ETS-1 CONTROL POINT GENERAL INDOCTRINATION COURSE

VOLUME ONE

NTO-T-0025

MASTER

NERVA Test Operations

Nuclear Rocket Development Station

Jackass Flats, Nevada

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GENERAL INDOCTRINATION COURSE

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LIST OF ABBREVIATIONS

ACV	Analog Control Valve
AFEL	Assistant Facility Engineer - Left
AFER	Assistant Facility Engineer - Right
ARS	Analog Recording System
ASE	Assistant Stand Engineer
ATD	Assistant Test Director
ATE	Assistant Test Engineer
BCD	Binary Coded Decimal
BD	Burst Diaphragm
CFDTS	Cold Flow Development Test System
CPB	Control Point Building
CSE	Control Systems Engineer
CTE	Chief Test Engineer
DAS	Data Acquisition System
DDP	Digital Data Processor
DDS	Digital Data System
DTD	Deputy Test Director
EIV	Engine Installation Vehicle
EST	Engine System Test
E/STS-2/3	Engine/Stage Test Stand 2-3
ETC	Engine Test Compartment (Shields)
ETO	Engine Test Operations
ETS-1	Engine Test Stand No. 1
FAC	Facility Activation Controller
FC	Facility Control System
FC	Flow Controller
FCR	Forward Control Room
FCV	Flow Control Valve

FDET	Facility Data Evaluation Team
FEL	Facility Engineer - Left
FER	Facility Engineer - Right
FOSS	Facility Operation Shift Supervisor
FS	Flow Switch
GCS	Gate Controlled Switch
GFS	Gas Fill and Service
GSE	Ground Support Equipment
HPG	High Pressure Gas
L-3	L-3 Locomotive (RTS Prime Mover)
LFE	Lead Facility Engineer
LIE	Lead Instrumentation Engineer
LRE	Lead Reactor Engineer
LSE	Lead Safety Engineer
MCC	Manned Control Car
MCCC	Master Calibration and Channelization Control Panel
MCR	Master Control Room (E-MAD)
NERVA	Nuclear Engine for Rocket Vehicle Application
NES	Nuclear Exhaust System
NRO	Nuclear Rocket Operations (Sacramento)
NTO	NERVA Test Operations
NTR	North Terminal Room
PC	Pipe Chase
PC	Pressure Controller
PCV	Pressure Control Valve
PRV	Pressure Reducing Valve
PT	Pressure Transmitter
RADA	Remote Assembly-Disassembly Aid
REC	Remote Engine Control System
RIC	Remote Installation Console

RMSF	Radioactive Material Storage Facility
RSV	Remote Shutoff Valve
RTB	Resistance Temperature Bulb
RTS	Railroad Transport System
RTT	Resistance Temperature Transducer
RV	Relief Valve
SCR	Silicon-Controlled Rectifier
SSC	Support Service Contractor
STR	South Terminal Room
SV	Solenoid Valve
SVB	Solenoid Valve Box
TC	Temperature Controller
TC&P	Termination, Cabling and Patching
TCB	Test Cell Building
TD	Test Director
TDC	Test Diagnostic Center
TPA	Turbo Pump Assembly
TRB	Test Review Board
TS	Test Stand
TSA	Test Stand Adaptor
TSCS	Test Stand Control System
TSE	Test Stand Engineer
TSER	Test Stand Equipment Room
TSS	Test Simulation System
TSTB	Test Stand Terminal Box
TVC	Television Console
UTS	Upper Thrust Structure
WANL	Westinghouse Astronuclear Laboratory
WEMU	Weighted Envelope Mockup
XE	Experimental Engine
XECF	Experimental Engine Cold Flow
NECF	NERVA Engine Cold Flow

VALVES (XE Propellant Feed System)

CKV	Cooldown Check Valve
CSV	Cooldown Shutoff Valve
CVV	Cooldown Line Vent Valve
DCKV	Discharge Check Valve
HBVV	Hot Bleed Vent Valve
HPSV	Helium Purge Shutoff Valve
NCKV	Normal Cooldown Check Valve
PDKV	Pump Discharge Check Valve
PDSV	Pump Discharge Shutoff Valve
PDVV	Pump Discharge Vent Valve
PKV	Pneumatic Vent Check Valve
PSV	Propellant Shutoff Valve
SFV	Shielf Fill Valve
TBV	Turbine Block Valve
TPCV	Turbine Power Control Valve
TSV	Tank Safety Valve

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SECTION I
NERVA PROGRAM ORIENTATION

A. INTRODUCTION

During the past few years significant accomplishments have been made in nuclear rocket development. It is the purpose of this section to review the progress and to highlight the present status of the NERVA engine development. NERVA is part of the Rover nuclear rocket engine program which was initiated at the Los Alamos Scientific Laboratory in 1955. Table I-1 traces the key accomplishments of this development program from the beginning through the demonstration of feasibility, to the present phase of advancing the technology and extending performance.

The initial progress achieved by Los Alamos on the conceptual reactor design and fuel element development was rapid, and by 1959 the Kiwi series of reactor tests demonstrated the significant performance and potential of nuclear rocket engines, and stimulated interest in the development of a flight-type engine. The NERVA (Nuclear Engine for Rocket Vehicle Applications) Program was initiated in 1961. This effort, under the direction of the Space Nuclear Propulsion Office of NASA and the AEC, is being performed by the Aerojet-General Corporation as the prime contractor, and the Westinghouse Electric Corporation as the principal subcontractor for the nuclear subsystem development. The Kiwi development program demonstrated feasibility and proof-of-principle of the nuclear rocket reactor. The NERVA Program is intended to extend these principles to practical application in the development of a system that would withstand the loads, environment, and operating requirements

of flight. The Kiwi and NERVA reactor programs have been closely co-ordinated to provide a continuing, logical development, and the chronology of progress clearly highlights the noteworthy advance that has been achieved in our basic technological understanding of the operating potentials and characteristics of the nuclear rocket engine.

Figure I-1 shows a schematic of the technology engine which is designed as a ground test system that delivers approximately 55,000 pounds of thrust. Liquid hydrogen (LH_2) is delivered to the turbopump by dewar pressure. The turbopump increases the LH_2 pressure to 940 psia and provides approximately 75 pounds/second through the pump discharge line to the nozzle inlet torus. At this point a small fraction of the LH_2 is by-passed around the nozzle coolant tubes to cool the nozzle-to-pressure-vessel closure bolts. The remainder of the LH_2 flows through the nozzle U-tubes, through the outer reflector of the reactor core and into the dome end plenum of the pressure vessel. Here the hydrogen is reversed in direction and passed through the reactor fueled section where it is heated and into the thrust chamber formed by the convergent section of the nozzle. The hot hydrogen from the thrust chamber accelerates through the nozzle throat thereby producing the required engine thrust.

A small portion of the core exit hot gas is drawn off at the hot bleed port located in the convergent section of the nozzle and mixed with cold diluent extracted from the dome end of the pressure vessel. This fluid is used to power the turbine that drives the turbopump. The hydrogen mass flow rate to the turbine is controlled by the turbine power control valve. Turbine flow is exhausted through the two control nozzles.

Under operating conditions, the temperature of the hydrogen entering the reflector is approximately 130°R . The reflector consists of 12 beryllium sectors, each containing a control drum. Boral plates in these drums supply the poison for reactor control. The hydrogen cools the various parts of the reflector, and the gas temperature reaches approximately 220°R before passing through the core. The NRX-A reactors are right circular cylinders and produce 1120 Mw of power at nominal full power. In the core, nuclear energy increases the gas temperature by more than 4000°R . The core consists of graphite fuel elements combined into clusters.

The NRX reactor tests and the first engine system test (NRX/EST) were performed at the Nuclear Rocket Development Station (NRDS) with the system in the upfiring position shown in Figure I-2. The test assembly is mounted on the test car as shown and is connected to the test cell. For the NRX tests the turbopump is auxiliary gas driven by a facility installed turbopump, and for the NRX/EST the turbopump was mounted on the test car and was driven by the hot bleed gas from the nozzle.

All future engine system tests, starting with the testing of the first experimental engine (XE-1) in the fall of 1967, will have their components in flight oriented configuration and will be tested in the down-fired position at ETS-1. An important capability of this test stand is altitude simulation, and consequently a significant step forward in the knowledge of nuclear rocket engine operation in space will be achieved in this testing. Performance margin evaluations will be conducted with the XE-1 and XE-2 engines presently scheduled in the NERVA technology development program.

Any appraisal of progress implies a comparison with the developmental status at some previous key date. The period of early 1964 has been selected as a base point for comparison, for at this date there were a great many feasibility questions. Some of these were of second order, but a number of key questions existed.

1. Can a reactor be constructed that will produce optimum propellant temperatures and maintain structural integrity and reliability for useful operating periods?
2. Will the reactor have multiple restart capability?
3. Will the control of the engine be inherently stable, simple and reliable?
4. Will engine performance be predictable by use of analog and digital models?
5. Will non-nuclear hardware such as the turbopump, nozzle, valves, lines, instrumentation, etc., be reliable for useful operating periods?

B. REACTOR ENDURANCE

In early 1964 the structural integrity of the reactor had not been demonstrated. The core vibration questions introduced by the Kiwi-B4-A test were not completely eliminated. The cold flow tests on Kiwi and NRX-A1 were designed to demonstrate that the problem was understood and corrected. At that time no power test had been conducted on the reactor design principle selected for the NERVA development.

Figure I-3 lists the key tests that have been conducted since that period and the cumulative time at nominal full power. In 1964 the power tests conducted on Kiwi-B4-D, NRX-A2, and Kiwi-B4-E showed that the structural problem with the reactor had been corrected and operation was achievable at high chamber temperatures for significant periods of time. It then became necessary to show that the system would operate for useful mission times.

Early estimates of required engine operating times for useful missions varied up to twenty minutes. Later mission studies indicate times up to 40 minutes for the more ambitious missions. However, the nominal operating time for a favorable Mars mission is in the 20-30 minute range, and the operating time for a very useful lunar mission is 10 minutes for the large size (200-250 K thrust) NERVA engine and 20 minutes for a 55,000 pound thrust engine.

These operating times should be compared with the endurance test times actually achieved in the NRX-A3, NRX/EST, and NRX-A5 tests. The NRX-A3 reactor was operated in its first run for 3.5 minutes and was inadvertently (scram from full power) shutdown due to a facility circuitry malfunction. It was restarted and operated at full power for a period equivalent to the test cell propellant capacity, for a total operating time of 16.3 minutes at or near full power and temperature.

At this point in the program, it was determined that an early engine system test was feasible. Therefore, the planned NRX-A4 reactor test was changed to the NRX/EST, and the planned reactor objectives were combined with a series of key engine system objectives. This system was started ten times to power, and the total operating time at power conditions was 116 minutes. The time at full power was approximately 28 minutes. The NRX-A5 reactor was operated for two periods for a total of thirty minutes at full power operation.

The Phoebus 1A test by Los Alamos Scientific Laboratory was conducted on 25 June 1965 for a period of 10.5 minutes. This test was the first of the Phoebus series of tests directed toward a higher thrust and performance reactor. At the present time, the experience on Rover systems tested since 1964 includes over 100 minutes of operation at or near full operating power and temperature.

C. RESTART CAPABILITY

In addition to the endurance tests which were conducted, the table in Figure I-3 shows starts to power conditions that have been achieved. The first restart was achieved on Kiwi-B4-E, and since that time experience has been gained on 21 starts--1 on Kiwi-B4-D, 2 on Kiwi-B4-E, 2 on NRX-A2, 3 on NRX-A3, 1 on Phoebus 1A, 10 on NRX/EST and 2 on NRX-A5.

The prime purpose of the restart capability requirement was for ground testing so that extended endurance data could be obtained with limited facility hydrogen supplies. In addition, various engine system tests were required, and it was essential that a single reactor be used for those experiments.

A number of these restarts were made under conditions worthy of particular note. The shutdown on NRX-A3 was very severe because flow to the reactor was inadvertently lost while the reactor was at full power. The reactor was scrammed and the temperature transient to which the test article was subjected was very large. A thorough analysis indicated that the reactor integrity, while somewhat impaired, was capable of a restart and that no impairment to the nozzle or other system components was detected. Restart was demonstrated on 20 May 1965.

A restart of interest is run 2 of EP-11B on NRX/EST. During previous restarts, the engine component material temperatures were ambient, and the hydrogen was heated by the stored energy in these components prior to entering the core. The question arose: could the engine system be subjected to an excessive temperature transient similar to that expected in space? To investigate this point, the outer reflector was cooled to 60°R prior to the restart. No severe system transient occurred and the system started up satisfactorily by using nuclear rather than stored energy.

D. ENGINE CONTROL

A major part of the early control efforts was applied to the development of an adequate understanding of the reactor dynamics under various power and flow conditions. Initial concerns included uncertainties in the temperature coefficient of reactivity and the reactivity effects of the gaseous and liquid hydrogen. Analytical studies indicated that the temperature coefficient of reactivity was negative; that is, a temperature increase results in a negative reactivity insertion and a consequent power decrease. Similarly, the hydrogen effect on the reactivity is proportional to its density; that is, a decrease in density reduces the moderating effect of the hydrogen and the reactor power decreases. Concern existed with the possibility that the introduction of liquid or high density hydrogen into the core could cause instabilities or would introduce control complexities. While analog computer studies indicated the inherent stability of the reactor system, it was necessary to demonstrate this feature by a series of experiments. The first startup of a nuclear reactor with hydrogen as a coolant was successfully achieved on Kiwi-B4-D. To explore the inherent stable and self-controllable properties of the reactor system, a series of experiments were conducted on NRX-A2 which included operation over a range of 20 to 60 Mw with the control drums fixed. On NRX-A3 a fixed drum startup was made from 1 Mw to 35 Mw. This startup was initiated by moving the control drums a predetermined amount and then maintaining them in a fixed position. The liquid hydrogen flow to the system was increased at a linear rate. The hydrogen density effect, as it passed through the core, caused the power to increase. A steady state condition was attained where the hydrogen density and temperature coefficient of reactivity effect balanced the reactivity inserted by the drums. Of particular significance was the stability and ease of control of the system during these tests.

The encouraging results of these experiments stimulated more ambitious tests on NRX/EST and NRX-A5. For the first time chamber pressure was controlled. The chamber pressure demand was slaved to measured chamber temperature and controlled the flow of drive gas to the turbine by properly positioning the turbine power control valve. During the NRX/EST tests the entire operating range of the engine was mapped, and transfer functions were made at

numerous operating points in order to develop an understanding of system dynamics. One of the NRX/EST experiments was a fixed drum startup to a higher power level of 250 Mw as indicated by the second curve in Figure I-4. During the NRX-A5 test series a reactor power level of 870 Mw was reached with the drums fixed, and the power level was then trimmed to full power. The original control system depended on a neutron feedback loop with temperature feedback as a trim to the power loop. The output of the neutron feedback error signal was used to vary the control drum position. The first tests made with the neutron feedback loop removed were conducted on NRX/EST. The neutron feedback loop was removed when the reactor was operating at stable power conditions. Examination of the test results indicated the adequacy of this type of control, thus allowing the simplification of the NRX-A5 control system. The two power runs made on the NRX-A5 reactor test were made without the neutron feedback loop.

Additional tests were conducted on an on-off type temperature control system during the NRX/EST tests. This type control could replace the proportional temperature control feedback loop which has been used and is presently being studied for future systems application.

The control test results to date indicate the wide latitude in control system design. The inherent stability of the engine system affords many opportunities of simplified and highly reliable control system design.

E. ENGINE COMPONENT RELIABILITY

During the NRX-A program, two major components of the technology engine were tested and their designs verified. These were the pressure vessel assembly including the forward closure and the stainless steel U-tube nozzle. NRX/EST allowed for extended duration testing of the engine turbopump assembly, the hot bleed port, the turbine power control valve, and miscellaneous engine lines and valves. Development of diagnostic and control instrumentation for use in a combined cryogenic and nuclear radiation environment has successfully continued throughout the NERVA program.

F. ENGINE PERFORMANCE PREDICTABILITY

The NRX/EST test demonstrated the functioning of the engine system during bootstrap startups. During this test series the engine system was subjected

to ten startups to power, of which eight were to high temperature conditions. **Figure I-5** shows a comparison of some calculated and measured engine parameters during such a startup. Prior to testing NRX/EST, engine cold flow start transients were investigated in the cold flow development test system (CFDTS). The results of these tests were duplicated during the cold flow tests on NRX/EST. The predicted calculated test parameters in all cases closely matched the actual test results.

G. FUTURE

The test results described indicate the progress that has been achieved in the nuclear rocket development since early 1964. The basic questions of feasibility have been answered and a firm technological base has been established.

The nuclear subsystem tests now planned include NRX tests to explore longer duration operation, and Phoebus reactor testing by the Los Alamos Scientific Laboratory to explore higher temperature and power operation. Mission studies have indicated that a single size engine of about 200,000 pounds thrust would be close to optimum for all the missions being considered in the late 1970's or 1980's. The Los Alamos Scientific Laboratory will test a reactor of this rating in their Phoebus 2A test.

Initial studies are underway to determine the optimum configuration for a NERVA engine (NE) which will develop approximately 200,000 pounds thrust, rather than the 55,000 pound size on which tests have been conducted to date. This engine will be developed and demonstrated through preliminary flight rating tests and available for use in manned planetary missions after 1975.

1955 to 1961	Research phase of the program conducted by the Los Alamos Scientific Laboratory. General design methods were established, controls data and materials information were accumulated, fuel element fabrication methods were developed and an initial reactor test was conducted.
1961	NERVA development team of Aerojet-General Corporation and Westinghouse Electric Corporation selected.
1962 to 1963	Kiwi power test series demonstrated successful reactor startup with liquid hydrogen. In November 1962 tests of the Kiwi-B4-A, which was the favored design for the NERVA engine, led to the identification of fuel element vibration and structural problems. Year of redesign, analysis, component and subsystem testing, and cold flow tests of Kiwi-B4-A and Kiwi-B4-B reactors that demonstrated cause of vibration and indicated that revised design approaches of Los Alamos and Westinghouse would lead to a stable design. Kiwi-B4-D and NRX-A1 cold flow tests indicated that the redesigns avoided the vibration problems.
1964	Kiwi-B4-D and Kiwi-B4-E successfully operated at full power and temperature, restart was included. NRX-A2 reactor operated at full power and temperature conditions. Restart tests were also conducted.
1964 to 1966	NRX-A3 operated successfully for over sixteen minutes at full power and temperature conditions. Three restarts demonstrated and fixed drum reactor transient test completed. Phoebus 1B reactor tested. The NRX/EST, the first breadboard engine system demonstrated bootstrap (self-starting) capability over a wide range of conditions; stability and predictability of engine performance over the full operating regime; and operated for a total of 29.5 minutes nominal full power. NRX-A5 operated for 29.4 minutes nominal full power.

TABLE I-1

PROJECT ROVER REACTOR DEVELOPMENT CHRONOLOGY

FIGURE I-1

FIGURE I-2

REACTOR IN UPWARD FIRING POSITION
FOR TRAINING USE ONLY

FIGURE I-2

FIGURE I-3

POWER OPERATING EXPERIENCE
FOR TRAINING USE ONLY

FIGURE I-3

FIXED CONTROL DRUM STARTUPS

FIGURE I-4

FIXED CONTROL DRUM STARTUPS
FOR TRAINING USE ONLY

FIGURE I-4

FIGURE I-5

EP-IVA ENDURANCE RUN
FOR TRAINING USE ONLY

FIGURE I-5

ETS-1 CONTROL POINT OPERATOR
GENERAL INDOCTRINATION COURSE

SECTION II
NRDS FACILITIES

A. MAJOR FACILITIES

The facilities at the Nuclear Rocket Development Station include Test Cell A, Test Cell C, R-CP, ETS-1, R-MAD, E-MAD, and support areas.

Test Cells A and C are capable of static firing reactors in the nozzle upward direction. Control of test operations at each test cell is from R-CP, Reactor Control Point Building, located two miles away.

Engine Test Stand No. 1 (ETS-1) is a complete facility in itself and is used to static test nuclear engines fired in the nozzle downward direction.

All three test areas are connected by railroad to both MAD buildings-- Reactor Maintenance, Assembly and Disassembly Building; and Engine Maintenance, Assembly and Disassembly Building.

The support area contains Administration and Engineering Building, Technical Shops, and Warehouses. Figure II-1 shows the respective locations of the facilities.

B. REFERENCE PUBLICATIONS

1. ROVER, The National Program for the Development of Nuclear Rockets; A Joint AEC-NASA Program.
2. NUCLEAR PROPULSION FOR ROCKETS, Los Alamos Scientific Laboratory, June 1964.

3. NUCLEAR ROCKET DEVELOPMENT STATION, Space Nuclear Propulsion Office, September 1963.
4. MAINTENANCE, ASSEMBLY AND DISASSEMBLY BUILDING FOR PROJECT ROVER, Los Alamos Scientific Laboratory.
5. NUCLEAR PROPULSION FOR SPACE, USAEC, May 1967.

In addition, the 13 minute color film E-MAD Training illustrates the E-MAD facility and the elaborate remote handling capabilities.

**NUCLEAR ROCKET DEVELOPMENT STATION
FACILITIES**
FOR TRAINING USE ONLY

FIGURE II-1

NERVA
TRAINING

ETS-1 CONTROL POINT OPERATOR
GENERAL INDOCTRINATION COURSE

SECTION III
ETS-1 FACILITY DESCRIPTION

A. GENERAL

The ETS-1 Area is a self-contained complex for the development and static test firing of a Nuclear Rocket Engine. Within the area are contained all the buildings and utilities, test structures, process storage, piping distribution system, and operations control center. The entire test complex is wired together by the Instrumentation and Controls Systems (I & C), along with its associated Data Acquisition Systems, for conducting and recording various types of test programs of the NERVA Engines. In order to understand better the relationship of the I & C Systems to the ETS-1 complex, it is well to look at the physical layout of the ETS-1 complex.

B. PHYSICAL LAYOUT

The overall facility is shown on the ETS-1 Site Plan, Figure III-1. During test runs all personnel will be stationed in underground buildings for protection. The major areas below grade are the Control Point Building, Forward Control Room, Test Cell Building, and Test Stand Equipment Room. These are connected by a tunnel some 1200 feet long and extends from the control point at the south end to the test cell at the north end. Essential utilities and all I & C Controls serve the area through this tunnel. Access to the underground areas is through the tunnel, or by stairways at each area. All general support buildings and test structures are located above grade.

The test facility is divided into major areas as a guide in locating various buildings and systems. The area code numbers and description are listed in Figure III-2. All test equipment and I & C components are keyed to these area designations.

1. Control Point Area. The center of activity during a test run is the control point area. From here all test operations are conducted, and all utilities are controlled.

a. Control Point Building. The test operations are run from the underground CPB. Access to this building is through the eight-foot square tunnel at the south, or by separate stairs leading from the surface. Offsets in the stair wells and tunnel act as neutron traps to prevent outside radiation scatter from entering the underground areas. The rooms are further protected from radiation effects by thick concrete ceilings and earth cover.

The facilities control, data acquisition, and recording systems are located in rooms as shown in Figure III-3. Also shown are the various operator control consoles and instrumentation racks.

b. Utility Equipment Building. The miscellaneous utilities are located above ground in the utility equipment building. These include boiler room, air conditioning equipment, and demineralizer equipment. The electrical equipment room contains power transformer and motor control center for operation of the electrical equipment in this area. During a test run, the operation of most of the equipment in this building may be controlled remotely from a panel located in the utility equipment control room below grade.

