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NUCLEAR ROCKET OPERATIONS

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REPORT NO. RN-S-0378

TO

AEC-NASA SPACE NUCLEAR PROPULSION OFFICE

ETS-1 FACILITY SAFETY REPORT

JULY 1967

NERVA PROGRAM

CONTRACT SNP-1

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NUCLEAR PRODUCTS AND SERVICES GROUP

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

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REPORT NO. RN-S-0378

ETS-1 FACILITY SAFETY REPORT

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1. INTRODUCTION

The purpose of this report is to show that the ETS-1 facility is adequate from the design standpoint to support the X-engine test program without compromise to the safety of personnel, the facility, or the test article. It is the third in a series of reports which document the status and results of a continuing safety evaluation of the ETS-1 complex.

The initial ETS-1 safety report was issued in October of 1962.⁽¹⁾ It was prepared based upon utilization of ETS-1 for flight engine development and, to a large extent, upon preliminary or conceptual facility-system designs. Subsequent to its issuance, many of the utilization requirements imposed on the facility by the engine development program were changed. As a result, a second report⁽²⁾ was prepared to evaluate these changes, as related to safety, and also to upgrade the content of the initial report to reflect the design and construction status of the facility as of mid-1965.

Since publication of the second report, the X-engine design has been completed, the engine test program has been finalized, and the requirements imposed by the program on the operation of facility systems have been established. Consequently, the present report was prepared, first, to document the safety evaluations performed on each of the ETS-1 systems which interface directly with engine test operations, and second, to show that the facility is adequate from the design safety standpoint to support the X-engine test program. The report evaluates each of the facility systems which will be utilized during X-engine testing and which may be expected to have a definite influence on test safety. It does not consider either the procedural aspects of facility system operation, the adequacy of administrative controls, or

(1) Operational Safety Evaluation of ETS-1 Complex, AGC Report No. 2316, 31 October 1962. (CRD)

(2) Preliminary ETS-1 Design Safety Evaluation, RN-TM-0237, September 1965.

the design, operation and control of the test article. These considerations, as they relate to safety, are covered separately in the XE Safety Analysis Report and in the Safety Evaluation Reports which will subsequently be prepared for the testing of each engine in the engine test series.

Section 2 of this report gives a brief description of the overall facility design and layout, and Section 3 provides a brief description of the XE test system design. These sections have been included in the report to impart a basic understanding of the interrelationships which will exist between the test article and the facility during engine test operations. Section 4 presents the facility system evaluations. For each system considered, requirements and characteristics, operation and control capabilities, safety features, and consequences of system or component malfunctions, as appropriate, are discussed. The evaluation of each system is concluded with an evaluation summary which indicates why the system is considered adequate from the safety standpoint to support the X-engine test program.

2. PHYSICAL DESCRIPTION AND LAYOUT

2.1 FACILITY ORIENTATION

The ETS-1 complex is located at the Nuclear Rocket Development Station (NRDS) in the Jackass Flats region of the Nevada Test Site, about 80 mi northwest of Las Vegas. A map of the Jackass Flats area is given in Figure 2.1. The relative location of the test facilities at NRDS is shown in Figure 2.2. ETS-1 is located about 2 mi west of Test Cell C and about 2 mi north of the E-MAD building. The E-MAD facility is used for assembly and checkout of the engine prior to testing and for remote disassembly and post-operative examination of the engine and its components after testing. The test stand is connected to E-MAD by a standard-gage railway which is used for transport of an assembled engine between the two facilities.

The ETS-1 complex provides facilities for static testing of the NERVA X-Engine. In addition to the actual stand, the complex includes a complete instrumentation and control system, process and fluid systems, an electric-power generation and distribution system, a nuclear exhaust system, and a sealed environmental test compartment. Also provided at the facility are safety systems and equipment and radiation shielding for the protection of personnel, facility components, and test hardware. A plot plan of the ETS-1 complex is shown in Figure 2.3, and a detailed plan of the test-stand area is shown in Figure 2.4. Aerial views of the complex are provided as Figures 2.5 and 2.6.

The ETS-1 complex can be considered as divided into four main areas:

- (1) Control-point and utility-equipment area.
- (2) Forward control room, fill station, and gas-storage area.
- (3) Test-cell building and cryogenic-storage area.
- (4) Test-stand area.

Figure 2.1 - Site Orientation

Figure 2.2 - NRDS Aerial Mosaic

Figure 2.4 - Test-Stand-Area Plan

Figure 2.5 - Aerial View of ETS-1

Figure 2.6 - Aerial View of ETS-1

Each of these areas is furnished with electrical equipment for control of the components in that area. This electrical equipment consists of power sources, solenoid-valve boxes, motor control centers, and terminal boxes and cabling for control of components remotely from the control-point building. Each section or area within the main facility areas identified above is classified in accordance with the appropriate hazardous-area designations of the National Electrical Code, and equipment that satisfies the basic requirements of the code for hazardous areas is installed within these areas.

2.1.1 Control-Point and Utility-Equipment Area

The control-point building, which is located in the control-point and utility-equipment area, is a reinforced concrete structure buried 5-1/2 ft underground at the south end of the access tunnel approximately 1000 ft from the test stand. A plan of the control-point building is shown in Figure 2.7. The building houses the operations and safety consoles, recording equipment, TV monitors, and the safety graphic-display panel. A more detailed plan of the control room showing the location of the control consoles is given in Figure 2.8. The function of each console and the critical parameters and components they control are given in Table 2.1. The Safety Graphic Display Panel, which is located directly above the Lead Safety Engineer (LSE) Console, displays a map of ETS-1 showing the alarm status of the detectors and emergency switches located throughout the complex, the purge status of some facility components, door closure indications, and the status of area warning devices used to control personnel and vehicular traffic throughout the facility.

