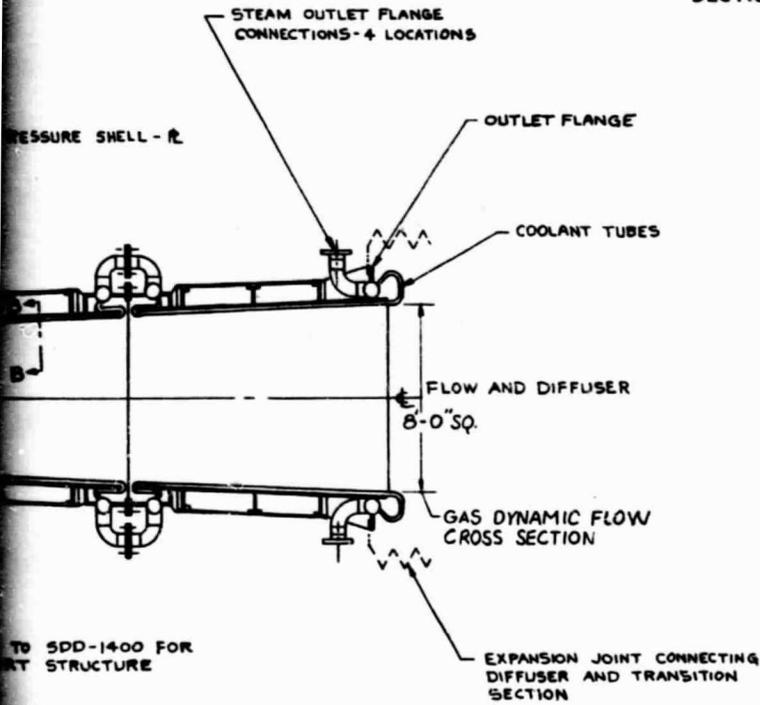
GENERAL NOTES

REF. DRAWING

SDD-1400 MHD DIFFUSER, PLAN AND ELEVATION



SECTION B-B

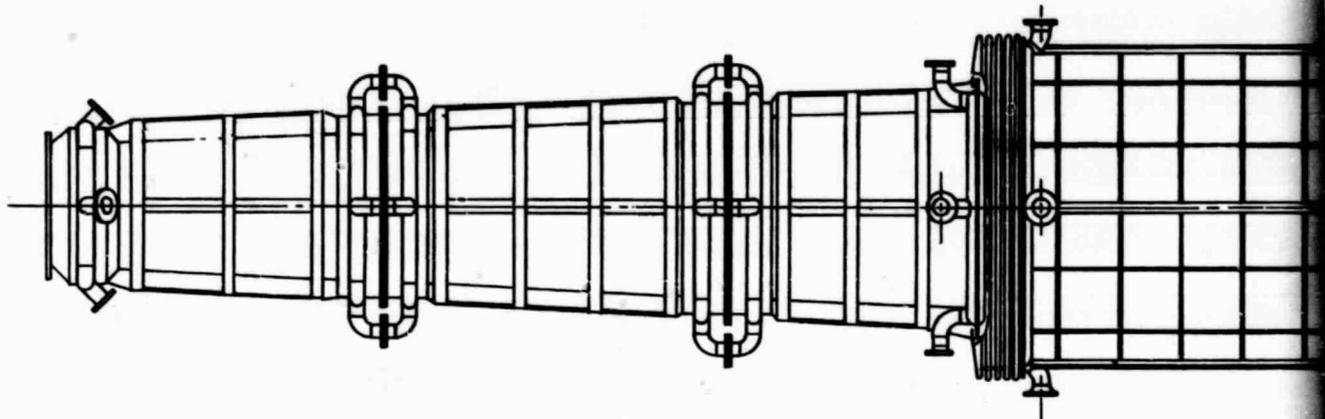


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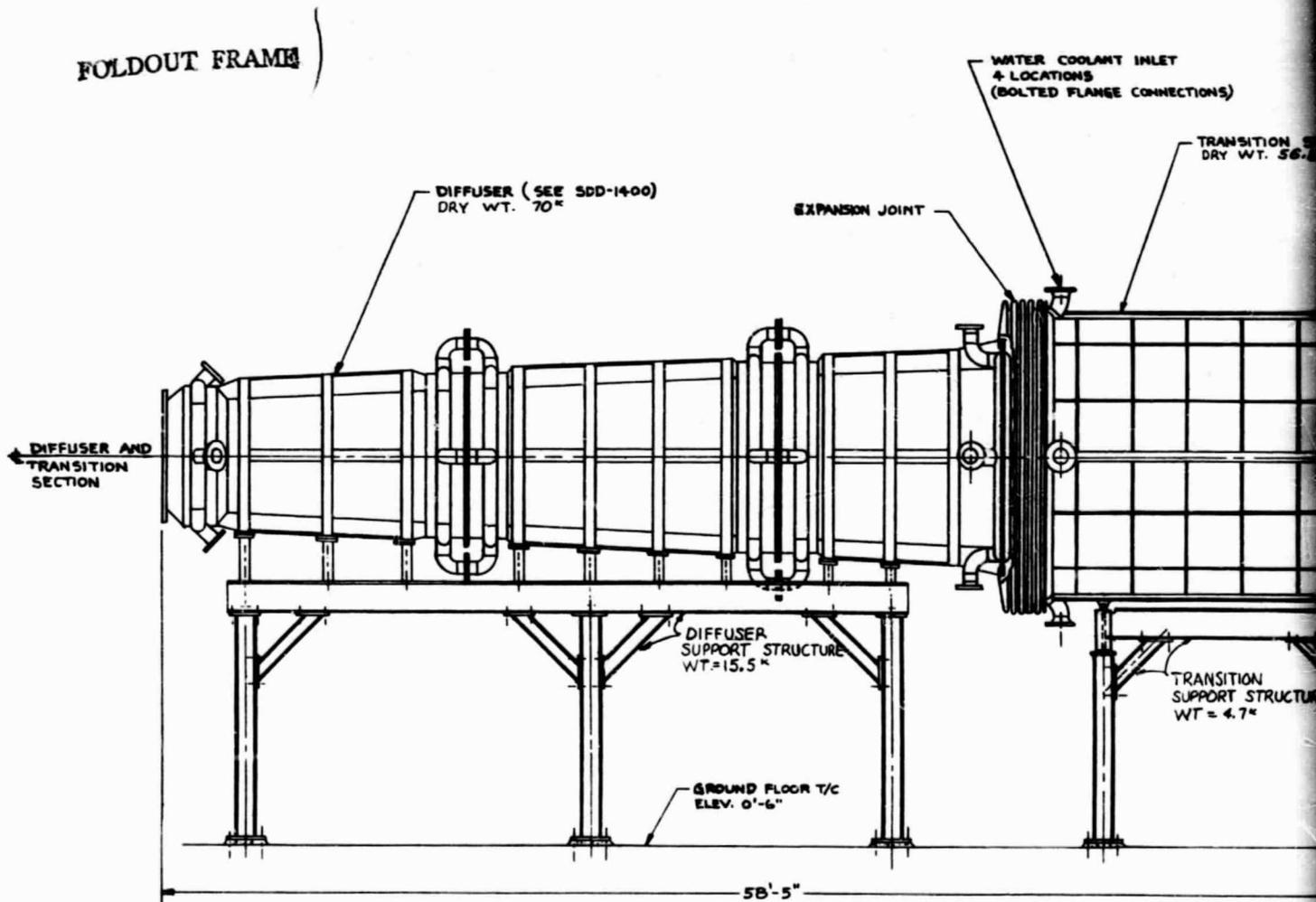
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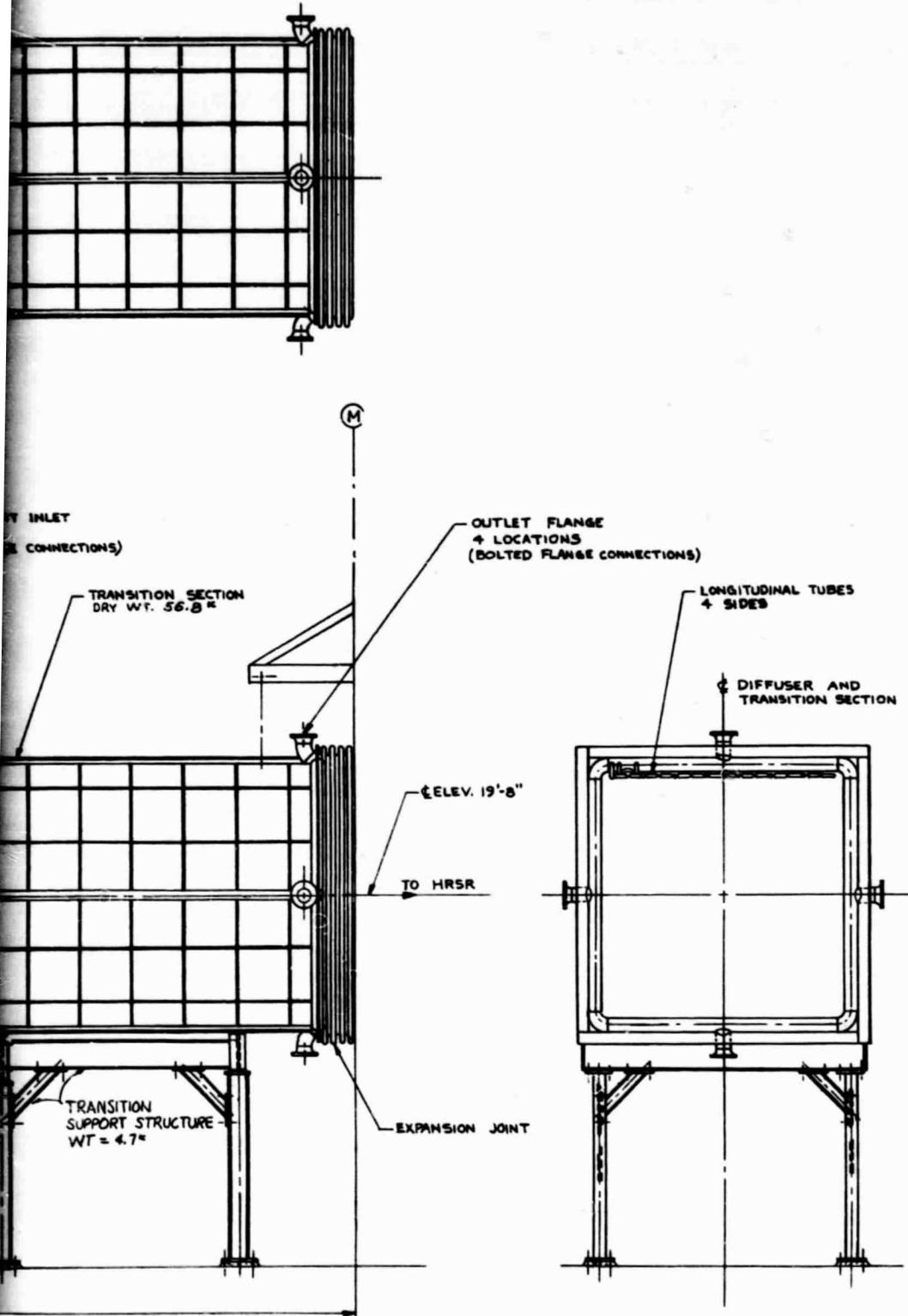
PLAN

FOLDOUT FRAME



SIDE ELEVATION

GENERAL NOTES



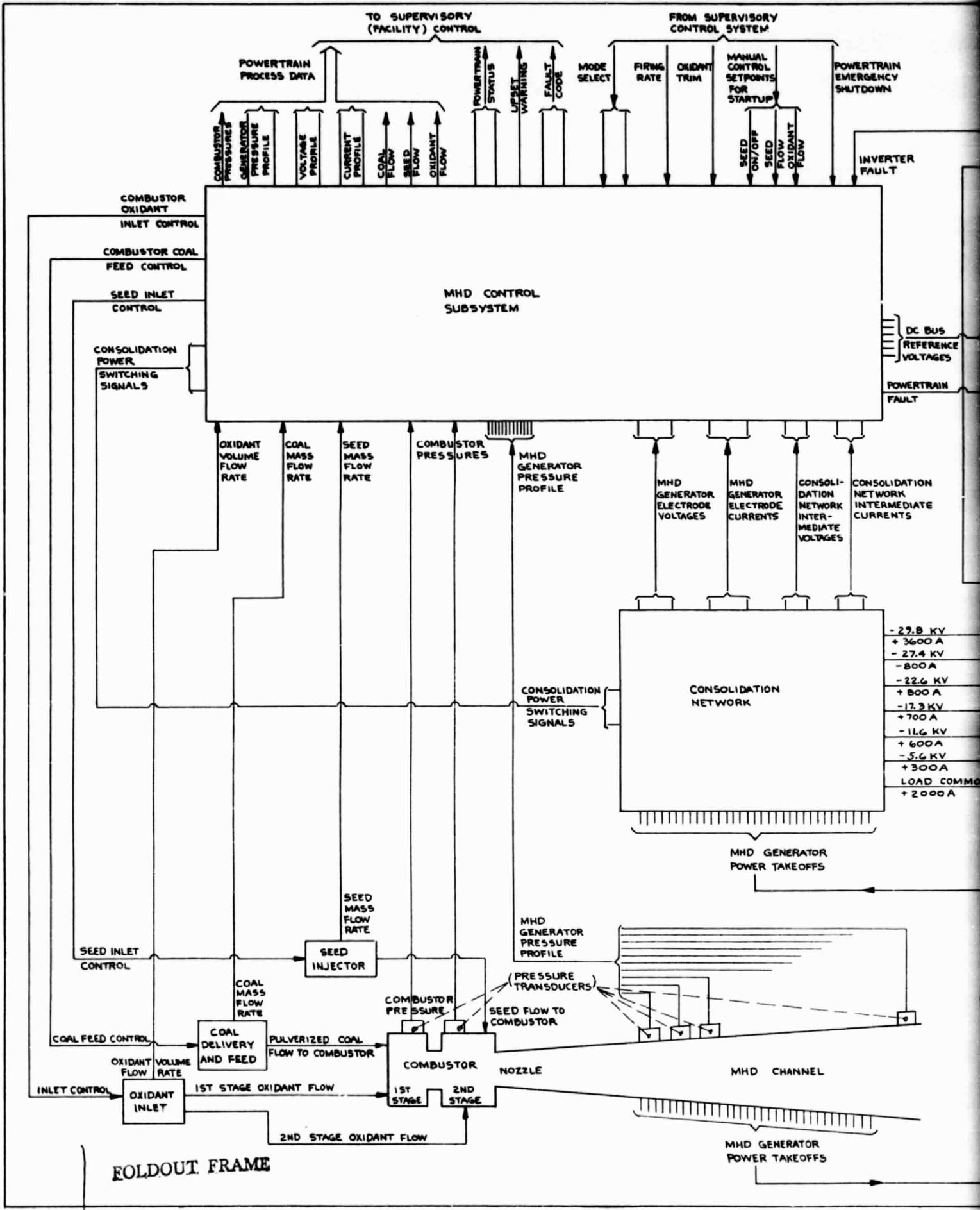
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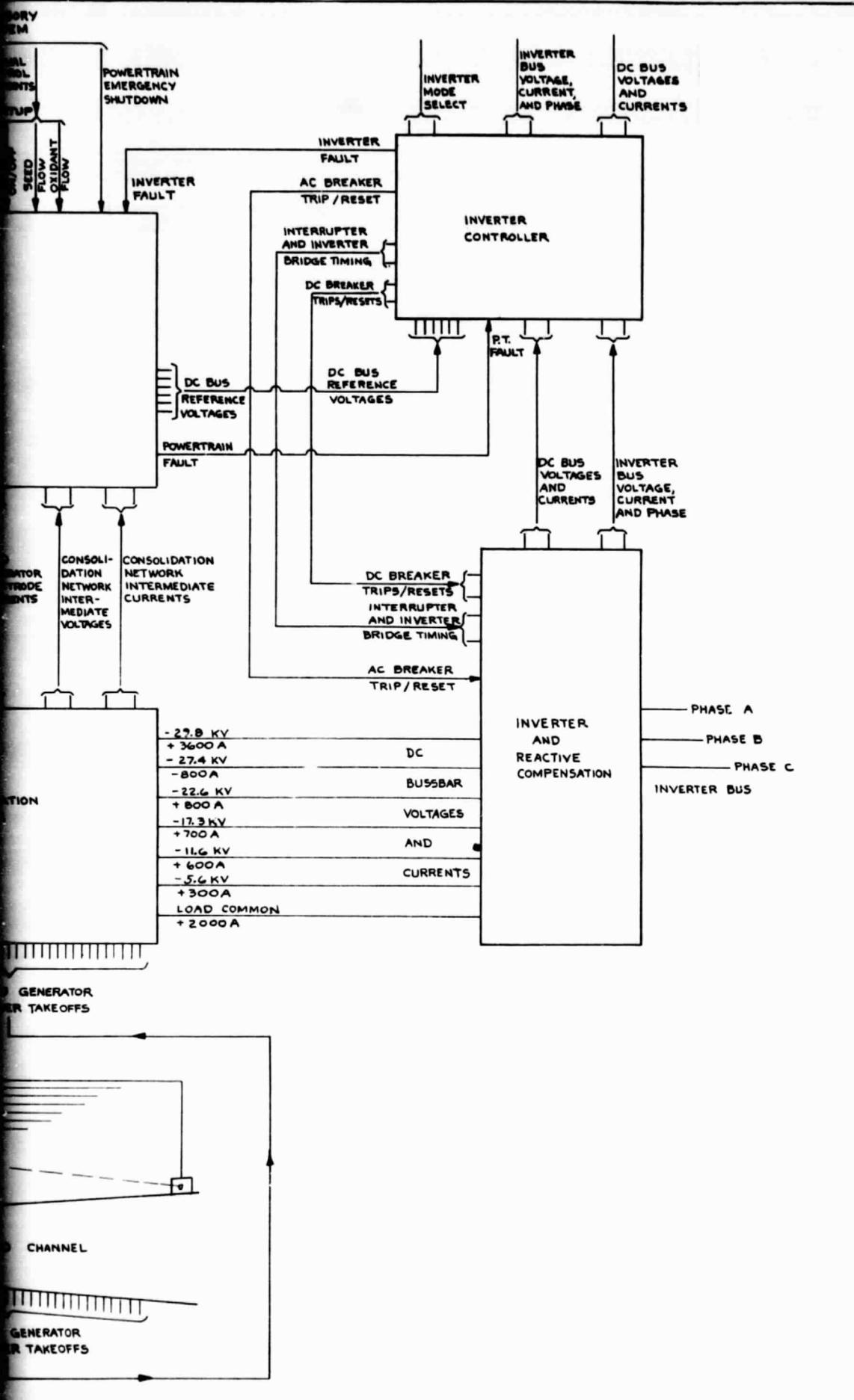
SDD-1400 MHD DIFFUSER, PLAN AND ELEVATION

FOLDOUT FRAME 2

OUTLET END VIEW

SYN	NO	REVISION DESCRIPTION	APPROV
DOE - NASA			
MHD PROJECT OFFICE		LEWIS RESEARCH CENTER CLEVELAND, OHIO 44135	
PROJECT: MAGNETOHYDRODYNAMICS ENGINEERING TEST FACILITY			
DRAWING TITLE: CONCEPTUAL DESIGN - 200MWE MHD POWER TRAIN SYSTEM MHD DIFFUSER AND TRANSITION SECTION SUPPORT STRUCTURE PLAN AND ELEVATION			
APPD. MROZ/BERCAW		DATE 2-23-81	
SCALE NONE	DRAWING NUMBER	SDD-1402	REV

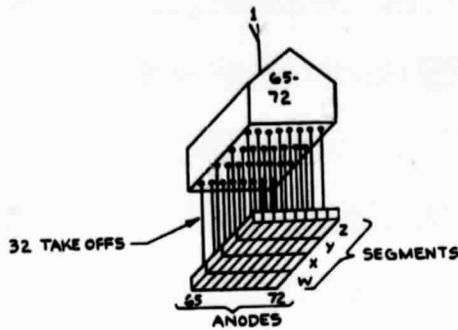




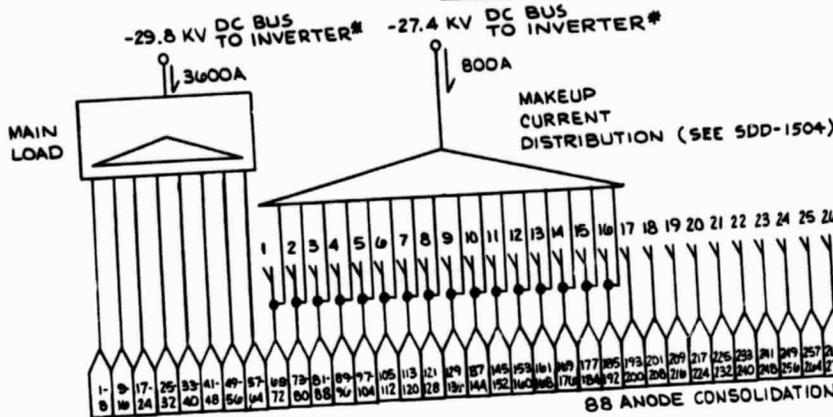
GENERAL NOTES

FOLDOUT FRAME 2

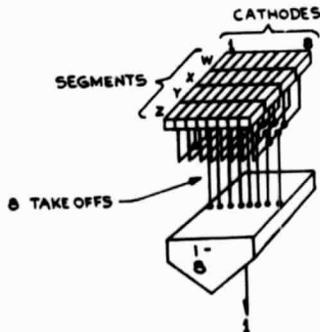
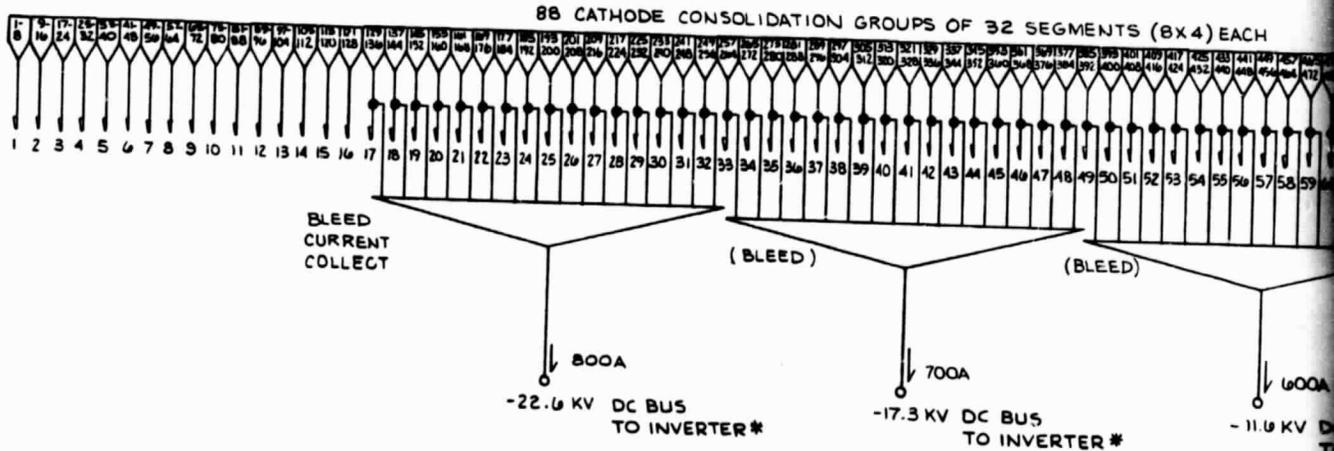
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DOE - NASA			
MHD PROJECT OFFICE		LEWIS RESEARCH CENTER CLEVELAND OHIO 44135	
PROJECT: MAGNETOHYDRODYNAMICS ENGINEERING TEST FACILITY			
DRAWING TITLE: CONCEPTUAL DESIGN - 200 MWE MHD POWER TRAIN SYSTEM MHD CONTROL SUB SYSTEM AND INTERFACE BLOCK DIAGRAM			
APPD. BENTS/BERCAW		DATE 2-23-81	
SCALE NONE	DRAWING NUMBER SDD-1500	REV	



5 STAGE ANODE CONSOLIDATION--
 (2 STAGES PER ELECTRODE ASSEMBLY)
 3 STAGES PER 8 ELECTRODES
 TYPICAL CONSOLIDATION GROUP -- (SEE SDD 1502)



CHANNEL INLET

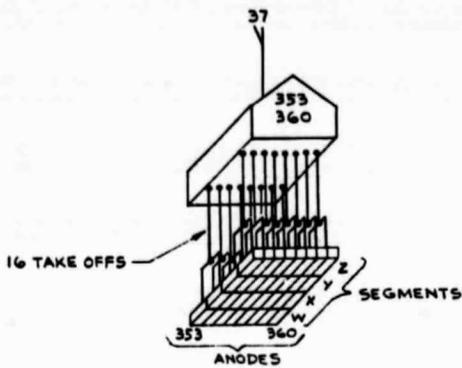


3 STAGE CATHODE CONSOLIDATION--
 (3 STAGES PER ELECTRODE ASSEMBLY)
 3 STAGES PER 8 ELECTRODES
 TYPICAL CONSOLIDATION GROUP -- (SEE SDD-1503)

FOLDOUT FRAME

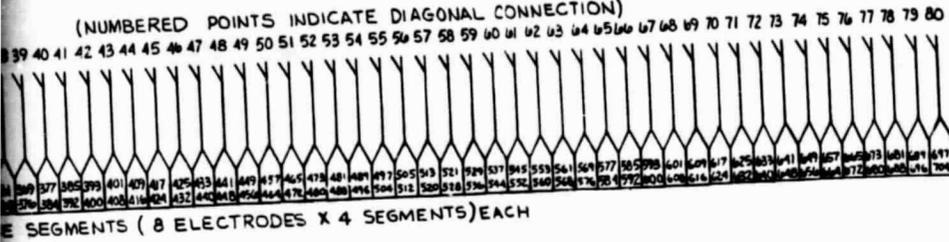
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GENERAL NOTES



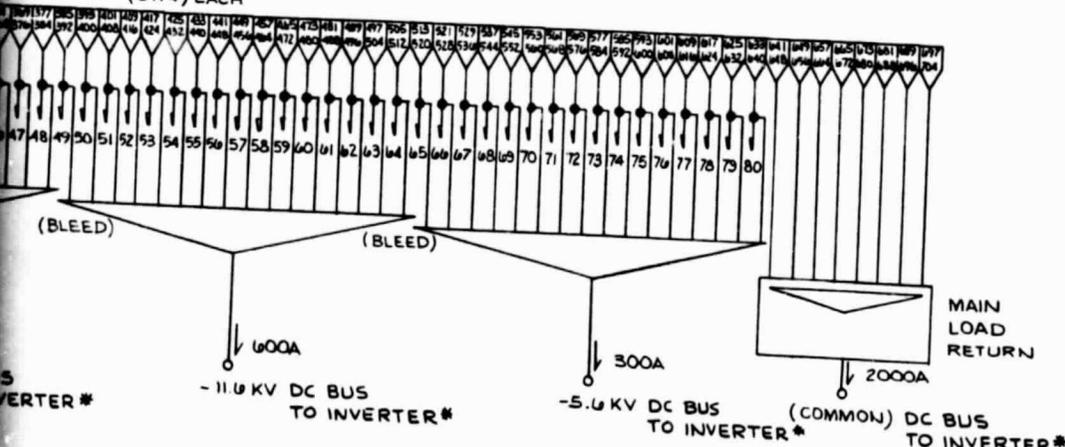
4 STAGE ANODE CONSOLIDATION --
(1 STAGE PER ELECTRODE ASSEMBLY)
3 STAGES PER 8 ELECTRODES
TYPICAL CONSOLIDATION GROUP

(NUMBERED POINTS INDICATE DIAGONAL CONNECTION)



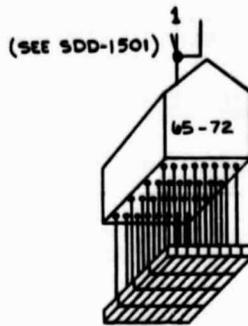
CHANNEL EXIT

SEGMENTS (8x4) EACH



FOLDOUT FRAME 2

SYN	NO	REVISION DESCRIPTION	APPROVE
DOE - NASA			
MHD PROJECT OFFICE		LEWIS RESEARCH CENTER CLEVELAND, OHIO 44135	
PROJECT: MAGNETOHYDRODYNAMICS ENGINEERING TEST FACILITY			
DRAWING TITLE: CONCEPTUAL DESIGN - 200 MWE MHD POWER TRAIN SYSTEM CONSOLIDATION NETWORK CONNECTION DIAGRAM			
APPRO. BENTS/BERCAW		DATE 2-23-81	
SCALE NONE	DRAWING NUMBER SDD-1501	REV	



5 STAGE ANODE CONSOLIDATION
 (2 STAGES PER ELECTRODE ASSEMBLY)
 3 STAGES PER 6 ELECTRODES

DIAGONAL TIE POINT
 (SEE SCJ-503) 1

FROM MAKEUP
 CURRENT
 DISTRIBUTION

PHASE A TRIGGER

PHASE B TRIGGER

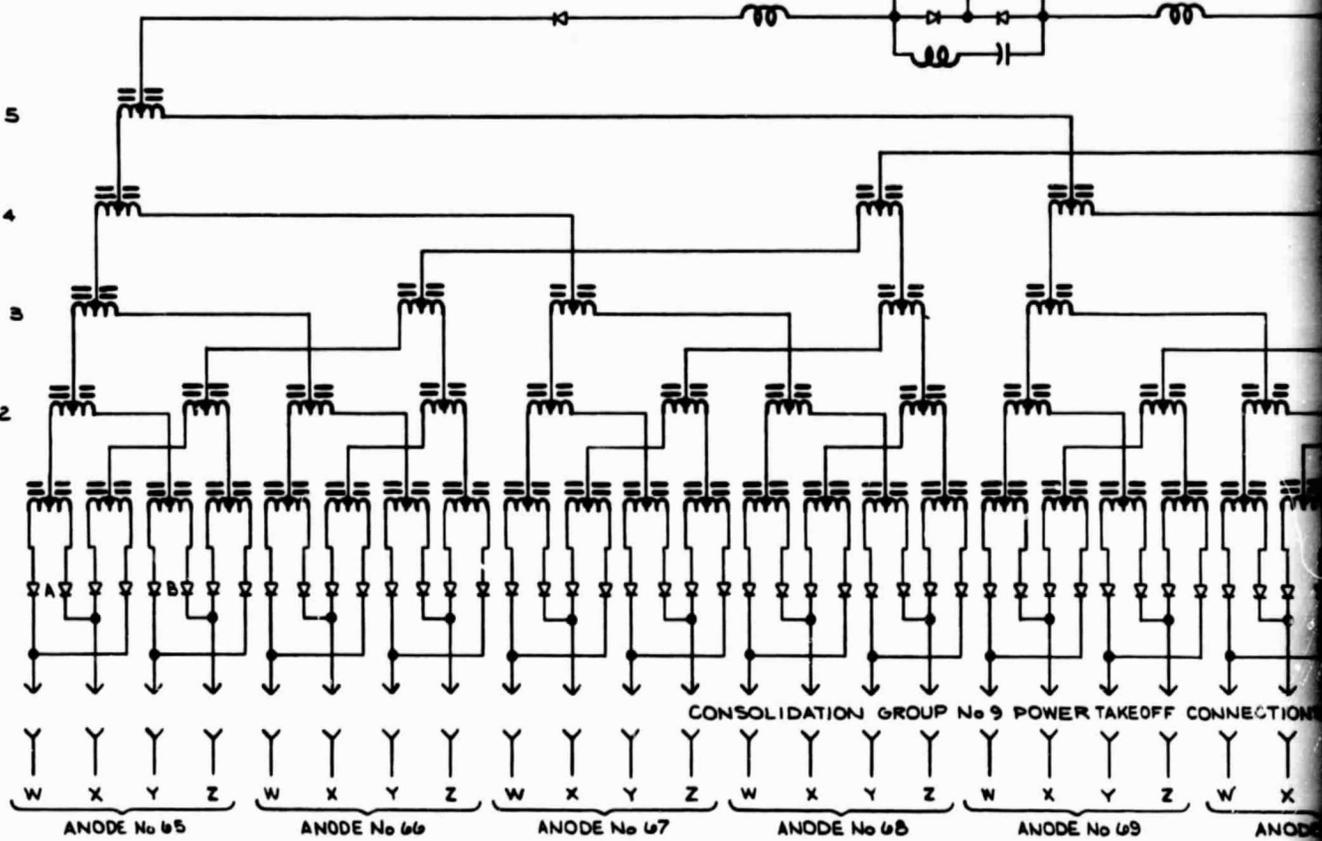
STAGE 5

STAGE 4

STAGE 3

STAGE 2

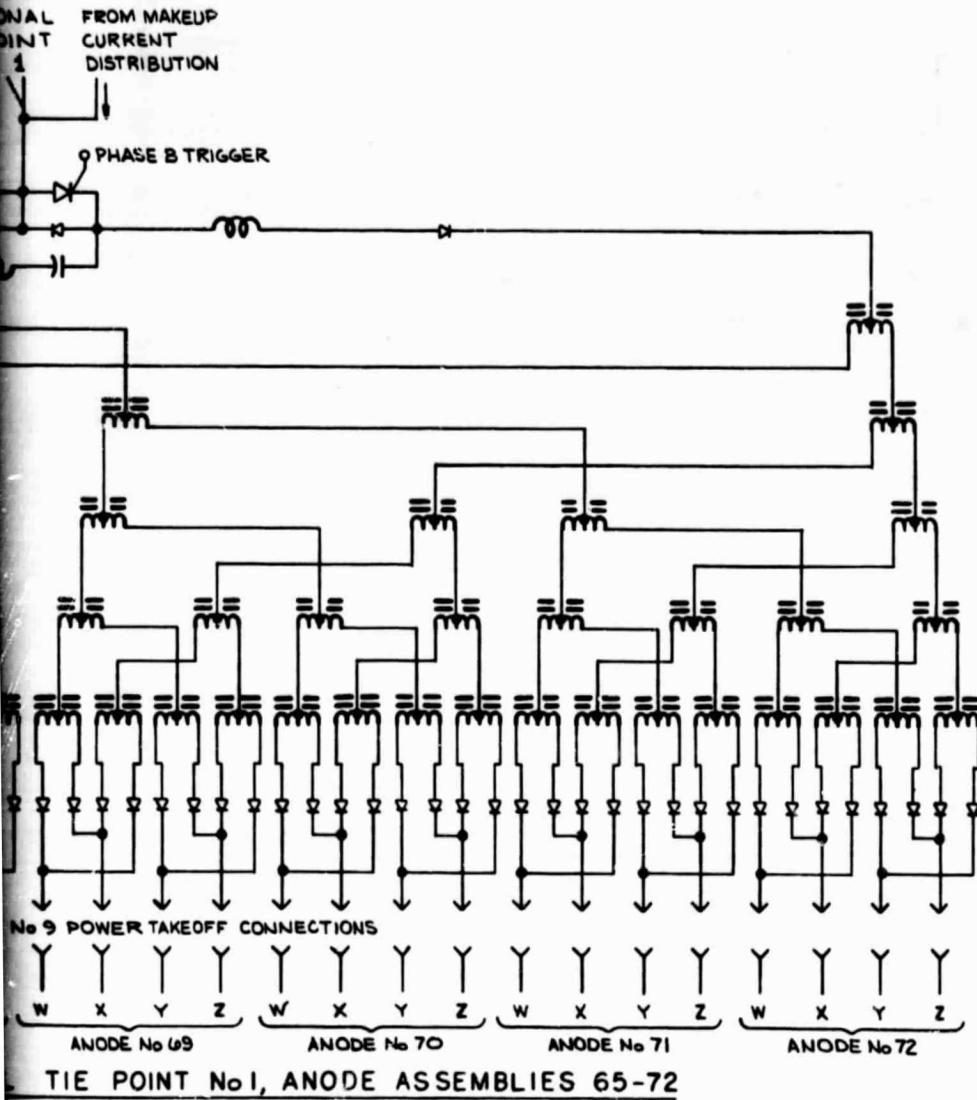
STAGE 1



ANODE CONSOLIDATION GROUP No 9, DIAGONAL TIE POINT No 1, ANODE

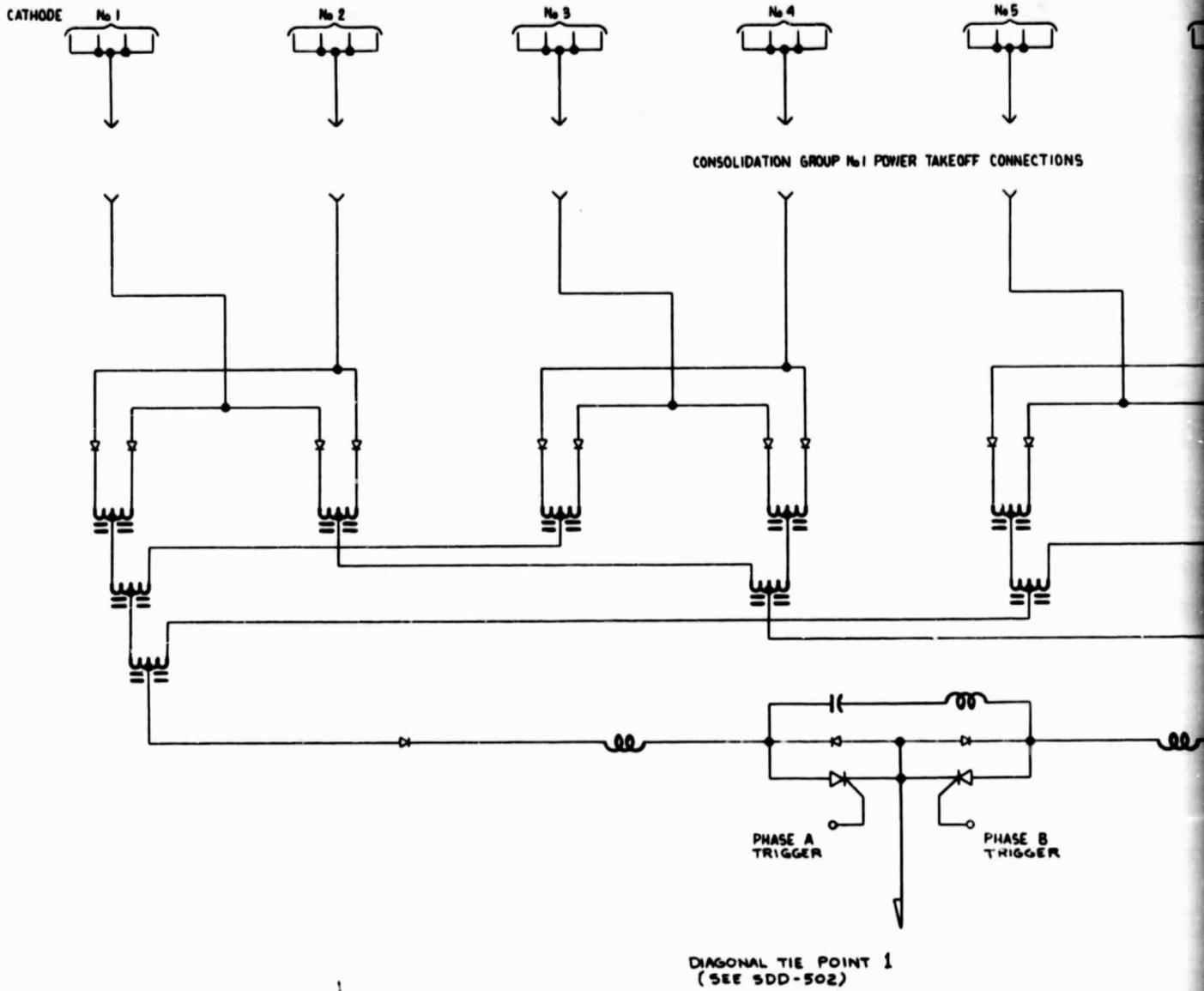
EOLDOUT FRAME

GENERAL NOTES



FOLDOUT FRAME 2

SYN	No	REVISION DESCRIPTION	APPROVE
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MPO PROJECT OFFICE		SYSTEMS MANAGER CENTER CLEVELAND, OHIO 44135	
PROJECT: MAGNETOHYDRODYNAMICS ENGINEERING TEST FACILITY			
DRAWING TITLE: CONCEPTUAL DESIGN - 200 MWE MHD POWER TRAIN SYSTEM CONSOLIDATION NETWORK DETAIL -- 5 STAGE ANODE CONSOLIDATION			
APPD. BENTS/BERCAW		DATE 2-23-81	
SCALE NONE	DRAWING NUMBER SDD-1502	REV	



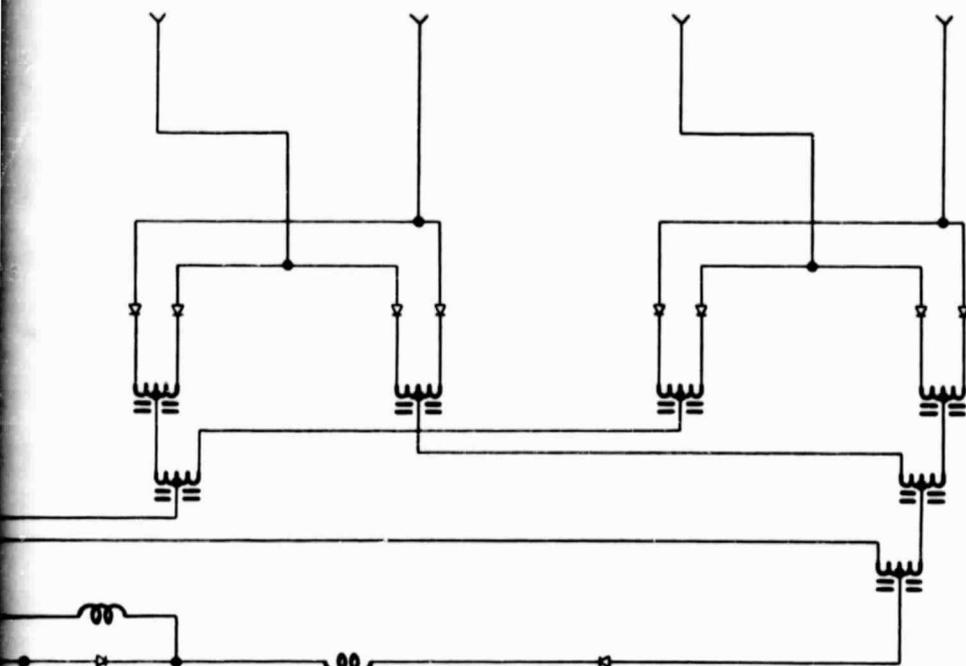
FOLDOUT FRAME

CATHODE CONSOLIDATION No. 1, DIAGONAL TIE POINT No. 1, CATHODE ASSE

GENERAL NOTES

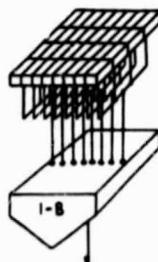


POWER TAKEOFF CONNECTIONS



PHASE B TRIGGER

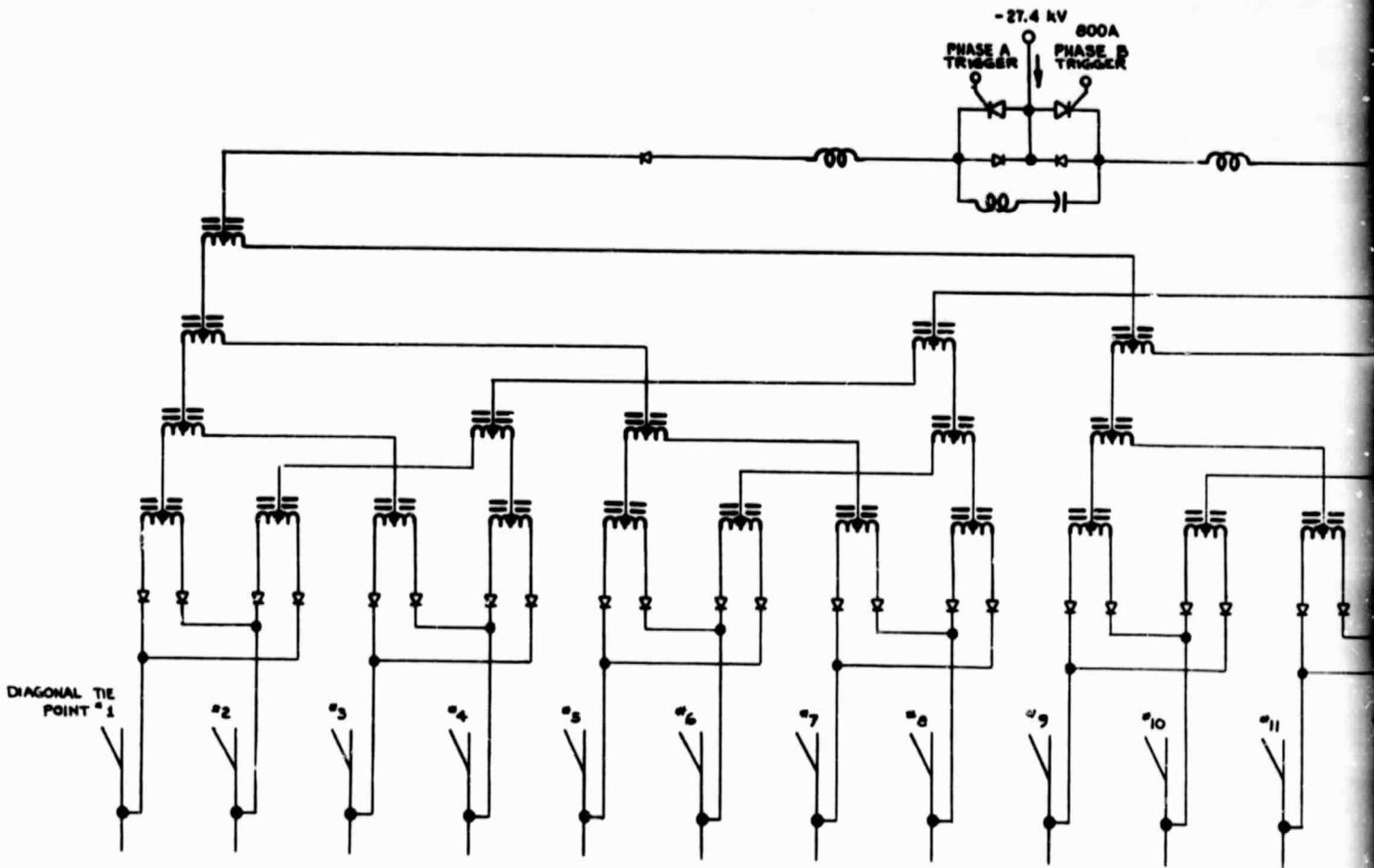
TIE POINT No 1, CATHODE ASSEMBLIES 1-8



3 STAGE CATHODE CONSOLIDATION
 (0 STAGES PER ELECTRODE ASSEMBLY)
 3 STAGES PER 8 ELECTRODES

BOLDOUT FRAME 2

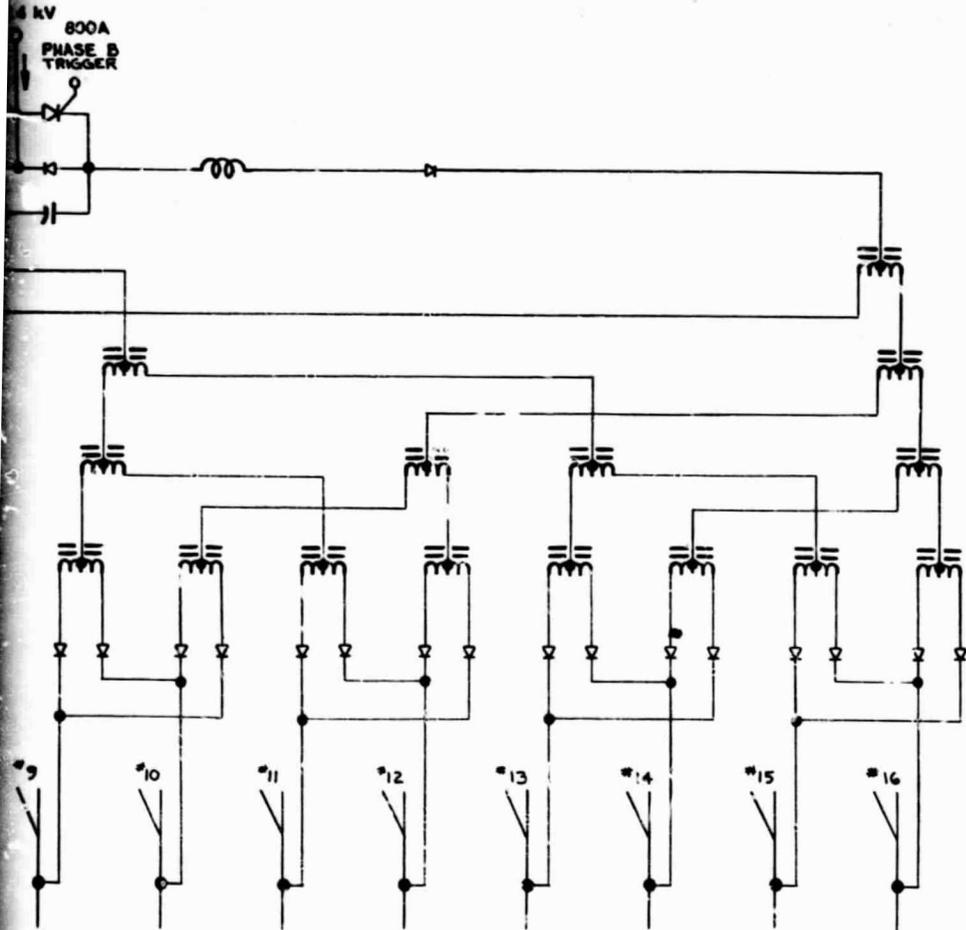
REV	NO	REVISION DESCRIPTION	APPROVE
DOE - NASA			
MHD PROJECT OFFICE		LEHIGH RESEARCH CENTER EASTLEIGH, OHIO 44022	
PROJECT: MAGNETOHYDRODYNAMICS ENGINEERING TEST FACILITY			
DRAWING TITLE: CONCEPTUAL DESIGN - 200 MWE MHD POWER TRAIN SYSTEM CONSOLIDATION NETWORK DETAIL -- 3 STAGE CATHODE CONSOLIDATION			
APP. BENTS/DERCAW			DATE 2-23-81
SCALE NONE	DRAWING NUMBER	SDD-1503	
			REV



ANODE CONSOLIDATION GROUPS 9-25

FOLDOUT FRAME

GENERAL NOTES



ION GROUPS 9-25

2
FOLDOUT FRAME

SYM	NO	REVISION DESCRIPTION	APPROVE
DOE - NASA			
MHD PROJECT OFFICE		LEWIS RESEARCH CENTER CLEVELAND OHIO 44133	
PROJECT: MAGNETOHYDRODYNAMICS ENGINEERING TEST FACILITY			
DRAWING TITLE: CONCEPTUAL DESIGN - 200 MWE MHD POWER TRAIN SYSTEM CONSOLIDATION NETWORK DETAIL -- MAKE UP CURRENT DISTRIBUTION			
APPD. BENTS/BERCAW		DATE 2-23-81	
SCALE NONE	DRAWING NUMBER SDD-1504	REV	

Appendix B
SDD 502
February 20, 1981

APPENDIX B

OPTIMIZATION OF AN MHD CHANNEL FOR THE ETF CONCEPTUAL DESIGN

OPTIMIZATION OF AN MHD CHANNEL FOR THE ETF CONCEPTUAL DESIGN

Appendix B
SDD 502
February 20, 1981

The conceptual design of the Engineering Test Facility (ETF) is being defined¹ and managed by NASA Lewis Research Center for the Department of Energy (DOE). Toward this goal, an effort has been directed to identify the preliminary design of a 540 MW thermal input, ETF-size channel through the optimization of the performance of the entire MHD system.

Previous studies^{2,3} have considered the optimization of power plant performance in terms of the MHD power (P_{MHD}) or the net power ($P_{NET} = P_{MHD} - P_{CPR}$), where P_{CPR} denotes the MHD cycle compressor power consumption). These analyses, which utilized a modified chemical equilibrium program⁴ and a quasi-one-dimensional channel code², yielded results which applied strictly only to power plants in which the MHD generator is cooled with high temperature boiler feedwater. These analyses have been extended to the case where low temperature boiler feedwater is used to cool the MHD generator. In addition to the normal constraints considered for channel optimization, we have found that the variation of channel heat loss with channel length and the effects of this heat loss on the thermodynamic efficiency of the steam bottoming plant are important in establishing the optimum generator length.

In this appendix, the procedures and computations used to identify the optimum MHD channel for a 540 MW_T ETF-scale plant are presented. Our results show that the best plant performance is obtained for a channel length of ≈ 12 m. In the initial ETF studies^{5,6} the channel length was 16 m. This reduction in channel length could result in considerable savings in both the channel and magnet costs. In addition to the identification of the optimum channel parameters, possible trade-offs between the level of oxygen enrichment and the electrical stress on the channel are also discussed in this appendix.

Assumed Inlet Conditions

The conditions used in these calculations are consistent with those designated for the ETF¹. The plant is sited in Montana (elevation = 3300 ft., ambient pressure = 0.89 atm, and mean ambient temperature = 42°F). The fuel is Montana Rosebud coal dried to 5% moisture and the oxidant is oxygen-enriched air preheated to 1100°F. Two levels of oxygen enrichment, 30 and 35% oxygen by volume, were considered. The combustion gas conditions are computed for an oxygen stoichiometric ratio of 0.9, with a combustor-nozzle heat loss of 5% of the total thermal input (the coal higher heating value). The seed is injected as K_2CO_3 with the potassium being 1% of the total mass flow rate.

Optimization Procedure

The power plant performance is maximized with respect to the parameters B_{MAX} , Ma , L , per cent O_2 enrichment, P_C , and K_{MIN} , as well as the axial profiles of B and K and the channel design constraints. The channel design constraints² and the limiting values used for much of the study are:

1. axial electric field, $E_x < E_{x,MAX} = 2.5$ kV/m
2. transverse electrical field, $E_y < E_{y,MAX} = 4.0$ kV/m
3. transverse current density, $J_y < J_{y,MAX} = 10$ kA/m²
4. Hall parameter, $\beta < \beta_{MAX} = 4$

This choice of limiting values approximately represents the current technology status^{7,8} of channel hardware based on limited endurance tests. The electrical stresses resulting from too high a value of E_x , E_y , or J_y can cause interelectrode and/or sidewall breakdown. If β is too high, non-uniformities and current leakage paths within the MHD channel can be amplified and the generator performance will be degraded. In the analysis, the design constraint limits are maintained by varying the B -field and load parameter axial profiles² along the channel. The channel is operated in the Faraday mode at nearly constant Mach number.

To obtain the channel design conditions for a prescribed channel length and an assumed diffuser pressure recovery coefficient (0.46), several iterations are required to meet the prescribed diffuser exit pressure. For a range of combustor pressures, P_C , the correct exit condition is obtained by adjusting the minimum load parameter (K_{MIN}). For each P_C and K_{MIN} combination the channel calculations give the performance parameters required for the overall plant calculation; i.e., the total MHD power and the total channel heat loss (Q_{MHD}). Also calculated are the axial profiles of the plasma conditions and the channel loft. By assuming a polytropic efficiency (0.898) and pressure drop fraction (0.1), the cycle compressor power consumption is calculated. Using the specific power of the air separation unit (204 KWh/equivalent ton of pure oxygen), the ASU compressor power is also computed for the level of oxygen enrichment under consideration. Finally, the bottoming steam cycle efficiency (η_S) and the overall thermodynamic plant efficiency (η_{TH}) are obtained. The combustor pressure which gives the maximum plant efficiency is then selected. The value of Q_{MHD} has a direct effect on the value of η_S because the channel is assumed to be cooled with low temperature boiler feedwater (< 300°F). Using such low temperature feedwater for cooling the channel requires the elimination of some low temperature regenerative feedwater heaters which could otherwise be used, and the result is that η_S decreases with increasing Q_{MHD} .

Results

Hundreds of calculations were performed to cover a wide variation of the parameters considered in order to identify the channel that will result in the best η_{TH} . These calculations were organized into two sets. In the first set, the axial profile of the magnetic field and load parameter were adjusted to keep the electrical field, current, and Hall parameter constraints within limits without concern for magnet constructability. From these calculations an optimum B-field profile was selected and a preliminary magnet design approximating this profile was obtained from the Francis Bitter National Magnet Laboratory⁹. A second set of calculations was then performed with the B-field profile fixed at the designed profile. The results are summarized in two sets of data: thirteen "computer generated B" cases and eighteen "National Laboratory B" cases, respectively.

Computer Generated-B Cases: Tables 1 to 3

To illustrate the optimization for case 1 refer to Table 1 where data for subcases 1-1 thru 1-5 are tabulated for a common $L = 10$ m and 30% O_2 enrichment. The combination of P_C and K_{MIN} has been iterated and the values satisfying the prescribed diffuser exit pressure are shown in Figure 1. Sub-case 1-1 indicates the highest thermodynamic cycle efficiency in the set and is optimal. In Figure 1 the highest η_{TH} (41.23%) occurs at $P_C = 4.2$ atm. For the 10 M channel P_C cannot be increased beyond 4.2 atm without causing a lowering of K_{MIN} below 0.677 and this in turn will cause $E_{x, MAX}$ to be exceeded. Typical axial profiles of B , E_x , E_y , J_y , K , β , and P_{MHD} are plotted in Figure 2. All the remaining cases in Tables 1 to 3 represent optimum cases arrived at in the manner illustrated for Case 1.

Comparing cases 1 to 3 for $L = 10$, 12, and 15 m with 30% O_2 enrichment, the 12 M channel is found to have the highest η_{TH} (41.37%), while for 35% O_2 enrichment (cases 4 to 6) the highest η_{TH} (41.44%) is found for the 10 m channel. The variations of η_{TH} with channel length are presented in Figure 3 for the two levels of oxygen enrichment.

The dependence of η_{TH} on B_{MAX} and Ma is shown in Figure 4. At $B_{MAX} = 6$ Tesla, the optimum performance is obtained at a Mach number of 0.9. Lowering B_{MAX} lowers the overall plant efficiency and shifts the optimum Mach number to supersonic values. These results, also illustrated in Tables 2 and 3, indicate that the final selection of the optimum configurations may depend upon a tradeoff study between magnet cost and system efficiency. Another factor which might result in better performance for low B-fields is a change in channel length, which was held constant in this portion of the study.

National Magnet Laboratory-B Cases: Table 4

The previous cases provided magnetic field profiles designed from the channel performance point of view. Together with the channel loft they provided the basic requirements for a detailed magnet design. These detailed designs were supplied by the National Magnet Laboratory⁹. The B-field profiles supplied are shown in Figure 5 for active lengths of 10, 12, and 15 m. The power plant performance was then maximized using these National Magnet Laboratory-B profiles and oxygen enrichment levels of 30% (cases 14 to 22) and 35% (cases 23 to 31) by volume. The results are given in Table 4. The decrease in η_{TH} compared to the previous computer designed-B cases is within 0.32-0.85 of a point.

The effect of variations in $E_{x,MAX}$ on η_{TH} was also investigated and the results are shown in Figures 6 and 7 for 30% and 35% O₂ enrichment, respectively. From the design point of view, the 35% O₂ enrichment channel is preferable to the 30% O₂ enrichment channel because the optimum performance is obtained at lower values of $E_{x,MAX}$. Furthermore, the Hall electrical field does not reach the critical value until much later in the channel for the higher enrichment case, as shown in Figure 8. This means reduced stress levels for the channel. However, a larger ASU is required for the higher enrichment case.

Concluding Remarks

The initial design parameters (B-field, Combustor Pressure, Length, Load Parameter, Mach Number, and Oxygen Enrichment) of the 540 MW_T ETF (200 MW_e) channel have been adjusted to obtain the maximum plant efficiency. The results are:

1. In the oxidant enrichment range of 30-35%, the conditions of $B_{MAX} = 6$ Tesla, $M_a = 0.9$ and $L = 12$ m yield an overall plant efficiency, $\eta_{th} = 41\%$, which is the highest of all cases surveyed.

2. Repeating the optimization procedure for channels using the National Magnet Laboratory-B profiles has shown little change in η_{TH} from the original computer generated-B channels. However, additional work is required to study the effect of the magnetic field on the transition sections at both ends of the channel.

3. A lower B_{MAX} results in a higher M_a for optimum performance, but results in lower η_{TH} for the same channel length.

4. Higher oxygen enrichment results in a shorter channel and a lower E_x , MAX, but requires a larger air separation plant. Consequently, the selection of the oxygen enrichment level still depends upon further study of the air separation plant, especially on the economy of size.

5. When the effects on the bottom cycle efficiency of cooling the channel with low temperature feedwater is taken into account, optimum performance is obtained at significantly shorter channel lengths than were previously thought necessary.

Nomenclature:

B	Magnetic field, tesla
E	Electric field, kV/m
J	Electrical current density, kA/m ²
K	Faraday load parameter or factor
L	Channel length, m
Ma	Mach number
O ₂	Oxygen enrichment, % by volume
P	Pressure, atm
P	Electrical power, MW
u	Velocity, km/S
Q	Heat loss in the channel, MW
β	Hall Parameter
η	Thermodynamic cycle efficiency

Subscript:

ASU	Air Separation Unit
C	Combustor
CPR	MHD cycle compressor
MAX	Maximum; critical
MIN	Minimum
NET	Net
S	Steam Bottoming Cycle
TH	Overall Cycle of MHD/Steam Plant
x	Axial
y	Transverse

References

1. Bercaw, R. W. and G. R. Seikel, "Engineering Test Facility Design Definition," NASA TM-81499, 7th International Symposium on Engineering Aspects of MHD, 1980.
2. Pian, C. C. P.; Seikel, G. R.; and Smith, J. Marlin, "Performance Optimization of an MHD Generator with Physical Constraints," NASA TM-79172, 14th Intersociety Energy Conversion Engineering Conference Symposium, 1979.
3. Pian, C. C. P.; Staiger, P. J.; and Seikel, G. R., "MHD Performance Calculations with Oxygen Enrichment," NASA TM-79140, 18th Symposium on Engineering Aspects of MHD, 1979.
4. McBride, B. J. and Gordon, S., "Computer Program for Calculations of Complex Chemical Equilibrium Compositions, Rocket Performance, Incident and Reflected Shocks, and Chapman-Jouquet Detonations," NASA SP-273, 1976.
5. Avco Everett Research Lab., Inc., "Engineering Test Facility Conceptual Design," Final Reports DOE/FE/2614-3, November 1979.
6. General Electric Company, "MHD-ETF Program Final Report," DOE/FE/2613-7, October 1979.
7. Kessler, R., "Open-Cycle MHD Generator Channel Development," 15th International Engineering Conversion Engineering Conference Symposium, 1980.
8. 7th International Conference MHD Electric Power Generation Symposium, Vol. I, Sessions D, E, 1980.
9. Private communication with Francis Bitter National Magnet Lab, MIT, Cambridge, Massachusetts, 1980.