Certain features of the air conditioning system are of special importance to operating personnel and electronic systems. All air that enters the facility is cleaned by passing through absolute filters to remove micron size particles that may be radioactive from hot runs. Some 20% of the entering air goes through humidity conditioning equipment to maintain approximately 10 - 15% relative humidity. Heating, cooling, and humidity control are both for personnel comfort and to maintain most efficient operation of electronic equipment. Further, all movement of air travels up the tunnel and exhausts at the test stand.

2. Power Substation Area. Electrical power is delivered to the ETS-1 substation at 69,000 volts. In the transforcer yard it is stepped down to 4160 volts for distribution to power subcenters in various areas. Located in the diesel generator building are three 150 kw diesel driven generators that supply power to the essential bus during tests. Adjacent to the south side of the diesel generator building are three trailers, two of them each contain a 250 kw diesel driven generator, and the third has the control center. These trailers furnish power to the instrument bus during tests. All five diesels are controlled from the Control Point Building.

3. Forward Control Area. In the Forward Control Area there are three major groups of activities: (a) truck unloading and valve manifold, (b) fill station building compressor and equipment rooms, (c) lower level Forward Control Room.

a. All process gases and liquids are trucked in and unloaded at the valve manifold for distribution to their respective storage containers. Liquid oxygen is the one exception in that it is unloaded directly into the LO_2 dewar without going through the fill station valve manifold.

b. The fill station building contains high pressure compressors for pumping process gases up to bank storage pressures. These gases are helium, hydrogen, and nitrogen. For safety when handling hydrogen, this room has a separate air supply and exhaust system for maintaining it at a lower pressure than the rest of the building.

In the adjacent room there are two low pressure compressors, one for utility air and one for instrument air. The motor control center for all electrical equipment in this area is in the utility room behind the compressor location.

c. Figure III-4 shows the lower level and Forward Control Room with racks for signal conditioning equipment and Digital Data System. These racks are wired through terminal strips in panels in the termination room to the tunnel cable trays. In the adjoining utility room are the 28 vdc battery supply, two 400-cycle generators (future use), and local air conditioning equipment.

4. Storage Farm Area. All process gases and liquids are stored in the tank farm area. The process gases, helium, hydrogen, and nitrogen, have

various uses which are discussed in Section VI. These gases are stored in high pressure horizontal tanks V-3201 thru V-3209. The quantity of each gas storage is a function of individual test requirements. Flexibility of tank usage is achieved by valves and piping manifold located under the canopy shelter along one end of the tank row.

Process liquids are the cryogenics LH_2 , LN_2 and LO_2 . Liquid hydrogen is stored in a 250,000 gallon dewar V-3801, liquid nitrogen in a 31,000 gallon dewar V-3601, and liquid oxygen in a 22,000 gallon dewar V-2801.

Adjacent to the liquid nitrogen dewar is a pump/vaporizer unit for converting LN_2 to GN_2 . A similar pump/vaporizer unit for converting LH_2 to GH_2 is outside the northeast wall of the liquid hydrogen dewar. In operation this equipment draws the cryogenic liquid from its respective storage dewar, pumps it up to tank pressure, then through vaporizing coils where heat transfer converts liquid to gas, and the gas in turn is piped to the proper high pressure gas storage tank.

Also stored in the tank farm is liquid propane in a 15,000 gallon horizontal tank V-3401. Most of the propane serves as liquid fuel to the steam generator. A portion of propane is vaporized into gas for use in pilots atop flare stacks and pilots on the NES exhaust duct outlet. Flare Stack FS-3801 provides for safe burnoff of large emergency releases of LH_2/GH_2 from storage vessels in the Tank Farm Area.

5. Test Stand Area. There are six major centers in the Test Stand Area: (a) Test Stand, (b) Engine Test Compartment, (c) Exhaust Duct Vault, (d) Pipe Chase, (e) Steam Generator, (f) Test Stand Equipment Room, (g) Test Cell Building.

a. Test Stand. The Test Stand is an aluminum structure 122 feet high. Within the stand are the liquid hydrogen run tank engine interface support frame and thrust measurement, deluge system, service elevator, weather doors, and flare stacks. The lower portion has the test stand adapter with provisions for mounting the NERVA engine. This includes the capability for remotely connecting and disconnecting all process piping, and instrumentation and controls, to the engine. Along the south base of the aluminum

structure is a concrete shadow wall, 38 feet high and 3 feet thick, which affords radiation protection to the facility connections entering the Test Stand.

b. Engine Test Compartment. Six sections of radiation shields join to form the Engine Test Compartment. The ETC provides a gas tight enclosure for operating the engine in an inert environment below atmospheric pressure, in addition to reducing radiation damage to surrounding area.

c. Exhaust Duct Vault. The large concrete vault below the test stand contains the engine exhaust duct and support structure. A rolling door across the north end of the vault can be moved to the closed position after a hot run. This concrete door confines high level radiation within the duct vault, and allows for quicker access of personnel to the test area.

<u>ITEM</u>		<u>PROCESS FLUID</u>	<u>CAPACITY</u>	<u>WORKING PRESSURE PSIG</u>
V-2801	Liquid Oxygen Storage Vessel	LO ₂	22,000 Gal.	400
V-3201	High Pressure Gas Storage Vessels	He, GN ₂	1763 Ft ³ Water	2500
V-3202	High Pressure Gas Storage Vessels	He, GN ₂	1763 Ft ³ Water	2500
V-3203	High Pressure Gas Storage Vessels	He, GN ₂	1763 Ft ³ Water	2500
V-3204	High Pressure Gas Storage Vessels	He, GN ₂	1769 Ft ³ Water	2500
V-3205	High Pressure Gas Storage Vessels	He, GN ₂	1766 Ft ³ Water	2500
V-3206	High Pressure Gas Storage Vessels	He, GN ₂	1763 Ft ³ Water	2500
V-3207	High Pressure Gas Storage Vessels	He, GN ₂ , GH ₂	2382.6 Ft ³ Water	2500
V-3208	High Pressure Gas Storage Vessels	He, GN ₂ , GH ₂	2393.1 Ft ³ Water	2500
V-3209	High Pressure Gas Storage Vessels	He, GN ₂ , GH ₂	2409.5 Ft ³ Water	2500
V-3401	Liquid Propane Storage Vessel	C ₃ H ₈	15,000 Gal.	400
V-3601	Liquid Nitrogen Storage Dewar	LN ₂	28,000 Gal.	250
V-3801	Liquid Hydrogen Storage Dewar	LH ₂	250,000 Gal.	100
V-5001	Liquid Hydrogen Run Tank	LH ₂	77,000 Gal.	50
V-5002	HP Liquid Hydrogen Emergency Cooldown	LH ₂	4,400 Gal.	1500
T-3302	Process Water Storage Tank	Demin. H ₂ O	2,500,000 Gal.	atmos.

TABLE III-1
PROCESS LIQUID AND GAS STORAGE

TEST STAND AREA	TEST CELL BUILDING	FORWARD CONTROL ROOM	CONTROL POINT BUILDING
Transducers:	Active Signal Conditioners	Data Acquisition System Narrow Band Amplifiers	Analog Recorders
Diagnostic	Passive Signal Conditioners	Data Acquisition System Wide Band Amplifier	Analog Tape Search Unit
Test Stand Control System	Signal Conditioner Output Patchboards	Data Patchboards	Event Recorders
Facility Control System	Gas Detection Electronics	Low Pass Pre-Sampling Filters	Digital Data System
Control Elements:	FC and TSCS Narrow Band Amplifiers	Digital Data System:	Formatter Units
Valves	FC and TSCS Wide Band Amplifiers	Data Acquisition Units	Tape Switching Unit
Position Potentiometers	Master Calibration and Channelization Control Panel	Forward Control Room Console	Digital Tape Recorders
Neutronic Detectors	Digital Data System Test Cell Console		Master Control Console
Combustible Gas Monitors	Test Stand Control System, Test Simulation System		Timing System
			Electrical Power Control System
			Test Diagnostic Center
			Communications System
			Television System
			Test Operations Consoles

TABLE III-2

MAJOR LOCATIONS OF I & C COMPONENTS

FIGURE III-1

ETS-I SITE PLAN
FOR TRAINING USE ONLY

GENERAL AREA	AREA CODE	AREA SPECIFIC DESIGNATION	GENERAL AREA	AREA CODE	AREA SPECIFIC DESIGNATION
Control Point Area	10	*Control Point Recorder Room 107	Test Stand Area	40	*Test Cell Building Electronic Room 104
	11	*Control Point Terminal Room 106		41	*Test Cell Building South Terminal Room 105
	13	*Control Point Electronic Control Room 108		42	*Test Cell Building North Terminal Room 103
	14	*Control Point Control Room 118, ETS-1		43	*Test Cell Building Equipment Room 102
	15	*Control Point Room 120		44	*Test Cell Building, Battery Room 100
	16	*Control Point Observation Room 119		50	*Test Stand Equipment Room
	17	*Control Point Data Processing Room 117		51	Test Stand Equipment Chase
	20	Utility Equipment Building		52	Test Stand Duct Vault
				53	Test Stand Pipe Chase
				54	Test Stand Pad
Power Substation Area	24	Diesel Generator Building	Miscellaneous Areas	55	Test Stand I&C Terminal Box Rack
	25	Electrical Substation		56	Test Stand Engine Section
Forward Control Area	27	Truck Unloading Station		57	Test Stand Upper Level Above El. 3848
	30	Fill Station Building		58	Drainage Ditch and North Area
	31	Forward Control Room 101 & 102			
	33	Forward Control Equipment Room 100			
	34	Propane Storage			
Storage Farm Area	28	LO ₂ Storage Area		06	Process Water Storage & Piping
	32	High Pressure Gas Storage		12	*Access Tunnel
	36	LN ₂ Storage			
	38	LH ₂ Storage			

* Denotes Underground Area

FIGURE III-3
CONTROL POINT BUILDING
FOR TRAINING USE ONLY

FIGURE III-4

FORWARD CONTROL ROOM FOR TRAINING USE ONLY

FIGURE III-4

FIGURE III-5

TEST CELL BUILDING
FOR TRAINING USE ONLY

FIGURE III-5

ETS-1 CONTROL POINT OPERATOR
GENERAL INDOCTRINATION COURSE

SECTION IV
FACILITY PROCESS SYSTEMS

A. INTRODUCTION

The Facility Process Systems include the storage and handling of all process liquids and gases up to the point of tie-in to the Test Stand at the main header block valves. This section covers the off loading at the Fill Station, gas compression, liquid-to-gas conversion, distribution and storage. Subsequent Section V discusses the use of the process liquids and gases in the Test Stand.

B. NITROGEN SYSTEM

1. Properties. Nitrogen is colorless, odorless, inert, boils at -320°F , weighs 6.74 #/gal at boiling point, is nontoxic but can cause asphyxiation by the displacement of breathing air.

2. Uses. Gaseous N_2 is used for (1) purging and inerting of flare stacks, electrical junction boxes, communication panels and flow lines, (2) leak checks, (3) actuation pressure for most RSV's, (4) pressurization gas for LN_2 dewar, LO_2 dewar and propane vessel, and (5) cooldown of engine.

Liquid N_2 is used for (1) cooldown of engine, and (2) conversion to GN_2 because it is more convenient and economical to store as a liquid.

3. Facilities. Figure IV-1 is a schematic diagram of the facility nitrogen system. The fill station is located at the southeast end of the test stand complex in the area 27. It can accommodate 2 truck-mounted nitrogen converters simultaneously. These converters can pump from their own

liquid storage directly into the high pressure vessels at the rate of approximately 75,000 scfh each. The truck mounted converters are only used when the facility converter is disabled, or if a large amount of gas is needed in a short time. Both the facility converter and the truck mounted converters can be operated simultaneously.

Gas from the fill station flows thru line 100-GN₂ to the area 32 fill headers then into the desired high pressure vessel, V-3201, V-3202, and V-3203. Liquid nitrogen is also unloaded at the fill station. From the vendor trucks the LN₂ flows thru 1-LN-3" to storage dewar V-3601. One truck load is approximately 40,000 pounds, or 6000 gallons, and can be unloaded in 1½ hours.

4. Storage Vessels. Gaseous nitrogen is stored in V-3201, V-3202, and V-3203. These vessels are rated 1763 cu ft at 2500 psig, and each holds approximately 300,000 scf of gas. These three vessels, as well as V-3204, V-3205 and V-3206, are located in a metal building just north of the fill station. The building is maintained at a minimum temperature of 100°F to avoid low temperature embrittlement of the storage vessel metal.

The nitrogen storage vessels are connected thru appropriate valving to 1-GN-8", the main nitrogen header. The bypass valves to V-3201 and V-3203 are normally open to maintain pressure in the header up to the header block valve. This pressure is used for the actuation and purge supply which will be discussed later.

Liquid nitrogen is stored in V-3601. This vessel is vacuum-jacketed and has a capacity of 28,000 gallons with a working pressure of 250 psig. Liquid N₂ flows thru 36-RSV-326 and 2-LN-4" to the N₂ mixing station then to the test stand. This vessel is the source of LN₂ for the facility LN₂ converter thru 36-RSV-701 and line 227-LN-2".

V-3601 is pressurized thru 18-GN-1, 36-RSV-108 and 36-RSV-325 from the main N₂ header.

The liquid level is indicated on a Δ P gage calibrated in gallons of LN₂ and thru a Δ P transducer which has its indicator on the FER console. The vacuum in the annular space is maintained by a continuously operating Kinney vacuum pump.

5. Converter. The LN_2 converter is manufactured by the Hoffman-Paul Division of Air Reduction Co., Inc. It consists of a 2-cylinder high pressure pump, an ambient air vaporizer, an electric vaporizer, and an assortment of valves, gages and controls. After setup, chilldown, and starting, the converter needs no attention and will shut down automatically when the discharge pressure reaches 2500 psig. The normal capacity of the converter is 50,000 scfh.

6. Actuation System. The actuation system originates at the main header 1-GN-8" upstream of the header block valve. In area 32 the actuation pressure is reduced to 1000 psig. The actuation gas is then piped to the actuation panels at each solenoid valve box where the pressure is reduced to 500 psig. The actuation gas is piped in to the SVB and to a series of manifolds. The manifolds supply the gas for actuation of each RSV in the system. In the line to the actuator of the RSV is a Jamesbury shutoff valve and a 4-way solenoid control valve. The operation of the RSV is to be covered by another section.

Each SVB complex has a backup system of gas using several K-bottles at high pressure. The system is equipped with pressure reducers, relief valves, etc., and a pressure switch which will bring the K-bottles on the line in the event that the normal actuation pressure is lost.

7. Purges. Nitrogen purges are plumbed to the molecular seals on the flare stacks, the LH_2 12" vent line, and all SVB, communication panels, and junction boxes in locations where H_2 concentrations may occur.

8. Header. The main nitrogen headers 1-GN-8" originates as the high pressure vessel manifold; however, an 8" RSV isolates the manifold from the header. Line 4-GN-2" tees off the header and supplies gas to pressurize the LO_2 and propane tanks. Line 18-GN-1" pressurizes the LN_2 dewar. The 8" line then proceeds thru the mixing station to the test stand.

C. HYDROGEN SYSTEMS

1. Properties. Hydrogen is colorless, odorless, and the lightest of all elements. It boils at -423°F , weighs .596 #/gal at boiling point, and is not toxic. It requires low flash energy to ignite, and burns with an almost invisible flame.

2. Uses. Gaseous H_2 is used to pressurize the LH_2 storage and run dewars, and for engine cooldown. Liquid H_2 serves as the engine propellant, cooldown fluid, and also for conversion to GH_2 storage at high pressures.

3. Facilities. Figure IV-2 is a schematic diagram of the facility hydrogen system. The LH_2 fill station is located next to the LN_2 fill station. A 2" vacuum-jacketed line extends to V-3801, the storage vessel, thru appropriate valves, filters, etc. The line is purged with helium both before and after transferring LH_2 .

Truck unloading is performed with great care to avoid any leakage that may cause a concentration of combustible gas. All tools used in the operation are of a non-sparking material to avoid any possible ignition. A truck contains approximately 12,000 gallons and requires about 1 hour to unload.

4. Storage Vessels. Gaseous hydrogen is stored in outdoor vessels V-3207, V-3208, and V-3209. They are rated 2395 cu ft at 2500 psig, and each holds approximately 400,000 scf of gas. These three vessels are located east of the building containing the nitrogen and helium vessels. They are connected to 1-GH-6" thru appropriate valving.

Liquid hydrogen is contained in the large, spherical, vacuum-jacketed dewar V-3801 which has a capacity of 250,000 gallons of 100 psig working pressure. This hydrogen is used to fill the run vessels and to supply the LH_2 to GH_2 converter. The vacuum in the dewar annular space is maintained at 2-10 microns by intermittent operation of the Kinney vacuum pump system located adjacent to the dewar. This vacuum pump is also used to evacuate the vacuum-jacketed transfer lines and for cleanup of the main headers after running hydrogen thru them.

Dewar V-3801 is pressurized from line 1-GH-1 $\frac{1}{2}$ " which originates upstream of the header block valve. The pressurization valve can be operated either in the manual or automatic mode and will be covered in another section.

5. Converter. The LH_2 to GH_2 converter is manufactured by the Cosmodyne Corporation and is similar in operation to the LN_2 converter. The output of this converter is 75,000 scfh. The installation allows for an alternate source of supply to the pump. A truck can be connected directly

to the supply line, thus avoiding the necessity of pressurizing the large dewar, and the need of the extensive post-run cleanup of the pressurization lines and flare stack. This converter also operates under automatic control, but is always observed while running to detect any possible leakage from any of the components.

D. HELIUM SYSTEM

1. Properties. Helium is colorless, odorless, inert, boils at -452°F , weighs 1.045 #/gal at the boiling point, and like nitrogen is non-toxic but can cause asphyxiation by displacement of breathing air.

2. Uses. Due to its low temperature characteristics, helium serves to purge LH_2 lines because nitrogen is unsuitable. It is used for pressurization and also as a leak check medium with the CEC leak detector. A very small leak can be located by using a minimum quantity of helium in a pressurized line or vessel.

3. Facilities. A schematic diagram of the facility helium system is shown in Figure IV-3. Helium is shipped in large high pressure tube trailers with a capacity of approximately 120,000 scf at 2600 psig. The fill station can accommodate two trailers simultaneously. To unload the trailers, the trailer pressure and the storage vessel pressures are equalized by free flow thru the fill system. When free flow stops, valves are arranged to divert the helium supply thru the compressor building. In the compressor building are two Corblin compressors, which are operated until the supply pressure from the truck is depleted to a pressure of 250 psig. There are three small tube trailers at the fill station and connected to the fill header with flex hoses. These trailers provide an extra storage capacity which is used for small purge operations.

Two Corblin compressors, C3002A and C3002B, are located in the compressor building. The suction and discharge line are plumbed so that either or both compressors can be operated as required. The compressors are two-stage, diaphragm type, water-cooled units. Helium is drawn thru the inlet check valve into the chamber above the diaphragm by the downward stroke of the piston, which is separated from the diaphragm by a volume of oil. On the upward stroke the piston flexes the diaphragm upward and discharges the gas thru the discharge check valve.

The compressed helium passes thru water-cooled heat exchangers between the compression stages, and after the second stage, then to the high pressure storage vessels.

4. Storage Vessels. Helium is stored in V-3204, V-3205, and V-3206. These vessels have an average volume of 1766 cubic feet at 2500 psig. The capacity at 100°F is approximately 265,000 scf each. They are located in the same building as the nitrogen vessels. The vessels are connected to the header manifold 106-He-6" thru appropriate valving similar to the nitrogen vessels.

5. Headers. Helium is provided at the test stand thru 106-He-6" for the large volume uses of the engine and test stand purging.

Another line branching off of the vessel manifold transports helium to the fill station for use during hydrogen unloading operations.

A third line 1-He-2" provides, thru a regulator, a source of low pressure helium for purging in the LH₂ storage and converting areas and on the test stand.

E. LO₂ SYSTEM

1. Properties. Liquid oxygen is pale blue, odorless, boils at -297°F, and weighs 9.51 #/gal.

2. Use. At ETS-1 the only use for LO₂ is as the oxidizer for propane in the steam generator.

3. Facilities. LO₂ is stored in V-2801, a 22,000 gallon dewar with a pressure rating of 400 psi. This vessel is equipped with a small vacuum pump which runs continuously on the annular space.

GN₂ is used to pressurize the vessel for a test. An unloading pad and fill line are located adjacent to the storage vessel rather than in the fill station. The LO₂ header to the steam generator is a foam insulated line.

F. PROPANE

1. Properties. Propane, C₃H₈, is colorless, boils at -51°F, weighs 4.24 #/gal, and has a mercaptan additive that gives it a powerful smell.

2. Uses. Propane is used as a liquid fuel in the steam generator, and as a gas in the igniters at the flare stacks and the NES exhaust duct outlet.

3. Facilities. The fill station for the propane system is adjacent to the LH_2 and LN_2 stations. Propane is unloaded differently than the other commodities. The truck contains an engine driven pump which propels the liquid to the storage tank. The vent gas from the tank is returned to the truck thru a second line. The storage vessel contains 15,000 gallons at 400 psi operating pressure. The vents are normally closed to prevent boiloff at the ambient temperature. This vessel is not vacuum-jacketed. The pressure in the vessel will correspond to the vapor pressure of propane. The propane tank is fitted with temperature conditioning equipment, consisting of a refrigeration compressor, expansion valves, cooling coils, insulation etc., for control of the propane temperature during the warm months.

GN_2 is used to pressurize the tank for a test or other steam generator operations. Another item in the propane system is the propane vaporizer, a device for supplying gas to the flare stacks. The operation of the vaporizer is very similar to that of a gas-fired water heater - a gas flame heats liquid propane to convert it to gas. Automatic temperature and pressure controls are provided.

The liquid propane header to the steam generator is a 4" foam insulated line.

G. VACUUM SYSTEM

A large two-stage vacuum pump system, located in the 38 area, is used for the evacuation of the annular space of LH_2 storage vessel V-3801, the vacuum jackets of the liquid hydrogen lines, and any of the gaseous hydrogen lines. A 6" vacuum header 10-VA-6" runs into the 32 area parallel to the vessel manifolds. This line can be used to evacuate any of the three main headers, the three fill headers, or any of the high pressure storage vessels.

H. GENERAL

All storage vessels are equipped with pressure transducers and gages. The liquid storage vessels also have liquid level indicators of the ΔP type.

The LH₂ vessel also has auxiliary methods; (1) continuous capacitance which indicates the percent level in the vessel, (2) point capacitance which does not work at all, (3) point resistors which are located at several levels in the tank. When the liquid hydrogen covers a resistor, the resistance changes and indicates this by a light on the FER console.

FACILITY HYDROGEN SCHEMATIC DIAGRAM
FOR TRAINING USE ONLY

FIGURE IV-2

ETS-1 CONTROL POINT OPERATOR
GENERAL INDOCTRINATION COURSE

SECTION V
TEST STAND PROCESS SYSTEMS

A. INTRODUCTION

The ETS-1 Test Stand Process System does not differ much from any other rocket test stand. The facility differs in its nuclear aspects, but the process systems provide the same functions as any other test stand. The lack of an oxidizer circuit for the main test article is very obvious. The NERVA rocket need only be supplied with a fuel; liquid hydrogen.

The test stand consists basically of three major systems; the run, the cooldown, and the miscellaneous support systems.

The run system includes the low pressure LH_2 system. The cooldown system includes many subsystems which are the fluids necessary to perform a controlled cooldown of the reactor. The miscellaneous support systems are the actuation and purge systems necessary to operate the test stand and engine controls.