During engine test operations, all personnel at the facility (approximately 150) are located in the control-point building. The safety of these personnel has been analyzed in terms of the protection afforded them against excessive radiation exposures in the event of a maximum

Figure 2.7 - Plan of ETS-1 Control-Point Building

Figure 2.8 - Control-Room-Console Layout

TABLE 2.1

FUNCTION OF ETS-1 CONTROL CONSOLES

<u>Console</u>	<u>Function</u>
Chief Test Engineer (CTE)	<p>Provides for selection of engine control modes such as ganged-drum position, log power with period selection, temperature with ramp rate selection, pressure with ramp rate selection.</p> <p>Provides for selection of the following actions: start reactor, start engine run, program hold, shutdown, manual scram, emergency shutdown, close pressure loop, bypass of chillover delay, and bypass of automatic startup circuit.</p> <p>Provides for control of engine valves PSV, PDSV, and PDVV.</p> <p>Provides monitors for the following engine control parameters: control temperature, control pressure, TPCV position, inner-reflector temperature, log power demand, temperature demand, pressure demand.</p> <p>Provides monitors for the following noncontrol parameters: linear power, LH₂ flow, turbine speed, turbine inlet temperature, turbine inlet pressure, pump discharge pressure, pump inlet pressure.</p> <p>Provides engine valve position monitors for CSV, PDSV, PSV, PDVV, TBV.</p>
Assistant Test Engineer (ATE)	<p>Provides monitors and controls for individual drum position and drum locking.</p> <p>Provides monitors for engine temperatures and permits selection of temperature used for control.</p> <p>Provides monitors for selected log count rate channel, reactor period, chamber temperature average, in-core temperature average, 12 selected engine-reactor temperatures, individual control-drum position and average, and lock-unlock status of each control drum.</p>

TABLE 2.1 (Cont.)

<u>Console</u>	<u>Function</u>
Lead Reactor Engineer (LRE)	<p>Provides for selection of: log count rate channel for display on ATE console; linear power indication and range displayed on CTE console; log power detectors (either S-2 shield or engine mounted) to be used for engine control; and period, fixed-power, and floating-power set points for engine safety system.</p> <p>Provides controls for manual reject of each of 3 log-power channels, manual reset of each of 2 log-power average circuits, manual bypass of period, fixed-power and floating-power scram circuits, exponential and ramp set of the automatic startup circuit, and the source drive system for checkout of the nuclear instrumentation.</p> <p>Provides monitors for neutron count-rate channels, linear-power channels, log-power channels, active-bypass status of each channel, and computed power.</p>
Test Stand Engineer (TSE)	<p>Provides for control of the engine cooldown process by control and monitoring of the valve positions, flows, and temperatures and pressures of the LH₂ system, LN₂ system, GH₂ system, GHe system, and GN₂ system.</p>
Assistant Stand Engineer (ASE)	<p>Provides for control and monitoring of the valve positions, flows, temperatures and pressures of the run-tank pressurization system, high-pressure LH₂ tank-pressurization system, engine-valve actuation-gas supplies, and engine purge system.</p>

TABLE 2.1 (Cont.)

<u>Console</u>	<u>Function</u>
Lead Instrumentation Engineer (LIE)	Provides for control and monitoring of the data acquisition equipment, including; digital tape recorders, analog tape recorders, events recorder, high-speed oscillographs, signal-conditioning equipment, and automatic or manual calibration of all data channels.
Lead Facility Engineer (LFE)	Provides monitoring and control of NES duct cooling system, engine-test-compartment H ₂ -O ₂ analyzers, and ETC purge system.
Facility Engineer Left - "A" (FEL-A)	Provides monitors and controls for setup of the propane, LOX, and H ₂ O used in operating the steam generators.
Facility Engineer Left - "B" (FEL-B)	Provides monitors and controls for startup, run, and shutdown of the steam-generator system.
Facility Engineer Right (FER)	Provides monitors for the liquid levels in the LH ₂ and LN ₂ storage tanks and provides controls for pressurization of the LN ₂ storage tank and ignition of LH ₂ storage-tank ² flare.
Gas Fill Service (GFS)	Provides monitors and controls for setup and fill operations of the high-pressure gas systems, including GH ₂ , GHe and GN ₂ . Controls main block valves to the gas headers.

TABLE 2.1 (Cont.)

<u>Console</u>	<u>Function</u>
Remote Installation Console (RIC)	<p>Provides monitors and control for remote installation of the facility side shields, including the GN₂ purge flow and GN₂ flow to the conoseals and bellows seals.</p> <p>Provides for control of the side-enclosure-shield lock devices and provides monitors for ETC shield temperatures.</p> <p>Provides for operation and control of the engine-shield fill-and-drain system.</p>
Lead Safety Engineer (LSE)	<p>Provides readout of the criticality monitor level and permits selection of trip point.</p> <p>Provides for monitoring of radioactive gas and particulate detection system, facility neutron and gamma detectors, wind direction and speed, H₂ concentration, and combustible-gas (propane) concentration.</p> <p>Permits manual activation and reset of the fire-protection system and manual activation of the area surveillance and warning system.</p> <p>Provides for communications between ETS-1 and other site areas, such as NRDS security, road blocks, and the NRDS Fire Department.</p>
Test Director (TD)	<p>Provides for communication on all nets, including the RF nets and the PA system.</p> <p>Provides two video monitors and a selector for obtaining input from any of the TV camera locations.</p>

TABLE 2.1 (Cont.)

<u>Console</u>	<u>Function</u>
Deputy Test Director (DTD)	<p>Provides for communication on all nets, including the RF nets and the PA system.</p> <p>Provides monitors for selected parameters (functions or parameters to be monitored must be selected in advance and wired in).</p> <p>Provides ready lights to indicate status of all consoles in the control room.</p> <p>Permits control of the timing system for marking of important events.</p>

accidental release of fission products from the engine. The details of this analysis and the conclusions drawn therefrom are presented in Appendix B. Basically, it is concluded that the facility affords adequate protection against excessive radiation exposures to personnel if the control-point building is upwind of the test stand during engine power testing.

Also located in the control-point and utility-equipment area are the electric-power substation, the diesel-generator building, and the utility-equipment building. The utility-equipment building, which is located above ground in the same general area as the control-point building, houses the process-water demineralization plant, a portion of the emergency 28-vdc backup batteries, the main power transformers, and the main components of the facility heating, ventilating, and air-conditioning system.

2.1.2 Forward Control Room, Fill Station, and Gas-Storage Area

The forward control room, a reinforced concrete structure covered with 5-1/2 ft of earth, is located midway along the tunnel between the test stand and the control-point building at a distance of approximately 500 ft from the stand. The building houses the data-acquisition system, signal conditioners, recording equipment, components of the engine programmer, test-stand control system hardware, a portion of the 28-vdc backup batteries, and includes a room for maintenance and repair of electronic equipment. This building is not occupied during engine testing.

The high-pressure gas-storage farm is located above ground approximately 400 ft from the test stand. The area contains nine gas bottles rated at a 2500-psi working pressure for storage of the gaseous hydrogen, nitrogen, and helium. Six of these bottles are used for inert-gas storage only, and are enclosed within a metal building whose interior is maintained at a temperature of approximately 100°F so that the temperature of the vessels is maintained above the nil-ductility-transition temperature for carbon steel and so that deleterious effects to the vessel from work hardening are reduced.