TABLE 1: COMPUTER GENERATED-B CASES FOR $B_{MAX}=6$ (TESLA); $M_a=0.9$;
 $L=10, 12, 15$ (M); AND $O_2=30, 35$ (Z-VOL)

CASE NO	VOL Z O2	PRODUCT MASS FLOW KG/S	FINAL PRODUCT MASS FLOW KG/S	OXIDANT MASS FLOW KG/S	CHANNEL LENGTH M	COMBUSTOR PRESSURE ATM	MHD POWER HJE	CHANNEL HT LOSS MWT	CYCLE O2 COMPRES			BOTTOM CYCLE			GROSS THERM		
									COMBUSTOR PRESSURE	HT LOSS	POWER MW	COMPRES POWER MW	INPUT MWT	EFF %	STM CYC	OUTPUT MWT	EFF %
1-1	30.0	133.0	161.10	110.50	10.090	4.2	88.21	17.34	21.21	11.62	426.55	39.40	135.21	539.81	222.5	41.23	
1-2	30.0	133.0	161.10	110.50	10.010	4.1	87.64	17.32	20.82	11.62	426.72	39.40	135.68	539.81	222.4	41.21	
1-3	30.0	133.0	161.10	110.50	10.000	4.0	87.03	17.45	20.42	11.62	426.93	39.39	136.14	539.81	222.3	41.18	
1-4	30.0	133.0	161.10	110.50	10.010	3.9	86.31	17.60	20.01	11.62	427.25	39.38	136.64	539.81	222.1	41.14	
1-5	30.0	133.0	161.10	110.50	10.040	3.8	85.59	17.75	19.59	11.62	427.64	39.38	137.16	539.81	221.8	41.09	
2	30.0	133.0	161.10	110.50	12.050	4.7	92.53	20.58	23.05	11.62	424.07	39.23	131.69	539.81	223.3	41.37	
3	30.0	133.0	161.10	110.50	15.040	5.1	95.87	25.90	24.48	11.62	422.16	38.90	128.12	539.81	223.0	41.32	
4	35.0	117.5	145.57	95.37	9.970	5.8	97.50	23.28	22.93	15.37	422.86	39.07	126.90	539.19	223.4	41.44	
5	35.0	117.5	145.57	95.37	12.000	6.4	100.56	28.56	24.58	15.37	421.46	38.71	123.21	539.19	222.8	41.31	
6	35.0	117.5	145.57	95.37	14.930	7.3	102.69	36.48	26.75	15.37	421.49	38.08	118.39	539.19	220.1	40.81	

TABLE 2: COMPUTER GENERATED-B CASES FOR $B_{MAX}=5$ (TESLA); $L=12$ (M);

$O_2=30$ (%-VOL); AND $Ma=0.95-1.15$

CASE NO	VOL O2	PRODUCT MASS FLOW KG/S	FINAL PRODUCT MASS FLOW KG/S	OXIDANT MASS FLOW KG/S	CHANNEL LENGTH M	COMBUSTOR PRESSURE ATM	MHD POWER MUE	CHANNEL HT LOSS MWT	CYCLE COMPRES POWER MW	O2 COMPRES POWER MW	BOTTOM CYCLE			CYC STN EFF	CYC STN MUE	CYC COAL INPUT MWT	CYC COAL OUTPUT MWT	CYC COAL INPUT MWT	CYC COAL OUTPUT MWT	GROSS THERM AC CYC	MACH NO
											INPUT MWT	EFF	Z								
7	30.0	133.0	161.10	110.50	11.990	4.3	83.29	21.66	21.60	11.62	431.86	39.20	136.05	539.81	218.5	40.48	0.95				
8	30.0	133.0	161.10	110.50	11.990	4.3	83.54	20.13	21.60	11.62	431.61	39.27	136.28	539.81	219.0	40.57	1.05				
9	30.0	133.0	161.10	110.50	12.040	4.3	83.21	19.15	21.60	11.62	431.94	39.32	136.61	539.81	219.0	40.57	1.10				
10	30.0	133.0	161.10	110.50	12.070	4.2	81.60	18.30	21.21	11.62	433.16	39.36	137.67	539.81	218.5	40.47	1.15				

TABLE 3: COMPUTER GENERATED-B CASES FOR $B_{MAX}=4$ (TESLA); $L=12$ (M);

$O_2=30$ (%-VOL); AND $Ma=1.15-1.35$

CASE NO	VOL O2	PRODUCT MASS FLOW KG/S	FINAL PRODUCT MASS FLOW KG/S	OXIDANT MASS FLOW KG/S	CHANNEL LENGTH M	COMBUSTOR PRESSURE ATM	MHD POWER MUE	CHANNEL HT LOSS MWT	CYCLE COMPRES POWER MW	O2 COMPRES POWER MW	BOTTOM CYCLE			CYC STN EFF	CYC STN MUE	CYC COAL INPUT MWT	CYC COAL OUTPUT MWT	CYC COAL INPUT MWT	CYC COAL OUTPUT MWT	GROSS THERM AC CYC	MACH NO
											INPUT MWT	EFF	Z								
11	30.0	133.0	161.10	110.50	12.000	4.0	72.05	19.88	20.42	11.62	441.91	39.31	141.66	539.81	213.0	39.45	1.15				
12	30.0	133.0	161.10	110.50	12.070	4.1	72.09	17.79	20.82	11.62	442.27	39.41	141.84	539.81	213.2	39.50	1.25				
13	30.0	133.0	161.10	110.50	12.170	3.8	68.99	16.00	19.59	11.62	444.15	39.49	144.20	539.81	212.5	39.37	1.35				

TABLE 4: NATIONAL MAGNET LABORATORY-B CASES FOR $B_{MAX} = 6$ (TESLA);

$M_a = 0.9$; $L = 10, 12, 15$ (M); AND $O_2 = 30, 35$ (XVOL)

CASE NO	VOL O2	P-PRODUCT MASS FLOW KG/S	FINNL PRODUCT MASS FLOW KG/S	OXIDANT CHANNEL LENGTH M	COMBUSTOR PRESSURE ATM	MHD POWER NME	CHANNEL HT LOSS MWT	CYCLE COMPRES		O2 COMPRES		BOTTOM CYCLE STN EFF		CYC STN OUTPUT NME		CYC COAL INPUT MWT		GROSS THERM AC POWER NME		CYC EFF	E _{X-MAX} KV/N
								POWER MW	EFF	POWER MW	EFF	INPUT MWT	EFF	OUTPUT NME	INPUT MWT	POWER NME	EFF				
14	30.0	133.0	161.10	110.50	9.890	4.0	84.61	17.60	20.42	11.62	429.35	39.39	137.08	539.81	229.8	40.91	2.5				
15	30.0	133.0	161.10	110.50	10.000	3.5	81.01	17.06	18.30	11.62	430.84	39.42	139.91	539.81	220.1	40.78	2.0				
16	30.0	133.0	161.10	110.50	10.360	3.0	74.33	17.14	15.97	11.62	435.18	39.42	143.98	539.81	217.6	40.30	1.5				
17	30.0	133.0	161.10	110.50	12.000	4.5	88.62	21.39	22.36	11.62	427.28	39.20	133.51	539.81	221.2	40.99	2.5				
18	30.0	133.0	161.10	110.50	11.990	3.9	85.95	20.26	20.01	11.62	427.61	39.26	136.23	539.81	221.3	41.00	2.0				
19	30.0	133.0	161.10	110.50	11.960	3.3	79.31	19.55	17.16	11.62	431.40	39.30	140.75	539.81	219.3	40.62	1.5				
20	30.0	133.0	161.10	110.50	14.620	5.0	90.49	26.21	24.13	11.62	427.19	38.90	130.43	539.81	220.0	40.76	2.5				
21	30.0	133.0	161.10	110.50	14.790	4.5	90.18	24.60	22.36	11.62	425.72	39.00	132.05	539.81	221.3	41.60	2.0				
22	30.0	133.0	161.10	110.50	15.180	3.7	84.67	24.39	19.17	11.62	428.05	39.02	136.23	539.81	220.1	40.76	1.5				
23	35.0	117.5	145.57	95.37	9.880	5.5	92.46	23.54	22.12	15.37	427.09	39.07	129.36	539.19	220.9	40.97	2.5				
24	35.0	117.5	145.57	95.37	9.980	5.1	92.23	22.11	20.98	15.37	426.18	39.15	130.51	539.19	221.8	41.14	2.0				
25	35.0	117.5	145.57	95.37	10.070	4.1	86.41	20.98	17.82	15.37	429.85	39.22	135.01	539.19	220.6	40.90	1.5				
26	35.0	117.5	145.57	95.37	11.860	6.0	94.56	28.75	23.46	15.37	426.33	38.72	126.26	539.19	219.9	40.78	2.5				
27	35.0	117.5	145.57	95.37	11.780	5.6	95.52	26.61	22.39	15.37	424.30	38.86	127.13	539.19	221.7	41.12	2.0				
28	35.0	117.5	145.57	95.37	12.080	4.7	92.00	25.09	19.77	15.37	425.20	38.97	130.54	539.19	221.6	41.10	1.5				
29	35.0	117.5	145.57	95.37	14.660	7.2	94.59	36.81	26.40	15.37	429.24	38.11	121.81	539.19	215.5	39.96	2.5				
30	35.0	117.5	145.57	95.37	14.770	6.5	96.72	34.31	24.73	15.37	425.44	38.31	122.86	539.19	218.6	40.54	2.0				
31	35.0	117.5	145.57	95.37	14.830	5.5	96.27	30.88	22.12	15.37	423.28	38.56	125.71	539.19	221.0	40.99	1.5				

$B_{\max} = 6(T)$, $E_{x,\max} = 2.5 (KV/M)$
 $L = 10(M)$, $E_{y,\max} = 4.0 (KV/M)$
 $M_a = 0.9$, $J_{y,\max} = 10.0 (KA/M^2)$
 $O_2 = 30(\text{vol}\%)$, $\beta_{\max} = 4.0$

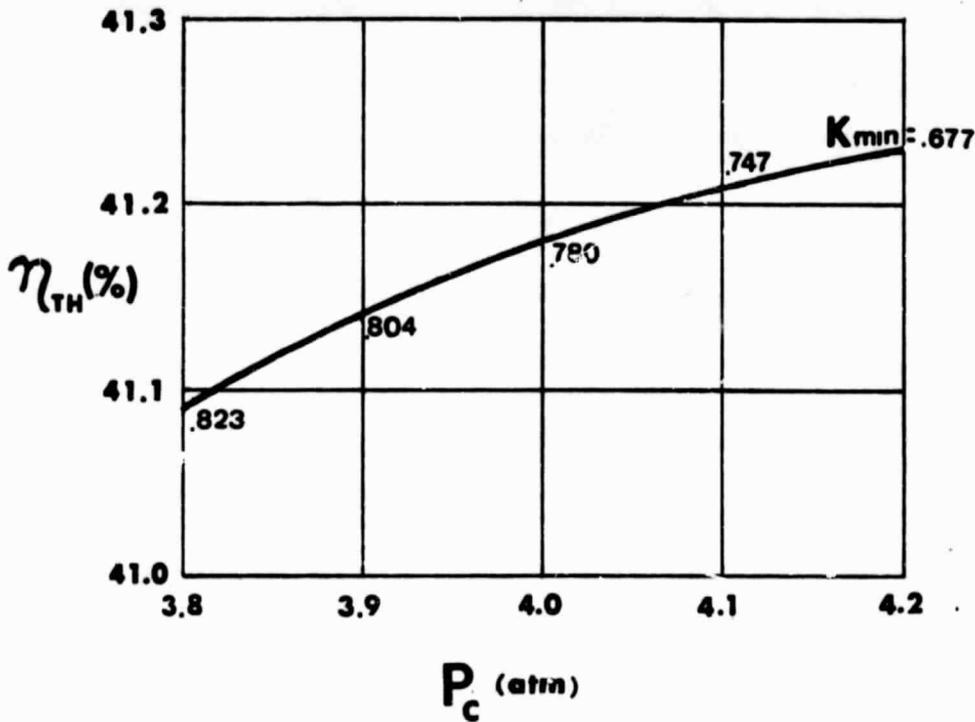


Figure 1. - Plant Efficiency vs. Channel Inlet Stagnation Pressure and Minimum Load Parameter for a 10-Meter (M) Channel.

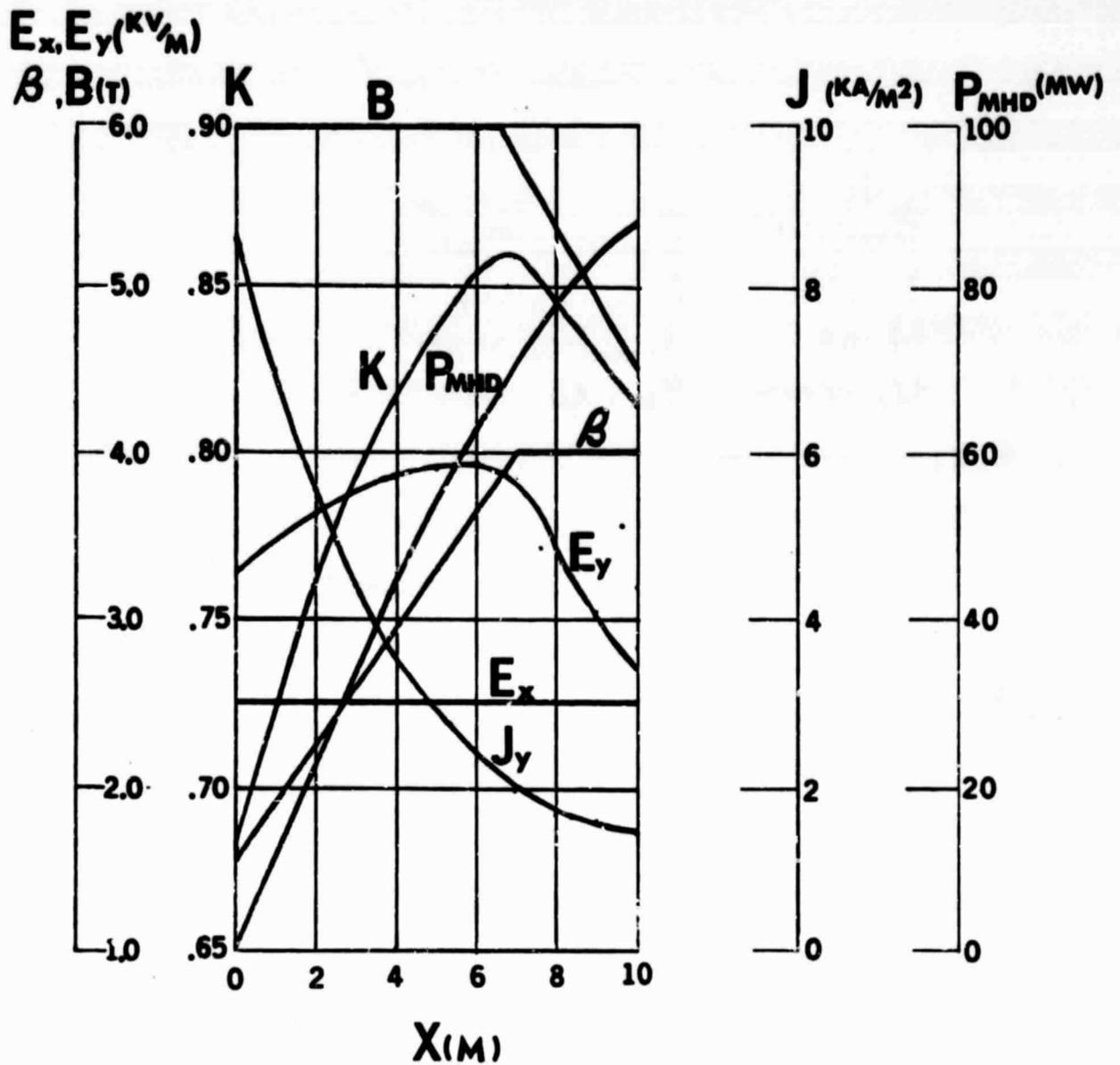


Figure 2. - Typical Axial Variations of B , K , E_x , E_y , J_y , β and P_{MHD} of the 10-Meter (M) Channel (The Optimum Design Case 1-1: $O_2 = 30\%$, $Ma = 0.9$, $P_c = 4.2$ atm).

$B_{max} = 6 \text{ (T)}$ $E_{X,max} = 2.5 \text{ (KV/M)}$
 $M_o = 0.9$ $E_{Y,max} = 4.0 \text{ (KV/M)}$
 $\beta_{max} = 4.0$ $J_{Y,max} = 10.0 \text{ (KA/M}^2\text{)}$

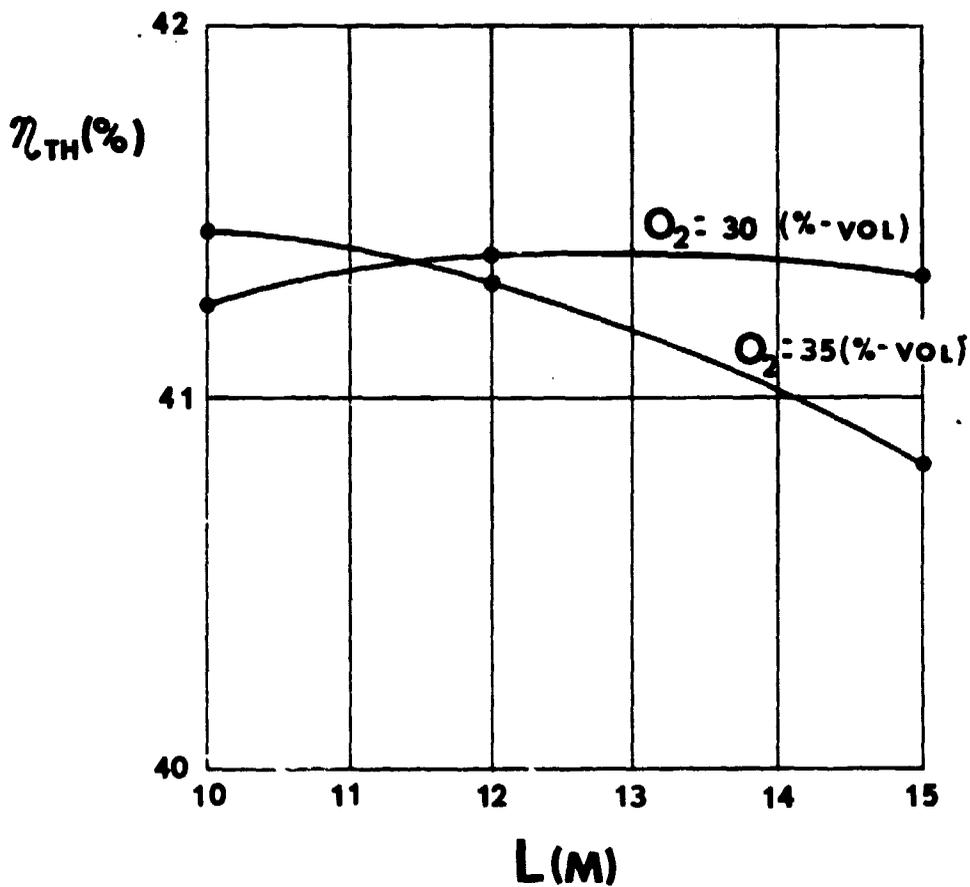


Figure 3. - Optimum Cases for Different Channel Lengths in Meters (M) and Oxygen Enrichments.

C-51

$$L = 12(\text{M})$$

$$O_2 = 30(\text{vol}\%)$$

$$E_{x,\text{max}} = 2.5(\text{KV/M})$$

$$E_{y,\text{max}} = 4.0(\text{KV/M})$$

$$J_{y,\text{max}} = 10.0(\text{KA/M}^2)$$

$$\beta_{\text{max}} = 4.0$$

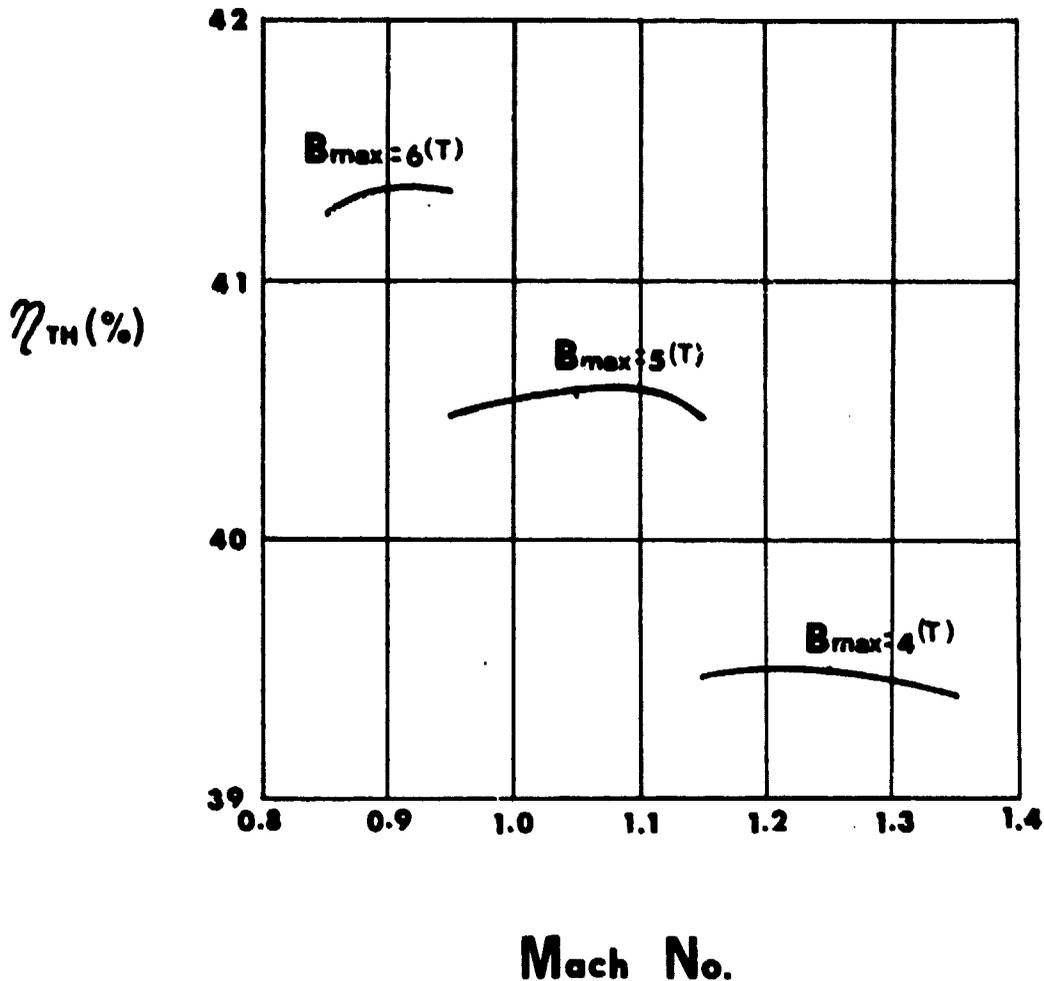


Figure 4. - Plant Efficiency Optimization for $B_{\text{max}} = 4, 5,$ and 6 Tesla (T) at a Range of Channel Mach No. Under Common Constraints.

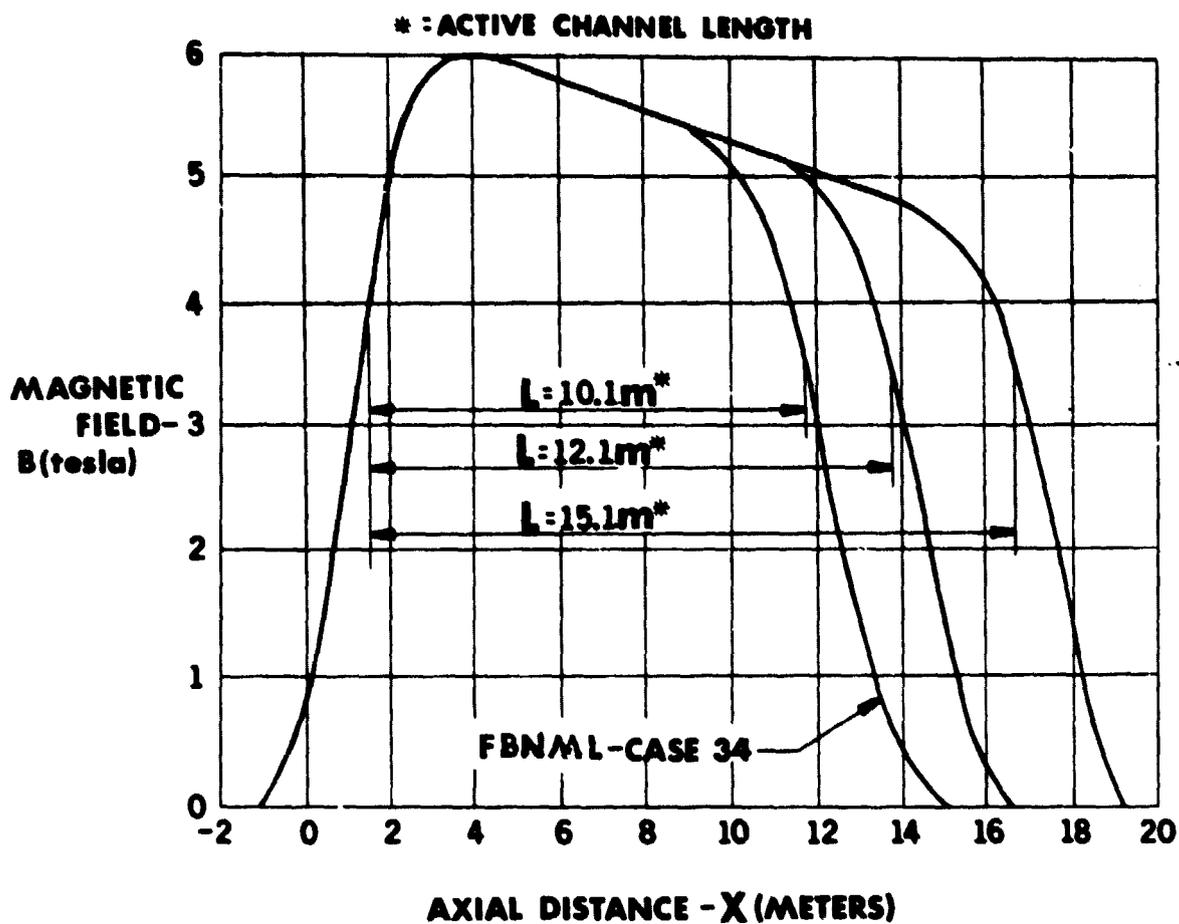


Figure 5. - National Magnet Laboratory Axial Profiles of B-Field.

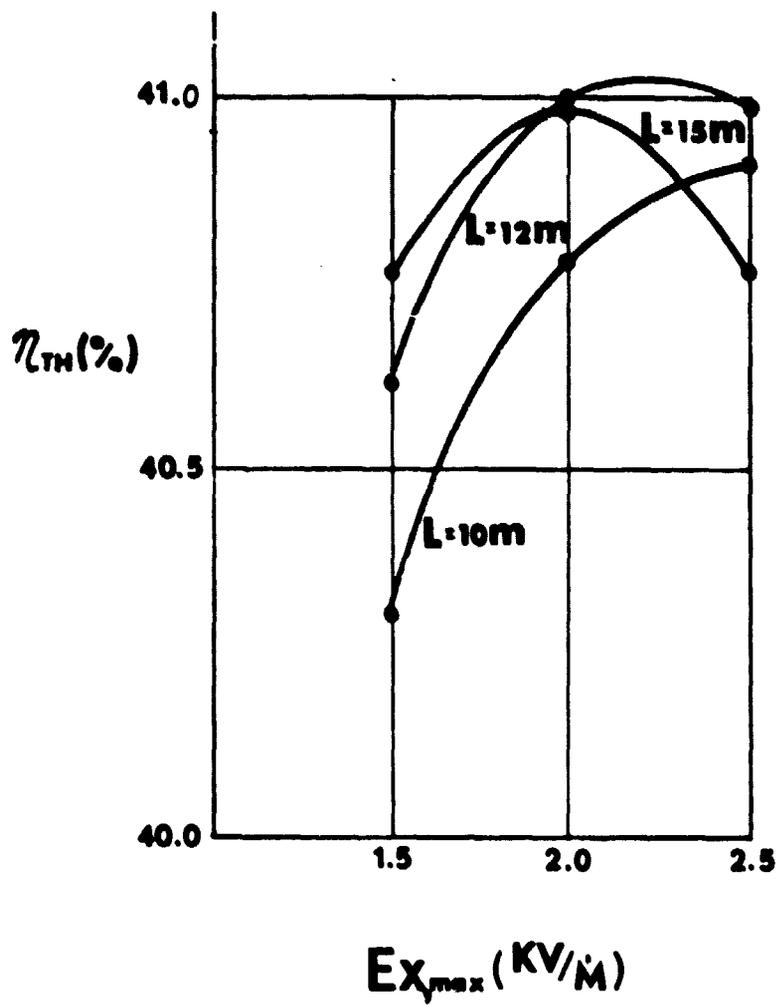


Figure 6. - National Magnet Laboratory-B Cases for 30%-O₂ and Ma = 0.9.

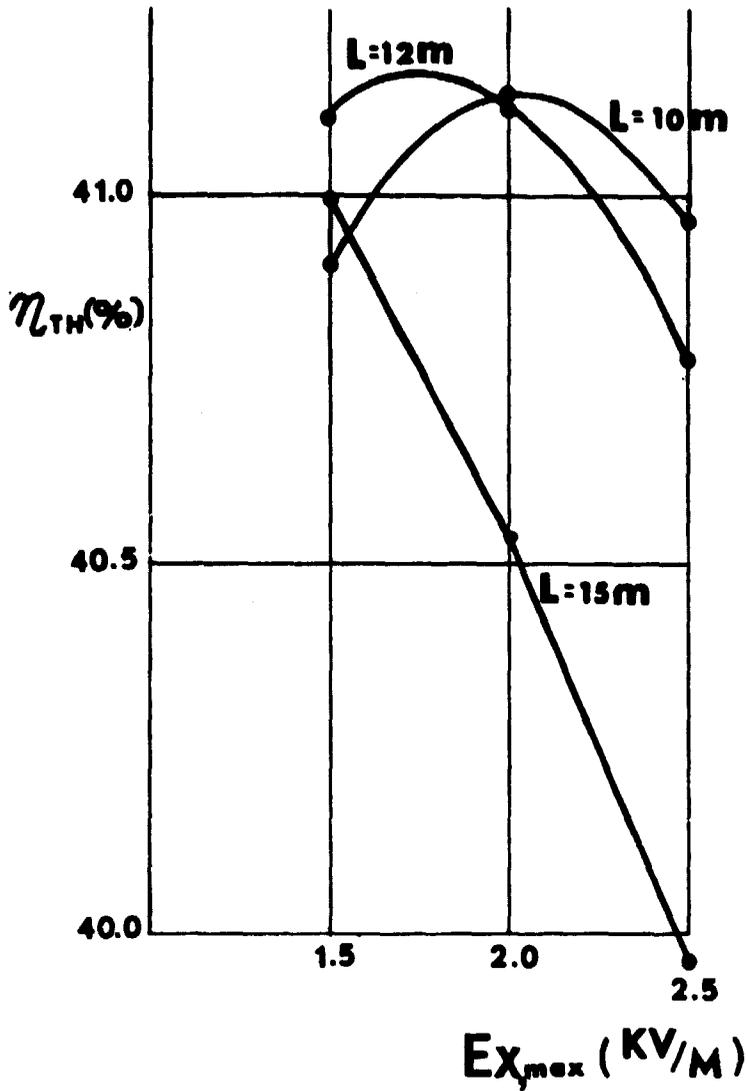


Figure 7. - National Magnet Laboratory - B Cases for 35%-02 and $Ma = 0.9$.

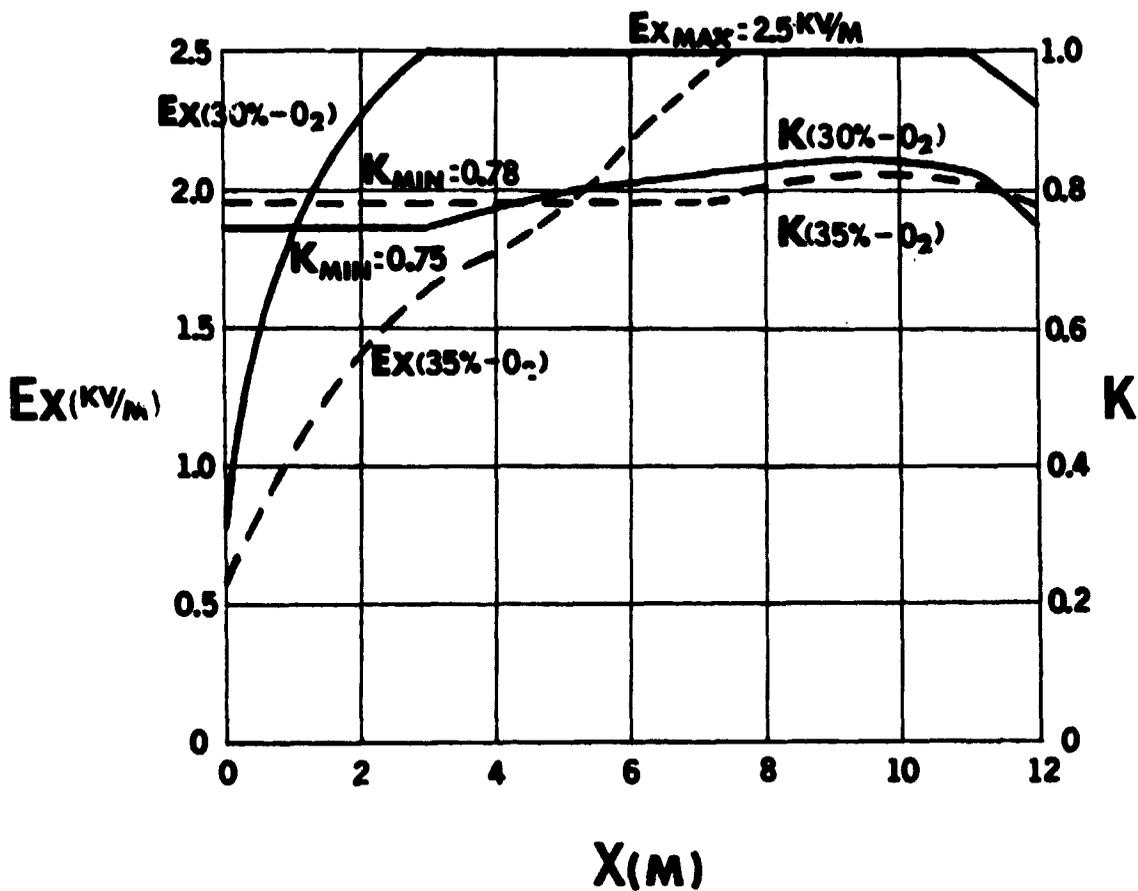


Figure 8. - Axial Development of Hall Electric Field E_x and Loading K (for National Magnet Laboratory -B, $O_2 = 30, 35\%$, and $L = 12M$)

APPENDIX C
FOR
SDD-502
MHD POWER TRAIN SYSTEM

MAGNETOHYDRODYNAMICS
ETF ENGINEERING SUPPORT ACTIVITIES
ENGINEERING STUDIES
SUBTASK WORK ORDER 201(1)

THE EFFECT OF A SHORTENED
ETF CHANNEL ON PLANT EFFICIENCY

PREPARED FOR:

MHD PROJECT OFFICE
NASA LEWIS RESEARCH CENTER
CONTRACT NO. DEN 3-224

PREPARED BY:

GILBERT ASSOCIATES, INC.
P.O. BOX 1498
READING, PA 19603

DECEMBER 1980

TITLE: The Effect of a Shortened ETF Channel on Plant Efficiency

SCOPE:

An analytical evaluation was made of the effect of shortening the effective MHD channel length on net power plant efficiency. This study used the same thermal properties and component arrangement as the current DRD (Reference 1).

FINDINGS:

Shortening the effective length of the ETF channel from 16 to 10 meters causes only modest penalties in net power plant efficiency. The reduction in output power from the shorter channel is offset by the reduction in compressor power requirement, and by the partial recovery in the steam bottoming cycle of the energy not extracted by the channel. These separate effects combine to limit net efficiency losses to only 0.29 percentage points.

RECOMMENDATIONS:

Further study is required before a final decision is made to reduce MHD channel length. Although efficiency calculations indicate that the channel length can be reduced without a significant loss in system performance, an evaluation of reduced channel electrical stresses, through a reduction in magnetic field strength and/or supersonic flow velocities, on channel lifetime and reliability must be performed. The benefits of operating in a supersonic mode to eliminate channel/diffuser pressure pulse interaction with the combustor should be studied. Finally, a complete economic evaluation must be performed on the compressor, combustor, channel, magnet train for all cases.

PROCEDURE:

GAI analytically evaluated the performance of MHD channels of varying length using GAI's quasi-one-dimensional computer code PROMETHEUS. Net power plant performance was then estimated in detailed system energy balances prepared using GAI's PROTEUS system modeling computer code.

DISCUSSION:

This study evaluates the effect on plant performance of reducing the ETF channel length. The efficiency penalty for a shorter channel is shown to be small. Since a shorter channel requires a shorter and less expensive magnet, this loss in efficiency appears to be a worthwhile trade.

The base system used a 16 meter long MHD channel. This channel is a slight variant of the channel described in the Design Requirements Document (DRD, Reference 1), in that coal transport gas was included in this combustion system whereas the DRD system had ignored the effect of this gas. Three shorter MHD channels were also considered, having 12 meter, 10 meter, and 7 meter lengths. The assumptions used in establishing these channels and in their estimated performance are compared to the DRD estimates in Table 1. The shorter channels produce less power and reject a greater proportion of their input energy to the steam bottoming cycle.

While shorter MHD channels produce less power they have a higher power density and a lower ratio of heat loss to power output. This is because the most efficient MHD power generation occurs at the entrance where plasma conductivity is highest. The shorter channels have a smaller pressure drop and as a result its compressor power requirements are lower. Since power produced by the channel and power required by the compressors are both reduced, a greater proportion of the input energy appears as steam output. This partial compensation in output by the steam cycle results in a modest drop in plant efficiency when channel length is reduced.

Table 2 presents a summary of the plant performance of the four MHD topping cycles. Two methods of condensate cooling water integration are presented in this table. The first method, "Series A", maintains the turbine steam extraction point for the deaerator fixed. (Figure 1 illustrates the condensate flow sequence used in both cooling methods.) Since deaerator pressure (and thus temperature) are fixed by this first method, the condensate temperature leaving the coolant passages for the MHD channels varies as the heat loss in the MHD channel. The second method of integrating the condensate coolant, "Series B", maintains fixed coolant discharge temperature by allowing the deaerator extraction point pressure to vary. Since the shorter MHD channels require less cooling, the deaerator pressure and temperature can increase, resulting in greater regenerative heating with deaerator extraction steam.

In every case evaluated in this study the "Series B" fixed coolant discharge temperature cases were found to have greater plant efficiency than the fixed deaerator pressure cases ("Series A"). In addition, the shorter MHD channel cases were lower in plant efficiency than the longer channel cases, although

the amount of efficiency lost is modest. Since only 0.29 points in net ETF plant efficiency is lost when channel length is reduced from 16 meters to 10 meters, the reduced complexity of the channel and reduced cost for the magnet with that 37 percent length reduction appears to be an attractive trade. Greater reductions in length below 10 meters causes an ever increasing rate of efficiency loss, hence it would appear that 10 meters is the minimum practical length reduction for the ETF. Since the rate of plant efficiency penalty increases with reduced channel length, it would be more conservative to make a length reduction to only 12 meters, a 25 percent reduction (which, while not evaluated, can be expected to drop efficiency by about 0.16 percentage points) thereby assuring only minimal impact on plant efficiency.

TABLE 1
MHD CHANNEL PERFORMANCE

	DSD Appendix A Channel	Series A and B Study Channels				
		Base Cycle 16 M	12 M	10 M	7 M	
COMBUSTOR:						
Preheat	- °F	1,100	1,100	1,100	1,100	1,100
Moles Oxygen in Oxidant	- %	35	35	35	35	35
Stoichiometry	-	0.90	0.90	0.90	0.90	0.90
Gas Flow	- kg/s	117.1	118.9	118.9	118.9	118.9
Coal Input	- MWt	543.1	543.1	543.1	543.1	543.1
Discharge Pressure	- atm. abs.	6.07	5.98	5.28	4.83	3.98
Discharge Temperature	- K	2,809	2,804	2,796	2,789	2,776
	- °F	4,596	4,588	4,572	4,561	4,536
Heat Loss	- MWt	25.4	25.4	25.4	25.4	25.4
	% coal input	4.67	4.67	4.67	4.67	4.67
CHANNEL:						
Length	- m	15.86	16.07	12.00	9.97	7.00
Inlet Mach Number	-	0.85	0.85	0.85	0.85	0.85
Constant Velocity	- m/s	783	781	750	779	777
Exit Mach Number	-	0.94	0.94	0.93	0.92	0.91
Inlet Cross Section	- m x m	0.52x0.52	0.53x0.53	0.56x0.56	0.59x0.59	0.65x0.65
Exit Cross Section	- m x m	1.21x1.21	1.22x1.22	1.20x1.20	1.20x1.20	1.19x1.19
L/D, inlet	-	27.0	27.0	18.9	15.1	9.6
Gross Power Output	- MWt	106.2	106.6	99.3	94.0	82.5
Heat Loss	- MWt	35.9	35.9	29.5	25.8	19.7
	% MHD output	33.8	33.7	29.7	27.4	23.9
	% coal input	6.6	6.6	5.4	4.8	3.6
Extraction Ratio	-	0.211	0.211	0.196	0.186	0.163
Loading Parameter	-	0.78	0.78	0.78	0.78	0.78
Maximum Magnetic Field	- Tesla	6	6	6	6	6
Maximum Jy	- A/m ²	6,418	6,400	6,750	7,007	7,535
Maximum Ex	- V/m	2,500	2,500	2,500	2,500	2,500
Maximum Ey	- V/m	3,663	3,665	3,650	3,646	3,638
Maximum Hall Parameter	-	3.6	3.6	3.6	3.7	3.7
DIFFUSER:						
Pressure Recovery	-	0.46	0.46	0.46	0.46	0.46
Exit Pressure	- atm. abs.	0.83	0.83	0.83	0.83	0.83
Exit Temperature	- K	2,207	2,206	2,256	2,287	2,341
	- °F	3,513	3,512	3,602	3,657	3,753
Heat Loss	- MWt	27.2	27.1	29.0	30.2	32.5
	coal input	5.0	5.0	5.3	5.6	6.0

— Data Continued —

TABLE 2
 1100°F Oxidant Containing 35 Mole Percent Oxygen

Channel Length, meters	Series A - Fixed Reactor Pressure			Base System			Series B - Fixed Channel Coolant Discharge Temperature		
	7	10	12	10	16	16	7	10	14
Plant Efficiency %	36.34	36.04	37.16	37.37	37.37	37.37	36.50	36.50	37.00
Points Change in Efficiency	-1.03	-0.53	-0.21	0.00	0.00	0.00	-0.79	-0.79	-0.29
Net Power MW	199.134	201.098	203.607	204.706	204.706	204.706	200.429	200.429	203.170
Net Power MW	82.667	93.952	99.324	106.576	106.576	106.576	82.667	82.667	93.952
Steam Gross Power MW	170.027	164.777	162.164	158.202	158.202	158.202	171.262	171.262	165.813
Steam Net Power MW	137.102	129.354	125.564	119.900	119.900	119.900	138.338	138.338	130.300
Auxiliary Power MW	20.435	21.409	21.281	21.769	21.769	21.769	20.376	20.376	21.172
Channel Pressure atm	3.90	4.03	5.28	5.90	5.90	5.90	3.90	3.90	4.03
Compressor Power MW	3.788	4.314	4.399	4.702	4.702	4.702	3.788	3.788	4.314
Air Compressor Power MW	32.925	35.423	36.600	36.302	36.302	36.302	32.925	32.925	35.423
Total Compressor Power MW	36.713	39.737	40.998	41.004	41.004	41.004	36.713	36.713	39.737
Channel Q Loss MW	19.726	25.015	29.477	35.074	35.074	35.074	19.726	19.726	25.015
Diffuser Q Loss MW	32.468	30.157	28.974	27.108	27.108	27.108	32.468	32.468	30.157
Σ Q Loss MW	52.194	55.172	58.451	62.182	62.182	62.182	52.194	52.194	55.172
Steam Flow %	311.51	299.94	293.91	284.73	284.73	284.73	311.51	311.51	299.94
Bottoming Efficiency %	39.60	39.26	39.07	38.76	38.76	38.76	40.06	40.06	39.617
Stack Temperature °F	250.96	200.3	203.6	315.8	315.8	315.8	316.6	316.6	316.7
Channel Coolant Inlet Temperature °F	169.2	169.2	169.2	169.2	169.2	169.2	227.5	227.5	206.2
Channel Coolant Exit Temperature °F	229.0	250.3	263.6	285.9	285.9	285.9	206.7	206.7	206.7

Engineering Study 201(1)
 Table 2

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SYSTEM DESIGN DESCRIPTION

SDD-503

MAGNET SYSTEM

FOR

MAGNETOHYDRODYNAMICS

ENGINEERING TEST FACILITY

CONCEPTUAL DESIGN - 200 MWe POWER PLANT

SYSTEM DIAGRAM (SCHEMATIC) DWG. D4456

PREPARED BY

FRANCIS BITTER NATIONAL MAGNET LABORATORY

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Alm Hatch 7/31/81
ENGINEER DATE

Al Thome 7/31/81
REVIEWED DATE

[Signature] 7/31/81
APPROVED - HEAD, MHD DIVISION DATE

Revision: A
Date: 7/31/81

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
MAGNET SYSTEM

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MHD-ETF 200 MWe Power Plant Magnet System - Interim Criteria for Personnel and Equipment Exposure to Magnetic Fields (7 sheets). Document No. A4442		
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Standard (Proposed)

"Structural Design Basis for Superconducting Magnets", H. D. Becker,
MIT/FBNML, August 1980.

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CONCEPTUAL DESIGN
MHD - ETF 200 MWe POWER PLANT MAGNET SYSTEM

SYSTEM DESIGN DESCRIPTION

1.0 FUNCTION AND DESIGN REQUIREMENTS

This section summarizes the functional requirements and design criteria including system interfaces of the ETF Magnet System as shown in System Diagram, Drawing D4456. The system described herein fulfills the design requirements as set forth in the "Design Requirements Document" (DRD).

1.1 FUNCTIONAL REQUIREMENTS

The major functional requirements of the Superconducting Magnet System are to:

1. Provide the high-intensity magnet field in the large volume needed for MHD power generation, with minimum magnet system power consumption.
2. Operate as a self-contained system, maintaining the necessary cryogenic environment for its superconducting coils continuously without external support except for plant utilities (electric power, cooling water, etc.) and a supply of liquid nitrogen.

The minimum power consumption requirement is satisfied by the use of superconducting (zero-resistive) windings in the magnet; any other type of winding would involve power consumption so high as to outweigh the advantages of MHD power generation.

The Superconducting Magnet produces its high magnetic field within a cavity (warm bore) which extends through the middle of the magnet assembly and is open at both ends. Since it is necessary that the MHD channel be mounted in this cavity, the magnet must:

1. Provide the necessary internal volume for the channel, associated structures, piping and power leads, and provide access for connections at both ends.
2. Incorporate means to facilitate removal and replacement of the channel.
3. Incorporate means to protect the magnet against channel faults.

The internal volume (warm bore) of the ETF magnet is tapered, becoming larger toward the exit end, to accommodate the taper of the MHD channel. The ends of the bore are flared to maximize access.

To facilitate channel changeout, rollers and floor-mounted tracks are provided to permit rolling the magnet sideways. In addition, the magnet warm bore is equipped with internal tracks which support the channel and permit channel withdrawal in the downstream direction. Changeout is accomplished by unfastening flow-train flanges/removable sections near each end of the channel, rolling the magnet and channel aside to clear the diffuser, and then withdrawing the channel onto a special cart mating with the downstream end of the warm bore.

Protection for the magnet against channel faults is provided by an electrically insulating, water-cooled warm bore liner which is a part of the magnet assembly. Should a plasma leak occur in the channel wall, the insulation-coated inner surface of the liner serves as an ablative shield during a period in which the flow-train can be shut down. Should the plasma jet continue long enough to burn through the liner inner wall, a protective water deluge will be provided from the liner water passage.

It is also necessary that the magnet be protected against internal faults. Superconducting magnet windings are subject to an uncontrolled transition to the resistive state (a quench) under certain abnormal operating conditions such as loss of liquid helium coolant. Overheating and damage to windings can result. Protection against this contingency must be provided. The ETF magnet system incorporates quench detection circuitry which triggers automatically an emergency discharge system and discharges the magnet before damage to the windings can occur as a result of a quench.

1.2 SYSTEM INTERFACES

Major interfaces with the magnet system are:

MHD power train
Magnetic interaction with personnel and with equipment (forces and torques)

Facility interfaces are:

- Barriers, markings, etc., for personnel safety and/or exclusion
- Air separation unit (liquid nitrogen flow)
- Circulating water system
- Instrument air system
- Vents to atmosphere (helium and nitrogen gas)
- Plant service air system
- Electrical system (power, lighting and ground)
- Foundations
- Cranes

At the magnet-power train interface, magnetic field is provided by the magnet for power generation, and mechanical support is provided by the magnet warm bore to hold the MHD channel in place against vertical and transverse loads (gravity, magnetic and seismic effects on channel and associated equipment which lies within the magnet warm bore).

The magnet is not designed to support the following:

Axial loads on channel (loads parallel to plasma flow)

Axial, vertical or transverse mechanical loads from power train equipment external to the warm bore (combustor, diffuser, etc.)

The magnet-power train interface is depicted conceptually in Drawing D4439. Additional detail is given on Drawing SDD1101 in SDD502 on the MHD power train system. Channel insertion into and removal from the magnet warm bore exit opening are accomplished with the magnet in the rolled-aside position as shown in the phantom view in Drawing D4445. The combustor, plasma duct assembly, a major portion of the nozzle and a major portion of the diffuser are assumed to remain stationary. Small removable sections of nozzle and diffuser are provided to facilitate channel removal.

When the magnet is secured in the operating position (See Drawing D4443) the plasma upstream (inlet) end-face of the magnet warm bore liner and the warm bore centerline are at pre-determined fixed locations (non-adjustable relative to the foundation). Alignment of power-train flanges C and D (see Drawing D4439) is accomplished by means other than moving the magnet.

The magnet system - air separation unit interface involves the supply of liquid nitrogen from the air separation unit to the magnet system. A steady-state flow of liquid nitrogen as listed in Drawing D4453 is delivered from the air separation unit to the magnet system liquid nitrogen storage tank and is used for:

1. Precooling helium gas in refrigerator/liquefier.
2. Trace cooling liquid helium transfer lines.
3. Cooling of magnet thermal radiation shield.

The magnet system liquid nitrogen storage tank provides bulk storage of liquid nitrogen for use in refrigerator pre-cooling, etc., when the air separation unit is not in operation.

The interface with magnetically affected equipment, magnetic structure and personnel involves the interactive forces and adverse effects which are possible as a result of relatively high fields ("fringe fields") produced by the magnet in the surrounding area. The facility in the vicinity of the magnet is designed to accept these conditions. Guidelines are provided in Specification A4442, which is attached to the end of this SDD. Estimated boundaries of critical fringe field zones around the installed ETF magnet are shown in Drawing D4444.

1.3 DESIGN CRITERIA

Design criteria for the Superconducting Magnet System include the system outputs in terms of magnetic field volume, intensity and uniformity, derived inputs and accompanying mechanical and electrical requirements which are used in the selection, sizing and design of components and to determine performance.

Criteria used for final Magnet System selection and conceptual design were:

1. The Magnet System design shall be based primarily on the current state of the art. (Where the scale-up in size necessitates extending the technology, in critical areas, beyond today's experience, the design shall be substantiated by laboratory tests or equivalent experience either actual or anticipated).
2. The Magnet System design shall be based on one or a combination of the several concepts under study/development within the MHD superconducting magnet discipline.
3. The Magnet System design shall employ construction and assembly techniques that are scalable to magnet systems required for commercial size MHD/steam generators (500 to 2000 MWe output). (Scaling to commercial size will involve increasing magnet overall dimensions by factors up to 2 and weight by factors up to 7.)
4. The Magnet System design shall minimize overall cost including site-related manufacturing costs. (Since the magnet assembly is so large that transportation in one piece from the factory to the Montana site will not be practical, the design shall provide for factory fabrication of all major subassemblies in sizes that can be rail/road transported to the site without excessive cost, and can be site-assembled with minimum on-site labor.)
5. Supporting subsystems (such as the Cryogenic Support Equipment, the Power Supply and Discharge Equipment and the Vacuum Pumping Equipment) shall represent current technology and shall be readily available and highly reliable.

The magnet conceptual design described in Section 2 of this SDD draws heavily on an integrated design and development program for superconducting MHD magnets currently underway at MIT/FBNML under DOE sponsorship. This program, started in 1976, includes subcontracted and in-house design studies,^{1,2,5*} management of test facility magnet design and procurement, and laboratory investigations¹¹ of superconductors, insulators, structural materials and other components. A major objective of the program is to evaluate a number of design concepts for commercial-size MHD magnets and make selections based on assurance of meeting performance

*Superscripts refer to references listed in the Appendix.

requirements, reliability, manufacturability and overall cost effectiveness. Specific studies and designs which have influenced the ETF conceptual design include those listed below:

Superconducting MHD Magnet Design Study⁴ (1977),
Avco Everett Research Laboratory, Inc.

Superconducting MHD Magnet Design Study⁵ (1977),
Magnetic Corporation of America.

"Cask" Superconducting MHD Magnet Design⁶ (1979),
General Dynamics

ETF - Superconducting MHD Magnet Design⁷ (1979),
Avco Everett Research Laboratory, Inc.

CFFF - Superconducting MHD Magnet Design⁸,
Argonne National Laboratory

CDIF - Superconducting MHD Magnet Design⁹,
General Electric Co.

Stanford Superconducting MHD Magnet Design¹⁰,
General Dynamics

The particular configuration selected for the ETF magnet, a rectangular saddle-coil magnet with rectangular bore, is considered suitable for the application because the bore shape permits most effective utilization of the magnet's high field volume and the coil shape lends itself to ease of manufacture and structural support. Since the design is in many respects a scale-up of the CDIF Superconducting Magnet, it can be verified by experience with the latter. The use of cable conductor fully supported by an insulating substructure is considered advantageous for ease of manufacture of conductor, ease of winding and to enhance the cryostatic stability of the winding by minimizing the size of possible friction-generated disturbances at the surface of the conductor.

Engineering design criteria for all disciplines are in accordance with applicable codes, standards, regulations and guides issued by governmental agencies and recognized by standards organizations.

1.3.1 Codes and Standards

1.3.1.1 Standards for Magnetic Force Containment Structures

Design of magnet structures which contain major magnetic forces are in accordance with the following interim standard¹²:

"Structural Design Basis for Superconducting Magnets",
H. D. Becker, Francis Bitter National Magnet Laboratory,
Massachusetts Institute of Technology, August, 1980.

1.3.1.2 Code for Pressure Vessels

Pressure vessels and vacuum vessels in the magnet system are in accordance with the following:

ASME Boiler and Pressure Vessel Code, Section 8, Division II.

1.3.1.3 Other Codes and Standards

In addition to the specific requirements of 1.3.1.1 and 1.3.1.2, the magnet system design is in accordance with applicable codes, standards and guides issued by the following organizations:

- a. American National Standards Institute (ANSI)
- b. American Society for Testing and Materials (ASTM)
- c. American Welding Society (AWS)
- d. Manufacturing Standardization Society of the Valve and Fitting Industry (MSS)
- e. Pipe Fabricators Institute (PFI)
- f. Occupational Safety and Health Administration (OSHA)
- g. Instrument Society of America (ISA)
- h. National Fire Protection Association (NFPA)

1.3.1.4 Criteria for Personnel and Equipment Exposure to Magnetic Fields

Interim criteria in effect for personnel and equipment exposure to magnetic (fringe fields) in the region immediately surrounding the magnet are in accordance with the guidelines contained in Specification A4442, attached at the end of this SDD.*

1.3.2 Design Parameters

The design parameters of the magnet are dictated by the needs of the MHD generator in terms of magnetic field and volume to house the channel with its associated structure, piping and power leads in the high field region.

The primary design parameters are listed in Table I.

*It should be noted that the standards set forth here are more restrictive than the design standards actually employed in Volume I of this CDER.

TABLE I Sheet 1 of 2

MAGNET SYSTEM
DESIGN PARAMETERS

Magnetic Field

Peak on-axis field	6 T
Active field length	12.1 m (39' 8")
On-axis field, start of active length	4.0 T
On-axis field, end of active length	3.5 T

Flow Train Interface

Warm bore aperture*, start of active length	55" x 71"
Warm bore aperture*, end of active length	81" x 106"
Channel weight to be supported in magnet warm bore	54,000 lbs.
Maximum force** exerted on magnet by flow train, axial direction (parallel to plasma flow)	TBD***
Maximum force** exerted on magnet warm bore by flow train, vertical (in addition to channel weight)	TBD***
Maximum force** exerted on magnet warm bore by flow train (transverse)	TBD***
Voltage stand-off capability of warm bore liner electrical insulation	TBD***
Vibration applied to magnet by flow train	TBD***

Operational

Service life	30 years
Number of cool-down/warmup cycles	60
Number of charge/discharge cycles (0 - design current - 0)	600
Maximum allowable cool-down time	30 days
Maximum allowable warm-up time	30 days
Minimum charge time, 0 to full field	45 min.
Minimum discharge time, full field to 0 field, non-emergency mode	45 min.
Maximum allowable emergency discharge time, full field to 0 field	3 min.
Maximum allowable terminal voltage during emergency discharge	10,000 V
Current regulation, steady state operation (drift)	2%

* Inside water-cooled warm bore liner

** Force caused by magnetic interaction of channel and its power leads with the field produced by the magnet coils.

*** TBD - To be defined after detail design is complete.

TABLE I Sheet 2 of 2

Environment

Altitude above sea-level	3,300 ft.
Outdoor temperature, maximum	105 °F
Outdoor temperature, minimum	-35 °F
Seismic zone	2

1.3.2.1 System Diagram

The system diagram (schematic) for the magnet system is shown in Drawing D4456.

1.3.2.2 Magnetic Field

The magnetic field required for the ETF channel is a dc field having its peak intensity a short distance downstream from the channel inlet and then decreasing along the channel axis toward the exit end. The magnetic field profile along the bore axis and the configuration and dimensions of the cavity (warm bore) as needed for the ETF channel are shown in Drawing D4439. Maximum allowable variations in magnetic field profile and field in channel cross-sections are given in Drawing D4448. The bore axis is horizontal and the main field direction is horizontal and perpendicular to the bore axis.

The magnet system is intended for continuous operation at design field for long periods of time, as necessary to meet base-load MHD generator requirements. The system must be capable of maintaining the designed field profile for all steady-state, plant transient, load-transient and part-load operation of the MHD/steam plant.

1.3.2.3 Magnet Charging and Discharging

The magnet power supply and discharge system must be capable of raising the magnetic field from zero to rated field in less than one hour, of automatically maintaining a constant field at any selected level between zero and rated field and of reducing the field from rated to zero in approximately 3 minutes under emergency conditions, as required for convenient and safe operation of the MHD generator.

1.3.2.4 Magnet Winding Characteristics

The magnet winding is designed for cryostability; i.e. it incorporates sufficient normal conductor in parallel with superconductor and has sufficient cooling such that in the event of a disturbance which drives a portion of the winding into the non-superconducting state, all the current in that portion will be carried temporarily by the normal conductor without exceeding the superconductor critical temperature, and the winding will revert to the superconducting state after the disturbance passes.

The magnet winding is so designed that with the winding operating at rated magnetic field (6 T peak on-axis) and at rated temperature (4.5 K), the current in all parts of the winding is at least 15% lower than the short-sample critical current of the conductor at 4.5 K and the local magnetic field.

1.3.2.5 Cryogenic Insulation

Cryogenic insulation and thermal shielding provided in the magnet enclosure and in other cryogenic components are designed to minimize ambient heat leakage into low-temperature regions.

1.3.2.6 Quench Protection

The emergency discharge (dump) system is capable of safely discharging all magnetic energy stored in the magnet at its rated operating condition. Voltage and temperature rise in the winding during such a discharge are within limits compatible with the materials and insulation thickness used.

1.3.2.7 Vapor Cooled Power Leads

Vapor cooled power leads are capable of operating safely and without damage with zero helium (coolant) flow during an emergency discharge.

2.0 DESIGN DESCRIPTION

2.1 SUMMARY DESCRIPTION

The superconducting magnet system is an advanced technology system that provides the magnetic field required by the MHD channel for power generation.

The system consists of the magnet and accessory equipment, comprising subsystems as listed below:

- Magnet assembly
- Cryogenic support equipment
- Power supply and discharge equipment
- Vacuum pumping equipment
- Roll-aside drive equipment
- Protection/control equipment and instrumentation

Plan and elevation views of the magnet system including accessory equipment are shown on Drawing D4445.

Major interfaces are:

- MHD power train
- Magnetic interactions with personnel and equipment (forces and torques) in the near vicinity of the magnet assembly

Facility interfaces are:

- Barriers, markings, etc., for personnel safety and/or exclusion**
- Air separation unit (liquid nitrogen flow)**
- Circulating water system**
- Instrument air system**
- Vents to atmosphere (helium and nitrogen gas)**
- Plant service air system**
- Electrical system (power and lighting)**
- Foundations**
- Cranes**

The magnet assembly consists of liquid helium cooled superconducting coils in a cryogenically - insulated enclosure (vacuum vessel) with a cavity (warm bore) extending through the center horizontally, open at both ends. The outline dimensions of the magnet assembly and the dimensions of the cavity, which diverges from plasma upstream (inlet) to plasma downstream (exit) end, are shown on Drawing D4441. The cavity is designed to house the MHD channel, which is inserted and withdrawn from the large (exit) end opening. The magnetic field in the cavity is oriented in a primarily horizontal direction perpendicular to the long axis of the cavity. The magnet does not incorporate a ferromagnetic flux-return-path or other means to reduce fringe magnetic fields.

The cryogenic support equipment consists of a helium refrigerator/liquifier, a helium compressor package, storage tanks, heat exchangers, transfer lines and controls as required for cooling down the superconducting magnet windings, maintaining them continuously at liquid helium temperature during facility operating and standby periods, and warming up the windings when an extended dead plant condition is anticipated.

The power supply and discharge equipment consists of a rectifier-type dc power supply, discharge resistors, circuit-breakers and controls as required for charging the magnet, maintaining it at the desired field strength during MHD generator operation and discharging it under both normal and emergency (fast) shut-down conditions.

Vacuum pumping equipment consists of diffusion pumps and mechanical pumps for evacuating the magnet vacuum vessel prior to and during initial magnet cooldown and for removing from the vacuum vessel any helium leakage that may occur from the coil container during magnet operation. A utility vacuum pumping system for servicing the cryogenic support equipment is also provided.

The roll-aside drive equipment consists of hydraulic cylinders for moving the magnet on its tracks and the associated hydraulic pump package.

Protection and control equipment consists of instrumentation to detect abnormal conditions in the magnet system and controls to automatically activate protective measures. Also included are instruments and controls to permit remote monitoring and manual control of major functions of the magnet and associated equipment at the power plant control room.

The magnet system includes, in addition to the above subsystems, piping and wiring necessary to interconnect subsystem equipment items and to connect these items to local utility outlets provided as part of the facility. Utility requirements are summarized in Table II.

2.2 DETAILED DESCRIPTION

The detailed description which follows covers the MHD magnet system conceptual design selected for use in the ETF Conceptual Design Engineering Report. Magnet system floor space, foundation and utility requirements contained in this document are based on this particular conceptual design and the estimated magnet system costs and construction schedule herein are also based on this design. It is intended that this design description be considered only a "design basis" which fulfills the design requirements as set forth in the MHD-ETF Design Requirement Document. This design, not intended to be restrictive with respect to the magnet system to be finally developed for the ETF, is representative of design concepts being developed at MIT/FBNML with inputs from Avco Everett Research Laboratory, Inc.,^{4,7} Magnetic Corporation of America,⁵ General Dynamics,^{6,10} Argonne National Laboratory,⁸ and General Electric.⁹

2.2.1 Magnet Assembly

The design characteristics of the magnet assembly are given in Table III and on the following:

- Drawing D4441 - Outline
- Drawing D4450, Sheets 1 through 4 - General Assembly
- Drawing D4439 - Field Profile and Bore Dimensions
- Drawing D4448 - Limits on Variation in Magnetic Field

The major components comprising the magnet assembly are as listed below. They are identified on Drawing D4450.

- Superconducting windings (coils) including winding substructure
- Winding containment vessels
- Main force containment structure
- Thermal radiation shield
- Low-heat-leak support struts
- Vacuum vessel (magnet enclosure) including warm bore
- Water-cooled warm bore liner
- Roll-aside system (rollers, track, actuators, hold-down brackets)
- Vapor-cooled electrical leads
- Internal instrumentation wiring and piping

TABLE III Sheet 1 of 2

MAGNET SYSTEM
MAGNET DESIGN CHARACTERISTICS

Magnetic Field:

Peak on-axis field	6 T
Active field length	12.1 m (39' 8")
Field at start of active length, B_{IN}	4 T
Field at end of active length, B_{EX}	3.5 T
Peak field in winding	7.6 T
Variation in channel, plane of B_{IN}	+4% -0%
Variation in channel, plane of B_{PEAK}	+2% -2%
Variation in channel, plane of B_{EX}	+2% -2%
On-axis field variation axially, relative to straight line tangent to upstream and downstream field crests.	+2% -0%

Dimensions:

Aperture, warm bore inlet*	55" x 71"
Aperture, start of active length*	55" x 71"
Aperture, end of active length*	81" x 106"
Aperture, warm bore exit*	85" x 111"
Length of warm bore	49' 9"
Distance, bore inlet to start of active length	3' 6"
Vacuum vessel overall length, including water-cooled warm bore liner	54' 4"
Vacuum vessel outside diameter	27' 6"

Dipole Moment

$13.8 \times 10^8 \text{ Am}^2$

Winding Characteristics:

Design current	24,400 A
Winding current density (J)	$1.42 \times 10^7 \text{ A/m}^2$
Conductor current density (J) wire	$8.16 \times 10^7 \text{ A/m}^2$
LHe to conductor ratio (volume)	1.1

*Inside water-cooled warm bore liner

TABLE III Sheet 2 of 2

Heat flux**	< 0,15 W/cm ²
Ampere turns	27.9 x 10 ⁶
Ampere meters	10.76 x 10 ⁸
Inductance	9.7 henries
Stored energy	2900 MJ
Winding Dimensions:	
Depth (build), winding cross-section	37.5"
Height, winding cross section, one quadrant	40.7"
Gap (distance from winding to bore surface inside warm bore liner)	16.7"
Winding envelope volume, total	2671 cu. ft
Conductor:	
Type	Cable
S. C. material	NbTi
Overall diameter	1.0"
Strand diameter	0.046"
Cu/SC in high field regions	6
Total length conductor	140,000'
Weights:	
Conductor	224,000 lbs.
Insulation	(included in substructure)
Substructure	198,000 lbs.
Superstructure and coil containment vessels	1,100,000 lbs.
Total cold mass	1,522,000 lbs.
Thermal radiation shield, cold mass supports, etc.	66,000 lbs.
Vacuum vessel and mounting feet	346,000 lbs.
Miscellaneous	66,000 lbs.
Total Magnet Weight	2,000,000 lbs.
Cryogenic Data:	
Operating temperature at winding	4.5 K
Heat leak to LHe region	180 watts
Liquid helium for lead cooling	75 l/hr.

** Heat flux is stability criterion (heat flux at cooled surface of conductor with all current in copper, in highest-field region).

2.2.1.1 Windings and Substructure

The magnet windings consist of a pair of saddle-shaped coils, each made of 572 turns of superconducting, cable-type conductor 1 inch in diameter, as described in Section 2.2.1.2. The turns are insulated from each other and are individually supported by a substructure consisting of stacks of fiber glass-plastic bars or plates notched to fit the conductors. The windings are bath-cooled by liquid helium and are designed for cryostatic stability.

The windings are designed to produce the on-axis field profile shown on Drawing D4439 and to produce uniformity of field in the channel cross-section as shown on Drawing D4448. The configuration of the winding envelope is shown on Figure 1. The design current density in this envelope is constant throughout the envelope and is conservatively low (1.42×10^7 A/m²).

The winding of each coil is made up of 26 saddle-shaped layers, each layer containing 22 turns. A cross-section of the windings of the two coils and their winding containment vessels in the plane of peak on-axis field is shown in Figure 2. Through-bolts are used to clamp the winding and substructure in place in the containment vessels. After the windings are installed, cover plates are welded in place, as shown. A springplate between cover and winding and spring-shims at the inner wall of the coil container are provided to compress the winding within the containment vessel, thus minimizing conductor motion during charging.

Space is provided at the outer extremities of the exit-end cross-overs for layer-to-layer splices in the conductor. The winding is so designed that layer-to-layer splices are not required at the inside transitions. One splice is installed within each layer, in the exit -end cross-over region, for grading purposes, as described in Section 2.2.1.2.

To provide room for power leads to the coils, "dummy layers" of substructure are provided in the exit end turns. Superconducting power leads extend upward from the coils through the "dummy layers" into a plenum chamber located just above the exit end-turns. Cross-connections and connections to vapor-cooled power leads leading to the external power supply are made in the chamber. The coils are series connected, with only two vapor-cooled leads provided between coils and power supply.

Each coil, with its substructure is enclosed in a heavy-walled, stainless steel containment vessel as described in Section 2.2.1.3. When in service, the coils are immersed in liquid helium which fills the containment vessel. The substructure incorporates a system of passages which ensure access for helium coolant to all parts of the windings. The substructure system is designed to support individual conductors against both gravity and magnetic forces and to transmit the total accumulated forces to the walls of the containment vessel. The forces are then transmitted through these walls to the main force containment structure which is external to the containment vessel as described in Section 2.2.1.4. The cable-type conductor is a stranded cable as described in Section 2.2.1.2.