B. RUN SYSTEM

1. V-5001 LH_2 Run Tank. The V-5001 LH_2 run tank located in the test stand is a 77,000 gallon dewar and supplies the engine with liquid hydrogen. It is a vacuum jacketed aluminum dewar which has been proof-tested to 82 psig with an allowable working pressure of 50 psig. The 4" x 6" relief valve is set to relieve at 55 psig, and the burst disc in parallel with it is designed to rupture at 65 psig.

The pressurization for V-5001 comes from line 4-GH-6"-AS, and is a branch of 15-GH-6"-FC which operates at a maximum pressure of 2500 psig.

The header pressure is reduced to 500 psig by PRV-426. PRV-426 is a 2" grove regulator with a capacity factor, CV, of 20, and is remotely loaded with helium. Upstream of PRV-426 is GF-16 with a capability of filtering down to 10 microns. PCV-165 is the pressure control valve downstream of PRV-426 which controls the pressurization of V-5001. The valve is a 2" annin valve with a CV of 13. Filter GF-52 is installed at the inlet of V-5001 and has a capability of filtering down to 10 microns.

The vent system of V-5001 flows into FS-5001. The vessel is capable of two types of venting. Variable venting rate is regulated by pressure control valve PCV-180. Rapid venting is accomplished by opening RSV-390.

The hydrogen is vented into FS-5001 and burned approximately 30 feet above the test stand.

The discharge system from V-5001 is 201-LH-8"-AS. Immediately below V-5001 are two butterfly valves; RSV-455 (2") and RSV-132 (8"). Line 201-LH-8"-AS is a foam insulated line. Below RSV-455 and RSV-132 are two Potter turbine flowmeters. Below the flow meters is a cone-type wire-type 4 x .041" diameter screen. PCV-579 is a 3" annin pressure control valve which enables the chilling of the main propellant line down to the engine interface.

The fill system for V-5001 consists of line 3-LH-6"-LV. This is a 600 ft. vacuum jacketed line from V-3801 to V-5001. RSV-252 is a block valve in 3-LH-6" which can isolate the transfer to V-5002.

The vacuum systems of 3-LH-6"-LV and V-5001 operate at approximately 5 microns.

2. V-5002 LH₂ Run Tank. V-5002 is another liquid hydrogen vessel at ETS-1. This is a high pressure dewar set up to provide high pressure LH₂ for engine cooldown.

The fill system is a two-inch line off of 3-LH-6" just upstream of RSV-252. The fill valve for V-5002 is RSV-106.

The vessel will operate at a nominal pressure of 1000 psig. The vessel design is such that the vessel has been proof-tested to 1875 psig.

The vent system of V-5002 flows into 21-GH-6" which flows GH_2 into FS-5001. RSV-109 is the two-inch vent valve tied in with PCV-250 for auto-control venting. RSV-110 is the 4" vent valve for rapid venting.

The relief valve on V-5002 is set to relieve at 1575 psig and the burst diaphragm is designed to rupture at 1600 psig at 72°F.

The outlet line of V-5002 is tagged 4-LH-6"-HV. This is the high pressure cryogenic cooldown line. 4-LH-6"-HV is approximately 80% vacuum jacketed. In this line is PCV-472 which is the LH_2 cooldown control valve. It is a hydraulically operated 4" valve with a CV of 290. This is a fail open, flow under the plug valve.

C. COOLDOWN SYSTEMS

The cooldown systems of the test stand consists basically of five systems. Specifically, the systems are the LH_2 , GH_2 , LN_2 , GN_2 , and He systems.

The LN_2 system consists of the nitrogen mix station, 225-LN-4" line and the tie into 4-LH-6". In the original design the mix station was designed to mix LN_2 and GN_2 to give a cold nitrogen supply gas to the test article. This requirement has since been deleted. The LN_2 flows thru FE-52 and is controlled by PCV-517 (CV = 110). The maximum operating pressure of this system is limited to 250 psig.

In the mix station there also exists a low pressure GN_2 system controlled by PRV-107 and FCV-50. This system supplies both a low pressure cooldown circuit thru RSV-134 and an alternate ETC purge supply thru RSV-548. The maximum operating pressure of this system is 500 psig.

The gaseous hydrogen cooldown circuit supply comes from 15-GH-6". PCV-251 is the GH_2 control valve. This is a hydraulically operated PCV with a CV of 195. Upstream of PCV-251 is FE-15 for measuring the GH_2 flow rate. Tied into the GH_2 system is a high pressure GN_2 system coming thru RSV-134. This system comes from 1-GN-8" and ties into 15-GH-6" just upstream of FE-15.

The He cooldown system includes 106-He-6"-FC controlled by PCV-471. PCV-471 (CV = 290) is a hydraulically operated PCV.

The GN_2 , GH_2 , and He cooldown systems all integrate just upstream of RSV-454 and RSV-460. The LN_2 and LH_2 systems integrate with the gas systems downstream of RSV-454 and RSV-460. All of the cooldown fluids eventually flow into 4-LH-6"-HV, thru the top shield, and to the engine interface.

D. MISCELLANEOUS SUPPORT SYSTEMS

1. Actuation and Purge Systems. The actuation and purge systems of the test stand consist of five basic systems; the control drum and TPCV actuation, the engine valve actuation, the TPA and engine purge, the disconnect actuator supply, and the ETC purge system.

a. Control Drum and TPCV Actuation System. The control drum and TPCV actuation system is broken into two parts. Line 201-He-2" is the 1500 psig helium supply for checkout of the control drums and TPCV. PRV-402 is the primary stepdown regulator and PRV-200 is the control regulator. Line 201-GH-2" is the supply of GH_2 for the run condition. PRV-402 is the primary stepdown regulator and again PRV-200 is the control regulator. Downstream of PRV-200 in the control drum actuation is a double block and vent system. GLV-2334, GLV-2332, and RSV-444 will be mechanically locked with GLV-2334 closed, GLV-2332 open, and RSV-444 closed. The TPCV actuation line is 240-GH-2" and the control drum actuation line is 201-GH-2".

b. Engine Valve Actuation System. The engine valve actuation system is a regulated helium system. PRV-485 will step the helium from 201-He-2" from 1500 psig to 500 psig for valve actuation. RSV-702 is the valve actuation shutoff valve. 217-He-1" is the engine valve actuation supply line.

c. Engine Purge System. The engine purge system comes from PRV-439. PRV-439 is the stepdown regulator for the 100 psig helium purge manifold. The engine purge supply valve is RSV-446, which allows helium to flow thru line 204-He-1". Also off of the 100 psig helium purge manifold stems the supply for the heated helium purge thru PRV-437 and HT-1.

d. Disconnect Actuator Supply. The disconnect actuators are supplied with 85 psig of GN_2 from PRV-405 and SV-464. The main supply for this system comes from line 9-GN-8". PRV-416 steps the 2500 psig in 9-GN-8" to 500 psig and PRV-405 steps this 500 psig to 85 psig.

e. ETC Purge System. The ETC purge system has two supplies of GN_2 . FCV-50 thru RSV-548 is a low pressure supply from the mix station. PCV-446 and PCV-447 are two control valves which stepdown the 2500 psig from 9-GN-8" to a controlled flow for the ETC purge. These control valves have a capability of flowing a maximum of 30 lb/sec and also control down to .516/sec. RSV-727 is in the purge line to the ETC and shuts off the supply to the purge ring.

2. Helium Purge System. The helium purge manifold on the test stand is supplied from 1-He-2" which operates at 1500 psig. PRV-26 steps this pressure to 100 psig for purging. The purge system is for purging the cryogenic systems and the engine.

Helium is also used to purge the top shield penetrations in which pass lines which contain liquid hydrogen. V-5001 cable duct and V-5002 manway are also purged with helium during liquid hydrogen operation. The use of helium is to eliminate any air which could form liquid air in the areas which come in contact with LH_2 .

3. Vacuum System. Vacuum pump VP-5001 is the main vacuum source for the test stand. The vacuum system consists of 3-LH-6", 4-LH-6", V-5001, and V-5002. All these systems operate from 1 to 5 microns. VP-5001 is a KDH-1200 Kinney pump. It consists of a 1200 CFM roughing pump and a 130 CFM boost pump with a capability of .5 microns.

4. Hydraulic System. The test stand control valve hydraulic system has a 25 GPM at 3000 psig Vickers hydraulic pump. Each PCV has two 10-gallon accumulators for fail safe operation. A backup hydraulic system also exists in a 4 GPM at 3000 psig pump. The backup pump will operate at 2000 psig with the main system operating at 2750 psig. Should the main system fail, the backup system will carry the load. Should both pumps fail, the accumulators can operate each PCV approximately 10 cycles.

E. REFERENCES

A deeper understanding of ETS-1 process systems can be obtained by reading the ETS-1 Data Book (NTO-R-086), reviewing the ETS-1 composite drawings, and a first hand look at the actual systems.

FIGURE V-1

HIGH PRESSURE COOLDOWN
SYSTEM - LH₂
FOR TRAINING USE ONLY

FIGURE V-1

FIGURE IV-2

HIGH PRESSURE GAS COOLDOWN SYSTEM
FOR TRAINING USE ONLY

FIGURE V-2

FIGURE V-3

LN₂ COOLDOWN SYSTEM
FOR TRAINING USE ONLY

FIGURE V-3

FIGURE V-4

LOW PRESSURE GN₂ PURGE
AND COOLDOWN SYSTEM
FOR TRAINING USE ONLY

FIGURE V-4

TEST STAND LOW PRESSURE LH₂ SYSTEM
FOR TRAINING USE ONLY

FIGURE V- 5

ETS-1 CONTROL POINT OPERATOR
GENERAL INDOCTRINATION COURSE

SECTION VI-A
ENGINE TEST COMPARTMENT

A. FUNCTION OF ENGINE TEST COMPARTMENT AND SHIELDS

The Engine Test Compartment and shields have three basic functions:
(1) to provide a safe, oxygen-free, operating environment for the engine,
(2) to provide radiation shielding in accordance with the requirements of safety, for the simulation of space radiation conditions, for economy of material selection elsewhere in the facility and to permit optimum use of ETS-1 and adjacent NRDS areas, and (3) to permit reductions in ambient atmospheric pressure around the engine in order to partially simulate space environmental conditions.

B. DESCRIPTION AND OPERATION

1. Engine Test Compartment and Shields. The Engine Test Compartment (ETC) is an environmental chamber which consists basically of six shield components, shown in Figure VI-A-1. Top and bottom shields are mated with two halves of the side shields to form a closed cylindrical container. A half donut-shaped intermediate shield is attached to each of the side shields. The intermediate shields mate with an engine shield which is located at the upper end of the thrust chamber when the two side shields are engaged in the test position. The bottom shield contains a nozzle penetration for the Nuclear Exhaust System duct. This area can be covered by a portable duct cover shield when the side shields are not in the sealed position. The side shields and the duct cover shield are remotely placed into position. Penetrations into the compartment for the fuel line, purge line, thrust measuring components, electrical lines, and instrumentation leads are in the top shield.

To engage the side shields in the test position with the top and bottom shields requires the use of a special seal mechanism that enables evacuation and purging of the ETC, as shown in Figure VI-A-1. NERVA Test Operations require that the ETC be initially purged with GN_2 to reduce oxygen content to less than 4 percent, then evacuated to 7 psia for pre-fire or post-fire operations and to 1 psia during full power engine operations. Initial evacuation is accomplished with the steam ejectors in the NES duct, with the pumping action of the engine flow providing the 1 psia operating environment. Leakage of air into the compartment must be zero, and leakage of inert gas into the compartment from seals and buffer zones will be determined experimentally during ETC activation.

a. Top Shield. The top shield is a cylindrical tank of aluminum alloy construction approximately 17.5 feet outside diameter and 30 inches deep. This shield contains two layers of lead located near the top surface of the shield. The layers are separated to allow cooling water flow during engine test operations. Figure VI-A-1, Section A-A, is a typical cross section of the top shield showing location of the lead shielding.

The top shield is designed to support dynamic and static loads. In addition, the shield provides support for the top seal mechanism bellows and seal blades, cooling water supply and return manifolds, and internal piping and spray nozzles.

The top shield contains penetrations for the engine fuel cool-down and other fluids supply lines, ETC purge piping, thrust measuring, electrical and instrumentation connections to the engine and thrust ring.

The top shield is filled with demineralized water from the process water system through permanent shield/facility interface connections controlled by Fill Valve 50-RSV-303. During test operations, continuous water flow is maintained through the shield by opening the fill valve to vent the water overhead into the drain piping system.

b. Bottom Shield (S_4). The bottom shield is a cylindrical tank of aluminum alloy construction approximately 16.2 feet outside diameter and 30 inches deep with a nozzle penetration 6'-9 5/8" in diameter to accommodate the Nuclear Exhaust System duct. This shield contains a 2" thick

layer of lead located near the bottom surface of the shield, and a $\frac{1}{4}$ inch thick boral plate located near the top surface of the shield. This shield is filled with cooling water during test operations which is circulated on both sides of the lead layers and boral plates. Figure VI-A-1, Section B-B, is a typical cross section of the bottom shield showing location of the shielding materials.

The bottom shield provides support for the bottom seal mechanisms, cooling water supply and return manifolds, and internal piping.

The bottom shield is filled with demineralized water from the process water system through permanent shield/facility interface connections controlled by Fill Valve 50-RSV-306. During test operations, continuous water flow is maintained through the shield by opening the fill valve to vent the water overboard into the drain piping system. The bottom shield cooling water flow rate is approximately 650 gal/min.

c. Side Shields (S1 and S2). There are two symmetrical side shields of aluminum alloy construction. In the sealed position they form a vertical cylinder. This cylinder is 22.5 feet outside diameter, 17.5 feet inside diameter, and approximately 30 feet in overall height. The internal surface of the shields is fabricated of cellular aluminum extrusion to which a $\frac{1}{4}$ inch thick boral plate is fastened internally. A 2-inch thick lead shield is located in the skirted portion of each side shield, near the bottom. Figure VI-A-1, Section C-C, and Detail 5, shows the location of the shielding materials.

Each side shield is supported by a transfer car which travels on rails to and from the test position. When not in test position, each shield is stored on the rails approximately 200 feet from the test stand centerline, at "park" position. Transfer of the shields may be controlled remotely or from the local control panels. The mechanical drive mechanism for the transfer system is an endless steel cable and drum unit driven by an electric motor. The power sheaves for each unit incorporates a hydraulically operated positive tension device which maintains a positive uniform cable tension on the drive cables at all times. A slow speed motor is incorporated with the main drive system for "inching" the movement of each shield during the last 12 inches of travel toward the test position.

To mate the shields to form the ETC, each side shield is moved forward individually from the "park" position at a speed of 15 ft/min. At "Station 1," approximately 12 inches from the "Test" position, the shield stops automatically and the high speed motor is locked out. The shield may then be "inched" forward at a speed of 6 inches/min. At "Station 2," approximately 8 inches from "Test," the electrical connector panels are engaged, tying the shield to the facility electrically. At Station 2, several interlocks must be satisfied or further movement is not possible. A "bellows up," "bottom trough down" and "latch retract" signal must be satisfied. Since the "latch retract" signal must come thru the S1 electrical connector panel, it is necessary to move S-1 into position first, and S2 out first when demating to maintain continuity. At "Station 3," water fill position, the shields must be stopped manually. "Station 3" is approximately 3 inches from "Test" position. Shield water fill and drain connectors are engaged at this position.

Due to deflection of the transfer car structural beams by the weight of the water, the shields are canted forward approximately $1\frac{1}{2}$ inches at the top in the empty condition. When filled, the shields become vertical and therefore must be filled with water prior to mating. Filling is accomplished by opening valves 50-RSV-304 (S1) or 50-RSV-305 (S2) when the shields are stopped at "Station 3." When shields are full, they are moved forward to "Test" position at inching speed. Six alignment transducers read out on the RIC console display the shield position during the final 6 inches of shield movement.

The two side shields are locked together, when in test position, with twelve locking mechanisms on each side. These mechanisms are pneumatically operated, over-center cam devices which will not unlock in the event of pneumatic pressure failure.

Continuous cooling water flow is maintained during test operations by opening the fill valves 50-RSV-304 (S1) and 305 (S2) and allowing water to overflow into the drain piping system. The cooling water flow rate thru each side shield is approximately 1200 gal/min. Cooling water enters the side shield at the top, circulates down thru the internal surface extrusions around the boral plate, under the lead shield at the bottom, and back out at the top of the shield.

Water is drained from the shields to the deluge system by opening valves 50-SV-356 (Shield S1) and 50-SV-355 (Shield S2) when the shields are at Station 3 after being backed out from "Test" position. Drain valves are interlocked and may not be opened unless a "latch retract" signal is available.

d. Intermediate Shield. The intermediate shield is composed of two symmetrical halves attached to each of the side shields. Together the two halves form a hollow right cylindrical tank 17.2 feet outside diameter, 9.8 feet inside diameter and approximately 40 inches high. When the engine and side shields are in test position, the intermediate shield mates with the external engine shield forward of the pressure vessel.

The intermediate shield is constructed of aluminum alloy with a one-inch layer of lead near the top surface and a $\frac{1}{4}$ inch boral plate near the bottom surface of the shield. There is also a $1\frac{1}{2}$ inch layer of lead near the inside diameter of the shield. The intermediate shield is filled with water during test operations through piping from the side shields. Figure VI-A-1, Detail 4, shows the arrangement of the shielding materials within the intermediate shield. The cooling water flow rate through each intermediate shield half is approximately 250 gal/min.

The intermediate shield is supported by the four water fill pipes fixed vertically to the water header at the top of the side shields. The intermediate shields elevation could be adjusted if necessary by changing length of the water fill and discharge lines.

e. Duct Cover Shield (S3). The duct cover shield is supported by a transfer car and is moved into position to cover the exhaust duct opening in the bottom shield following an engine test, and after the side shields are moved to the PARK position. This shield protects personnel from exhaust duct residual radiation while performing operations in the test stand after the engine is removed.

The duct cover shield has a rectangular shape and is approximately 24 feet 7 inches wide by 38 feet long, and has a maximum height of 2 feet 2 inches. It is constructed from carbon steel, for structural members, concrete for ballast, and utilizes lead for the radiation shielding material. The lead

is installed in two layers, one layer is a fixed tray and the other is a movable tray. The movable tray is pneumatically operated by a manually operated GN_2 connection and can be moved in and out of the area directly under the engine, when the duct cover shield is in the test position.

The duct cover shield is remotely controlled with a drive mechanism similar to that used for the side shields. The normal storage position is approximately 200 feet from the centerline of the test stand in the area near Side Shield S2.

An engine access work platform is currently being designed for mounting on the S3 transfer car. This platform would be used for engine access prior to runs and prior to ETC shield mating.

f. Control and Instrumentation. Engine Test Compartment operations are controlled from either the two local control panels or from the remote control consoles in the Control Point Building. One local panel controls the operations for Side Shield S1 and the pump, seals, and latch operations. The other panel controls the operations for Side Shield S2 and Duct Cover Shield S3. These local control panels also include the necessary indicator lights for each of the control functions. There are no pressure, temperature, flow rate, etc., readouts on the local panels.

The local control panels are portable, hand-carried units with signals supplied by electrical cables. The local control panel for the S1 shield, pumps, seals, and latches is normally stored behind the shadow shield on the south wall of the Steam Generator Room and has 65 feet of electrical cable. The other local control panel for S2 and S3 shields has 30 feet of electrical cable and is normally stored on the south side of the shadow shield, west of the test cell centerline.

Remote control operation of shield functions is performed from the Remote Installation Console (RIC). Control of the shield cooling water valves 50-RSV-303, 50-RSV-304, 50-RSV-305, and 50-RSV-306 is from the Lead Facility Engineer Console (LFE). The remote control consoles in the Control Point Building enables these operations to be performed: (1) transfer the shields, (2) establish seals, and (3) fill and drain water from the shields. The remote control console also contains indicator lights for pressure, temperature, and flow indications necessary to monitor these operations.

Operation of the local control panels is only with a permissive signal from the RIC console. Power must be applied to the RIC console and selector switch pressed in "LOCAL" position to enable the local control panels. In addition, the "Local Power" switch on the RIC must be turned on.

g. Top Closure Seal. The top closure seal provides an air-tight joint around the upper circumference of the ETC by using an inflatable stainless steel bellows ring with attached double plate blades in conjunction with a stationary trough shown in Figure VI-A-1, Detail 1. The bellows and double plate seal blades are supported from the top shield and the trough is supported by the side shields. This trough contains a eutectic mixture of lead (45 percent) and bismuth (55 percent). The eutectic is normally melted by electric heating coils located near the bottom of the troughs. When the bellows are pressurized with GN_2 , the double plate blades move downward into the molten eutectic. The blades are sealed as the eutectic solidifies.

Further sealing protection against air leakage into the ETC is obtained by pressurizing the space between the seal blades with GN_2 inert buffer gas. Pressurization of the bellows is remotely controlled by valve 50-SV-149 to a design working pressure of 18 psig. The buffer gas pressurization is remotely controlled by valve 50-SV-148 to a design working pressure of 2 psig.

The eutectic trough is also equipped with water cooling coils which provide cooling of the eutectic and also prevents melting of the eutectic during test operations. Cooling water flow is controlled with valves 50-SV-381 to shield S1 and 50-SV-379 to shield S2. These cooling coils may be manually connected to a portable Steam Generator System to melt the eutectic in event of electric heater malfunctions.

The mating plane of the two halves of the upper trough is sealed with a silicone rubber elastomer seal that is water cooled thru passages just beneath the seal mating surface in the S2 shield. The seal cooling water flow is controlled remotely thru valve 50-SV-2710. A spring loaded "gate" on the S1 upper trough ends is actuated by the action the upper bellows seal blades. When the upper blades are lowered into the molten eutectic, the gate is depressed allowing eutectic to flow thru and form a continuous "trough" around the seal blades.

The demating of the top closure seal is accomplished by re-melting the eutectic and pulling a vacuum in the upper bellows ring raising the seal blades out of the molten eutectic trough. The gate assemblies are then released and "cut off" the eutectic metal in the trough at the mating plane when the eutectic is subsequently solidified.

Controls and indicator lights for upper trough eutectic heating are located on the S-1 local control panel and also on the RIC console. When the top heat control is turned on, twelve heater elements in the top trough are energized. A thermocouple is attached to each heater element and in addition there are 18 thermocouples located within the trough sensing temperature of the eutectic. 20 temperature controllers located in the Test Stand Building control the heater temperatures between 351°F and 386°F, and the eutectic temperature between 280°F and 285°F. Melting temperature of the eutectic is 255°F. A "TOP TROUGH MOLTEN" light is illuminated on the S1 local control panel and the RIC console when a summation of 8 of the eutectic thermocouples indicate above 255°F. Additionally, 4 top trough eutectic temperatures are readout on the duct and shield monitor on the LFE console.

A four-position "TOP SEAL CONTROL" switch is located both on the S1 local control panel and the RIC console as well as bellows "UP" and "DOWN" indicator lights. The four control positions are: "PRESS" - bellows extended; "VACUUM" - bellows retracted; "OFF" - bellows in neutral position; and "PURGE" - bellows extended and seal blade and gasket purge applied.