Four oxygen analyzers are installed in the building to warn personnel of an oxygen-deficient environment should gas-bottle leakage occur. The analyzers provide signals for local readout and audible alarm at the building entrance and for remote visual and audible alarms at the LSE Console in the control-point building. Furthermore, the building entrance is kept locked when personnel access is not required.

The propane storage tank and propane vaporizer are located to the east of the gas-storage farm. The truck unloading station and the fill-station building are located just south of the gas-storage farm. The fill-station building is a concrete block structure that houses air compressors, high-pressure gas compressors, vacuum pumps, and associated equipment.

2.1.3 Test-Cell Building and Cryogenic Storage Area

The test-cell building is a reinforced concrete structure covered with 6 ft of earth and located near the test-stand terminus of the access tunnel approximately 100 ft from the test stand. The building houses signal-conditioning equipment, control-system components, cable termination points, and a portion of the 28-vdc emergency-power battery supply.

The test-stand equipment room is located at the test-stand end of the access tunnel immediately adjacent to the test-stand elevator shaft and stairwell. The room is constructed of reinforced concrete, is covered with 9-1/2 ft of earth, and houses mechanical equipment used for the operation and maintenance of the test stand.

A blast door is located in the access tunnel between the test-stand equipment room and the test-cell building. The door has been designed to protect personnel and equipment from over-pressurization in the event of an explosion resulting from a large hydrogen spill in the test-stand area (see Section 4.15).

The cryogenic storage facilities consist of a 250,000-gal, 100-psig, LH₂ storage Dewar; a 4400-gal, 1500-psig, LH₂ Dewar; a 28,000-gal, 250-psig, LN₂ storage Dewar, and a 22,000-gal 400-psig, LO₂ storage Dewar. A basin is provided beneath the large LH₂ storage Dewar to retain liquid hydrogen from a major spill or a vessel rupture. The basin is spread with gravel to increase the LH₂ evaporation rate.

The test-cell building and cryogenic storage area are separated from the test-stand area by a 3-ft-thick concrete shadow-shield wall approximately 95 ft long and 38 ft high. The primary purpose of the shield is to reduce the environmental radiation levels in the liquid and gaseous storage areas after engine power tests and before the engine is removed from the stand. Analysis indicates that personnel can have limited access to the storage farm area approximately 1 hr after a full-power full-duration test and can have unlimited access within one day after shutdown.

The steam-generator system (SGS), which is used to supply super-heated steam to the nuclear-exhaust-system (NES) duct during engine test operations, is located on the south side and near the east end of the shadow-shield wall. The generators are contained within a reinforced concrete blast enclosure that is open to the northeast. As protection against fire, the enclosure is ventilated and equipped with a heat-activated water-deluge system. The ventilation system in this area is automatically shut down if the deluge system is activated.

2.1.4 Test-Stand Area

The test-stand area is the location at which the test article is mated with the facility to provide an integrated test system. This area contains a superstructure, a run tank, an engine test compartment, and the NES duct. Portions of the fluid-transfer systems are terminated in this area to provide engine coolant, postoperational cooldown fluids, pneumatic-actuation supply fluids, inert-gas purge, water for cooling of facility components and for shielding, and steam for the NES-duct ejector system.

The test stand (Figure 2.9) supports the engine, a 77,000-gal 50-psig LH_2 run tank, and the miscellaneous piping systems required for engine operation. The structure is made of aluminum and is formed by four main vertical columns connected by a network of cross-braces and trusses. The engine load is transmitted to the main support structure through four thrust supports.

The engine test compartment (ETC) comprises four shields that enclose the engine during test. The shields include two semicylindrical movable side shields, a top shield, and a bottom shield that has an opening at the center for passage of the engine exhaust gases into the duct. When closed, the shields reduce the radiation environment outside the compartment during and after engine operation. The joints between the shields are double-sealed and purged to prevent air from entering the compartment during test operations.

The NES duct and vault are located directly below the ETC. The duct directs the hydrogen exhaust from the engine away from the facility so that it may be safely burned in the open atmosphere. In addition, the duct functions to produce a low-pressure condition in the test compartment so that during engine operation the exhaust gases fully expand in the nozzle; and, in conjunction with the steam generator system, the duct prevents the backflow of air into the exhaust system and ETC during both normal engine operating conditions and malfunctions.

The drainage ditch north of the test stand provides both an access route to the duct vault for duct installation and maintenance operations and a flow path away from the facility for water used to cool the duct and ETC shields during engine testing.

Figure 2.9 - Test-Stand and Duct-Vault Elevation

2.2 PROCESS AND FLUID SYSTEMS

The process and fluid systems at ETS-1 provide the storage vessels and transfer lines for the various fluids required for facility support and engine testing. The principal fluids provided are gaseous and liquid hydrogen and nitrogen; helium; liquid oxygen; liquid propane; and process water. The gaseous hydrogen is used for engine cooldown, turbine-power-control-valve (TPCV) and control-drum actuation, and pressurization of the LH_2 storage vessels. Liquid hydrogen is the primary coolant for the engine during power testing and during cooldown and is the source of gaseous hydrogen for the GH_2 system. Gaseous nitrogen is used to pressurize the LN_2 , LO_2 and propane vessels; to actuate pneumatic valves; to actuate the engine-to-stand remote disconnect actuators; and to purge the flare-stacks, the steam generators, the ETC, and the engine. Liquid nitrogen is used to cool the engine during portions of the engine-cooldown period and serves as the source of gaseous nitrogen for the GN_2 system. Helium is provided to purge the LH_2 systems, to check out the TPCV and control-drum actuators, and to cool the engine during the early stages of emergency cooldown. Propane and oxygen are used as the fuel and oxidizer in the production of steam by the steam-generator system. Propane is also burned by the propane flares at the top of the test-stand superstructure, in the storage-tank farm, and near the base of the test stand at the exhaust end of the NES duct. Finally, process water is used by the steam generators in the production of steam, as shielding material in the ETC shields and the external engine shield, for fire protection, for spray cooling of the test stand, and for cooling the NES duct, the ETC shields, and the steam generators.

A simplified flow schematic of the primary ETS-1 process and fluid systems is shown in Figure 2.10. The storage capacities and operating pressures of the primary fluids are summarized in Table 2.2. In addition to the primary fluid systems at ETS-1, there are flare, vacuum, utility-water, diesel-fuel, hydraulic, and plant-air systems.