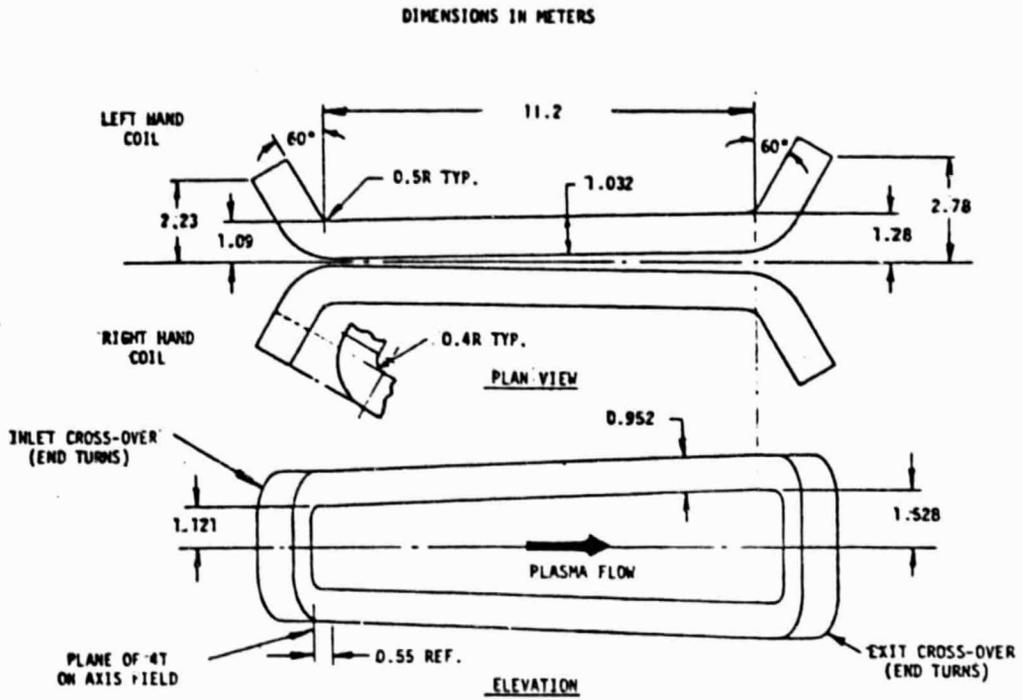


Fig. 1
CONFIGURATION OF WINDING ENVELOPE

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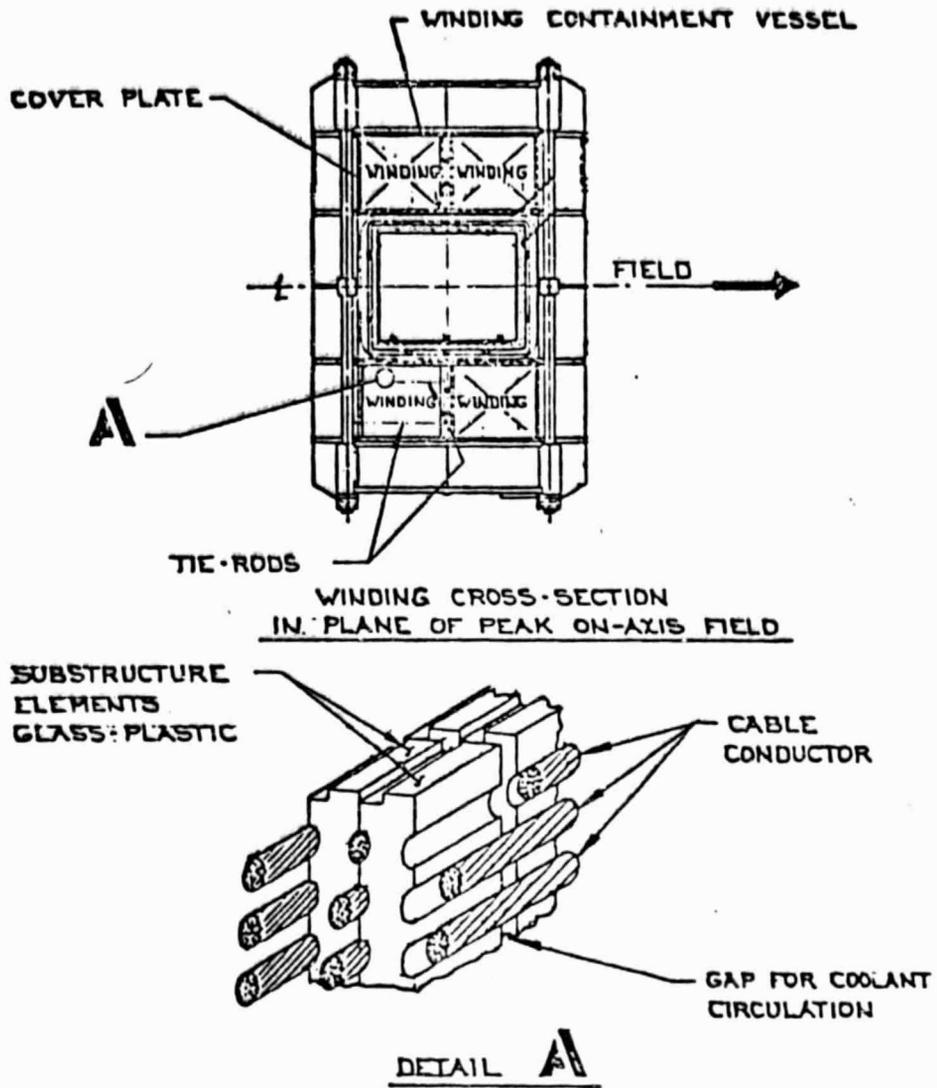


Fig. 2
WINDING CROSS-SECTION
INCLUDING SUBSTRUCTURE

2.2.1.2 Conductor

The conductor consists of a cable of wires of two types: multi-filament niobium-titanium/copper (NbTi/Cu) monolithic wire and copper wire. The characteristics of the cable are outlined in Figure 3 and in Table IV. The finished cable consists of 7 units where each unit contains 37 strands. Each strand is 0.046 in. (0.11684 cm) in diameter and is either copper or NbTi/Cu composite

The critical current for the cable is 28,700A at 4.5 K and 7.6 T for grade A conductor, and at 4.5 K and 5.0 T for grade B conductor. The ratio of operating to critical current is, then, $24,400/28,700 = 0.85$. The cable conductor has been designed to be cryostatically stable relative to the disturbances expected during operation. This implies that sections of conductor which are driven out of the superconducting state and into a normal condition are sufficiently well cooled to allow recovery to a superconducting condition. The field distribution in the winding has been analyzed to allow it to be divided into two regions for conductor grading purposes. The grade A conductor experiences a maximum field of 7.6 T and consists of 222 strands of NbTi/Cu monolith and 37 strands of copper distributed in the cable as indicated in Table IV. The table also gives the wire distribution for the grade B conductor which experiences a maximum field of 5.0 T and consists of 108 strands of NbTi/Cu composite and 151 strands of copper wire. The total conductor weight for the magnet is about 1.02×10^5 Kg based on 63,980 ft. (19,500 m) of grade A cable and 75,980 ft. (23,160 m) of grade B cable.

Each coil consists of 26 layers of conductor wound in "plates" with 22 turns per plate. The boundary within the winding which separates the grade A from the grade B conductor is shown in Figure 4. The schedule of lengths required for each coil is given in Table V. Conductor delivered to the winding facility will be in finished lengths corresponding to this table plus an allowance for tolerances. Each end of each piece of NbTi/Cu monolith wire is tested for critical current before being cabled as well as tested for dimensions, filament pattern, twist pitch, and copper to superconductor ratio. Resistance ratio for the copper wire used in the cable is tested on a sampling basis developed as part of an overall conductor quality assurance plan.

Twenty-one joints between conductors are required for each coil. Joints are located in the crossover region of the winding at the high field end of the magnet. The configuration for a typical joint is shown on Drawing D4457. The joint is 18 inches long and will be formed near the winding after trial fitting the conductor in place, marking and cutting to length. The cable ends to be joined will then be clamped between two "L-shaped" copper sections, drilled and cross-pinned, solder filled, and placed in prepared grooves in the substructure. It is expected that the average joint resistance will be about $1.5 \times 10^{-9} \Omega$.

2.2.1.3 Winding Containment Vessels

The two winding containment vessels enclose the two saddle coils and follow closely the contours of the coils. The vessels are mounted on either side of the centerline of the magnet and seat against each other on the vertical plane

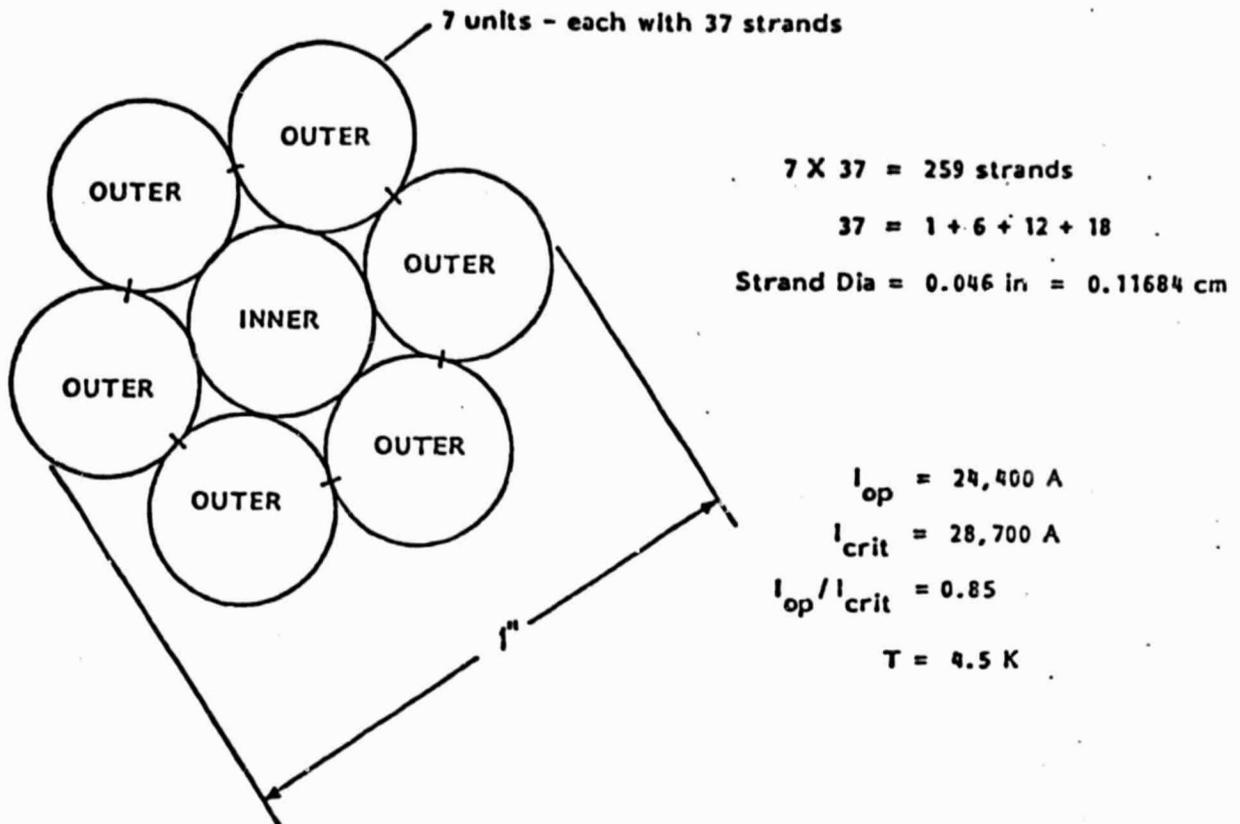


Fig. 3

SUPERCONDUCTING CABLE CONSTRUCTION

TABLE IV
MAGNET SYSTEM
CABLE CONDUCTOR CHARACTERISTICS

	Grade A	Grade B
Magnetic field [T]	7.6	5.0
NbTi current density [A/cm ²]	7.22 x 10 ⁴	1.466 x 10 ⁵
Total strands	259	259
Number Cu strands	37	151
Number SC monoliths	222	108
Cu/SC ratios:		
SC monolith	5:1	5:1
Overall cable	6:1	13.4:1
Heat Flux		
All strands [W/cm ²] (100% of surface)	0.145	0.134
Outer strands only [W/cm ²]	1.04	0.96
Inner cable of 37 strands:	Cu	Cu
Outer 6 cables of 37 strands:		
Center, 1 strand	mono	Cu
Row number 1, 6 strands	mono	mono
Row number 2, 12 strands	mono	mono
Row number 3, 18 strands	mono	Cu
Finished length required (m)	19,500	23,160
Mass/length (kg/m)	2.34	2.41
Finished mass (kg)	45,630	55,820

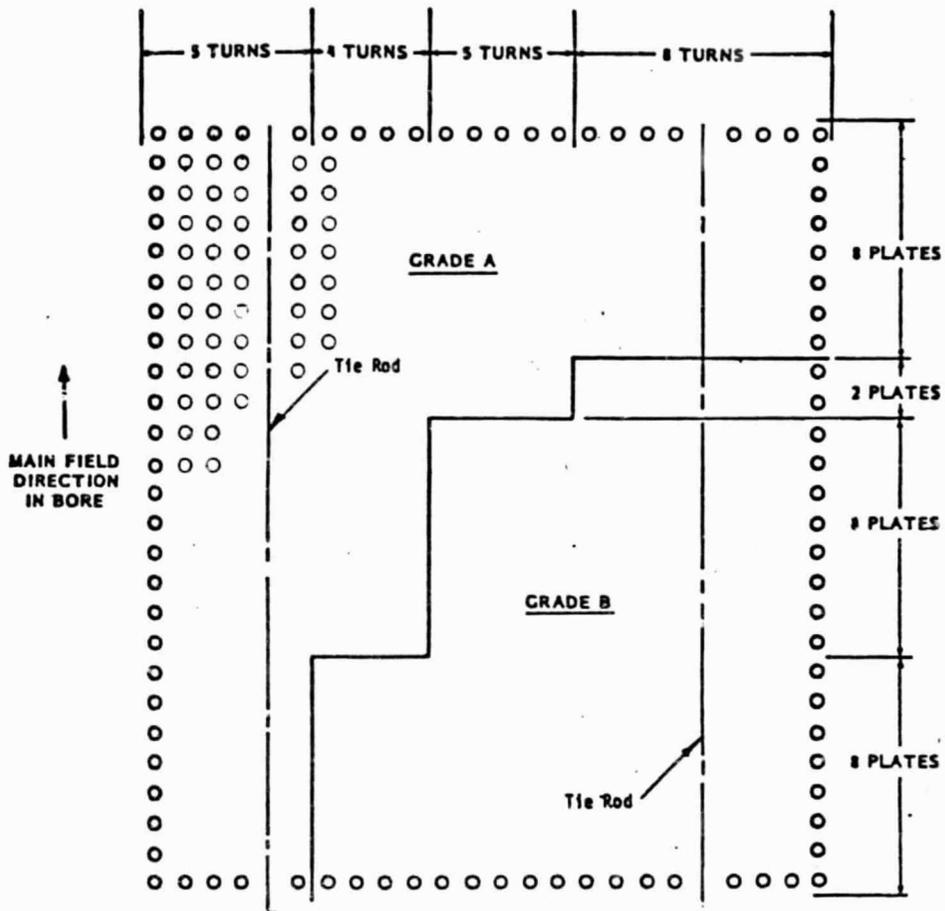


Fig. 4

WINDING CROSS SECTION ILLUSTRATING GRADING

TABLE V
MAGNET SYSTEM
SCHEDULE OF CONDUCTOR LENGTHS REQUIRED FOR EACH COIL
(Lengths in meters)

<u>Grade A</u>	<u>Grade B</u>
369	686
365	1,362
361	1,350
357	1,338
648	1,177
642	1,020
636	1,010
630	1,000
989	807
1901	
1576	
1560	
<u>1544</u>	<u> </u>
11,580	9,750

through the centerline. They are separate units, identical in design except that one is right-handed and the other left-handed. Cross-connections are provided to distribute liquid helium between the vessels and to maintain equal pressures within them.

The main functions of the vessels are to maintain the windings in a bath of liquid helium and to serve, in combination with the main structure, as structural support for the coils. The coil containment vessels are located inside a vacuum vessel and are designed for a maximum internal pressure of 3 atmospheres with an external vacuum. The containers are designed to carry the entire longitudinal magnetic force produced by the coil-ends and to share radially outward (vertical and transverse) magnetic loading with the main force containment structure.

A large plenum chamber is incorporated as a part of the coil containment vessels just above the exit end turns. The chamber and associated manifolds cross-connect the two containment vessels, provide a reservoir for liquid helium above the level of the windings and provide access to the windings for power leads, coolant connections, vents and instrumentation. A plenum chamber is also incorporated above the inlet end turns. This chamber, smaller than the exit-end chamber, provides access to the windings for emergency vent and instrumentation.

The coil containment vessels, plenum chambers and covers are made of Type 316 low-carbon nitrogen stabilized stainless steel (316 LN).

2.2.1.4 Main Force Containment Structure

The major function of the force containment structure (superstructure) is to hold the magnet windings in place against magnetic forces. This structure surrounds the coil containment vessels and is exposed to the vacuum existing in the vacuum vessel. Magnetic forces on the windings are carried via substructure into the walls of the coil containment vessels and through them to the superstructure, which is clamped or welded to them. In the end-turn regions of the magnet the superstructure is integral with the coil containment vessels and consists mainly of stiffeners and/or gussets welded to the coil containers. In the middle region, the superstructure consists of built-up I-beams and tie-bolts clamped around the coil containers but not welded to them.

The overall design of the main force containment structure is shown on Drawing D4450. In the middle region of the magnet (between the end-turn regions) the main structure consists of 28 rectangular frames, each having two 23 inch deep built-up I-beams and two 6 inch diameter tie rods. The frames are designed to be assembled around the winding containment vessels after the windings are installed and the vessels sealed. The tie-rods have threaded ends which pass through collars welded to the ends of the I-beams. Nuts are installed on the tie-rod ends and adjusted to ensure tight, even clamping of the frames to the winding containment vessels. At the beginning of end turn regions, special beams and stiffeners are welded in place after the containment vessels are

sealed. The entire force containment structure is designed in a manner so as to provide maximum access to structural welds and to winding containment vessel welded joints for inspection purposes.

The force containment structure is made of Type 316 low carbon, nitrogen stabilized (316 LN) stainless steel. The design bending stress in the I-beams and tension stress in the tie-bolts is 60,000 psi.

The force containment structure is in intimate contact with the liquid-helium-filled winding containment vessels and therefore operates at liquid helium temperature. Tracer tubes are attached to outer portions of structure for use in removing heat during cool-down of the cold mass (winding, containment vessels and superstructure).

Main structural members in the end-turn region incorporate brackets and pads to mate with low-heat-leak support struts (described in Section 2.2.1.6) which position the windings, containment vessels and superstructure (cold mass) within the vacuum vessel, support the weight of the cold mass and resist forces which result from seismic causes and the magnet's reaction with external objects.

2.2.1.5 Thermal Radiation Shield

The thermal radiation shield consists of an aluminum alloy shell covered with multi-layer insulation, located within the vacuum jacket and forming a thermal radiation barrier between the cold mass (winding and main structure) and the warm surfaces of the vacuum jacket including the warm bore tube. The purpose of the shield is to minimize thermal (radiative) heat transfer from the warm walls of the vacuum jacket to the cold mass. The aluminum alloy shell of the shield is maintained at liquid nitrogen temperature by a system of tracer tubes attached to the shell and supplied with liquid nitrogen from bulk storage. Blankets of multi-layer insulation are attached to both sides of the aluminum alloy shell. The thermal radiation shield is held in place within the vacuum jacket by low-heat-leak supports which fasten to the cold mass. The tracer tubes on the shield are supplied with liquid nitrogen from a reservoir located in the stack at the exit end of the magnet above the end turns. The boil-off from the tracer tube system is returned in manifolds at the top of the shield to the upper part of the liquid nitrogen reservoir in the stack. Cold-boil off gas in the nitrogen reservoir is carried upward through tracer tubes in the stack to an atmospheric vent. The liquid nitrogen level in the reservoir is maintained automatically by transfer of liquid from the liquid nitrogen storage tank which is a part of the cryogenic support system.

The aluminum alloy shell of the thermal radiation shield is composed of a number of panels connected to each other by means of electrically insulated joints. This subdivision of the shield into electrically isolated sections is done to minimize the occurrence of circulating current in the aluminum shell, and the associated magnetic forces that would occur during charging and discharging of the magnet. The thermal shield between the warm bore tube and the cold structure immediately surrounding the bore tube is similar to

the shield outside of the cold mass except that it is supported through low-heat-leak supports to the warm bore itself, instead of to the cold mass. This permits assembly and disassembly of the warm bore tube and its thermal shield as a unit, separate from the rest of the magnet assembly.

The thermal radiation shield surrounding the middle portion of the cold mass is located close to the vacuum jacket surface and is therefore spaced well away from the cold mass and the main structure in that portion of the magnet. This permits access of personnel to the inside of the radiation shield for inspection of the cold mass and structure. Access openings with covers will be provided in the thermal radiation shield for personnel to enter this space.

2.2.1.6 Low-Heat-Leak Support Struts

Struts of fiber glass epoxy designed to minimize heat leakage are used to support the cold mass within the vacuum jacket and are the only structural connections between the cold mass and the warm structure in the base of the vacuum jacket. Four vertical struts, one near each corner, support the weight of the cold mass. Three cross struts, located in the base of the vacuum jacket, stabilize the cold mass and restrain motion in the axial and transverse direction. Two of these stabilizing struts are mounted at 45° to the center line near the exit end of the magnet and serve to prevent both axial and transverse motion of the cold mass at that end. The single transverse strut near the inlet end of the magnet restrains only transverse motion. All seven struts are equipped with ball joints at each end, so that thermal contraction of the cold mass during cool down can take place without imposing any thermal stresses on the struts. The strut system is designed with inherent compensation for thermal motion of the cold mass, so that the axial centerline of the cold mass will remain substantially coincident with the centerline of the vacuum jacket in both the warm condition and the cold (cooled down) condition.

The support struts are designed not only to carry the gravity forces of the magnet, but also to carry seismic forces and the forces produced by magnetic interaction of the magnet and the magnetic material that may be present in the facility surrounding.

Heat leakage from warm surroundings to the cold mass through the strut system is minimized by the use of fiber glass material in the struts, which has a very low thermal conductivity. Heat leakage is further reduced by heat stations near the warm end of each fiber-glass section. The heat stations are maintained at liquid nitrogen temperature by liquid nitrogen supplied from the thermal radiation shield cooling system. The axial positioning of the cold mass is such that the vertical centerline of the cold stack at the exit end, where most of the connections, both cryogenic and electrical are made, will remain nearly coincident with the vertical centerline of the warm extension on the vacuum jacket. The relative motion here, during cool down, is not expected to exceed 1/2 inch. The offset in the axial direction of the warm and cold stack centerlines at the inlet end of the magnet, during cooldown, will be approximately 1½ inches. Flexible members will be placed in both stack assemblies to accommodate the offsets indicated.

2.2.1.7 Vacuum Jacket and Warm Bore

The vacuum jacket is a cylindrical vessel, mounted horizontally, with a rectangular warm bore extending from one end to the other along the horizontal centerline. At the base of the vacuum jacket, a mounting system is provided which accepts the warm ends of the low-heat-leak cold mass support struts and transmits the loads from the struts, and the gravity load of the vacuum jacket itself, to the rollers and track on which the entire magnet is mounted. Track and roll-aside provisions are described in Section 2.2.1.11. The purpose of the vacuum jacket is to enclose the magnet cold mass assembly and thermal radiation shield and to provide vacuum insulation around these items. The warm bore of the vacuum jacket serves to support the warm bore liner described in Section 2.2.1.8 which in turn supports the MHD channel. Stacks are provided at the top of the vacuum jacket at the exit end and inlet end for cryogenic piping, electrical connections and instrument wiring communicating with the magnet winding and cold mass. Connections are provided in the lower portion of the vacuum jacket for vacuum (diffusion) pumps and also for safety blowout disks. Manhole covers are provided on the vacuum jacket so that with the internal pressure returned to atmospheric, personnel will have access to the inside of the jacket for inspection purposes. Large sections of the vacuum jacket shell on both sides are so designed that they may be completely removed to provide full access to the middle portion of the cold assembly in the event that major overhaul is required.

The vacuum jacket and bore tube are constructed of 304 stainless steel.

2.2.1.8 Water-Cooled Warm Bore Liner

The magnet is provided with a warm bore liner to protect the magnet against accidental discharge of energetic plasma from the MHD train or intense electrical arcing in the power takeoff.

The warm bore liner covers the entire inside of the magnet bore including the end flares and a portion of the end-faces of the magnet vacuum vessel as shown on Drawing D4450. The interior of the magnet warm bore is lined with an insulating material, such as NEMA G-7 glass reinforced silicone, to provide insulation between the warm bore liner and the magnet itself. The metallic water jacket of the warm bore liner is grounded through a bleeder resistor while insulated from the magnet. The warm bore liner therefore functions as a ground fault detector since, if an electrical breakdown between the MHD train and the metallic parts of the liner occurs, the liner potential would rise above ground to a level which could be used to initiate combustor shutdown. The warm bore liner itself is composed of a triple wall, plug welded metallic structure, in which water is circulating, covered on the inside by an ablative layer of glass-reinforced silicone insulation. During normal operation, a modest water flow is maintained in the metallic structure. This small flow is adequate to carry off any heat

generated by the MHD flow train and controlled coolant water temperature could be utilized to prevent condensation in the bore during periods when the MHD train is not in use. In the event of a gas discharge from the train, or heavy electrical arcing, the G-7 insulator is designed to remain functional for a period of at least 10 sec. This is adequate time for the combustion chamber to be shut down to terminate the dangerous situation. It would then be necessary to cut out and replace damaged insulation to restore the liner to full service. This could be done in place. In the event that the combustor is not shut down and the insulation burns through, the warm bore liner is designed to provide protection by failure, i.e. by burning through the metallic wall and discharging up to 200 gpm into the bore of the magnet. In the event that this occurs, it would be necessary to withdraw the warm bore liner, cut out and replace the damaged section, and reinstall the warm bore liner.

Drawing D4450 shows the warm bore liner as installed in the bore of the magnet. The liner is built in two sections. The largest section is inserted from the downstream end of the magnet and extends to the upstream end of the bore taper. It is contoured so as to cover completely the bore as well as the opening of the aperture in the magnet end. The smaller section is inserted from the upstream end and mates up with the larger section on matching dowels. The small space in between the two sections is filled with G-7 on assembly. All coolant connections to the warm bore liner are at the ends of the magnet. No water flows between the two sections. (See Figures 5 and 6).

Figure 7 shows the cooling and instrumentation arrangements for the warm bore liner. In normal operation, approximately 40 gpm flows through the liner. In the event of burn-through into the water passage, this flow could increase to as much as 200 gpm. This increase in flow and the associated drop in pressure is detected and utilized to activate a warning light on the main control panel and signal for shutdown of the combustor.

The MHD channel, perhaps with the nozzle or a portion of the nozzle attached, is inserted into the warm bore liner from the downstream end from a dolly with tracks which match the tracks in the warm bore liner. The tracks are carried on the bore of the magnet through jack screws which protrude through the warm bore liner to contact the insulation on the bore. With these jacks, it is estimated that the tracks can be leveled to a flatness of approximately 0.100" throughout the length. Experience with large MHD generators has indicated that it is difficult to assure track flatness to a greater degree than 0.100". Therefore, some flexibility will need to be built into the supports for the MHD channel. The track is segmented at a number of locations in order that the track will not become a short circuit path for electrical breakdown. Bleeders are utilized to distribute the voltage over the track segments.

2.2.1.9 Vapor-Cooled Electrical Leads

Two helium vapor-cooled electrical leads will be mounted in the stack at the exit end of the magnet assembly. The leads will be designed to carry the rated magnet current of 24,4000 amperes with a total flow of helium coolant not

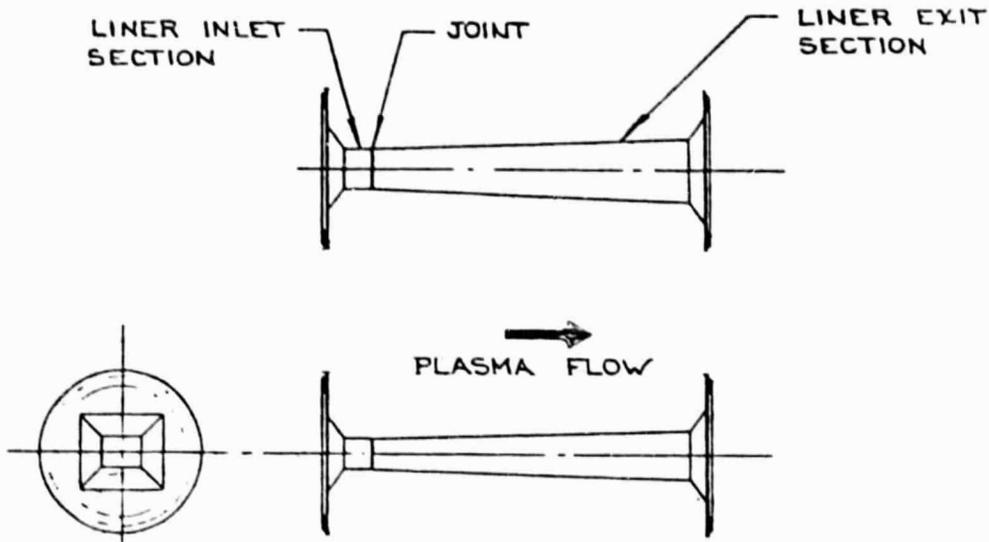


Fig. 5
WATER-COOLED WARM BORE LINER CONFIGURATION

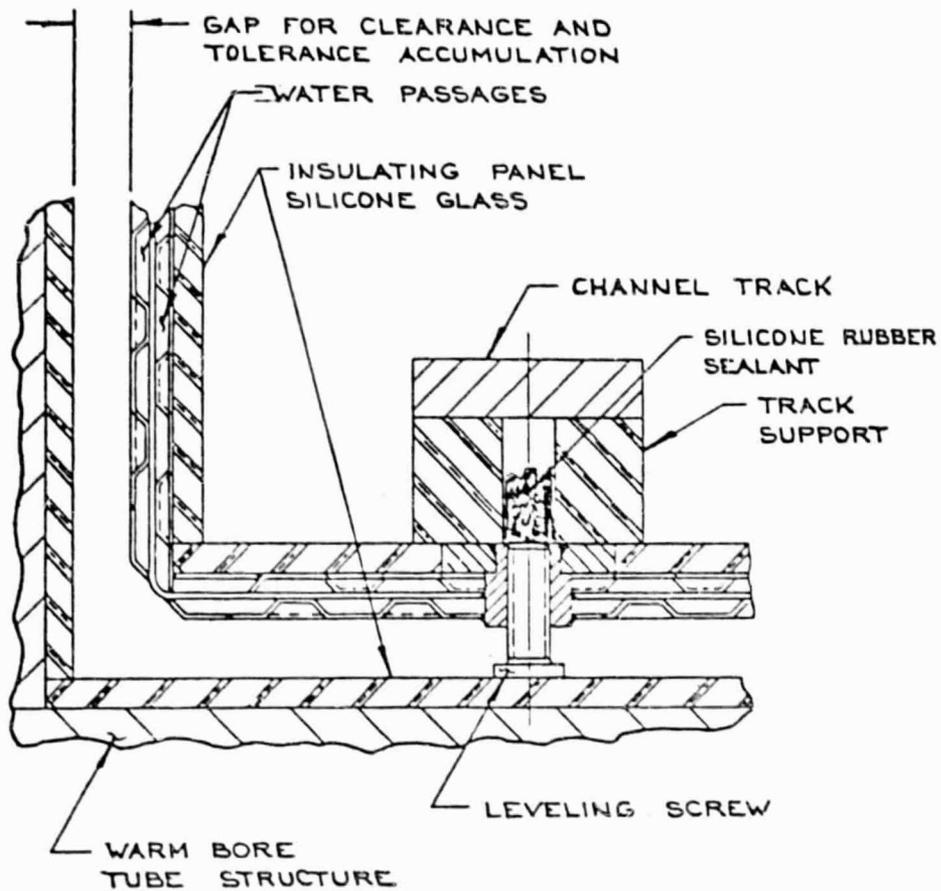


Fig. 6

WATER-COOLED WARM BORE LINER CONSTRUCTION

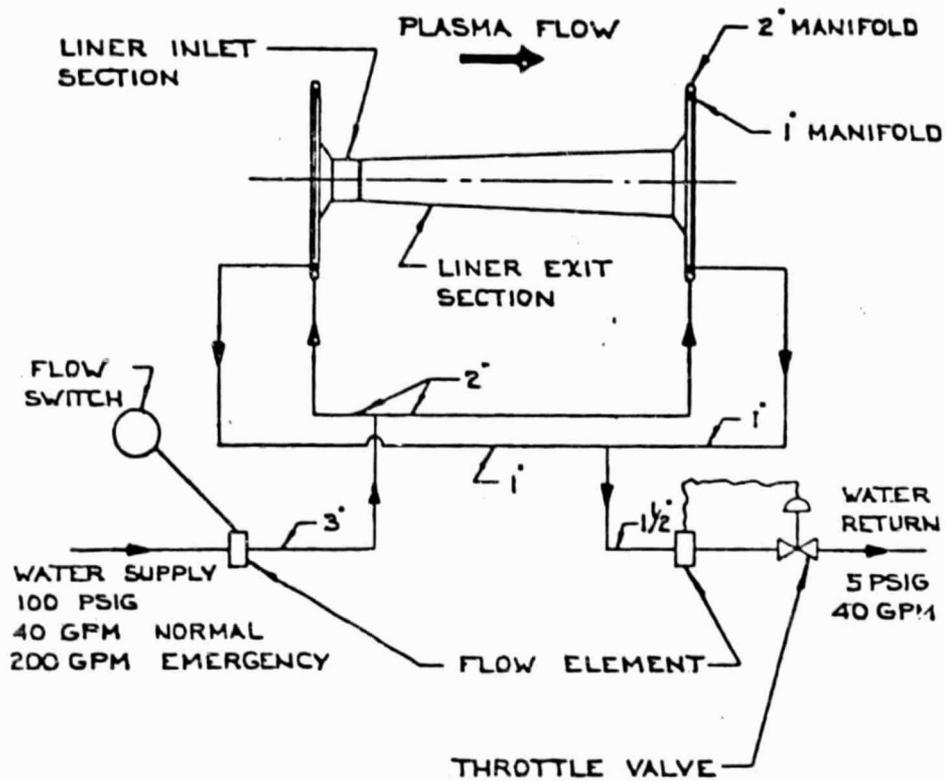


Fig. 7
 WATER-COOLED WARM BORE LINER
 WATER FLOW SCHEMATIC

exceeding 2.5 grams per second. At 0 current flow the heat leakage into the liquid helium region of the magnet through the vapor cooled leads will not exceed 35 watts, with approximately 1.5 grams per second total cooling flow through the pair of leads. The leads are so designed that, during an emergency discharge of the magnet from 24,400 amperes current they will not over-heat dangerously even though there is no coolant flowing in them.

Automatic valves will be provided in the discharge piping from each lead which, when combined with temperature sensors in the exit end of each lead, will automatically control the helium gas flow through the leads in order to maintain the temperature of the exit gas at slightly below room temperature. Flow meters will be provided in the discharge of each lead and their readout will be connected to the magnet control system, arranged so that in the event of flow stoppage, an emergency signal will be transmitted to the control station.

2.2.1.10 Internal Instrumentation, Wiring and Piping

Instrumentation installed in the magnet assembly is listed in Table VI. Power leads are installed in the plenum chamber above the winding containment vessels at the exit end, connecting the two windings in series and connecting the outer terminals of the windings to the lower ends of the vapor-cooled leads. The connecting power leads consist of copper-stabilized NbTi superconductor backed by extra copper, exposed to liquid helium coolant and supported. Piping is installed in the stacks and winding containment vessels to direct the flow of helium during cool-down, to permit purging the bottom of the containers, and to handle helium transfer into, and venting out of, the magnet during steady-state operation. Piping is installed in the stacks and in the vacuum space to carry liquid nitrogen to the stack nitrogen reservoir and to the thermal shield and other parts of the assembly requiring nitrogen cooling.

2.2.1.11 Roll-Aside Mechanism

The magnet assembly is mounted on a roller and track system so arranged that the magnet assembly can be rolled sideways a distance of approximately 34 feet, to facilitate installation and removal of the MHD channel. With this arrangement, it is necessary that disconnect flanges and/or short removable sections be located in the flow train just upstream of the magnet inlet face and just downstream of the magnet exit face. The combustor, and major portions of the nozzle and the diffuser are assumed to be permanently mounted to foundations. The disconnect flanges/removable sections are so designed that when separation has been effected, the magnet and the MHD channel can be rolled aside as a unit, with the flanges sliding out of engagement. The magnet and channel are then rolled sufficiently far to the side so that the channel can be removed from the exit end of the magnet without interfering with the diffuser. A special cart will be provided to support the channel as it is withdrawn from the magnet

TABLE VI
MAGNET SYSTEM
MAGNET ASSEMBLY INSTRUMENTATION

Voltage measurement	<p>Across each winding layer</p> <p>Across magnet terminals below vapor-cooled leads</p> <p>Across vapor-cooled leads (cold to warm ends)</p>
Temperature measurement	<p>At 10 locations on winding substructure</p> <p>At 10 locations on main force containment structure (superstructure)</p> <p>At 10 locations on winding containment vessels</p> <p>At 10 locations on thermal radiation shield</p> <p>At cold end of each support strut</p> <p>At intermediate station of each support strut</p> <p>At upper (warm) end of each vapor-cooled power lead</p>
Strain measurement (strain gages)	<p>At 10 locations on superstructure</p> <p>On each support strut</p>
Liquid level measurement	<p>Probes at 8 levels in magnet winding coil containment vessels (for measurement during LHe fill)</p> <p>Series of probes or equivalent level indicating equipment for continuous measurement of LHe level between coil-top and maximum working level in helium reservoir located in magnet service stack</p> <p>Equipment for level measurement in thermal shield liquid nitrogen reservoir in service stack</p>
Pressure and vacuum measurement	<p>Pressure in winding containment vessels</p> <p>Pressure in water-cooled warm bore liner</p>
Flow measurement	<p>Gaseous helium exit from each vapor-cooled lead</p> <p>Water to water-cooled warm bore liner</p>

and transported to a channel overhaul area. A new or rebuilt channel can be inserted into the magnet bore from the magnet exit end and then the magnet and channel can be rolled back into operating position and the flanges fastened.

The tracks on which the magnet rolls consist of structural I-beams fastened to the foundation provided in the facility, and capped by flat tracks on which the rollers ride. The edges of the tracks are machined surfaces on which guide rollers ride, in order to keep the magnet assembly centered on the tracks. There are four sets of main rollers, one set under each of the four corners of the magnet vacuum jacket. The commercial roller units used will have a combined rated capacity of approximately four times the total weight of the magnet assembly, thus assuring long life. Structural members and mounting pads will be provided between the base of the vacuum jacket and the roller assemblies so that weights will be correctly distributed and so that adjustment of the magnet in the axial and vertical dimension can be made during the initial installation, in order that the centerline of the warm bore will be in its predetermined proper location.

A pair of double acting hydraulic actuators (telescoping hydraulic cylinders) are provided for moving the magnet assembly on the tracks. A cylinder unit is located outboard of each track structure, running parallel to the track. The cylinders are energized from an hydraulic power pack mounted with other magnet accessories.

Holddown brackets will be provided under the four corners of the vacuum jacket base. The lower portion of each hold down jacket will be fastened to the structural I-beam which supports the track. The upper portion of each bracket will be attached to the magnet base. A flanged joint in each bracket will be so arranged that its fasteners can be easily removed when it is desired to roll the magnet aside. The holddown bracket and the track in the region of the brackets will be capable of withstanding forces including seismic forces and magnetic forces that may result from reaction of the magnet with surrounding equipment.

2.2.2 Cryogenic Support Equipment

The cryogenic support equipment consists of the following major components:

- Refrigerator/liquefier
- Compressor package
- Liquid helium storage
- Gaseous helium storage tanks
- Liquid nitrogen storage tank

Cool-down heat exchanger
 Warm-up heat exchanger
 Cryogenic system piping, wiring, instrumentation
 and controls

The helium piping for the cryogenic support equipment is shown on Drawing D-4452. The nitrogen piping for the cryogenic support equipment is shown on Drawing D-4453.

The purpose of the cryogenic support equipment is to cool the magnet winding and main structure from room temperature to liquid helium temperature, to maintain the cold mass at liquid helium temperature (and filled with liquid helium) for long periods of time with magnet operating at rated field strength and MHD system at rated power, and to warm up the cold mass to room temperature in the event that repairs or long plant shut down (several months) are necessary.

The cryogenic support equipment is provided with automatic controls so that it maintains the magnet at the desired operating temperature for long periods of time without special attention from operators. The cryogenic support equipment requires the following utilities:

- Electric power
- Cooling water
- Compressed air
- Bulk liquid nitrogen (continuous supply)
- Initial charge of helium
- Make up helium (not to exceed 1200 SCF per month,
 under normal operating conditions)

The helium refrigerator/liquifier, compressor package and helium storage tanks operate as a closed-loop refrigeration system. The gaseous helium storage tanks have sufficient capacity so that in conjunction with the liquid helium storage tank they can contain the entire system charge of helium when the magnet is warmed to room temperature. Under conditions of emergency discharge (quench) of the magnet, helium is vented through the emergency vent system of the magnet to atmosphere. This helium is not recovered and it will be necessary to replace the lost helium by purchase from commercial supplier. An atmospheric pressure recovery system for emergency vent gas is not provided, because the emergency discharge condition represents an abnormal occurrence not expected to happen under regular operating, startup, and shutdown conditions of the magnet system.

2.2.2.1 Component Characteristics

The refrigerator/liquifier is a mechanical refrigeration unit equipped with a system of turbo-expanders and heat exchangers capable of the following performance:

Liquid helium (gas return at 300 K)	125 l/hr
Refrigeration at 4.5 K (gas returned at 4.5 K)	250 W

Helium filtering and purifying equipment is included in the refrigeration unit. Under steady-state operating conditions the refrigerator/liquifier receives gaseous helium from the compressor package at approximately 25.5 psig and delivers liquid helium to the liquid helium storage tank at approximately 4.5 K and 22 psia. Helium gas boil-off from the storage tank and magnet returns to the refrigerator/liquifier at slightly above 4.5 K.

The compressor package includes oil lubricated screw-type compressors, lubricating system, oil separators, motors, and controls. Under steady-state conditions it supplies approximately 120g/sec (952 lbs/hr) gaseous helium to the refrigerator/liquifier at the required pressure and receives return gas from the refrigerator/liquifier and magnet vapor-cooled power leads at slightly above atmospheric pressure.

The liquid helium storage tank is a vacuum-insulated tank which receives liquid helium from the refrigerator and supplies it to the magnet. The tank capacity is 2000 gallons. The normal operating pressure is approximately 22 psia.

The gaseous helium storage tanks store room temperature helium gas at pressures ranging between the suction and discharge pressure of the compressor package. The volumetric capacity of each tank is 90,000 gallons for a total capacity of 180,000 gallons (24,000 cu ft.) When the magnet is shut down and allowed to warm up to room temperature, the original liquid helium inventory of the magnet boils off and becomes helium gas at room temperature. This gas is compressed by the compressor package and is delivered to the gaseous helium storage tanks which are large enough to hold the entire helium inventory, except for that in the form of liquid in the liquid helium storage tank.

The liquid nitrogen storage tank is an insulated cryogenic tank which receives liquid nitrogen from the air separation plant and supplies it to the refrigerator/liquifier (for pre-cooling helium gas), to the magnet thermal radiation shield and to the tracer lines of the cold helium transfer piping. During cool-down of the magnet from room temperature, the liquid nitrogen storage tank supplies liquid to the cool-down heat exchanger. The tank capacity is 9000 gallons and its normal operating pressure is 30 psig. A connection is provided for filling from tank truck to handle demand during magnet cool-down and/or when air separation plant is not operating.

The cooldown heat exchanger is a surface-type heat exchanger which employs liquid nitrogen to cool helium gas delivered from the compressor package and supplies it to the magnet for initial cooldown purposes. The exchanger is capable of cooling the full discharge flow of the compressor package from room temperature to 100 K.

The warm-up heat exchanger contains electric resistance heaters which heat cold helium gas from the magnet during magnet warm-up, and deliver the warmed gas to the suction of the compressor package at approximately room temperature and with flow equal to full compressor capacity.

The cryogenic support system includes all interconnecting piping and wiring (dc power bus, instrument wiring, control wiring, etc.) between components of the system and between the system and the magnet. The system includes instruments to monitor the operation of all components, controls for start-up, automatic steady-state operation and shut-down and safety devices to protect all components. An instrument and control panel is mounted in the cryogenic system area for local start-up, operation and shut-down of the system.

2.2.2.2 System Operation, Steady State

Under steady-state conditions (magnet at liquid helium temperature, either charged or discharged) the refrigerator/liquefier operates continuously delivering liquid helium into the liquid helium storage tank as shown on the helium system diagram, Drawing D4452.

Liquid helium from the liquid storage tank is delivered to the magnet as required to maintain the liquid level in the helium reservoir (located inside the magnet enclosure above the winding containment vessels) within the design operating range. Transfer is controlled automatically, in response to a liquid level sensor in the magnet helium reservoir.

Helium boil-off in the magnet returns in part through the vapor-cooled power leads to the suction of the compressor package and in part to the refrigerator. Boil-off from the storage tank returns to the refrigerator. The gas which passes through the leads is heated to room temperature. The other returns are cold (slightly above 4.5 K) and are carried to the refrigerator in insulated transfer lines. They are then warmed in the refrigerator heat exchangers before going to compressor suction.

The refrigerator/liquefier design capacity is about 50% greater than that required for steady-state magnet cooling. To prevent over-filling the liquid helium storage tank, a liquid level sensor in the tank automatically limits the maximum level to a preset point by energizing an electric heater in the tank.

The gaseous helium storage tanks, connected in parallel, supply helium gas to the compressor suction when liquefaction rate exceeds boil-off. The same tanks receive and store excess helium gas when boil-off exceeds liquefaction rate.

2.2.2.3 Cool-down and Warm-up

Cool-down of the magnet from room temperature is accomplished by closed-loop circulation of helium gas using the cool-down heat exchanger (see Drawing D4452) in conjunction with the compressor package, gaseous helium storage

tanks and refrigerator/liquefier. At the start of cooldown the thermal radiation shield of the magnet is cooled to about 80K with liquid nitrogen from the liquid nitrogen storage tank. The refrigerator/liquefier is temporarily bypassed and helium gas is pumped by the compressor package through the cool-down heat exchanger and the magnet windings. In the heat exchanger, liquid nitrogen supplied from the nitrogen storage tank cools the helium gas to approximately 100 K. The cold helium then flows through an insulated pipe to the magnet winding containment vessels, where it is distributed by manifolds to the lower portions of the windings. Cooling by convection takes place in the windings and substructure. The main structure is cooled by conduction through the containment vessel walls. The return gas, warmed by heat removed from the windings, is taken out through manifolds in the upper portion of the winding containment vessels and carried back to the compressor suction.

When the windings and substructure are cooled to a temperature of approximately 120 K, the refrigerator/liquefier is connected into the loop and the cool-down heat exchanger is bypassed. The expansion engines of the refrigerator/liquefier are used to further lower the temperature of the helium gas going to the magnet. When the temperature of the magnet windings and substructure approaches liquid helium temperature, bulk liquid helium is transferred into the winding containment vessels from the liquid helium storage tank and/or bulk carriers.

Warm-up of the magnet is accomplished by closed-loop circulation of helium gas using the compressor package and the warm-up heat exchanger. The refrigerator/liquefier is bypassed and room temperature gas from the compressor is circulated through the magnet windings and returned to the compressor package via the warm-up heat exchanger. The latter warms the gas to room temperature from the lower temperatures at which it leaves the magnet.

Speeds of cool-down and warm-up are limited by the rate of gas circulation (compressor capacity) and by considerations of thermal stress. In the system described here, cool-down and warm-up can each be accomplished in less than 4 weeks.

2.2.3 Power Supply and Discharge Equipment

The power supply and discharge equipment consists of the following major components:

- Power supply package (includes rectifiers, transformers and controls)
- ac circuit breakers
- dc circuit breakers (switches)
- Discharge resistor package

The power supply and discharge system is shown diagrammatically on Drawing D4454.

The purpose of the power supply and discharge system is to charge the magnet, to maintain the magnet at desired field strength for long periods of time and to discharge the magnet under either normal shut-down or emergency (fast) shut-down conditions. Controls and a control panel are incorporated in the power supply package for local start-up, operation, monitoring, and shut-down of the system. Provisions are included for remote control from the facility control station and for tie-in with quench-protection and other safety systems.

Circuit breakers, both ac and dc, are mounted in cabinets adjacent to the power supply package. The ac breakers interrupt the three phase input from facility power and have characteristics as follows:

Rated voltage	- 4.16 kV
Rated continuous current	- 1200 A rms
Normal continuous current	- 400 A rms
Rated interrupting current	- 12,000 A rms
Normal interrupting current	- 5000 A rms
Type	- Draw-out air circuit breaker

The dc circuit breakers (switches) are single pole air circuit breakers, each having switch contacts ganged to provide a continuous rating of 24,400 A. These switches are normally closed. They are opened in sequence when emergency discharge is called for, the sequence being as follows:

	<u>Current at Opening</u>
Main switch	24,400 A
First auxiliary switch	10,000 A
Second auxiliary switch	4,000 A

Interlocks are provided to prevent opening of the auxiliary switches at currents above those listed. The terminal voltage of the magnet during the discharge sequence never exceeds 10 kV.

The discharge resistor package consists of stainless-steel resistor elements supported in a high-temperature-resistant, insulating structure and immersed in water in a non-metallic tank having a capacity of 5000 gallons. When the total stored energy of the magnet is transferred into the resistor package, the water temperature rise will not exceed 90° F. The tank has a float-controlled cooling water inlet valve to maintain (full) water level automatically with an orifice discharge designed for a continuous flow of 50 GPM. The resistor package functions in the heat-sink mode during emergency discharge, with substantially all of the absorbed energy being stored in the resistors and water bath. The water circulation restores the resistor package to room-temperature after a discharge has taken place.

The power supply and discharge system characteristics are listed in Table VII.

TABLE VII
MAGNET SYSTEM
POWER SUPPLY AND DISCHARGE
SYSTEM CHARACTERISTICS

Rated current	24,400 A
Rated voltage	108 V
Current regulation	2%
Minimum charge time 0 A to 24,400 A (L = 9.7 henries)	45 min.
Minimum discharge time 24,400 A to 0 A, normal discharge	45 min.
Minimum discharge time, emergency, 24,500 A to 0 A	< 3 min.
Discharge resistors, resistance	
Main	0.41 Ω
First auxiliary	0.59 Ω
Second auxiliary	1.20 Ω
Maximum discharge voltage	10 kV

2.2.3.1 Component Characteristics

The power supply package incorporates a 12-pulse controlled rectifier having four groups of three-phase half-wave connections in parallel through three inter-phase transformers as shown in Drawing D4454. Each group has one SCR arm per phase and each arm has five individually fused water-cooled SCRs in parallel. Current balancing reactors ensure equal current division in the arm. The power supply package delivers its maximum voltage during the charging period. The current ramps up from zero to its maximum value during the charging period. At the end of the charging periods the SCRs are phased back and the power supply delivers just enough DC voltage to overcome the drop in the connections and the DC bus bars (about 10 percent of the maximum voltage). The power output of the supply is 2650 kW at the end of the charging period and is about 300 kW during normal operation.

The four groups are supplied from the three-phase transformers each having two secondary windings. The star and delta connections of the primary windings of the transformers make the output of the power supply a 12-pulse DC output. The output has a peak-to-peak ripple of 3.6 percent of the DC voltage. As the inductance of the magnet coil is very large there is practically no ripple in the magnet current. The power supply is designed to work as an inverter (during normal magnet discharge) to transfer stored energy from the magnet into the power grid. To accommodate this feature, the transformers have a continuous rating of 2650 kVA. Considering the dusty and warmer than normal environment of the power station where the power supply is intended to be used, the transformers and rectifiers are totally enclosed in the cabinets. The transformer cabinets may be provided with air/water heat exchangers of suitable capacity in consultation with the transformer manufacturers.

2.2.4 Vacuum Pumping Equipment

The vacuum pumping equipment consists of the following:

- Diffusion pumps, magnet vacuum vessel (2 pumps)
- Mechanical vacuum pump package, magnet vacuum vessel (2 pumps)
- Utility vacuum pump package

The location of the above-listed pumps in the facility are shown on Drawing D4445.

The diffusion pumps and mechanical (fore) pumps connected in series to the magnet vacuum vessel are for the purpose of initially evacuating this vessel to a pressure below 1×10^{-4} torr (as required for effective thermal insulation) and of maintaining an insulating vacuum in the vessel in the event that helium leakage develops within the vessel during its service life.

Vacuum valves are installed between the vacuum vessel and the diffusion pumps for the purpose of preventing back-leakage of air should one or both of the pumps fail or when pumps are shutdown after a satisfactory vacuum is established. During initial evacuation of the room-temperature magnet and

vacuum vessel assembly, leak tests are made to ensure that there are no helium leaks. Cool-down is started after leak-tight conditions are established and a vacuum of 10^{-4} torr or better is established. The vacuum valves are then closed, because cryo-pumping by the cold surfaces inside the vacuum space will condense any residual air leakage or gas produced by out-gassing of surfaces, and maintain a vacuum well below the initial (pumped) warm vacuum. If, during operation, small helium leakage develops and tends to degrade the vacuum, the vacuum pumps can be reactivated and the valves opened so that operation of the magnet can continue. The mechanical pumps are located remote from the diffusion pumps in order that they may be in a low fringe field zone where maintenance and/or repairs can be performed on an 8 hour shift basis.

The utility vacuum pump package is for the purpose of evacuating and purging cryogenic support equipment and maintaining vacuum in the vacuum jackets of accessory equipment such as the refrigerator/liquefier.

2.2.5 Protection/Control Equipment and Instrumentation

Protection systems, devices and controls are provided to ensure safety of personnel and equipment and for convenient control of the magnet system. A quench protection system is provided to sense the initiation of a quench (an abnormal event involving transition of magnet winding from superconducting to resistive mode), and to actuate automatically an alarm and a time-delayed emergency (fast) discharge of the magnet. This system protects the winding against damage due to resistive over-heating. Alarms and time-delayed emergency discharge are provided which are actuated by the following abnormal conditions:

- Low liquid helium level in magnet winding containment vessels
- Over-temperature of vapor-cooled power leads
- Loss of vacuum in magnet vacuum vessel
- Over-temperature of water-cooled dc bus system between power supply and magnet

Positive means are incorporated in the magnet power supply to ensure that current cannot be increased above current required to produce 6 T peak on-axis field under any circumstances. (This is a precaution against over-stressing magnet structure).

The following controls and monitoring instruments are provided at the facility control station.

Controls

- Magnet charge
- Magnet discharge, normal
- Magnet discharge, emergency
- Magnet current control

Instruments

Magnet current (indicate and record)

Warning lightsQuench

Low liquid helium level in magnet

Over-temperature of vapor-cooled leads

Loss of vacuum in magnet vacuum vessel

Over-temperature of water-cooled dc bus

Over/under pressure in winding containment vessels

Low water pressure in water-cooled warm bore liner

High water flow (leakage) in water-cooled warm bore liner

Instrumentation provided in the magnet system for monitoring and control includes that listed in Table VIII.

3.0 SYSTEM LIMITS AND SAFETY PRECAUTIONS

3.1 OPERATING LIMITS

Operating limits of the magnet system are shown on Table IX.

3.2 HAZARDS

Magnetic field (fringe field) produced by the magnet in the region surrounding it is a potential hazard to personnel and equipment. This hazard exists only when the magnet is charged. The extent of the fringe fields and precautions to be taken are described in Specification A4442, attached. It should be noted that the standards used in Volume I of this CDER are less restrictive than the ones set forth in Specification A4442.

Voltage up to 10 kV exists across the magnet terminals during emergency shut-down of the magnet. Busses leading from the magnet to the emergency discharge resistors are suitably protected for this voltage. The main discharge resistor has a grounded center tap so the voltage to ground does not exceed 8 kV. Instruments in contact with the magnet windings are subjected to these voltages during emergency shut-down. This is to be taken into account in the design of the instruments and read-out system. Except for the hazards mentioned above, no personnel hazards are expected to exist in the Magnet System beyond those normally observed in piping systems up to 300 psia pressure, hydraulic actuator systems (2000 psig) and in cryogenic systems.

3.3 PRECAUTIONS

Precautions against adverse effects of fringe magnetic fields are described in Specification A4442 (Appendix A).

TABLE VIII Sheet 1 of 2
 . MAGNET SYSTEM
 INSTRUMENTATION, MONITORING AND CONTROL

Magnet

Warm Bore

Magnetic field in peak field region
 Pressure in water-cooled warm bore liner
 Water flow rate to water-cooled warm bore liner

Windings

Magnet (coil) current
 Magnet (coil) voltage across cold terminals
 Winding temperature (for cooldown)
 Layer to Layer voltages

Power Leads

Positive current lead temperature
 Positive current lead voltage drop
 Positive current lead gas flow rate
 Negative current lead temperature
 Negative current lead voltage drop
 Negative current lead gas flow rate

Cryogenics (Internal)

Liquid helium level in winding containment vessels (for initial fill)
 Liquid helium level in service stack liquid helium reservoir
 Pressure in winding containment vessels
 Vacuum in vacuum vessel
 Liquid nitrogen level indicator in service stack liquid nitrogen reservoir

Structure and Thermal Radiation Shield

Thermal radiation shield temperature
 Cold structure temperature
 Cold structure strain gauges
 Support strut strain gauges

Power Supply

Voltage across main discharge resistor
 Voltages across auxiliary discharge resistors
 Current in discharge resistor circuit
 Diode temperatures
 Discharge switch status indicators
 Discharge resistor temperatures
 Ground fault sensor (current in main discharge resistor center tap to ground)

TABLE VIII Sheet 2 of 2

Cryogenic Support System

Compressor package suction pressure
Compressor package discharge pressure
Gaseous helium purity
Liquid helium storage dewar liquid level
Liquid helium storage dewar pressure
Gaseous helium storage vessel pressure
Liquid nitrogen storage tank liquid level
Liquid nitrogen storage tank pressure

TABLE IX
MAGNET SYSTEM
OPERATING LIMITS

<u>Magnet</u>	<u>Units</u>	
Field, peak on-axis		
Rated	T	6
Maximum operating range	T	0-6
Current		
Rated	A	24,400
Maximum operating range	A	0-24,400
Pressure in winding containment vessel		
Normal operating	psia	19
Maximum design	psia	45
Pressure in vacuum vessel		
Maximum operating	torr	10 ⁻⁴
Normal operating	torr	<10 ⁻⁵
Pressure in thermal radiation shield coolant tubes		
Normal operating	psia	15
Maximum design	psia	60
Pressure in water-cooled warm bore liner		
Normal operating	psig	100
Maximum design	psig	150
Vapor-cooled power leads		
Normal operating temperature at gas exit end	°F	40
Maximum allowable temperature at gas exit end	°F	180
Winding, substructure and superstructure		
Maximum allowable temperature differential during cool-down/warm-up	°F	100
Liquid helium storage tank		
Normal operating pressure	psia	21
Maximum design	psia	TBD
Gaseous helium storage tank		
Normal operating pressure	psia	270
Maximum design pressure	psia	300
Liquid nitrogen storage tank		
Normal operating pressure	psig	30
Maximum design pressure	psig	TBD
Hydraulic actuator system		
Normal operating pressure	psig	TBD
Maximum design pressure	psig	TBD

4.0 OPERATION

4.1 STARTUP

The magnet has superconducting windings which must be at liquid helium temperature for operation. Initially, the windings are cooled from room temperature, a process requiring several weeks (See Section 4.1.1). Once cold, the magnet can be charged and discharged relatively quickly. The magnet is kept cold continuously for long periods of time, and is allowed to warm up only in the event of a facility shut-down of several months duration or other unusual circumstance.

4.1.1 Initial Startup

Initial startup of the magnet system after installation or after warm-up for extensive overhaul requires a sequence of starting operations involving both accessory equipment and the magnet. These operations are outlined in Table X. It is assumed that utilities (cooling water, electricity, compressed air, etc.) are available and connected and that pumps, compressors, etc. in the system are charged with lubricating oil. It is further required that bulk liquid nitrogen and liquid helium be available by truck-delivery.

4.1.2 Startup from Cold Condition

When starting the (discharged) magnet from the cold condition it is necessary only to charge using the power supply. (See Table X.) Charging can be accomplished in less than one hour.

4.2 NORMAL OPERATING MODE

The magnet will be operated continuously at its rated current and field during all normal operation.

The magnet system is capable of operating continuously at current and field below rated, should less than rated field be desired for flow train operation.

4.3 NORMAL SHUTDOWN

Normal shutdown of the magnet involves discharging through the power supply. Stored energy in the magnet is fed back into the facility electrical system during normal discharge. Discharge can be accomplished in less than one hour.

TABLE X Sheet 1 of 2

MAGNET SYSTEM
STARTING OPERATIONSInitial Startup (from warm condition)

1. Evacuate magnet vacuum jacket using main diffusion pumps and fore pumps.
2. Verify vacuum in jackets of refrigerator/liquifier, liquid helium storage tank, liquid nitrogen storage tank and vacuum insulated transfer lines. Pump down with utility vacuum system if necessary.
3. Evacuate and purge interiors of helium and nitrogen storage tanks, piping systems, heat exchangers, etc., and fill with dry gas (helium or nitrogen, as required)
4. Evacuate and purge magnet winding containment vessels and thermal shield piping, and fill with dry gas.
5. Fill liquid helium storage and liquid nitrogen storage tanks from bulk transport vehicles.
6. Shake-down test refrigerator/liquifier.
7. Cool and fill magnet thermal radiation shield and reservoir with liquid nitrogen.
8. Start magnet winding cool-down by circulating helium gas in a closed loop through liquid nitrogen cooled cool-down heat exchanger and magnet winding container, using refrigerator compressors.
9. When winding temperature is lowered to about 120 K, connect refrigerator expanders into the loop to reduce temperature of cooling stream below liquid nitrogen temperature.
10. When winding temperature is approximately 10K, start liquid helium fill of coil containers and deactivate cooldown loop.
11. Change over refrigerator/liquifier to liquify into liquid helium storage tank.
12. When liquid level in reservoir above winding containers reaches operating level, change over to automatic operation of liquefier/refrigerator system.
13. Charge the magnet using the power supply. (Note: The initial charging of the magnet will be part of a magnet system shakedown test with special procedures and use of diagnostic instrumentation).

TABLE X Sheet 2 of 2

Startup from Cold Condition

1. Verify that liquid helium level in reservoir above winding coil containers is at operating level.
2. Charge magnet using the power supply.

4.4 EMERGENCY SHUTDOWN

Emergency shutdown of the magnet is accomplished by the activation of circuit breakers in the dc power supply system, causing magnet current to flow through a bank of water-cooled resistors where electro-magnetic energy which was stored in the magnet coils is absorbed. Current and field are reduced to 10% of rated values in approximately 30 seconds. Further discharge to 0 current requires an additional 2 minutes.

Both manual and automatic activation of the emergency discharge circuit breakers are provided for. Manual operation will be by means of an emergency push-button at the main control station of the facility. Automatic operation will be actuated by a quench protection system and/or other sensors as described in Section 2.2.5.

5.0 MAINTENANCE

5.1 SURVEILLANCE AND PERFORMANCE MONITORING

Instrumentation is provided for surveillance and performance monitoring in three areas as listed below:

Main Control Room

Major parameters of magnet and subsystems

Local Control Panels

Refrigerator/liquefier system
 Nitrogen system
 Power supply system
 Main vacuum pumping system
 Hydraulic actuator system
 Utility vacuum pump

Special Panels for Shakedown Testing

Magnet parameters significant for initial (shakedown) testing and diagnostics

5.2 INSERVICE INSPECTION

The magnet has access provisions for periodic inspection of main structure, to be accomplished in accordance with appropriate standards (see Section 1.3.1).

The accessory systems and associated piping, valves and controls are subject to periodic inspection to ascertain that the equipment is working properly.

5.3 PREVENTATIVE MAINTENANCE

A schedule will be provided to alert the operators that certain pieces of apparatus need periodic overhaul, maintenance, etc., depending on the recommendations of the equipment manufacturer.

5.4 CORRECTIVE MAINTENANCE

5.4.1 Manufacturer's Instructions

A complete file of instruction books will be available at the plant to guide the plant personnel in maintenance and overhaul of any piece of equipment. If necessary, a representative of the manufacturer can be present to supervise the overhaul or replacement of plant equipment.

5.4.2 Spare Parts

The manufacturers will supply lists of recommended spare parts to be kept in inventory at the plant. Complex parts requiring long lead time for delivery will be included in the plant inventory.

SYSTEM DESIGN DESCRIPTION

MAGNET SYSTEM

APPENDIX "A"REFERENCE DOCUMENTSREFERENCE DOCUMENTS - ATTACHED

<u>Specification</u>	<u>Document No.</u>
MHD-ETF 200 MWe Power Plant Magnet System - Interim Criteria for Personnel and Equipment Exposure to Magnetic Fields (7 sheets)	A4442
<u>Drawings</u>	<u>Drawing No.</u>
MHD-ETF 200 MWe Power Plant Magnet System - Drawing Index	D4429
MHD-ETF 200 MWe Power Plant Magnet System - Field Profile and Bore Dimensions	D4439
MHD-ETF 200 MWe Power Plant Magnet System - Outline	D4441
MHD-ETF 200 MWe Power Plant Magnet System - Foundation	D4443
MHD-ETF 200 MWe Power Plant Magnet System - Fringe Magnetic Field Zone Boundaries	D4444
MHD-ETF 200 MWe Power Plant Magnet System - Plan and Elevation, Magnet and Accessories	D4445
MHD-ETF 200 MWe Power Plant Magnet System - Limits on Variations in Magnetic Field Profile and Field in Channel Cross-section	D4448
MHD-ETF 200 MWe Power Plant Magnet System - General Assembly	D4450 Sh. 1-4
MHD-ETF 200 MWe Power Plant Magnet System - Diagram, Helium Piping	D4452
MHD-ETF 200 MWe Power Plant Magnet System - Diagram, Nitrogen Piping	D4453
MHD-ETF 200 MWe Power Plant Magnet System - Diagram, Electrical Power Supply and Discharge System	D4454
MHD-ETF 200 MWe Power Plant Magnet System - System Diagram (Schematic)	D4456
MHD-ETF 200 MWe Power Plant Magnet System - Typical Joint in Superconducting Cable	D4457

REFERENCE DOCUMENTS - NOT ATTACHED

Technical Papers and ReportsRef. No.

1. "Magnet-Flow Train Interface Considerations", P. G. Marston, A. M. Dawson, A. M. Hatch, MIT/FBNML; T. R. Brogan, MEPPSCO, Inc. 19th Symposium, Engineering Aspects of MHD, the University of Tennessee Space Institute, Tullahoma, TN, June 1981.

Technical Papers and Reports (cont'd)

Ref. No.

2. Final Report, "High Current Composite Superconductor Study for Baseload MHD Magnet Systems", B. A. Zeitlin et al, Intermagnetics General Corp., Guilderland, NY, May 1977, prepared for MIT/FBNML.
3. Technical Report "Impact of High Current Operation on Cost of Superconducting Magnets for Large Scale MHD Applications" R. J. Thome, et al, Magnetic Corporation of America, May 1978, prepared for MIT/FBNML.
4. Final Technical Report, "Design of Superconducting Magnets for MHD Applications", A. M. Hatch, et al, AVCO Everett Research Laboratory, Inc., June 1977, prepared for DOE (formerly ERDA) ERDA FE-2285-19.
5. Final Report "Design of Superconducting Magnets for MHD Applications", R. J. Thome, et al, Magnetic Corporation of America, June 1977, prepared for DOE (Formerly ERDA) ERDA FE-2217-15.
6. Final Technical Report, "Cask Commercial Demo Plant MHD Superconducting Magnet System - Conceptual Design", S. L. Ackerman, et al, prepared for MIT/FBNML by General Dynamics Convair Division, December 1979.
7. Report, "Design and Cost for the Superconducting Magnet for the ETF MHD Generator", J. L. Zar, AVCO Everett Research Laboratory, Inc., April 1979, prepared for MIT/FBNML.
8. "The Fabrication Experiences and the Performance Test of the Coal-Fired Flow Facility Superconducting Dipole Magnet", S. T. Wang, et al, Argonne National Laboratory, 19th Symposium, Engineering Aspects of MHD, the University of Tennessee Space Institute, Tullahoma, TN, June 1981.
9. "Status of the CDIF Superconducting Magnet", R. L. Rhodenizer, et al, General Electric Co., Proceedings of the Superconducting MHD Magnet Design Conference, MIT, Cambridge, MA, March 1980.
10. "Stanford 7 Tesla Magnet, Design of the Stanford Superconducting Magnet (SSM)", J. F. Parmer, General Dynamics Convair Division, the 1980 Superconducting MHD Magnet Design Conference, MIT, Cambridge, MA, March 1980.
11. "Operation of the MHD Component Test Facility and First Experimental Results", Y. Iwasa et al, MIT/FBNML, Cryogenic Engineering Conference and International Cryogenic Materials Conference, San Diego, CA, August 1981.

Standard (Proposed)

Ref. No.

12. "Structural Design Basis for Superconducting Magnets, H. D. Becker, MIT/FBNML, August 1980.

Note: This "Interim Criteria" is not an approved document. It has been issued for review and comments only.

Entire Specification Attached

Revision Sheets Only Attached

SPECIFICATION TITLE SHEET

THIS SHEET IS A RECORD OF EACH ISSUE OR REVISION TO THE SUBJECT SPECIFICATION. EACH TIME THE SPECIFICATION IS CHANGED ONLY THE NEW OR REVISED SHEETS NEED TO BE ISSUED.