Controls for S1 and S2 trough cooling and seal cooling are located on the RIC console.

h. Bottom Closure Seal. The bottom closure seal around the lower circumference of the ETC is similar to the top seal, with several exceptions, as seen in Figure VI-A-1, Detail 3. The bottom seal has two sets of fixed double plate blades; one set is fixed around the circumference of the side shields, the other set is fixed around the circumference of the bottom shield. The bottom trough is a continuous trough that is suspended within a rotating ring by a series of roller bearing cam followers. After the eutectic within the trough is molten, the rotating ring is rotated thru an arc of 8° 30' by four hydraulic cylinders. Cam slots machined in the rotating ring cause

the bottom trough to raise $3\frac{1}{4}$ inches. The side shield seal blades, bottom shield seal blades, and lower bearing blocks of the convolute seals are thus immersed in the molten eutectic which is then solidified to form the bottom closure seal.

After the eutectic solidifies, the space between both sets of seal blades is pressurized with a buffer gas (GN_2). Buffer gas pressure is controlled by valves, 50-SV-146 to the blades attached to the bottom shield, 50-SV-154 to the blades attached to the side shield S1, and 50-SV-144 to the blades attached to the side shield S2.

The bottom shield seal blades are attached to the bottom shield with an aluminum bellows to allow for relative movement between the side shields and bottom shield during test operations. Due to slightly undersize manufacture of the bellows and seal blades, there is a very tight fit between the ambient temperature inner seal blade and inside diameter of the thermally expanded lower trough containing the molten eutectic. It is therefore necessary to stop the lower trough movement momentarily just as the blade is immersed in the eutectic, allowing the seal blades to expand prior to full raising of the trough.

The bottom eutectic trough also has cooling coils for aid in solidification of the eutectic and to prevent melting of eutectic during test operations. Cooling water is controlled remotely by 50-SV-377. The cooling coils also have the capability to be connected to a portable steam generator for emergency eutectic melting in case of heater or electrical malfunctions.

Eutectic temperature control is identical to that for the top closure seal. Controls and indicators for bottom trough hydraulic pump, bottom trough position, and eutectic heating are available on both the S1 local control panel and the RIC console. Controls for bottom trough cooling, and seal blade buffer zone purges are located on the RIC console.

i. Convolute Seals. The convolute seals form an airtight seal along the vertical longitudinal seam between the two side shields. These seals consist of a metallic, inflatable seal with two convolutions. When pressurized, the convolutions expand and form a seal with the adjoining seal surface. The side shields are held together by the latch mechanisms described in section (c) above. To further ensure against leakage of air

into the ETC, the space between the two convolutions and the adjoining seal surface is pressurized with GN_2 inert buffer gas. The convolute seal pressure is controlled by valve 50-SV-154 to a design working pressure of 5 psig, and the buffer gas pressure is controlled by valve 50-SV-144 to a design working pressure of 2 psig.

Figure VI-A-1, Detail 2, is a typical cross section thru the convolute seals and side shield bearing blocks. The convolutes are made of beryllium copper, .007 in thickness. They are attached and sealed to grooves in the S1 bearing blocks held down with rods and clamp bars.

The lower end of the convolute seals and bearing blocks are immersed in the bottom eutectic trough and thus forms a positive buffered seal. The inside of the inner convolute seal is constructed so as to bear against the top trough elastomer seal described in (g) above, forming a seal between the top seal and vertical seal. Buffer gas is provided to the seal area thru milled slots in the S2 bearing block.

Controls for the convolute seal pressurization and buffer zone flow are located on the RIC console.

Needless to say, the convolute seals are extremely fragile and susceptible to damage. Wooden convolute seal protective covers have been made and are attached to the shields when they are not mated. Protective covers for protection of the mating machined surface on the S2 shield have also been provided.

C. VALVE FAILURE MODES

All purge and buffer zone GN_2 solenoid valves are "fail run." The normal, or de-energized position of the valve is to provide flow or pressure to all seals and buffer zones. Latch cylinders are de-energized closed, and upper bellows pressurized in normal position. All shield moving controls, water drains, and latch retract must be energized to operate; therefore, the "local power" switch on the RIC console is designed to prevent any inadvertent signal creating a problem during a run.

The shield cooling water valves 50-RSV-303, 50-RSV-304, 50-RSV-305 and 50-RSV-306 are de-energized open, and actuators spring loaded open in case of pneumatic failure.

FIGURE VI-A-1 (of 2)

ENGINE TEST COMPARTMENT
RADIATION SHIELDS
FOR TRAINING USE ONLY

FIGURE VI-A-1(2 of 2)

ENGINE TEST COMPARTMENT
RADIATION SHIELDS
FOR TRAINING USE ONLY

ETS-1 CONTROL POINT OPERATOR
GENERAL INDOCTRINATION COURSE

SECTION VI-B
NUCLEAR EXHAUST DUCT

A. GENERAL

The exhaust system for the NERVA engine is designed to accomplish the following:

Duct the hydrogen exhaust from the engine to a sufficient distance away from the test facility so that it may be safely burned in the open air.

Prevent air from entering the exhaust system and the engine test compartment under normal or malfunction engine operating conditions.

Provide altitude conditions after engine startup to allow fully expanded flow in the nozzle.

Supplementary information on both the Duct and Steam Generator System is found in REON report RN-S-0174, entitled Nuclear Exhaust System (NES) Use and Operational Manual.

B. NES DUCT

1. General Design. The NES duct, as shown diagrammatically in Figure VI-B-1, consists of Section 1, primary vertical straight section with transition cone; Section 2, 90° elbow section with off-set cone; and

Section 3, secondary horizontal straight section with a steam ejector and a 45° exit elbow.

FIGURE VI-B-1
NES Duct
Principal Sections

These three sections together with a supporting truss assembly constitute the duct-truss assembly, Figure VI-B-2. The duct is fabricated from Type 347 stainless steel, and the truss is made of Type 304 stainless steel. As shown in Figure VI-B-3, Section 2 of the duct is constructed of round tubes welded together and Sections 1 and 3 are constructed of sheet and angle sections welded together to provide rectangular channels. Thus, the duct utilizes two types of double wall construction to provide longitudinal channels for the flow of cooling water between the inner and outer walls. Section 2 is provided with an additional water jacket, as described more fully below, to prevent entrance of air into the duct in the event of penetration or other failure of the tubular wall construction of this section.

The offset configuration of the transition cone immediately downstream of the 90° elbow and the provision of a drain at the low point of the 45° exit elbow are for the purpose of preventing the accumulation of a pool of water in Section 3 should there be a rupture of a coolant passage wall on the inside of the duct during an engine test. By thus preventing an accumulation of water in Section 3, the possibility of an excursion is reduced to a minimum in the event that pieces of the reactor core become dislodged during an engine test run and are carried downstream through Section 1 into Section 3.

2. Principal Duct Sub-Assemblies. The complete duct-truss assembly, Figure VI-B-2, consists of upper and lower duct-truss assemblies, Figures VI-B-4 and VI-B-5, joined at a severance plane located between the top of Section 2 and the bottom of Section 1. The upper duct-truss assembly consists of Section 1 and the upper truss assembly. The lower duct-truss assembly consists of Section 2 and the lower truss assembly.

The duct-truss assemblies are joined by Marman clamps at the severance plane to facilitate the assembly and separation operations.

Longitudinal truss members, which carry the water to the duct manifolds, provide the support for the duct and transfer the structural loads from the duct to the vault walls.

3. Connections Between Duct and Truss. The duct is supported in the truss assembly at a number of points, as shown in Figure VI-B-6. A pair of hinged supports, located on each side of the 90° elbow section, carries the vertical and horizontal loads. Three pairs of roller supports provided between the duct and truss carry the transverse loads. One of the pairs is located on opposite sides of Section 1, and two are located on opposite sides of Section 3. In this manner, the duct is permitted to expand thermally, both circumferentially and longitudinally, from the hinged support.

4. NES Vault. The NES duct is housed in a concrete vault located below the engine in the ETS-1 test stand. One end of the vault is open to permit installation and removal of the duct and to provide ventilation during engine tests.

After an engine test, the aluminum covered concrete door is closed to cover the opening of the vault, thus shielding personnel against emission of nuclear radiation by any fission products which might be plated out on the exhaust system during the firing or by the induced radioactivity of the exhaust system and the vault structure. The aluminum covering protects the door from the intense heat of the burning hydrogen exhausted from the duct.

During an engine test, the NES vault area will be subjected to a water spray for the purpose of cooling the structural members of the NES duct supports.

The concrete walls of the vault are three feet thick to provide radiation shielding for personnel requiring access to adjacent pipe chase and equipment vaults after a test firing.

5. Support of Duct-Truss Assembly in Vault. The duct-truss assembly is supported at both sides of the ETS-1 vault by front and rear trunnions, Figure VI-B-7. As shown in Figure VI-B-2, the trunnions are connected to the main truss assembly by means of butterfly trusses. To facilitate ease of shipment, these trusses are field-assembled to the main truss. All four trunnion points carry both vertical and horizontal loads. Four jacking interface bearing plates are provided on the truss, as shown in Figure VI-B-2, so that the duct-truss assembly can be elevated or lowered during installation and removal.

6. Radiation Shielding. A water-filled duct radiation shield, Figure VI-B-2, surrounds the upper portion of Section 1 to absorb the high level neutron radiation from the NERVA engine and thereby prevent structural damage to the ETS-1 Facility walls. The shield consists of upper and lower sections.

The upper section is at the duct inlet. Water fills this area and discharges into the lower section immediately below.

The lower section is open at the top permitting overflow of excess water to the vault floor. A flexible seal is provided between the bottom of the shield and the outer wall of Section 1 to accommodate relative thermal expansion.

7. Section 2 Jacket. A water-filled jacket provided around the outside of the 90° elbow section prevents the flow of outside air into the duct if damage should occur to the elbow surface or cooling tubes during a test firing.

Water is supplied, and pressure maintained, by a direct gravity connection between the jacket and the duct shield water tank. If penetration damage should occur to the inner surface of the duct elbow, water will flow from the tube(s) into the duct interior. If weld failure between the tubes should occur, water will flow from the elbow jacket into the duct interior.

In the event of failure of the outer walls of the elbow tubes, water will flow from the tubes into the jacket and back up to the shield tank. In all cases, air will be prevented from mixing with the hydrogen in the duct interior.

The water line between the jacket and the shield tank is instrumented to determine flow direction as a means of detecting and analyzing duct damage in this area.

8. Steam Ejector. Steam at 125 psia is ejected into the duct through a steam ejector system, Figure VI-B-8, consisting of a sonic nozzle arrangement encircling the duct at the inlet of Section 3. The primary purposes of the steam ejector are: (1) to act as a check valve which prevents air from backflowing into the duct and mixing with the hydrogen prior to and during engine startup, and (2) to fill the engine compartment and duct, and thus prevent entrance of air during shutdown or engine malfunction.

The ejector operates as required, covering the period prior to engine startup, and continues throughout the entire test firing sequence, the engine H_2 cooldown, and the engine compartment GN_2 postfire purge. The ejector also provides a partial vacuum (approximately 7.5 psia) in the duct and engine compartment prior to engine firing and during engine bleedin.

The steam ejector design consists of an uncooled torus constructed of 16 inch diameter pipe. A series of two-dimensional nozzles, attached to the torus, discharges the steam downstream into the secondary duct section along its inner surface. The ejector ring is designed to expand circumferentially and longitudinally to permit relative movement caused by thermal expansion between the ejector and the water-cooled duct sections.

The nominal steam properties and the ejector design parameters are:

Specific heat ratio, steam	1.25
Molecular weight, steam	18-21
Temperature, steam	1600-1760°R
Nominal pressure, steam (ejector)	100-115 psia
Flow rate, steam	115-130 lb/sec
Secondary ejector nozzle throat area	119 in. ²
Thrust produced by ejector	20,000 lb. horizontal

9. Combined Ejector Operation. In addition to the steam ejector at the inlet of the duct secondary section, the GH_2 flow from the engine nozzle, through the duct primary section, provides further reduction in pressure within the ETC and exhaust duct. The combined effect of the steam ejector and engine nozzle ejector is to reduce the exhaust duct system pressure to about 1.5 psia.

In operation, high-velocity gas or steam flowing through primary and secondary ejectors, function similarly as rotating metal parts, are used to transfer momentum to the pumped gas in a vacuum pump. When a stream of gas or vapor enters an empty chamber, it expands and converts its pressure energy into velocity energy, where the direction of flow is determined by the nozzle and chamber geometrics, and the pressure drop across the entrance throat. The high-velocity stream creates a turbulent layer between itself and the gas to be pumped. This turbulence results in a transfer of momentum to the gas being pumped, so that there is a net component of velocity imparted to the gas in the direction of flow of the working fluid out the exhaust duct.

10. Duct Exhaust. As the exhaust gas leaves the secondary ejector, it is discharged diagonally upwardly through the 45° exit elbow, after which it burns in the air, as illustrated in Figure VI-B-9. Igniters are provided at the exit of the duct, and also at the end of the drain extending below the 45° elbow.

11. Water System. A plastic-lined 42-inch diameter pipe, approximately 6,600 feet long, connects the 2,750,000 gallon demineralized water storage tank to the test stand pipe vault area adjacent to the NES duct vault. Because a difference in elevation of approximately 500 feet between the demineralized water storage tank and the duct water inlet, gravity feed to the test stand is adequate and pumping from the storage tank to the test stand is not required. The resultant simplicity is an important factor in the overall reliability of the water system.

12. Duct Water Flow Requirements. The ETS-1 process water cooling system is designed to provide sufficient cooling water, at a nominal inlet temperature of 85°F , to the NES duct to prevent damage to the duct inner wall during operation. The design of the duct is such that, except for the

elbow, the maximum duct inner wall temperature, under normal operations, will not exceed 1460°R. At the elbow the maximum inner wall design temperature is approximately 1640°R.

These design temperature values are based upon theoretical determinations and scale-model experimental determinations of heat transfer from the hot gas to the coolant water. This involves heat transfer through the hot-gas boundary layer, the inner wall of the duct, and the coolant water boundary layer.

The design bulk temperature for the outlet water is 140°F. The maximum overload bulk temperature for the outlet water is 180°F. System pressure resulting from the height differential of approximately 500 feet between the 2,750,000 gallon storage tank and the duct water inlet produces the water flow through the entire duct-truss assembly and related piping.

Design flow requirements for the duct:

	Nom. Inlet Flow ($\pm 3\%$)	Min. Calc. Flow Press. Duct Inlet	Duct Δ P, Manifold to Manifold	Bulk Temp., Duct Inlet	Design Bulk Temp., Duct Outlet	Overload Bulk Temp., Duct Outlet
	gpm	psig	psi	°F	°F	°F
Section I	11,750	191	79	85	140	180
Section II	11,150	191	136	85	140	180
Section III	15,125	187	65	85	140	180
Total	38,025					

Design flow requirements for the facility support items are 1800 gpm for the steam generator and 600 gpm for the engine shield. The total design flow requirement for the NES duct and the facility support items is 40,425 gpm. This is based upon a minimum head of 10.0 feet of water in the 2,750,000 gallon storage tank.

13. Duct Water Flow Circuit. As shown in the flow diagram of Figure VI-B-8, individual duct section water flow rates can be pre-set by means of orifices located in the outlet line from each duct section. The

orifices in the duct outlets control flow through each duct section, while flow control valves maintain a back pressure on the system.

During the filling of the duct water system, water from the primary section return headers is used to fill the duct water shield jacket. Flow from the shield jacket, together with flow from the vents in the upper truss assembly, is directed into the duct water shield tank, from which a small portion flows into the duct elbow jacket. The latter is designed to prevent the entrance of air into the interior of the duct in the event of penetration failure of the duct tubes or welds.

When Section 1 and the upper truss inlet and outlet headers are filled, water from Section 1 fills the shield jacket, then overflows into the shield tank below the jacket, at which point it is joined by flow from the vents in the upper truss. A portion of this water then flows into the elbow jacket. After the shield tank and elbow jackets are filled, water overflows down the shield tank sides into the duct vault.

A drain for 10 gpm flow is provided in the elbow jacket to drain the water shield tank and elbow jacket, thereby creating circulation during operation and permitting drainage after operation.

Water is supplied to the duct through RSV-296, RSV-297 and RSV-298, which are 4", 12" and 36" butterfly valves respectively.

Flow control is maintained by the proper positioning of FCV-30, FCV-31 and FCV-32, which are $1\frac{1}{2}$ ", 6" and 20" plug type valves.

The supply and flow control valves are designed to fail "in-place."

14. Control Room Operations. The duct cooling water is controlled from the Lead Facility Engineer (LFE) console. Additional pertinent duct parameters are monitored from the fifty channel bar graph display located atop the Remote Installation Controls (RIC) console.

Switches are located on the LFE console to open and close RSV-296, RSV-297, RSV-298, and to position FCV-30, FCV-31 and FCV-32.

Meter displays are provided in the LFE console to monitor the following parameters:

Ejector Steam Pressure	P-239
Ejector Steam Temperature	T-159

Elbow Jacket Flow	F-60
Section No. 1 Inlet Flow Left	F-54
Section No. 1 Inlet Flow Right	F-55
Section No. 2 Inlet Flow Left	F-57
Section No. 2 Inlet Flow Right	F-56
Section No. 3 Inlet Flow Left	F-58
Section No. 3 Inlet Flow Right	F-59
Section No. 1 Outlet Temp. Left	T-66
Section No. 1 Outlet Temp. Right	T-57
Section No. 2 Outlet Temp. Left/Upper	T-67
Section No. 2 Outlet Temp. Left/Lower	T-58
Section No. 3 Outlet Temp. Left	T-68
Section No. 3 Outlet Temp. Right	T-59
Elbow Section Temperature	T-77
Process Water Supply Pressure	P-168
Duct Supply Pressure	P-597
Duct Discharge Pressure	P-596
Duct Supply Temperature	T-47
Duct Discharge Temperature	T-48
Process Water Tank Level	L-15
50 FCV-31 Position	L-31
50 FCV-32 Position	L-32
Duct Medium Flow	F-31
Duct High Flow	F-32

The total instrumentation required for complete evaluation of duct performance is shown in Figure VI-B-10.

FIGURE VI-B-2

TYPICAL ELBOW SECTION 2

TYPICAL STRAIGHT SECTION 1 & 3

NES DUCT COOLANT PASSAGE CONFIGURATION

FIGURE VI-B-3

UPPER DUCT-TRUSS ASSEMBLY
AS SHIPPED

FIGURE VI-B-4

LOWER DUCT-TRUSS ASSEMBLY
AS SHIPPED

FIGURE VI-B-5

NOTE

LOADS SHOWN ARE THE MAXIMUM AT EACH STATION AND DO NOT OCCUR SIMULTANEOUSLY FOR REACTION LOADS AT SUPPORTS ON EACH SIDE OF DUCT, DIVIDE INDICATED LOADS BY 2

SECTION THROUGH WEST ELEVATION

NORTH ELEVATION

FIGURE VI-B-7

TEST STAND & EXHAUST
DUCT VAULT
FOR TRAINING USE ONLY

FIGURE VI-B-8
NES PROCESS WATER SYSTEM
FLOW DIAGRAM
FOR TRAINING USE ONLY

FIGURE VI-B-10
**EXHAUST DUCT
 INSTRUMENTATION AND FLOW DIAGRAM**
 FOR TRAINING USE ONLY

ETS-1 CONTROL POINT OPERATOR
GENERAL INDOCTRINATION COURSE

SECTION VI-C
STEAM GENERATOR SYSTEM

A. INTRODUCTION

The Steam Generator System (SGS) in Figure VI-C-1 is designed to provide steam to the NES duct secondary ejector so that air is prevented from entering the exhaust system and the engine test compartment under normal or malfunction engine operating conditions. The ejected steam will also reduce pressure to 7.5 psia in the engine test compartment.

The Steam Generator System provides this steam by a continuous combustion of propane and oxygen with water injected into the products of combustion. The temperature of the steam can be controlled by varying the amount of water injected. The combustion process is fuel rich so that a minimum of free oxygen is present in the steam.

B. COMPONENTS

The Steam Generator System is housed in a reinforced concrete enclosure which is located at the base of the ETS-1 superstructure above the pipe chase and immediately behind the reinforced concrete shadow shield, Figure VI-C-2. The SGS is connected to the NES duct by a 20-inch steam line. Liquid oxygen is stored in a 22,000 gallon, 400 PSIG dewar approximately 400 feet from the SGS enclosure. The LO_2 is fed through a six inch insulated line.

Propane is stored in a 15,000 gallon, 400 PSIG tank, approximately 550 feet from the SGS enclosure. Flare stack 5003 located on top of the test stand west side is used to burn off any excess propane.

The Steam Generator System consists of three steam generator sub-units, or modules, which are connected to a steam plenum mixing and discharge chamber. Each generator module is equipped with its own controls, instrumentation, safety, and sequence units such that each of the three modules may be operated independently or in pairs.

Each module is composed of three combustion stages - first, second and main, as illustrated in Figure VI-C-3. The internal wall of each stage and plenum is cooled by external circulation of water through concentric jackets. The coolant water outlet of the first and second stages and the plenum are piped to a drain; however, the coolant water outlet of the third stage is routed to the coolant water inlet of the plenum. The water used to make steam is injected into the main stage only. The operation of the SGS is controlled remotely from the Facility Engineer Left (FEL) console, Figure VI-C-4, in the Control Point Building.

C. OPERATION

1. General. Ignition of the steam generator module combustion process is accomplished by a two stage, spark initiated, igniter which is commonly called IDLE STEAM. Idle steam is obtained by igniting the first stage propellants of the module with a spark plug which in turn ignites the second stage propellants.

Main stage combustion is called FULL STEAM and is ignited by the second stage combustion. The ignition of the main stage is the primary purpose of the first and second stage; consequently, the main stage produces 99% of the steam generator output.

Only two of the three modules that comprise the Steam Generator System are required to produce the design steam output. The third module is brought to IDLE STEAM and placed on STANDBY when the other modules are at full steam. Standby status will cause the module to proceed automatically to full steam if one of the two modules at full steam fails or is manually shut down. A module at full steam can be commanded back to IDLE STEAM or completely shut off.

A SGS flow schematic is presented as Figure VI-C-5.

2. Run Preparation. Before the SGS can be placed in operation, the LO_2 and propane tanks must be pressurized and the propellants bled-in. The gaseous nitrogen system and water system must also be set up.

3. Idle Steam. The generator module may be commanded to idle steam by depressing the START switch on the FEL console, and the following events automatically occur:

- a. Main purge valve opens
- b. Igniter-fire signal
- c. Spark on
- d. First stage purge off
- e. First stage propellant valves open
- f. First stage combustion occurs
- g. First stage chamber pressure switch signal
to second stage igniter
- h. Second stage purge off
- i. Second stage propellant valves open
- j. Spark off
- k. Second stage combustion occurs
- l. Second stage chamber pressure switch signals
STEAM IDLE light to light on console
- m. Full steam switch armed

4. Full Steam. Once the idle steam light is lit, the module is normally allowed to run for 60 seconds, after which it is commanded to full steam by depressing the FULL STEAM ON switch on the FEL console, and the following events automatically occur:

- a. Injection water flow valve opens
- b. Pressure switch across the water venturi signals
the main propellant valves
- c. Main LO_2 purge off
- d. Main LO_2 valve opens
- e. After $3/4$ second, main fuel valve opens
- f. FULL STEAM light on console lit

- g. After six seconds of full steam, all cut-off circuits are disarmed except the high temperature steam cutoff, low pressure differential across main stage, and low differential pressure across injection water venturi.

5. Standby. After two of the three modules are at full steam, the remaining module may be placed on standby by depressing the STANDBY switch on the FEL console. This will cause the standby module to proceed automatically to full steam if one of the other modules malfunction or is shut down.

6. Return to Idle Steam and Shutdown. A module at full steam can be returned to idle steam by depressing the START switch on the FEL console. A module at full steam or idle steam can be shutdown by depressing the STOP switch.