Figure 2.10 - Simplified Flow Schematic of ETS-1 Fluid Systems

TABLE 2.2

SUMMARY OF ETS-1

PROCESS AND FLUID STORAGE CAPABILITY

<u>Fluid</u>	<u>Number of Tanks</u>	<u>Tank Capacity</u>	<u>Working Pressure, psig</u>	<u>Designation</u>
LH ₂	1	250,000 gal*	100	Storage Dewar (V-3801)
LH ₂	1	4400 gal*	1500	High-pressure Dewar (V-5002)
LH ₂	1	77,000 gal*	50	Run tank (V-5001)
LN ₂	1	31,000 gal*	250	Storage Dewar (V-3601)
LO ₂	1	22,000 gal*	400	Storage Dewar (V-2801)
Propane	1	15,000 gal*	400	Storage vessel (V-3401)
GH ₂	3	2395 cu ft	2500	V-3207, V-3208, V-3209
He	3	1766 cu ft	2500	V-3204, V-3205, V-3206
GN ₂	3	1766 cu ft	2500	V-3201, V-3202, V-3203
Water	1	2,500,000 gal	-	Storage tank (V-3302)

*Includes 10% ullage volume.

2.3 COMMUNICATIONS AND TV

2.3.1 Communications System

The ETS-1 communications system comprises three major subsystems: interphone, public address (PA), and radio frequency (RF).

The interphone subsystem is connected by 26 trunk lines to approximately 138 self-operated interphone stations located throughout the complex. Calling capability is provided by 49 of these stations through use of the area PA systems. Seven special stations in the control room provide RF capability in addition to interphone and PA functions. Initial contact for interphone conversations must be made by prearrangement or by paging over the PA system.

The PA subsystem is connected to 35 speakers within the complex that can be operated simultaneously or individually within selected areas. A switch at the Assistant Test Director's Console allows all other PA conversations to be overridden in an emergency.

The RF subsystem provides communication links between a fixed station at the control-point building and personnel in remote areas. Two RF nets are used, one for safety communications between the LSE Console and NRDS safety personnel, and one for conversation between personnel at the control-point building and personnel at E-MAD, the engine transport system, or other remote locations.

2.3.2 Television System

Remote observation of all critical functions at ETS-1 is provided for operating personnel by means of a closed-circuit TV system employing eighteen (18) cameras at key locations. Any eight of these cameras can be controlled and displayed for the operating team in the control room.

The basic function of the system is to provide visual indication in the control room of activities at the test stand and in the surrounding areas. Prior to actual tests, the equipment is used to monitor general areas within the facility and to ensure the evacuation of all personnel from potentially hazardous locations. During preparations for engine testing, the TV system is used to assist in the remote handling of equipment used at the test stand. During engine tests, the system provides a visual display of the engine area and all supporting equipment.

The system is also used in support of engine installation, closure of the ETC side shields, and monitoring of facility components, such as the flare stacks. Cameras are located to provide comprehensive coverage of each phase of equipment installation and of the test firing and to monitor all aboveground areas within the confines of the ETS-1 complex for personnel safety. Two TV cameras are installed in the upper-thrust-structure module of the engine to monitor environmental conditions. A kinescope camera is used to record the most pertinent events during assembly and testing. Figure 2.11 is a plot plan showing the location of TV cameras.

TV CAMERA STATION SYMBOLS

- CONCRETE PIER
- PIPE STAND
- ⊗ TRIPOD

TV CAMERA LOCATIONS FOR VIEWING ENGINE

STATION	TYPE OF LENSE	VIEWING FLEXIBILITY
1	AUTOMATIC ZOOM F/L 300 MM	PAN & TILT
2	AUTOMATIC ZOOM F/L 300 MM	PAN & TILT
3	4 POSITION TURRET	PAN & TILT
4	AUTOMATIC ZOOM F/L 300 MM	PAN & TILT
5	AUTOMATIC ZOOM F/L 300 MM	PAN & TILT

Figure 2.11 - TV Camera Locations

3. XE TEST SYSTEM

The purpose of this section is to provide a basic understanding of the interrelationships between the test article and the facility during engine test operations. A more detailed and comprehensive description of the XE test system may be found in AGC-WANL Report NJD-009, Safety Analysis Report for X-Engine Testing, (C/RD).

The X-engine is a close-coupled, downward-firing, nuclear rocket engine designed for NERVA ground-test development at ETS-1. The engine uses liquid hydrogen both as a propellant and as a coolant for the reactor core. The engine develops a nominal thrust of 56,900 lb, with an overall specific impulse of 739 sec at a chamber temperature of 4090°R, a chamber pressure of 563 psia, a nozzle flow rate of 70 lb/sec, a total mass flow rate of 77.6 lb/sec, and a reactor power level of 1126 Mw. The engine is 273 in. long and 102 in. in diameter and weighs approximately 40,000 lb. An artist's concept of the X-engine is shown in Figure 3.1.

The engine is designed as two separate modules. The lower module consists of: the nozzle, pressure vessel and reactor assembly; the lower thrust structure; the external engine shield; the control-drum actuators; and the lower-module instrumentation. The upper module consists of the upper thrust structure, which houses the turbopump assembly (TPA), lines, valves, and upper-module instrumentation. The upper module can be remotely replaced if a major upper-module component fails. All fluid lines and electrical wires from the upper module to the lower module pass through remote connectors.

A test-stand adapter (TSA), which provides the transition from the engine to the test stand, houses the remote connectors used to attach the engine to the test-stand adapter, the remote line disconnects, and all line and instrumentation cables leading from the facility to the engine. The propellant shutoff valve (PSV) and supporting instrumentation are also housed in the adapter.

Figure 3.1 - XE Engine Concept

The engine system consists of the following major subsystems: (1) a propellant feed system that includes a turbopump assembly, lines, and pneumatically actuated valves; (2) a reactor assembly controlled by pneumatically operated control-drum actuators; (3) a regeneratively cooled U-tube nozzle; (4) a pressure-vessel assembly; (5) an external shield; (6) an upper and lower thrust structure; (7) a pneumatic actuation system; (8) a controls system, and (9) diagnostic instrumentation.