THE EXACT SHEETS CHANGED AND THE NATURE OF THE CHANGE SHOULD BE NOTED UNDER REMARKS. THESE REMARKS ARE NOT A PART OF THE SPECIFICATION. THE REVISED SHEETS BECOME PART OF THE ORIGINAL SPECIFICATION AND SHALL BE COMPLIED WITH IN THEIR ENTIRETY.

REVISIONS	REV.	DATE	BY	APP'D	REMARKS			
	A	12/16/80	AMH		Sheets 2 and 3 - minor rewording to clarify			
	B	2/5/81	AMH		All sheets rewritten. Max. Field for 8 hr exposure changed from 0.03 T to 0.01 T			
	C	2/18/81	AMH		Sheets 1-4 revised. Limit for un authorized personnel changed from 0.005 T to 0.0005 T. In table on Sheet 4, 0.03 T changed to 0.05 T			
	D	3/3/81	AMH		Rewritten. Section 5 revised; Sec. 6 and Fig. 2-4 deleted			
ISSUED		DATE	BY	APP'D	TITLE:			
		12/11/80	AMH		MHD-ETF 200 MWe POWER PLANT MAGNET SYSTEM			
FRANCIS BITTER NATIONAL MAGNET LABORATORY MASSACHUSETTS INSTITUTE OF TECHNOLOGY					INTERIM CRITERIA FOR PERSONNEL AND EQUIPMENT EXPOSURE TO MAGNETIC FIELDS			
					SH	OF	SPECIFICATION NO.	REV.
					1	7	A4442	D

1. Purpose

The purpose of this document is to define interim criteria to serve as guidelines in providing for the protection of personnel and equipment from adverse effects of magnetic (fringe) fields in the ETF.

2. Introduction

The (unshielded) superconducting magnet in the ETF will, when charged, produce relatively high DC magnetic fringe fields in the region around it. Specifically, fields between 1 and 2 tesla will exist close to the outer surface of the magnet enclosure and fields of 0.0005 tesla (8.3 times the earth's magnetic field) will exist at a distance of 270 feet from the magnet. The field decreases exponentially as one moves away from the magnet, dropping off approximately as the reciprocal of the distance cubed in regions remote from the magnet.

The use of shielding to reduce fringe fields of large magnets has been investigated. Results indicate that shielding of the entire magnet assembly to reduce fringe fields to very low levels is prohibitively expensive.

With the magnet not shielded, relatively large forces will be produced by the interaction of fringe fields with magnetic material located near the magnet. Objects of such material, not adequately secured, will be accelerated toward the magnet and may become dangerous missiles. The functioning of many types of equipment will be adversely affected by the near fringe fields. This specification establishes interim exposure limits for personnel, guidelines for the location of electrical accessory equipment in relation to the magnet, and procedures for determining the magnetic force interaction between ferromagnetic structures and the magnet.

The most practical and economical means of coping with fringe fields appears to be the separation of personnel and sensitive equipment from the magnet by appropriate distances, as specified later herein. The use of local shielding, for example around a particular item of equipment or a control station, may be appropriate in cases where remote location is impossible or has serious disadvantages.

3. Personnel Exposure Limits

In the past, personnel exposure to DC magnetic fields equivalent to the ETF fringe fields has occurred on many occasions with no observed adverse effects. However, there has not yet been sufficient experience and medical investigation to serve as the basis for any final personnel exposure criteria.

The interim standards presented below are based on recommended standards included in a letter from Dr. Edward L. Alpen, University of California, to Dr. Kenneth R. Baker, ERDA, dated July 23, 1979. They are intended to serve as preliminary guidelines during the ETF conceptual design stage and are subject to change as more information and experience are accumulated.

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The standards are limited to constant DC fields because the rate of change of field during charging and discharging of the magnet is so slow that it is not a significant factor affecting personnel or equipment. Rapidly cycling magnetic fields cannot be produced by the ETF magnet system.

Interim Standards for Personnel Exposure to Magnetic Fields (ETF)

a. Limits for Approved Personnel

	<u>Magnetic Field</u> <u>Not Exceeding</u> (tesla)
Exposure for entire work-days (8 hour work-days, 5 days per week)	0.01
Exposure for 1 hours or less per work-day	0.1
Exposure for 10 minutes or less per work-day	0.5

b. Limits for Others

Unapproved personnel shall be limited to areas where magnetic field is less than 0.0005 tesla (no time limit).

c. Fringe Field Zones

Estimated boundaries of 0.5 T, 0.1 T, 0.01 T and 0.0005 T zones around the installed ETF magnet are shown on Dwg. D4444.

d. Approved Personnel

Prior to the initial charging of the magnet, all facility personnel and others who may be expected to approach the charged magnet closer than the 0.0005 tesla perimeter shall be given a medical examination to determine that they are in good health and do not have any implanted devices (pace-makers or other such devices) that may be adversely affected by magnetic fields. Approval for exposure to fields between 0.0005 tesla and 0.01 tesla and for exposure to higher fields within the limits of Section (a) above, shall be based on that examination, and on reexaminations at appropriate intervals.

e. Use of Tools and Equipment by Personnel

Hand tools and portable equipment for use inside the 0.01 tesla perimeter shall be only such items as are specifically approved by the facility supervisor for such use (non-magnetic and/or determined to be suitable for use in the presence of high fields).

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Implementation

The facility in the vicinity of the magnet shall have appropriate caution signs, rope barriers, colored lines and/or other means permanently installed to identify areas where fields above 0.0005 tesla, 0.01 tesla, 0.1 tesla and 0.5 tesla will exist when the magnet is charged.

4. Effect on Equipment Function

DC magnetic fields such as will exist around the ETF magnet may have serious adverse effects on the functions of equipment with moving parts, electrical devices, instruments and controls. In most cases, the maximum field in which any particular item will operate without suffering adverse effects can be determined only by test and/or experience. When equipment is purchased, the equipment suppliers should be requested to specify the maximum field in which the equipment can be operated safely and without adverse effect on performance. However, very little experience or test data is available to date and suppliers may be unable to specify environmental field limits.

The table below is intended to provide general guidelines for initial planning or the ETF facility with respect to environmental field limits for equipment.

Tentative Guidelines
Environmental Magnetic
Field Limits for Equipment
Instruments, etc.

	<u>Environmental Field Limits</u> (tesla)	
	<u>Maximum</u> (functional)	<u>Recommended</u> (to allow for personnel access)
LHe storage tank	Note 1	0.05
Liquefier/refrigerator	0.05	0.01
Refrigerator compressor package	0.05	0.01
Liquid nitrogen storage tank	Note 1	0.05
Gaseous helium storage tank	Note 1	Note 2
Cool-down heat exchanger	Note 1	0.05
Warm-up heat exchanger	Note 1	0.05
Mechanical vacuum pump	0.05	0.01
Diffusion pump	Note 1	Note 2
Dump resistor	Note 1	0.05
Circuit breakers	T.B.D.	0.01
Rectifiers and diodes	T.B.D.	0.01
Transformers	T.B.D.	0.01

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Power supply controls	T.B.D.	T.B.D.
Ammeters	T.B.D.	-
Volt meters	T.B.D.	-
Flow-meters (float type)	T.B.D.	-
Transducers, pressure	T.B.D.	-
Transducers, linear	T.B.D.	-
Thermocouples	No limit	-
Strain Gages	Note 3	-
Recorders	T.B.D.	-

Note 1 No limit on environmental field from functional standpoint. However, forces on ferromagnetic parts must be considered (See Section 5).

Note 2 It is not expected that personnel access will be required when magnet is charged.

Note 3 Strain gage systems may require compensation.

5. Magnetic Force Interactions

Magnetic force interactions between the charged magnet and magnetic materials close to the magnet will be quite large. For example, a one cubic foot sphere of steel located beside the magnet and 20 ft. from its centerline would be attracted to the magnet by a force of over 2 short tons. By rough approximation, this force drops off inversely as the fourth power of the distance from the magnet. At 40 ft., the magnetic force on the sphere of steel will be about equal to its weight. (490 lbs.) The estimated maximum attractive force on a mild steel block (expressed as ratio of magnetic force to gravity) versus distance from the ETF magnet center is shown by the curve on Figure 1.

Guidelines for equipment and structure close to the magnet are as follows:

a. Flow-Train Components

The combustor, nozzle, channel, diffuser and associated piping and structure should be made of non-magnetic material.

b. Coal, Slag and Seed Systems; Heat Recovery System, Piping, etc.

Components of coal, slag and seed systems, heat recovery system and other items of equipment that are less than 70 ft., from the magnet centerline (i.e. - in zone of 0.1 "g" or greater) and are of ferromagnetic material should be designed to take account of magnetic loading in addition to other types of loading.

c. Structure

Facility structure and other facility items including overhead crane components, etc. that are less than 70 ft. from the magnet centerline should

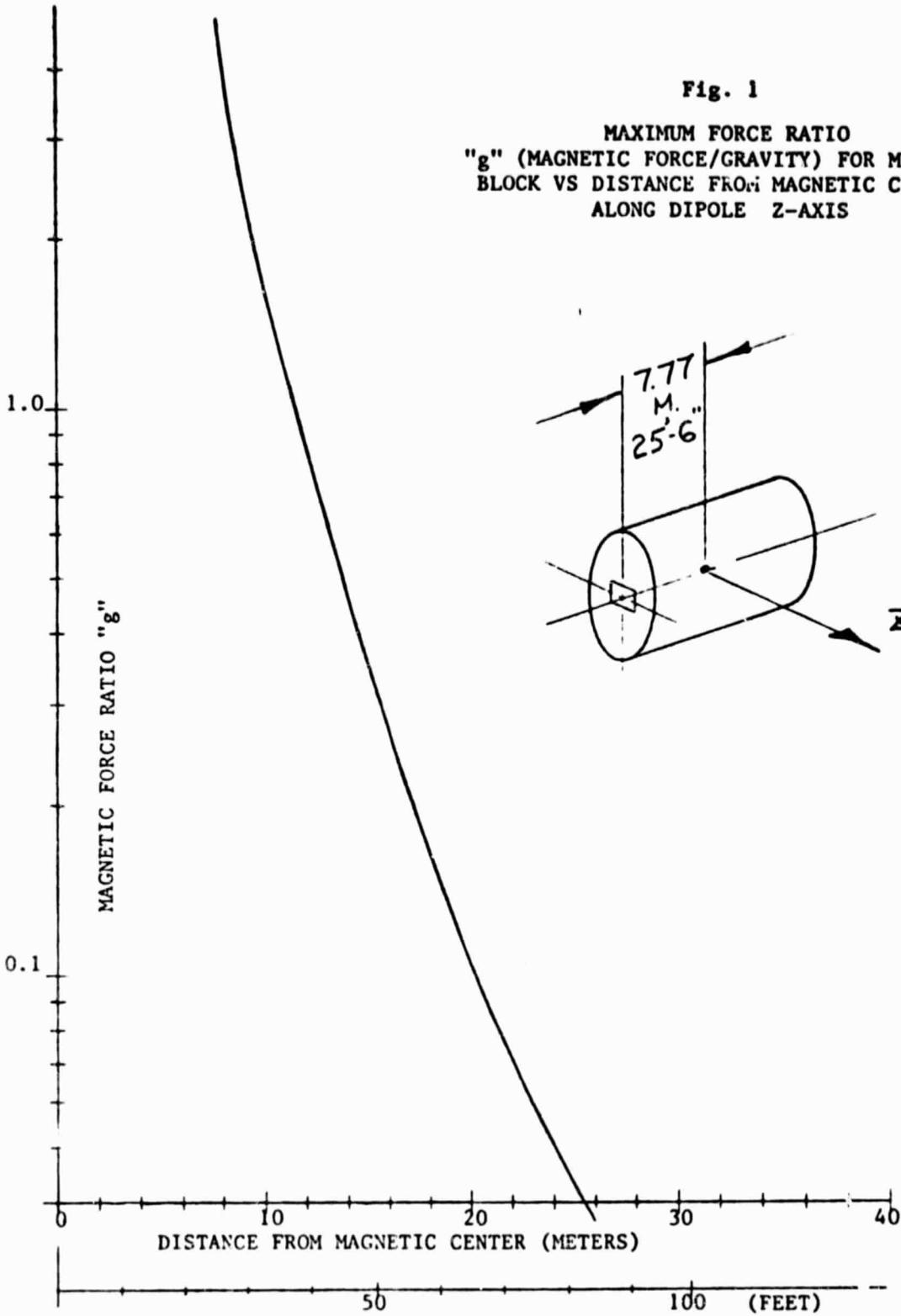
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be designed to take account of magnetic loading. Rough estimates of the maximum attractive force on small magnetic objects (< 500 lbs) located well away from the magnet (> 70 feet) may be made using the curve on Figure 1. For larger and/or closer objects, more accurate means for load determination are generally necessary, considering both force and torque interactions and taking into account the magnetization characteristics and geometry of the object. In such cases, the MHD Magnet Group, Francis Bitter National Magnet Laboratory, Massachusetts Institute of Technology should be contacted.

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Fig. 1

MAXIMUM FORCE RATIO
"g" (MAGNETIC FORCE/GRAVITY) FOR MILD STEEL
BLOCK VS DISTANCE FROM MAGNETIC CENTER,
ALONG DIPOLE Z-AXIS



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			TITLE:
			MHD-ETF 200 MWe POWER PLANT MAGNET SYSTEM
DWG NO.	SHEETS	REV	
D4429	1	B	DRAWING INDEX
D4439	1	B	FIELD PROFILE AND BORE DIMENSIONS
D4441	1	C	OUTLINE
D4443	1	C	FOUNDATION
D4444	1	B	FRINGE MAGNETIC FIELD ZONE BOUNDARIES
D4445	1	A	PLAN AND ELEVATION
D4448	1	O	LIMITS ON VARIATIONS IN MAGNETIC FIELD PROFILE AND FIELD IN CHANNEL CROSS-SECTION
D4450	4	A	GENERAL ASSEMBLY
D4452	1	B	DIAGRAM, HELIUM SYSTEM
D4453	1	B	DIAGRAM, NITROGEN SYSTEM
D4454	1	C	DIAGRAM, ELECTRICAL POWER SUPPLY AND DISCHARGE SYSTEM
D4456	1	A	SYSTEM DIAGRAM (SCHEMATIC)
D4457	1	O	TYPICAL JOINT IN SUPERCONDUCTIVE CABLE

BOLDOUT FRAME

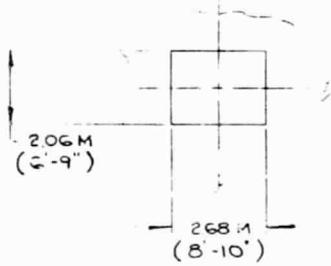
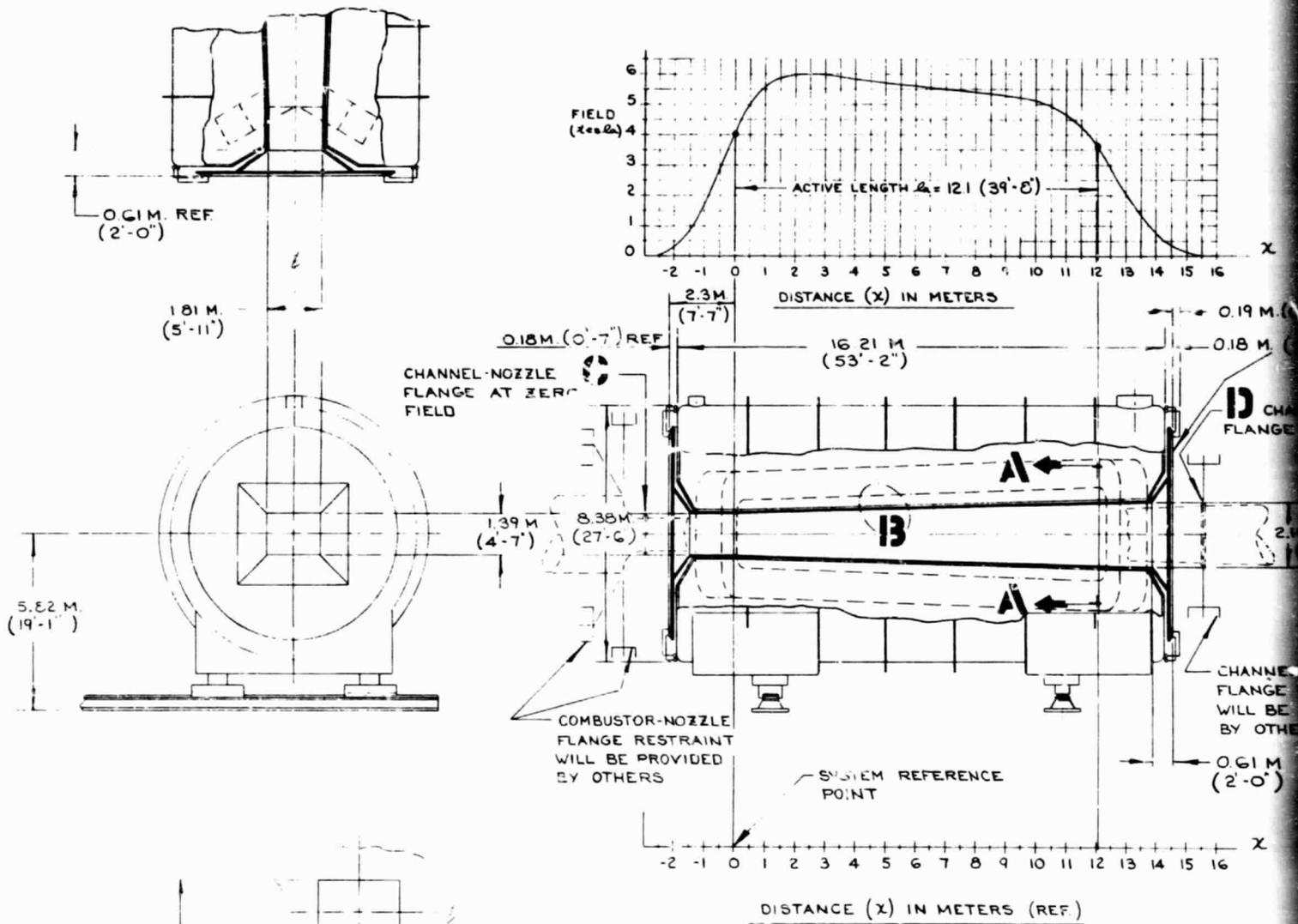
FOLDOUT FRAME 2

B	D4429 REV B WAS REV A D4443 REV C WAS REV B D4450 REV A WAS REV O D4452 REV B WAS REV A D4453 REV B WAS REV A D4454 REV C WAS REV B	<i>AMH</i>	7-29-81	<i>AMH</i>
A	D4429 REV A WAS REV O D4454 REV B WAS REV O	<i>AMH</i>	2-25-81	<i>AMH</i>
REV.	DESCRIPTION	BY	DATE	APPD
TITLE: MHD-ETF 200 MWe POWER PLANT MAGNET SYSTEM				
DRAWING INDEX				
DESIGNED	<i>AMH</i>	2-17-81	SCALE	1:1
CHECKED	<i>AMH</i>	2-17-81	DATE	4429
APPD	<i>AMH</i>	2-19-81	REV	B

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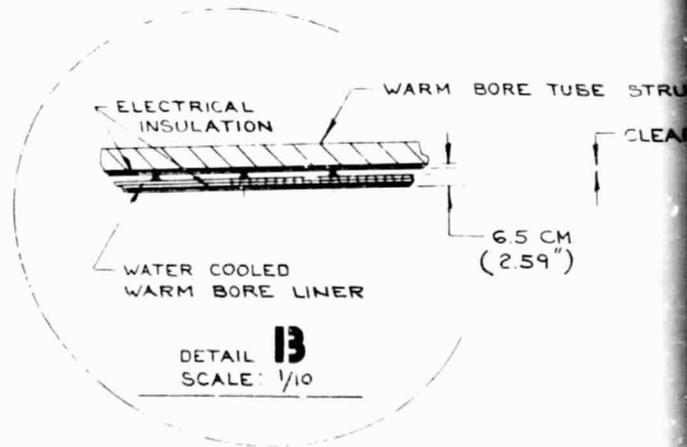
TOLERANCES UNLESS OTHERWISE SPECIFIED
MACHINING - FRACTIONS & DECIMALS - DIMENSIONS & ANGLES & 1/4"
CASTING - FRACTIONS & DECIMALS - DIMENSIONS & ANGLES & 1/4"
LITREAU ALL DIMENSIONS - DIMENSIONS & ANGLES & 1/4"
MACHINING SURFACES - DIMENSIONS & ANGLES & 1/4"
DO NOT SCALE FOR CONSTRUCTION

ORIGINAL PAGE IS
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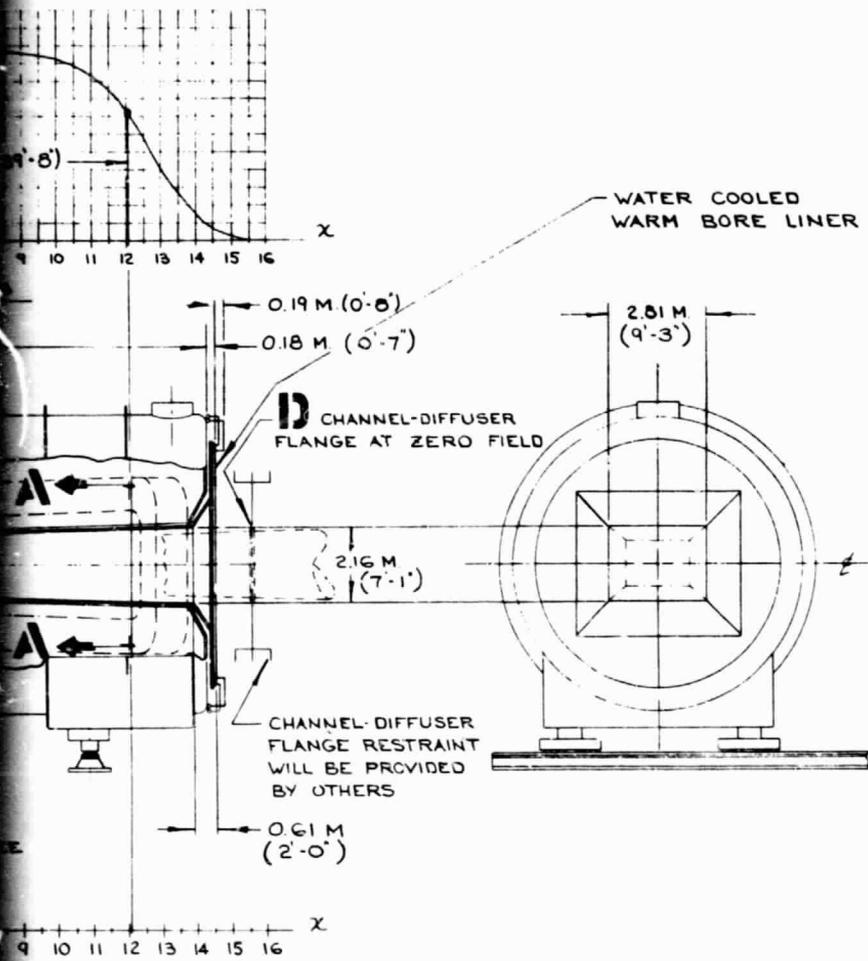


SECTION **A-A**

FOLDOUT FRAME

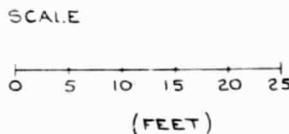
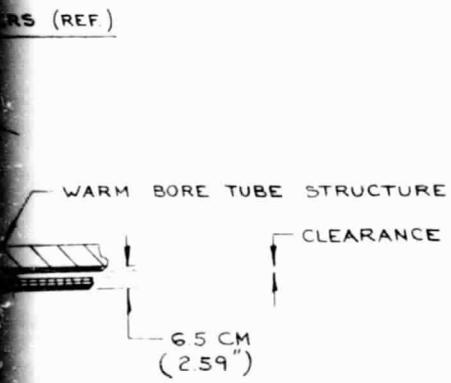


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REFERENCE DRAWINGS
D-4441 OUTLINE
D-4450 SHT. 1,2,3,4 GENERAL ASSY

WELDOUT FRAME ?

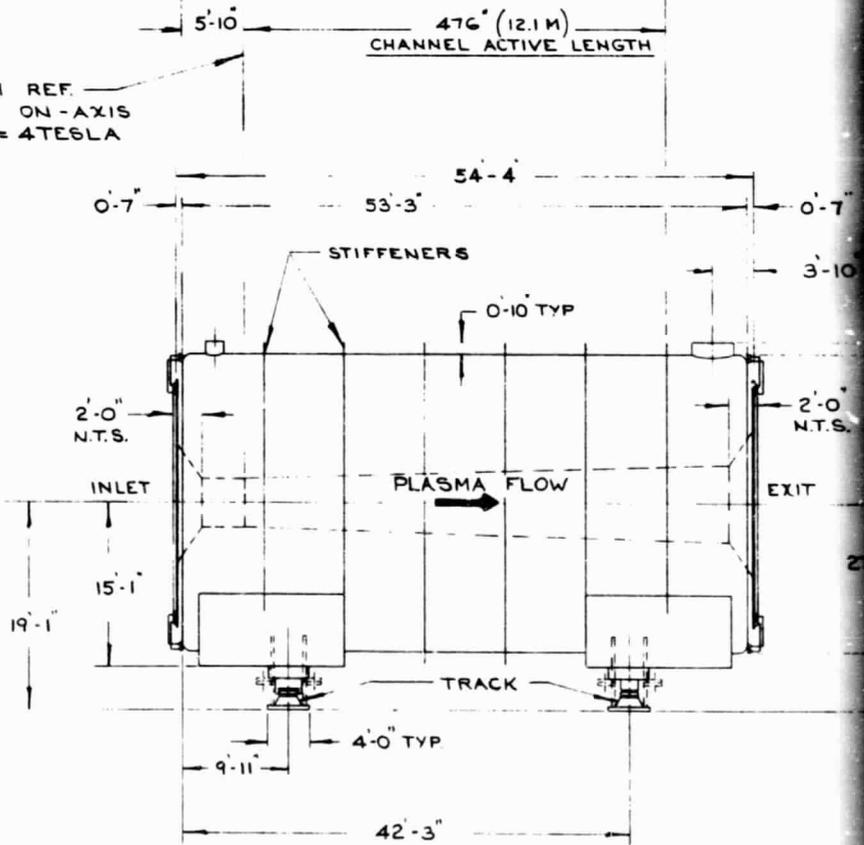
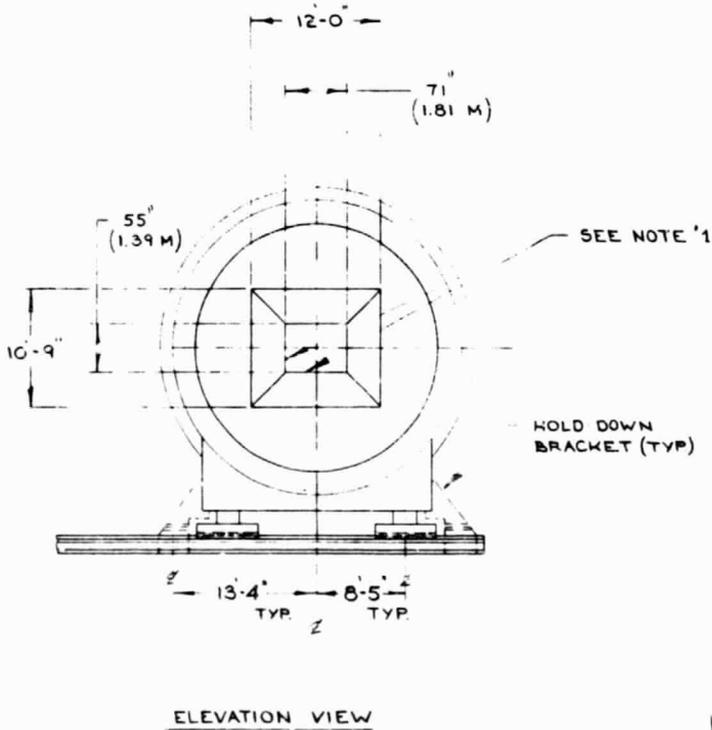
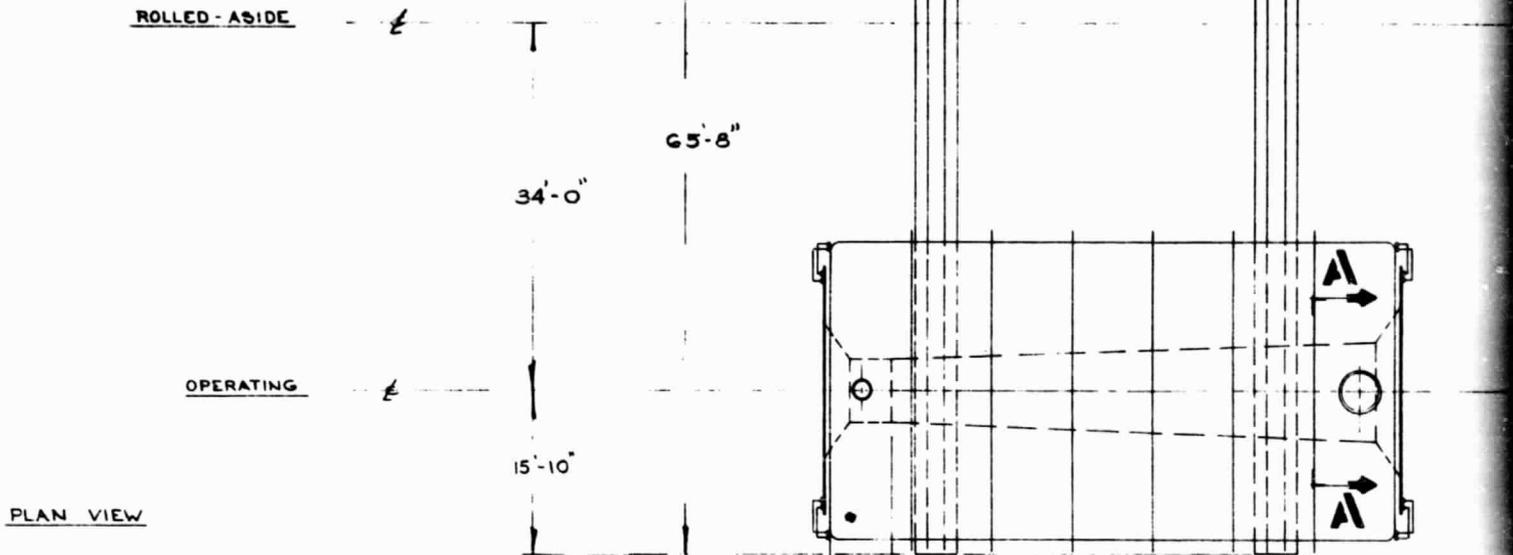


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TOLERANCES UNLESS OTHERWISE SPECIFIED
DRAUGHTING - FRACTIONS 1/16, 1/8, 3/16, 1/4, 3/8, 1/2, 5/8, 3/4, 7/8, 1, 1 1/8, 1 1/4, 1 1/2, 1 3/4, 2, 2 1/4, 2 1/2, 2 3/4, 3, 3 1/4, 3 1/2, 3 3/4, 4, 4 1/4, 4 1/2, 4 3/4, 5, 5 1/4, 5 1/2, 5 3/4, 6, 6 1/4, 6 1/2, 6 3/4, 7, 7 1/4, 7 1/2, 7 3/4, 8, 8 1/4, 8 1/2, 8 3/4, 9, 9 1/4, 9 1/2, 9 3/4, 10
MAGNETS - FRACTIONS 1/16, 1/8, 3/16, 1/4, 3/8, 1/2, 5/8, 3/4, 7/8, 1, 1 1/8, 1 1/4, 1 1/2, 1 3/4, 2, 2 1/8, 2 1/4, 2 1/2, 2 3/4, 3, 3 1/8, 3 1/4, 3 1/2, 3 3/4, 4, 4 1/8, 4 1/4, 4 1/2, 4 3/4, 5, 5 1/8, 5 1/4, 5 1/2, 5 3/4, 6, 6 1/8, 6 1/4, 6 1/2, 6 3/4, 7, 7 1/8, 7 1/4, 7 1/2, 7 3/4, 8, 8 1/8, 8 1/4, 8 1/2, 8 3/4, 9, 9 1/8, 9 1/4, 9 1/2, 9 3/4, 10
DO NOT SCALE FOR CONSTRUCTION

REV	DESCRIPTION	BY	DATE	APPD
B	REDRAWN WITH CHANGES TITLE WAS "ETF-MAGNET FIELD PROFILE & BORE DIMENSIONS"	Adler	2-13-81	QWH
A	REDRAWN & REVISED WAS: C-4439	Adler	11-13-80	QWH
TITLE: MHD-ETF 200 MWe POWER PLANT MAGNET SYSTEM				
FIELD PROFILE AND BORE DIMENSIONS				
DATE	11-13-80	SCALE	1/100	APPD
DATE	12-16-80	D 4439		B
APPD	QWH			

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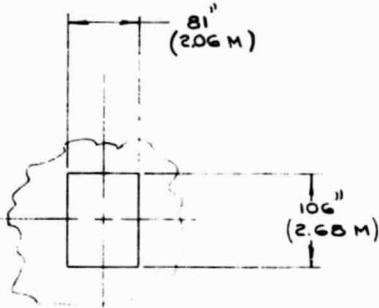


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NOTE:

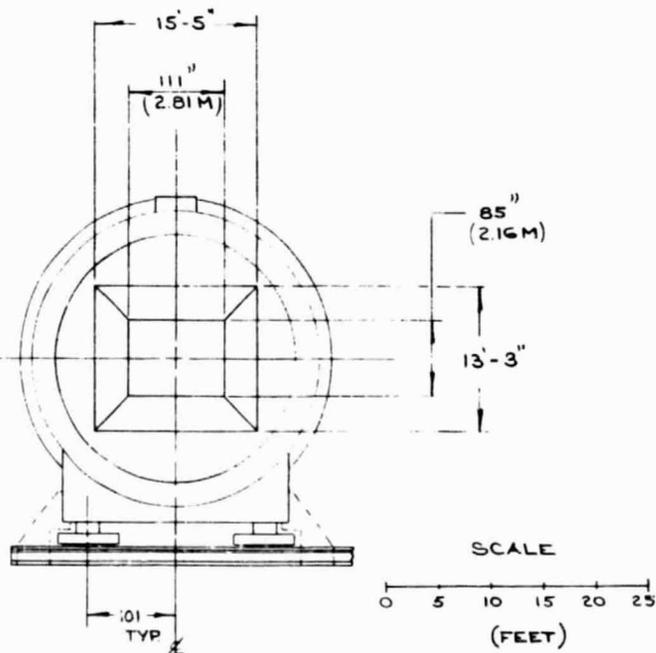
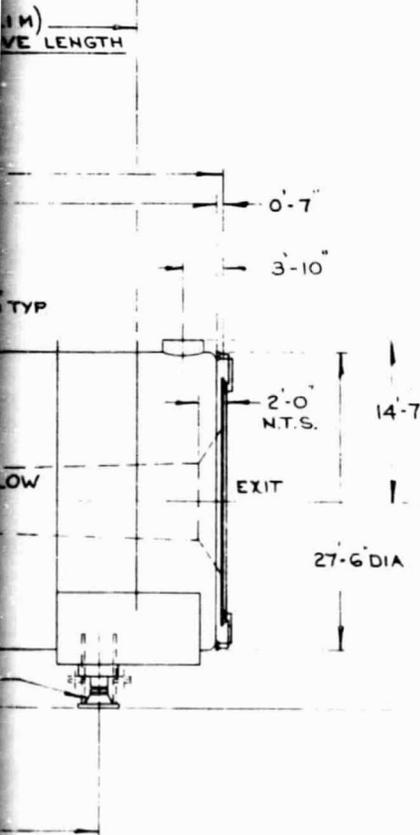
1. BORE CROSS-SECTION DIMENSIONS ARE INSIDE WARM BORE LINER
2. DIMENSIONS ARE IN FEET EXCEPT WHERE OTHERWISE NOTED
3. HOLD-DOWN BRACKETS ARE DESIGNED TO HOLD MAGNET FIRMLY IN PLACE IN "OPERATING" POSITION. THEY WILL BE DISENGAGED WHEN MAGNET IS TO BE ROLLED ASIDE



REFERENCE DRAWINGS

- D-4443 FOUNDATION
- D-4439 FIELD PROFILE AND BORE DIMS.

FOLDOUT FRAME 2



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TOLERANCES UNLESS OTHERWISE SPECIFIED
MACHINING - FINISHES & 1/2" DIA. SURF. & 1/4" DIA. SURF. & 1/8" DIA. SURF.
CASTING - FINISHES & 1/2" DIA. SURF. & 1/4" DIA. SURF. & 1/8" DIA. SURF.
MACHINE FINISHES & 1/2" DIA. SURF. & 1/4" DIA. SURF. & 1/8" DIA. SURF.
DO NOT SCALE FOR CONSTRUCTION

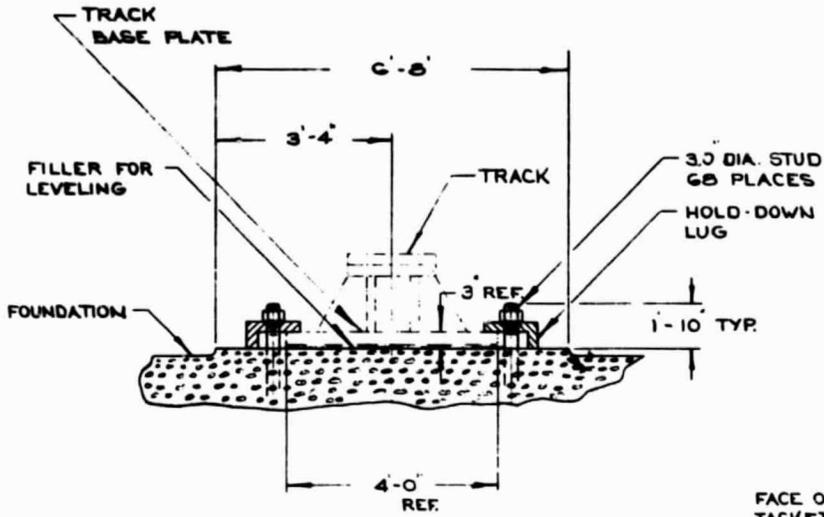
REV	DESCRIPTION	BY	DATE	APPD
C	REDRAWN WITH CHANGES TITLE WAS "ETF MAGNET OUTLINE." DIMS WERE IN INCHES	Hubley	2-16-81	Quilley
B	REDRAWN WITH CHANGES WAS C-4441	Hubley	12-5-80	J.J.

TITLE:
MHD-ETF 200 MWe POWER PLANT
MAGNET SYSTEM

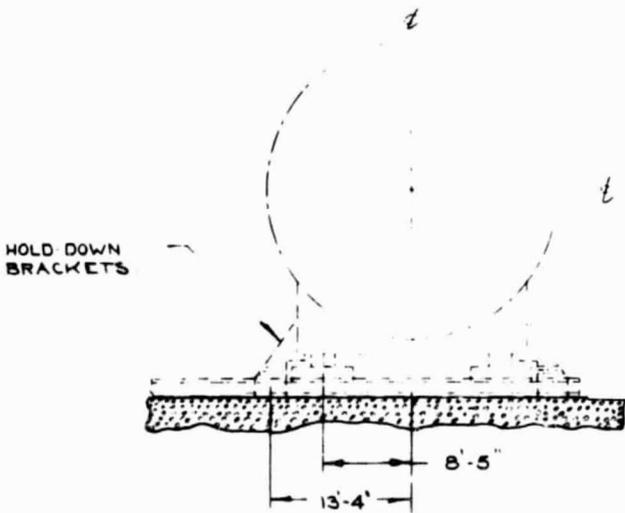
MAGNET OUTLINE

DESIGN: Hubley	DATE: 12-5-80	SCALE: 1/100	DWG. NO: 4441	REV: 1C
APPD: Quilley	DATE: 12-16-80			

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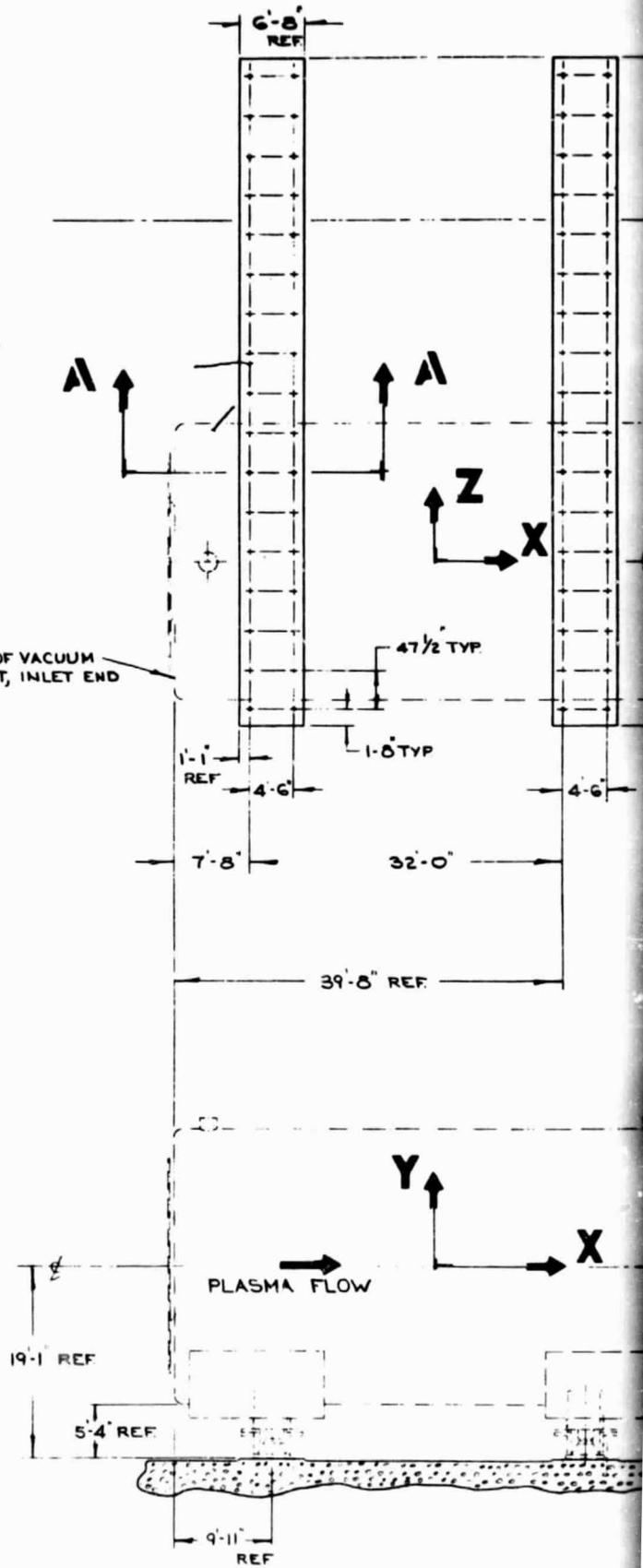


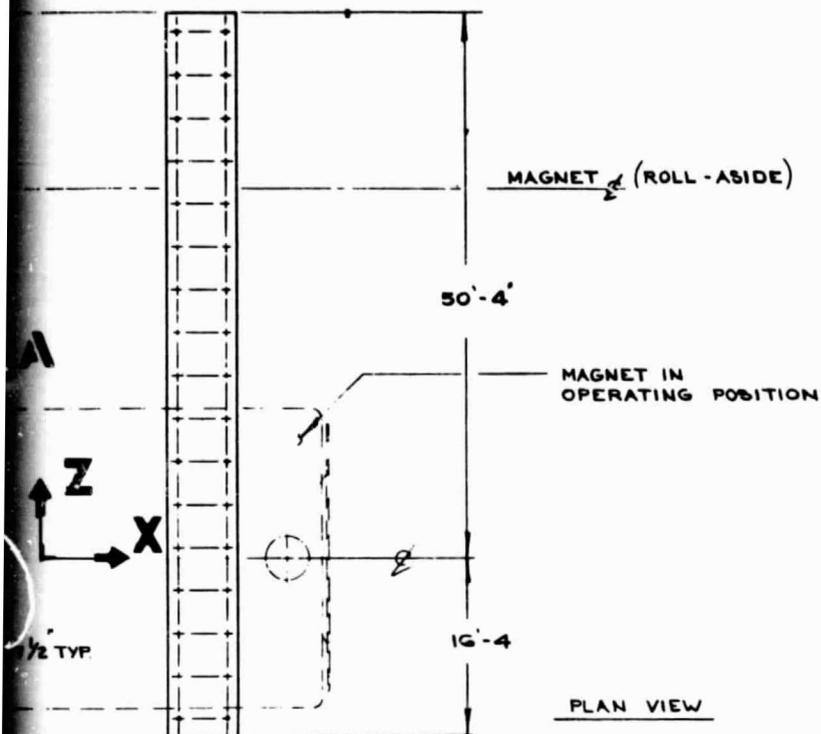
SECTION **A-A**
SCALE: 1/20



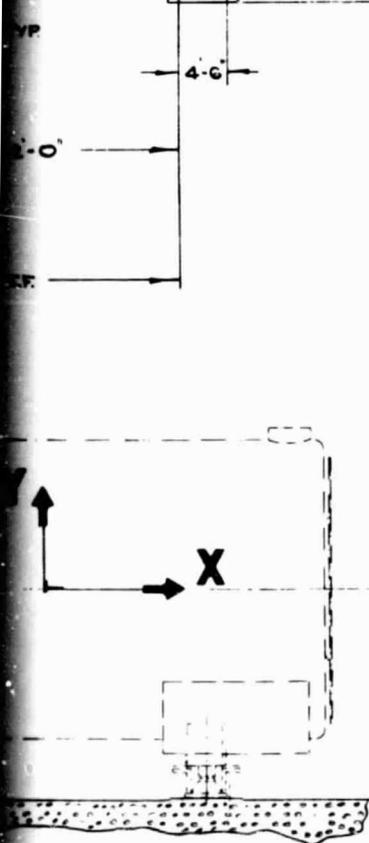
FOLDOUT FRAME

FACE OF VACUUM
JACKET, INLET END



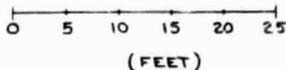


PLAN VIEW



ELEVATION VIEW

SCALE



NOTE:

1. DIMENSIONS ARE IN FEET
2. FOUNDATION UNDER RAILS SHALL BE CAPABLE OF CARRYING THE FOLLOWING GRAVITY LOAD WITH MAGNET IN ANY POSITION ON RAILS.
WEIGHT, MAGNET—2,000,000 LBS
WEIGHT, CHANNEL—54,000 LBS
TOTAL—2,054,000 LBS
3. HOLD-DOWN BRACKETS ARE DESIGNED TO HOLD MAGNET FIRMLY IN PLACE IN "OPERATING" POSITION. THEY WILL BE DISENGAGED WHEN MAGNET IS TO BE ROLLED ASIDE.
4. FOUNDATION UNDER RAILS IN REGION OF MAGNET "OPERATING" POSITION SHALL BE CAPABLE OF CARRYING THE FOLLOWING MAXIMUM LOADS APPLIED AT CG. OF MAGNET (ASSUMED TO BE AT GEOMETRIC CENTER OF MAGNET.)

DOWNWARD (Y DIRECTION)

GRAVITY	2,054,000 LBS
SEISMIC ($\frac{2}{3}g$)	1,369,333 LBS
MAGNETIC	500,000 LBS
TOTAL	3,923,333 LBS

LONGITUDINAL (X DIRECTION)

SEISMIC (1g)	2,054,000 LBS
MAGNETIC	500,000 LBS
MHD REACTION	100,000 LBS
TOTAL	2,654,000 LBS

TRANSVERSE (Z DIRECTION)

SEISMIC (1g)	2,054,000 LBS
MAGNETIC	500,000 LBS
TOTAL	2,554,000 LBS

REFERENCE DRAWING

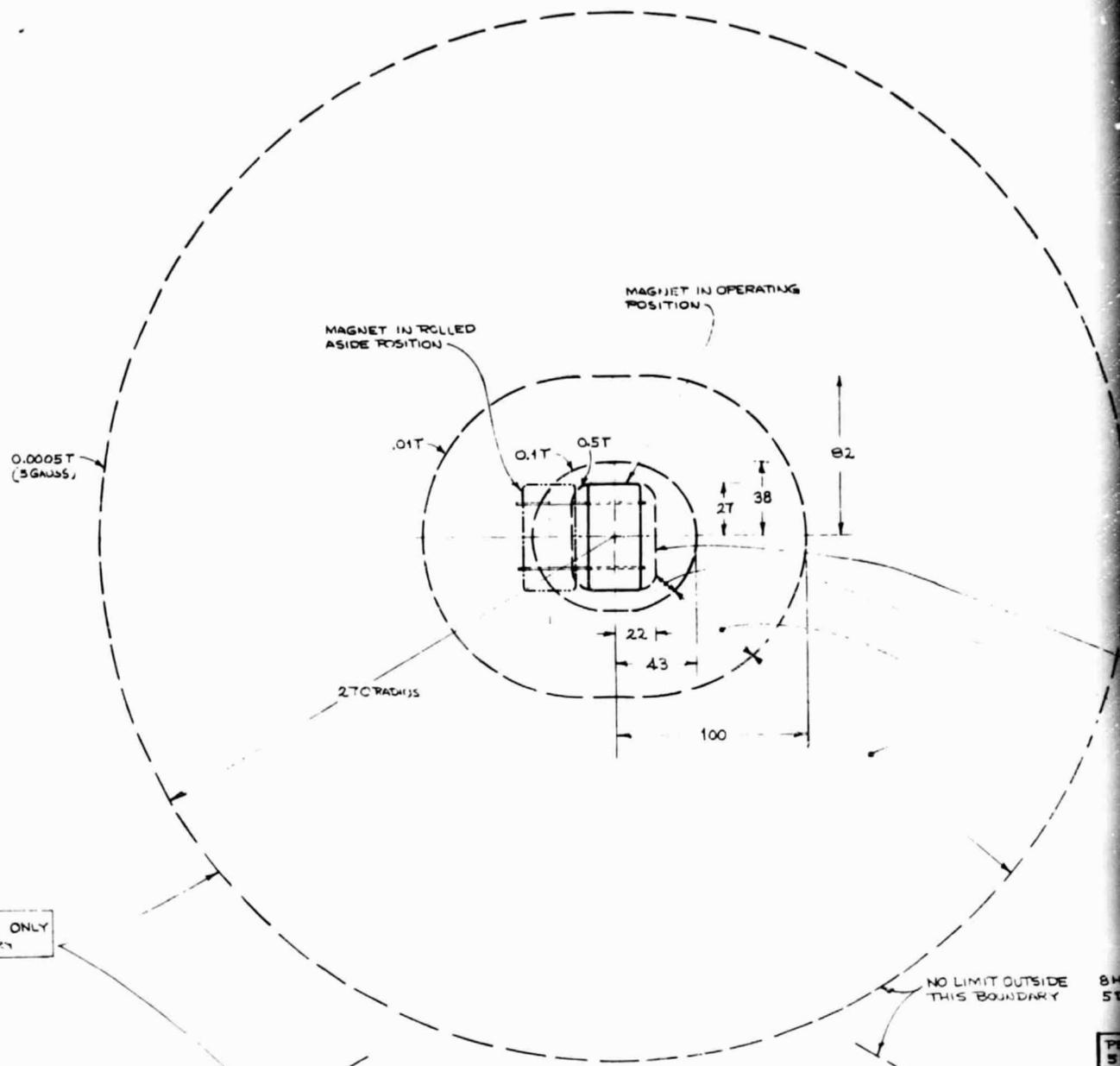
D-4441 OUTLINE

FOLDOUT FRAME

REV	DESCRIPTION	BY	DATE	APPD
C	CHANNEL WEIGHT WAS 170,000 LBS	ALL	7-29-81	DMH
B	REDRAW WITH CHANGES TITLE WAS 'ETF-MAGNET FOUNDATION'	ALL	2-17-81	DMH
A	REDRAWN WITH CHANGES WAS C-4443	ALL	12-8-80	DMH
TITLE: MHD-ETF 200MWe POWER PLANT MAGNET SYSTEM				
FOUNDATION				
DATE	12-6-80	SCALE	1/100	APPD
BY	DMH	DATE	12-16-80	NO. 4443
BY	DMH	DATE	12-16-80	10

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TOLERANCES UNLESS OTHERWISE SPECIFIED
MILLING - FRACTIONAL DIMENSIONS ± .005 IN
TURNING - FRACTIONAL DIMENSIONS ± .005 IN
DRILLING - FRACTIONAL DIMENSIONS ± .005 IN
DIMENSIONS UNLESS OTHERWISE SPECIFIED ARE IN INCHES
DO NOT SCALE FOR CONSTRUCTION

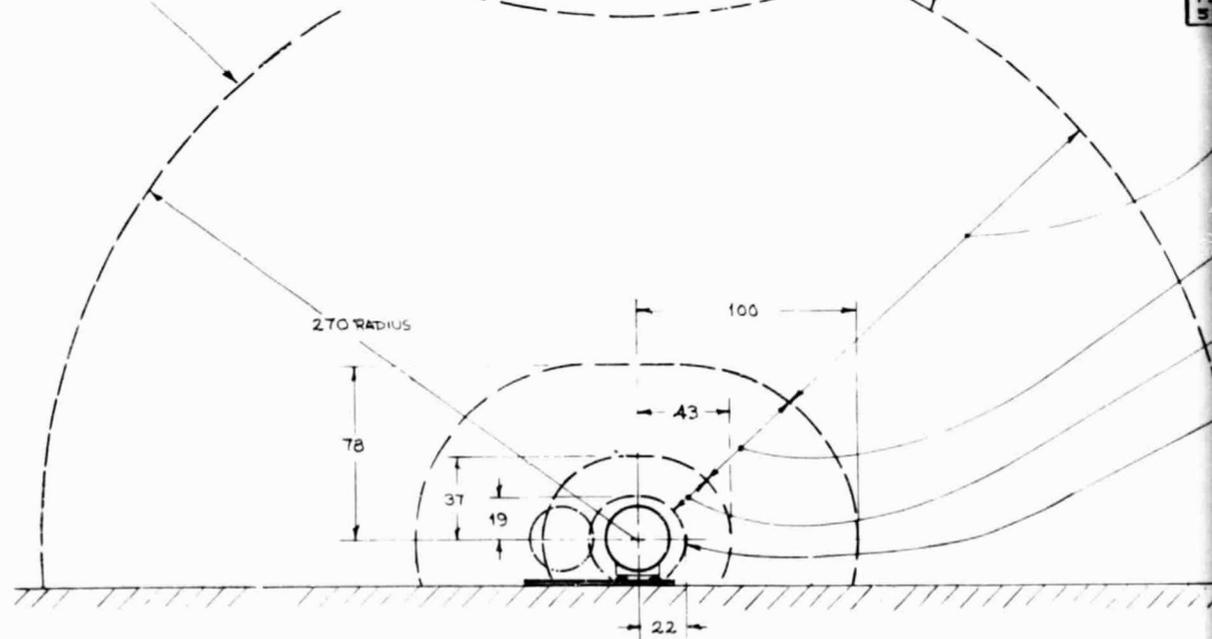


APPROVED PERSONNEL ONLY
WITHIN THIS BOUNDARY

NO LIMIT OUTSIDE
THIS BOUNDARY

840
50

PF
5

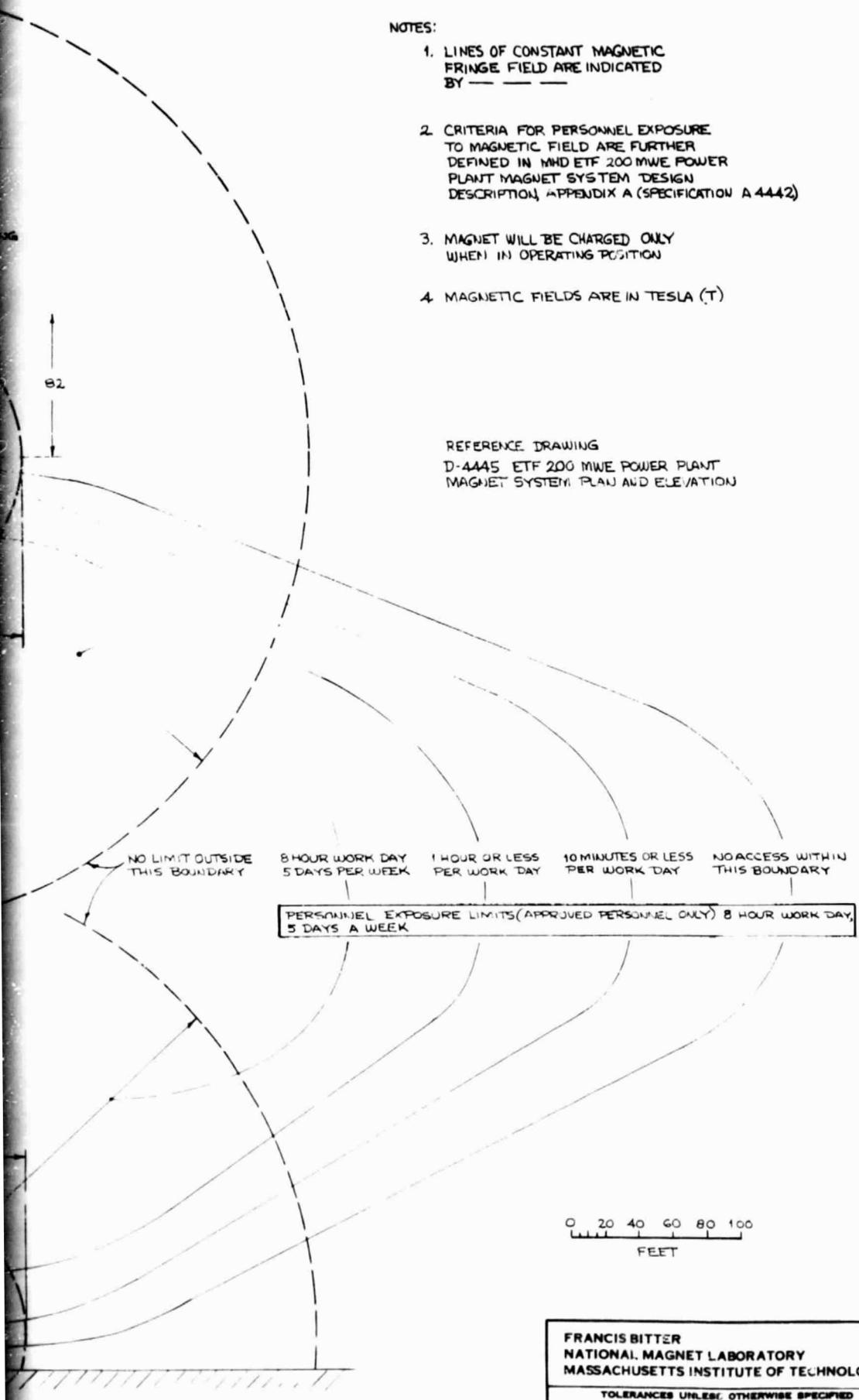


FOLDOUT FRAME

NOTES:

1. LINES OF CONSTANT MAGNETIC FRINGE FIELD ARE INDICATED BY _____
2. CRITERIA FOR PERSONNEL EXPOSURE TO MAGNETIC FIELD ARE FURTHER DEFINED IN MHD ETF 200 MWE POWER PLANT MAGNET SYSTEM DESIGN DESCRIPTION, APPENDIX A (SPECIFICATION A 4442)
3. MAGNET WILL BE CHARGED ONLY WHEN IN OPERATING POSITION
4. MAGNETIC FIELDS ARE IN TESLA (T)

REFERENCE DRAWING
 D-4445 ETF 200 MWE POWER PLANT
 MAGNET SYSTEM: PLAN AND ELEVATION



FOLDOUT FRAME 2

REV.	DESCRIPTION	BY	DATE	APPD
B	REVISED AND REDRAWN TO SMALLER SCALE. ADD 0.0005T BOUNDARY. DELETE 0.005T BOUNDARY.	NLD	2-18-81	AmH
A	REVISED AND REDRAWN. PLAN VIEW ROTATED 180°. 0.03 TESLA BOUNDARY DELETED. ACCESS. EQUIP. DELETED. 0.005 TESLA BOUNDARY ADDED.	F.M.	2-3-81	AmH

TITLE: MHD-ETF 200 MWE POWER PLANT MAGNET SYSTEM				
FRINGE MAGNETIC FIELD ZONE BOUNDARIES				
DATE: N.L.D.	2-18-81	SCALE: 1:40	REV. BY	
DATE: AmH	2-19-81	D	4444	B
APPD: AmH	2-19-81			B

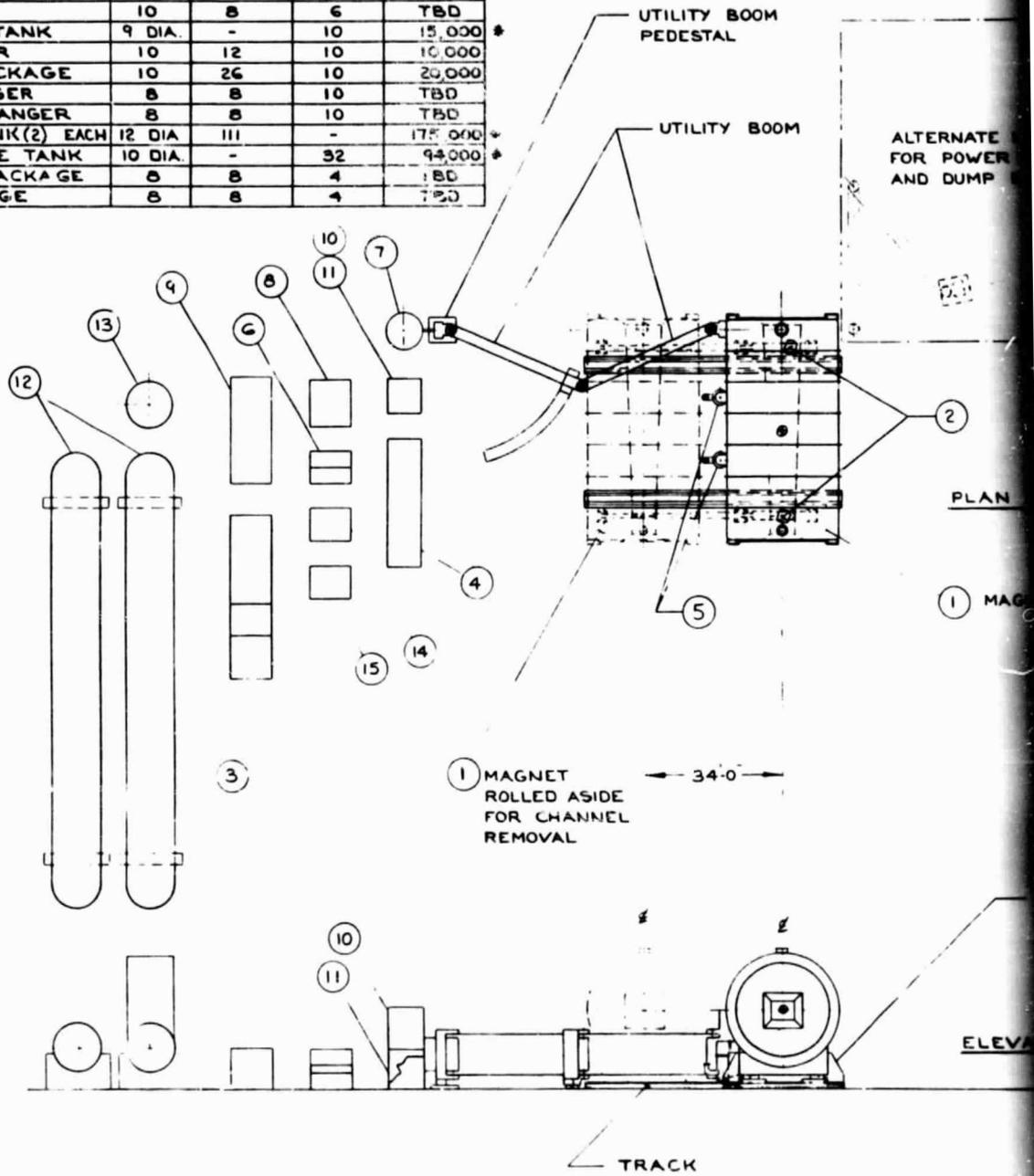
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TOLERANCES UNLESS OTHERWISE SPECIFIED
 MACHINING - FINISHES: 1/64 DECIMALS AND ANGLES 1/16°
 GRINDING - FINISHES: 1/128 ANGLES 1/32°
 BREAK ALL SHARP EDGES REMOVE ALL BURRS
 MACHINING SURF. MARK CONCENTRICITY AND T.I.R.
 DO NOT SCALE FOR CONSTRUCTION

ACCESSORY ENVELOPE DIMENSIONS IN FEET
(PRELIMINARY)

ITEM NO	DESCRIPTION	WIDTH	LENGTH	HEIGHT	WEIGHT
1	MAGNET	29	55	31	2,000,000
2	HYDRAULIC ACTUATORS (?) EACH	2 DIA.	25	-	TBD
3	POWER SUPPLY PACKAGE (SEE NOTE 2)	10	40	12	TBD
4	DUMP RESISTORS	10	30	8	100,000
5	DIFFUSION PUMPS (2) EACH	3 DIA.	-	10	TBD
6	VACUUM PUMP PACKAGE	10	8	6	TBD
7	LIQUID HELIUM STORAGE TANK	9 DIA.	-	10	15,000 *
8	LIQUIFIER / REFRIGERATOR	10	12	10	10,000
9	HELIUM COMPRESSOR PACKAGE	10	26	10	20,000
10	WARM-UP HEAT EXCHANGER	8	8	10	TBD
11	COOL-DOWN HEAT EXCHANGER	8	8	10	TBD
12	GASEOUS HELIUM STORAGE TANK(2) EACH	12 DIA.	111	-	175,000 *
13	LIQUID NITROGEN STORAGE TANK	10 DIA.	-	32	94,000 *
14	UTILITY VACUUM PUMP PACKAGE	8	8	4	TBD
15	HYDRAULIC PUMP PACKAGE	8	8	4	TBD

* FILLED



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NOTES :

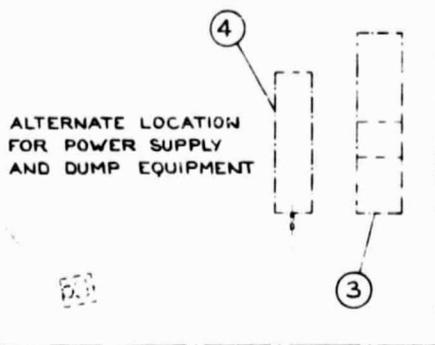
1. EQUIPMENT MAY BE REARRANGED PROVIDED FOLLOWING CONSTRAINTS ARE OBSERVED:

ITEMS 3, 6, 8, 9, 14, & 15 MUST BE NOT LESS THAN 100'-0" FROM MAGNET CENTERLINE, (MAGNETIC EFFECTS.)

ITEMS 3, 4, 7, 8, 9, 10, 11, 13, & 15 MUST BE SO LOCATED THAT LENGTH OF PIPING AND ELECTRICAL CABLES TO UTILITY BOOM PEDESTAL WILL BE AS SHORT AS PRACTICAL, CONSISTENT WITH NOTE 1 ABOVE.

ITEMS 12, & 13 MAY BE LOCATED OUTDOORS. ALL OTHER ITEMS ARE INTENDED TO BE LOCATED INDOORS (SHELTERED FROM WEATHER AND SUB-FREEZING TEMPERATURE.)