D. PERFORMANCE

1. Capacity. The Steam Generator System will produce a nominal 132 lb/sec of steam at 110 psig and 1460°R. The nominal inputs requirements to the SGS are 14 lb/sec propane, 33.4 lb/sec oxygen and 76 lb/sec water. The composition of the generated steam is approximately 80% water, and the majority of the remaining 20% is carbon monoxide and carbon dioxide.

2. Status. The SGS has undergone a development test program during which it performed for 1000 seconds at full steam while delivering the design steam capacity.

FIGURE VI-C-3
 NES STEAM GENERATOR COMBUSTION
 ELEMENT
 FOR TRAINING USE ONLY

FIGURE VI-C-4

FEL CONSOLE LAYOUT
FOR TRAINING USE ONLY

FIGURE VI-C-5
STEAM GENERATOR MODULE
SCHEMATIC PIPING DIAGRAM
(FOR TRAINING USE ONLY)

ETS-1 INSTRUMENTATION AND CONTROLS
INTRODUCTORY COURSE

SECTION VI-D
FACILITY, DUCT, AND SHIELD MONITOR

A. INTRODUCTION

As a part of the ETS-1 I&C System, the purpose of the Facility Control subsystem is to control the various test site support facilities and to provide indication and recording of the behavior of these facilities during a test run. Within the Facility Control subsystem, the Facility, Duct, and Shield Monitor provides display of the various parameters reflecting the performance and the behavior of the duct and shields surrounding the test stand.

The Facility, Duct, and Shield Monitor (FD&S Monitor) is a programmable data multiplexing and digital processing system which accepts up to 71 channels of analog data from transducer signal conditioners at the Test Cell Building and provides processed signals for display of this data on the consoles and display panels at the Control Point (CP). Up to 36 of the input channels may be processed according to a preselected proportionality or a programmed piecewise linear approximation for digital display in standard engineering units; channels so processed are referred to as engineering units (EU) channels. The remaining input channels may be compared with presettable caution and alarm levels to provide a go-caution-alarm (GCA) status display for each channel; channels so processed are referred to as GCA channels. In addition, the FD&S Monitor provides transmission of full-scale and zero reference levels to check constantly the operation of the system.

Analog input channels are time-division multiplexed at a 100 channel-per-second rate prior to analog-to-digital conversion and transmission to the Control Point. The multiplexing format is a 110-channel-sample frame consisting of two similar sub-frames. Each sub-frame includes all of the 35 GCA channels interlaced in a 2:1 ratio with half of the EU channels. One of the two reference levels constitutes the 54th sample in each sub-frame while the last sample position is used for synchronization check. Thus, engineering unit displays are up-dated once per frame while GCA displays are up-dated twice per frame.

A one megacycle input from the ETS-1 Timing System is the basic time reference both for multiplexing and the counting techniques used in GCA comparison and EU conversion. The FD&S Monitor requires power at 115 volts, 60 cps. The 28-volts used to energize the GCA and EU displays are provided by a power supply within the monitor.

The FD&S Monitor occupies three racks, shown in Figure VI-D-1, at the Control Point, and includes three chassis at the Test Cell (TC) Building. The units comprising of FD&S Monitor are listed with their location in Table VI-D-1. Practically all of these units are logic blocks, thumbwheel switch chassis, or pinboards, reflecting the digital nature of the FD&S Monitor and its extensive programming facilities. The Control Point racks also include PU-10 Power Panels and a Standard Communication Panel (PA-5) and terminal box (DD-2).

B. SYSTEM DESCRIPTION

The block diagram of the Facility, Duct, and Shield Monitor is shown in Figure VI-D-2. Each important data processing function is shown, with functions grouped according to the chassis in which they are performed. Although the more subtle timing lines are not shown on the block diagram, their essential function of ordering the sequence of system operation and assuring the synchronism of system events are implicit in the following system description and are summarized by the system timing diagrams.

1. Multiplexing, A/D Conversion and Data Transmission. The FD&S Monitor receives a one megacycle basic time reference from the ETS-1 Timing System at the Control Point. This input is entered into the 3-decade EU

span circuit counter which, along with generating the various rates used to determine the span of EU conversion, supplies a 1-kc pulse rate to the FD&S Monitor Timing chassis.

The processing of the 1-kc input is represented by lines a and b of Figure VI-D-3. The signal is entered into a $\div 10$ counter which derives the 100 cps input for the channel counters, thus determining the multiplexing rate and the sample duration. This millisecond counter is not a standard BCD stage but rather consists of a $\div 5$ stage followed by $\div 2$ stage, providing a symmetrical 100 cps output. The value in the counter is decimal decoded, effectively dividing each 100 cps cycle, and therefore each channel sample or word, into 10 equal segments. These millisecond pulses are used to control the processing of the channel word and constitute the millisecond timing lines.

The symmetrical 100 cps signal drives the channel counters both at the Test Cell to select the channel and at the Control Point to identify each channel received. Each channel counter consists of a $\div 11$ stage followed by a $\div 5$ stage operating into decimal decoders to provide 11 consecutive 10 millisecond pulses and 5 consecutive 110 millisecond pulses. These two pulse trains are fed into the channel identification matrices. The matrices detect the various combinations of 11 and 5 pulse outputs to obtain the 55 channel positions in a sub-frame. The $\div 2$ stage identifies the sub-frame. Channel positions determined only by the 11 and 5 outputs occur twice per frame; GCA and synchronization channels are so determined. Channel positions determined by the output of all three channel counting stages appear once per frame; EU channels are identified in this manner.

Because channels are to be processed at a 100 pps rate, system operation must be sequenced so that an input channel is sampled, digitized, transmitted, and compared or converted without interfering with the following channel. This means that the inherent delays, particularly in relay multiplexing, digitizing, and the serial transmission of data, must be accounted for so that, once all information is at the Control Point, sufficient time remains to process this information before the channel counter is advanced to the next position.

Although the 100 cps multiplexing rate implies a maximum of 10 milliseconds to process each channel, this time is expanded to 15 milliseconds by interlacing the selection and the processing of different channels; i.e., the Test Cell multiplexer is selecting one channel while the data of the previous channel (as inserted into the down counter) is still being processed at the CP. This is accomplished by inverting the 100 cps signal supplied to the CP counter with respect to the signal used at the Test Cell. Since these signals are symmetrical, the TC channel counter is one-half step ahead of the CP counter, increasing the channel processing time for each channel to 15 msec, with 5 msec for sampling, 5 msec for A/D conversion and data transmission and 5 msec for channel processing.

The two channel counters must be kept in step with respect to each other if each channel is to be properly identified and processed at the Control Point. Since the 100 cps signal to the Test Cell counter is transmitted an appreciable distance, wave shaping is provided to recondition this signal before it is applied to the counter. Nevertheless, a pulse may get lost. Therefore, the system includes a synchronism circuit which monitors the last position in each sub-frame as determined by each of the counters. If synchronism is not detected during the required 5 millisecond interval, the TC and CP channel counters are reset and then restarted; a continuing lack of synchronism causes an alarm indication.

The channel ID matrix, operating from the Test Cell channel counter, selects each of the input channels according to the multiplexing format, causing that channel to be sampled by energizing a corresponding relay through a lamp driver circuit. The sampled channel is applied to an A/D converter which, when strobed, converts the input analog signal into a 12 bit BCD coded digital value. Referring to the timing diagram Figure VI-D-3, the A/D converter is interrogated by the negative-going edge of the 100 cps pulse, with conversion of a particular channel taking place at the same time as the Control Point channel counter is being advanced to identify that channel. By the end of conversion, the three-decade digitized value has been transmitted serially to the Control Point and shifted into the down counter. Meanwhile the channel has been identified at the Control Point by either the GCA or EU channel identification matrices; the proper method of

processing has been set up and the corresponding circuits have been cleared to accept new data, and the constants of conversion or comparison have been selected.

The millisecond counter has been sequentially energizing the millisecond timing lines since the start of conversion. It takes somewhat less than 5 milliseconds for the data to be converted, transmitted and shifted into the down counter, so that when the millisecond counter reaches position 5, the down counter control is strobed, down counting begins from the digital channel value and the channel is processed.

The down counting rate is 125 kc, obtained from the EU span counter. Referring to the timing diagram, a full scale value of 500 is counted down in four milliseconds. Therefore, the channel is processed and transferred into storage circuits no more than nine milliseconds after the start of A/D conversion.

2. GCA Processing. During down counting, the value in the counter is constantly compared with fifteen preselected alarm and fifteen preselected caution levels. The alarm and caution levels detected are correlated to the status levels selected for the channel being processed (assuming that it is a GCA channel) as determined by the GCA level programmer. The results of the correlation are stored in the GCA time shared storage circuit which will have been cleared of the previous channel just prior to the initiation of down counting.

On the ninth millisecond pulse, the GCA storage circuits are strobed causing the Caution and Alarm signals to be inserted into the storage circuit corresponding to the channel being processed. The output of each storage circuit drives a three-colored channel display on the LFE or RIC Consoles through an independent GCA driver circuit, maintaining this status display until the channel is again sampled and a new status signal is supplied.

The logic of the GCA driver circuits is such that the presence of both alarm and caution level provides an Alarm signal to the three-colored display; the presence of a caution level but not an alarm level provides a Caution signal; the absence of both alarm and caution levels becomes a Go

signal. An alarm level without a caution level indicates that an error has been made and a GCA error signal is provided. This alarm signal is derived directly from the GCA time shared storage.

3. EU Processing. Because down counting proceeds at a constant rate, the time required to count from the inserted channel value to zero is proportional to the channel value. By causing a second counter to accumulate counts during this count down time, the final value in the "up" counter will equal the channel value multiplied by the ratio of the up counting rate to the down counting rate. By inserting an initial offset value into the up counter, it is possible to solve a linear relation between the transducer value and the corresponding value in standard engineering units. Where the conversion from transducer output to standard engineering units value involves a non-linear relation, the total counting period is divided into 10 segments, with the up counting rate multiplied by a different selectable proportionality factor during each segment. The complex relation is thereby reduced to a series of linear approximations and with the correct selection of slope for each segment, the final value in the up counter is a fairly accurate conversion of the channel value.

The basic up counting rates determine the full scale value (span) of the channel value. These rates are derived by the three-decade counters in the EU span unit, operating from the 1 mc input. Each decade has associated logic gates which add the outputs of decimal decoders operating from the counter decades to form a series of rates. That is, the first decade produces nine pulse rates of from 100 to 900 kpps; the second decade produces nine pulse rates of from 10 to 90 kpps; and the third decade produces nine pulse rates from 1 to 9 kpps. These pulse rates are strobed and timed so that they may be added by thumbwheel switches in the EU Span Set chassis which contains one three-decade switch for each of the EU channels. The output of the EU Span Set chassis is 36 pulse rates, each associated with one EU channel and each selectable from 0 to 999 kpps in 1 kpps steps. These various rates are correlated with the channel being processed as determined by the EU channel ID matrix. If the channel being processed requires a linear conversion, the basic span rate selected is presented to the Linearization chassis where it is divided by 4, and gated into the up counter.

To process non-linear channels, the Linearization chassis divides the basic span rate by 20 in a decade divider followed by a binary divider. These dividers have associated logic gates which add the outputs of decoding gates to form a series of rates from 0.1 to 2.0 times the basic rate. By appropriately selecting these multiplied rates during various segments of the count down period, the system may perform a second or third order conversion. The segment generator divides the full scale down count value (500 counts, the maximum value of the analog input channels) into ten equal divisions by monitoring every 50th position between 50 and 500. These down counter segments and the 20 multiplied counting rates are applied to the EU Linearization Programmer, a pinboard which allows the operator to select the rate desired for each segment. Up to 12 different linearizations may be programmed on the pinboards at one time. The 12 resultant trains of pulses, along with the unlinearized rate for linear channels, are presented to a channel address circuit which selects the desired combination of rates.

Prior to the initiation of down counting (and up counting) the EU offset set circuits are strobed by the three millisecond timing line. This strobe inserts the operator-selected initial value corresponding to the EU channel being processed into the up counter. When down counting is initiated, the up counter control is also enabled, passing the selected pulse rate through a normalizing division to the up counter. The up counter continues to accumulate counts at the selected rate or combination of rates until the down counter has reached zero, at which time counting up also ceases. The up counter value is presented to the EU storage circuits and, at 9.2 milliseconds, the three-decade BCD value is set into the storage circuit corresponding to the channel being processed. Note that this circuit will have been cleared at five milliseconds. The stored BCD value is applied to decimal decoders and these decoders present the digital value to the display on the graphic display panel, maintaining this display until the EU channel is again sampled and calculated.

C. SYSTEM OPERATION

The Facility, Duct, and Shield Monitor is essentially a computer which determines the status of GCA channels and the parameter value corresponding to EU channel inputs. As such, it must be programmed to process properly,

each input channel; once programmed, the only operator action required is a quick turn-on and check procedure as described in C-2.

1. Controls and Displays. The FD&S Monitor includes active displays to permit operator monitoring of system operation and to implement system calibration and checkout. These displays, the associated controls, and the system power controls are described in the following paragraphs:

a. Power Controls. The system is powered in three sections: Control Point logic, Display, and Test Cell logic power. Power is applied through the PU-10 Power Panel AC Instrument power circuits in Control Point racks 34, and 35 and Test Cell Building rack 42, respectively. Note that Control Point logic power (R34) should always be supplied before display power (R35).

b. Control Panel. The FD&S Monitor Control Panel contains displays to permit a quick check of the system performance during normal operation and calibration and checkout controls to permit a detailed check of GCA and EU programming (calibration), and to determine that data from the Test Cell is being properly multiplexed and transmitted (checkout). Each Control Panel control and display, as shown in Figure VI-D-4, is described with respect to function and use in the following paragraphs:

(1) MASTER RESET Control. The system utilized bistable multivibrators for counting and rate division. When power is first applied, these multivibrators may be randomly set or reset and it is conceivable that a meaningless code (e.g., 1111) may be present. The MASTER RESET control is a momentary push-button switch which when depressed, causes a zero-volt pulse to be applied to a d-c reset input or to the common reset input of all counter stages, thereby assuring that, when the control is released, all counter decades will start from zero. The operator should give a MASTER RESET command immediately after the system has been turned on.

(2) Counter Operation Indicators. The 12 indicators at the bottom left of the Control Panel display the status of the millisecond and Control Point channel counter stages. The significance of each indicator and the proper flashing rates are given in Table VI-D-2.

(3) ALARM Indicators. The three-operation error indicators are located directly above the MASTER RESET control.

(a) OVER 5 Alarm. This alarm indicator is illuminated when a value in excess of 599 has been inserted into the down counter; the system does not process such a value. In no instance should this indicator be illuminated in the calibrate mode of operation. In the operate mode, this alarm indicates that a value in excess of full scale has been received from the Test Cell A/D Converter. The operator may check this by positioning the channel select switches to the channel on which the alarm was detected and observing the value set into the down counter. If this alarm persists for a given channel, the signal conditioner for that channel should be checked for proper full-scale output. If this alarm persists for several channels, check the A/D Converter.

(b) CHAN COUNT Alarm. This indicator is illuminated when a synchronization error is detected between the Test Cell and Control Point channel counters. This condition is normally corrected automatically and the alarm indication is removed before it can be observed. If the indication persists, the system is not taking corrective action and should be master reset. If the alarm indicator continues flashing, check that the TC Multiplexer is operating.

(c) GCA Alarm. A GCA error indicates that an alarm level but no caution level has been detected for a GCA channel. Check that no GCA channel has been programmed to a caution level higher than the alarm level selected for that channel.

(4) OPERATE/CALIBRATE Control. It is evident from the system description that processing of both the GCA and EU channels is performed on the value inserted into the down counter. With the OPERATE/CALIBRATE control in the OPERATE position, the digitized channel value from the Test Cell A/D Converter is shifted into the down counter; this is the normal mode of operation. With this control in the CALIBRATE position, data shift-in is inhibited and a value determined by the position of the three-decade CALIBRATE PERCENT control is inserted into the down counter for each channel. With a known value inserted into the down counter, the operator may check the performance of both the GCA and EU processing circuits and

may determine the validity of programming.

(5) CALIBRATE PERCENT Control. The CALIBRATE PERCENT control is a three-decade thumbwheel switch into which the operator inserts the percentage of full scale (i.e., the percentage of 500) to be inserted into the down counter in the Calibrate mode of operation. This control is deactivated in the Operate mode. Note that the maximum value that can be inserted into the down counter in the Calibrate mode is 119% of full scale (595). When the CALIBRATE PERCENT switch is set to any value in excess of 119, the coding of the switch is invalid. The selected percentage of full scale should appear in the three-character down counter display.

(6) Channel Select Switches. The operator may select a given channel for Control Point readout by means of the FUNCTION and the two CHANNEL NUMBER switches on the Control Panel. Each time the system arrives at the channel position determined by the setting of these three switches, the value in the down counter prior to down counting and the value in the up counter after completion of channel processing are displayed.

(a) FUNCTION Control. The FUNCTION control selects the type of channel to be displayed. In the full scale (FS) or zero (Z) positions, the corresponding reference level channel is selected. In the EU and GCA positions, the EU or GCA channel corresponding to the position of the two CHANNEL NUMBER switches is selected.

(b) CHANNEL NUMBER Switches. With the FUNCTION switch in the EU or GCA position, the selected channel is determined by the sum of the channel number units and channel number tens switches, e.g., with the FUNCTION switch on EU, the channel tens switch at 20 and the channel units switch at 5, EU channel 25 is selected for Control Panel readout.

(7) DOWN COUNTER Digital Display. The three-character DOWN COUNTER display indicates the value inserted into the down counter for the selected channel. Note that this display is applicable in both Calibrate and Operate modes. In the Calibrate mode, the value displayed should correspond to the calibrate percent selected.

(8) UP COUNTER Digital Display. The three-character UP COUNTER display indicates the value in the up counter at completion of

processing of a selected channel. With the FUNCTION switch in the EU position, the display should be identical to the engineering units display for the selected channel on the Graphic Display panel. With the FUNCTION switch in the GCA position, the up counter display should always be 000. This display is applicable in both Calibrate and Operate modes.

c. Test Cell Multiplexer. Although the Facility, Duct, and Shield Monitor is operated, calibrated, and checked out from the Control Point Control Panel, the Test Cell Multiplexer, Figure VI-D-5 contains local displays to indicate the operation of the Test Cell channel counters and a control to permit local reset. The counter indicator nomenclature and correct flashing rates listed in Table VI-D-2 apply equally to the Multiplexer indicators.

The Test Cell RESET control does not reset the Control Point circuits directly. Rather, by resetting the Test Cell channel counter, a synchronization error is introduced which, at the end of the sub-frame, causes the entire system to be reset.

The Test Cell Multiplexer also contains a SYNC Alarm indicator which is identical in function to the CHAN COUNT alarm indicator on the Control Panel.

2. System Turn-On Procedure. The following procedure is to be observed to power the system and assure proper performance prior to operation. It is assumed that the system has been properly programmed and calibrated according to the instructions in Sections 3, 4, and 5.

a. Apply power to the system logic by switching to the INSTRUMENT AC POWER circuit breaker on the power panel in Control Point rack 34. The power panel indicator and the displays on the Control Panel should then be illuminated.

b. Apply power to the Test Cell Multiplexer and A/D Converter by switching on the INSTRUMENT AC POWER circuit breaker on the power panel in Test Cell rack 42. The power panel indicator and the displays on the multiplexer should then be illuminated.

c. Depress and release the MASTER RESET control on the Control Panel. No alarm indications should be present and the counter indicators on

both the Control Panel and the Multiplexer should be flashing at the proper rates.

d. Position the mode selector to CALIBRATE and the PERCENT CALIBRATE switch to 100. Rotate thumbwheel switch only so as to increase the displayed number. The down counter display should read 500.

e. Position the FUNCTION selector to Z; the up counter display should read 500. Position the FUNCTION selector to FS; the up counter display should read 500.

f. Position the PERCENT CALIBRATE switch to 50 and repeat step (e). Both up counter and down counter displays should read 250 in both positions.

g. Position the PERCENT CALIBRATE switch to 000 and repeat step (e). Both up counter and down counter displays should read 000 in both positions.

h. Position mode switch to OPERATE and repeat step (e). Up counter and down counter displays should both read 500 at the FS position and 000 at the Z position.

i. Turn on Display power by switching on the INSTRUMENT AC POWER circuit breaker on the power panel in Control Point rack 35. The power panel indicator should be illuminated. Assuming proper inputs, the system is now operating fully.

3. FD&S Monitor Programming. Programming involves supplying enough known information about the behavior of each channel parameter to permit the system to perform a meaningful and unambiguous status determination or conversion of each channel voltage input. Therefore, before attempting to program the FD&S Monitor, the operator must know the critical values of each GCA channel as well as an empirical relation between each signal-conditioned EU channel and the parameter in engineering units to which it corresponds.

The FD&S Monitor is programmed by the means of the pinboards and thumbwheel switches contained in the Control Point chassis. All pinboards should be programmed only with the diode plugs supplied and only when the system power is off; thumbwheel switches should be rotated only in the direction of

the operator. Thumbwheel switches are all three-place controls. When related directly to the digitized input (e.g., GCA level set), each switch unit corresponds to 0.01 volts; when related to the converted parameter (e.g., EU span set and offset set) the significance of each switch unit must be determined from the transducer-parameter relation, keeping in mind that the maximum displayed value of the parameter may not exceed 999.

a. GCA Programming. GCA programming involves two steps; selecting 30 critical input levels (15 caution and 15 alarm) and programming each GCA channel to one caution level and one alarm level. The former function is performed by appropriately positioning each of the 30 three-decade thumbwheel switches on the GCA Level Set chassis (34G); the latter function is performed by inserting one diode plug into the caution section and one plug into the alarm section of each row on the pinboard in the GCA Programmer chassis (34H).

(1) GCA Level Select. The GCA Level Set chassis, Figure VI-D-6, contains 15 three-digit CAUTION switches and 15 three-digit ALARM switches. After determining the several minimum signal conditioner outputs for which caution is to be indicated, position each of the thumbwheel switches in the CAUTION sections to one of these levels. After determining the several minimum signal conditioner output levels for which alarm is to be indicated, position each of the switches in the ALARM section to one of these levels. Switches that are not used should be set to a value between 600 and 799.

(2) GCA Level Programming. GCA level programming is performed on a 35 by 30 contact pinboard, Figure VI-D-7, with one of the 35 GCA identification lines appearing on each of the pinboard rows, one of the caution level detected lines appearing on each pinboard column in the caution section, and one of the alarm level detected lines appearing on each pinboard column in the alarm section. The operator inserts two diode plugs into each row: one plug in the column corresponding to the caution level number (as selected on the GCA Level Set thumbwheel switches) and one plug in the column corresponding to the alarm level number for the channel identified on that pinboard row. For example, if GCA channel 1 has a caution level of 3.69 volts and an alarm level of 4.55 volts and that caution level set switch 5

and alarm level set switch 8 were positioned to 369 and 455 respectively, the operator would program GCA channel 1 by inserting a diode plug into row 1, column 5 of the caution section of the GCA Programmer pinboard and a diode plug into row 1, column 8 in the alarm section of the pinboard.

Note that no more than one caution level and one alarm level may be selected for each GCA channel. The caution level selected for a particular channel must be less than or equal to the alarm level or the system will provide a GCA error indication. Note that if a GCA channel is not programmed to a caution or an alarm level, a constant caution or alarm indication will be provided for that channel.