A flow schematic of the engine system is shown in Figure 3.2. The turbopump assembly delivers liquid-hydrogen propellant through the pump discharge line to the nozzle-manifold inlet. The hydrogen cools the nozzle as it passes through the nozzle tubes into the reflector. The hydrogen passes through the reflector, simulated shield, flow screen, core support plate, core, and thrust chamber, and then through the nozzle into the exhaust system. A portion of the hot hydrogen from the thrust chamber passes through the hot-bleed port, where it is mixed with cooler hydrogen that flows from the pressure-vessel dome through the diluent line. The mixed gas then flows through the turbine inlet line to the turbine and on out through two turbine exhaust lines and nozzles. An alternate flow path for reactor coolant is provided to the pump discharge line for emergency use if primary coolant flow is lost during engine operation.

The engine control system (ECS) provides remote-control capability for startup, operation, and shutdown of the engine system. The measured engine parameters that are used for control are log nuclear power, chamber temperature, and chamber pressure. The ECS is shown schematically in Figure 3.3. The major control loops are drum position, nuclear power, temperature, TPCV position, and pressure. Each loop can be controlled either manually or automatically. The feedback control loops within the system consist of engine control sensors, signal-conditioning amplifiers, compensation amplifiers, logic functions, and transmission lines. In addition, the system includes: averaging and reject circuits for the chamber thermocouples, core thermocouples,

3-4

Figure 3.3 - XE Control-System Schematic

chamber pressure transducers, and LnN detectors; coincidence circuits to open and close various control circuits at predetermined values; temperature, pressure-error, TPCV-position, and drum-position override circuits to protect the reactor if power-, temperature- or pressure-control loops malfunction; scram and emergency shutdown circuits; and oscillator inputs for introducing forcing function signals to various control loops for transfer-function determination. The ECS provides operator selection of one of four preset temperature ramps and continuous selection of minimum reactor period during power ramping. In addition, a backup in-core averaged temperature signal and an alternate averaged log-nuclear-power signal may be selected.

The X-engine, though capable of operating over a wide range of conditions, is limited by a number of constraints. These constraints are indicated on the steady-state operating map, Figure 3.4, as a function of chamber temperature and chamber pressure. Steady-state parameter schedules of the X-engine at intermediate-power and at full-power conditions are presented in Figures 3.5 and 3.6, respectively.

TANK PRESSURE = 35 PSIA EXCEPT WHERE NOTED
TANK TEMP = 38°R

Figure 3.4 - XE Steady-State Constraint Map

NERVA ENGINE SYSTEM - XE1
(21% POWER LEVEL)

OVERALL ENGINE THRUST, lb	16164
MAIN THRUST CHAMBER THRUST, lb	15775
TURBINE EXHAUST NOZZLE THRUST, lb	389
OVERALL ENGINE SPECIFIC IMPULSE, sec	504
CHAMBER SPECIFIC IMPULSE, sec	536
TURBINE NOZZLE SPECIFIC IMPULSE, sec	149
TURBINE POWER CONTROL VALVE POSITION, deg	37.8
AMBIENT PRESSURE, psia	1 25
REACTOR POWER LEVEL, M.W.	238
TURBOPUMP POWER, M.W.	6
PUMP EFFICIENCY, %	60 6
TURBINE EFFICIENCY, %	34 0
NPS, psi	13 2
TURBOPUMP SHAFT SPEED, rpm	11028
NOZZLE EXPANSION RATIO	10.
TURBINE EXHAUST NOZZLE AREA RATIO	3 2

STATION	NO	FLOW lb/sec	PRESSURE psia	TEMP °R	HEAT FLUX btu sec
TANK OUTLET	1	32.3	35.0	38 0	
PUMP INLET	2	32.3	34.3	38.8	
PUMP OUTLET	3	32.1	267	42.2	
NOZZLE MANIFOLD INLET	4	32.1	262	42.2	
NOZZLE OUTLET	5	32.1	227	74	6828
REFLECTOR OUTLET	6	32.1	218	121	4624
SHIELD OUTLET	7	29.8	214	124	232
CORE OUTLET	8	29.8	170	2200	216427
NOZZLE CHAMBER	9	29.5	170	2200	
DILUENT BLEED INLET	10	2.26	215	122	
DILUENT BLEED OUTLET	11	2.26	198	138	
HOT BLEED	12	.36	171	2200	
HEAT EXCHANGER INLET	13	2.62	169	413	
TPCV INLET	15	2.62	163	402	
TURBINE INLET	16	2.62	103	402	
TURBINE OUTLET	17	2.88	29	322	
TURBINE EXHAUST NOZZLE	18	2.88	8.0	322	

Figure 3.5 - Steady-State Parameter Schedule at 21% Power

NERVA ENGINE SYSTEM - XE 1
(100% POWER LEVEL)

OVERALL ENGINE THRUST, lb	56904
MAIN THRUST CHAMBER THRUST, lb	54627
TURBINE EXHAUST NOZZLE THRUST, lb	2277
OVERALL ENGINE SPECIFIC IMPULSE, sec	739
CHAMBER SPECIFIC IMPULSE, sec	780
TURBINE NOZZLE SPECIFIC IMPULSE, sec	326
TURBINE POWER CONTROL VALVE POSITION, deg	48.6
AMBIENT PRESSURE, psia	1.25
REACTOR POWER LEVEL, M.W.	1126
TURBOPUMP POWER, M.W.	4.8
PUMP EFFICIENCY, %	66.7
TURBINE EFFICIENCY, %	40.0
NPSP, psi	11.0
TURBOPUMP SHAFT SPEED, rpm	22004
NOZZLE EXPANSION RATIO	10
TURBINE EXHAUST NOZZLE AREA RATIO	3.2

STATION	NO	FLOW lb/sec	PRESSURE psia	TEMP °R	HEAT FLUX btu sec
TANK OUTLET	1	77.6	35.0	38.0	
PUMP INLET	2	77.6	31.0	38.4	
PUMP OUTLET	3	77.0	961	50.8	
NOZZLE MANIFOLD INLET	4	77.0	935	50.8	
NOZZLE OUTLET	5	77.0	747	131	24531
REFLECTOR OUTLET	6	77.0	716	212	21820
SHIELD OUTLET	7	71.6	702	216	1084
CORE OUTLET	8	71.6	563	4090	1021064
NOZZLE CHAMBER	9	70.0	563	4090	
DILUENT BLEED INLET	10	5.39	708	214	
DILUENT BLEED OUTLET	11	5.39	653	250	
HOT BLEED	12	1.60	563	4090	
HEAT EXCHANGER INLET	13	6.99	553	1170	
TPCV INLET	15	6.99	517	1140	
TURBINE INLET	16	6.99	415	1140	
TURBINE OUTLET	17	7.60	123	878	
TURBINE EXHAUST NOZZLE	18	7.60	34.4	878	

Figure 3.6 - Steady-State-Parameter Schedule at 100% Power

4. FACILITY SYSTEM EVALUATIONS

Each of the ETS-1 facility systems that is utilized during X-engine testing and which is expected to have a direct influence on test safety is evaluated in this section. For each of these systems, the following information is discussed as appropriate: system requirements and characteristics, operation and control capabilities, safety features, and consequences of system or component malfunctions as they affect the safety of the facility or the test article. The discussion of each system is concluded with an evaluation that briefly summarizes the safety aspects of the system design and operation and which indicates why the system is considered adequate from the safety standpoint to support the X-engine test program.