2. POWER SUPPLY PACKAGE (3) INCLUDES RECTIFIER, CIRCUIT BREAKERS, TRANSFORMERS AND CONTROLS



PLAN VIEW

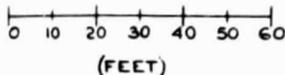
(1) MAGNET IN OPERATING POSITION

HOLD DOWN BRACKET

ELEVATION VIEW

FOLDOUT FRAME 2

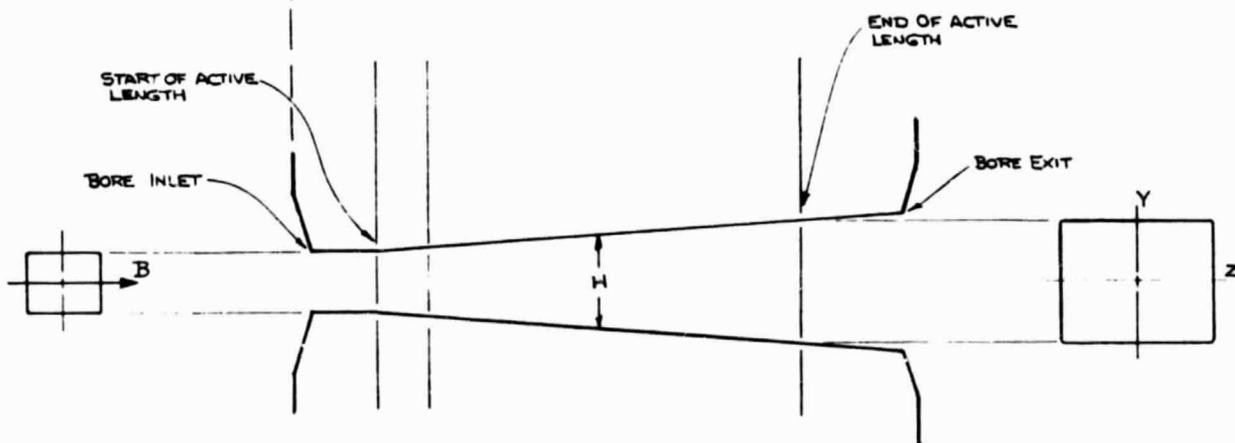
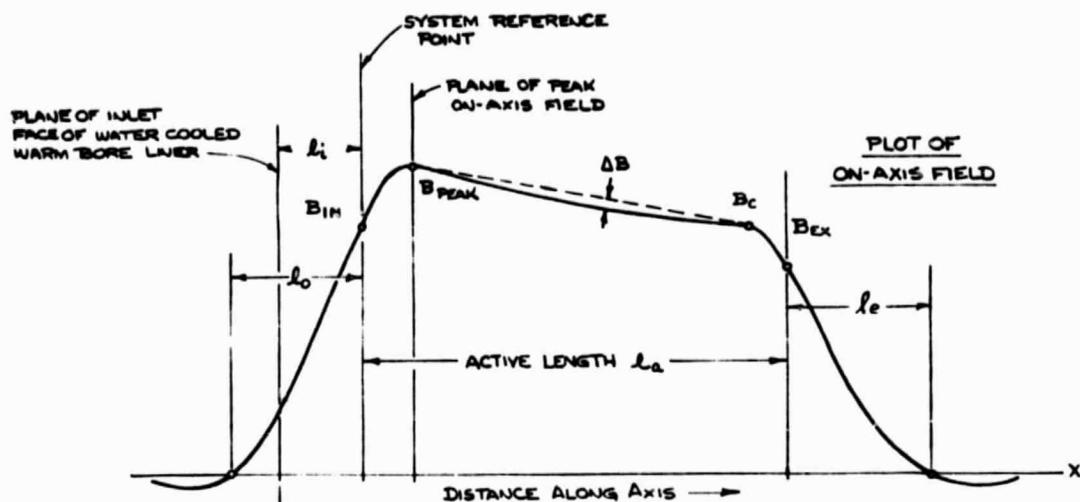
SCALE



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TOLERANCES UNLESS OTHERWISE SPECIFIED
DIMENSIONS - FRACTIONS 1/16 3/32 1/8 AND 3/16
DECIMALS - FRACTIONS 1/16 3/32 1/8 AND 3/16
HOLD ALL SHARP EDGES REMOVE ALL BURRS
MACHINE SURFACES TO FINISH SPECIFIED AND T.I.D.
DO NOT SCALE FOR CONSTRUCTION

A	REDRAWN WITH CHANGES TITLE WAS ETf-MAGNET SYSTEM - PLAN AND ELEVATION	AMH	2-6-81	AMH
REV.	DESCRIPTION	BY	DATE	APPD
TITLE: MHD-ETF 200 Mwe POWER PLANT MAGNET SYSTEM				
PLAN AND ELEVATION				
DESIGNED BY	2-6-81	SCALE	1" = 20'	SHEET NO.
DRAWN BY	AMH	DATE	2-6-81	REV.
CHECKED BY	AMH	DATE	2-6-81	APPD
			D 4445	A



FOLDOUT FRAME

MAX. VARIATION IN
 MAX. VARIATION (BETWEEN BREAK
 MAX. VARIATION PER SECTION IN THE
 MAX. VARIATION SECTION IN THE
 MAX. VARIATION SECTION IN THE
 MAX. VARIATION SECTION IN THE
 MAX. DISTANCE, LENGTH
 MAX. DISTANCE, TO START OF
 MAX. DISTANCE, OF ZERO ON-AXIS

NOTE:
 1. CHANGE OF

MAX. VARIATION IN ACTIVE LENGTH, l_a	$\pm 1\%$
MAX. VARIATION (ΔB) FROM STRAIGHT-LINE ON-AXIS PROFILE BETWEEN B_{peak} AND B_c	+2% -5%
MAX. VARIATION FROM ON-AXIS FIELD IN CHANNEL CROSS-SECTION IN PLANE OF B_{in} (SEE NOTE 1)	+4% - 2%
MAX. VARIATION FROM ON-AXIS FIELD IN CHANNEL CROSS-SECTION IN PLANE OF B_{peak} (SEE NOTE 1)	$\pm 3\%$
MAX. VARIATION FROM ON-AXIS FIELD IN CHANNEL CROSS-SECTION IN PLANE OF B_{ex} (SEE NOTE 1)	+7% -5%
MAX. DISTANCE, l_i , FROM INLET FACE TO START OF ACTIVE LENGTH	23m (7'-6")
MAX. DISTANCE, l_o , FROM POINT OF ZERO ON-AXIS FIELD (UPSTREAM) TO START OF ACTIVE LENGTH	3m (9'-10")
MAX. DISTANCE, l_e , FROM END OF ACTIVE LENGTH TO POINT OF ZERO ON-AXIS FIELD (DOWNSTREAM)	3.5m (11'-6")

REFERENCE DRAWING

D 4439 FIELD PROFILE AND BORE DIMENSIONS

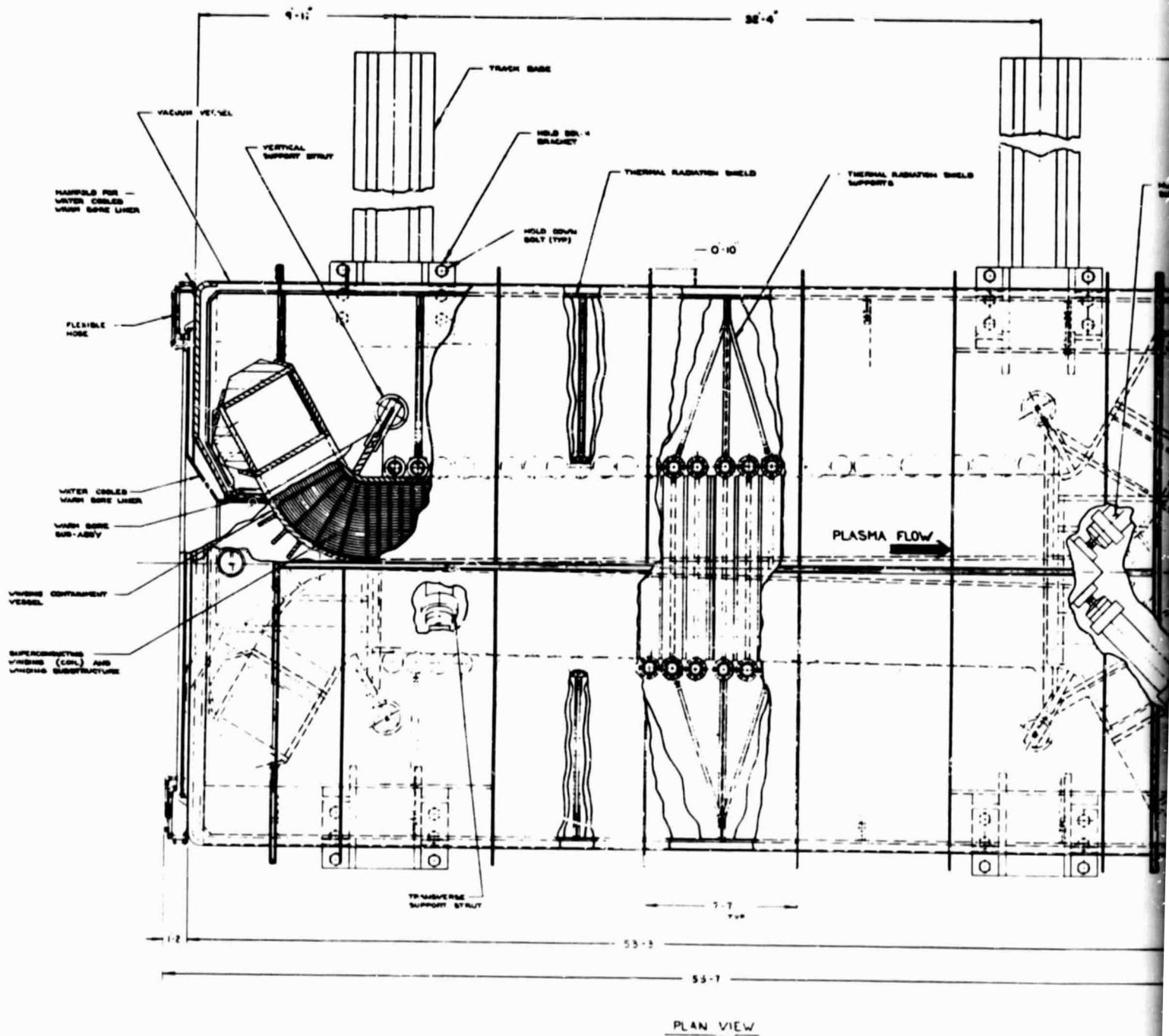
NOTE:

1. CHANNEL CROSS-SECTION IS TAKEN TO BE A SQUARE OF 0.7H ON SIDE, WHERE H IS WARM BORE DIMENSION

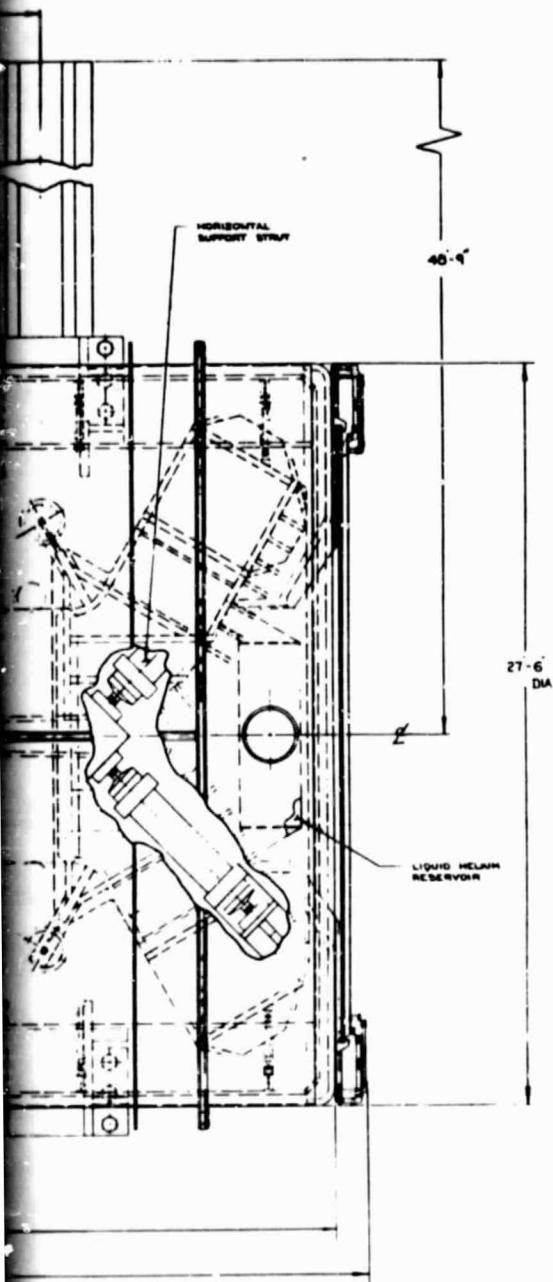
FOLDOUT FRAME ?

FRANCIS BITTER NATIONAL MAGNET LABORATORY MASSACHUSETTS INSTITUTE OF TECHNOLOGY		REV DESCRIPTION BY DATE APPD			
		TITLE: MHD-ETF 200 MW _e POWER PLANT MAGNET SYSTEM			
<small>TOLERANCES UNLESS OTHERWISE SPECIFIED DIMENSIONS - FRAMES & HOLES UNLESS OTHERWISE SPECIFIED DIMENSIONS - PARTS & FITS UNLESS OTHERWISE SPECIFIED DIMENSIONS - ALL DIMENSIONS UNLESS OTHERWISE SPECIFIED DIMENSIONS - ALL DIMENSIONS UNLESS OTHERWISE SPECIFIED DO NOT SCALE FOR CONSTRUCTION</small>		LIMITS ON VARIATIONS IN MAGNETIC FIELD PROFILE AND FIELD IN CHANNEL CROSS-SECTION			
		<small>DRW. N.L.D.</small>	<small>2-17-81</small>	<small>SCALE</small>	<small>DATE</small>
		<small>DATE</small>	<small>2-19-81</small>	<small>DRW.</small>	<small>4448</small>
		<small>APPD.</small>	<small>2-22-81</small>	<small>DRW.</small>	<small>4448</small>

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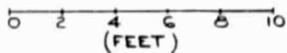


FOLDOUT FRAME



FOLDOUT FRAME

SCALE

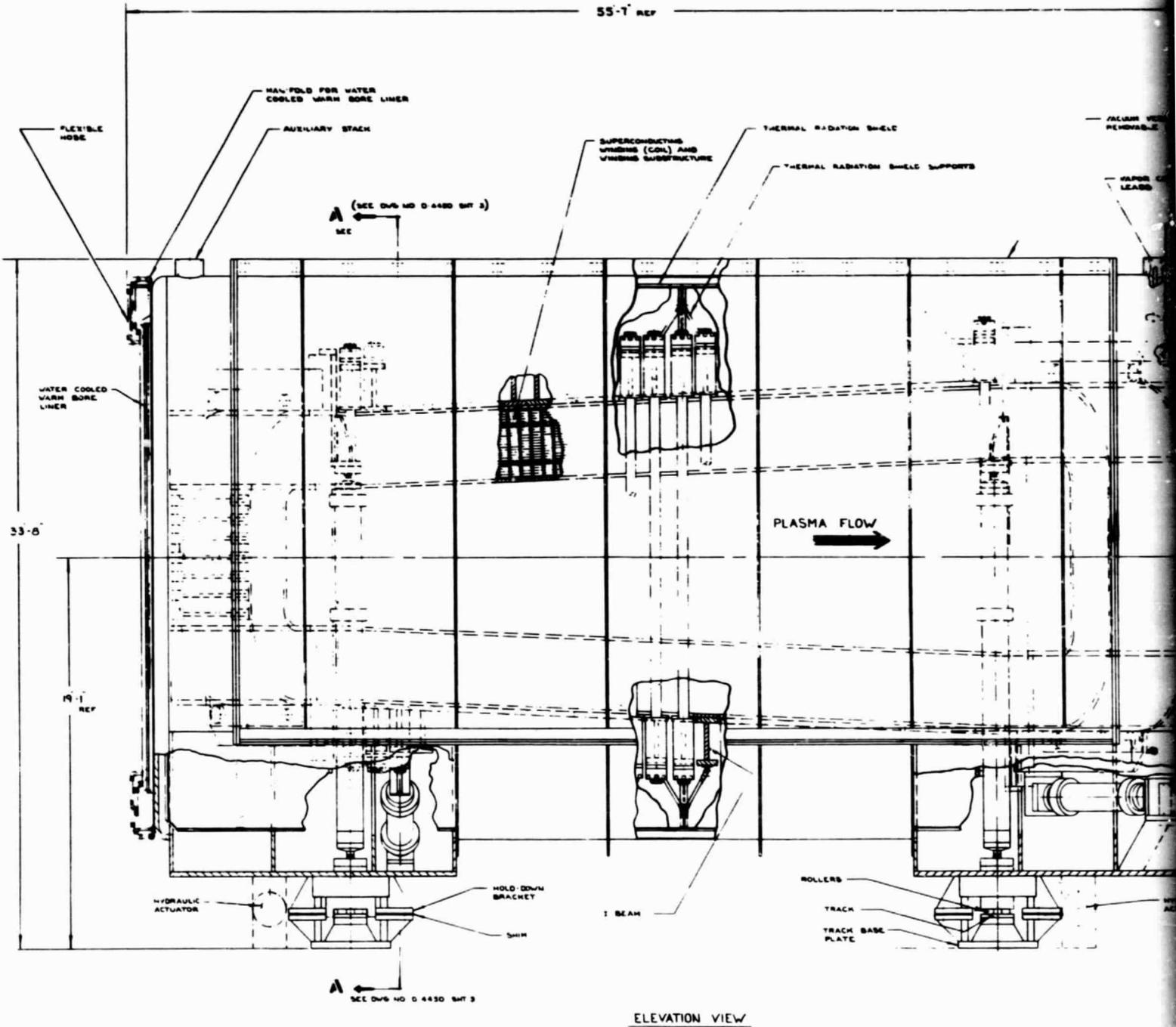


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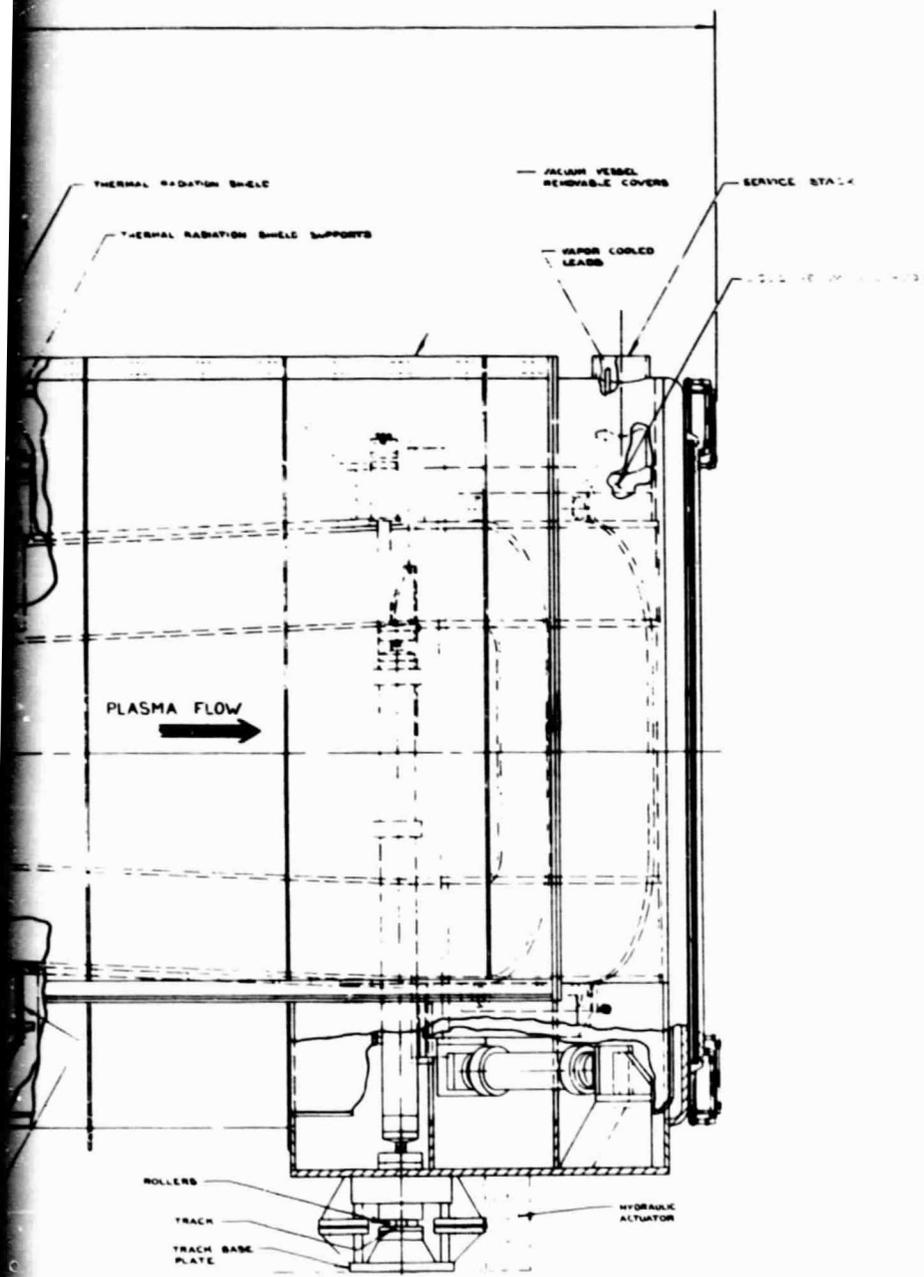
TOLERANCES UNLESS OTHERWISE SPECIFIED
MACHINING - FRACTIONS 1/32" DECIMALS .001" ANGLES .5°
CASTING - FRACTIONS 1/32" DECIMALS .005" ANGLES .5°
WELDING ALL WELDING DIMENSIONS UNLESS OTHERWISE SPECIFIED
MACHINE SURFACES UNLESS OTHERWISE SPECIFIED CONCENTRICITY AND T.Y.S.
DO NOT SCALE FOR CONSTRUCTION

A	TITLE BLOCK DOUBLED IN SIZE	7-29-81	RMH	
REV.	DESCRIPTION	BY	DATE	APPD
TITLE: MHD-ETF 200MW POWER PLANT MAGNET SYSTEM				
GENERAL ASSEMBLY PLAN VIEW				
DATE	BY	SCALE	SHEET 1 OF 4	
7-29-81	RMH	1:1	4450	A

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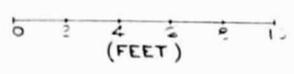
FOLDOUT FRAME



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VIEW

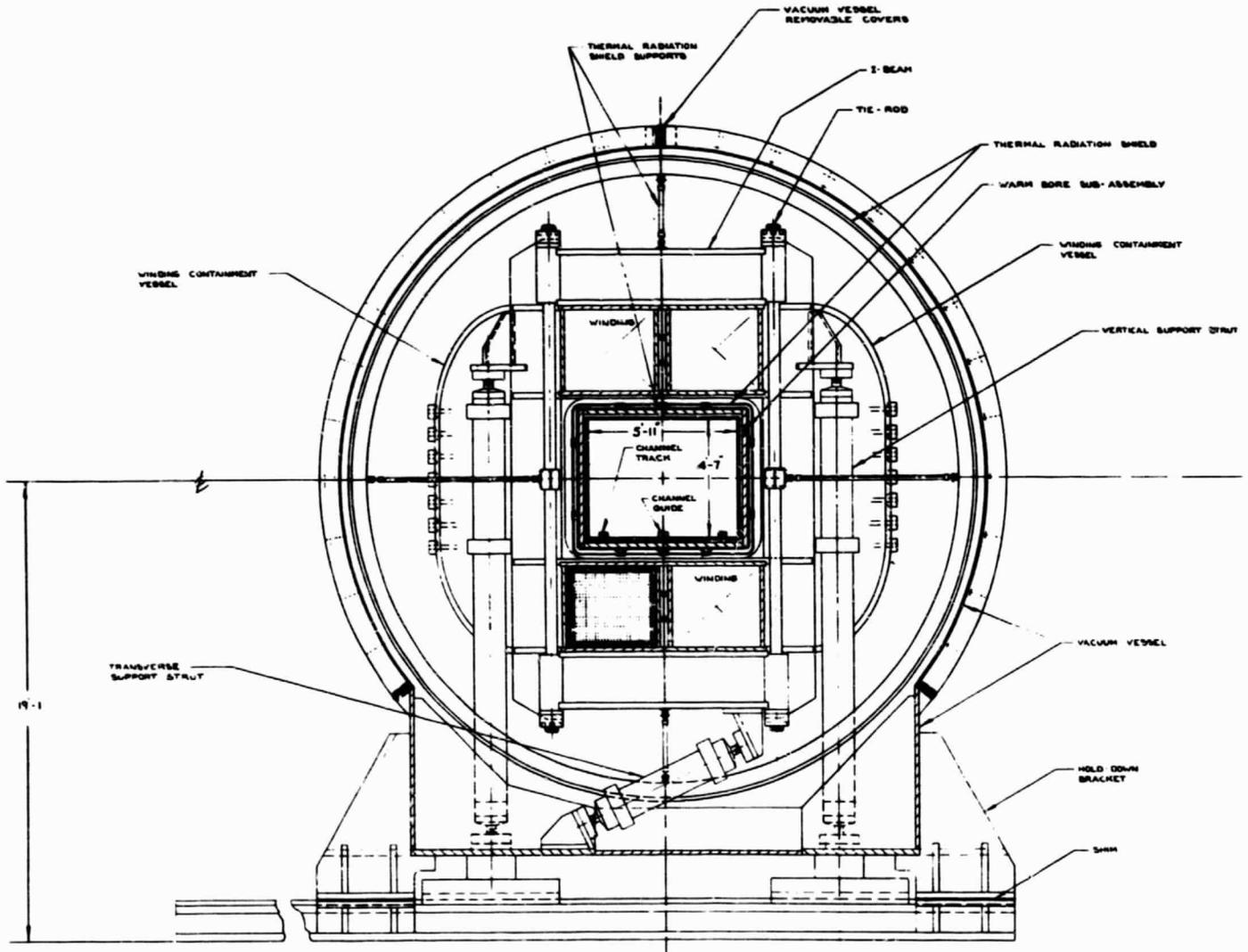
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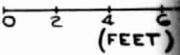
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DATE	REVISED	NO.	OF	
1-21-81		2	4	
DATE	REVISED	D		A
2-12-81		4450		
DATE	REVISED			
2-2-81				



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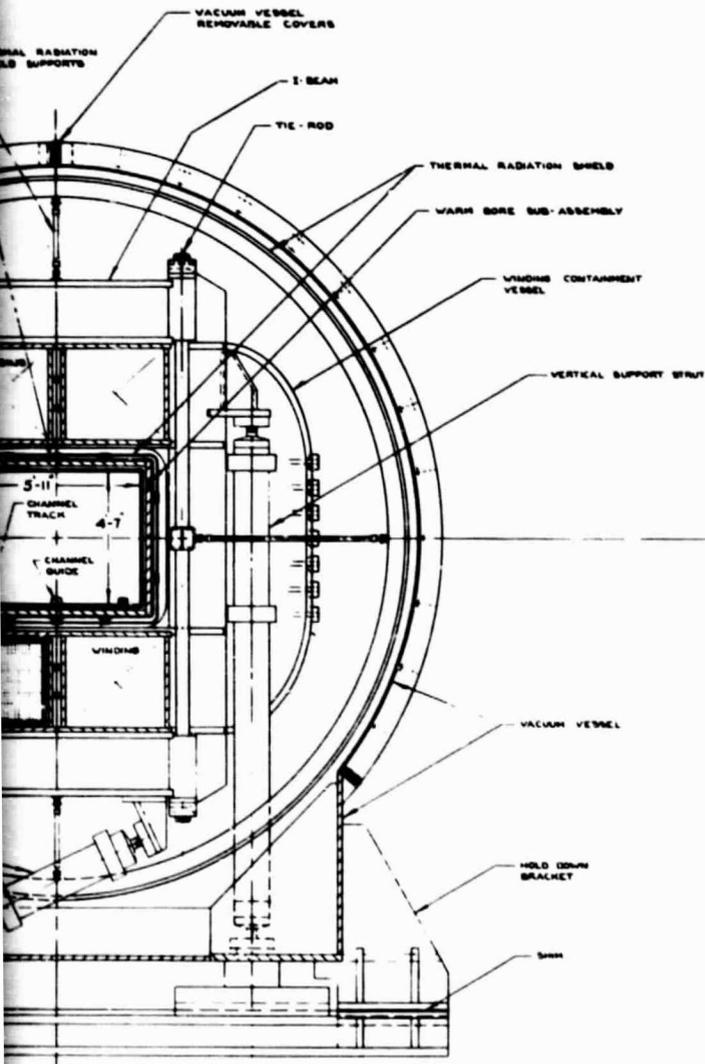
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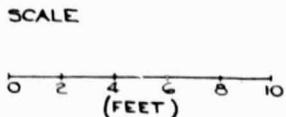
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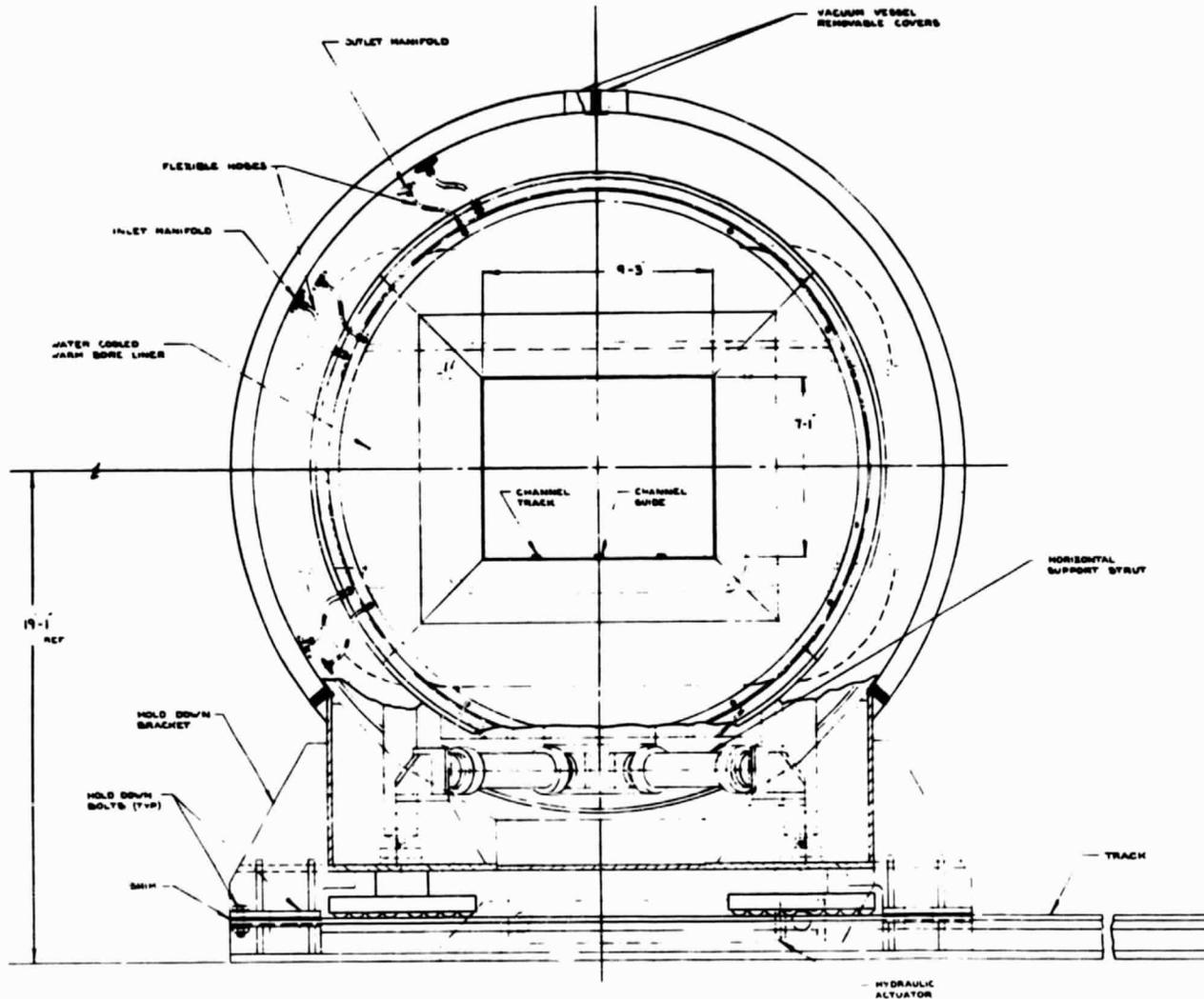


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DO NOT SCALE FOR CONSTRUCTION

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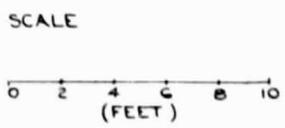


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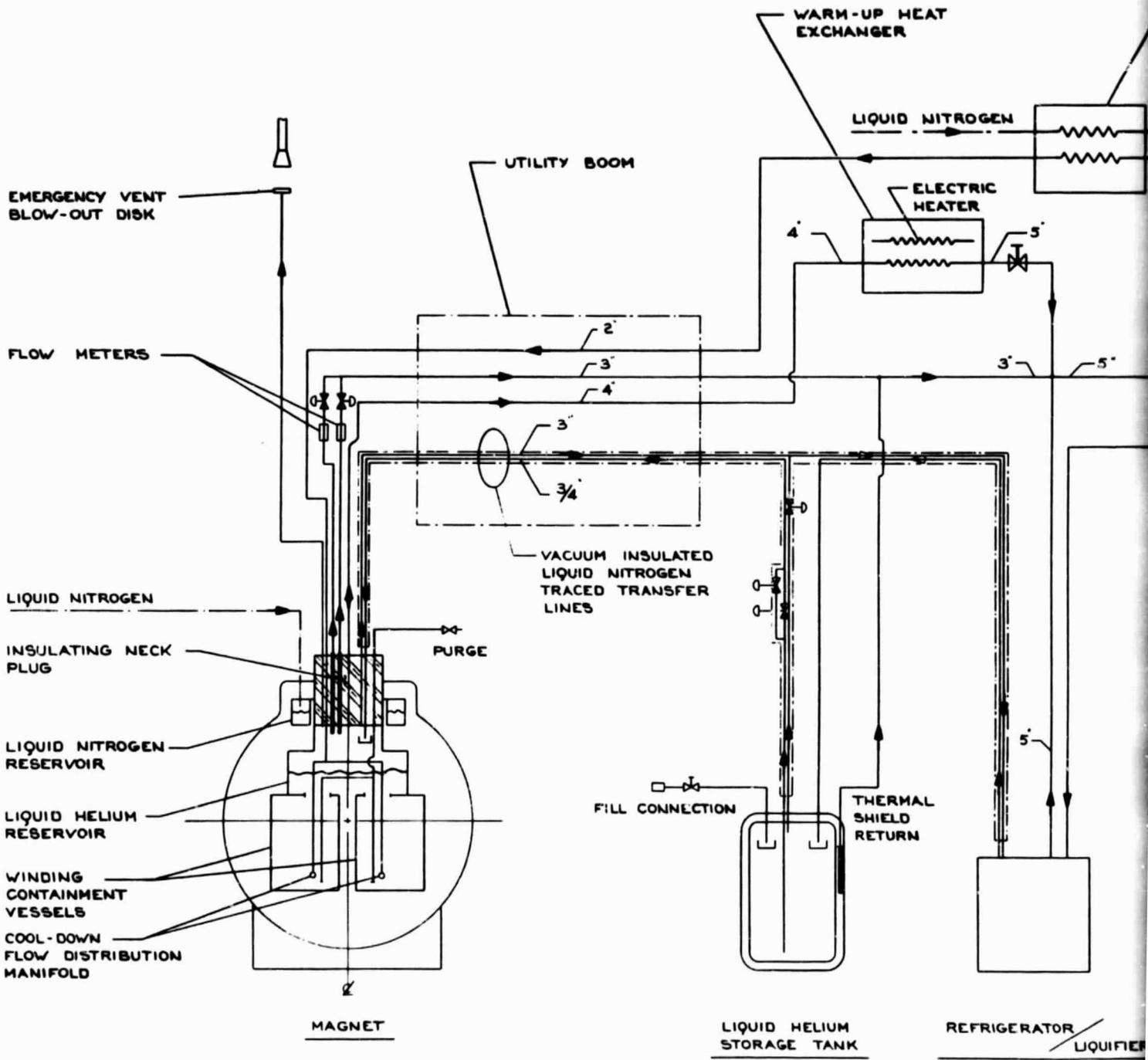
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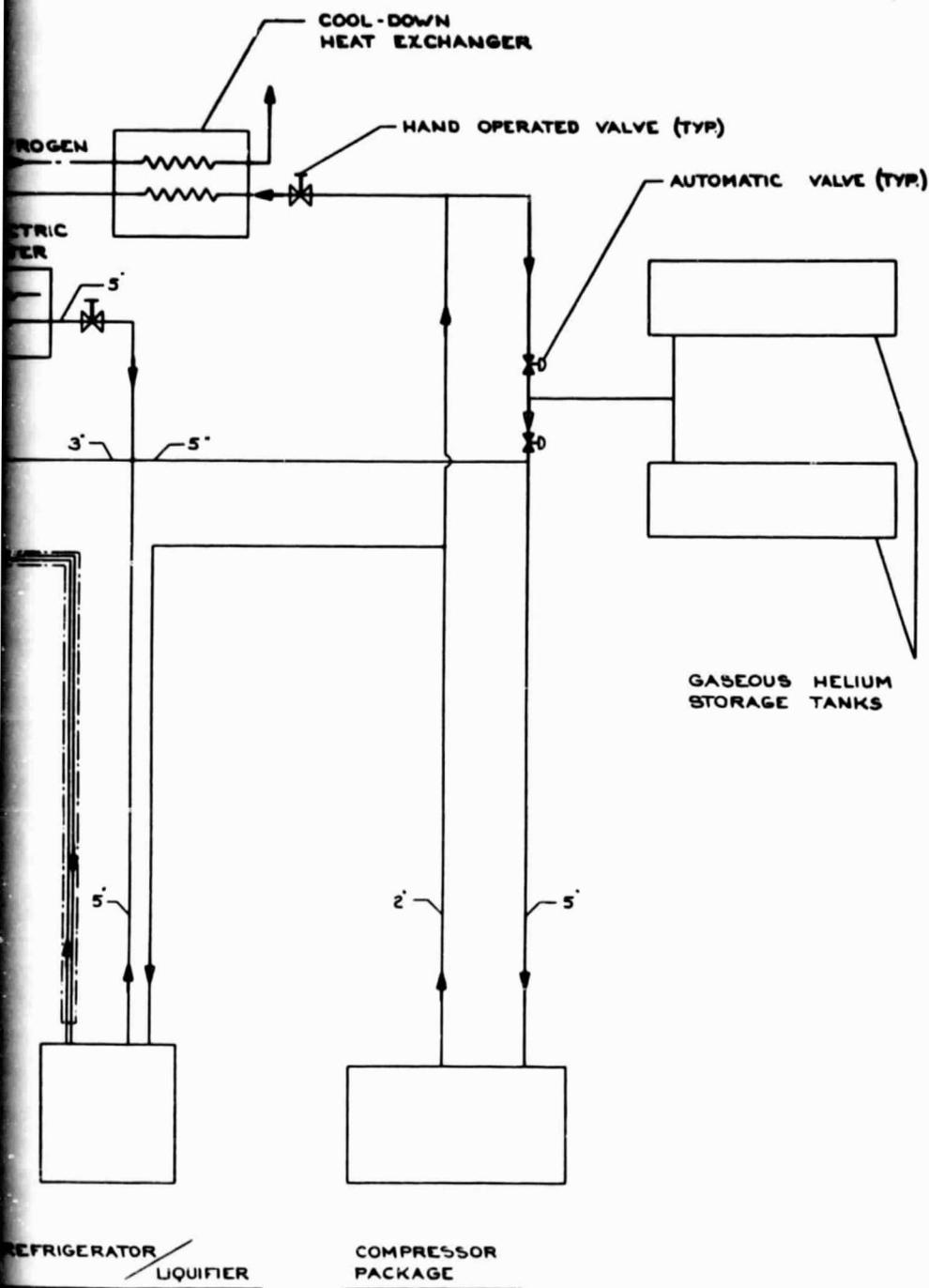
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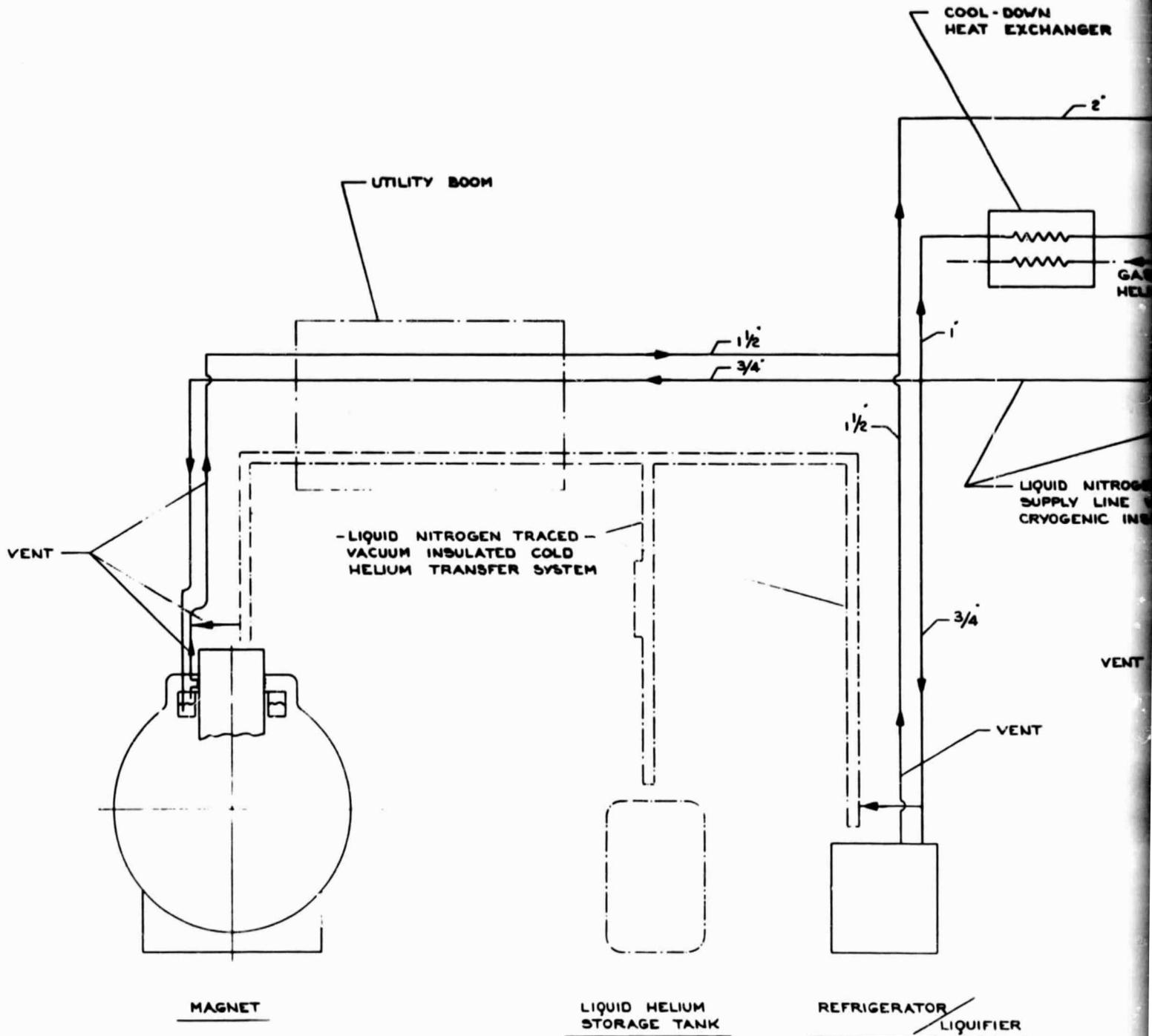
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- D-4445 PLAN AND ELEVATION
- D-445C SYSTEM SCHEMATIC

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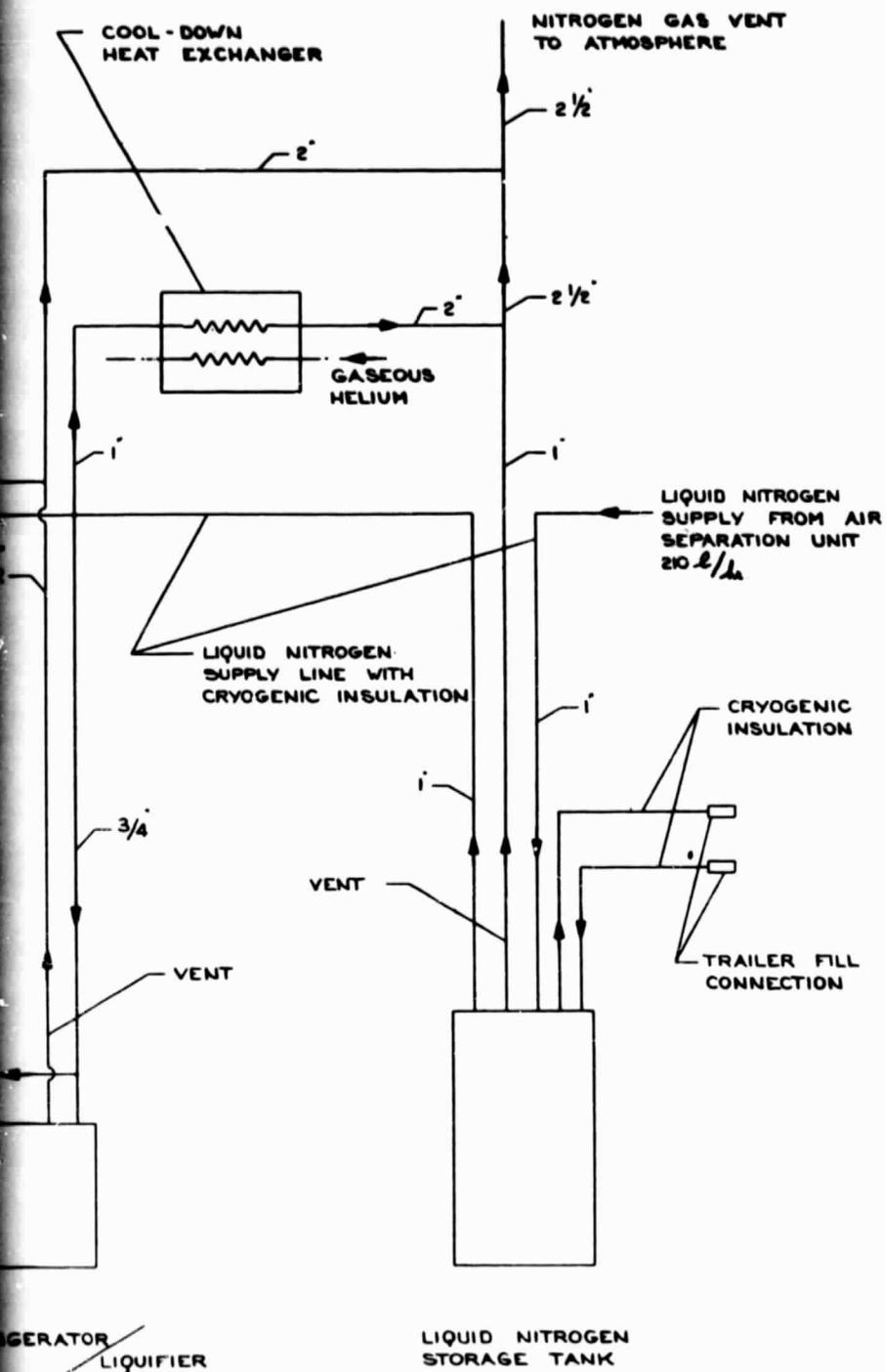
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DIAGRAM, HELIUM SYSTEM				
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2-13-81	<i>QmH</i>	NONE		
3-13-81	<i>QmH</i>			
2-13-81	<i>QmH</i>			
4452				B

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DO NOT SCALE FOR CONSTRUCTION



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REFERENCE DRAWINGS

- D-4452 DIAGRAM, HELIUM SYSTEM
- D-4445 PLAN AND ELEVATION
- D-4456 SYSTEM SCHEMATIC

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MAGNET SYSTEM

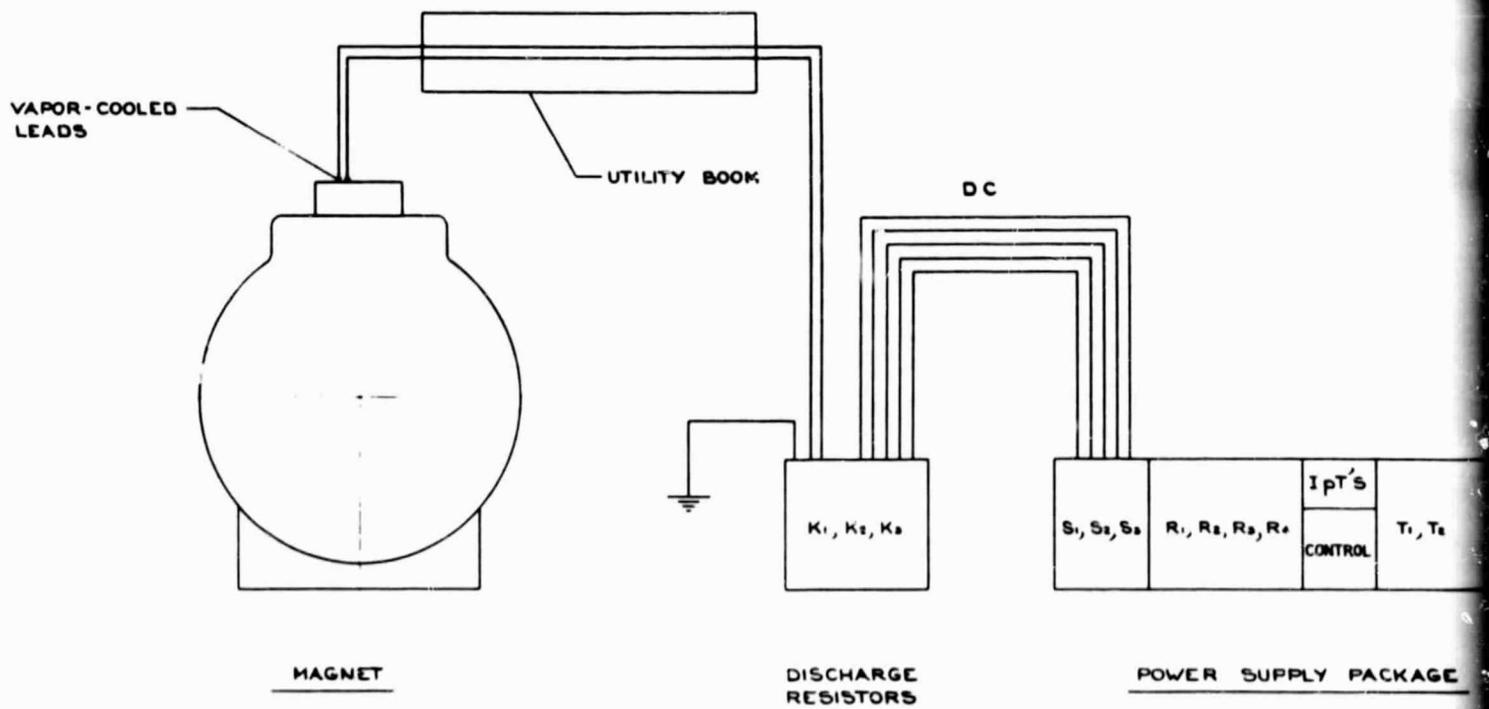
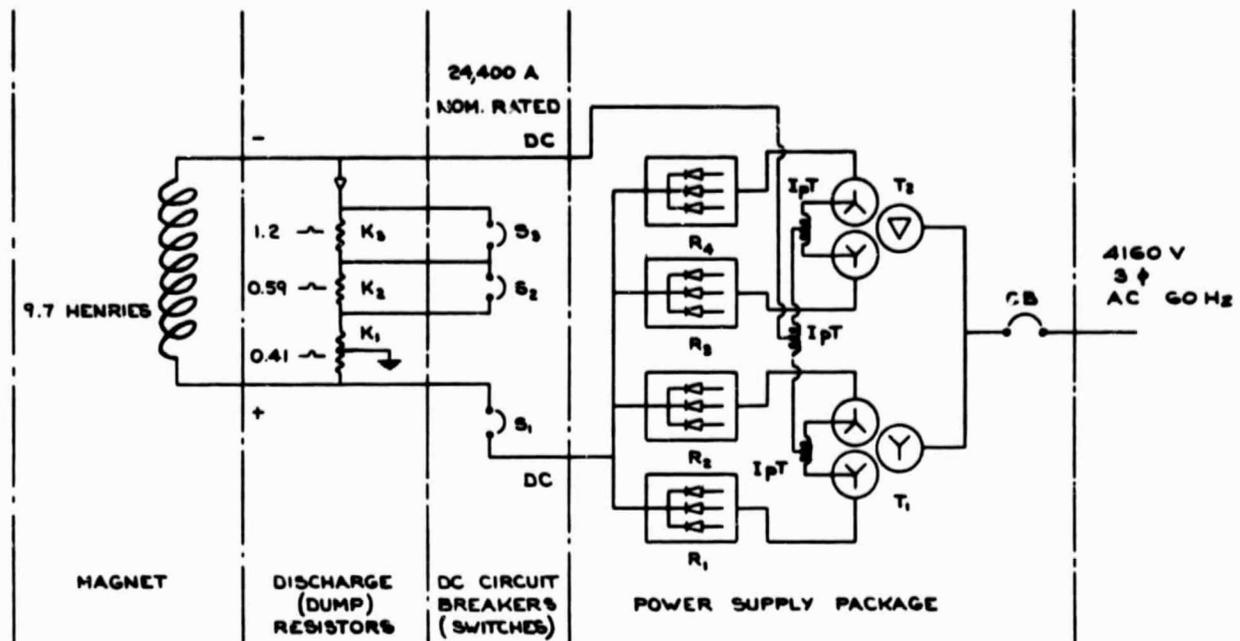
DIAGRAM, NITROGEN SYSTEM

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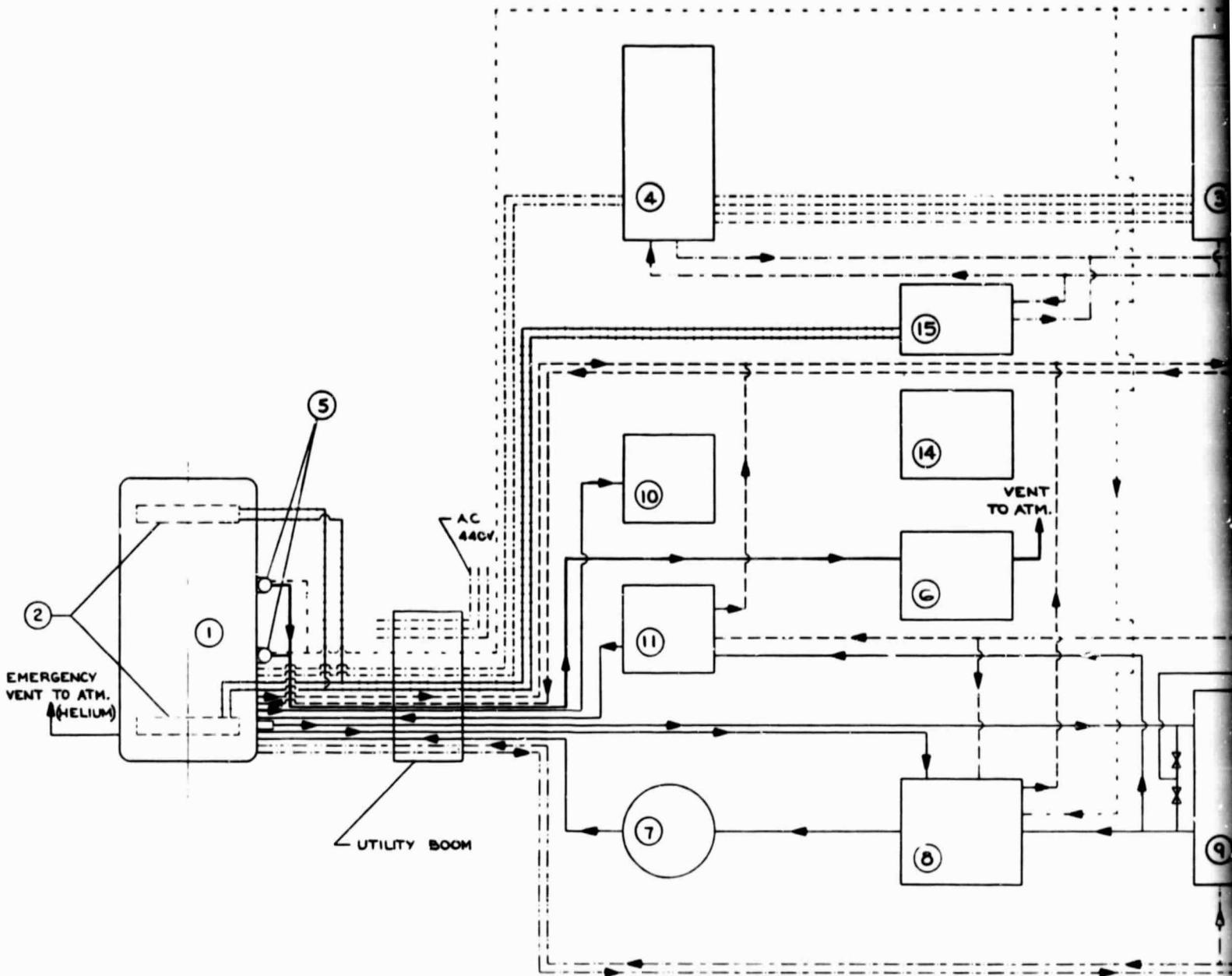
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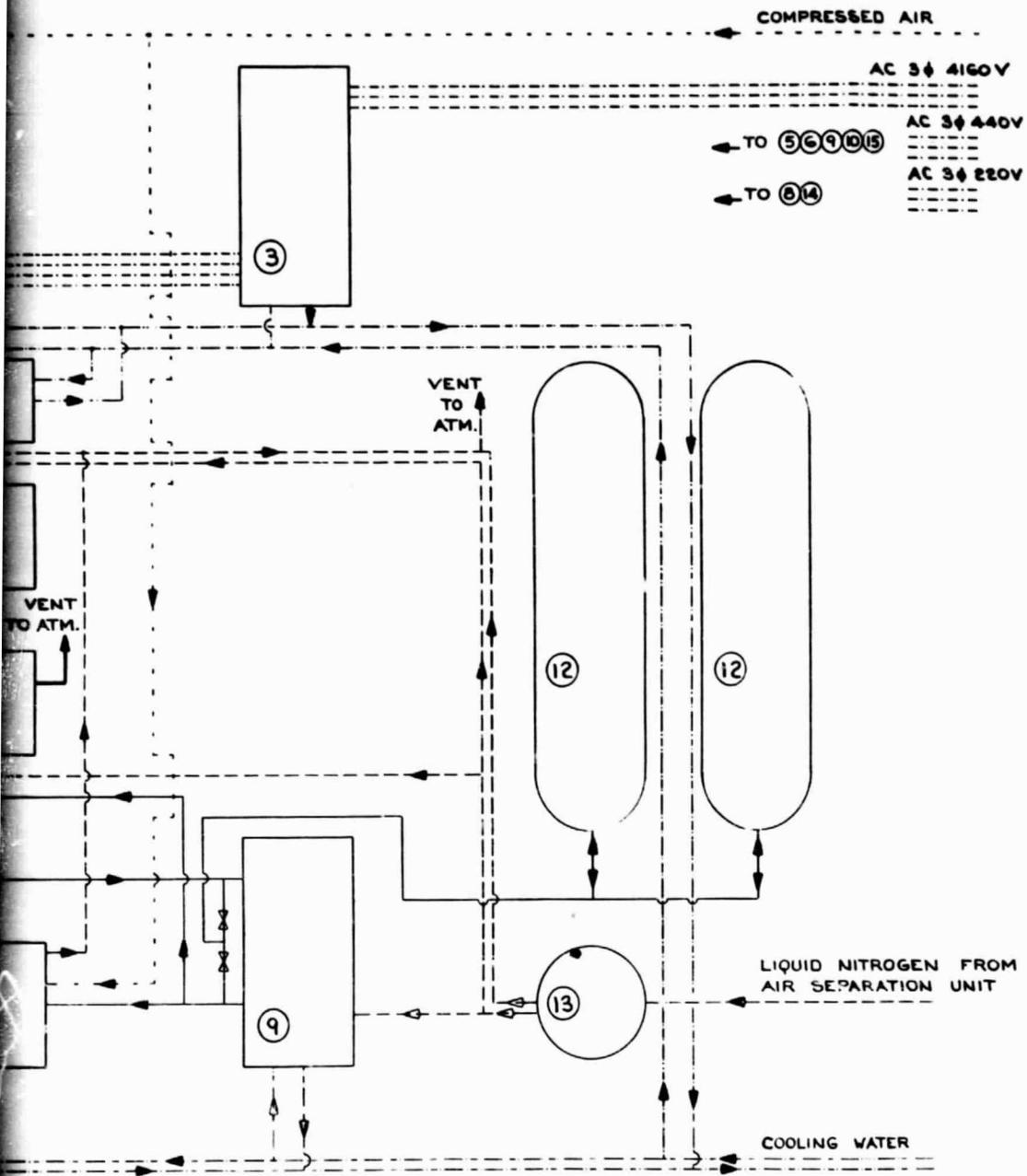


ITEM NO	DESCRIPTION
1	MAGNET
2	HYDRAULIC ACTUATORS
3	POWER SUPPLY PACKAGE
4	DUMP RESISTORS
5	DIFFUSION PUMPS
6	VACUUM PUMP PACKAGE
7	LIQUID HELIUM STORAGE TANK
8	LIQUIFIER / REFRIGERATOR
9	HELIUM COMPRESSOR PACKAGE
10	WARM-UP HEAT EXCHANGER
11	COOL-DOWN HEAT EXCHANGER
12	GASEOUS HELIUM STORAGE TANK
13	LIQUID NITROGEN STORAGE TANK
14	UTILITY VACUUM PUMP PACKAGE
15	HYDRAULIC PUMP PACKAGE

LEGENT

- = HELIUM
- - - = NITROGEN
- · - · = WATER
- — — = VACUUM
- · · · = HYDRAULIC FL
- - - - = COMPRESSED
- · · · · = ELECTRICITY

FOLDOUT FRAME



REFERENCE DRAWINGS

- D-4450 GENERAL ASSEMBLY
- D-4445 PLAN AND ELEVATION
- D-4452 DIAGRAM, HELIUM SYSTEM
- D-4453 DIAGRAM, NITROGEN SYSTEM

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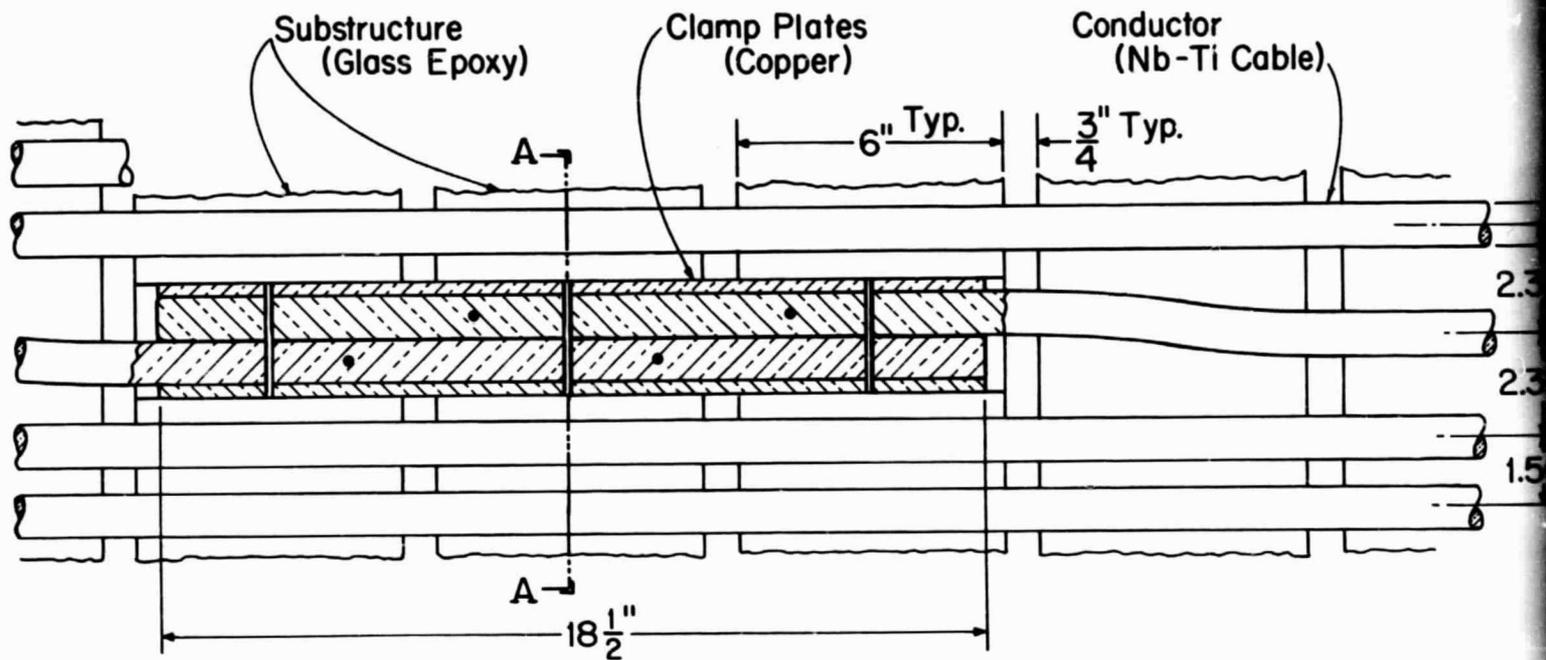
LEGENT

- = HELIUM
- - - = NITROGEN
- · - · = WATER
- · — · = VACUUM
- · · · = HYDRAULIC FLUID
- · - · - · = COMPRESSED AIR
- - - - - = ELECTRICITY

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TOLERANCES UNLESS OTHERWISE SPECIFIED
 MACHINING - FRACS ± 1/32 DEC'S ± .000 ANG'S ± .10°
 CASTING - FRACS ± 1/32 ANG'S ± 1°
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 MACHINE SURFACES TO IDENTIFY AND T.Y.D.
 DO NOT SCALE FOR CONSTRUCTION

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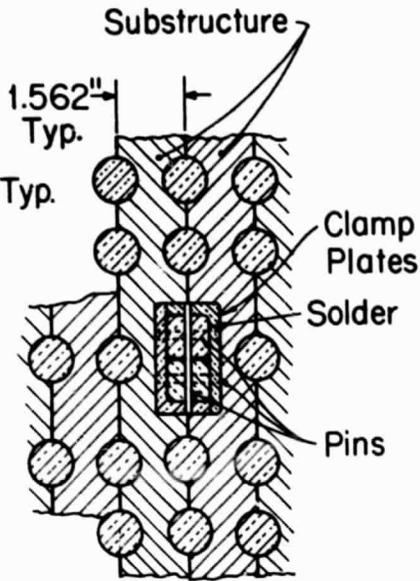
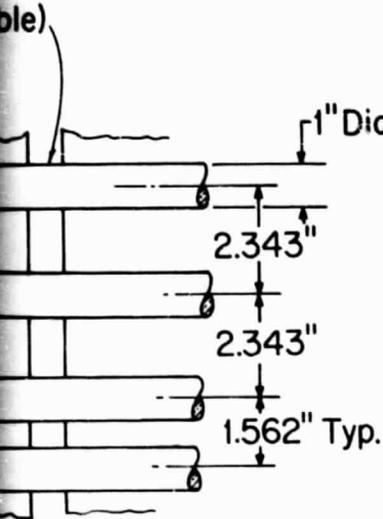
Notes:

Joints must be staggered so even though sequential plates same turn numbers. Hence, for the next plates toward o

Joint Procedure:

1. Cut cables to length
2. Clamp in "L" shaped
3. Drill & pin (typical)
4. Solder fill

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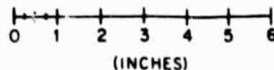


Section A-A

st be staggered so they don't lie one over the other,
 gh sequential plates may need them between the
 numbers. Hence, place one on this end. Then one
 t plates toward other end, etc.

cedure:
 cables to length
 mp in "L" shaped copper blocks
 l & pin (typical)
 der fill

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TOLERANCES UNLESS OTHERWISE SPECIFIED
 MACHINING - FINISH & 1/16 DEC'S & .000 ANG'S & 1/16"
 CASTING - FINISH & 1/32 DEC'S & .000 ANG'S & 1/16"
 BORE ALL SHARP EDGES REMOVE ALL BURRS
 MACHINE SURFACES OF CONCENTRICITY AND T.I.R.