(3) Programming of Inverse Relation Channels. The system has been designed assuming a direct relation between signal conditioner output and danger level. However, the system will handle inverse functions (i.e., some minimum output value required for a GO status) if the GO and ALARM status outputs for that channel are reversed, either at the rear of rack 36 or at the channel status indicators. An inverse relation channel is programmed by selecting the caution level as before, but by selecting an alarm level corresponding to the minimum voltage required for a GO status.

b. Linear EU Programming. The conversion of a linear EU channel is determined by the initial value (zero-offset) and the span (full-scale value minus initial value) of the engineering unit parameter as a function of the channel input. Initial offset and span selection for each of the 24 linear EU channels are performed from the Initial Offset Set (35G) and Span Set (35H) chassis respectively. The selection of constants for the first 12 Engineering Unit's (non-linear) channels is described in paragraph c.

(1) EU Initial Offset Set. The EU Initial Offset Set chassis, Figure VI-D-8, contains 36 three-digit thumbwheel switches, each handling the initial offset (V_0) of the labeled EU channel. Determine the parameter value corresponding to a signal conditioned transducer output of zero-volts for each of the 36 EU channels, non-linear as well as linear. Position each thumbwheel switch to the initial offset value for the corresponding channel. Program negative offset values by positioning the corres-

ponding thumbwheel switch to the 1000 complement of the negative offset; e.g., an offset of minus 42 is programmed as 958. Negative offset programming is valid as long as the final calculated value is positive.

(2) EU Span Set. The EU Span Set chassis, Figure VI-D-9, contains 36 three-digit thumbwheel switches, each handling the full-scale span (S) of one of the labeled EU channels. Determine the difference between the parameter values corresponding to a signal-conditioned transducer output of zero-volts and 5.00 volts for EU channels 13 through 36. Set each calculated span value into the thumbwheel switch for the corresponding EU channel.

(3) Special Cases. The initial and or final values for some EU channels may not be empirically known but may be mathematically extrapolated from known values. Although these extrapolated values may have no physical significance, this procedure is the simplest way to determine a linear curve in the system.

c. EU Linearization. Engineering unit's channels 1 through 12 are to be programmed for engineering units conversion of non-linear transducer-parameter relations. The initial offset values for these channels should be determined and selected in the same way as for linear EU channels. The procedure for determining the span and linearization factors is given below. Linearization schemes for the first 12 EU channels are programmed on the pinboards in the two EU Linearization Programmer chassis (35G and 35H); see Figure VI-D-10.

The span and linearization factor determination for each linearization channel is performed in four steps:

(1) Determine the engineering unit value corresponding to signal conditioned inputs at each segment boundary (i.e., inputs of 0.00, 0.50, 1.00, 1.50, etc. volts).

(2) Calculated the span of the parameter within each segment (s_i).

(3) Calculate the span set (S) of the channel from the largest segment span according to the relation:

$$S = 5 s_{i \max}$$

Set this value into the span set thumbwheel switch for the channel being processed.

(4) Calculate the linearization factor for each segment according to the relation:

$$L_i = 100 \frac{s_i}{s^i}$$

Program the linearization pinboard for the channel being determined by inserting a diode pin in the sockets corresponding to the linearization factor (column) calculated for each segment (row). When programming is complete, there must be one and only one pin in each pinboard row.

The form suggested for the linearization calculations is shown in Figure VI-D-11 with sample calculations for the relation shown in Figure VI-D-12. Standard rounding procedures are to be used in the calculations. The values of the parameter at segment boundaries may be determined experimentally or extracted from the transducer transfer curve.

4. System Calibration and Programming Checkout. The following procedures should be followed to checkout the programming of the Facility, Duct, and Shield Monitor.

a. Apply power to the system by closing the INSTRUMENT AC POWER circuit breaker on the PU-10 in rack 34. The indicator on the power panel and the displays on the FD&S Monitor Control Panel should become illuminated. Apply power to the Test Cell logic by closing the INSTRUMENT AC POWER circuit breaker on the PU-10 at Test Cell rack 42. The indicator on the power panel and displays on the Test Cell Multiplexer should become illuminated. Display power need not be supplied for calibration.

b. Depress and release MASTER RESET. The counter operation indicators on the Control Panel should be flashing at the rate indicated in Table VI-D-2. No alarms should be present. If a GCA alarm is observed, either now or during the remainder of the calibration procedure, check that no GCA channel was programmed for a higher caution than alarm level.

c. Position mode control to CALIBRATE, the FUNCTION switch to FS, and the PERCENT CALIBRATE switch to 100. The down counter and up counter displays should both read 500. Switch the FUNCTION selector to Z; the down counter should read 000 and the up counter display should read 500.

d. Position the FUNCTION switch to EU, the PERCENT CALIBRATE switch to 000, and the channel number switches to 1. The down counter display should read 000 and the up counter display should read the initial offset value selected for EU channel 1. Switch the PERCENT CALIBRATE control to 100 in increments of 10%. The down counter display should increase in increments of 50. Wait for the up counter display to be updated at each position and record the value displayed, Figure VI-D-10. The recorded value at each increment should agree with the programmed value, within the system tolerance and programming rounding. The pinboard linearization program may be modified to compensate for errors due to rounding the linearization factor.

e. Repeat step (d) for EU channels 2 through 12, recording the up counter display for each increment of each channel, comparing these readings with the programmed values, and modifying the program where necessary.

f. Position the channel number switches to 13. With the PERCENT CALIBRATE switch at 0, 50, and 100, the up counter display should read the EU channel 13 initial offset, midpoint, and final parameter values, respectively.

g. Repeat step (f) for EU channels 14 through 36.

If proper values are obtained at each percentage of full-scale for each EU channel, EU programming may be assumed to be correct. The operator may then proceed to step (h) of the checkout procedure, subsection C-2, page VI-D-11, to place the system into full operation.

<u>NAME</u>	<u>LOCATION</u> <u>(Rack)</u>
Control Panel	CP34
Timing Chassis	CP34
TCB Multiplexer	TC42
A/D Converter	TC42
Down Counter	CP34
GCA Level Set	CP34
GCA Comparison	CP34
GCA Level Programmer	CP34
EU Span	CP35
EU Span Set	CP35
EU Linearization	CP35
Linearization Programmer	CP35
EU Offset Set	CP34
EU Offset	CP35
Display Storage (6)	CP36
GCA Indicator Driver	CP36
EU Indicator Driver (4)	CP36
Calibration Storage	CP36
Logic Power Supply	CP34
TC Logic Power Supply	TC42
Indicator Power Supply	CP35

TABLE VI-D-1
FACILITY, DUCT, AND SHIELD MONITOR
EQUIPMENT LIST

<u>DESIGNATION</u>	<u>SIGNIFICANCE</u>	<u>FLASHING RATE</u>
1ML	millisecond counter 2^0	400 cps
2ML	millisecond counter 2^1	200* cps
4ML	millisecond counter 2^2	200* cps
5ML	CP multiplexing rate	100 cps
UL	11 position counter 2^0	50 per 1.1 sec
TL	11 position counter 2^1	30 per 1.1 sec
SL	11 position counter 2^2	10** per 1.1 sec
RL	11 position counter 2^3	10** per 1.1 sec
ZL	5 position counter 2^0	4 per 1.1 sec
YL	5 position counter 2^1	2*** per 1.1 sec
XL	5 position counter 2^2	2*** per 1.1 sec
WL	Subframe Identification	1 per 1.1 sec

* lamps on for different duration - see Figure VI-D-3

** lamps on for 40 msec and 30 msec respectively

*** lamps on for 220 msec and 110 msec respectively

TABLE VI-D-2
CHANNEL AND MILLISECOND COUNTERS
INDICATOR FLASHING RATES

F, D&S MONITOR TIMING DIAGRAM

FIGURE VI-D-3
FACILITY, DUCT, AND SHIELD MONITOR
TIMING DIAGRAM
FOR TRAINING USE ONLY

FIGURE VI-D-4

CONTROL PANEL
(FOR TRAINING USE ONLY)

FIGURE VI-D-4

FIGURE VI-D-5

TEST CELL MULTIPLEXER (FOR TRAINING USE ONLY)

FIGURE VI-D-5

FIGURE VI-D-8

EU INITIAL OFFSET SET CHASSIS
(FOR TRAINING USE ONLY)

FIGURE VI-D-8

EU SPAN SET CHASSIS
(FOR TRAINING USE ONLY)

FIGURE VI-D-9

FIGURE VI-D-10

EU LINEARIZATION PROGRAMMER
(FOR TRAINING USE ONLY)

FIGURE VI-D-10

LINEARIZATION COMPUTATION AND CALIBRATION CHECK

EU CHANNEL NO. _____

PARAMETER SAMPLE

RELATION		COMPUTATION			CALIBRATION CHECK			
input (x)	parameter (y)	segment	s_i	L_i (%)	calibrate %	downcounter (x')	upcounter (y')	L_i (revised)
0.00	57 y_o	1			000	000	57	
0.50	168		111	20	010	050	168	20
1.00	270	2	102	18	020	100	269	18
1.50	372	3	102	18	030	150	371	18
2.00	471	4	99	18	040	200	471	18
2.50	538	5	67	12	050	250	539	12
3.00	583	6	45	8	060	300	584	8
3.50	610	7	27	5	070	350	611	5
4.00	628	8	18	3	080	400	629	3
4.50	647	9	19	3	090	450	646	3
5.00	700	10	53	9	100	500	696 701	10

$$s_i = y_i - y_{i-1}$$

$$S' = 5 s_i \max$$

$$L_i = \frac{s_i}{S'}$$

$$y_o = \underline{57}$$

$$S' = \underline{555}$$

SAMPLE LINEARIZATION CALCULATIONS
 (FOR TRAINING USE ONLY)

FIGURE VI-D-11

**TYPICAL TRANSDUCER TRANSFER
CURVE**
(FOR TRAINING USE ONLY)

FIGURE 71-D-12

ETS-1 INSTRUMENTATION AND CONTROLS
INTRODUCTORY COURSE

SECTION VI-E
FACILITY CONTROL SYSTEM
SYSTEM CONTROL HARDWARE

A. INTRODUCTION

The Facility Control System may be divided into two subsystems: (1) the Fluid Process Controls, and (2) the Test Stand Support Equipment Controls. The purpose of these subsystems is as follows:

1. Fluid Process Control. This subsystem provides control for all the gases and liquids that serve the test stand and engine during test operations. These controls include switches, valves, and display consoles.

2. Test Support Equipment Control. This subsystem provides control for the test stand auxiliary equipment such as the Duct, Shields, and Steam Generator and also displays the applicable parameters of this equipment.

In addition to these functions, the Facility Control System conditions and buffers system signals which are recorded by the Data Acquisition System.

This section covers the typical control devices in the Facility Control System.

B. GENERAL DESCRIPTION

1. Equipment Areas. The ETS-1 Complex is divided into four broad areas:

- (1) Control Point and Utility Equipment Buildings
- (2) Forward Control Room, Fill Station and Storage Areas

(3) Test Cell Building and Liquid Storage Area

(4) Test Stand and Test Stand Area

Each of these areas is furnished with certain electrical equipment required for control of the components in that area. This equipment consists of power sources, solenoid valve boxes, motor control centers, and the necessary terminal boxes and cabling to control these components remotely from the Control Point Building.

2. Equipment Identification. Identification of components in the various areas is accomplished by an area number prefix. The prefixes are 10 for the Control Point and 20 for the Utility Equipment Building above grade at the Control Point. The Forward Control Room and Fill Station prefix is 30. The Test Cell Building prefix is 40 and the Test Stand Building and Test Stand Area is 50. An example of this notation is 50-RSV-438. The number 50 locates Remote Shutoff Valve 438 in the Test Stand Area. The number 438 is the series number of the component, in this case a Remote Shutoff Valve (RSV).

C. OPERATION

The components used in the Facility Control System include valve control and transducers for indication and control. In Section IV, transducer types and operation were covered. This section will describe typical valve control, both binary and analog types, pressure regulating valve with remote dome loading, and a typical motor control circuit.

There are four types of operational valves employed in the Facility Control System:

- (1) Solenoid Valves (SV)
- (2) Remote Shutoff Valves (RSV)
- (3) Analog Control Valves (PCV, TCV, FCV)
- (4) Pressure Regulating Valves (PRV)

Each of these valves and associated circuitry are shown in Figures VI-E-1, 2, 4, and 5, respectively.

1. Solenoid Valves. Solenoid valves are of the binary type, i.e. they operate in one of two positions: either OPEN or CLOSED, with no intermediate control position. They are operated, as shown in Figure VI-E-1, from the Control Point Building. A valve command from the control console activates the low current transfer relay which in turn closes a contact in the local power supply to operate the valve. Indication of valve operation is sent back to the control console from a separate contact in the power transfer relay.

Control of solenoid valves depends upon the position of the permissive operate switch in the solenoid valve box. When a safe/operate switch is moved to the SAFE position, it will open the operating circuit and also break a series circuit which will present a NOT-READY light on the appropriate console.

2. Remote Shutoff Valves. Remote shutoff valves are of the binary type (OPEN/CLOSED) and are controlled in the same manner as solenoid valves. The electrical difference in the valve control is the indication circuit. The remote shutoff valve utilizes open and closed limit switches mounted on the valve topworks. The safe/operate switch must be in the OPERATE position or the valve cannot be actuated from a remote console.

Figure VI-E-2 shows the operational difference between the solenoid valve and the remote shutoff valve. The remote shutoff valve control consists of a solenoid pilot valve located in a solenoid valve box. This solenoid pilot valve controls the actuation gas which operates the RSV. When the control switch at the CP console is operated, 28 vdc energizes a power transfer relay, which in turn furnishes 28 vdc from a local power supply to the solenoid pilot valve. The solenoid pilot valve operates and allows an actuation gas to pass through and pneumatically operate the RSV. When the RSV operates, the valve stem strikes limit switches which give an OPEN or CLOSED indication back at the Control Point.

In contrast, the solenoid valve requires no actuation gas as it is located in the line and directly controls the process flow.

3. Analog Control Valve. The third type of valve is the analog control valve which can be placed in any intermediate position from full open to full closed, corresponding to a demand signal. The analog control

valves are used in control loops in both the Facility Control System and in the Test Stand Control System. These valves are classified by the type of feedback transducer that was to be used in the control loops. Design changes since the original control conception have resulted in some changes in types of feedback transducers; however, the valve designations have not been changed. The three classifications are:

- a. Pressure Control Valve
- b. Temperature Control Valve
- c. Flow Control Valve

The function and various control modes of analog control valves are listed in Table VI-E-1. The analog control valves include both pneumatically operated valves and hydraulic valves.

a. Pneumatically Operated Valves. The analog valve shown in Figure VI-E-3 consists of three main control units: (1) an electro-pneumatic transducer which converts an electrical signal into a pneumatic output signal, (2) a valve positioner which receives the pneumatic signal and translates it into pneumatic supply pressure for actuating the control valve, and (3) the control valve which is positioned by the pneumatic supply pressure from the valve positioner. In operation, an increase in the electrical signal from either a manual or auto demand will produce a downward force on the transducer beam causing it to move the baffle toward the nozzle. Nozzle back pressure is increased until the force exerted by it on the beam equals that exerted by the coil. The beam is thus rebalanced at an increased nozzle back pressure (output pressure) proportional to the increased signal. Thus, in a direct acting transducer, an increase in electrical signal results in an increase in pneumatic output pressure. By reversing the leads to the coil, the electro-pneumatic transducer may be used to cause a reverse action, whereby an increase in electrical signal decreases the output pressure.

When an increase in flow is demanded and the transducer has responded to its signal, the pneumatic output signal from the transducer is increased and higher pressure nitrogen (instrument pressure) is supplied to the bellows chamber of the valve positioner unit. This exerts a downward force on the positioner spring, at the same time closing the exhaust port of

the three-way pilot valve and opening supply pressure actuating pressure to the chamber below the control piston. The analog control valve now opens to increase the flow as demanded. This increased pressure below the piston causes it to rise in the dome, compressing the spring against the bellows until the spring force is equal to the bellows pressure force. At this point, the pilot valve is moved away from the exhaust seat cutting off the supply pressure from the actuating tubing. The pilot valve then maintains a control position between the seats allowing a constant small bleed at the exhaust to maintain sensitivity and avoid a flat spot in operation. The analog control valve then remains at the new position to allow that specific increase in flow.

b. Pneumatic Valve Control Circuit. As can be seen on Figure VI-E-3, the instrument pressure control range is from 3 to 15 psi. An example of a typical circuit with a 1.5 ma dc input signal utilizing a controller with a coil resistance of 2,600 ohms is shown in the sketch below. As the input signal is varied from 1 to 5 ma, instrument pressure would vary from 3 psi full close to 15 psi full open.

The simplified pressure control valve control circuit, Figure VI-E-4, shows the controls and circuits required to operate the pneumatic analog control valve. This schematic includes provisions for both manual and automatic valve control.

The pneumatic controller controls the position of the valve directly from the wiper of the manual demand pot. This signal goes directly to the electro-pneumatic converter and is sent to the valve as a 0-18 psig signal. The valve is set up to respond to 3-15 psig. Valve position is displayed on the console and is not a portion of the controller.

The automatic portion of the controller utilizes pressure as the feedback signal. The measured pressure and the demand pressure are summed

and integrated. The output of the auto controller is a valve position demand. Transfer from manual to auto is accomplished by zeroing the error between the manual demand and the output of the auto controller. This eliminates the introduction of a transient during the transfer operation.

c. Hydraulic Valve Control Circuit. The simplified hydraulic pressure control valve control circuit is shown in sheet 2 of Figure VI-E-4. The hydraulic controller differs from the pneumatic controller in that the signal from the controller is an error signal rather than a position demand. The hydraulic actuation requires an error position feedback in an external loop. This feedback is provided by the valve stem position potentiometer. The manual demand is summed with the feedback position by amplifier 1 to produce the error signal. Auto control utilizes pressure as the feedback in the same manner as the pneumatic control. In the auto mode, the output of the auto controller is a position demand which is then summed with the actual position to provide an error signal to the servovalve.

Both the pneumatic and hydraulic controllers provide a follow-up circuit to the manual pot when operated in auto mode. The follow-up circuit tracks valve demand rather than actual valve position.

4. Pressure Regulating Valves. The final type of valve and its control is the Pressure Regulating Valve. This valve is controlled by a device located in a solenoid valve box. The internal electrical circuit of this device, known as a remote loader, consists of nothing more than two solenoid valves. One of the valves serves to pressurize or load the dome, and the other acts as a vent valve to unload and adjust the pressure in the dome.

To Load: Close vent switch and adjust pressure by closing momentary load switch.

To Unload: Open vent switch to completely unload, or use the spring loaded momentary vent switch to decrease pressure.

The operation of this valve is shown in Figure VI-E-5. When the vent switch on the console is closed, it turns the red light ON. At the same time, 28 vdc is passed through the closed momentary vent switch to pick up the power relay K and complete the circuit through the SAFE OPERATE switch. When the K relay closed, it closed the KA contact and reversed the KB contacts. Through the KA contact circuit 28 vdc is picked up at the power supply in the particular field area, and power is applied to the vent solenoid valve to vent the PRV dome loader.

When the KB contacts reversed upon power application to relay K, 28 vdc was supplied to the CLOSED light on the console. Prior to closing the vent switch to ON, it can readily be seen that the OPEN light is on.

When the vent switch of the remote loader is closed, pressurization of the dome can be accomplished by pressing the momentary load switch to ON. The circuit for this valve is the same as the vent circuit with the exception of the momentary vent switch. The regulating valve is now being dome loaded to control the pressure downstream of the valve. To increase the pressure downstream the momentary load switch is depressed, and to decrease downstream pressure the momentary vent switch is depressed.

The following sketch is a simplified piping arrangement for pressurizing or venting the dome of the PRV.

In this example, the pressurizing gas is the process gas itself. In other cases, the control supply pressure may come from a separate gas header for valve actuation or a portable high pressure gas storage cylinder.

D. TYPICAL MOTOR CONTROL CIRCUIT

In each of the equipment areas, motor control centers have been installed which contain motor starters. At this equipment the 480 volts is stepped down

to 120 volts through a control transformer. Figure VI-E-6 shows a typical motor control circuit, in this case for a gas compressor at the Fill Station. In the circuit, a normally closed contact labeled STOP provides remote stop capability. When the STOP switch on the console is depressed, a relay picks up and opens the contact which breaks the circuit to the CR relay. This in turn opens the CR contacts in the motor circuit and stops the motor.

The next interlock is a flow switch. This contact is closed when cooling water picks up a flow switch which energizes a relay to close the contact. All other interlocks operate in a similar manner, although they may be sensing a different parameter.

When all interlocks are satisfied and the LOCK OUT SWITCH closed, the operator can start the compressor by depressing the START switch on the console. The relay K7 picks up and closes its contact which completes the circuit to the CR relay. The CR relay closes its contacts and locks in on a set of these contacts. At the same time K1 relay energizes and closes a contact for indication at the console. The closed CR contacts in the 480 volt circuit pick up the Timer Relay (TR). The TR contacts are closed in the start coil circuit which applies power to the motor windings. When the S coil is energized, its contact picks up the M or main contactor in the motor circuit. The M coil locks in on its own contact. After a preset time, usually a matter of 5 to 20 seconds, the TR contacts in the S coil circuit open to de-energize the S coil; this closes the S contact in the R or run coil. The TR contact in the run coil circuit closes at the same instant as the TR contacts in the start coil circuit opens. The motor is now running at rate speed and the compressor loads or unloads as set in the pressure switches P1 and P2.

E. TYPICAL CONTACT CLOSURE

The final circuit is a typical contact closure that indicates a low/high level, pressure drop, etc. An example of this is mentioned in the above section that describes motor control. If the cooling water flow switch dropped out due to loss of flow, it would not only stop the compressor but a relay contact would complete a circuit to an alarm indicator on the operating console as shown in Figure VI-E-7.

<u>VALVE NO.</u>	<u>FUNCTION</u>	<u>CONTROL MODE</u>
A. Valves in the Facility Control System for pressure control:		
38 PCV-248	Pressurization of Liquid	1. Manual valve position control.
38 PCV-179	Hydrogen Storage Dewar V3801	2. Automatic Pressure Control.
B. Valves in the Test Stand Control System to control facility parameters:		
50 PCV-250	Pressurization of LH ₂	1. Manual valve position control.
50 RSV-109	High Pressure Run Tank V-5002	2. Automatic Pressure Control.
50 PCV-165	Pressurization of LH ₂	1. Manual valve position control.
50 PCV-180	Run Tank V-5001	2. Automatic Pressure Control.
50 PCV-472	Flow of LH ₂ Cooldown	1. Manual valve position control. 2. Automatic Pressure Control. (Nozzle Torus Pressure) 3. Programmed temperature control.
50 PCV-251	Engine Cooldown using GH ₂	1. Manual valve position control. 2. Automatic Pressure Control. (Nozzle Torus) 3. Programmed temperature control.
50 PCV-471	Engine Cooldown using He	1. Manual valve position control. 2. Automatic Pressure Control. (Nozzle Torus) 3. Programmed temperature control.
50 FCV-50	Flow of GN ₂ for Purging	Manual valve position control.
50 PCV-517	Flow of LN ₂ for Cooldown	Manual valve position control.
C. Valves in the Test Stand Control System to control the engine:		
TPCV (Turbine Power Control Valve)	Flow of propellant to the turbine drive.	1. Manual valve position control. 2. Manual Pressure Loop. 3. Programmed engine control.