As a result of the detailed safety evaluations performed prior to and during the preparation of this report, numerous requirements for system modifications or design changes were identified. Though many of these changes have not yet been accomplished, the systems described herein reflect the planned or contemplated system changes that are considered necessary for the safety of ETS-1 test operations. Thus, this section of the report does not necessarily reflect the status of the as-installed or as-designed systems at ETS-1, but rather, on the basis of latest design information available and results of the safety evaluation studies, reflects the systems as they are expected to be when XE-1 testing is initiated.

4.1 ENGINE TEST COMPARTMENT (ETC)

The ETC and its associated radiation shields have four basic functions: (1) to provide a safe oxygen-free operating environment for the engine during test, (2) to permit reduction in atmospheric pressure around the engine to partially simulate space environmental conditions, (3) to reduce the irradiation of engine components located above the engine external shield and to facility components located outside the engine compartment, and (4) to allow greater personnel access to facility areas after engine shutdown.

The engine-compartment radiation-shield system consists of a top shield, two semicylindrical side enclosure shields with intermediate segment shields, a bottom shield, a duct cover shield, two side-shield transfer cars, a duct-cover-shield transfer car, a shield control system, shield instrumentation, and a GN_2 and water distribution system. The two side shields, when mated with the top and bottom shields, form a closed cylindrical container that constitutes the ETC. An intermediate shield consisting of two half-donut-shaped segments of rectangular cross section is suspended from the top of the side shields to the elevation of the external engine shield (see Figure 4.1.1). The bottom shield contains an exhaust penetration that interfaces with the NES duct. The penetration can be covered by a moveable duct cover shield when the side shields are not in the sealed position.

The ETC has been designed to maintain a seal between its internal and external environments for internal pressures in the range between 1 psia and ambient pressure. The ability of the latch mechanism on the two side enclosure shields to hold these shields together limits the maximum allowable internal pressure of the compartment.

The ETC shield configuration is shown in Figure 4.1.1 as it will appear during engine testing (section taken looking towards drainage ditch).

Figure 4.1.1 - ETC Shield Configuration

A plan of the test-stand area showing the normal storage locations of the side shields and the duct cover shield is given in Figure 2.3. A photograph of the S-2 side shield is shown in Figure 4.1.2.

4.1.1 Top Shield

The engine-compartment top shield is a circular tank of aluminum construction approximately 17.5 ft in outside diameter and 30 in. deep. Demineralized water flows through the shield for cooling and neutron attenuation. Two 1-in. lead plates near the top of the shield provide additional gamma-ray attenuation. The shield has cylindrical openings that extend through the shield for the thrust-transfer columns, for piping of fluids required in the compartment during test, and for electrical and instrumentation connections to the engine and thrust ring. The shield penetrations are double-sealed and buffered with GN_2 . The top shield provides support for the top seal ring and seal mechanism and for cooling-water supply and return manifolds.

4.1.2 Side Shields

The two side shields are right circular semicylinders of 22.5-ft OD, 17.5-ft ID, and approximately 31-ft overall height. Demineralized water flows through the 30-in. cavity in each shield for cooling and neutron attenuation. A 1/4-in. boral plate near the inside surface of each shield minimizes reflection of neutrons to the reactor and thereby minimizes reactor perturbations resulting from the shield. A 2-in. lead plate near the bottom of the shield provides additional shielding for the seal components and for structural members below the shield.

The two intermediate-shield segments are suspended by 3-in. pipes from the top of the side shields to a position about half-way down the inner surface of the side shields. The pipes, which are connected to a water manifold at the top, provide the paths for water flow to and from the segments. The segment shields have an inner diameter of 8.7 ft, an outer

Figure 4.1.2 - ETC S-2 Side Shield

diameter of 17.2 ft, and a thickness of 40 in. A 1/4-in. boral plate is located near the bottom surface of each segment shield, and lead plates 1-1/2 and 1 in. thick are positioned in the shield near the inner and top surfaces, respectively. When the engine and side shields are in the test position, the intermediate shield mates with the external engine shield above the pressure vessel (see Figure 4.1.1).

The neutron detectors used to provide the primary nuclear input signals to the engine control and safety systems are contained in three instrumentation thimbles located in the S-2 shield. A source drive system is used to check out these detectors remotely prior to engine startup. Each of the three thimbles containing the nuclear detectors has associated with it a source and a source-drive mechanism. The system functions by remotely positioning the sources through a pneumatic tube into the vicinity of each of the detectors. The change produced in the detector output display verifies that the detectors, the associated instrumentation, and the display and recording devices are functioning properly. When not in use, the three sources are stored in shielded containers on the S-2 transfer car.

During nontest periods, the side shields are stored at a point approximately 200 ft from the test-stand center line (see Figure 2.3) and are chocked at this point to prevent movement by high winds. The shields are positioned at the test stand immediately prior to the tests. Each side shield is supported on a transfer car that travels to and from the test stand on rails. The mechanical drive for this system is an endless steel cable and a drum unit that is driven by an electric motor. A slow-speed motor and necessary controls are incorporated with the main drive system for "inching" of the transfer car during the last 12 in. of travel at the test-stand end. All fluid and electrical connections are made and all interlocks are activated at a station 8 in. from the test position. Water fill and drain is accomplished at a station approximately 4 in. from the test position. Continuous water flow

is maintained during test operations by opening the fill valves and allowing water to overflow from the shields into the drain piping system.

Each of the vertical planes where the side shields join have positive mechanical locks to secure the shields to each other and to hold against the seal purge-gas pressure. The locking mechanism uses an over-center cam principle to prevent accidental opening of the lock if pneumatic actuation pressure is lost. The locking mechanism consists of a total of 24 latches (12 on each side) operated in sets of four by 6 pneumatic cylinders. The locking mechanism can be disengaged by using the manipulators on the engine installation vehicle (EIV) if the pneumatic cylinders or their control circuits should fail.