DO NOT SCALE FOR CONSTRUCTION

REV.	DESCRIPTION	BY	DATE	APPD
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TYPICAL JOINT IN SUPERCONDUCTING CABLE				
DRN. N.L.D.	2-16-81	SCALE 1:2	ENT. OF	
DRW. <i>[Signature]</i>		D 4457		REV.
APPD.				BY

SYSTEM DESIGN DESCRIPTION
SDD-504
HEAT-RECOVERY/SEED-RECOVERY SYSTEM
FOR
MAGNETOHYDRODYNAMICS (MHD)
ENGINEERING TEST FACILITY (ETF)
CONCEPTUAL DESIGN - 200 MWe POWER PLANT

Douglas K. Warinner *August 18, 1981*
SYSTEM ENGINEER - Douglas K. Warinner DATE

REVIEWED _____ DATE

Robert W. Bercaw *Aug 18, 1981*
APPROVED - Robert W. Bercaw DATE

Revision: 1
Date: September 25, 1981

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
HEAT-RECOVERY/SEED-RECOVERY SYSTEM

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1.0 FUNCTION AND DESIGN REQUIREMENTS

This document describes the Heat-Recovery/Seed-Recovery (HR/SR) System shown on the System Heat- and Mass-Balance drawing 8270-1-540-314-001. This document includes equipment and piping requirements, design criteria, component descriptions, system-function descriptions, descriptions of interfaces with other systems, descriptions of operating modes, and safety and maintenance requirements.

1.1 FUNCTIONAL REQUIREMENTS

The functional requirements of the Heat-Recovery/Seed-Recovery System are to:

- 1) utilize the energy stored in the gases exhausting from the MHD power train;
- 2) control the MHD power plant emissions; and
- 3) recover the seed.

The Heat-Recovery/Seed-Recovery System uses design practices for conventional fossil-fired steam plants wherever possible to meet the ETF functional requirements. It consists of a Boiler and a Particulate Control System. The Boiler utilizes the heat for:

- 1) generating steam to power turbines to drive the electric-power generator and compressors,
- 2) preheating the MHD-power-train oxidant, and
- 3) aiding in preheating the boiler feedwater.

The Boiler resembles a conventional fossil-fired boiler which has had the burner replaced by the MHD Power Train. It generates steam in a furnace similar to the conventional radiant furnace. Steam is also generated in the MHD diffuser and transition section cooling jacket. The ETF boiler superheats and reheats steam. It incorporates an economizer to utilize some of the available low-grade heat to preheat the boiler feedwater. However, the ETF economizer provides less heat recovery than in a conventional power plant, because much of the feedwater heating is accomplished by cooling the MHD combustor and channel.

The Boiler also contains the Intermediate Temperature Oxidant Heater (ITOH) in which the flue gas heats the oxidant (enriched to 30 mol % O₂) provided by the Oxidant Supply System before the oxidant is piped to the MHD combustor.

The Boiler assists in controlling the plant emissions and recovering the seed. To do this, it must provide the proper conditions for the completion of various chemical reactions while the flue gases cool.

The flue gas entering the Boiler contains large amounts of oxides of nitrogen (NO_x) as a result of the high-temperature in the MHD combustor. The Boiler chemically reduces the NO_x by maintaining the flue gas in a reducing atmosphere at the proper temperature and stoichiometry (air-to-fuel stoichiometric ratio (SR) = 0.90) for the time required to allow the NO_x to decay to below the EPA's power-plant effluent limits. This function is performed in the entrance section of the radiant boiler known as the NO_x -Control Furnace.

The reducing atmosphere required for the NO_x reduction process contains unburned gases which must be burned prior to release to the atmosphere. This is performed in a second radiant-boiler section known as the Afterburner. The combustion of the unburned gases must be completed in a manner that minimizes the formation of NO_x . The final SR must be greater than 1.0 to ensure the formation of K_2SO_4 rather than the other compounds. Formation of K_2SO_4 is required to meet the SO_2 emission standards and to recover the seed in a usable form.

A significant percentage of seed from the flue gas is removed in the boiler. Both seed and slag condense on the heat-transfer surfaces and are collected at the bottom of various chambers in the boiler. Because it is uneconomical to recover seed which has dissolved in slag, the boiler must be designed to physically separate the collection zones of the two substances. Although this is not entirely possible, the lower condensation temperature of the seed does result in a preferential collection of the slag on the radiant boiler walls and of the seed on the convection heat-transfer surfaces.

An electrostatic precipitator (ESP) completes the functions of emissions control and seed recovery by capturing the solidified fly ash and seed particles entrained in the flue gases leaving the boiler.

1.1.1 Design Rationale

The design rationale is to employ conventional power-plant design practice and to digress only where necessary, thereby minimizing design time, cost, and engineering development.

The steam-generating unit selected for the HR/SR system is a balanced draft, drum-type radiant boiler. The heat absorption equipment in the boiler consists of a wet-bottom water-cooled furnace, superheater, reheater, intermediate temperature oxidant heater, and high temperature economizer. The final stage of solids removal is handled by an electrostatic precipitator (ESP). Figure 1 shows the HR/SR components.

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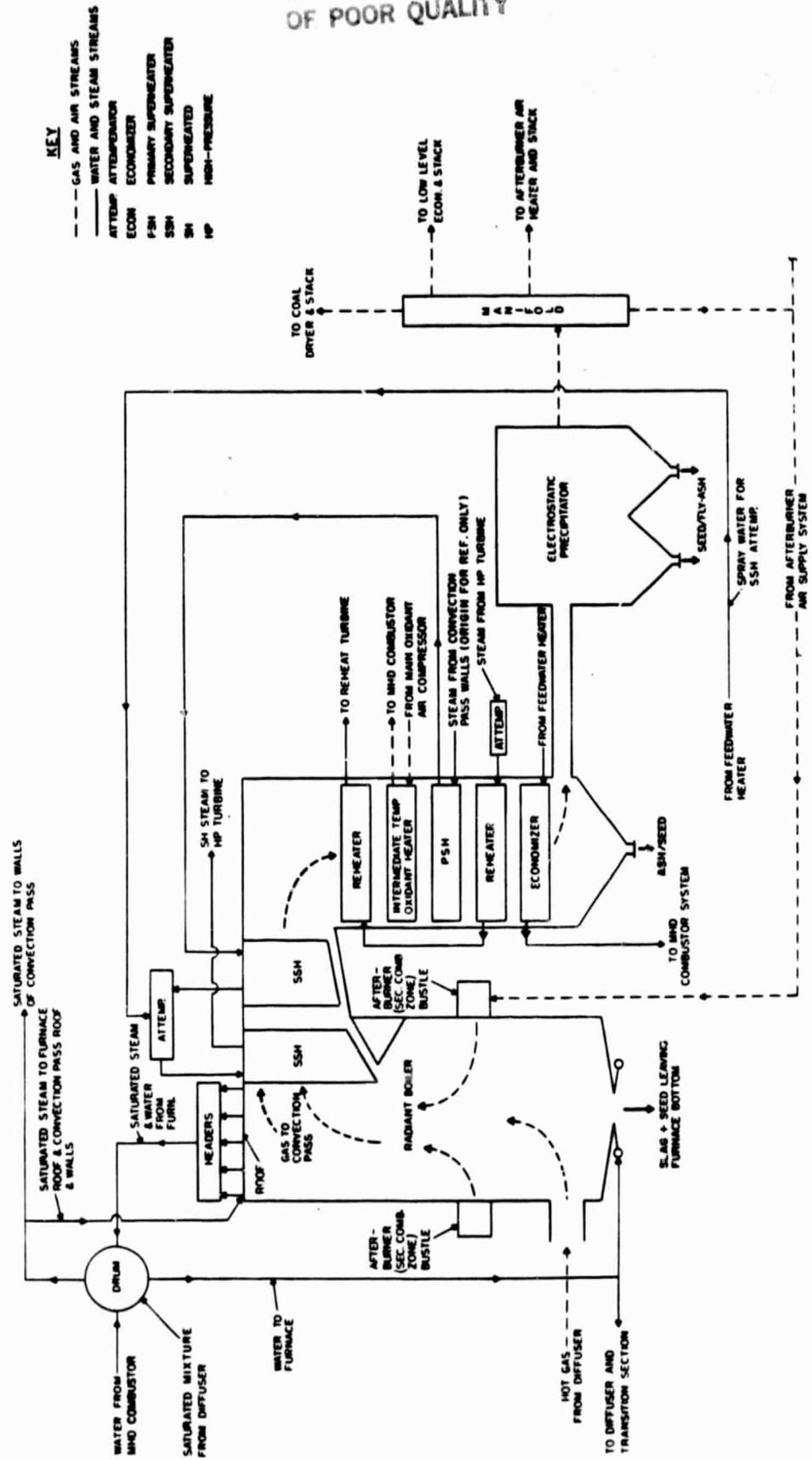


Fig. 1 HEAT RECOVERY/SEED RECOVERY SYSTEM

1.2 SYSTEM INTERFACES

The HR/SR System interfaces with other major systems in the plant. Figures 2a and 2b show HR/SR subsystems and their interfaces with the other plant systems. Table 1 lists the interfaces and describes the interface connections.

1.3 DESIGN CRITERIA

Design criteria cover the pressure and temperature ratings, gas purity, and systems design and operation limits used to select and design the required components. Engineering design criteria are in accordance with applicable codes, standards, regulations, and guides issued by governmental agencies and recognized standards organizations.

1.3.1 Codes and Standards

System engineering design is in accordance with applicable codes, standards, and guides issued by the following organizations:

1. American National Standards Institute (ANSI)
2. American Society of Mechanical Engineers (ASME)
3. American Society for Testing and Materials (ASTM)
4. American Welding Society (AWS)
5. Manufacturers Standardization Society of the Valve and Fittings Industry (MSS)
6. Pipe Fabrication Institute (PFI)
7. Occupational Safety and Health Administration (OSHA)
8. Instrument Society of America (ISA)
9. National Fire Protection Association (NFPA)
10. National Electric Code (NEC)
11. National Electrical Manufacturer's Association (NEMA)
12. American Institute of Steel Construction (AISC)
13. Steel Structures Painting Council (SSPC)
14. American Concrete Institute (ACI)

1.3.2 Design Parameters

1.3.2.1 Input to the HR/SR System

The input to the HR/SR System is the exhaust gas from the MHD combustor power train. The combustor burns Montana Rosebud coal (dried from a nominal 22.7 to 5% moisture) with oxygen-enriched air (30 mol % oxygen). The stoichiometric ratio (SR) of the gas entering the HR/SR boiler is 0.90. (See Page 7 of Reference 1 (SDD-502) in Appendix A.)

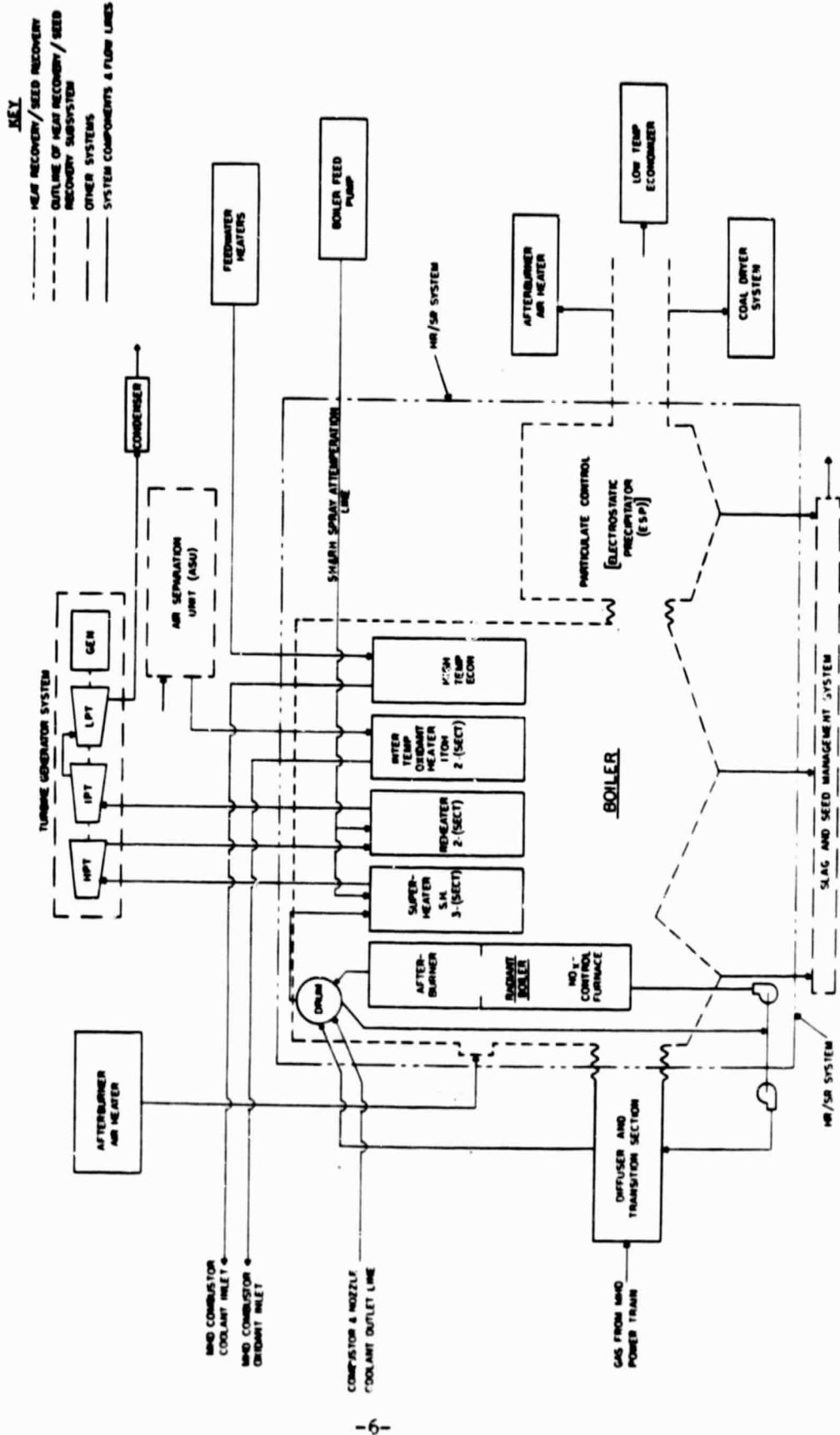


Fig. 2B HR/SP SYSTEM INTERFACES

TABLE 1
HR/SR-PLANT INTERFACES

<u>HR/SR Subsystem/Component</u>	<u>Type of Interface*</u>	<u>Interfacing Plant System/Component</u>
1) Steam Drum and Downcomer	Boiler Steam/Water Circuits	MHD Power Train/Diffuser and Transition Section Cooling Jacket
2) Boiler/Radiant Boiler NO _x -Control Furnace (Inlet)	3500°F, 13.00 psia, less than or equal to 300 fps flue-gas duct	MHD Power Train Diffuser-Transition Section
3) Boiler/Afterburner	300°F low-press. air duct	Afterburner Gas Supply Air Heater System
4) Boiler/Drum Feedwater (Inlet)	2100 psi, 590°F feedwater line	MHD Combustor and Nozzle Coolant Outlet Line
5) Boiler/Superheater (Outlet)	1910 psi, 1005°F main steam line	Main Steam/High-Pressure Turbine inlet line
6) Boiler/Reheater (Inlet)	451 psi, 649°F cold reheat steam line	Cold Reheat Steam/High-Pressure Turbine outlet line
7) Boiler/Reheater (Outlet)	429 psi, 1000°F reheated steam line	a) Hot Reheat Steam/Intermediate-Pressure Turbine Inlet b) Oxidant Supply System/ASU Compressor Drive-Turbine c) Oxidant Supply System/Oxidant Compressor Drive-Turbine
8) Boiler/Intermediate Temperature Oxidant Heater (Inlet)	72 psi, 432°F oxidant low-temperature duct	Oxidant Supply System/Oxidant Compressor Outlet line
9) Boiler/Intermediate Temperature Oxidant Heater (Outlet)	70 psi, 1100°F oxidant high-temperature duct	MHD Power-Train Combustor/Oxidant Inlet Line
10) Boiler/High Temperature Economizer (Inlet)	Approximately 2200 psi, 450°F feedwater line	Boiler Feedwater/Steam-Extraction Feedwater Heaters-Outlet

*Note: Temperatures and pressures cited are nominal values.

TABLE 1 - continued

HR/SR-PLANT INTERFACES

<u>HR/SR Subsystem/Component</u>	<u>Type of Interface*</u>	<u>Interfacing Plant System/Component</u>
11) Boiler/High-Temperature Economizer Outlet	Approximately 2200 psi, 530°F feedwater line	MID Power-Train Combustor/Coolant Jacket Inlet
12) Particulate-Control Subsystem Electrostatic Precipitator Outlet	Atm. press., 480°F clean flue gas ducts	a) Low-Temperature Economizer b) Afterburner Gas Supply System/Hot Gas Inlet c) Coal Management System/Pulverizer
13) HR/SR System Slag, Ash, & Seed Collectors	Atm. press., room temperature, transport duct for granulated materials in slurries and as dry powder	a) Slag Management System b) Seed Management System c) Seed Management System
a) Radiant Boiler/Slag Collector Dump Line		
b) Convection Heater Section/Collector Dump Line		
c) ESP/Collector Dump Line		
14) HR/SR System-Miscellaneous Auxiliary Air, Water, & Drain Line Connections	2200/700 psi, 300°F water line 450 psi, 650°F steam line 2200 psi, 630°F steam line	a) Boiler Feedwater Pump Outlet/Bleed b) Cold Reheat Steam c) Piped to outside of HR/SR Building
a) SH/RH Spray Attenuator		
b) Sootblowers		
c) Boiler Safety Relief Valve on Steam Drum		
d) Boiler Chemical Additive Feedline	2200 psi, 630°F water line	d) Feedwater Treatment Auxiliary System
e) Boiler Blowdown & SH & RH Drain lines	2200 psi, 630°F water line	e) Power-Plant Waste-Treatment Drain
f) HR/SR Controls Operator/Air Supply lines	125 psi, 80°F air line	f) Instrument or Air

*Note: Temperatures and pressures cited are nominal values.

1.3.2.2 NO_x-Control Parameters

A gas stoichiometric ratio of 0.9 at the HR/SR inlet was established as the economical lower limit required to achieve the NO_x equilibrium values required to meet environmental standards. This compromise value yields low formation of NO_x in the power train with optimum channel performance.

NO_x is reduced by holding the hot furnace inlet gases at high temperature levels for more than two seconds. The ETF design provides for approximately 1.3 seconds of residence time for the gas above 3200°F, and 2.2 seconds total above 2800°F. The average gas velocity through the furnace is held below around 24 ft/sec. to provide this residence time. (This is an example only; the actual value is determined by the boiler design.)

The gas temperature is limited to 2900°F max. at the discharge of the NO_x-Control Furnace section of the radiant boiler. At 2900°F all NO_x reduction reactions have essentially stopped and the equilibrium values of NO_x concentration are well below the EPA limit of 400 ppm.

1.3.2.3 Convection-Pass Gas Velocity

The gas stream in the convection pass carries relatively large amounts of particulate solids formed by the condensation and solidification of the fly-ash and seed material. Maximum gas velocity limited to about 35 or 45 ft/sec to minimize erosion problems in the HR/SR.

1.3.2.4 Recirculation Ratio

A circulation ratio of about 4 or 5 to 1 is chosen to put the HR/SR furnace in an operating regime similar to that used for a commercial, 2085 psia drum-type boiler. Water recirculation pumps are used to maintain the proper distribution of flow between the Boiler and the Diffuser and Transition Section Coolant Jacket.

1.3.2.5 Seed and Ash Fraction Deposition

The design of the HR/SR allows for coal-ash and seed material to leave the gas stream at three collection points of the HR/SR system. Table 2 lists the best engineering estimates of the ANL ETF Subproject Office on the proportioning of this solid material between the three collection points. The values in Table 2 are in good agreement with those of B&W in Reference 3 (see Appendix A). However, theoretical arguments in Reference 2 bring these ratios into question. Thus, these numbers are left unresolved pending experimental data.

1.3.2.6 Pressures, Temperatures, and Mass Flow Rates

The design pressures, temperatures, and flow rates are in accordance with the system heat- and mass-balance drawing 8270-1-540-314-001. Air and oxidant pipe sizing is based on pressure drop, as a percent of normal (design) pressure, as determined from an economic study with turbine Valves

TABLE 2

Seed-Removal/Ash-Removal

<u>Solids Collection Point Location</u>	<u>% of Total Input Material Ash</u>	<u>Seed</u>
Furnace Bottom	50	approx. 0
Convective-Pass Hopper	5-15	45
Electrostatic Precipitator Hopper	35-45	55

Wide Open (VWO) and with the HR/SR steam outlets at Maximum Continuous Rating (MCR) conditions. Steam velocity is limited to 1,000 feet per minute per inch of internal diameter.

1.3.2.7 Steam Parameters

The High-Pressure Turbine inlet steam conditions are 1000°F and 1815 psia. Feedwater pumps and associated valves and piping control the inlet pressure while spray attemperation controls (limits) the inlet temperature. (The limit of 1000°F is based on industry accepted temperature limits for acceptable creep in the boiler tubes over the life of the plant and the acceptable materials strength of conventional plant turbine blades and seals. The pressure limit is determined by the minimum size of 1st-stage turbine blades in a readily available turbine-generator of this capacity.)

1.3.2.8 Oxidant Temperature

The Oxidant outlet temperature limit is 1100°F. (This was established on the basis of estimated acceptable rates of corrosion of metal walls operated in the presence of sulfur compounds.)

1.3.2.9 Afterburner Stoichiometric Ratio

The stoichiometric ratio in the afterburner is 1.05. (A value greater than 1.0 is required to meet EPA requirements for CO and hydrocarbons and to prevent excessive corrosion of the bare-metal slagging-walls of the Radiant Boiler's second section (the Afterburner) and subsequent downstream components. The SR of 1.05 is selected to ensure formation of K_2SO_4 , to minimize (a) the formation of KOH and K_2S , (b) the reformation of $K_2CO_3 + SO_2$, and (c) other unwanted compounds of sulfur, and to maximize CO burnout.

1.3.2.10 Spray Attemperation

Spray attemperation at the inlet to the final stage of the reheater and superheater is minimal. (This minimizes plant efficiency loss. A nominal 2-3% of steam by weight is adequate to yield the 80% of steam flow design control point for spray attemperation, yet minimize the loss in cycle efficiency from reheater spray attemperation.

1.3.2.11 Flue-Gas Exit Temperature

The HR/SR cleaned flue-gas outlet temperature is 480°F. (This was selected in order to achieve reasonable coal-drying gas flow rates and heat input to the Afterburner Air Heater.)

2.0 DESIGN DESCRIPTION

The Heat-Recovery/Seed-Recovery System consists of two major subsystems:

- 1) the Boiler
- 2) the Particulate Control Subsystem.

2.1 SUMMARY DESCRIPTION

The Boiler performs all of the functions of the HR/SR System excepting those of seed recovery and particulate control which are shared with the Particulate Control Subsystem. Most components of the Boiler contain the flue gas and/or transfer heat from the flue gas to the MHD oxidant or the steam supply for the turbines, but the components must be configured and integrated so that the exhaust gas processing functions are also accomplished.

The major components of the Boiler are:

- NO_x-Control Furnace (lower section of Radiant Boiler)
- Afterburner (upper section of Radiant Boiler, and air "bustle" or "windbox")
- Convection Pass Enclosure
- Steam drum, recirculating pumps, and piping
- Superheater and attemperator
- Reheater and attemperator
- Intermediate temperature oxidant heater (ITOH)
- High temperature economizer
- Soot blowers

The MHD exhaust gases (flue gases) enter near the bottom end of the radiant boiler, exit from its top, and then flow through radiant and convective passes containing the superheater, reheater, intermediate temperature oxidant heater, and high-temperature economizer. Saturated steam is generated in the walls of the Radiant Boiler and also in the walls of the MHD power-train diffuser and transition section. The conventional steam drum configuration is used for separating the steam from the recirculating water. Special considerations are made in the design of the recirculating water system to ensure adequate cooling of the diffuser and transition section. Steam heating in the superheater and reheater is conventional, but the design of these components accounts for corrosion and fouling problems caused by the heavy seed loading of the flue gases. Spray attemperators are used to control and maintain superheat and reheat steam outlet temperature below 1000°F at the higher power levels.

The Intermediate Temperature Oxidant Heater (ITOH) receives oxygen-enriched air from the Oxidant Supply System and preheats it to 1100°F for use in the MHD combustor.

The Boiler controls plant emissions and recovers the seed. In order to do this, it must provide the proper conditions for the completion of a variety of chemical reactions during the cooling of the flue gases. Oxides of nitrogen (NO_x) are present in the flue gas as a result of the high temperature developed in the MHD combustor. While the concentration of NO_x is limited by operating the MHD combustor with excess fuel, it would still exceed the emission standard if it were not reduced in the Boiler. Reduction is accomplished by configuring the NO_x -Control Furnace, the lower section of the Radiant Boiler, to control the cooling rate of the flue gas so that a low equilibrium NO_x value is approached prior to the time when the gas reaches the temperature (approximately 2900°F) at which the reduction reactions are frozen.

The completion of combustion of the exhaust gases to eliminate unburned hydrocarbons and carbon monoxide is accomplished in the Afterburner (upper portion of the radiant boiler) using preheated air from the Afterburner Gas Supply System. Mixing is provided by a set of nozzles which are fed by a windbox that encircles the furnace. The Afterburner must be designed to complete combustion and avoid temperatures which would reform NO_x . (The design avoids local zones having a reducing atmosphere which would cause corrosion of the superheater and other heat exchange surfaces.)

Sulfur dioxide (SO_2) emissions are controlled in the ETF by reaction of the sulfur with the potassium in the seed. These reactions occur as the flue gas cools in the radiant boiler. The amount of afterburner air is adjusted to maximize the formation of K_2SO_4 , rather than other potassium compounds.

The NO_x -Control Furnace (the lower section of the Radiant Boiler) is designed to have slagging walls and the afterburner walls are designed to operate at a sufficiently high temperature to inhibit the condensation of seed. Wet seed and ash collects on the secondary superheater while dry seed collects on the other convective surfaces. Soot blowers are provided to remove the ash and seed from the surfaces so that it falls into the hopper at the bottom of the convection pass.

The Particulate Control Subsystem reduces the inventory of all particulates in the plant gas effluent to below the environmental standards and completes the recovery of the seed from the flue gas. It does not include the clean up of the coal drying medium which is performed by the Coal Management System. The subsystem is comparable to the one in a conventional pulverized-coal-fired power plant, but it must contend with a much higher loading of very fine particulates. Major elements include:

- Electrostatic precipitator (ESP)
- Duct work
- Instrumentation and control.

2.2 DETAILED DESCRIPTION

The HR/SR design described in this report is not a fully developed design. It is a design concept consolidated from various studies. The design reports used to develop the concept for the 200 MWe ETF Power Plant HR/SR include references 3 through 7 listed in Appendix A.

For the most part, the ETF design is based on that of reference 3. This design concept encompasses features from references 3 and 5. Thermodynamic balances by the HR/SR boiler designer are necessary to complete the detailed design description.

The details of the heat exchanger elements are subject to change. This includes not only the sizing and ordering of the elements of the superheater, reheater, and ITOH but also the choice of either steam or evaporation cooling of the connection pass enclosure. All heat lost to the walls of the diffuser and the transition section is transferred to a high-pressure cooling-jacket that produces about 5% quality steam in the cooling jacket outlet lines. The cooling jackets are integrated with the HR/SR steam generation system. Detailed descriptions of the MHD Power-Train Diffuser and Transition Section Cooling Jacket and Piping are described in the System Design Description for the MHD Power Train (SDD-502) and will not be repeated here.

2.2.1 Major Boiler Subsystem Equipment

2.2.1.1 Radiant Boiler

Hot gas leaving the MHD Channel at near-sonic velocities is reduced in the Diffuser described in Reference 1 (see Appendix A) to a reasonable radiant-boiler entrance-velocity of approximately 300 fps.

The temperature of the flue gas entering the Radiant Boiler is at or near 3500°F and is cooled to near the 2350°F dew point of the K₂SO₄ vapor before it exits the Radiant Boiler and enters the section of the Convective Pass Enclosure with radiant pendant heaters.

The Radiant Boiler is a multifunction device consisting of two sections, a NO_x-Control Furnace and an Afterburner.

The NO_x-Control Furnace section is designed to receive 1,048,569 lb/hr of flue gas from the diffuser outlet at the conditions of 3532°F and 13.00 psia. The design of the furnace is based on the premise that the flue gas is the combustion product of a 90% stoichiometric ratio (SR) of oxygen enriched air (30 mol % O₂) and Montana Rosebud coal. The MHD combustor is expected to reject 65% of the coal ash. Therefore, the gas carries 35% or 4033 lb/hr of the coal ash as slag and all of the seed through the channel and diffuser into the furnace. The flue gas in the NO_x-Control Furnace section cools from 3500°F to below 2900°F in a controlled heat loss manner so as to provide a minimum residence time of 2 seconds at temperatures above 2900°F, allowing the NO_x formed in the MHD power train to decay to below EPA-allowed values.

Supplemental air mixed with flue gas is injected into the mainstream in the afterburner section to burn the remaining combustibles in the hot substoichiometric flue-gas. Sufficient air is added to raise the stoichiometric ratio to 1.05. The result is a "lean-burn" condition wherein the CO and any carbon burn over an extended distance as the gas moves through the combustion region above the injectors. Flue gas is mixed with the air to limit or control the flue gas temperature to about 2400°F at the secondary superheater.

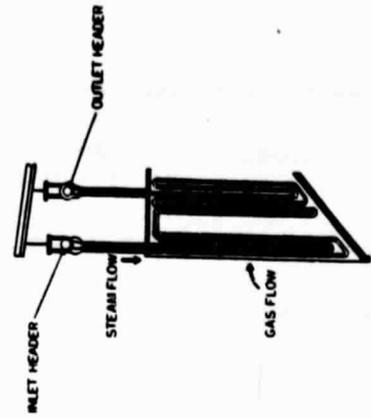
Seed condenses in the upper portion of the afterburner section as the gas temperature drops below the seed condensation temperature. The 1.05 stoichiometric ratio of the gas provides a slightly oxidizing atmosphere. Gas with this stoichiometric ratio has the proper oxygen partial pressure for optimum yield of K_2SO_4 formation as the K_2 vapor reacts with SO_2 to yield K_2SO_4 liquid which finally freezes out in the gas as dry, fine, particulates of K_2SO_4 .

The Radiant Boiler membrane-tube walls are constructed of 2-1/2" O.D. tubes on 3" centers. The dimensions of the enclosure are 30' in width by 52' in depth and a height of 143' from the slag tap bottom to the Radiant Boiler roof. The furnace bottom slopes from the front and rear walls at an angle of 7° toward the center, and an opening of 3' by 52' is provided to tap the molten slag off the bottom floor. The entrance from the MHD Power Train to the NO_x -Control Furnace Section of the Radiant Boiler is an opening of 144 ft² in the lower portion of the front wall.

The NO_x -Control Furnace extends to a height of 65 feet. The vertical membrane tube walls and the floor are studded with 5/8" studs and coated with a ruby-ram mix, alumina or other refractory (see Figure 3) to the afterburner secondary air plena. The refractory coating lowers heat absorption rate in the lower furnace to reduce the flue gas cooling rate and thereby improve the rate of NO_x reduction. The refractory coating maintains a higher surface temperature to ensure that molten slag flows freely down the vertical surfaces to the furnace floor. In addition, the refractory coating helps to protect the furnace tube wall from corrosion in the high-temperature reducing atmosphere.

The afterburner air supplied from the afterburner gas supply system first enters the air distribution duct plenum at a rate of 311,000 lb/hr which yields an overall flue gas stoichiometric ratio of 1.05. The combustion air is then distributed to the ports located 66' from the bottom of the radiant boiler and spaced four feet apart. The air injection ports are arranged in an opposed and staggered configuration on each of the chamber walls. To promote good mixing, the air is injected normally into the flue gas stream at a velocity of 124 ft/sec. The air streams penetrate 12'-15' into the flue gas and spread 8' to cover the entire furnace cross sectional area and induce mixing eddies in the flue gas as it proceeds up into the afterburner section of the Radiant Boiler (see Figure 3).

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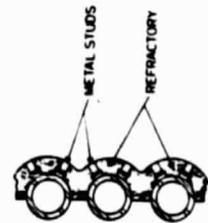
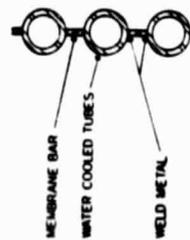
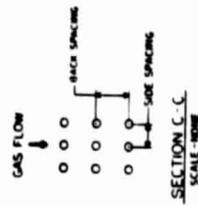
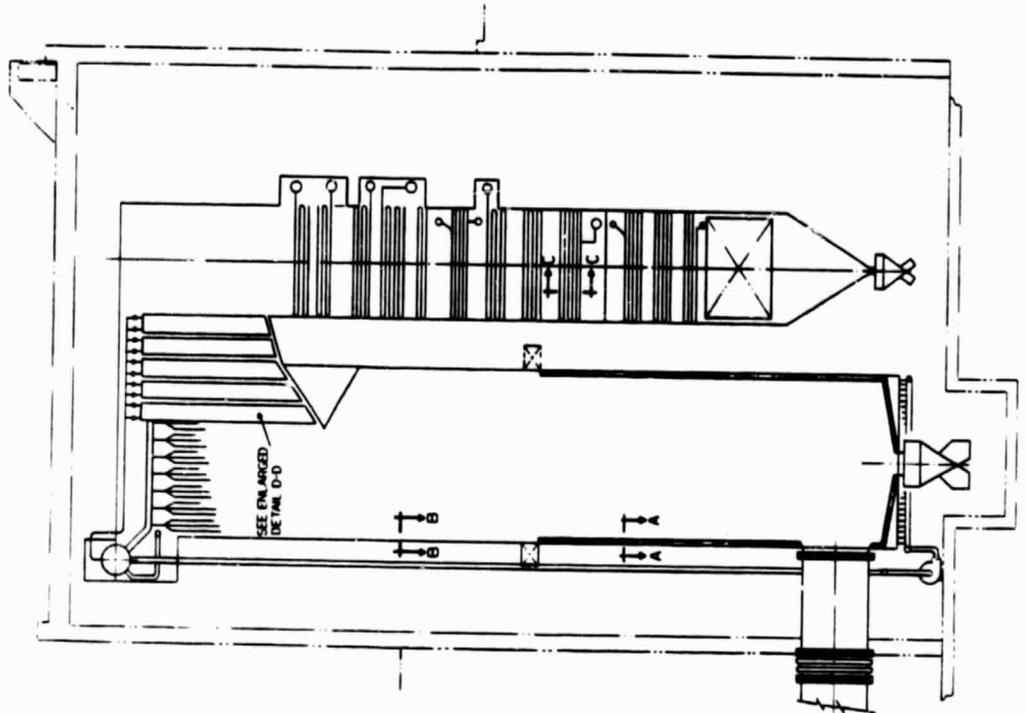


FIG. 3 HR/SR BOILER MEMBRANE AND REFRACTORY WALLS AND SECONDARY SUPERHEATER

In this section of the radiant boiler, the enclosure walls are constructed of bare membrane tubes as shown in Figure 3. Studs and refractory are not applied in order to minimize buildup of the slag and reduce the possibility of shedding of large chunks of deposits that could impact and damage the floor.

The flow path is constricted near the middle of the afterburner section to a width of 20' by bending the rear wall tubes into lower and upper sloping floors at 30° and 35°, respectively, as shown in figure 3. The gas flows is thereby redirected from the afterburner to the cross-pass section of the convective pass enclosure and is prevented from bypassing portions of the secondary superheater pendant platens in the horizontal flow cross-pass section where much of the seed condenses.

2.2.1.2 Convective-Pass Enclosure

The Radiant Boiler terminates at the horizontal cross-pass which conducts the flue gas to the top of the convective down-pass. The cross pass of the Boiler contains the radiant heat transfer pendant panels used for finish superheating of steam. Approximately 1,360,000 lbs/hr of flue gas at around 2500°F flows horizontally and exits the convective heat exchanger horizontally at about 1900°F. The secondary stage or finish superheating of the steam to 1000°F is accomplished in the radiant heat transfer pendant platen heaters in the seed condensing cross-pass.

Heat transfer from the gas to the walls is predominantly radiative, although convective heat transfer can account for as much as 30% of the total heat transfer by the time the gas leaves the cross pass. However, because of the adverse fouling properties due to the viscous nature of semi-fluid K_2SO_4 and the narrow temperature range between the boiling temperature of 2350°F and the solidification temperature of 1950°F, no attempt is made to optimize the design of the cross-pass for convective heat-transfer. Instead, the design of the seed condensing section is optimized for radiative heat transfer and liquid seed film formation and solidification on all vertical surfaces. In the present design, some seed is likely to condense and freeze in the secondary superheater pendants.

Flue gas leaves the cross pass and flows down the convective back-pass. In order of the flue gas flow, the heat exchangers in the convective back-pass enclosure are 1) the final reheater, 2) the intermediate temperature oxidant heater (ITOH), 3) the primary superheater, 4) the first stage reheater, and 5) the high-temperature economizer.

The flue gas exits the horizontal convection cross pass through the screen at 1655°F and enters an open chamber 52' wide, 19' deep, and 18' high where the flue gas changes its flow direction from horizontal to downward flow.

A set of membrane walls is designed to enclose the down-flowing gas stream and the heat absorbing banks such as the intermediate temperature oxidant heater and the primary superheater. The enclosure walls are constructed of 2-1/2" on O.D. tubes on 3" side spacing. The entire enclosure is 19' deep, 52' wide, and 122' high. As the flue gas cools from 1655°F to 650°F, the solid-seed fine particles in the gas stream plus a major portion of the frozen seed and ash collected on the heat transfer surfaces (greater than 1,100 lb/hr) should fall to the bottom of this enclosure. The hopper at the bottom has a 50° slope to help remove the solids. The enclosure walls are cooled by saturated steam and provide for the first stage of steam superheat.

2.2.1.3. Steam Drum Section

As shown in Figure 2b, a combination of saturated steam and water enters the steam drum from the Radiant Boiler enclosure walls and the diffuser and transition section cooling jackets. These flows are mixed with fresh feedwater from the MHD combustor. The steam drum separates the mixture into dry steam and water. The dry steam is passed on to the superheater and the water is returned to the Radiant Boiler and cooling jackets via a downcomer (pipe), distribution piping, and lower headers. Pumps are used to control circulation.

The five-foot diameter steam drum extends over the full width of the Radiant Boiler. Permanent welded connections are made to the boiler headers and bolted-flange connections are made to the Diffuser and Transition Section Coolant Jacket Riser. An isolation valve is provided between the flange and the steam drum to prevent steam drum drainage should the Diffuser and Transition Section be removed.

2.2.1.4. Superheater

Steam from the drum passes through multiple connections to headers supplying the furnace roof tubes and pendant convection pass sidewall tubes. This steam then passes from the furnace roof outlet headers and pendant convection pass sidewall outlet headers to the horizontal convection bank enclosure inlet headers, wall tubes, and outlet headers in succession. The steam next flows to the primary superheater bank in the convection pass.

Steam rises through the primary superheater and discharges through its outlet header to piping that feeds the pendant secondary superheater inlet header in the furnace penthouse. From the first bank (as described from the standpoint of the superheated steam flow path) of the secondary superheater platens, the steam enters piping containing a spray attemperator. The steam exits the attemperator, enters the final bank of pendant secondary superheater platens, and discharges through piping that connects to a high pressure turbine. This flow path is shown in Figure 4.

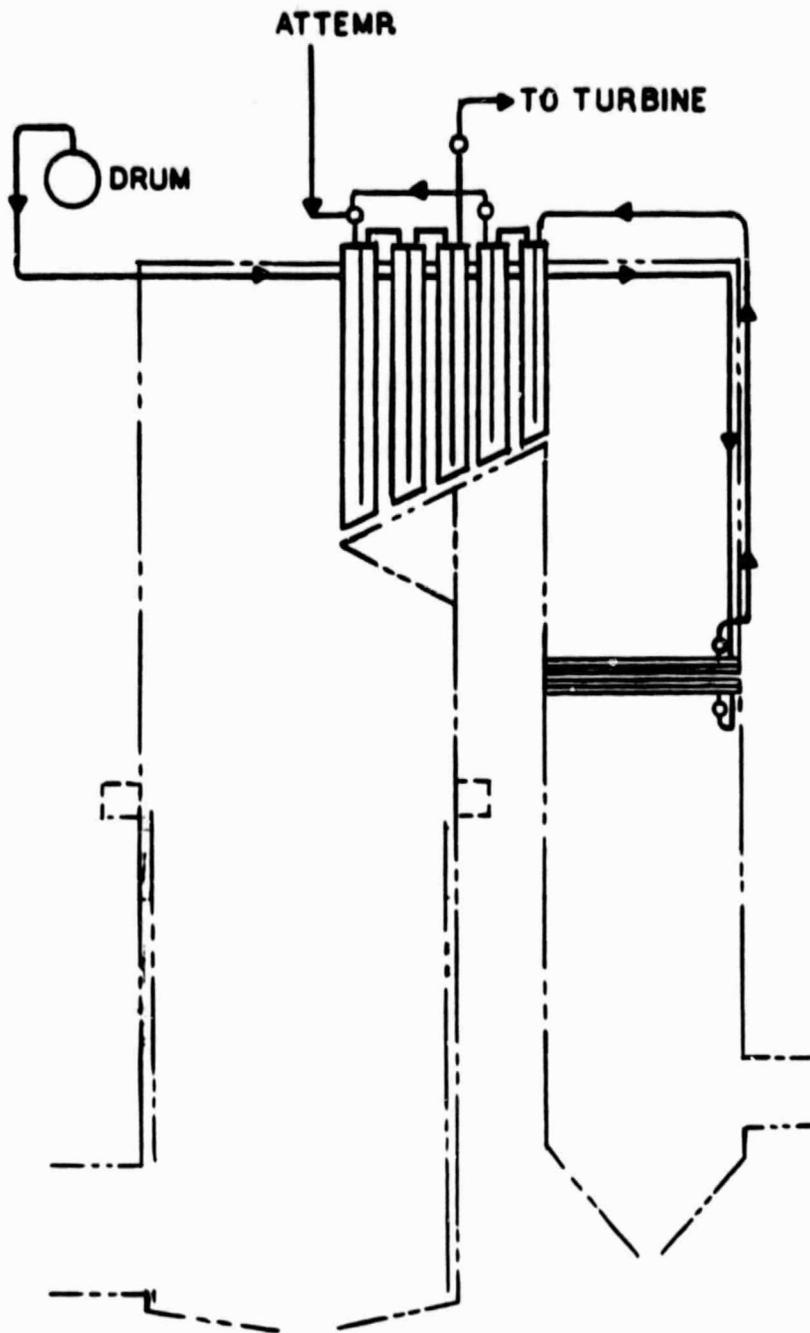


FIGURE 4
SUPERHEATER STEAM PASS

The primary superheater (PSH) is designed to heat 1,070,992 lb/hr of saturated steam from 637°F to approximately 690°F before the steam is further heated to 1005°F in the secondary superheater. The PSH is constructed of 2.0" tubes on 4.0" side spacing and 2-3/4" back spacing.

The steam flows counter to the flue gas in six passes. The PSH is divided into two banks. The upper bank consists of four steam passes and the lower bank of two steam passes. Each steam pass has 62 tubes* across the width and 4 rows in an in-line arrangement (see Figure 3, Section C-C). The flue gas flows across the superheater banks at a nominal velocity of 35-45 ft/sec. Sootblowers (located in a 2' cavity above the PSH and below the ITOH) clean the PSH and ITOH tube banks.

The secondary superheater (SSH) is divided into two sections, one located adjacent to the upper furnace and the other in the horizontal convection pass upstream from the back pass. The SSH is designed to receive 1,070,992 lb/hr of superheated steam from the primary superheater at the conditions of 690°F and 2011 psia, and to heat the steam to the outlet conditions of 1005°F and 1910 psia. Figure 4 shows the superheated steam pass through the Boiler.

The roof enclosure is constructed of bare membrane tubes with 2-1/2" O.D. on 2-3/4" side spacing. The first superheater platen bank is located above the furnace constriction and in the convection cross-pass of the Convective-Pass Enclosure. This superheater bank consists of about ten platens across the furnace width. Each platen has two steam passes with several tubes for each steam pass. The platens are constructed of 2.0" O.D. tubes on 2-3/4" back spacing and measure 20' in height. To promote solids removal from the platen surface, four sootblowers are provided in front of the platen bank. In a 2' cavity between the rear part of the platen bank and the upper furnace exit screen, three sootblowers are provided to clean the tube surface in both directions.

The 2150°F flue gas exits the upper furnace through the furnace rearwall screen and reaches a second superheater platen bank in the horizontal pass. This superheater bank consists of the same number of platens across the same width. Each platen has four steam passes, with several tubes for each steam pass. The platens are constructed of 2.0" O.D. tubes with 2-3/4" back spacing, and measure 17' high from the platen bottom to the roof. In a 2' cavity in the middle of this section, two sootblowers are provided for solids removal.

As the flue gas is cooled from 2540°F to 1655°F in the SSH zones, the seed condenses as fine mist. In the proximity of the SSH tube surface, gas at this low temperature contains seed that could precipitate into fine solid particles and adhere to the superheater tubes. The sootblowers periodically blow the tube surface with steam and break the solid deposits into fine particles which are then carried farther downstream by the flue gas.

*The number is based on the design given in Reference 4.

2.2.1.5 Reheater

Steam returning from the high-pressure turbine passes through a reheat spray attemperator located in the inlet piping to the first stage of the two-stage reheater (as seen by the reheat steam flow) set of reheat superheater banks. The steam then flows to the final set of reheat superheater banks, and from there to piping connected to the reheat turbine. Figure 5 illustrates the location of the convective reheater in the back-pass section of the Boiler.

The first-stage reheater is the first or low-temperature section of the two-section steam reheater. The location of this section in the flue-gas stream is between the primary superheater and the high-temperature economizer.

The first-stage reheater is designed to receive 986,470 lbs/hr of steam from the high-pressure turbine discharge at 450 psig and 649°F. Approximately two-thirds of the reheating is accomplished in the first stage of reheat resulting in a steam discharge temperature of approximately 880°F. No spray attemperation is used in the first stage of reheat.

The first-stage reheater section consists of 2.5" O.D. horizontal tubes spaced 4.5 inches apart in the longitudinal axis (horizontal plane) with these planes of horizontal tubes spaced 6.75 inches apart vertically. Soot blowers are used to periodically clean the surfaces of the tube banks with 450 psig steam. The dry seed and fly-ash particles are collected at the bottom of the chamber in a collection bin. Materials of construction vary in the first-stage reheater, depending upon the temperature regime of each set of tube banks. The lower operating-temperature tubes are made from SA204 GrT12 steel. The higher operating-temperature tubes are made from SA213 GrT12 and SA213 GrT22 steel. The parallel steam pass tubes are welded to common headers made from similar metals as the tubes.

The final-stage reheater is the second or high-temperature steam section of the two-section steam reheater. It is located in the flue-gas flow path near the top of the back-pass ("down-pass") immediately downstream from the secondary superheater pendant. The final-stage reheater is designed to receive 986,470 lbs/hr of steam from the first-stage reheater at 440 psig and 880°F. Approximately one third of the reheating is accomplished in the second stage, thereby resulting in a steam discharge temperature of 1000°F. Feedwater at 300°F and 700 psig is sprayed into the 880°F steam inlet to the first-stage reheater to attemperate the steam and thereby control the steam outlet temperature to no more than 1000°F. The amount of spray attemperation used in the reheater is kept to 2-3% of the steam flow by weight in order that the penalty (in loss of plant efficiency resulting from reheat-steam attemperation) be kept to a practical minimum. The spray-water lines are designed for a capacity of 30,000 lbs/hr.

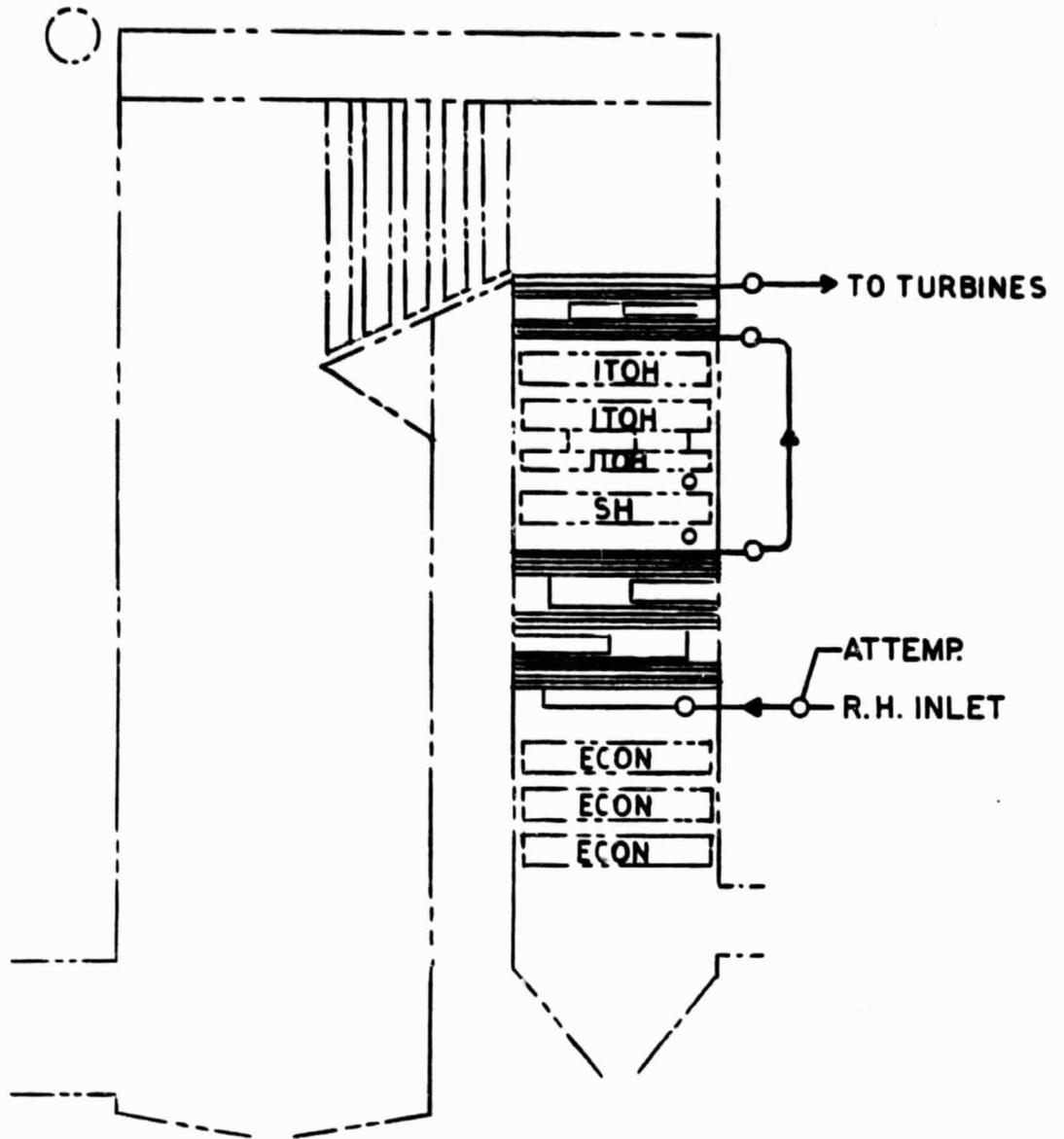


FIGURE 5
REHEATER STEAM-PASS

The final-stage reheater is constructed similar to the first-stage reheater. The material of construction of the final-stage reheater tubes is SA213 GrTP304H. The inlet and outlet headers to which each tube is attached are also made from SA213 GrTP304.

Type IR soot blowers dislodge fly-ash, slag, and seed.

2.2.1.6 Intermediate Temperature Oxidant Heater

As the flue gas changes its flow path from horizontal to downflow in the cavity above, it reaches the first set of heat absorption banks at 1600°F. A study of the gas temperature profile versus the temperatures of steam and air indicates that in order to obtain a sufficient temperature differential to provide a driving force for the convective heat transfer, it is desirable to locate the intermediate temperature oxidant heater (ITOH) above the primary superheater and below the finish reheater.

The ITOH is designed to heat 867,852 lb/hr of oxygen-enriched, compressed air from an inlet temperature of 433°F to an outlet temperature of 1100°F for combustion. The ITOH is constructed of 3.0" O.D. tubes on 7" side spacing and 3-3/4" back spacing. The ITOH is divided into four tube banks; each tube bank consists of two oxidant passes and each oxidant pass has 36 tubes across the width and 6 rows in an in-line arrangement. In a 2' cavity between each two banks, sootblowers are provided for solid deposits removal.

Figure 6 shows the combined flow pattern of cross-flow and parallel-flow arrangement (i.e., the oxidant enters at the hot end and exits at the cool end of the unit). This arrangement maintains the tube metal temperature below 1300°F. This design feature eliminates exotic and expensive materials for the ITOH.

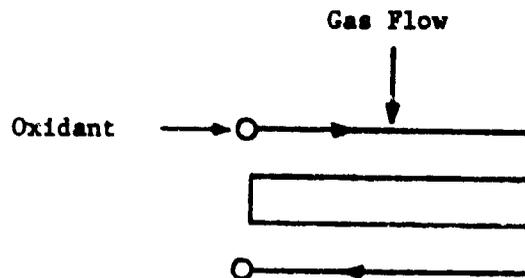


Figure 6 Cross Flow and Parallel Flow Arrangement

The flue gas flows across the tube banks at a nominal velocity of 35 to 45 ft/sec and a mass flow rate of 1,357,352 lb/hr, and leaves the ITOH at approximately 1300°F.

2.2.1.7 High-Temperature Economizer

The high-temperature economizer is located near the bottom of the enclosure unit, immediately upstream of the exit to the ESP. It heats the feed water from 450°F to 530°F with the 1,357,352 lb/hr of flue gas which leaves at 481°F. The two streams are arranged in cross-flow and counter-flow. (This unit will be ineffective for 450°F to 481°F, but is included to study possible detrimental effects in a larger MHD plant.)

The high-temperature economizer is constructed of 2.0" O.D. tubes on 3.0" side spacing and 2-3/4" back spacing. The unit consists of two tube banks with 24 passes per bank. Each tube pass has about 60 tubes across the enclosure width of 19' and one row of tubes. The tubes are arranged horizontally in a rectangular array. The array is normal to the vertical gas flow stream.

2.2.2 Particulate Control Subsystem: Electrostatic Precipitator

To meet the EPA standard of 0.03 lb particulate/10⁶ Btu, a Rothemuhle electrostatic precipitator separates the coal fly-ash and seed from the combustion gases before the gases are sent up the stack.

The Rothemuhle precipitator is sized by using the following criteria:

Gas Flow Rate	1,332,088 lb/hr
Solids Flow Rate	28,618 lb/hr (90% K ₂ SO ₄)
Inlet Temperature	481°F
Effective Migration Velocity	0.148 fps
Gas Velocity	2.96 fps
Design Efficiency	99.8%

The Rothemuhle electrostatic precipitator consists of three major components: collection plates, discharge electrodes, and rappers. Nineteen-inch wide roll-formed panels provide a maximum of quiescent zones that reduce re-entrainment of the ash.

The precipitator utilizes rigid-frame discharge-electrodes which are individually supported and guided at four locations. The electrodes are evenly spaced between the collection plates. A series of these frames are supported from a four point suspension system. Proper selection of the discharge-electrode-wire shape allows for maximum power input throughout the precipitator.

The electrical load requirements are shown on Drawing 8270-1-802-206-003 in SDD-801 (Electrical Load System).

The rappers are of the falling hammer type located internally to apply sufficient rapping forces directly into the discharge electrodes and collecting plate curtains. This results in the removal of even the most difficult dust. The staggered rapping sequence reduces reentrainment to produce a lower continuous opacity for a given outlet dust loading.

A solid-state transformer-rectifier control system features two thyristors which regulate the primary current from 5% to 100%. To provide maximum collection efficiency, the controls integrate the precipitator voltage upward to the threshold of sparking. As sparking develops, the controls modulate backwards to quench arcs and return to threshold. Spark, quench, and recovery rates can be adjusted to match precipitator load conditions.

2.2.3 Piping and Valves

The HR/SR System piping is chromium-molybdenum alloy steel and carbon steel in accordance with the standards listed in Section 1.3.1. Stop valves and control valves, provided by the turbine manufacturer, are located at each inlet to the HP and IP turbines. Safety valves, provided by the HR/SR manufacturer, are located at the Superheater outlet headers, and the Reheater inlet headers. Removable Blocking devices are located in each Cold Reheat line at the Reheater inlet. These are used for hydrotesting the Reheater and initial steam blowout.

The Steam Drum is fitted with safety valves.

The HR/SR System piping is designed with welded joints in accordance with ANSI B31.1. Valves are forged alloy steel or carbon steel with weld ends and designed in accordance with ANSI B16.34.

Piping materials are in accordance with the following:

<u>System</u>	<u>Material-ASTM No.</u>
Main Steam	Chrom-Moly Steel - A335
Cold Reheat	Carbon Steel - A106
Hot Reheat	Chrom-Moly Steel - A335

Valve materials are compatible with pipe materials.

2.2.4 Electrical

Motor-operated valves are 460 volts, 3 phases, 60 Hertz, with power supplied from 480-volt motor control centers. Solenoid valves will be coordinated with instrumentation power sources. The auxiliary power loads required by the boiler and ESP (i.e., the HR/SR) are shown in Drawing No. 8270-1-802-206-003 in the Electrical Load System SDD (SDD-801).

2.2.5 Instruments, Controls, and Alarms

2.2.5.1 Pressure Indicators

Pressure test connections are provided on the boiler drum; the superheater, upstream and downstream of each attemperator; each superheater outlet line, and outlet header; the two leads to the High-Pressure (HP) turbine; HP turbine exhaust header, downstream of each reheat attemperator; on each reheater outlet header; each Intermediate Pressure (IP) turbine inlet line; each IP turbine lead downstream of the stop valves and each reheater outlet line; and the main steam line.

2.2.5.2 Pressure Transmitters

Pressure transmitters are provided on the boiler drum for computer input, main control switchboard indication, and recording. This signal is also used to compensate drum level in the analog feedwater control system.

2.2.5.3 Pressure Switches

A pressure switch located downstream of the superheater controls the electromatic valve on high pressure signals. A selector switch, located on the main control board, enables the operator to place this operation in the manual (open valve), or automatic mode.

2.2.5.4 Temperature Elements

Thermocouples for temperature measurements by computer are provided as follows:

- Boiler Steam Drum
- Superheater outlet upstream of attemperators
- Superheater inlet downstream of attemperators
- Cold reheat header ahead of attemperators
- Cold reheat downstream of attemperators
- Hot reheat outlet

Temperature indicators are provided on the main control board for steam temperature of the main steam, the turbine bypass, downstream of the desuperheater, and hot reheat outlets.

2.2.5.5 Temperature Recorders

Temperature recorders are provided on the main control switchboard for:

- Superheater inlet upstream of attemperators
- Hot reheat outlet

2.2.5.6 Test Thermowells

Thermowells, for the installation of test thermocouples and/or RTD's, are provided in the following locations:

- Superheater outlet stream of attemperators
- Superheater inlet downstream of attemperators
- Main steam line
- Each main stream turbine lead
- Cold reheat upstream of attemperators
- Cold reheat downstream of attemperators
- Reheater outlets
- Hot reheat to IP turbine

2.2.5.7 Temperature Transmitters

Temperature transmitters are provided at the following locations to transmit temperature signals as indicated:

- Main stream line for feedwater flow analog control system interlock.
- Superheater outlet for superheat steam temperature analog control system interlock.
- Combined reheater outlet for reheat steam temperature analog control system interlock.
- Turbine bypass downstream of the desuperheater to signal the main control room indicator, the computer, and alarm on high temperature.

2.2.5.8 Level Recorder

A level recorder is provided on the main control switchboard for drum level.

2.2.5.9 Level Indicators

Three level indicators are provided on the steam drum, for normal, high-level, and wide-range indication. A level indicator is provided on the main control switchboard for drum level indication.

2.2.5.10 Level Switches

Two level switches are provided on the cold reheat drain pot shown in SDD-011. One switch opens and closes the diaphragm-operated drain valve, which empties the drain pot to the condenser. The other level switch signals an alarm in the main control room for emergency high drain pot level, closes the reheat attemperator block valves, and closes the motor operated isolation valves in the extraction lines.

2.2.5.11 Level Transmitters

Three level transmitters (LT) are provided on the boiler drum.

One LT for computer input and for main control switchboard indication.

One LT for computer input, low-level alarm, high-level alarm, and low-low level trip.

One LT for feedwater flow analog control system and main control switchboard recorder.

2.2.5.12 Analysis Element

Provisions are made on the boiler drum, the superheater inlet, the main steam header, cold reheat header, and the hot reheat header for steam sampling.

2.2.5.13 Control Switches

<u>Function</u>	<u>Control Location</u>
Turbine Bypass & Condensate to Turbine Bypass Desuperheater	Main Control switchboard
Electromatic Valve (Manual/ auto/off)	Main control switchboard

2.2.5.14 Control Initiated by Operator

The control and instrument readouts for the system are located on the main control switchboard.

2.2.5.15 Equipment Vendor Supplied Systems

The operation and control of the HR/SR System is affected by many other systems. Several of these systems have a major portion of equipment supplied by the boiler and ESP manufacturers.

The equipment, piping, and controls for these systems are covered in the manufacturer's instruction books and certified drawings. Alarms, controls, and permissives associated with those systems are covered in this SDD only to the extent that these devices interface with other equipment in the main or reheat steam system, or signal the main control room for alarm or indication.

2.2.5.16 Flue Gas Control and Diagnostics

Special diagnostic equipment is required to allow for proper operation of the ETF as a first-of-a-kind system. The ETF HR/SR includes instruments and gas flow control devices similar to that listed in the Preliminary Design Report for the 20Mwt HR/SR unit being developed by Babcock and Wilcox for the U. S. Department of Energy under contract DE-AC-02-79CH10018.

3.0 SYSTEM PROTECTION AND SAFETY PRECAUTIONS

3.1 PROTECTIVE DEVICES

The major equipment operating limits and protective devices are described and included in System Design Descriptions noted in References 1 and 8.

The piping and valve design limits are equal to or greater than those of the connecting equipment. Therefore, no additional protective devices are required in the steam system. The major equipment have safety and relief valves or burst disks.

3.2 HAZARDS

The high-temperature flue-gas constituents include lethal amounts of carbon monoxide in the front end of the HR/SR. This flue gas is contained in the HR/SR system components primarily because the HR/SR operates at a slightly negative pressure. Consequently, the lethal gases can escape only if the induced draft fan at the base of the discharge stack fails to maintain the required negative pressure throughout the entire HR/SR. This can occur if either the fan drive fails or a structural collapse; the gas duct or the HR/SR blocks the flow of gas. Limited access to potentially hazardous areas, adequate ventilation in personnel access areas, and monitoring of HR/SR flue gas pressure with appropriate warning devices to indicate malfunction are precautions used to prevent injury to plant personnel.

No other special provision for the area around the HR/SR is required other than that normally provided in a conventional power plant.

All piping, valves, safety pressure-release valves and HR/SR components containing pressurized fluids will be designed to meet the requirements of the ASME codes, OSHA, and EPA regulations.

3.3 PRECAUTIONS

Conventional boiler design practice is used. This includes exercising all precautions normally taken in such designs to prevent serious damage to equipment or injury to personnel in the event of malfunction or failure of equipment.

The problems of turbine induction water damage and boiler/turbine temperature mismatches are discussed in other System Design Descriptions and in manufacturer's instructions.

After periods of Boiler layup and prior to Boiler startup, all main steam system drain valves must be opened.

4.0 MODES OF OPERATION

4.1 STARTUP

Coordination of metal temperatures in the HR/SR, turbine, and main steam piping is of primary importance in order to limit thermal stresses. The temperature of the turbine prior to startup may be between ambient and/or rated temperature. The HR/SR can have a range of initial pressure and temperature conditions which affect the conditions of the steam supplied. Because of numerous startup conditions, general categories are covered:

startup,
normal operation, and
shutdown.

Any startup situation is preceded by first aligning the system for normal operation. This includes valve line-up, and the following:

1. Preboiler cycle cleanup to acceptable purity conditions.
2. Boiler filled and vented at startup drum level.
3. Systems operational for boiler feed, condensate, and circulating water.
4. Auxiliary steam operational for initial deaeration, turbine seals, and steam jets (if applicable).
5. Condenser vacuum established.
6. The temperature of the gas entering the secondary superheater and reheater is limited until these components have been boiled dry of accumulated condensate.
7. Necessary prewarming of turbine rotors, on turning gear, since the initial temperature of the steam available at the superheater outlet for rolling the turbine is about 600°F. This is done by introducing low temperature auxiliary steam through the turbine gland steam piping to reduce the mismatch between the temperature of the turbine and the main steam supply.
8. The HR/SR temperature is established by operating the MHD Power Train combustor on oil. When boiler pressure exceeds auxiliary steam pressure the main steam flow is increased.
9. After MHD Power Train firing is initiated, the increasing boiler steam-drum temperature begins to produce steam. This steam is used to replace auxiliary steam for deaeration purposes. At approximately

600°F drum metal temperature, firing is maintained at temperature for 10 percent steam flow. Gas temperatures into the reheater section are monitored during this operation. The reheater gas temperatures must be maintained below the manufacturer's limits since there is no cooling flow in the reheater prior to initial turbine roll.

10. During boiler warmup operation, boiler blowdown is monitored to achieve acceptable solids concentration levels, and all steam piping are drained when warmed.
11. When main steam pressure reaches 200 psig minimum, the stop-valve by-passes are opened to prewarm the HP turbine casing, to further reduce turbine thermal stresses. This occurs while the turbine is on turning gear. Throughout the turbine prewarming operation, turbine metal temperatures are monitored and maintained according to the limits set by the turbine manufacturer.