TABLE VI-E-1

VALVE FUNCTION AND CONTROL MODES

FIGURE VI-E-1
TYPICAL SOLENOID VALVE
SCHEMATIC DIAGRAM
FOR TRAINING USE ONLY

FIGURE VI-E-2
TYPICAL REMOTE SHUT-OFF VALVE
SCHEMATIC DIAGRAM
FOR TRAINING USE ONLY

FIGURE VI-E-3

TYPICAL ANALOG CONTROL VALVE
TOPWORKS PIPING
AIR-TO-OPEN/SPRING-TO-CLOSE
FOR TRAINING USE ONLY

FIGURE VI-E-4
SHEET 1 OF 2

TYPICAL PNEUMATIC PRESSURE CONTROL
VALVE SCHEMATIC DIAGRAM
FOR TRAINING USE ONLY

FIGURE VI-E-4
SHEET 2 OF 2
TYPICAL HYDRAULIC PRESSURE CONTROL
VALVE SCHEMATIC DIAGRAM
FOR TRAINING USE ONLY

FIGURE VI-E-5
TYPICAL PRESSURE REGULATING VALVE (PRV)
SCHEMATIC DIAGRAM
FOR TRAINING USE ONLY

SYMBOLS

EXAMPLE SHOWN IS FOR WORTHINGTON COMPRESSOR C-3001

- FS FLOW SWITCH
- LOS LOCK OUT SWITCH
- P1 PRESSURE SWITCH 1
- TS THERMAL SWITCH
- SV1 SOLENOID VALVE UNLOADER 1
- CR CONTROL RELAY
- CR CONTROL RELAY CONTACT
- K1 REMOTE INDICATING RELAY
- K7 CONTACTS OF K7 - REMOTE START

- TR TIMER RELAY
- S "START" COIL
- M "MAIN" COIL
- R "RUN" COIL
- R RUN CONTACT
- R RED INDICATING LAMP
- |— OPEN CONTROL RELAY CONTACT
- |/— CLOSED CONTROL RELAY CONTACT

FIGURE VI-E-6
TYPICAL REMOTE MOTOR CONTROL
SCHEMATIC DIAGRAM
FOR TRAINING USE ONLY

FIGURE VI-E-7

**TYPICAL CONTACT CLOSURE
SCHEMATIC DIAGRAM**
FOR TRAINING USE ONLY

FIGURE VI-E-7

ETS-1 INSTRUMENTATION AND CONTROLS
INTRODUCTORY COURSE

SECTION VI-F
FACILITY CONTROL SYSTEM - CONSOLE OPERATION

A. FACILITY CONSOLES

The Facility Consoles provide controls and indication for the liquid and gas systems at ETS-1. They also serve a similar function for the test stand auxiliary equipment including the duct, shields, and steam generators.

The location of all CP Control Room Consoles is shown in Figure VI-F-1. The Facility Consoles are:

1. Gas Fill and Service
2. Facility Engineer - Right
3. Remote Installation Console
4. Facility Engineer - Left
5. Lead Facility Engineer

The positions AFER and AFEL are 8 channel Beckman recorder locations. Qualified operators will man these stations during an entire run.

The functions controlled from the five Facility Consoles include:

1. Gas storage
2. Liquid storage
3. Transfer of liquids and gases
4. Emplacement of shields
5. Operation of steam generators
6. Water flow through duct and shields
7. Gas sampling of engine compartment

B. GF&S CONSOLE

The primary purpose of the GF&S console is to set up the gas storage and transfer system. The GF&S console is set up prior to any operation of the facility since all facility actuation gas must come from the nitrogen bottles controlled from this console.

Figure VI-F-2 is the GF&S console layout diagram. The left half of the console contains the valve switching capability and indication to fill the nine storage bottles.

The right half of the console includes compressor controls, header valves, and indications to enable remote operation of compressor systems.

C. FER CONSOLE

The primary function of the FER console is the fill, storage, and transfer of liquid hydrogen. The FER console operations are mostly concerned with the period preceding the engine run. During run conditions the FER has monitoring capability for the flare stacks.

The FER console layout is shown in Figure VI-F-3. The left half of the console includes controls for: (1) emergency gaseous nitrogen activation, (2) pressurization and venting of the liquid nitrogen dewar, and (3) pressurization and venting of the liquid hydrogen storage dewar V-3801. The liquid level of the hydrogen storage dewar is displayed on analog as well as on point indications.

Located on the right half of the console are the controls and indicators for operation of the flare stacks. The designation FS3801 is the storage dewar flare, FS5001 the run tank flare, and FS5003 the steam generator flare. The flare system includes gas sampling and ignite capability. In event that topping of the run tank is required, topping control capability is included on the FER console.

D. REMOTE INSTALLATION CONSOLE

The primary purpose of the RIC is remote installation of the engine, side shields, and duct cover shield. In addition, the RIC controls movement of the vault door and has indicators for monitoring removal of the duct.

The RIC and the LFE work as a team in positioning and aligning the side shields prior to an engine run. During the run the RIC monitors shield and duct parameters.

The RIC console layout is shown in Figure VI-F-4. The left half of the console includes controls and indication for movement and alignment of the shields.

Located on the lower right panel are the seal make-up controls for the shields and indicator lamps for duct removal. The upper right panel contains indicators for monitoring shield temperatures, and purge gas in the duct.

Mounted above the four RIC console panels is the 50 channel bargraph recorder. This instrument provides a graphic display of duct temperatures, pressures, and flow.

E. FEL CONSOLE

The primary purpose of the FEL console is operation of the steam generators. The steam generators are used to inert the duct prior to engine firing. In addition they produce a partial vacuum at the engine nozzle which simulates space conditions. The FEL is in operation immediately before and during the engine test run.

The FEL console, shown in figure VI-F-5, is considered to be divided into seven sections.

1. Gaseous nitrogen and water
2. Propane
3. Liquid oxygen
4. Steam Generator No. 1
5. Steam Generator No. 2
6. Steam Generator No. 3
7. Steam Generator Plenum

Analog meter displays on the upper half of the console aid the operator in (1) pressurization of the LO_2 and Propane tanks, (2) bleed-in of LO_2 and Propane, and (3) evaluation of the performance of each steam generator unit.

The lower panels provide controls for each individual system. Should one of the steam generators automatically shut down, the lower panel also includes indicator lamps to indicate the mode of malfunction.

F. LEAD FACILITY ENGINEER

The primary function of the LFE console is the operation of the duct and shield system. Prior to the engine run the LFE and RIC work together in positioning the shields. During the engine run, the LFE controls water flow through the duct and shields. During cooldown, after the engine run, the LFE monitors duct and shield temperatures and controls water flow through these systems as required for cooling.

Figure VI-F-6 is the LFE console layout diagram. The upper left panel of the console contains indicators for monitoring duct temperature pressure and water flow. The water flow through the duct is controlled from the lower left panel.

The upper right panel of the console contains indicators for monitoring the hydrogen and oxygen content in the engine compartment and shield temperature indicators. Water flow through the shields is controlled from the lower right panel.

G. SUMMARY

The GF&S console is used to set up the gas storage prior to the run.

The FER console is used to fill, store and transfer liquid hydrogen prior to the run.

The RIC console is used to remotely install the engine and align the shields prior to the engine run.

The FER console is used to operate the steam generators during the engine run.

The LFE console is used to control water flow through the shields and duct during the engine run.

CONTROL ROOM CONSOLE LAYOUT
FOR TRAINING USE ONLY

FIGURE VI-F-1

FIGURE VI-F-2
GAS FILL & SERVICE
CONSOLE
FOR TRAINING USE ONLY

FIGURE IV-F-3
FACILITY ENGINEER-RIGHT
CONSOLE
FOR TRAINING USE ONLY

FIGURE VI-F-4

REMOTE INSTALLATION CONSOLE
FOR TRAINING USE ONLY

FIGURE VII-F-5
FACILITY ENGINEER - LEFT
CONSOLE
FOR TRAINING USE ONLY

FIGURE VI-F-6
LEAD FACILITY ENGINEER
CONSOLE
FOR TRAINING USE ONLY

ETS-1 CONTROL POINT OPERATOR
GENERAL INDOCTRINATION COURSE

SECTION VII
ELECTRICAL POWER SYSTEM

A. INTRODUCTION

1. General Information. The only means of transporting energy in the form of electricity is over transmission lines. An electrical power system consists of three principal components; the generating stations, the transmission lines, and the distribution systems. The transmission lines are the connecting lines between all the generating stations and the distribution system. A distribution system connects all of the individual loads in a given area to the transmission lines.

The first transmission lines were single-phase, and the energy was usually consumed for lighting only. The advantage of polyphase motors was apparent immediately, and a two-phase ac distribution system was demonstrated in 1893. Transmission of electrical energy in the United States is now entirely by means of alternating current.

One reason for the early acceptance of ac systems was the transformer, which makes possible the transmission of electric energy at a voltage higher than the voltage of generation or utilization. A higher voltage of transmission requires less line current for the transmission of a given amount of power and, therefore results in lower I^2R losses in the line. An ac generator is a simpler device than a dc generator, and this is an additional advantage of ac systems.

In a dc transmission system ac generators supply the dc line through a transformer and electronic rectifier. An electronic inverter changes the

direct current to alternating current at the end of the line so that the voltage can be reduced by a transformer. Economic studies have shown that a dc overhead transmission is not now economical over distances of less than 350 miles; however, the demand for large blocks of power remote from the present generation stations suggests the interconnection and transmission of power between neighboring system and regions by dc.

2. Utilization of Power and Stability. Interconnection of systems increases the amount of current which flows when a short circuit occurs on a system and requires the installation of breakers able to interrupt a larger current. The disturbance caused by a short circuit on one system may spread to interconnected systems unless proper relays and circuit breakers are provided at the point of interconnection. Not only must the interconnected system have the same nominal frequency, but also the synchronous machines must remain in step with the synchronous machines of the interconnected systems.

The current which flows in an ac generator or synchronous motor depends on: (1) the magnitude of its generated or internal voltage, (2) the phase angle of its internal voltage with respect to the phase angle of the internal voltage of every other machine in the system and (3) the characteristics of the network and loads. For example, two ac generators operating in parallel but without any external connections other than the parallelizing circuit will carry no current if their internal voltages are equal in magnitude and in phase. If their internal voltages are equal in magnitude but different in phase, the voltage of one subtracted from the voltage of the other will not be zero, and a current will flow, as determined by the difference in voltages and the impedance of the circuit. One machine will supply power to the other, which will run as a motor rather than as a generator.

The phase angles of the internal voltages of synchronous machines remain constant only as long as the speeds of the various machines remain constant at the speed which corresponds to the frequency of the reference phase. When the load on any one generator or on the system as a whole changes, the current in the generator or throughout the system changes. If the change in current does not result in a change in magnitude of the internal voltages of the machines, the phase angles of the internal voltage

must change. Thus, momentary changes in speed are necessary to obtain adjustment of the phase angles of the voltages with respect to each other, since the phase angles are determined by the relative positions of the motors. When the machines have adjusted themselves to the new phase angles, or when some disturbance causing a momentary change in speed has been removed, the machines must operate again at synchronous speed. If any machine does not remain in synchronism with the rest of the system, large circulating currents result and in a properly designed system, the operation of relays and circuit breakers removes the machine from the system. The problem of stability is the problem of maintaining the synchronous operation of the generators and motors of the system.

3. Redundancy in Power Systems. The reliability of any power system is only as good as its transmission line and its ability to handle sudden applications of large loads. In any transmission line subject to high winds and storms, phase to ground or phase-to-phase faults occur which will interrupt the service by operation of relays and breakers. For instance, the high voltage between a conductor and the grounded supporting tower causes ionization which provides a path to ground for the charge induced by the lightning stroke. Once the ionized path to ground is established, the resultant low impedance to ground allows the flow of power current from the conductor to ground and through the ground to the grounded neutral of a transformer or generator, thus completing the circuit. The opening of circuit breakers isolates the faulted portion of the line from the rest of the system and interrupts the flow of current in the ionized path which allows deionization to take place. The removal of the faulted transmission line should not interrupt service provided by local generation.

During critical testing periods utility power and local generation are in parallel, and the failure of either one should not interrupt service. The local generation should be of sufficient capacity and redundancy to allow partial failure of its capabilities without power interruption. An important problem in efficient system operation is that of determining how the total generation required at any time should be distributed among the various generating systems and among the units of each system.

4. ETS-1 Power Criteria. The terms stability and stability limit are applied to both steady-state and transient conditions. Steady-state

stability limit refers to the maximum flow of power possible through a point without the loss of stability when the power is increased very gradually. Transient stability limit refers to the maximum flow of power possible through a point without the loss of stability when a sudden disturbance occurs. The analysis of any power system to determine its transient stability involves some mechanical properties of the machines of the systems, for after every disturbance the machine must adjust the relative angles of their rotors to meet the conditions of power transfer imposed. The problem is mechanical as well as electrical, and certain mechanical principles must be kept in mind when considering the problem.

The stability limits (steady and transient) imposed on the ETS-1 power system by the criteria are as follows:

a. 480 Volt, 60 Cycle Utilization Power.

Frequency

- (1) Steady State regulation 60 cps $\pm$ 0.3 cps
- (2) Maximum allowable recovery time (no load to full load) - 0.2 seconds
- (3) Overshoot and undershoot - maximum 2%
- (4) Maximum variation at constant load $\pm$ 0.5%

Voltage

- (1) Regulation $\pm$ 5%
- (2) Recovery to within operating band in 0.2 seconds
- (3) Constant load variation $\pm$ 5%
- (4) Voltage overshoot and undershoot $\pm$ 20% recoverable within .2 seconds to operating band

b. 400 Cycle AC System. 120/208v $\pm$ 1.5%, 3 phase, 400 $\pm$ 2.0 cps, 1% total harmonic distortion, 5 kw rating per generator. Each generator shall have a motor (60 cps) power factor of unity at full (5 kw) load, unity to 0.9 from half-load to full load and an efficiency of at least 70% and the allowable temperature rise shall be 50°C with pf's from 1 to 0.8 lead or lag. The output

voltage of the generator will be stabilized within one minute after startup and will remain within a $\pm \frac{1}{2}\%$ regulation band at any constant load from 0 to 5 kw, and over an ambient temperature range of 0° to 125°F.

After stabilization, the output voltage shall not deviate more than $\pm 25\%$ from pre-set value in event of sudden application or removal of rated kw at rated power factor. Recovery to within the regulated band shall be complete in 0.2 seconds.

- c. 28 Volt DC System. 28v (adjustable from 22 to 32v) 400 Amp. It shall have dynamic regulation of $\pm 1.0v$ from no-load to full load over a 10% input range with a ripple of less than 3 mv rms (at output voltage setting) at any load or any line condition. It shall have a response of 200 microseconds in the event of sudden application or removal of full load at any input line voltage. A maximum output variation of $\pm 0.5v$ due to transient loads is permissible.

B. GENERAL DESCRIPTION

The power generation and distribution system shown in Figure VII-1 is divided into three distinct buses: (1) the utility load bus, (2) the essential load bus, and (3) the instrument load bus.

1. Utility Power and Distribution. The utility power and distribution system supplies power to the complete ETS-1 complex during periods of non-testing. During periods of testing, the utility power system supplies only facility support items such as motors, fans, lighting, etc. It is also intended to back up the other two buses. This will be discussed in the Operational Philosophy section of this document.

This system receives power at 138 kv from Nevada Power Company or Amargosa Valley Cooperative, Incorporated, where it is stepped down to 69 kv at the Jackass Flats Substation. It enters into ETS-1 substation on a 69 kv line, where it is stepped down to 4160 volts by a 2,500 kva transformer and enters the switchgear on a main breaker. (Allis-Chalmers type ACB, MA 75.)

This breaker is protected by 50/51 and 50/51 N over-current relays, GE type 1 AC. Power passes through the closed breaker to the utility bus, where it is distributed to the loads through five feeder breakers. The feeder breakers are the same type as the main breaker described above. They also are protected by 50/51 and 50/51 N relays. These protective relays, by proper setting, afford selective tripping, i.e., tripping nearest the fault.

2. Essential Power and Distribution. The essential power and distribution system supplies power to control circuits, vital motor loads and any load which requires a high degree of reliability, but is not necessarily sensitive to harmonic transients or minor voltage fluctuations. This system receives power from the utility bus during periods of non-testing and from three 308 hp Caterpillar diesels, model D-375, each driving Allis-Chalmers type AWB 150 kw, generators 187.5 kva with 0.8 power factor during test periods.

During non-testing periods, power is routed through a utility bus tie breaker which is the same as the other utility breakers. The utility tie breaker is protected by 50/51 and 50/51 N over-current relays of the same type described above.

During test periods, power is supplied to this bus from the three Caterpillar diesel generators through their individual output breakers which are protected by 50/51 and 50/51 N over-current relays, identical to those described above. Also, a reverse power relay is installed on all three generators. These relays are Westinghouse type CRN-1.

This power, either during testing or non-testing, is routed to the loads through two feeder breakers which are protected by 50/51 and 50/51 N over-current relays, the same as described above. All breakers on the essential load bus are Allis-Chalmers Air Circuit Breakers type MA 75B.

3. Instrument Power and Distribution. The instrument power and distribution system supplies power to loads such as data acquisition and signal conditioning equipment, or vital loads which are sensitive to transient harmonics or voltage fluctuations.

During periods of non-testing, the utility power is fed to the instrument bus through the tie breaker which is protected by 50/51 and 50/51 N over-current relays.

The breaker and relays are as previously described. During test periods, power is supplied to the buses from two Cummins diesels through the generator output breakers, GE type AK-1-25, which are protected by series over-current devices in the breaker, and a reverse power relay GE type 1 BC. Power then passes through this breaker to the generator control trailer to generator #1 and #2 breakers which are protected by 50/51 over-current relays with voltage restraint GE type 2 JCV, and through this breaker to an output breaker protected by a timeover current relay GE type 1 AC. From this breaker, the power is applied to a 500 kva transformer and stepped up from 480 volts to 4160 volts. At this point, it is impressed on the instrument bus through a breaker in the unit substation which is the same as all breakers on the utility and essential buses. It is protected by over-current relays 50/51 and 50/51 N GE type 1 AC. Three feeder breakers distribute this power to the various loads. These breakers and protection relays are the same type as stated for the essential and utility buses.

C. OPERATIONAL PHILOSOPHY

The power and distribution system at ETS-1 is intended to be operated in the following manner:

1. Non-Testing Configuration. During non-testing periods, the power to the three buses will be provided by the utility power system through the tie breakers to the essential and instrument buses. The diesel generators would be available in the event of failure of Nevada Power.

2. Testing Configuration. The power system at ETS-1 will be set up in the following manner during test periods:

- a. The utility bus will be supplied from Nevada Power. All breakers on the bus will be closed including the tie breakers.

- b. The essential bus loads will be supplied with power from the three Caterpillar diesels and will be paralleled to the utility bus through its tie breaker.

Operation in this manner will afford maximum reliability by having the three diesel generators carry essential loads with Nevada Power as back up. In the event of a fault on Nevada Power system, the hi-speed Westinghouse types H3 (under voltage) and HV3 (reverse power) relays will open the tie breaker protecting the essential bus. The diesel generators will see a minimum load transient as they had been carrying the essential loads. On the other hand, if the diesels should fail (an unlikely circumstance) Nevada Power will assume the essential loads.

c. The instrument bus is designed to supply power loads which are sensitive to transients. Due to the nature of these loads, such as low power consumption, no large inductive circuits, etc., this bus will be divorced from Nevada Power during testing periods.

It should be pointed out at this time that the two diesel generators supplying this bus were designed to operate independently of any outside power source.

Should either diesel generator fail, its protective circuits will remove it from the line. At this point in time, if necessary, the running diesel generator could then be momentarily paralleled back with Nevada Power until the load was transferred to Nevada Power.

Upon completion of testing, the instrument bus will be momentarily paralleled to Nevada Power and the diesels will be removed from the bus.

The best estimate of instrument bus loads indicates that either of the two diesel generator sets is capable of carrying this bus, which essentially gives the system 100% backup.

D. CONTROLS

The controls for the power generation and distribution system are a combination of remote and local operations. The diesel generators cannot be started remotely, but are started locally and warmed up. The three diesel generators supplying the essential bus can only be synchronized to the essential bus remotely from the power control panel in the recorder room of the CP area. Here the three diesels can be removed from the bus, and regulated according to voltage, frequency or load. The two diesel

generators supplying the instrument bus can be either synchronized locally or remotely, removed from the bus locally or remotely, and regulated according to voltage, frequency, or load.

It should be pointed out that the three diesel generators supplying the essential load bus can be adjusted in "Master and Slave" combination with the utility bus or with each other. This is accomplished by the governor speed droop and response settings. The two diesel generators supplying the instrument bus cannot be used in Master and Slave configuration due to their governor and voltage regulator design. These diesel control systems are designed to be operated in "Load Share." If the two diesels were in parallel with the utility power, the diesels by nature of their controls would try to assume more than the demand of the bus and would always tend to overload. These diesels would actually begin to feed power back into the utility system.

The power control panel in the recorder room of the CP area is provided with controls and indication for: (1) the utility tie breaker, (2) the bus-tie breakers feeding the essential and instrument bus, (3) the five diesel breakers, (4) the instrument bus breaker to the control trailer, and (5) the feeder breaker to the instrument bus 500 kva transformer. The power panel also provides voltage indication, frequency indication, and synchroscopes with which to parallel the buses together or the diesels to their respective buses. Also provided, are kw meters to indicate bus demand and diesel output for the three buses and the diesel generators.

The power panel provides indication and control of the three 400 ampere rectifiers and their associate battery banks shown in Figure VII-2. Accordingly, the three rectifiers can be remotely started and stopped. When remotely stopped the dc contactor to the dc bus automatically drops out. In this event, the battery assumes the bus loads. The contactor can be closed from the power panel only after the respective rectifier has been started. The internal temperatures of the rectifiers are displayed, as well as the dc bus voltages, on the power panel. The output voltage of the rectifiers is adjustable locally with a potentiometer from 22 to 32 volts dc.

The two 400 cycle motor generators, shown in Figure VII-3, are also controlled from the power panel which indicates the running or running

standby condition of each. These units can be controlled locally also. Racks 56, 57 and 58 next to the power panel each contain three channel strip chart recorders with which voltage, frequency or kw of the power system can be recorded. The signals to these recorders are provided by transducers within the power panel which condition the signals for recorder acceptance.

E. CONCLUSION

The bus kva power capabilities for the instrument and essential load buses are as follows:

	<u>Essential Bus</u>	<u>Instrument Bus</u>
CP	225.0	112.5
FCR	112.5	45.0
TCB & TSB	<u>150.0</u>	<u>75.0</u>
	487.5 kva	232.5 kva

These kva ratings included consideration of future ETS-2 loads during the design.

Based upon the above power (kva) 100% demand, it can be readily seen, in considering a load diversification factor and no ETS-2 load, that two out of the three essential load diesel generators could carry the essential bus with one running on standby. The same consideration when made for the instrument bus indicates only one diesel is needed with the other diesel floating. However, this bus is designed so that the two diesels are in load share configuration.

ETS-I POWER SUPPLY
FOR TRAINING USE ONLY

FIGURE VII-1

D.C. POWER SUPPLY
FOR TRAINING USE ONLY

FIGURE VII-2

ETS-1 INSTRUMENTATION AND CONTROLS
INTRODUCTORY COURSE

SECTION VIII
COMMUNICATION SYSTEM

A. FUNCTION OF COMMUNICATION SYSTEM

The Communication System functions are divided into three categories. Listed in the order of usage, these categories are: support and checkout of the Instrumentation and Control System; personnel safety; and support of countdown, engine-run operation, and maintenance assembly and disassembly.