4.1.3 Bottom Shield

The bottom shield is a cylindrical tank 16.2 ft in diameter, 30 in. deep, and with a central opening 6.8 ft in diameter to accommodate exhaust flow to the duct. Near the top surface of the shield is a 1/4-in. boral plate. A 2-in. lead plate is positioned inside the shield near the bottom surface. The bottom shield provides support for the bottom seal ring and seal mechanism, cooling-water supply and return manifolds, and internal piping. The bottom shield also provides for attachment of the exhaust-duct seal mechanism.

4.1.4 Engine-Compartment Seals

4.1.4.1 Top Eutectic Seal

The top eutectic seal (Figure 4.1.1) seals the upper circumference of the ETC by using an inflatable metallic bellows ring with attached double-plate blades in conjunction with a stationary trough that contains a eutectic mixture of lead (45%) and bismuth (55%). The bellows and

double-plate blades are supported from the top shield, and the trough is supported by the side shields. Pressurizing the bellows with GN_2 displaces the double-plate blades downward into the molten eutectic. The blades and eutectic form a seal 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 . During a test, the GN_2 pressure to the space between the seal blades is monitored to detect leaks.

The eutectic is melted by electric heating coils near the bottom of the trough. Three separate heating units are provided, each of which has been designed with the capability to melt the eutectic alloy. The trough is also equipped with water cooling coils that prevent melting of the eutectic during test operations. The cooling coils can be manually connected to a steam supply system to melt the eutectic if the electric heater units malfunction.

4.1.4.2 Bottom Eutectic Seal

The bottom eutectic seal seals the lower circumference of the ETC in a manner similar to the top eutectic seal. 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. A movable eutectic trough is supported from the bottom-shield support structure. The trough is raised by hydraulic cylinders which rotate the trough through an arc of $8^\circ - 30'$. On rotation, the trough travels up an inclined plane on rollers until both sets of double plate blades are immersed in the molten eutectic. After the eutectic solidifies, the space between both sets of seal blades is buffered with GN_2 .

4.1.4.3 Convolute Seals

The convolute seals seal the ETC along the vertical longitudinal seam between the side shields. The convolute seals consist

of a metallic, inflatable seal with two convolutions. When pressurized, the convolutions expand and form a seal with an adjoining seal surface. Prior to pump-down of the engine compartment by the steam-generator system, the side shields are held together by the latch mechanisms described previously. To further ensure against leakage of air into the ETC, the space between the two convolutions and the adjoining seal surface is buffered with GN_2 .

4.1.5 Duct Cover Shield and Transfer Car

The purpose of the duct cover shield is to protect personnel working in the test-stand area from the residual activity in the duct after the engine is removed from the stand. The duct cover shield is supported on a transfer car that is driven and positioned in a manner similar to that described for the side shields except that its capability for position accuracy is not as great.

The shield is constructed of lead and consists of two sections, both of which are 3 in. thick. The bottom section of the shield is fixed to the transfer car, and the top section is on rollers that allow it to slide over the top of the bottom section. With this arrangement, either 3 or 6 in. of lead can be positioned over the duct with the engine removed.

4.1.6 Control and Instrumentation

The ETC shield operations are controlled from either local control panels or the Remote Installation Console in the control-point building. There are two local control panels; one controls the side shield S-1 operations and the seal and latch operations; the other controls the operations for side shield S-2 and duct cover shield S-3.

Shield operations can be performed remotely from the Remote Installation Console in the control-point building; i.e., the shields can be

transferred, the seals can be established, and shield-water fill-and-drain operations can be performed. The console also has indicator lights for monitoring pressures, temperatures, and flows during these operations.

4.1.7 ETC Purge System

The ETC purge system is used to reduce the amount of oxygen in the test compartment during pretest periods before hydrogen flow is started to the engine and to reduce the amount of hydrogen in the test compartment after an engine test before steam flow to the duct is terminated. During engine testing, the system provides a constant purge flow to the upper-thrust-structure module of the engine; and during engine cooldown with hydrogen, the system increases the mass flow through the duct to prevent entry of air.

A simplified flow schematic of the ETC purge system is shown in Figure 4.1.3. The primary flow path is through either RSV-222 or the 3/4-in. bypass valve RSV-853. A backup or emergency flow path that will be used if a failure occurs in the primary path is provided through RSV-548. Purge gas (GN_2) enters the ETC through a purge ring which surrounds the test-stand adapter and through a line which penetrates the test-stand adapter and exhausts into the upper-thrust-structure module (UTSM) of the engine. The purge-gas flow out of the purge ring is designed to be ten times as great as the flow into the upper thrust structure.

The purge ring consists of a 4-in. pipe drilled with 82 holes approximately 1/2-in. in diameter. The holes are sized and positioned for 75% flow upward and 25% flow downward. Flow through the purge ring is controlled with RSV-727. To maintain the ten-to-one flow split between the purge ring and the upper thrust structure when RSV-727 is open, an orifice to restrict flow is installed in the UTSM purge line.

PCV-447 is used to control system flow rates below 6 lb/sec, and PCV-446 is used to control flow rates above 6 lb/sec. Analysis indicates

Figure 4.1.3 - ETC Purge-System Schematic

that if PCV-446 fails open with 2500 psig supply pressure, the maximum flow through the purge ring (with RSV-727 open) is 44 lb/sec with a pressure of 437 psig occurring immediately downstream of PCV-446. Under these conditions system pressures do not exceed allowable values; however, if RSV-727 is closed when PCV-446 fails, overpressurization of the purge system is expected. To protect against this situation, RSV-727 is installed as a fail-open valve with flow under the plug and a pressure-switch override is located upstream of the valve to command the valve open if the upstream pressure reaches 275 psig.

Prior to engine startup, the ETC purge system is used to purge air from the compartment until the oxygen concentration, as indicated by the gas sampling and analyzing system described in Section 4.1.8, is approximately 3% or less by volume. This operation is performed prior to the introduction of hydrogen into any of the lines entering the compartment. The GN_2 flow rate during the purge operation is approximately 11 lb/sec, 10 lb/sec through the purge ring and 1 lb/sec into the upper-thrust-structure module. After the flow from the steam-generator system is stabilized, the valve in the purge-ring supply line (RSV-727) is closed and only the 1-lb/sec flow to the compartment continues.