4.2 NORMAL OPERATION

The normal load range of the HR/SR System is categorized as base load with part-load operation between 75 and 100 percent. Should the unit be operated below this level, administrative action provided would ensure that drain valves would open at 35 percent and lower load ratings. Also the Steam Bypass System may be activated at 50 percent or lower steam flow to the main turbine. The system is capable of operating satisfactorily and with no special operator action in the event of load change on the unit. During normal operation, the system is controlled and monitored from the plant control room.

4.3 SHUTDOWN

For operator-initiated shutdown, the unit is brought down to minimum load, and turbine is tripped. The electromatic valve may be used for venting. This is done by selecting the "Manual" position on the control room selector switch.

During the shutdown process, the main steam and reheat startup drains must be opened to drain all moisture from the steam lines. (In a normal, controlled shutdown the steam line drain valves open at about 15 percent turbine-generator load. No other operator action is required.) On a turbine-generator trip the stop valves in the steam leads and the non-return valves in the extraction lines close automatically. Operator attention is required to confirm operation and status of these valves.

During periods of shutdown, the HR/SR and main steam piping should be filled with nitrogen. (This reduces the formation of corrosion products which can cause increased maintenance problems.)

4.4 SPECIAL OR INFREQUENT OPERATION

Operation below 75 percent load on the steam turbine-generator is a transient condition. Procedures must be established for the facility control room operation utilizing the Steam Bypass System, reducing load to 50 percent, or to a controlled shutdown mode. Below 50 percent load the unit may proceed to a controlled shutdown mode, according to the judgement of the operators.

The majority of the auxiliary equipment is redundant or can be bypassed if problems develop. If bypassed equipment upsets the performance of the unit or tends to degrade the life of other apparatus, then operation of the system must be controlled to either reduce turbine-generator load, or go into a shutdown mode.

5.0 MAINTENANCE

5.1 SURVEILLANCE AND PERFORMANCE MONITORING

A facility control room computer system monitors significant data points in the HR/SR and the Main and Reheat Steam Systems to parallel the automatic controls. This computer system provides plant operating personnel with any off-design performance or operating data. Periodic calibration and maintenance is performed on all analog and digital instrumentation to verify computer readout.

5.2 INSERVICE INSPECTION

The Steam Drum, Radiant Boiler, Superheater, Reheater, ITOH, Electrostatic Precipitator and all piping, valves, controls, gauges, pipe supports, etc., are inspected periodically during system operation to verify proper equipment condition and operation.

5.3 PREVENTIVE MAINTENANCE

Maintenance is scheduled through computerized records. Part replacement is scheduled during a plant planned shutdown near the end of the part's recommended life cycle.

5.4 CORRECTIVE MAINTENANCE

5.4.1 Manufacturer's Instructions

A complete file of instruction books is available at the plant to guide the plant personnel in maintenance and overhaul of any pieces of equipment. If necessary, a representative of the manufacturer can be present to supervise the overhaul or replacement of plant equipment.

5.4.2 Spare-Parts Inventory

The manufacturers supply lists of recommended spare parts. Critical parts are kept in inventory at the plant. Complex parts requiring long lead time for delivery are included in the plant inventory.

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5.0 MAINTENANCE

5.1 SURVEILLANCE AND PERFORMANCE MONITORING **MHD-ETP PROJECT**

SYSTEM DESIGN DESCRIPTION

A facility control room computer system monitors significant data points on the HR/SR and the Main and Reheat Steam Systems to parallel the automatic controls. This computer system ~~is used to monitor the system~~ **HEAT-RECOVERY/SEED-RECOVERY SYSTEM** with any off-design performance or operating data. Periodic calibration and maintenance is performed on all analog and **APPENDIX A** instrumentation to verify computer readout.

REFERENCE DOCUMENTS

5.2 INSERVICE INSPECTION

REFERENCE DOCUMENTS - ATTACHED

The Steam Generator, Reheater, ITOH, Electrostatic Precipitator and all piping, valves, controls, gauges, pipe supports, etc. are inspected periodically during system operation to verify proper equipment condition. ^{None}

REFERENCE DOCUMENTS - NOT ATTACHED

5.3 PREVENTIVE MAINTENANCE
Reports

Maintenance is scheduled on computerized records. Part reports are scheduled during the life cycle of the part and at the part recommended life cycle.

- 2) Im, K. H. and Chung, P. M., Particulate Deposition from Turbulent Parallel Streams, ANL/MHD-81-2, February 1981.

5.4 CORRECTION

5.4.1 Man

A complete file of plant personnel necessary to perform the overhaul

- 3) "Conceptual Design of a Heat Recovery and Seed Recovery Subsystem for Parametric Analysis of Open Cycle MHD for Potential Early Commercial MHD Power Plants," Final Report, May 8, 1980, prepared by Babcock & Wilcox for General Electric Company/NASA.

5.4.2 Spares

The maintenance records are kept in files for delivery

- 4) "Heat Recovery and Seed Recovery Development Project Scale Up to Large Size System Report," October 1, 1980, prepared by Babcock & Wilcox for the U. S. Department of Energy.
- 5) "Conceptual Design of a Heat Recovery and Seed Recovery Subsystem for Parametric Analysis of Open Cycle MHD for Potential Early Commercial MHD Power Plants (A 200 MW Design Scaled Down from an 1100 MW Design)," September 26, 1980, a report prepared by Babcock & Wilcox.
- 6) "Heat Recovery and Seed Recovery Development Project Conceptual System Design Description Report," prepared by Babcock & Wilcox for the U. S. Department of Energy, April 11, 1980.
- 7) "Engineering Test Facility Conceptual Design" Final Report prepared by AVCO Everett Research Laboratory, Inc., for the U. S. Department of Energy, June 1978.
- 8) SDD-011: Main and Reheat Steam System
- 9) SDD-801: Electrical Load System

continued -

Fluid System Diagrams

Diagram Number

Main and Reheat Steam
Extraction Steam
Auxiliary Steam
Boiler Feedwater

8270-1-501-302-011
8270-1-503-302-041
8270-1-507-302-051
8270-1-521-302-081

Other Diagrams

System Heat and Mass Balance
MHD Building Section
Heat Recovery Seed Recovery Building
Section
Electrical Load One Line Diagram
480 V Power

8270-1-540-314-001, Rev. 0
8270-1-300-010-002, Rev. 0
8270-1-300-010-003, Rev. 0
8270-1-802-206-003, Rev. 0

SYSTEM DESIGN DESCRIPTION

SDD-505

INVERTER SYSTEM

FOR

MAGNETOHYDRODYNAMICS

ENGINEERING TEST FACILITY

CONCEPTUAL DESIGN - 200 MWe POWER PLANT

Kenneth G. Grieder Sept 25, 1981
SYSTEM ENGINEER DATE

Donald M. Kauenzahn Sept. 25, 1981
REVIEWED DATE

Robert L. Lawik Sept. 25, 1981
APPROVED DATE

Revision: 1
Date: Sept. 25, 1981

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
INVERTER SYSTEM

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1.0 FUNCTION AND DESIGN REQUIREMENTS

This document presents a description of the Inverter System from the consolidated terminals of the power producing MHD generator to the ac Power Bus System as depicted on Drawing No. 8270-1-802-206-001. This document includes descriptions of system functions, interfaces with the electrical and cooling systems, equipment and space requirements, design criteria, component descriptions, operating modes, and safety and maintenance requirements.

1.1 FUNCTIONAL REQUIREMENTS

1.1.1 General

The Inverter System is designed to invert dc power taken from the powertrain consolidation network terminals (dc bus) into ac line frequency power which is then delivered to the 34.5 kV ac system bus. The Inverter System is designed to cope with ac line voltage transients from outside the system and with power channel voltage and current fluctuations. It is also designed to regulate the operating point voltage on each dc bus terminal. The Inverter System is designed to take the channel output from startup to shutdown and to accommodate any operating power level between 30 percent and 100 percent load.

The power converting system is controlled through firing angle control of individual bridge inverters, derived at the central computer in the plant main control room.

The inverter accepts unregulated, unfiltered dc electrical power from the MHD generator via the dc buses (see Figure 1 in Section 1.3.2.2), converts this power to fixed voltage, regulated, 60 hertz line frequency three phase ac, and delivers it to the ETF inverter output bus. It regulates the electrical power output of the power train according to the incoming dc bus power from the electrical consolidation network and generation control commands from the supervisory (facility) control system. It acts to control the dc bus voltages and currents by varying the instantaneous rate at which power is converted and delivered to the inverter bus. It acts within its capacity to maintain the dc bus conditions within the stated operational limits. It acts within its capacity to maintain conditions at the inverter output bus within normal limits. It protects the power train from external electrical disturbances by disconnecting itself from the inverter bus whenever the normal limits are exceeded for an indefinite period of time or whenever the inverter bus emergency limits are exceeded. It protects the other electrical systems within the ETF from disturbances caused by the power train by crowbarring the dc bus whenever the operational limits are exceeded or when commanded to do so by the supervisory control system or safety interlocks. It acts within its capacity to stabilize the power train. It acts within its capacity to stabilize the inverter bus.

1.1.2 Inverter Bus Normal Limits

The inverter delivers 3-phase ac electrical power to the inverter output bus and acts, within its capacity, to maintain these conditions within these normal limits:

<u>Conditions</u>	<u>Normal Limit Range</u>	
Normal rms voltage	34.5 kV	+ 5%
Variation of any line-to-line voltage from 3-phase average		+ 2%
Variation of any line-to-line neutral voltage from 3-phase average		+ 3%
Frequency	60 Hz	+ 0.5 Hz
Power Factor	0.95 leading to 0.80 lagging	
Harmonic voltage content		
-- any single harmonic	less than 1% of fundamental	
-- algebraic sum	less than 3% of fundamental	

1.1.3 Inverter Bus Emergency Limits

The following abnormal bus conditions will not cause failure of the inverter to deliver electrical power but may result in less than rated power delivery, an increase in harmonic content, or a decrease in power factor during the length of the disturbance:

Emergency steady state rms voltage	34.5 kV	+10%/-20%
Number of single and/or multi-phase faults on bus	6 max per month	
Maximum short-circuit current, one cycle	22,000 A at 34.5 kV single phase 22,000 A at 34.5 kV symmetrical 3-phase	
Fault duration	3 to 600 cycles	
Minimum period between faults	6 sec	
Automatic recovery following utility network fault	5 sec	
Lightning strikes		
--peak current	10,000 A	
--number components per strike	two	
--maximum surge-arrested voltage	18 kV (6 kV winding) 35 kV (12.47 kV winding) 95 kV (34.5 kV bus)	
Frequency deviation	-3 Hz to +1 Hz	
Max. transient voltage during breaker operation	80 kV (34.5 kV Breaker) 36 kV (12.47 kV breaker) 36 kV (6 kV breaker)	

1.1.4 DC Bus Normal Operation Limits

These are the normal limits for conditions within the power train dc bus. The inverter accepts electrical power from the dc bus under these conditions and acts within its capacity to maintain the inverter input bus normal limits:

<u>Conditions</u>	<u>Normal Limit Range</u>
DC Bus Voltage	
Minimum	50% of nominal voltage*
Peak	120% of nominal voltage*
Voltage Ripple (peak-to-peak)	10% of steady state value, maximum
Nominal voltages (See Figure 1, Section 1.3.2.2 are	29.8 kV; 24.2 kV; 18.2 kV; 12.5 kV; 4.8 kV
DC Bus Current, Continuous at 50% nominal** current minimum	
Nominal: 2,000 A for -29.8 kV to 0V. connection; 300 A for - 29.8 kV to -5.6 kV connection; 600 A for - 29.8 kV to -11.6 kV connection; 700 A for - 29.8 kV to - 17.3 kV connection; and 800 A for - 27.4 to -22.6 kV connection.	110% peak, sustained 20 min. or less (but not above 120% power, see Figure 1.)
Maximum duration of fault condition from inverter malfunction	100 milliseconds

In the event of an inverter malfunction, the inverter will first attempt to clear itself through corrective actions which do not interrupt the dc bus currents. If the malfunction persists, the inverter will initiate safe emergency turndown, unloading of the MHD generator, and then shut itself down forcing the inverter input dc bus current and inverter output ac bus current to zero.

1.2 SYSTEM INTERFACES

The dc terminals of the power converting bridges interface with the consolidation network output terminals. Power, up to the maximum designed level, is transferred from the MHD generator to the inverter.

Inverter System control is via low power level control wires between the power system control center and the inverter thyristor gating terminals. Since these gating terminals are at various voltage levels, suitable electrical isolation is provided between the control circuits and the actual control wires.

The 34.5 kV, 3 phase, 60 Hz power from the Inverter System interfaces with the ETF installation 138 kV substation through a 90 MVA, 34.5-138 kV step-up transformer up to the system rated capacity. The interface with the 138 kV substation is discussed in System Design Description SDD-801, "Electrical System".

The inverter subsystem interfaces with:

1. The electrical consolidation network through the dc bus connections at the input terminals as shown on Figure 1 in Section 1.3.2.2.
2. The 138 kV substation through the circuit breaker. The 138 kV substation is the electrical tie between the Inverter System, the turbine generator, the oxidant compressor motor startup transformer, the two station service transformers, and two utility company service entrances. This interface has been designated as the 138 kV substation interface. It is a seven-terminal connection as shown on Drawing No. 8270-1-802-206-001.
3. The supervisory (facility) control system through numerous coaxial cables and twisted pair signal connections which relay inverter status and bus condition information to the supervisory control system and generation control commands back to the inverter controller.
4. The MHD power train controller through twisted pair signal connections which convey inverter fault information.

The major components of the inverter subsystem include:

1. DC bus input switchgear (and dc interrupters)
2. DC input filters and smoothing reactors
3. Inverter bridges
4. Volt amp reactive (var) compensation (line commutation and capacitor banks)
5. Harmonic filters
6. Output transformer
7. AC switchgear
8. Protective devices (including breakers and surge suppressors)
9. Instrumentation and control transducers
10. Instrumentation and control signal processing (controller)
11. Remote and local control panels
12. Cooling system (forced air inclusive)

The inverter is located in a separate area at a considerable distance from the magnet but adjacent to the consolidation network. Leading into the inverter are pairs of solid copper busbars from the electrical consolidation network enclosure. Leading out of the 20 MW inverters are three separate legs, one for each inverter bus, which are also of solid construction. There are cables leading out from the 4 MW inverters.

Cooling

Provisions are made for heat removal from the dc interrupter and inverter bridges. Semiconductor components within the inverter will dissipate up to 2 MW, but are kept at a temperature of 85°C or less. The transformer requires cooling to dissipate up to 1 MW at 125°C or less. Forced air cooling is used.

Electrical Power

The inverter enclosure requires 125 or 240 volt, 3-phase, 60 Hz line service.

1.3 DESIGN CRITERIA

MHD channel electrodes are connected diagonally and subdivided into 5 operating segments of different voltages and currents. The major portion of the MHD power is extracted from connections at each end of the channel (59.6 MW) and the remainder is taken from 4 other segment connectors (30.77 MW) for a total of 90.37 MW.

Power output of the channel varies according to the mass flow of fuel, down to 30 percent of the nominal rating. Both voltage and current are proportionately reduced as fuel flow is reduced. The ETF design criteria specifies normal load reductions to 75 percent of rated power. However, the inverters have been designed to operate from 100 percent to 30 percent rated power to provide redundant capability.

1.3.1 Codes and Standards

Design criteria are in accordance with applicable codes, standards, regulations, and guides issued by governmental agencies, recognized standards organization, and the issuing contractor including the following:

1. American National Standards Institute (ANSI)
2. Institute of Electrical and Electronic Engineers (IEEE)
3. Instrument Society of America (ISA)
4. National Electric Code (NEC)
5. National Electrical Manufacturers' Association (NEMA)
6. National Fire Protection Association (NFPA)
7. Occupational Safety and Health Administration (OSHA)
8. Insulated Cable Engineers Association (ICEA)

1.3.2 Design Parameters

1.3.2.1 Line Commutated Inverter System

Current source, line commutated inverter units have been selected for the ETF because of the MHD generator voltage and current characteristics. To reduce complexity, simplify the design, and make maintenance simpler, the system employs only two inverter unit sizes, 20 MW and 4 MW. Three 20 MW units are ganged in series to take the main load; the auxiliary loads (makeup and bleed currents) are taken by fourteen 4 MW units arranged in series-parallel connections. The inverter unit arrangement is shown in Figure 1. The main load inverters operate at or near their rated MVA, while the 4 MW units generally operate at less-than-rated capacity. The fourteen 4 MW inverters are served by four 17 MVA transformers of identical design, while a single 105 MVA transformer serves the main load inverters.

Passive elements are employed to provide reactive power compensation. At reduced loads the power factor will decrease since reduced dc bus voltage increases var generation; however, since voltage and current will be reduced together during normal operation, the net lagging vars will remain roughly the same. Three banks of 30 MVA power factor correcting capacitors are used; they provide 126 Mvar of leading reactive power to compensate for the lagging vars produced through firing angle delay.

Harmonic cancelling and filtering is employed to ensure ac waveforms that will not cause harm to either the transmission line customers or other generators within the system. The first four characteristic harmonics (5th, 7th, 11th and 13th) are suppressed in the 20 MW inverter units by phasing them apart from each other at 20° intervals. For the 4 MW units, loads are balanced between delta and wye transformer windings so that the 5th and 7th harmonics are cancelled. In addition, resonant filters are provided on the inverter bus for the 5th, 7th, 11th, and 13th harmonics while a high-pass filter is used to remove the higher harmonics.

Various line and dc bus voltage safety factors are also built into the inverters. The dc voltage safety factor, namely the ratio of (rectified dc) line voltage to the (actual dc) input voltage, which includes the steady-state variations expected in these voltages plus a 20 percent dynamic change in the line in the event of a line fault or the clearing of surge arrestors, exceeds 1.76 in all units. The ratio of nominal thyristor blocking voltage to the nominal voltage is 3.52 or better in all units. Because of these large safety factors, the instantaneous loss of commutation in any one unit in a series string is not catastrophic; the remaining inverters have sufficient reserve voltage capability to allow the failed unit to be bypassed, cleared, and re-instated within a few cycles.

1.3.2.2 Inverter Unit Arrangement

Figure 1 indicates the connection arrangement of the inverter units. This arrangement can also be seen on Drawing No. 8270-1-802-206-001 "ETF Electrical One Line Diagram". As discussed in the previous section, the 4 MW units are, in general, not loaded to their full capacity but share a common design so that system cost is minimized.

2.0 DESIGN DESCRIPTION

The Inverter System equipment consists of interface equipment matching the consolidation network terminals, series reactors, protective circuit breakers, inverter bridges, commutated inverters, bypass circuits for each inverter, line transformers, harmonic filters, and capacitive reactance compensation for the inverters.

Control of the power flow originates at the central control point and interfaces with the Inverter System through gate control of power thyristors in the inverter bridges.

2.1 SUMMARY DESCRIPTION (Reference Drawing No. 82/0-1-802-206-001)

The MHD generator connections are arranged to provide one large block of power as if the channel were a single, diagonally connected power source. This power amounts to 2/3 of the output of the channel and, to reduce harmonic effects on the line, is inverted in three equivalent series 20 MW inverters with a common 105 MVA transformer. With the three 20 MW inverters, the series reactance between the inverters and the channel is reduced and, although harmonic content cannot be completely removed with a line commutated inverter, harmonics through the 11th and 13th are greatly reduced.

The remainder of the channel is served by a group of fourteen 4MW inverters of lesser voltage and current and a group of 4 smaller transformers (17 MVA each). The inverters are protected on the dc side with circuit breakers and on the ac high voltage side with circuit breakers and disconnects. The inverter transformers are protected on the 34.5 kV side with oil filled, outdoor circuit breakers.

Since the line commutated system produces reactive vars somewhat in proportion to the actual power transferred to the ac line, the transformers are sized for these vars and large capacitor banks must be furnished for reactive compensation. Capacitor banks are mounted near the transformers and are provided with suitable switchgear and protective equipment.

2.2 DETAILED DESCRIPTION

2.2.1 Major Equipment

2.2.1.1 20 MW Inverters

These inverters have a nominal capacity of 2,000 amperes and 10,000 volts. Three of them are used in series across the main output of the channel. Each inverter is fired at the same phase angle, a function of power level, and each inverter is controlled in unison with the other two inverters to reduce harmonics.

To keep the circuitry for this circuit simple, the gating control of the inverters is not tied to the extinction angle of the particular wave being presented to a phase, but comes from a master control which sets the angles

precisely by digital means. Since each thyristor in the large series string in each of the inverter legs is at a different potential, each one has separate isolation for its gating signal.

Since the current to be switched by the 20 MW inverters is 2,000 amperes, their cost is minimized by choosing thyristors large enough to switch all current in a single device without need for paralleling. The General Electric C753 or its equivalent is used.

The voltage rating of the thyristors in these line commutated inverters takes into account all occurrences that could happen on both the dc and the ac side of the inverter. Factors bring the transformer ratio up to a peak voltage of 1.76 times the nominal dc voltage. Some of the factors are needed to maintain a safe firing angle and some are to take care of the probability that the ac line voltage will dip and there will not be enough voltage to make the current transfer at the appointed time. These factors may be reduced slightly but keeping them high tends to give better reliability. A 2.0 factor is used to account for ac line transients. Thus the 2 factors, 1.76 for peak transformer voltage and 2.0 for transients multiply to give a factor of 3.52 times the nominal dc volts for the peak forward and peak inverse voltage on the thyristors. For example, if 3,600 volt thyristor units are used, 12 thyristors are required per leg of the full wave, 3 phase bridge.

2.2.1.2 4 MW Inverters

The 4 MW inverters have a nominal capacity of 800 amperes and 5 kV. Even though the highest current per inverter is only 800 amperes, the lower current units, 300 and 700 amperes are of the same construction for replacement purposes and because thyristors come in discrete sizes and in a better construction and higher quality for larger units. These inverters use, typically, the GE type C602 and have 7 series units with an extra place for an 8th unit for redundancy and rapid replacement.

Since many different currents and voltages are used with these inverters, pairs of nearly equal, or equal, inverters are connected to delta and wye transformer windings which phase them at 30 degrees apart and tend to eliminate the 5th and 7th harmonics.

2.2.1.3 105 MVA Transformer for 20 MW Inverters

When three line commutated inverters are connected into a single transformer at a 20° electrical phase angle from each other, the current harmonics produced by each are cancelled by the other two and there will only be harmonics due to small variations in the firing angles (due to differences in the commutation overlap caused by differences in leakage reactance of the windings feeding the inverters). Precise firing eliminates a large portion of these firing angle differences and, since these three inverters are in series and must have the same current, there is nearly perfect harmonic cancellation.

Since all three inverter bridge voltages are at different dc potential levels, there are no common windings. Therefore, the 20 MW inverters are each supplied with a separate phase winding on the same transformer. The windings have nearly the same leakage reactance (usually done by making their geometry equivalent), to help cancel harmonics.

The output of this transformer is suitable for direct connection to the 34.5 kV high voltage power output line. The voltage of each of the windings is high enough to overcome all of the adverse factors in terms of voltage and is such that with a 1.76 factor between peak voltage and dc nominal there are 12,445 volts line to line on each of the inverter windings. The total capacity of the transformer is 105 MVA. A standard voltage ratio of 34.5 - 12.47 kV is used for this 105 MVA transformer.

The transformer secondary insulation voltage is determined by the transformer secondary voltage floating on the consolidation voltage. In calculating the worst case transformer secondary voltage, it was assumed that the most negative inverter failed in each string, with the remaining inverters continuing to operate.

The 105 MVA transformer does not use taps to try to reduce the lagging power factor produced during the lower voltage (lower power) operation.

2.2.1.4 17 MVA Transformers for 4 MW Inverters

The interconnection of the 4 MW inverters to the channel is accomplished using a somewhat special group of transformers. Since 5 of the inverters are on a 300 ampere circuit, the transformers are wound with 8 windings sized for these inverters. The remainder of the windings are sized for the 700 ampere inverters, and the 800 ampere winding is serviced from two windings paralleled on one of the transformers. The individual transformers, of which there are 4, have a primary winding set for the 34.4 kV intermediate voltage and 17 MVA with a set of 4 secondary windings as follows:

- 1 Delta winding with 575 Amps at 6,000 volts (6MVA)
- 1 Delta winding with 250 Amps at 6,000 volts (2.6 MVA)
- 1 Wye winding with 575 Amps at 6,000 volts (6 MVA)
- 1 Wye winding with 250 Amps at 6,000 volts (2.6MVA)

Differences in inverter dc voltage levels are resolved by phase control of the individual inverters.

2.2.1.5 90 MVA Inverter Bus Transformer

MHD power to the 138 kV substation is delivered via the 34.5 kV to 138 kV step-up transformer. To maximize this unit's efficiency, its impedance is reduced from a standard 8 percent to 6-1/2 percent. Its base rating at 55°C temperature rise is 90 MVA without forced air cooling and 120 MVA with fan cooling employed. Based upon a 10,000 MVA fault at the substation, the three phase line fault current on the 34.5 kV bus is 20,354 A (symmetrical).

The 90 MVA transformer is located outdoors between the inverter building and the substation.

2.2.1.6 DC Filter Reactors

As used here, the line commutated inverter system is a current source system and must have an input reactance to keep the current substantially constant. Since the current at minimum load is brought down to approximately 50 percent nominal full load current, the operation is in continuous conduction down to this current level. The borderline between continuous and discontinuous conduction in a dc system occurs when the current reaches 0 at the bottom of the ripple. This is set as the minimum inductance point; all higher currents are in continuous conduction and will not go to zero; all currents below this point will go through zero at the bottom of the ripple.

The branch of the circuit with the three phased inverters taking 60 MW of the dc power has a relatively high frequency ripple which reduces the size of the needed series reactance to 1.5 mH (continuous conduction at half current). This reactance is of the iron core "swinging type" and is designed for 1.5 mH at full load current with a higher value at half current to prevent discontinuous conduction.

The smaller inverters do not have as much ripple on their current since they are phased at 30 degrees apart. For the single inverter, there is no other inverter to share its current so it must have enough inductance in its circuit to keep it in conduction for 30°. These inductances are of the swinging choke type and are about twice the minimum figure at half current.

<u>Inverter Group</u>	<u>Required Inductance</u>
5 - 300 ampere inverters in series	min. 21.0 mH
4 - 600 ampere inverters in series	min. 8.0 mH
3 - 700 ampere inverters in series	min. 4.7 mH
2 - 800 ampere inverters in parallel	min. 6.0 mH
3 - 2,000 ampere inverters in series	min. 1.5 mH

2.2.1.7 Reactive Power Compensation

The general philosophy followed in this system design is to ignore the reactive power generated by the inverters and to compensate for it on the ac side. This approach is used to keep the design as simple and repetitious as possible. In addition, the large bank of capacitors makes a low resistance sink for high frequency currents, reducing the possibility of the high frequency currents being propagated throughout the system.

Part of the reactive compensation comes from the harmonic filter units, which are tuned to a particular frequency, and the remainder through the straight capacitor banks. It is necessary to have small 5th and 7th filters and small 11th and 13th filters plus a filter to catch the higher harmonics, in addition to setting up the inverters to cancel many of the harmonics. As the inverters are phase shifted to reduce the output power, the harmonic content of the output will increase even though a smaller amount of power is delivered to the system.

With an output power of 90 MW and a factor of 1.76 between dc volts and peak ac voltage, 130 MVAR of leading reactive power is provided.

Part of the 130 MVAR comes from the filter banks which carry leading 60 Hz reactive power as well as currents at their tuned frequency. The remainder of the capacitors are divided into three banks. These capacitors are brought on the line through 34.5 kV oil circuit breakers.

2.2.1.8 Harmonic Filters

Harmonics are cancelled by the three 20 MW inverter phasing system and by balancing the delta and wye windings in the summation of powers from the smaller inverters. Due to commutation overlap and differences in leakage reactance winding-to-winding, the actual cancellation is incomplete. The harmonic filters are designed to pick up remaining harmonics and to keep the system within reasonable bounds if some of the inverters are not in operation.

The lower frequency harmonics cause the most trouble on the power line and are the highest in absolute magnitude. In terms of the total ac current, the normal maximum harmonic current will be the system current divided by harmonic order (n), where n is 5, 7, 11, 13, 17, 19, 23, 25, etc. Some of these harmonics are missing where harmonic cancellation is employed. Table 1 shows the harmonic and the harmonic currents at 60 MW for the 3 large inverter systems and 30 MW for the rest, assuming 1 MW unbalance between delta and wye in the smaller inverters.

TABLE 1

Harmonic Level on 34.5 kV Bus Without Effect of Harmonic Filters
(Fundamental Current is 2,650 Amperes, rms)

Harmonic	P.U. Theory*	60 MW Inv.	30 MW Inv.	1 MW Unbal	Total %
5	0.175	-	-	5.16 A	0.2
7	0.111	-	-	3.26 A	0.1
11	0.045	-	40 A	1.32 A	1.56
13	0.029	-	25.6 A	0.86 A	1.0
17	0.015	26.6 A	-	0.4 A	1.0
19	0.010	17.6 A	-	0.2 A	0.7
23	0.009	-	8.0 A	-	0.3
25	0.008	-	7.0 A	-	0.3

* EPRI EL 1627 Project 1024-1 Nov. 1980 "Study of Distribution System Surge and Harmonic Characteristics" Appendix E, Calculation of Inverter Harmonics."

Each of the filters for the four lower harmonics is set below the harmonic resonance point by 0.3 harmonic ratio to fundamental (4.7 for the 5th. etc.). The capacitors are sized so that harmonic current is a minor factor in their loading (8 MVAR per bank) and the reactors are to be wound as Maxwell coils. The Maxwell coil provides the most reactance for a given length of wire which is easily predictable. These coils are mounted in the switchyard with at least 3 coil diameters between them.

Three coils are required for each three phase filter. The coils are mounted in series with the capacitor banks. Table 2 gives dimensions of the reactors. The copper is sized at 333 amperes/square inch of conductor and it fills 40 percent of the winding space for each turn. The wire is standard size and the insulation is gauged on the basis of the voltages in the circuit.

TABLE 2

Harmonic Filter Physical Sizing of Reactance

Harmonic	$X_c = X_L$ (ohms)	60 Hz Capacitor (Mvar)	Series Reactance (mH)	Estimated Diameter (inches)	Wt. Copper (lbs)	Tot. Wt. (est.) (lbs)
4.7	62.25	12.2	17.9	51.4	2,570	3,200
6.7	44.35	10.7	8.8	44.6	1,679	2,000
10.7	27.75	8.6	3.4	37.	958	1,200
12.7	23.4	8.5	2.4	34.5	777	1,000
16.7	35.6	4.1	2.7	27.2	381	500

The 4.1 MVAR reactors are for the 16.7th harmonic and high pass filter.

Each of the filter banks will be connected to the 34.5 kV by means of a 34.5 kV, 1200 A rated standard oil circuit breaker.

The high pass filter is designed to remove a considerable part of the harmonics at high end frequencies. It is designed to include the next higher characteristic harmonic than the one having the fixed frequency tuned filter. To broaden its range, it is built with a lower impedance level (Q) (more losses) than the fixed frequency filters.

The 4.1 MVAR capacitor bank for the high pass filter is chosen so that harmonic currents are a minor part of the current capability of the capacitors selected, so that they can be the same as the main bank of power factor correcting capacitors, thus reducing capacitor spares inventory.

The resonant frequency of the high pass filter is chosen at 16.7 times 60 Hz so that it is not in actual resonance with the 17th harmonic (which is quite large). The resistor, which reduces the Q of the circuit permitting it to cover a wider range of harmonics, is paralleled to the inductance on the basis that the 60 Hz impedance of the inductance is low and only the higher harmonic voltages will appear across the reactor. On the basis of a Q of 30, this resistor is 550 ohms. Each phase has a loss of about 1 kW and the resistor is sized to give a safety factor of 4 for this circuit element.

In the event that an inverter is not operating and cancelling harmonics, the various harmonic filters will see an added load. Since this part of the circuit is located outside in the substation area, the equipment supplied is amply designed physically to withstand the over voltage and currents caused by operation without full inverters.

2.2.1.9 Inverter Bypass Circuits

The inverter bypass consists of a string of thyristors capable of carrying the full dc inverter bridge current. In the event of a shoot-through of the inverter, the bypass is activated by gating its thyristors on with a pulse. Current flows through the bypass until the phasing of the inverter is advanced so that the inverter becomes a rectifier. At this point the rectifier is capable of diverting current away from the bypass and into the inverter acting as a rectifier. Once current stops on the bypass circuit, the thyristors regain control and voltage is held off. The rectifier, in the meantime, is phased back until it becomes an inverter and again takes its share of the load.

The bypass thyristors have to carry the entire dc current of the bridge for a short period of time. It is highly desirable that bypass thyristors be capable of carrying the whole current in one thyristor. General Electric Company C782, 2,400 volt thyristors are used. The means for grading the voltage between thyristors in the series string is similar to that used in grading the voltages along the series thyristor strings in the legs of the inverter bridges.

The smaller inverters are also be equipped with bypass circuits. In these cases, the large thyristors of the type used in the 20 MW inverter have enough current capacity and are used in the same series number that is used in the small inverter legs.

2.2.1.10 Inverter AC Circuit Breakers

Each inverter bridge is provided with a circuit breaker to disconnect it from the ac line in the event of a problem within the inverter. For the most part, the problems are temporary loss of voltage capability due to failure to commutate. If this is the case, the inverter will again be functional after voltage is reapplied and the inverter has gone through the regaining current control from the bypass circuit.

The protection for the transformers and the capacitors (harmonic filters and power factor correction) are 34.5 kV oil circuit breakers. The 120 MVA current rating of the 90 MVA MHD transformer is 2,008 A at 34.5 kV. Therefore, 2,000 A oil circuit breakers (O.C.B.) are selected for the 105 MVA inverter transformer protection and the 90 MVA MHD ac output transformer protection. (This is the maximum standard current rating for a 34.5 kV oil circuit breaker). The remaining O.C.B.'s are rated at 1,200 A which is the minimum standard rating available for a 34.5 kV oil circuit breaker.

The 34.5 kV, 1,200 ampere O.C.P.'s have a symmetrical interrupting current rating of 22,000 A at 38 kV (also rated at 24,200 A at 34.5 kV).

The criteria for selecting the MHD inverter ac bus voltage is focused on fulfilling all technical requirements at a minimum cost. Standard equipment is selected to keep the cost to a minimum. Also, the bus voltage is kept as low as possible without increasing the current beyond standard equipment ratings. Furthermore, the equipment is rated to withstand the maximum fault possible. Selection of a 34.5 kV bus voltage and the 120 MVA maximum transformer output sets the maximum current at 2,000 A. The 34.5 kV bus voltage is the lowest voltage rating to have a standard interrupting rating high enough for the fault current available from the 138 kV substation.

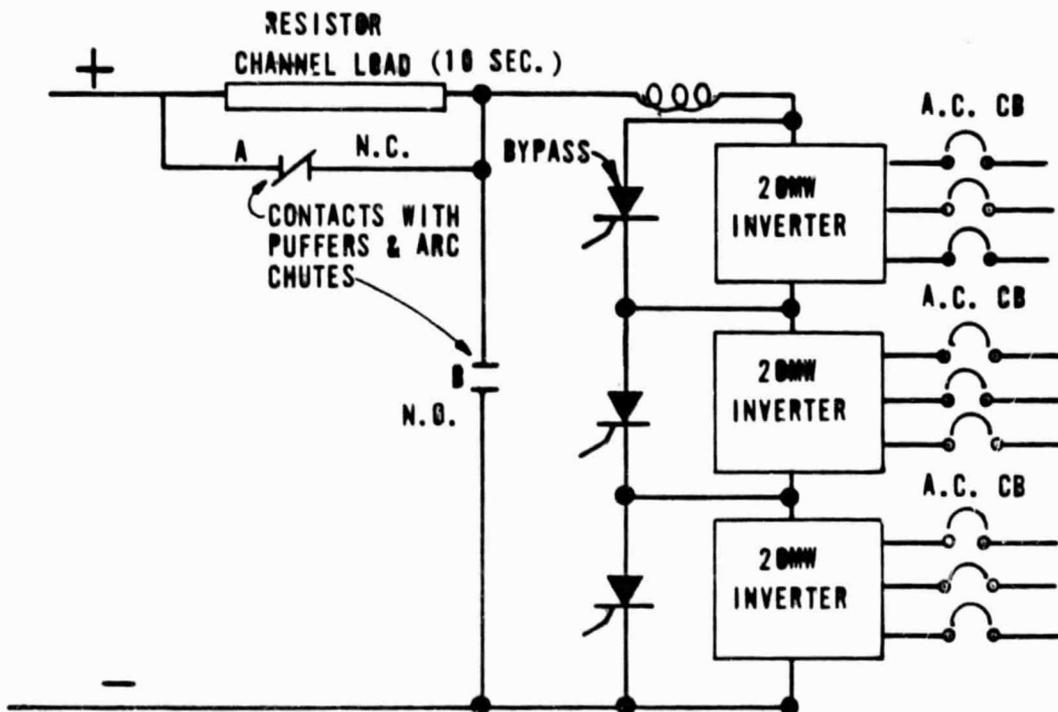
2.2.1.11 DC Resistor Loads, Interruption, and Crowbarring

A brute force system is used to dissipate the dc smoothing reactor current in the event of an inverter malfunction and to provide an alternate path for generator current to flow until the fault can be cleared or the generator unloaded. Resistor load banks and puffer type sulfur hexafluoride (SF_6) circuit breakers are used as shown in Figures 2 and 3. The purpose of each load bank is to act as the generator load for a ten-second period, if and when more than one inverter unit in a particular string fails. The sequence of this operation, initiated when the inverter string loses control and becomes shorted, is shown on Figures 2 and 3.

The three 20 MW inverters use a ten second resistor rated at 30 kV and 2,000 A. Breakers A and B operate as described in Figure 2. If fault clearing cannot be completed within 5 seconds, emergency generator turndown is initiated so that the generator and its power conditioning equipment is unloaded and de-energized within the remaining 5 second period.

Each of the 4 MW inverter strings uses a similar system of SF_6 puffer type circuit breaker except that, as shown in Figure 3, an additional breaker (Breaker C) is used. This breaker opens the inverter string at the end of 10 seconds, if the fault has not been cleared. The generator continues to operate in spite of the failure of any one particular string, but will revert to emergency turndown if additional strings, or the main load inverter, malfunction.

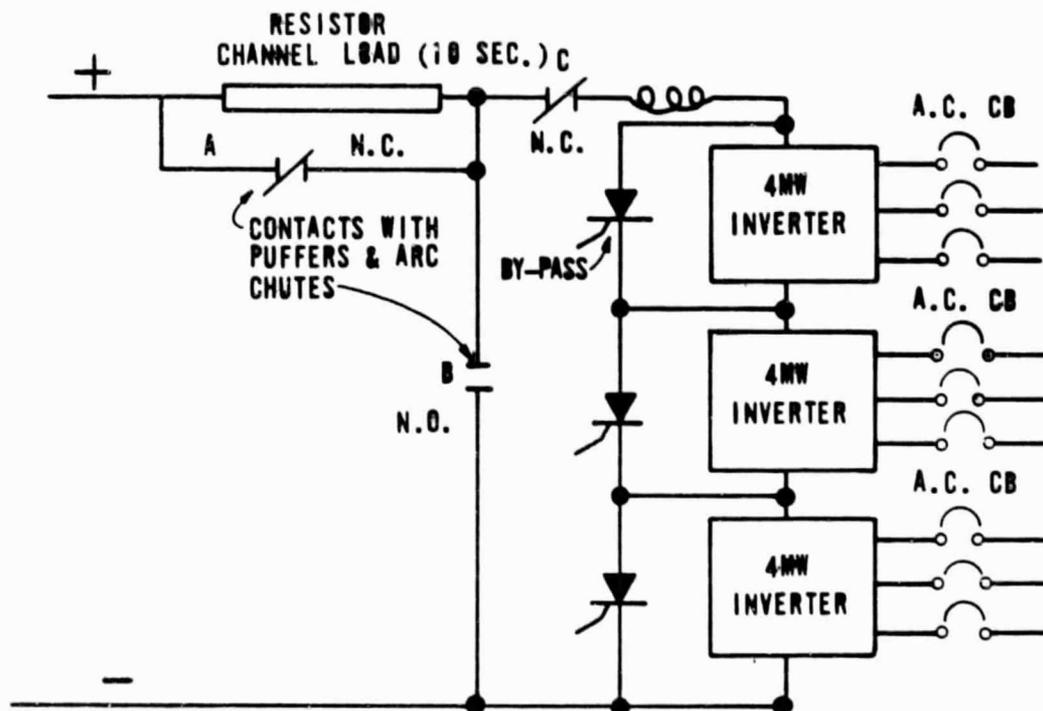
FIGURE 2
BRUTE FORCE SYSTEM TO REMOVE
CURRENT FROM THE 20MW INVERTER STRING
(SEE DWG. 8270-1-802-206-001)



SEQUENCE:

1. OPEN A.C. CB TO EACH OF THE 3 INVERTERS
2. OPEN A UNTIL CHANNEL LOADS SHIFTS INTO THE RESISTOR.
3. CLOSE B, RELIEVING INTERNAL PATHS IN THE INVERTERS OR BYPASS UNITS.
4. OPEN B AT END OF 5 SECONDS.
5. IF TROUBLE PERSISTS, SHUT DOWN CHANNEL WITHIN AN ADDITIONAL 5 SECONDS.

FIGURE 3
BRUTE FORCE SYSTEM TO REMOVE
CURRENT FROM EACH STRING OF 4MW INVERTERS
(SEE DWG. 8270-1-802-206-001)



SEQUENCE:

1. OPEN A.C. CB TO EACH OF THE 3 INVERTERS
2. OPEN A UNTIL CHANNEL LOADS SHIFTS INTO THE RESISTOR.
3. CLOSE B, RELIEVING INTERNAL PATHS IN THE INVERTERS OR BYPASS UNITS.
4. OPEN B AT END OF 5 SECONDS.
5. IF TROUBLE PERSISTS OPEN C WITHIN AN ADDITIONAL 5 SECONDS TO ALLOW CHANNEL TO OPERATE ON THE REMAINING INVERTER STRINGS.

2.2.1.12 Detailed Design and Location

Inverter Cooling

Forced air and convection cooling is employed thus allowing easy access to components when the power is off. Cooling for individual thyristors and their heat sinks is provided by a plenum chamber of moderate volume, supplied with pressurized air. Each thyristor and heat sink takes its air from a calibrated leak (opening) in the plenum chamber, which ensures uniform cooling for each assembly. Cooling air supply to each plenum is fed through ducting network, provided by the facility.

20 MW Inverters

Each individual thyristor is mounted on an aluminum heat sink with its own clamp. Assembly dimensions are approximately 15 in. by 15 in. by 18 in. long. Gating and grading resistor assemblies are also mounted to this module, in addition to the heat sink. Module size is 24 in. by 24 in. by 36 in. wide. Stacking the 12 modules needed for the applied voltage yields a stack that is 24 feet high. Rather than use a stack 24 feet high, the stack is broken into 2 sections of 12 feet each. Since each inverter bridge contains six legs there are 12 stacks of modules in all for a single 20 MW inverter. The stacks are arranged in groups of six, with a common plenum chamber between the backs of the six stacks, and warm air exiting from the front face of the modules. Inverter module access is entirely through the front face; a portable platform is provided for service personnel to gain entry for maintenance and replacement.

No supplementary mechanical lifting machinery is required for inverter service since all component parts are light enough to be removed and carried by hand.

The bypass thyristors are mounted in groups of stacks adjacent to the inverter stacks in a manner similar to the inverter bridge thyristors.

DC smoothing reactors are mounted at the end of each inverter bay. The output (ac) leads exit the bay via solid bus bars to the 105 MVA transformer which is located in the switchyard.

4 MW Inverters

Each 4 MW inverter is made up of six legs of individual modules which contain thyristor assemblies, grading resistors, gating, and protective circuits. The number of modules per leg is determined by the working dc voltage. The back of each heat sink face rests against a plenum chamber which is drilled to meter cooling air as previously discussed. Each module is approximately 18 in. by 18 in. by 18 in. high. They are stacked on an insulated platform which also contains the dc smoothing reactor. The ac breakers and 17 MVA transformers are located in the switchyard.

Bus Work and Interconnects

The dc currents to the inverter system are presented in seven copper bus bars of appropriate size for the currents delivered. This bus work is brought up to a height suitable to clear the inverter bay equipment and then drops vertically into each individual inverter unit. Once inside the individual inverter bay, the currents will pass through smoothing reactors before reaching the bridges. Reactors are air gap iron core type. Input disconnect, diversion, and isolation switching is located near the top of each bay between the buses and reactors.

The ac leads from the inverters exit via the top of each inverter stack and are routed to the vacuum breakers. The leads then pass through the walls of the inverter building to the transformers.

Gating and control leads are brought to the inverters through conduit to the control room.

2.2.2 Piping and Valves

Inverters are forced air cooled and, therefore, no piping or valves will be used. Air cooling, instead of water cooling, increases operating reliability.

2.2.3 Electrical

Approximately 90 MW of dc power from the various electrical segments of the MHD generator have to be inverted to 60 Hz 3-phase ac. The apparatus to make this conversion is described in the prior sections.

Restrictions on the ac power may limit the system to providing less than 1 percent of any particular harmonic and less than 3 percent for the algebraic sum of the harmonics.

On the dc end, provision are made to remove the inverters from the channel in the event of a short circuit or the equivalent since the channel could be damaged.

Since the basic ETF system is a current source system, the input reactor absorbs any ripple from the channel or from its consolidating system. This makes the inverting system insensitive to almost any transient that occurs in the consolidating network.

2.2.4 Instruments, Controls and Alarms

2.2.4.1 General

The 34.5 kV bus which distributes power to and from the inverters, is a primary reference for phase and voltage of the power system. To provide redundancy for this signal, there are two potential transformers capable of bringing signals of voltage and frequency at this bus to the control room. These two signals are to be brought to a common control room to display the frequency and voltage at any instant on the bus for all of the inverters and

the system. This also includes filters and check points can also be monitored by checking these signals to keep the reference from reacting to any frequency other than 60 Hz or its near equivalent.

The line frequency signals supply a digital reference, corrected every 30° at the line frequency. This digital reference, plus set-in delays, provides the timing for firing signals on all of the inverters. Inasmuch as the operation of the system is well below the constant extinction angle point as used in HV dc transmission lines, the digital system provides firing points that are spaced equally in time and help to cancel harmonics.

The entire group of inverters, once adjusted for nominal conditions and in an efficient power range for the generator, are phase shifted forward and backward as a unit. The master controller adds 1° to the firing points of all inverters as a group.

The individual groups of inverters are provided with means to set their phase angle with a certain number of points ahead or behind the preplanned master point. This allows them to make up for voltages in the channel which are not expected and to compensate for transformer voltages that are too high or too low for the voltages actually found. (The transformers were specified without taps to adjust this factor, taking a small penalty in vars formed to keep the system simple and repetitive.) Firing angle with digital readout display provided for each inverter. If desired, this information can be stored in a computer data bank to record transient behaviors.

The inverter margin angle for this system is relatively large and has a considerable factor of safety. The chance of a fault occurring due to a line transient is reduced from that found in the HV dc line. Nevertheless, if a dip in line voltage should occur during a firing pulse, and if it should last long enough to keep the thyristor from firing, a shoot-through could result.

To minimize the possibility of a shoot-through, the length of the firing pulse is set between 250 and 500 msec. This period is generally long enough to get the thyristor fired in spite of the dip. If it does not fire, a later phase firing will often regain control of the current and the system will continue running. This capability is improved by the inductance of the series reactor which keeps the current from rising too far before the next firing point occurs.

It is necessary to know which inverter is out of control in the event control of any single inverter is lost. Loss of control can be determined for a particular inverter by noticing its collapse in voltage. This collapse in voltage is entered into a computing network which changes the signal balance between the failed inverter and the others in series with it. This will allow the failed inverter to go to zero volts while the bypass for that inverter is switched into the circuit. The bypass diverts current from the faulted inverter until control is recovered. The inverter can then divert current out of the bypass and regain its previous position in the series inverter string. For each combination of operating and faulted inverters in a string, a particular program model resides in the computer to take care of any

particular situation. The computer program model designates which inverters are phased ahead and which are phased back, how fast and in what sequence. The initiating signal for this action is bridge dc voltage, suitably filtered and compared to other series bridges in the string.

The same inverter bridge voltage systems, plus a current signal, signifies that the entire string of inverters have lost control. The channel will be partly short circuited if this continues. In this case, the inverter must be separated from the channel and, if the fault is in the string of 3-20 MW inverters, the system will have to be shut down.

An emergency shutdown of the inverters results in the generator temporarily operating on fixed emergency resistance loads for a maximum of ten seconds. When this is the case, the inverters are brought back on line as a group with each sharing the resistor load, and with the resistor being dropped off when the inverter takes the load.

Dynamic control of the inverter bridge groups is accomplished by feedback control which adds or subtracts time to the firing signals in a manner appropriate with maintaining constant voltage or current as the control may designate. The execution of this control signal is digital but the speed and the pickup of the signal starts as an analog signal of voltage and current from some part of the channel. This signal is put into the computer to give the proper action signal.

Since it is necessary to monitor the total power produced by the channel after losses, current transformers and potential transformers are used on the high side of the 90 MVA step-up transformer. In the main control room, the basic data is shown in terms of MW and MVAR as well as displaying the actual voltages and currents.

The voltages and currents of the various segments of the channel are displayed and recorded in the computer data bank. This information will be held for a short time, then averaged, and then stored again. There is both a visual display of pertinent information and a stored data bank of information on the electrical system which helps to diagnose any troubles which may occur.

2.2.4.2 Diagnostics

The inverters consist of series thyristors in each leg with a voltage safety factor to prevent exceeding the ratings on transients. Failure of any one thyristor will not upset operation. Each module is equipped with a visual indication of whether the thyristor has failed to hold off voltage or not and, also, an indication showing that gate voltage was found at that position. These indicators fit into the visible fronts of the units and, since they are at high voltages above ground, are not normally carried to the control room. These indicators will be visually inspected on a predetermined time schedule depending upon how frequently faults occur.

2.2.4.3 Computer Control of Inverter System

Control of the inverter system arises through the time modulation of firing pulses to individual thyristors in the inverter bridges. These firing pulses originate, and are distributed from, an inverter controller unit which is located within a cabinet at an appropriate point inside the inverter building. This unit does not actually determine inverter firing angle but instead simply translates digital command information from the central computer to (time delay) firing pulses. The computer determines firing command and controls inverter system output on both the individual inverter units and as a sum of inverters. It controls the phasing of all inverters as a group and makes individual adjustments on each inverter bridge as needed. It provides a regulating position for inverter control such that generator voltage can be adjusted by varying the load, or inverter current varies to maintain a given generator voltage.

The computer acquires, processes, tabulates, and records inverter system data in addition to other system parameters. It provides information on the output of both the inverter and turbogenerator system and monitors voltage and current on a per phase basis. It senses faulty operation and provides a means of initiating corrective actions, including overload or fault tripping sequences to operate breakers and turndown the generator in case of such faults.

Power measuring functions are available to the central computer through current transformers on the 34.5 kV inverter bus and voltage taps.

2.2.4.4 Master Phase Reference, Line Synchronizing

The reference of line voltage phase is the primary reference for the entire output of the Inverter System. For this reason, data from the potential transformer is brought into the conditioning circuits and is filtered to keep harmonics from making check points come too soon or too late. Part of the problem is to make the circuits sensitive to sudden changes of phase such as might occur when a bank of power factor capacitors are switched in or out and yet not lose continuity if a line voltage transient occurs.

The system includes a reference oscillator whose frequency can be changed every 30° by a signal that combines the past six crossover points, weighs them, and decides whether to raise or lower the oscillator frequency. Raising the oscillator frequency tends to advance the phase of the reference while lowering will retard it.

In the event of a complete line failure at the inverter 34.5 kV bus, the frequency signal will remain as it was at the instant of failure and also will be connected into the power system master reference. With the rotating generator on line, there will be a voltage which will allow the inverter to feed the system when the outage occurs. In addition, there are ample leading vars to keep the system operating since a large number of capacitor banks are on line. If fuel can be reduced to where the system can be kept on in order to service local loads, the system has the capability to repair the full load as soon as voltage is restored. To be able to match this line frequency, the local Inverter System will have an input from the line voltage at the main

incoming breaker before the breaker is closed. Under certain conditions this line will become a reference which will be switched with the regular bus reference when the breaker is closed.

3.0 SYSTEM PROTECTION AND SAFETY PRECAUTIONS

3.1 PROTECTIVE DEVICES

All electrical equipment will be protected according to good design practice and the NEC.

The major equipment operating limits and protective devices are described and included in System Design Descriptions noted in Sections 1.2 and 2.2.2.

3.2 HAZARDS

No special personnel hazards are considered to exist in the Inverter System beyond those normally observed in conjunction with electrical systems.

The primary protection needed for a semiconductor power converter is voltage protection since the thyristors have little immunity to voltage transients. If a thyristor breaks over in either the forward or the reverse direction from a voltage spike, the device is usually damaged beyond further use. Usually such damage results in a short circuit which may damage other semiconductors in the circuit.

Individual thyristors are partly protected at their most sensitive point by the use of individual non-linear resistor type surge arresters. These are built into the individual thyristor modules in the inverter and provide the extra margin to keep the units working after a severe line transient.

Line transients and transients due to switching and faults in the electrical system are treated with surge arresters of the usual type. These surge arresters get rid of the bulk of the transient energy and make it possible for the smaller surge resistors to better protect the thyristors.

3.3 PRECAUTIONS

The requirements and recommendations for the prevention of electrical shock have been included in the system design and must be followed in the operation of the Inverter System.

4.0 MODES OF OPERATION

4.1 STARTUP

The steps to bring the channel to the temperature point necessary for coal ignition are described in Section 2.6.1. When the channel is up to the coal input point, there is an amount of heat going into the turbine boiler to provide starting and partial loading of the turbine. When the system is running smoothly in this manner, still without electrical output from the

channel, the inverter circuits are closed into the channel with the inverter phased for 50 percent nominal voltage. Seed is now introduced into the channel with an increase in fuel. The inverters start to pick up increasing power as the generator is brought to operating condition. The inverters are phased back as required to increase the power extraction. During this increase in MHD power level, the boiler/turbine system has been building from approximately half load to full load. This process will take 10 to 30 minutes to accomplish, from the point of first taking power through the inverter.

At the start of the inverting stage, the filter banks are brought on line, one at a time. Following this, the first of the power factor correcting capacitor banks are brought on and, as the current from the inverters increases, the remaining power factor correcting capacitor banks are brought on line. The current angle in the 34.5/138 kV step-up transformer is the criteria for bringing in more corrective capacitor banks. Another bank of 30 Mvar is brought in as power factor decreases to 0.8 lagging.

4.2 NORMAL OPERATION

The inverter is at normal operation when the channel has been brought up to full power and the ac line voltage limits are within ± 5 percent. The control does not have to be in a closed loop control mode, since major swings are not anticipated.

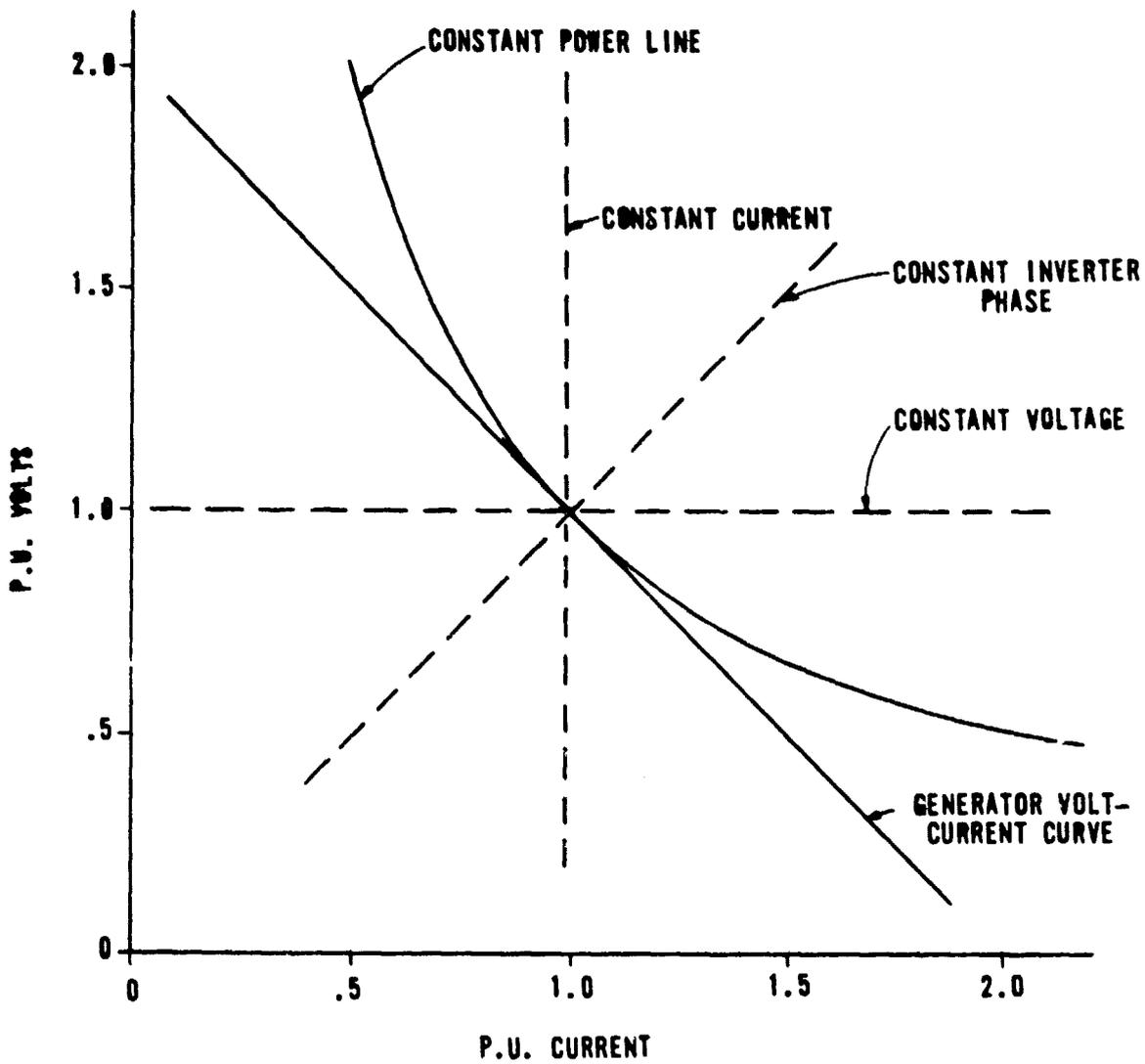
For long term operation, closed loop is preferable to open loop operation. When the channel is controlled on the basis of the overall dc voltage delivered to the three 20 MW inverters, the effect of an increase in channel power will be to increase the real power delivered. An increase in line voltage will not change the power delivered by the channel but it will change the power factor by increasing the production of lagging vars.

Manual control has been selected since a constant power line on the volt/current curve is essentially tangent to the volt/current line of the channel. The phase angle is essentially constant and this tends to cut the voltage-current line at right angles to improve stability as shown on Figure 4.

4.3 SHUTDOWN

The inverter power level is changed by either increasing or decreasing its voltage depending upon whether the system is operating at the peak power point or not. Since the inverter is set to regulate voltage, the voltage can be kept at a particular value and the fuel to the channel can be reduced. At some point the current will reach the minimum point at which the channel is to operate at that voltage. The inverter will then have to be phased forward to keep from losing load too fast. In the meantime, the turbine generator system is also losing load. At some point near 30 percent load, the seed and part of the fuel is reduced so that the inverter, though still connected to the line will drop out of conduction. At this point the fuel to the MHD generator is reduced to produce a normal shutdown of the turbine and alternator.

FIGURE 4
INVERTER LOAD CONTROL



4.4. SPECIAL OR INFREQUENT OPERATION

4.4.1 Operation With Failed 20 MW Inverter

Three 20 MW inverters are operated across the 29,800 volt channel in series. If any one of these inverters fails, the bypass circuit takes over and the inverter is brought back into the string again to take its normal role. If one of these inverters becomes damaged so that it will not invert, operation will be continued on the remaining inverters.

Operation with only two series inverters is not considered normal, but with reduced voltages, operation at partial load can be continued. The inverters have two useable safety factors which will allow them to take somewhat higher than normal voltage. A factor of 1.15 is used to cover transient dc voltage operation for higher than normal channel voltage.

Operation at 77 percent nominal voltage can be sustained with two inverters in series. If the current at this point can be brought to full load current or 10 percent above, between 77 percent and 85 percent power level can be reached on this pair of inverters alone. Since the other inverters on the channel can be loaded somewhat more heavily, it will be possible to bring the power level up to 90 percent or 95 percent.

There is imperfect cancellation of harmonics when only two of three inverters are operating in a phased group. The level of harmonics will rise to approximately 7 to 8 percent for the 5th harmonic and the harmonic filters will have to operate at higher current levels.

The 5th and 7th harmonic families are reduced by utilizing the individual inverter phase shifting ability and adjusting the two inverters so that one is firing 5° ahead of its normal point and the other 5° behind, or in such a way that the net difference in firing point between them is but 30° instead of 20°. In this circumstance, the blocks of current flow fulfill the requirement for cancellation since this is a current source inverter. The dc voltage across the inverters change individually so that one inverter takes more voltage (4 percent) than the mean voltage, and the other less. This reduces the total voltage with the same safety factor conditions as in the unshifted case.

A second voltage safety factor of 1.2 is used for dynamic ac voltage transients, which compromises the ability of the inverter to commute. This safety factor could be encroached upon depending upon the nature of the need to maintain a higher output from the system. The effect of reducing this margin is to increase the probability of being tripped off by a line transient over the normal probability.

4.4.2 Operation With Failed 4 MW Inverter Units

In the string of five 300 ampere inverters, there is an ample safety factor to allow the loss of one inverter while continuing operation.

The four inverter string has enough capability to make up nearly the entire voltage.

In the three inverter string, the problem of voltage capability is similar to that of the 20 MW inverters but it is handled by increasing the current in the string to hold the voltage down. Again, the harmonics are small because of the small total amount of power involved.

It is possible for operation to continue when either one or both of the 800 ampere loop parallel inverters fail. If one fails, the other inverter can take the full load. If both fail, the remaining generating loops have the capacity to take the excess current.

4.4.3 System Faults

4.4.3.1 Inverter Fault

There is always the possibility of a shoot-through simultaneously on all inverters. This might occur as a result of a sudden short circuit on the ac line which would hold the line voltage down long enough to cause a shoot-through in all units. Even opening of a tie breaker somewhere in the system might cause it. If this happens, there is a sudden loss of power being delivered to the power system. A short circuiting of the channel terminals would result. The inverters are sized to take this short circuit current for a short time after which the bypass units come in. The bypass units are sized to take the worst case generator short circuit.

The effect upon the channel itself of this short circuit current is a redistribution of losses within the channel and a probable increase of pressure at the end of the channel and at the inlet of the HR/SR. It is necessary to monitor the channel pressure at this point and provide a means to avoid or absorb the excess energy.

4.4.3.2 ac Circuit Breaker Trip and Failure to Reclose

When the system is operating at full load and for some abnormal reason, the circuit breaker opens on the main inverter transformer primary, the following actions will take place:

First, the other inverters will try to pick up load if the 60 MW inverters are removed. Probably this pickup of load will be limited to a maximum of 20 to 30 percent more current if the phasing is kept constant. The inverters should be set to phase back so that they are carrying no more than normal currents. At the same time, it is necessary to reduce the fuel and oxidant feed because gas temperature in the HR/SR will tend to increase. There will also be a pressure wave of hot gas entering the HR/SR as a result of removing the back pressure generated by the electrical output of the generator.

The control system prevents the hot gas pressure wave from appearing at the outlet of the channel by immediately switching the channel output to a nearly equal resistive load during the reduction of the fuel and oxidant input. The loss of the inverting action triggers the secondary load system very quickly so that the pressure wave is reduced.

5.0 MAINTENANCE

5.1 SURVEILLANCE AND PERFORMANCE MONITORING

An in-house computer system will monitor significant data points in the Inverter System to parallel the automatic controls. This will alert plant operating personnel to any off-design performance or operation. Periodic calibration and maintenance shall be carried out on all analog and digital instrumentation to verify computer readout.

5.2 INSERVICE INSPECTION

All instruments, controls, meters, protective equipment, etc., shall be inspected periodically during system operation to ascertain that the subject equipment is operating properly.

5.3 PREVENTATIVE MAINTENANCE

Computerized record keeping will be instituted to alert the operators that certain pieces of apparatus need periodic overhaul, recalibration, etc., depending on the recommendations of the equipment manufacturer. In general, the part will be replaced during planned shutdown if it is near the end of its recommended life cycle.

5.4 CORRECTIVE MAINTENANCE

5.4.1 Manufacturer's Instructions

A complete file of instruction books will be available at the plant to guide the plant personnel in maintenance and overhaul of any piece of equipment. If necessary, a representative of the manufacturer can be present to supervise the overhaul or replacement of plant equipment.

5.4.2 Spare Parts Inventory

The manufacturers will supply lists of recommended spare parts. Critical parts will be kept in inventory at the plant. Complex parts requiring long lead time for delivery will be included in the plant inventory.

MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION

INVERTER SYSTEM

APPENDIX "A"

REFERENCE DOCUMENTS

REFERENCE DOCUMENTS - ATTACHED

None

REFERENCE DOCUMENTS - NOT ATTACHED

System Design Description

Electrical System

Layout

Drawing No.

Plot Plan

8270-1-210-007-001

Inverter & Switchgear
Building - Plan

8270-1-810-002-001

Inverter & Switchgear
Building - Section

8270-1-810-002-002

Inverter & Switchgear
Building - Plan

8270-1-810-002-003

Electrical

Plant One Line

8270-1-802-206-001, Rev. 1

SYSTEM DESIGN DESCRIPTION

SDD-701

HEATING, VENTILATING AND AIR CONDITIONING SYSTEM

FOR

MAGNETOHYDRODYNAMICS

ENGINEERING TEST FACILITY

CONCEPTUAL DESIGN - 200 MWe POWER PLANT

FLUID SYSTEM DIAGRAMS NOS. 8270-1-721-902-001, 8270-1-722-902-001

Fred Z. Burlovski 3/20/81
SYSTEM ENGINEER DATE

Robert J. Evers 3/25/81
REVIEWED DATE

W. C. Sullivan 3/27/81
APPROVED DATE

Revision: 1
Date: September 25, 1981

Approved: W. C. Sullivan

**MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
HEATING, VENTILATING AND AIR CONDITIONING SYSTEM**

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1.0 FUNCTION AND DESIGN REQUIREMENTS

This document presents a description of the Heating Ventilating and Air Conditioning System as depicted on attached Flow Diagrams 8270-1-721-902-001 and 8270-1-722-902-001. The document includes descriptions of system functions, interfaces with other systems, equipment and piping requirements, design criteria, description of components, operating modes and safety and maintenance requirements.

1.1 FUNCTIONAL REQUIREMENTS

Functional requirements for winter heating are to provide freeze protection, prevent surface condensation, allow for maintenance and service during production down-time and provide a comfortable environment to the occupants. Functional requirements for ventilation are to prevent equipment overheating, dilute odors and provide effective temperature cooling for the workers in hot work areas.

Functional requirements for air conditioning are to provide controlled environment for temperature and humidity sensitive equipment to sustain equipment performance as well as workers' productivity and comfort.

Major components of the Heating, Ventilating and Air Conditioning (HVAC) System are as follows:

1. Centrifugal water chillers for offices, control room and inverter building.
2. Centrifugal water chillers for coal system control building.
3. Water chiller for warehouse offices.
4. Exhaust and makeup fans and fan units.
5. Steam and electric unit heaters.
6. Package oil fired boiler for warehouse heating and hot water.
7. Package oil fired boiler for coal system control building heating and hot water.
8. Perimeter hot water baseboard heaters.
9. Induced draft cooling tower to provide chiller condensers heat rejection.
10. Air cooled condensers for chiller units.
11. Condensate return units for pumping condensate to auxiliary system deaerator.
12. Steam-hot water converters, hot water storage tanks, heating hot water coils and condensate drain tanks with pumps for pumping condensate to auxiliary system deaerator.