1. Support of Installations and Checkout. An interphone and public-address system are provided to support the multitude of rack-to-rack and rack-to-console checkouts. Interphone stations are provided in sufficient quantity to facilitate the most congested operational or checkout areas.

2. Personnel Safety. In the interest of safety, communications are extended to all areas. Integration of systems is provided to insure maximum flexibility and utility for the Lead Safety Engineer.

3. Support of Countdown, Engine Run, and MAD. The Communication System contains an independent interphone system supplemented with a local and remote public address system to provide for systematic operation of the NERVA program. The system is capable of prearranged communications from point to point in any desired combination of stations. The system is also capable of providing conference calls.

A radio frequency system for linking the Lead Safety Engineer (LSE) to the NRDS safety radio net is available at the LSE's console. Two radio

frequency nets are available for communication between ETS-1, the prime mover, and E-MAD. The net selection to be used at ETS-1 is controlled from the Test Director's console only.

B. SYSTEM DESCRIPTION

The Communication System is composed of three subsystems: (1) Interphone Subsystem, (2) Public Address Subsystem, (3) Radio Frequency Subsystem. Block diagram of the Communication System is shown in Figure VIII-1.

1. Interphone Subsystem. Twenty-six trunk lines are provided for the interphone subsystem. The trunk lines are the main line electrical cables that connect the interphone panels together. Twelve of the trunk lines are assigned as "General" areas. These trunk lines are connected throughout the facility and are operable at each of the communications panels. The remaining fourteen trunk lines are distributed to various areas and provide communication between the specific areas and the control room. Two trunk lines connect between the Storage Farm area and the control room. Six trunk lines connect the CP to the Test Cell areas. Three trunk lines connect the CP to the Television system. The remaining three trunk lines were originally for use with the photo system and at present are not being used.

Approximately 138 communication stations are strategically located throughout the ETS-1 complex. All communications stations have interphone capability. Forty-nine interphone/P.A. stations provide the calling capability through the use of area P.A. Seven special stations, located in the control room, provide RF capability in addition to interphone and P.A. functions. Initial contact for interphone conversations must be made by pre-arrangement. From the interphone/P.A. stations initial contact is made by pre-arrangement or by paging over the area P.A. system. The interphone stations are connected in parallel, and any interphone station may be physically removed from the system without affecting the operation of the remaining units. Several parties can monitor or take part in the conversation on any particular trunk line. The party line capability provides for a maximum of thirty stations on one trunk line.

2. Public Address Subsystem. Three public address trunk lines connect the interphone/P.A. stations to thirty-five speakers located throughout the ETS-1 complex. The P.A. speakers are provided with cutout/override relays for area, universal, or emergency paging. Area speakers may be energized from any of the forty-nine interphone/P.A. or seven special communication stations. Universal paging may be energized from any of the seven special communication stations. Emergency paging, which overrides any other P.A. announcement, may be energized only from the special communication station assigned to the Assistant Test Director (ATD).

3. R.F. Subsystem.

a. The safety R.F. equipment consists of one duplex R.F. station tuned to the NRDS Safety Net Number 18. This station is controlled and operated from the Lead Safety Engineer's console (LSE) in the control point building.

b. General R.F. System consists of two simplex, dual channel, dual frequency transceivers capable of being energized and operated from any of the seven special communication stations, but the frequency (net) is controlled from the Assistant Test Director's (ATD) special communication station only. Net 24 is the ETS-1 and E-MAD operational net. Net 21 is the NTO Administration net and will not normally be used for ETS-1 test operations. There are also ten dual frequency portable transceivers (Handy Talkies), each equipped with helmet-mounted headsets. General R.F. communication subsystem will provide communication links between the following areas: (1) Control Room and remote areas, (2) Control Room and the E-MAD facility during engine transfer operations, (3) Control Room and the prime mover during engine installation.

C. EQUIPMENT DESCRIPTION

1. Standard Interphone Panel. The standard interphone panel provides the capability of maintaining a conversation after it has been initiated in some other way. It is an unpurged panel and is not employed in hazardous areas. The front panel layout is included in Figure VIII-2.

The front panel switches include: (a) power on-off switch, (b) trunk line selector switch, (c) headset-speaker switch. The trunkline selector switch selects a single interphone trunkline. The use of the first twelve

trunklines are available at any panel. The specialized area trunk line positions (SFA, TCA, and TV) provide communication lines within the specialized area or between the CP and the selected specialized area only. The headset-speaker switch in the speaker position permits receiving only. In the headset position both receive and transmit functions are available.

The speaker jack provides an output for a remote speaker. Remote speakers with twenty foot extension cables are provided for the communication system. There are two headset jacks which allow simultaneous use of two headsets from a single panel. Separate gain adjustments are provided for setting the speaker output level and the headset output level.

2. Purged Interphone Panel. The purged interphone panels are used in hazardous locations where there is danger of hydrogen concentrations. These units have O-ring fittings and caps to minimize leakage of the purge gas. These units are not entirely leak proof and a constant supply of nitrogen gas is supplied to the panels.

The front panel, see Figure VIII-2, is similar to the standard interphone panel. The headsets used with the purged interphone panels do not have a push to talk switch, but each purged interphone panel does contain a voice actuated relay circuit. The mike switch mounted on the front panel of the purged unit provides a voice position in which the sound actuated relay is in the circuit. With the mike switch in the open position the headset mike is connected to the trunk line at all times.

3. Standard Interphone/P.A. Panel. In addition to the interphone controls and indicators, the interphone/P.A. panels have a battery condition indicator, a P.A. indicator, and two P.A. controls. The front panel layout is shown in Figure VIII-3.

The P.A. panels operate from a 60 cycle primary power source. In the event of power failure, an emergency battery provides power for two hours of interphone operation. The battery indicator is a chemically operated device and indicates the elapsed time that the battery has operated.

A P.A. area selection switch permits the selection of any one of the three areas (1, 2, or 3) used at ETS-1. P.A. areas 1, 2 and 3 are shown in Figure VIII-7. Areas 4 and 5 were originally intended for ETS-2 and are not presently used. The P.A. indicator lamp shines whenever the P.A. area select

switch is not in the "interphone position." The P.A. control switch connects the headset microphone to the P.A. circuit and makes the desired local P.A. area subsystem operational.

4. Purged Interphone/P.A. Panel. Front panel layout of the purged interphone/P.A. panel is included in Figure VIII-3. It has the same interphone controls as the purged interphone panel, and in addition has the P.A. controls discussed previously. The battery condition indicator is located within the purged interphone/P.A. panel.

5. Special Communication Panels. Special communication panels provide interphone/P.A. and R.F. capability. Figure VIII-4 shows this front panel.

The network selector switch group consists of the Interphone, P.A., General R.F., and Safety R.F. switches. These switches are used to select and control the separate or simultaneous use of the three communication subsystems. Each switch contains a lamp which is lighted when a particular switch is in the "on" position.

The General R.F. switch is operational at each special communication panel. The Safety network is active at the Lead Safety Engineer's console only.

Two of the controls on the special communication panels are active only at the Assistant Test Director's (ATD) console. These are the R.F. channel selectors and the P.A. emergency override switch. Only the ATD has the capability of selecting which one of the two general R.F. communication nets will be used by all special communication panels. For emergency P.A. announcements the ATD has the capability of overriding all other P.A. conversations.

The P.A.-R.F. control completes the headset microphone or desk microphone circuit. The interrelationship between this switch and the network selection switches permits "listen-before-talking" operation. The P.A. selector switch in addition to the five individual areas also includes a position for paging all areas simultaneously.

D. EQUIPMENT LOCATION

1. Standard Interphone and Standard Interphone/P.A. Panels. Communication panels are placed throughout the rack installations in the top

panel of every third rack. A typical rack installation is shown in Figure VIII-5. The communication panels that are used with the consoles are placed either on the working area of the console or immediately adjacent to the console. The panels located in the above ground area are mounted in white enclosure boxes.

2. Purged Interphone and Purged Interphone P.A. The purged units are located in the tank farm area, the fill station area, the truck unloading station, the liquid hydrogen dewar, and on the test stand.

Since the test stand will be subjected to high radiation levels during engine tests, eleven of the purged units mounted on the test stand are removed prior to each engine test.

3. Special Communication Panels. The special communication panels are located on the following consoles in the control room:

- a. Lead Reactor Engineer's Console
- b. Chief Test Engineer's Console
- c. Lead Facility Engineer's Console
- d. Lead Instrumentation Engineer's Console
- e. Lead Safety Engineer's Console
- f. Assistant Test Director's Console
- g. Test Director's Console

4. Communication Racks. Two communication racks located in the Electronic Control Room are shown in Figure VIII-6. In the top of rack 21 is a standard interphone/P.A. panel. The safety R.F. equipment is located below the communications panel. The bottom two transceivers are the general R.F. nets.

Rack 20 houses the P.A. amplifier control panel, a dual channel trunk-line selector panel, and two magnetic tape recorders. The two tape recorders will be used for documentation during test operations.

E. EQUIPMENT OPERATION

1. General Operation. The Interphone/P.A. communication panels as well as the special communication panels each have a self-contained battery for emergency interphone operation in case of power failure. Should the breaker at the bottom of the rack be turned off or should the power source fail with the communication panel "on-off" switch in the "on" position, the

battery will last for only two hours. To prevent needless waste of batteries, all communication panels should be turned off except during actual use.

Certain interchange of communication panels is permitted. A Standard Interphone panel can be replaced by a Standard Interphone/P.A. panel. A Standard Interphone panel can be replaced by either the Purged Interphone panel or by the Purged Interphone/P.A. panel. But most important, a purged panel should never be replaced by a standard unit. Violation of this practice could result in a hydrogen explosion.

2. Interphone Operation. Day-to-day checkout and operation communication between the work stations is conducted via the interphone system.

The purged interphone panels employ a sound actuated relay circuit which requires a special operating technique. When operated in the "voice" position, approximately one second is required for the sound actuated relay to operate. A sound such as "oh" or "ah" should precede the message to allow time for this relay to operate. After the message is completed, the relay will remain energized for approximately three seconds. The sound actuated relay is bypassed when the mike is operated in the "open" position. In this mode of operation, the mike is connected to the interphone panel at all times, and any background noise is transmitted down the trunk line. Operation with mikes in the open position is satisfactory as long as there are a limited number of parties using the same trunkline. For countdown operation, when many parties will be on the same trunkline, the background noise would be prohibitive.

3. P.A. Operation. General P.A. capability to talk simultaneously to all P.A. areas is available only from the special communications panels. The Interphone/P.A. panels provide area paging only. The main function of the area P.A. is to provide a second method of establishing a conversation on the interphone subsystem. The only other means of establishing a conversation on the interphone panels is by prearrangement. The area P.A. is not to be used as an additional means of carrying on a conversation but is for paging purposes only.

The P.A. controls provide for "listen-before-talk" capability. Before making an announcement on the area P.A., the individual user must check to insure that no other announcement will be interrupted.

4. RF Systems. The safety net is controlled only from the Lead Safety Engineer's console. It is a duplex system. This means that it transmits on one frequency and receives on another. With a duplex system both parties can talk and listen at the same time.

The General RF nets are simplex systems which transmit and receive on the same frequency. With these sets, if both parties talk at once neither party will be able to listen. The word "over" is used to signify that the user is through talking and is ready to listen.

The General RF nets have capabilities for transmitting on net 24 or net 21. The net selection for the special communication panels is made from the ADT console only. A switch on each handy-talkie is used to select the desired net. Before operating a handy-talkie, the user must check that it is switched to net 24—the ETS-1 and E-MAD operations net.

5. Closing Considerations. The Communication System is provided to assist the operating personnel with the checkout, maintenance, and operation of the ETS-1 facility. The combined operation of interphones, P.A., and RF nets provide a versatile communication system. If used properly the communication system will save many man hours of effort. If improperly used, most areas of work will be adversely affected and human life could be endangered.

FIGURE VIII.1
COMMUNICATIONS SYSTEM
BLOCK DIAGRAM
FOR TRAINING USE ONLY

A. STANDARD INTERPHONE COMMUNICATIONS PANEL

B. PURGED INTERPHONE COMMUNICATIONS PANEL

FIGURE VII-2

A. STANDARD INTERPHONE/PA COMMUNICATIONS PANEL

B. PURGED INTERPHONE/PA COMMUNICATIONS PANELS

FIGURE VII-3

PUBLIC ADDRESS PANELS
FOR TRAINING USE ONLY

FIGURE VIII-3

FIGURE VIII-4

SPECIAL COMMUNICATIONS PANEL FOR TRAINING USE ONLY

FIGURE VIII-4

FIGURE VIII-5

TYPICAL COMMUNICATIONS PANEL
RACK INSTALLATION
FOR TRAINING USE ONLY

FIGURE VIII-5

FIGURE VIII-7
PUBLIC ADDRESS
SYSTEM AREAS
(FOR TRAINING USE ONLY)

ETS-1 CONTROL POINT OPERATOR
GENERAL INDOCTRINATION COURSE

SECTION IX
TELEVISION SYSTEM

A. GENERAL

The basic requirement for a closed circuit TV system is to provide visual indication, within the Control Center, of activities in the test stand area and immediate surroundings. Prior to actual tests, the equipment is used to monitor the general areas and to ensure the evacuation of all personnel from potentially hazardous locations.

During preparations for engine testing, the television equipment is used to assist in the operation of remote handling equipment at the test stand.

During engine test, the TV system provides a visual display of the engine area and all supporting equipment. The TV system is employed as a supporting medium in monitoring the duct during engine tests, installation of the engine, closure of the shields, and monitoring of such equipment as flare stacks during firing. Cameras are situated throughout the area in order to provide a comprehensive coverage of each phase of equipment installation and the test firing. In addition to observing the I & C System equipment installation and engine testing, the entire area within the confines of the ETS-1 complex is monitored for personnel safety.

B. SYSTEM DESCRIPTION

The TV System consists of fifteen camera stations; eight 21-inch monitors, ten 8-inch monitors, a master control console and associated

electronics equipment. The system provides a capability of displaying, on the various monitors, any eight scenes preselected from the fifteen camera stations. The 21-inch monitors in the Control Room and the 8-inch monitors in the Electronic Maintenance Room display eight scenes simultaneously, while the Test Director may select any two of these eight to be displayed on the 8-inch monitors at his console.

Ten of the 15 stations are permanently mounted with housing, pan and tilt units, and stations structures. Five of the stations are considered temporary and are mounted on tripods for easy removal. All of the TV cameras are equipped with accessory power drive mechanism. A total of twelve camera control units are located within the complex to control the electrical parameters of the TV cameras. The alignment controls of the camera are located within convenient viewing distance of the TV Control Console monitors.

A typical video chain is shown in the simplified block diagram in Figure IX-1. The video signal originating at each remote television camera is transmitted by cables from the TV station to Patchpanel No. 1. Twelve cables are connected between Patchpanel No. 1 and the camera control units located in the Control Point Building. Each camera control unit processes one video signal. A total of eight of the twelve video signals are patched through Patchpanel No. 2 to the video amplifiers. Three isolated outputs are provided by each video amplifier. One of these outputs goes to the 21-inch monitors in the Control Room. A second output loops through a video relay switcher rack. A third distribution amplifier output loops through two manual switchers and is terminated at an 8-inch monitor on the TV Control Console. The manual switchers are not shown on the simplified block diagram. The typical video chain described can be constructed in different ways by changing the selection of camera stations or camera control units. The three patchpanels provide the versatility to construct each video chain for maximum utility.

Any one of the eight channels displayed on the 8-inch monitors can be permanently recorded on the kinescope camera. The kinescope camera records video information, audio sound track, and timing information on 16 millimeter film at a rate of 24 frames per second. An interphone panel mounted in the

kinescope equipment rack provides selection of any one of the communication channels for recording on the sound track. Range time, in seconds, is displayed digitally in the upper right hand corner of each frame. The kinescope control panel is mounted on the television control console. From this control panel, selection of the TV monitoring input, and remote starting and stopping of the kinescope recorder are accomplished. The control panel also provides a visual indication, in minutes, of the amount of film left in the camera.

C. EQUIPMENT USAGE AND LOCATION

1. TV Cameras. Nine radiation resistant cameras and eight standard cameras are provided. The radiation resistant camera comprises a radiation resistant camera head, a radiation resistant cable, and a separate pre-amplifier. The camera head incorporates a non-browning faceplate of fused-silica, a non-browning vidicon, radiation resistant deflection coils, and a minimum of electronic components. The separate preamplifier is mounted in a concrete pier where the radiation level is reduced to permissive levels. The radiation resistant camera is designed to operate properly with a cumulative dosage up to 10^8 R and 10^{12} neutrons/cm². The standard camera includes the optics, vidicon, video preamplifier, and deflection circuits in one housing.

All of the cameras are remotely controlled from the master TV Console. Figure IX-2 lists the camera location and usage. Camera station 3 is the farthest from the control point, and it is the only station requiring a line drive amplifier to compensate for the long cable.

2. Patchpanels.

a. Patchpanel No. 1. Of the 15 TV camera stations located throughout the ETS-1 complex, only 12 are connected to camera control units at one time. The selection and activation of the 12 stations is made at Patchpanel No. 1. This patchpanel consists of an input section incorporating 18 connectors (one input from each of the ETS-1 camera stations, plus three spare inputs for future expansion) and an output section consisting of 12 similar connectors, one for each ETS-1 camera control unit. This panel is located in equipment racks in the Control Point Electronics Control Room.

b. Patchpanel No. 2. Of the 12 camera control units connected to camera stations, only 8 are monitored at one time. Selection of the channels to be monitored is made at Patchpanel No. 2. This patchpanel consists of an input patchboard incorporating 12 connections from the camera control units and an output patchboard with eight connections to the 8 video distribution amplifiers and associated accessory control boxes. The patchboards consist of cable-connector type patches and are located on the TV Console in the CP Electronics Control Room.

c. Patchpanel No. 3. Under normal circumstances, each of the 21-inch monitors located at the Control Room display a scene different from the other seven monitors. Proper patching at Patchpanel No. 3 permits two or more monitors to view the same scene. This patchpanel consists of 24 coaxial connections in an 8 (horizontal) by 3 (vertical) configuration and is located in an equipment rack in the CP Electronics Control Room. The top row of 8 connectors is connected to the video amplifier outputs. The second row contains the monitor inputs and the bottom row is wired to the monitor outputs.

3. Video Switchers. Video switchers are used to permit rapid selection of the video signals displayed on the various monitors. Both manual video switchers and relay video switchers are employed. The manual video switchers have pushbutton switching and cannot be operated from a remote location. Selection of signals from the relay video switcher is accomplished by energizing the switcher relays from a remote location.

a. Relay Video Switcher. A total of three relay video switchers are installed in the Electronic Control Room equipment racks.

The first relay video switcher provides selection of the video channels to be viewed on the 8-inch monitors at the Test Director's Console. Control for this switcher is also located on the TD Console.

The second relay video switcher provides selection of the video channel displayed on the Kinescope recorder. This relay has two separate outputs and is capable of supplying signals for two Kinescope recorders. The control unit for this switcher is mounted at the Television Control Console.

The third relay video switcher is a spare unit for future expansion.

b. Manual Video Switcher. Two manual video switchers are located on the Television Control Console. One manual switcher provides selection of the video channel to be viewed on the television waveform monitor. The second manual switcher is a spare unit for future expansion.

4. Control Panels. Figure IX-3 includes two monitors and the associated control panels on the Television Console. The TV system includes four of these identical units. The TV accessory controls are: (a) Pan and Tilt Controls, (b) Iris Controls, (c) Focus, (d) Lens Zoom, (e) Windshield Wipers, and (f) Horizontal Drive.

a. Pan and Tilt. Panning is the rotating of the camera in a horizontal plane. Tilting is the rotating of the camera in a vertical plane. Independent controls are provided to adjust the pan and tilt speeds. A joy stick permits simultaneous pan and tilt operation.

b. Iris Control. The iris control adjusts the iris diaphragm to provide lens speeds of $f/2.5$ to $f/22$. The vidicon tube is sensitive to excess light and will be damaged if left exposed to direct rays of the sun. When the TV camera is not in use, the iris should be closed to $f/2.5$ and the camera tilted down.

c. Focus. The camera focus has a range from six foot to infinity. The focus control varies the lens focus to obtain a sharp image.

d. Zoom Control. A 5:1 zoom lens is used with twelve of the camera stations. The zoom control provides both telephoto or wide angle effects. If the camera focus is set with the zoom control in the near position, the camera will remain in focus at all zoom positions.

e. Windshield Wipers. Camera stations 1 and 2 are located where they are subjected to spray from the exhaust duct. These two cameras are equipped with windshield wipers.

f. Horizontal Drive. This function is for moving cameras that are mounted on monorails or on a movable rod. None of the present camera stations include this capability.

5. TV Monitors. The synchronization signals for the monitors originate at the sync generator chassis located in the Electronics Control Room. The sync generator produces 525 horizontal scanning lines per frame. At the camera control units, the sync signals are fed to the camera deflection circuits and also combined with the video information. After amplification the composite video signals are patched to the monitors.

Each monitor has front panel controls for a-c power, brightness, contrast, vertical hold, vertical linearity, horizontal hold, and height. Video frequency response of the 8-inch monitors is $\pm$ 1db to 9 megacycles. For the 21-inch monitors the frequency response is $\pm$ 1db to 10 megacycles.

FIGURE IX-1
TELEVISION SYSTEM
SIMPLIFIED BLOCK DIAGRAM
FOR TRAINING USE ONLY

TV STATION NUMBER	TARGET AREA	SURVEILLANCE PURPOSE	LENS ZOOM	TURRET
1	Engine Connect, Shield Installation, Duct Pit	Remote Equipment Handling Firing Observation	Yes	No
2	Engine Connect, Shield Installation, Duct Pit	Remote Equipment Handling Firing Observation	Yes	No
3	Exhaust Area, Area Surveillance	Range Safety Firing Observation	No	Yes
4	Engine Connect, Shield Installation, Pad Area	Remote Equipment Handling Firing Observation Range Safety	Yes	No
5	Engine Connect, Shield Installation, Pad	Remote Equipment Handling, Firing Observation Range Safety	Yes	No
6	LO ₂ and LN ₂ Tanks, High Pressure Gas Storage Area, Area Surveillance	Range Safety, Equipment Observation	Yes	No
7	Fill Station High Pressure Gas Storage Area	Range Safety, Equipment Observation	Yes	No
8	LH ₂ and LOX Tanks, Flares, Gas Storage Area	Range Safety	Yes	No
11	Duct Vault Interior	Duct Removal and Pipe Chase	No	No
13	LH ₂ and LOX Tanks, Test Stand Flares, Main Dewar, Area Surveillance	Range Safety Equipment Observation	Yes	No
14	LH ₂ and LOX Tanks, Test Stand Flares, Area Surveillance Main Dewar	Range Safety Equipment Observation	Yes	No
15	Gas Storage Area, Fill Area Area Surveillance	Range Safety Equipment Observation	Yes	No
16	Gas Storage Area, Fill Area, Area Surveillance	Range Safety Equipment Observation	Yes	No
20	Storage Tanks Area Surveillance	Range Safety Equipment Observation	Yes	No
21	System Checkout and Maintenance	Test Setup	No	No

NOTE: WITH THE EXCEPTION OF DUCT INTERIOR ALL CAMERA POSITIONS ARE SHOWN.

SYMBOLS
TV CAMERA STATION
 ■ CONCRETE PIER
 • PIPE STAND
 ▣ TRIPOD

FIGURE IX-2
 TELEVISION
 CAMERA STATIONS
 FOR TRAINING USE ONLY