1.2 SYSTEM INTERFACES

Major systems which interface with the HVAC Systems are as follows:

1. Auxiliary Steam System
2. Fuel Oil System
3. Electrical

1.3 DESIGN CRITERIA

Design criteria include buildings winter heat losses, building solar heat gain, buildings heat losses and gain due to infiltration, buildings heat gain due to internal heat loads from equipment and people.

Design criteria also include fluid flow requirements, pressure temperature ratings and limits to be used in the selection of equipment and components.

Design criteria also include noise abatement and control, air filtration and purification.

Engineering design criteria for all disciplines is in accordance with applicable codes, standards, regulations, and guides issued by governmental agencies, recognized standards organizations, and Gilbert Associates, Inc.

1.3.1 Codes and Standards

System engineering design is in accordance with applicable codes, standards, and guides issued by the following organizations:

- | | |
|---|----------|
| 1. American Boiler Manufacturers Association | (ABMA) |
| 2. Air Conditioning Contractors of America | (ACCA) |
| 3. Air Diffusion Council | (ADC) |
| 4. American Foundrymen's Society | (AFS) |
| 5. American Gas Association | (AGA) |
| 6. American Insurance Association | (AIA) |
| 7. American Industrial Hygiene Association | (AIHA) |
| 8. Association of Home Appliance Manufacturers | (AHAM) |
| 9. Air Movement and Control Association | (AMCA) |
| 10. American National Standards Institute | (ANSI) |
| 11. Air-Conditioning and Refrigeration Institute | (ARI) |
| 12. Acoustical Society of American | (ASA) |
| 13. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. | (ASHRAE) |
| 14. American Society of Mechanical Engineers | (ASME) |
| 15. American Society for Testing and Materials | (ASTM) |
| 16. Building Officials and Code Administrators International, Inc. | (BOCA) |
| 17. Compressed Air and Gas Institute | (CAGI) |
| 18. Cooling Tower Institute | (CTI) |
| 19. Expansion Joint Manufacturers Association, Inc. | (EJMA) |

20. Heat Exchange Institute	(HEI)
21. Hydraulic Institute	(HI)
22. Hydronics Institute	(HYDI)
23. Institute of Boiler and Radiator Manufacturers	(IBR)
24. International Conference of Building Officials	(ICBO)
25. Mechanical Contractors Association of America	(MCAA)
26. National Environmental Balancing Bureau	(NEBB)
27. National Bureau of Standards	(NBS)
28. National Electrical Manufacturers Association	(NEMA)
29. National Fire Protection Association	(NFPA)
30. National Sanitation Foundation	(NSF)
31. Society of Automotive Engineers	(SAE)
32. Southern Building Code Congress International	(SBCC)
33. Sheet Metal and Air Conditioning Contractors' National Assoc.	(SMACNA)
34. Tubular Exchanger Manufacturers Association, Inc.	(TEMA)
35. Underwriter's Laboratories, Inc.	(UL)
36. Manufacturers Standardization Society	(MSS)

1.3.2 Design Parameters

Design parameters for steam line velocity is limited to 1,000 fpm per inch of internal diameter. Design velocities for chilled water mains are limited to 8 fps. Branch lines velocities are limited to 6 fps. Design velocities for hot water service lines are limited to 6 fps. Conditioned air duct pressure losses are limited to 0.15"/100 ft. All equipment design parameters are in accordance with Section 1.3.1, "Codes and Standards".

2.0 DESIGN DESCRIPTION

The Auxiliary Steam System will supply steam used for plant heating. The supply system consists of insulated piping, valves, controls, and interface components. Chilled water used for cooling of offices, control rooms, and power inverters is circulated through a system consisting of insulated piping, valves, controls and interface components. Hot water for heating is obtained from steam hot water convectors. The major equipment components are noted in Section 1.1 and 1.2.

2.1 SUMMARY DESCRIPTION

Auxiliary steam at approximately 30 psig and temperature between 300°F-330°F is used for plant steam and hot water heating. The auxiliary steam will be supplied from the cycle with supplementary backup provided by auxiliary, oil-fired boilers. Supplementary oil-fired package boilers are provided for the coal control building and warehouse. Steam unit heaters are individually controlled.

Computer room air conditioning units are provided with duct reheat coils and steam humidifiers for temperature and humidity control.

Chilled water units are controlled by load demand from maximum capacity down to 20 percent of their capacity.

Air conditioning units are controlled for quantity, quality, temperature and humidity of supplied air, and space sound criteria levels.

Electric unit heaters are individually controlled.

Ventilation fans for equipment cooling are thermostatically controlled.

Ventilation fans in potentially hazardous areas are intended to run continuously. Backup fans are provided in the event of operating fan failure.

Ventilation fans in buildings requiring general ventilation or spot cooling are manually controlled.

2.2 DETAILED DESCRIPTION

2.2.1 Major Equipment

Major equipment listing including tabulation of HVAC data is included in Table 2-1. (Final adjustments will be made to this table as the design progresses.)

The package boilers for coal system control building and warehouse are of the fire tube scotch marine type, low pressure steam, in accordance with Section IV (heating boilers) of ASME Code, with combination water column, pump control and low pressure cutoff, operating and firing control limits, enameled steel jacket with mineral fiber insulation, steam safety relief valves, flanged flue outlet, control cabinet, forced draft oil burner, steel skid base, fire tubes, furnace tube, steam disengaging area, rear combustion chamber and access doors.

Air handling units used for office air conditioning and power inverters cooling consist of modulating return, exhaust and outside air dampers, return air fan for an economizer cycle, disposable prefilters or inertial separator filters, 95 percent high efficiency permanent filters, air foil supply fans, associated ductwork, hot and chilled water coils, steam preheat coil, steam humidifier, controls for temperature, humidity, static pressure, fire and smoke detection. In addition, variable volume units include fan static limit features and control.

Ventilation fans used for heat removal, spot cooling and dilution ventilation are either centrifugal, propeller, axial, power roof ventilators or tubular, depending on specific requirements and physical availability. Some fans have reversible flow capability for versatility and effectiveness.

Fans in unattended area are thermostatically "step" temperature controlled. Wall fans with motorized wall louvers are interlocked to operate only when the louvers are open. Wall reversible fans are arranged for outside air intake on the windward side and exhaust on the leeward side.

Fans in areas of exposure to coal, methane and hydrogen gases are explosion proof and run continuously. Chlorine storage acid gas ventilation is also continuous and located on low side of the wall.

TABLE 2-1

BUILDINGS EQUIPMENT DATA

<u>DWG. ITEM</u>	<u>BUILDING</u>	<u>HEAT MBH</u>	<u>COOL TONS</u>	<u>VENTIL CFM</u>	<u>TOTAL HP</u>	<u>DESIGN BASIS</u>	<u>DESCRIPTION OF EQUIPMENT</u>
*1	Intake Structure	326.4	-	20,000	12	104°F Max 50°F Min	2-10,000 CFM Reversible, Wall Fans, 5 hp each, w/motorized wall louvers and 4-25 kW Electr. Unit Heaters with 1/2 hp Fans.
*4	Coal System Contr. Bldg.	2,120	10	36,000	31	75°F 50% RH 104°F Max 50°F Min	6,000 CFM, 7 1/2 hp ac Unit with steam preheat coil, hot water reheat coils and chilled water unit coil, incl prefilter and high eff. filter. One-2,500 MBH, 15 psig steam boiler. 7-170 MBH, 15 psig, 2,600 CFM steam unit heaters, 1/2 hp ea. 4-9,000 CFM. Wall or roof reversible flow fans with wall motor operated dampers, 5 hp fan motor each.
*7	Fuel Oil Tank, Dike and Pumphouse	104.5	-	3,000	1-1/2	104°F Max 50°F Min.	3,000 CFM air handling unit with electr. coils (all expl. proof) ducted air to and from area.

TABLE 2-1 (Cont'd)

DWG. ITEM	BUILDING	HEAT MBH	COOL TONS	VENTIL CFM	TOTAL HP	DESIGN BASIS		DESCRIPTION OF EQUIPMENT
						110°F Max 50°F Min 75°F 50% RH		
*9	Warehouse	2,160	7 1/2	26,000	15			5-20' x 20' offices with baseboard heat. 4,000 CFM air handling unit with chilled water coil and steam preheat coil, 3 hp. 7-1/2 ton chilled water rooftop unit with air cooled condenser. Plant area-use 12-170 MBH steam unit heaters, 2,600 CFM 1/2 hp each. In summer use 4-6,500 CFM reversible wall fans, 1-1/2 hp motor and motorized wall louvers. One-2,350 MBH 15 psig steam boiler.
14	Administr. Bldg.	2,600	90	Econ. cycle	50	75°F 50% RH		Variable volume system with economizer cycle. Air handling unit 30,000 CFM, 50 hp with filters, steam preheat coil, zone chilled water coils and perimeter hot water baseboard.
*13	Recircul. Wtr. Pumphouse	274.2	-	7,000	4	104°F Max 50°F Min		2-3,500 CFM revers. wall fans with motorized wall louvers, 1 hp each. 8-Electr. unit heaters 15 kW ea. with 1,150 cfm fan, 1/4 hp each.
23	Compressor Bldg.	6,050	-	271,800	130	104°F Max 60°F Min		4-8,000 CFM 10 hp, roof intake fans, ducted down into the area with inside-outside modul. dampers, steam heat coils in ducts for winter heating. 6-45,300 CFM roof units, 15 hp for ventilation.

TABLE 2-1 (Cont'd)

<u>DWG. ITEM</u>	<u>BUILDING</u>	<u>HEAT MBH</u>	<u>COOL TONS</u>	<u>VENTIL CFM</u>	<u>TOTAL HP</u>	<u>DESIGN BASIS</u>	<u>DESCRIPTION OF EQUIPMENT</u>
39	Coal Preparation & Misc. Gas. Bldgs.	1,384	-	29,200	16	104°F Max 50°F Min	8-Steam unit heaters, each 173 MBH 1/2 hp, 2,600 CFM Fan. Ventil. 4-7,300 CFM 3 hp revers. wall fans with motorized wall dampers.
32							
24	Auxil. Boiler Room	-	-	26,000	10	90°F Max 60°F Min	2-13,000 CFM, 5 hp roof fans with low manually operated wall louvers.
25	Condens. Polish. Bldg.	1,117	-	42,000	32-1/4	90°F Max 60°F Min	14,000 CFM air handling unit with outs-inside mix air dampers from boiler room and outside. 7-173 MBH, 1/2 hp 2600 CFM steam unit heaters and 3-14,000 CFM roof exhausters 7-1/2 hp each with motorized wall louvers.
27	Control Room	13.2	18.5	-	15	75°F 50% RH	AC unit with filters, steam preheat, unit chilled water coil, duct reheat, winter steam humidifier.

TABLE 2-1 (Cont'd)

DMC. ITEM	BUILDING	HEAT MBH	COOL TONS	VENTIL CFM	TOTAL HP	DESIGN BASIS	DESCRIPTION OF EQUIPMENT
26	Turbine-Generator Bldg.	1,216	11	300,000	131	104°F Max 60°F Min	24-51 MBH steam emergency unit heaters, 1/4 hp 1,500 CFM. 10-roof exhausters, 30,000 CFM each, some reversible, 10 hp. Motorized wall dampers. Additional revers. wall fans 4-10,000 CFM, 5 hp to maintain bldg. press above-0.125 and provide spot cooling. Provide for 8-20 x 20 offices w 1-6,000 CFM, 5 hp ac unit with heating and chilled water coils.
33	Heat & Seed Recov. Bldg.	1,800		1.15x10 ⁶	350	104°F Max 60°F Min	6-100,000 CFM roof exhausters 30 hp motor ea. 11-50,000 CFM air makeup-exhausters 15 hp with inertial separator filters for outside air intake. 16-115,000 Btu steam emergency unit heaters 1/4 hp 1,700 CFM around lower walls periphery.
34	MHD Building	4,870		269,000	260	104°F Max 60°F Min	20-245 MBH steam emergency unit heaters, 2,600 CFM 1/2 hp ea. 5-53,800 CFM roof exh. 5-53,800 makeup units with inertial separators and steam preheat coils. Exh-20 hp ea. Makeup - 30 hp ea.

TABLE 2-1 (Cont'd)

<u>DWG. ITEM</u>	<u>BUILDING</u>	<u>HEAT MBH</u>	<u>COOL TONS</u>	<u>VENTIL CFM</u>	<u>TOTAL HP</u>	<u>DESIGN BASIS</u>	<u>DESCRIPTION OF EQUIPMENT</u>
*18	Industrial Waste Bldg.	903	-	3,000	3 280 kW	110°F Max 60°F Min	7-40 kW Expl. proof electr. unit heaters and 2-1,500 CFM expl. proof roof exh. fans, 1-1/2 hp ea.
*17	Crusher House (2) & Transfer Houses	480		3,500/ 7,000	(2)141kW 7.5 hp	104°F Max 50°F Min	Provide radiant electr. heaters. Use fabric collector 3,500/7,000 CFM with gravity wall louvers (expl. proof fan and motor) 7-1/2 hp motor for ventilation.
35&36	Coal and Seed Feed Bldgs.	1,537	-	24,000	20	104°F Max 50°F Min	2-12,000 CFM, 10 hp air handling units to supply hot air from MHD Bldg. to each area. Use natural draft roof ventilator with manually operated wall louvers.
11	Main Guardhouse	166.2	6	-	3	75°F 50% RH	3,500 CFM, 3 hp ac unit with economizer cycle chilled water coil, reheat hot water coil and preheat steam coil.
31	Inverter Building	1,653	401	116,800	110	104°F Max 60°F Min	3-22,400 CFM 25 hp units and 3-36,000 CFM, 30 hp units, units with econom., cycle filters, chilled-hot water and steam reheat coils. One of each is on standby.
34	Consolidation	825	200	60,000	50	104°F Max 60°F Min	1-22,400 CFM and 1-36,000 CFM are standby units. 60,000 CFM, 50 hp ac unit for Consolid. Bldg.

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TABLE 2-1 (Cont'd)

<u>DWG. ITEM</u>	<u>BUILDING</u>	<u>HEAT MBH</u>	<u>COOL TONS</u>	<u>VENTIL CFM</u>	<u>TOTAL HP</u>	<u>DESIGN BASIS</u>	<u>DESCRIPTION OF EQUIPMENT</u>
30	Switchgear Bldg.	540	8	44,000	41	104°F Max 60°F Min	4-11,000 CFM roof exhausters with motor operated wall louvers, each 5 hp. 2-17,000 CFM 7-1/2 hp wall fans blowing from inverter bldg. 2-5,000 CFM ac units, 3 hp. each for heating of offices.

NOTES:

1. DWG. ITEM refer to DWG. No. 210-007-001.
2. Items marked with (*) are building heating/ac self-contained units; otherwise heating/ac is provided from central system.

Outside air makeup units or fans are equipped with inertial separators. Buildings with heat generating equipment have high outside and inside air intake modulating dampers to reclaim building heat for heating lower portions of the building.

Steam and electric unit heaters are self-contained with its own built-in thermostats to work independently. In addition, each unit is equipped with manual override so unit fans may run continuously if required to provide air circulation.

The central chiller is of the centrifugal type, complete with compressor, motors, evaporator, tower condenser, lubrication system and integral control system to operate between 20 percent and full capacity loads, including protective devices for high temperature, low temperature, lube oil pressure and bearing overheating.

Air cooled package chillers are complete as described above including heavy duty condenser cooling fans and bypass for close evaporator temperature control.

The cooling tower is of the induced draft type, constructed of corrugated glass reinforced polyester, or other noncorrosive materials, field assembled with adjustable pitch blade propeller type fans and structural framework to withstand 30 lb./sq.ft. wind pressure on any projected area.

Chilled and hot water pumps are centrifugal, single stage, with casing and seals suitable for a hydrostatic test pressure of twice the working pressure, complete with flexible coupling and mechanical shaft seals with shaft sleeves. Casings are cast iron, per ASTM A-48. Impellers are bronze per ASTM B-143. Shafts are carbon steel, per ASTM A-576, GR 1045 with bronze or stainless steel shaft sleeves.

2.2.2 Piping and Valves

All piping design is in accordance with ANSI B31.1. Steam horizontal lines are to be sloped downward one inch in 30 feet in the direction of flow. Drip legs with steam traps are installed at the end of each run. Piping materials are as follows:

Service	Size	Material
Steam	2" and smaller	XS, ASTM A106 GR. B
Steam	2-1/2" and larger	Std. wt. ASTM A106, GR B
Hot and Chilled Water	2" and smaller	Std. wt., ASTM A-53
Hot and Chilled Water	2-1/2" and larger	Std. wt. ASTM A-53 stl.

Valves used for heating, ventilating and air conditioning service comply with, but are not limited to, the latest editions of MSS and ANSI B16.10 standards.

2.2.3 Electrical

Boiler accessories and all other HVAC equipment are designed for 480 volt, 3 phase, 60 Hz power supplied from control centers. Instrumentation and controls are operated by 120v. 1 phase, 60 Hz which is coordinated with the instrumentation power sources.

2.2.4 Instruments, Controls and Alarms

Boilers for coal system control building and warehouse are furnished with control packages from the manufacturers. Controls include stack temperature with high and low alarms, amount of fuel oil used, steam and condensate temperatures, steam and condensate metering, pump control, low pressure cut off, operating and firing control limits, and forced draft oil burner control.

Chiller units are provided with an integral control panel and controls furnished by the manufacturer, requiring 120 volt, 1-phase, 60 Hz electrical power and 20 psig instrument air supply. Alarms are provided for unit high refrigerant temperature, refrigerant low temperature, oil pressure and bearings overheating.

Controls for air conditioning units, terminals, unit heaters, fans and air makeup units will be furnished to meet conditions as described in Section 2.1.

3.0 SYSTEM PROTECTION AND SAFETY PRECAUTIONS

3.1 PROTECTIVE DEVICES

Protective devices are included with the unit to trip a chiller in the event of high temperature, low temperature, low oil pressure and bearings overheating. Safety relief valves for refrigerant and air release tank over pressure are also included.

Boiler protective steam safety relief valves and other cutoff controls are described in Sections 2.2.1 and 2.2.4.

No additional protective devices are required.

3.2 HAZARDS

No special personnel hazards are considered to exist in the operation of boilers and any heating, ventilating or air conditioning units or systems, beyond those normally observed in conjunction with high temperature and 40 psig steam piping.

3.3 PRECAUTIONS

In areas of vital operations, such as control rooms, power inverters, battery rooms and sewage treatment plant, duplicate standby units are provided for

continuous uninterrupted operation. Emergency heaters are provided in all plant buildings to prevent freezing and enable personnel to comfortably perform maintenance and service work.

4.0 MODES OF OPEFATION

4.1 STARTUP

Startup of steam boilers to be in accordance with manufacturer's operating manual and instructions.

General building ventilation fans are individually started as required.

Starting of the main chiller unit requires establishing of water flow through its evaporator and condenser sections.

Ventilation and heating of unattended buildings housing production equipment are automatically controlled by space thermostats.

Steam unit heaters are operated by built-in thermostats. Main steam line valves are manually opened whenever heating is required.

Air conditioning units/variable volume terminals are controlled from space thermostats and humidistats. Perimeter hot water baseboard heaters are controlled from their own built-in thermostats.

4.2 NORMAL OPERATION

No special action is required for boilers or any heating, ventilating, air conditioning or chillers during normal operation.

4.3 SHUTDOWN

Equipment will shutdown automatically or manually as required.

Draining of water and steam lines will be required for seasonal or maintenance shutdowns.

4.4 SPECIAL OR INFREQUENT OPERATION

Special or infrequent operation of boilers or any HVAC system is not expected. Emergency and backup equipment is provided in critical areas.

5.0 MAINTENANCE

5.1 SURVEILLANCE AND PERFORMANCE MONITORING

Apart from local readouts, no special surveillance or monitoring is required with any of the units. Local condition instruments indicate operability and status of any of the units.

5.2 INSERVICE INSPECTION
 Valves used for heating, ventilating and air conditioning service comply with, but are not limited to, the latest editions of MSS and ANSI B16.10 standards. Following initial startup inspection, frequent inservice inspection is normally not required on HVAC equipment.

2.2.3 Electrical

Boiler weekly inspections include: checking stack temperature, steam pressure, accessories and all other HVAC equipment are designed for 480 volt, 3 phase, 60 Hz power supplied from control centers. Instrumentation and auxiliary equipment, exhaust gas composition, boiler operating characteristics and controls are operated by 120V, 1 phase, 60 Hz which is coordinated with the instrumentation power sources.

2.2.4 Monthly inspections include: checking blowdown and water treatment, quantity of combustion air supply, fuel system, and leaks.

Boilers for coal system control building and warehouse are furnished with annual inspections include: heat transfer surfaces, refractory, electrical system and valves. Controls include stack temperature with high and low alarms, amount of fuel oil used, steam and condensate temperatures, steam and condensate metering, pump control, low pressure cut off, operating and firing control limits, and forced draft oil burner control.

2.3 PREVENTATIVE MAINTENANCE

In general, valve repacking, changing of filters and replacing of parts which chiller units are provided with an air control panel and controls furnished by the manufacturer, requiring 120 volt, 1 phase, 60 Hz electrical power and 20 psig instrument air supply. Alarms are provided for unit high refrigerant temperature, refrigerant low temperature, oil pressure and bearings overheating.

5.2 CORRECTIVE MAINTENANCE

5.4.1 Manufacturer's Instructions
 Controls for air conditioning units, terminals, unit heaters, fans and air makeup units will be furnished to meet conditions as described in Section 2.1. A complete file of instruction books is available at the plant to guide the plant personnel in maintenance and overhaul of any piece of boilers or HVAC equipment. If necessary, either a representative of the manufacturer can be present to supervise the overhaul or replacement of the equipment, or services may be performed directly by the manufacturer's crew.

Protective devices are included with the unit to trip a chiller in the event of high temperature, low temperature, low oil pressure and bearings overheating. Safety relief valves for refrigerant and air release tank over pressure are also included. The manufacturers provide lists of recommended spare parts. Critical parts or equipment are kept in inventory at the plant. Parts requiring long lead time for delivery are included in the plant inventory. Boiler protective steam safety relief valves and other cutoff controls are described in Sections 2.2.1 and 2.2.4.

No additional protective devices are required.

3.2 HAZARDS

No special personnel hazards are considered to exist in the operation of boilers and any heating, ventilating or air conditioning units or systems, beyond those normally observed in conjunction with high temperature and 40 psig steam piping.

3.3 PRECAUTIONS

In areas of vital operations, such as control rooms, power inverters, battery rooms and sewage treatment plant, duplicate standby units are provided for

MHD-ETF PROJECT
 SYSTEM DESIGN DESCRIPTION
HEATING, VENTILATION AND AIR CONDITIONING SYSTEM
 APPENDIX "A"
REFERENCE DOCUMENTS

REFERENCE DOCUMENTS - ATTACHED

Fluid System Diagrams

Diagram No.

HVAC - Chilled Water

8270-1-721-902-001

HVAC - Steam - Hot Water

8270-1-722-902-001

REFERENCE DOCUMENTS - NOT ATTACHED

Layout

Inverter and Switchgear Building - Plan

8270-1-810-002-001

Inverter and Switchgear Building - Section

8270-1-810-002-002

Plot Plan

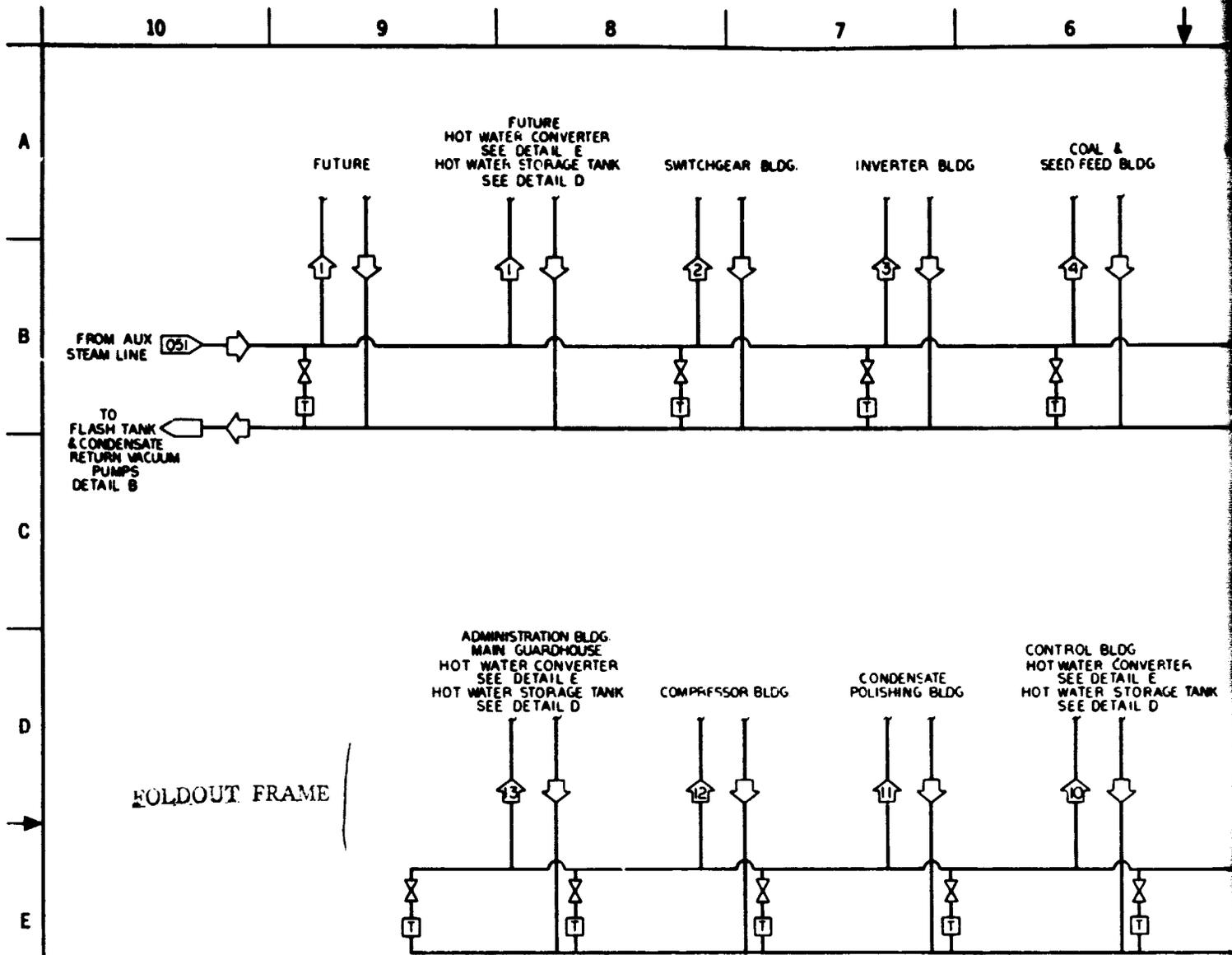
8270-1-210-007-001

System Design Descriptions

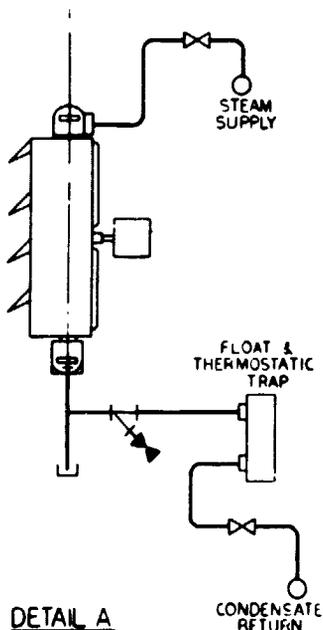
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Fuel Oil

Electrical

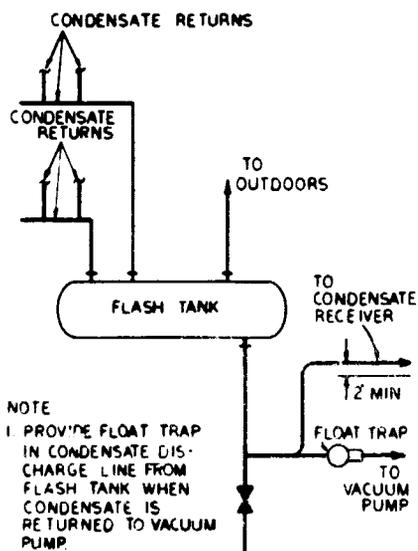


STEAM UNIT HEATER
HOOK UP - TYPICAL



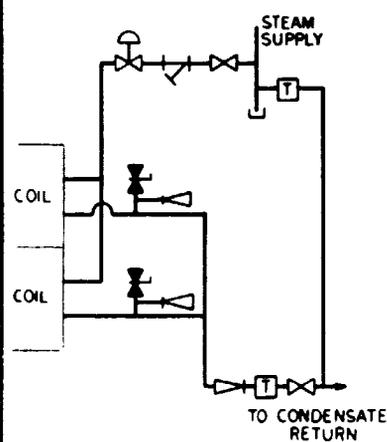
DETAIL A
TYPICAL 14 BUILDINGS

TYPICAL FLASH TANK PIPING



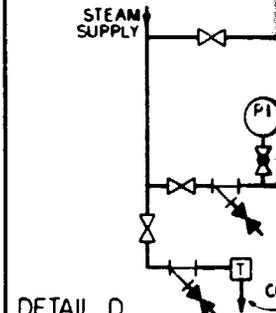
DETAIL B

STEAM PREHEAT COILS HOOK UP
TYPICAL



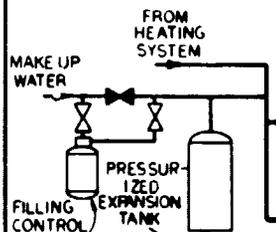
DETAIL C
TYPICAL BUILDINGS

STEAM HEAT T...



DETAIL D

DETAIL E



SYSTEM DESIGN DESCRIPTION

SDD-801

ELECTRICAL SYSTEM

FOR

MAGNETOHYDRODYNAMICS

ENGINEERING TEST FACILITY

CONCEPTUAL DESIGN - 200 MWe POWER PLANT

ELECTRICAL ONE LINE DIAGRAMS NO. 8270-1-802-206-001,

8270-1-802-206-002, AND 8270-1-802-206-003

Kenneth J. Miller 9/25/81
SYSTEM ENGINEER DATE

Kenneth J. Greuder 9/25/81
REVIEWED DATE

Jim Dilligis 9/25/81
APPROVED DATE

Revision: 1
Date: Sept. 25, 1981

**MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
ELECTRICAL SYSTEM**

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REFERENCE DOCUMENTS - NOT ATTACHED		

1.0 FUNCTION AND DESIGN REQUIREMENTS

This document presents a description of the bottoming cycle power distribution from the plant switchyard to the ac power bus system as shown on Drawing No.'s 8270-1-802-206-001, -002 and -003. Included are descriptions of the electrical distribution system design requirements, equipment locations and operating modes.

1.1 FUNCTIONAL REQUIREMENTS

The bottoming cycle electrical power system functions are to: Deliver generated power from the Engineering Test Facility (ETF) to the 138 kV substation and utility grid; distribute power from the 138 kV substation through the ETF bus system to all auxiliary bottoming and topping cycle systems for startup, normal running, and shutdown conditions; supply emergency power on loss of normal power for all plant critical loads to have an orderly emergency shutdown; and provide an uninterruptible power supply for essential computer, instrument, and control circuits.

1.2 SYSTEM INTERFACES

A 138 kV substation ring bus is provided to act as an interface to connect the topping cycle 34.5 kV inverter bus breaker and step-up transformer to the bottoming cycle turbine generator (TG) 22 kV isolated phase bus through its unit connected step-up transformer. In addition, two station service step-down transformers are tied to the ring bus; one for MHD, and the other for TG loads. These two transformers provide 4.16 kV power to buses for in-plant power distribution. The 138 kV substation ring bus also interfaces with two utility company 138 kV lines providing redundant channels for all incoming and outgoing power.

1.3 DESIGN CRITERIA

The bottoming cycle incorporates a steam turbine driven, 3,600 rpm, two pole, 3 phase, 22,000 volt wye connected, 45 psig hydrogen cooled synchronous generator, capable of continuous operation at rated capacity of 128 MW, 160 mVA, at 0.8 P.F. The generator is capable of accepting load change rates of 3 MW per minute from 3 percent to 100 percent load or a step change from 100 percent to 3 percent without tripping the turbine.

1.3.1 Codes and Standards

The generator, power transformers, 4.16 kV metal clad switchgear, 480 V load centers, 4.16 kV medium voltage motor starters, 480 V motor control centers, 4 kV and 460 V motors, power distribution panels, uninterruptible power supplies, cable and other plant miscellaneous equipment meet the requirements of the following applicable codes and standards:

1. American National Standard Institute (ANSI)
2. Institute of Electrical and Electronic Engineers (IEEE)
3. Instrument Society of America (ISA)

4. National Electrical Code (NEC)
5. National Electrical Manufacturers Association (NEMA)
6. Occupational Safety and Health Administration (OSHA)
7. National Fire Protection Association (NFPA)
8. Insulated Power Cable Engineering Association (IPCEA)

1.3.2 Design Parameters

The following parameters have been included in the Electrical System design:

1. Provision to supply redundant off-site power for maximum reliability during startup, shutdown, and loss of one utility line.
2. Backup station service transformer capacity to supply the total ETF auxiliary power requirement in the event of a failure in one of the station service transformers.
3. Provision for starting large motors so starting voltage drop will not be reflected through the whole plant distribution system.
4. An auxiliary power source complete with automatic synchronizing to keep all critical loads running in the event of loss of power to the plant auxiliary loads.
5. An uninterruptible power source for all critical computer, instrumentation, and control systems.
6. A manual and automatic system for synchronizing the TG with the utility grid from the main control room.
7. A coordinated selective trip protective relay system that is capable of isolating and interrupting faults at all voltage levels with a minimum disturbance to the distribution system.

2.0 DESIGN DESCRIPTION

2.1 SUMMARY DESCRIPTION

The ETF bottoming cycle electrical generation and auxiliary plant distribution system is completely dependent on the exhaust energy from the topping cycle for generation ability. During the startup and shutdown cycle when there is insufficient steam to run the TG, power is taken from the utility grid through the 138 kV substation and station service transformers. This power is distributed as required, through all auxiliary distribution system buses at various voltage levels to the topping and bottoming cycle equipment. When steam is available the TG is started and synchronized with the utility system. The generator is then capable of supplying the plant auxiliary power and sending the remaining power to the utility 138 kV grid system. The channel

will now be putting out maximum power through the inverter step-up transformer to the 138 kV substation ring bus. Since the inverters are line commutated, the output of the main inverter step-up transformer will always be synchronized with the TG step-up transformer at the 138 kV ring bus.

Four 900 kW combustion turbine generators have been provided on a critical 4.16 kV bus to supply auxiliary power if auxiliary power is lost from the 138 kV ring bus. When power is lost on the 4.16 kV critical bus, these generators will automatically start and synchronize, thus supplying power to all critical plant auxiliaries at the 4.16 kV and 480 V level that are required to effect an orderly plant shutdown.

2.2 DETAILED DESCRIPTION

2.2.1 Major Equipment

2.2.1.1 138 kV Switchyard Equipment

The switchyard is located on the east side of the plant adjacent to the 34.5 kV inverter bus and step-up transformer (see Drawing No. 8270-1-210-007-001). The switchyard has a 138 kV ring bus with six 138 kV lines connecting into the ring bus as follows:

1. Two 138 kV utility company lines each originating at different substations in the utility grid.
2. Two ETF 138 kV power output lines, one from the inverter step-up transformer and the other from the TG step-up transformer.
3. Two lines for auxiliary power flowing into the ETF facility (see Drawing No.'s 8270-1-802-206-001 and -002).

The ring bus is composed of six outdoor circuit breakers (independent tank, three pole, 145 kV, maximum 2,000A) and twelve manual outdoor disconnect switches (gang operated, 3 pole, center pivot, double break, 145 kV maximum, 2,000A). Each of the six lines terminate between two disconnect switches and breakers. The breaker will be used to disconnect the line in the event of a fault. The disconnect switches, one on either side of each breaker, make it possible to isolate any breaker in the ring for maintenance while keeping the ring bus energized with the facility in operation.

Motor operated 138 kV disconnect switches are provided in each of the 138 kV overhead lines connecting into the ring bus. These are used for isolating a line when the ring bus breaker for the line has been reclosed. These disconnects along with the ring bus breaker are controlled by switches located on the main control room panels.

2.2.1.2 Main Inverter Step-Up Transformer

One of the 138 kV overhead lines, from a motor operated disconnect switch at the south west side of the ring bus, is connected to the MHD cycle inverter step-up transformer. This transformer (90/120 MVA, 34.5 - 138 kV, delta wye,

55°C) has its 34.5 kV winding connected to the inverter output bus (See Drawing No.'s 8270-1-210-007-001 and 8270-1-802-206-001). The transformer supplies the total MHD cycle power output and also synchronizes the MHD cycle with the utility 138 kV system.

2.2.1.3 Turbine Generator Step-Up Transformer

A second ETF overhead 138 kV line, from a motor operated disconnect switch at the northwest corner of the ring bus, is connected to the TG step-up transformer. This transformer is rated 120/160 MVA, 22-138 kV, delta-wye, 55/65°C. An isolated phase bus rated 5,000A 25 kV, leaves the TG building and connects to the 22 kV winding of the TG step-up transformer located in the yard. All power generated in the TG cycle passes through this transformer and is synchronized with the 138 kV switchyard ring bus through the two breakers on either side of the TG transformer line connection.

2.2.1.4 Turbine Generator (TG)

This generator (160 MVA, 128 MW, 0.8 P.F., 22 kV, @ 3,600 rpm) has a static excitation system with equipment mounted in separate metal cubicles. All six ends of the generator's three windings exit from the base of the generator housing. The three output leads connect to the step-up transformer isolated phase bus, and the three neutral ends of the windings are connected to one side of the primary winding of a 15,000-240 V ac single phase distribution transformer. The other end of the primary winding is grounded. A resistor connected across the 240 V ac secondary provides high resistance grounding for the generator and limits the ground current to approximately 5 amps. All generator synchronizing, governor control, voltage regulator control and other generator control switches are located on panels in the main control room.

2.2.1.5 Oxidant Compressor Transformer and Motor

One of the switchyard 138 kV motor operated disconnect switches supplies an overhead line connected to the oxidant compressor transformer (15/20/25 mVA, 138-4.16 kV, 55°C). The secondary of the transformer is connected by the 3,000A, 5 kV non-segregated bus duct to two oxidant compressor breakers (4.16 kV, 350 MVA). One of the two breakers supplies the oxidant compressor induction motor (20,000 hp 1,800 rpm). The second breaker, which is interlocked with the oxidant compressor breaker, allows the oxidant compressor transformer to be used as a replacement transformer for the MHD station service transformer when it is not supplying the oxidant compressor motor (see Drawing No. 8270-1-802-206-002).

The 15/20/25 MVA oxidant compressor transformer has been selected with a 6 percent impedance. With this transformer impedance and 10,000 MVA short circuit level on the 138 kV utility system, the motor must be Code E to limit the starting voltage drop to approximately 30 percent. With 70 percent voltage at the motor terminals for starting, the motor will have 50 percent torque. The motor is on an isolated bus so that the reduced voltage will not effect the rest of the ETF distribution system when starting. The motor driven oxidant compressor is primarily for startup and shutdown. During normal plant operation, it is replaced by steam turbine driven compressors, and is on standby.

2.2.1.6 MHD and TG Station Service Transformers

The primary windings of the MHD and TG station service transformers are supplied through two 138 kV overhead lines originating at two 138 kV ring bus motor operated disconnect switches. Each transformer is rated 15/20/25 MVA, 138-4.16 kV, delta-wye, 55°C. The secondary winding of each transformer is connected to its respective 4.16 kV, 350 MVA breaker by the non-segregated 5 kV, 4,000 A bus duct.

2.2.1.7 Main MHD and TG 4.16 kV Metal Clad Switchgear

The main MHD and TG 4.16 kV 350 mVA metal clad switchgear has two buses, A and B. One is for MHD loads and the other for TG loads, with a normally open bus tie breaker between them. The switchgear supplies all the auxiliary power for the ETF through 10 feeder breakers on its buses. All breakers are stored energy, electrically operated, drawout type, with 350 MVA interrupting capacity. Either the MHD or the TG station service transformer can supply the total ETF auxiliary load with the 4.16 kV bus tie breaker closed if one transformer should fail. Under normal operating conditions a normally closed feeder breaker on MHD bus A will supply critical 4.16 kV switchgear bus C.

2.2.1.8 Critical 4.16 kV Metal Clad Switchgear

This 4.16 kV switchgear is located in the TG building on the basement floor. All ETF critical loads at the 4.16 kV and 480 V level receive power from this bus. In the event that normal power is lost to this bus "C", four 900 kW, 0.8 P.F. 4.16 kV, 3 phase, 60 Hz emergency combustion turbine generators will automatically start and synchronize to the bus. Each combustion turbine is equipped with a 125 V dc battery, charger and 125 V dc cranking motor for startup.

2.2.1.9 Medium Voltage 4.16 kV Starters

Full voltage, non-reversing, high interrupting, current limiting, fused drawout, air break contactor, 4.16 kV starters are provided for all ETF motors 250 hp and larger. Four rows of starters are provided in the ETF. The MHD 4.16 kV starter bus starter row is located in the Coal Preparation Building basement and is supplied power from 4.16 kV switchgear breaker 1A on MHD switchgear bus "A". The TG 4.16 kV starter bus starter row is located in the TG building basement and receives power from 4.16 kV switchgear breaker 4B on TG switchgear bus "B". The critical 4.16 kV starter bus 1 starter row is also located in the TG building basement and critical 4.16 kV starter bus 2 starter row is located in the HR/SR Building basement. These two starter rows receive their power from 4.16 kV critical bus C switchgear feeder breakers 3C and 5C.

2.2.1.10 480V Load Center - 1

The 480 V load center is double ended. A transformer (1,500 kVA 4,160 - 480 V, delta-wye, 80°C), is close coupled to bus A and bus B of the load center, with a normally open bus tie breaker connecting the two buses. If either

transformer is lost, the bus tie breaker can be closed to supply the two buses through the remaining transformer without any load reduction (see Drawing No. 8270-1-802-206-003).

The breakers are all electrically operated, stored energy, static trip type. All load feeder breakers are current limiting, fuse type that limit fault currents to a level which motor control center breakers can interrupt. Each feeder breaker in the 480V load center supplies power to the main bus of a motor control center located in the area of the motors it serves. The motor loads listed under the buses on the 480V one line diagram (See Drawing No. 8270-1-802-206-063) represent individual motor starters mounted in each motor control center. All motors 200 hp and smaller are assigned to the 480V system.

2.2.1.11 480V Cooling Tower Load Center

The cooling tower load center is single ended with a close coupled transformer (2,000 kVA 4,160 - 480V delta-wye, 115°C, AA dry type). It receives power from 4.16 kV switchgear breaker 3B. Two pump house motor control centers are serviced by this load center.

2.2.1.12 Coal Management Load Center and 4.16 kV Starter

Power is supplied to this single ended 480V load center from 4.16 kV switchgear breaker 7B, with a close coupled transformer (1,000 kVA 4,160 - 480V delta-wye 55/65°C).

One 4.16 kV fused current limiting starter is located with the 480V load center. The 4.16 kV full voltage non-reversing starter receives its power from the 4.16 kV primary cable supplying the 480V load center transformer.

2.2.1.13 Thaw Shed 480V Load Centers 1, 2, 3 and 4

Thaw Shed Load Centers 1 and 2 receive power from 4.16 kV switchgear breaker 5B. Thaw Shed Load Centers 3 and 4 are supplied power by 4.16 kV switchgear breaker 6. The four load centers are located in the Coal System Control Building. The load centers are all single end with close coupled transformers (2,000 kVA 4,160 - 480V Delta-wye, 55/65°C). Each load center has five feeder breakers, each supplying power to a 350 kW power distribution panel and its infrared heating load.

This is a large block of power which is used upon arrival of coal trains during sub-zero weather.

2.2.1.14 Critical 480V Load Center

The load center is located in the coal preparation building near the loads it supplies. Critical bus 4.16 kV switchgear breaker 4C supplies power to the load center transformer. This load center is single ended with a close coupled transformer (1,000 kVA, 4,160 - 480V, delta-wye, 115°C, AA dry type). One breaker in this load center supplies power to a critical service 480V 3 phase, 3 wire power distribution panel. This distribution panel provides 480V 3 phase power to two uninterruptible power supplies.

2.2.1.15 Uninterruptible Power Supply Systems

Two uninterruptible power supply systems (UPS) are provided for the ETF. One system will supply power to the inverter computer control system and electrical control system and the other UPS will provide power for a second computer with vital instrumentation and control systems. Each UPS system is capable of supplying a 35 kVA, 120/208 V 3 phase 4 wire load through a 3 phase 4 wire molded case power distribution panel. Each UPS system has a 60 cell, 125 V dc battery and redundant battery chargers and inverters. A static bypass switch with voltage regulated bypass transformer is provided for each UPS.

2.2.1.16 Plant dc System Equipment

A 125V dc, 60 cell, lead calcium battery rated at 1,000 ampere-hours, is the source of power for this system. A main dc power panel and three dc distribution panels are required to distribute the dc power through the ETF. This power is used for 125V dc control and indication on all the 4.16 kV and 480V switchgear breakers. Larger blocks of dc power are used during startup and shutdown. The battery is provided with a 3 phase, 480V battery charger.

2.2.2 Instruments, Controls and Alarms

2.2.2.1 Controls and Alarms

Main control room panels have a mimic bus diagram showing the complete electrical distribution systems from the substation 138kV ring bus down through the 4.16kV metal clad switchgear and 480V load center breakers. The mimic bus also includes all MHD cycle 34.5kV and 6kV breakers and disconnect switches. Control switches and or status indicating lights are located on the mimic bus for their respective breakers and disconnect switches. Symbols are used for transformers and generators. This gives the operator a complete diagram of the system with status of all breakers and disconnect switches in the generation and distribution systems.

All TG synchronizing switches, metering, generator voltage regulator and turbine governor control equipment are located on these panels. Metering includes ammeters, volt meters, watt meters, var meters, and power factor meters, receiving input from current and potential transformers in their respective circuit. Control and status information is also provided for all vital 4.16kV and 480V motors.

Annunciators are located in the control room to visually and/or audibly alarm all critical functions in the MHD and steam cycle systems.

2.2.2.2 Instrument Systems and Controls

Instrumentation for the MHD-ETF facility is electronic, utilizing a distributed control type signal transmission system, except in those cases where alternate methods are more suitable for functional or ambient considerations. The distributed control system employs multiplexing of remote signals to reduce the number of signal cables required in the plant.

Critical control functions are hard wired in a conventional manner for system reliability and to ensure an orderly shutdown in the event of multiplex system failure. Remaining functions are controlled through a plantwide distributed control system providing an uncluttered main control room layout using a Cathode Ray Tube (CRT) operator console.

Local control panels are provided in various areas of the plant where local control is desirable (air separation unit, coal preparation, etc). In all instances, local controllers are provided where needed, or the individual systems can be operated directly from the main control room.

Distributed control systems readily lend themselves to computer interface since system signals are available on the interconnect multiplex system. The computer equipment is connected to the multiplex system output and the computer can then interact with the operators and instruments in the system.

A host computer is provided for the purpose of guiding the operator or directly influencing the plant systems. The computer is capable of the following:

1. Performing calculations to evaluate present heat rates, plant efficiencies, etc.
2. Selecting parameters to be altered which will most effectively improve plant operation.
3. Providing guidance for sequences and ramp rates to simplify operator procedures during startup and transients.
4. Generating predictive feed forward signals for portions of the plant such as the air separation unit where lead time on load changes, etc., can be beneficial.

All annunciators, digital and analog instrumentation, and the host computer are powered from the uninterruptible power supply.

3.0 SYSTEM PROTECTION AND SAFETY PRECAUTIONS

3.1 PROTECTIVE DEVICES

A full complement of protective relaying including overcurrent, transformer differential, bus differential, generator differential, voltage, frequency and power directional relays are provided for overall system protection. All motor starters are provided with overload and under voltage protection. Large motors are provided with a combination of embedded thermocouples, time overcurrent, and differential relays to detect overcurrent in the windings.

3.2 HAZARDS

No special personnel hazards are considered to exist in the electrical distribution system. The equipment is standard commercially available electrical equipment that is in use in any standard power plant.

3.3 PRECAUTIONS

Special precautions are taken at the remote coal handling area as required by the National Electric Safety Code and National Electric Code for Class I, Division 1, Group D and Class II, Division 1, Group F locations.

4.0 MODES OF OPERATION

4.1 STARTUP SEQUENCE

When the plant is started, the status indicating lights for the manually operated disconnect switches on either side of the six ring bus breakers indicate the switches are closed. All breaker indicating lights indicate the breakers are open (see Drawing No. 8270-1-802-206-001). If all manually operated disconnect switches are not closed, an operator must be sent out to the switchyard to close them. These switches are only opened during breaker maintenance. All 138 kV motor operated switches are closed. The breakers on either side of the turbine generator 160 MVA step-up transformer ring bus connection must remain in the open position. These are the output breakers for the turbine generator. The ring bus breakers are closed one at a time, holding the breaker control switch in the closed position until the red "closed indication" light comes on. The closing of these breakers is supervised by an auto synchronizing check relay.

The primary of all five main plant transformers are then energized. The main secondary breakers on the inverter step-up transformer, MHD station service and TG station service transformers are closed. This energizes the 34.5 kV inverter bus, 4.16 kV main metal clad switchgear MHD bus A and TG bus B. Energizing the 34.5 kV bus energizes the firing control potential transformers (PT's) circuit (see Drawing No. 8270-1-802-206-002). Feeder breaker 3A on 4.16 kV MHD bus A is then closed to energize the 4.16 kV critical bus switchgear. All four feeder breakers to the 4.16 kV motor starter buses are closed. The primary 4.16 kV feeder breakers to all 480 V load center transformers are closed along with their main secondary breakers.

Following the above, all plant auxiliary loads can be started as required for the MHD cycle startup. When steam is available from the MHD cycle, the turbine generator can be brought up to rated speed and the generator synchronized to the 138 kV ring bus utility line across one of the 138 kV generator output breakers. The last generator output breaker may be closed without synchronizing, since the generator is now connected to the 138 kV system.

The TG cycle is now supplying power to ring bus, with part of the power going to the ETF auxiliaries through the MHD station service and TG station service transformers.

4.2 NORMAL OPERATION

Normal operation consists of monitoring all control and annunciator alarm points, meters and recorders to ensure that equipment is functioning as required. In the event of loss of a pump or fan, etc., the operator must ensure that the standby unit is started automatically or manually.

4.3 SHUTDOWN

The auxiliary load of the plant is reduced at a rate compatible with the MHD cycle channel thermal requirements. As the steam generated by the MHD cycle is reduced, the TG load must be similarly reduced. When it is reduced to zero, both 138 kV generator output breakers are opened. Then, auxiliary power required for final shutdown is supplied from the utility lines.

4.4 SPECIAL OR INFREQUENT OPERATION

Once a month the four emergency 900 kW 0.8 PF combustion turbine generators should be started simultaneously, and automatically synchronized to the critical 4.16 kV bus. A simulated drop in frequency signal is used to start the combustion turbines for test. This is done to ensure that the system will operate if there is an emergency loss of power to the two 15/20/25 MVA station service transformers.

5.0 MAINTENANCE

5.1 SURVEILLANCE AND PERFORMANCE MONITORING

All electrical equipment is monitored by protective relaying, temperature sensing devices, etc. These devices provide audible and visual alarm through an annunciator system in the main control room.

5.2 INSERVICE INSPECTION

All meters, controls, instruments, contactors, relays, status lights, etc., shall be inspected periodically during system operation to ensure that the equipment is operating properly.

5.3 PREVENTATIVE MAINTENANCE

A regular program of meggering and/or Hi-potting power cables, motor windings, transformer windings, etc., to establish a history record from the day the equipment is installed should be established. This will provide indications of possible failure trends in the equipment. All transformers and other equipment containing insulating oil shall have oil samples taken and analyzed for dissolved hydrocarbons, moisture and other impurities. All electrical equipment shall be maintained as recommended by the manufacturer.

5.4 CORRECTIVE MAINTENANCE

5.4.1 Manufacturer's Instructions

A complete file of manufacturers' instruction books on all electrical equipment are kept on file and made available to plant maintenance personnel. Manufacturers' service engineers are available to supervise or perform complex service tasks or those requiring special equipment.

5.4.2 Spare Part Inventory

A recommended list of spare parts is provided by the manufacturer for each piece of electrical equipment. Critical complex parts requiring long lead time for delivery are normally included in the plant inventory.

**MHD-ETF PROJECT
SYSTEM DESIGN DESCRIPTION
ELECTRICAL
APPENDIX "A"
REFERENCE DOCUMENTS**

REFERENCE DOCUMENTS - ATTACHED

Diagram No.

Electrical One-Line Diagram Primary Power	8270-1-802-206-001
Electrical One-Line Diagram 4160V Power	8270-1-802-206-002
Electrical One-Line Diagram 480V Power	8270-1-802-206-003

REFERENCE DOCUMENTS - NOT ATTACHED

Layout

Plot Plan	8270-1-210-007-001
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A

B

C

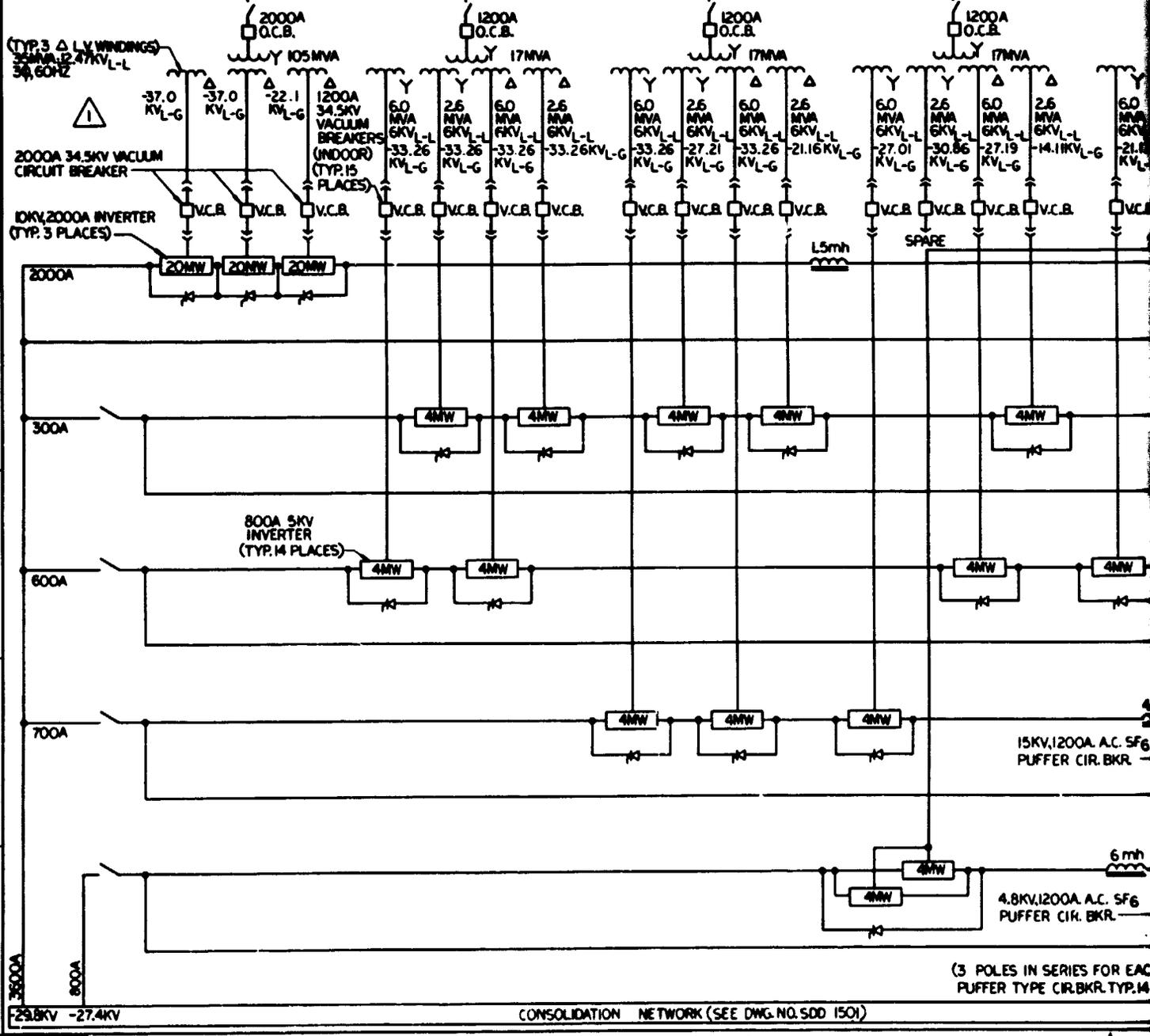
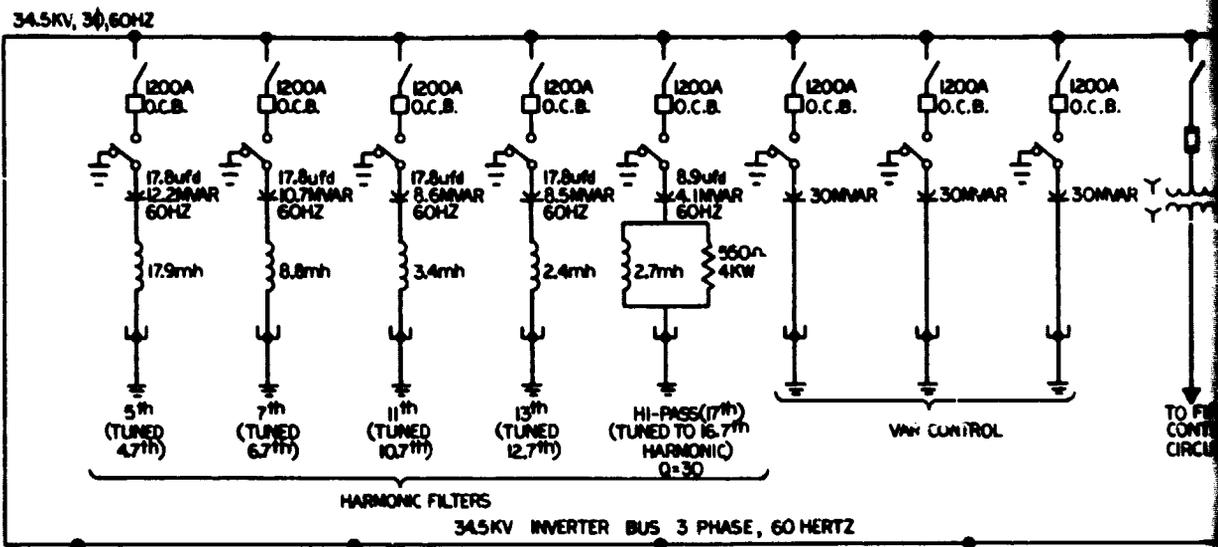
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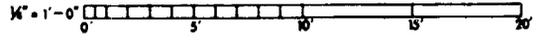
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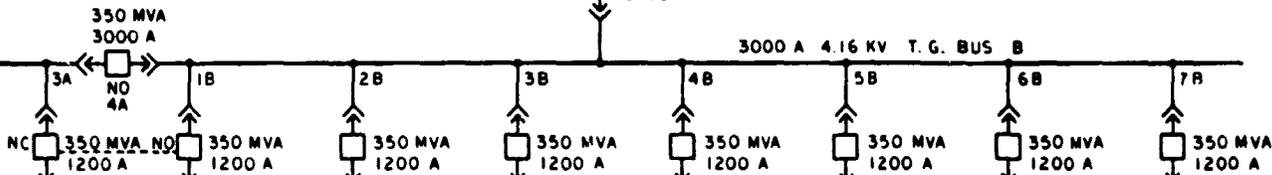
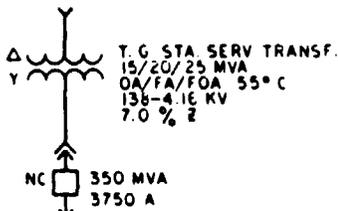
EOLDOUT FRAME



(3 POLES IN SERIES FOR EACH PUFFER TYPE CIR. BKR. TYP. 14)

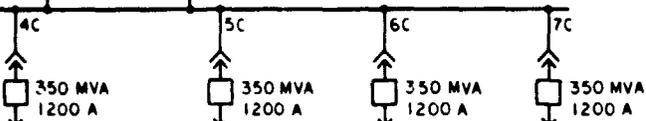
6 5 4 3 2 1

FROM 138 KV. SWITCHYARD
DISCONNECT SWITCH
SEE DWG. 8270-1-802-206-001



TO 480 V LOADCENTER 1
TO 480 V COOLING TOWER
T.G. TRANSF.
SEE DWG. NO. 802-206-003

TO 480 V THAW SHED
LDCTRS. 1 & 2
TO 480 V THAW SHED
LDCTRS. 3 & 4
TO 480V COAL
MANAGEMENT
SYS. LDCTR.
SEE DWG. NO. 802-206-003



TO CRITICAL
480 V. LDCTR.
DWG NO 802-206-003

EMERGENCY
900 KW 0.8 PF
COMBUSTION
TURB. GEN. 3

EMERGENCY
900 KW 0.8 PF
COMBUSTION
TURB. GEN. 4

CRITICAL 4.16 KV STARTER BUS 2

- 1. HI PRESS. WTR. ASH SLUICE PU. 1 - 300 HP
 - 2. " " " " 2 - 300 HP
 - 3. SERVICE & INST. AIR COMPR. 1 - 250 HP
 - 4. " " " " 2 - 250 HP
 - 5. FIRE PUMP - 250 HP
- TOTAL CONN. - 1350 HP
TOTAL RUNNING - 800 HP
TOTAL RUN. KVA = 0.9 KVA/HP x 800HP = 720 KVA

TYPICAL STARTER

T.G. 4.16 KV STARTER BUS

- 1. I. D. FAN A - 700 HP
 - 2. " " B - 700 HP
 - 3. " " C - 700 HP
 - 4. CIRC WATER PUMP A - 800 HP
 - 5. " " B - 800 HP
 - 6. " " C - 800 HP
 - 7. RAW WTR. TRANSF. PU. 1 - 400 HP
 - 8. " " " 2 - 400 HP
 - 9. RAW WTR. SUPPLY PU. 1 - 400 HP
 - 10. " " " 2 - 400 HP
 - 11. CLOSED CYC. COOL. WTR. PU. 1 - 250 HP
 - 12. " " " 2 - 250 HP
- TOTAL CONN. - 6600 HP
TOTAL RUNNING - 4050 HP
TOTAL RUN. KVA = 0.9 KVA/HP x 4050HP = 3645 KVA

TYPICAL STARTER

REFERENCE DWGS.

- 8270-1-802-206-001 - ONE LINE DIAGRAM-
PRIMARY POWER
- 8270-1-802-206-003 - ONE LINE DIAGRAM-
480 V POWER

I.B. NO. C-273-017

3-27-81	CONCEPTUAL DESIGN ISSUE	<i>Revised</i>
3/6/81	PRELIMINARY ISSUE	<i>Revised</i>
	RELEASED FOR	ENGR.

MAGNETOHYDRODYNAMICS
ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN

ONE LINE DIAGRAM
4.16 KV. POWER SDD-001
200 MW

DDE - NASA

OHIO PROJECT OFFICE

LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

APPR. H. RIGBO
DATE: 9-25-81

GILBERT ASSOCIATES, INC.
ENGINEERS AND CONSULTANTS BRANCO, PA.

DATE	BY	REV
3/27/81	<i>[Signature]</i>	1
3/6/81	<i>[Signature]</i>	2
9-25-81	<i>[Signature]</i>	3
DRAWING NUMBER 8270-1-802-206-002		
REV 1		

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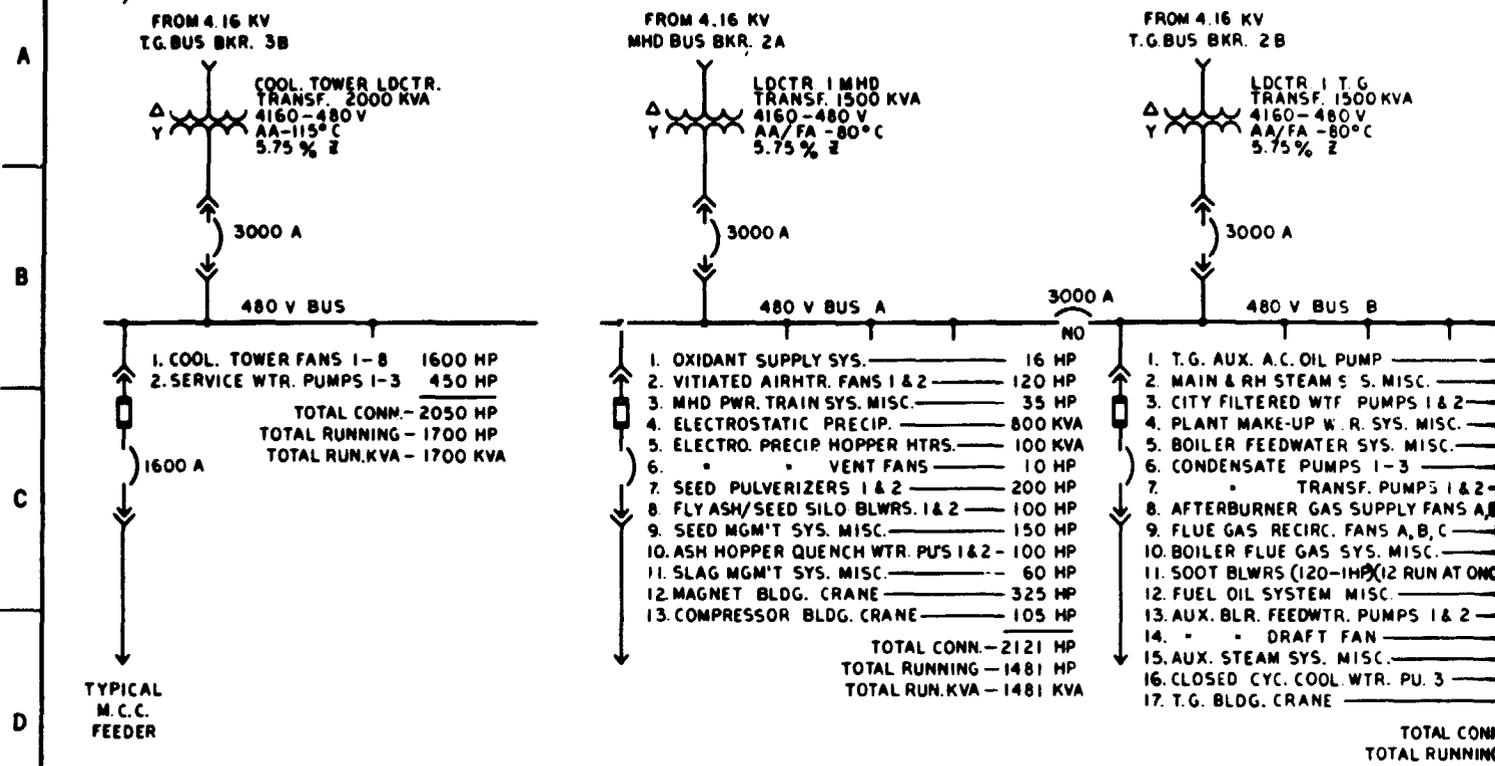
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SEE DWG. NO. 802-206-002



SEE DWG. NO. 802-206-002