After engine startup, the purge system continues to provide a 1-lb/sec flow through the engine upper thrust structure to purge any hydrogen that might leak from the engine components. This flow also supplements the expected ETC seal-leakage flow which is necessary to stabilize engine exhaust flow into the duct at the duct pull-in point (see Section 4.2).

During normal engine-shutdown operations, the purge system is again brought on at a flow rate of approximately 11 lb/sec before terminating steam-generator operation. The system continues to operate for approximately 16 sec after hydrogen flow is terminated.

The operation and use of the ETC purge system is discussed in greater detail in Section 4.2 in conjunction with the operation of the nuclear exhaust system.

4.1.8 ETC Gas Sampling and Analyzing System

The ETC gas sampling and analyzing system is used to sample the test-compartment atmosphere; to sense, measure, visually indicate, and record concentrations of hydrogen and oxygen; and to actuate remote alarm signals at specified concentration levels. The total response time for the system is estimated to be 10 to 20 sec depending on the ETC pressure at the time the samples are taken.

Gas is sampled at four locations in the ETC: (1) at the top of the compartment near the side shields, (2) above the intermediate shield close to the engine, (3) below the intermediate shield near the side shields, and (4) at the bottom of the compartment near the side-shield extensions. The four sample probes are connected in pairs to two redundant analyzer units, each consisting of a suction pump and a hydrogen and oxygen analyzer. The pumps are located at the 3848 level on the cold face of the test stand and the analyzer units are located in the test-cell building. The two probes connected to each unit have a valve scheme whereby samples to be analyzed can be taken from either probe or from both probes concurrently.

Both the hydrogen and oxygen analyzers are of the polarographic type where the gas is reduced (oxygen) or oxidized (hydrogen) at a catalytically-active electrode surface. This process yields an electrical current proportional to the number of molecules reacting at the electrode.

The output signal of the analyzer units is displayed and recorded in terms of % concentration by volume of hydrogen or oxygen in the gas sample. The hydrogen analyzers have two ranges, 0 to 5% by volume and 0 to 100% by volume. The oxygen analyzers also have two ranges, 0 to 6% by volume and 0 to 20% by volume. Range selection, readout of concentration levels, and alarm status are provided at the LFE Console in the control-point building; and alarm set points are adjusted at this location.

The primary function of the ETC gas sampling and analyzing system is to indicate the completeness of the ETC purge rather than to function as an oxygen or hydrogen warning system during engine operation. The system is therefore most useful before and after a test when the ETC is being purged.

During test operations, the ETC gas sampling and analyzing system is operated as follows. Prior to initiation of hydrogen flow, the oxygen content of the ETC is monitored to verify the adequacy of the compartment purge. After confirmation of the inert status of the ETC and initiation of hydrogen flow, monitoring of the oxygen content of the compartment is considered as a secondary source of information because (1) low pressure (as low as 1 psia) that exists in the compartment during engine power testing significantly increases the detector response time and (2) minor entrance of oxygen could result in an immediate fire that is not detectable, or the oxygen could be rapidly carried away before the subject system senses its presence (unless the entrance occurs very close to the sampling point). Any significant entrance of oxygen into the ETC is expected to be preceded by a malfunction condition that is indicated by changes in other parameters such as the pressure of the ETC convolute seal pressurization gases, the seal buffer gases, the ETC coolant water, or the penetration-port purges. Because the atmosphere in the ETC is expected to have a high hydrogen concentration during a test, the hydrogen detectors are not expected to be particularly useful during this period. After hydrogen flow is stopped at the conclusion of a test, the ETC atmosphere is continuously sampled and analyzed to determine when the GN_2 purge displaces the hydrogen-rich atmosphere and returns the ETC to a safe inert condition. This posttest phase of sampling and analysis continues until all engine-cooldown and purge operations are completed and the ETC is reopened.

4.1.9 Evaluation Summary

Examination of the structural and mechanical aspects of the ETC design has revealed no deficiencies that might adversely affect its

ability to maintain a safe oxygen-free environment around the engine during test operations. The compartment is completely sealed with double-walled seals that are buffered with nitrogen purge. A seal failure that results in significant air leakage into the compartment is considered highly improbable if the seals are properly mated during pretest ETC closure operations.

The purge system appears adequate to ensure an inert atmosphere in the compartment during pretest and posttest operations. Instrumentation is available to monitor and to verify the adequacy of this purge. Redundancy ensures that a single failure of the sampling and analyzer units does not prevent adequate monitoring of the gas environment of the compartment. In addition, instrumentation is provided to monitor the pressure of buffer gas to the compartment seals so that a seal failure can be detected.

Protection is also provided against failures that prevent separation of the side shields at the conclusion of engine testing. For example, there are three separate resistance-type heating units in both the top and bottom eutectic seals, each of which can melt the eutectic alloy. In addition, steam can be passed through the water cooling lines in the eutectic to accomplish the same purpose. Likewise, the mechanical locks that secure the side shields to each other can be operated by using the manipulators on the engine-installation vehicle if the pneumatic cylinders that operate these locks should fail. Thus, the design appears to have adequate provisions to ensure that the eutectic seals can be melted and the side shields can be separated.

On the basis of the preceding considerations, the design of the ETC is considered adequate from the safety standpoint to support the X-engine test program. Further evaluation of its use and operation is provided in Section 4.2 in conjunction with the evaluation of the nuclear exhaust system. The water fill-and-drain system for the enclosure shields is evaluated separately as a part of the process water system discussed in Section 4.3

4.2 NUCLEAR EXHAUST SYSTEM

The nuclear exhaust system (NES) is composed of two major subsystems, the duct assembly and the steam-generator system (SGS). The function of the duct assembly during engine testing is twofold: first, it directs the hydrogen exhaust gases expelled from the engine away from the test stand so they can be safely burned; second, by its supersonic diffuser action, it reduces the pressure in the ETC after engine startup to approximately 1 psia. The reduced back pressure permits the nozzle to flow full at a reduced chamber pressure. The function of the SGS is to provide a continuous flow of steam to the duct during engine operating periods. During the initial phases of engine boot-strapping, the steam flow through the duct reduces the back pressure on the turbine exhaust nozzles and thus results in partial simulation of high-altitude conditions for engine startup. In addition, the steam acts as an effective check valve when the ETC purge system is not operating and the hydrogen flow through the duct is insufficient by itself to prevent air from entering the system. Finally, under accident conditions involving sudden termination of hydrogen flow to the engine, the steam flow through the duct prevents the back flow of air into the system and, at the same time, prevents overpressurization of the ETC by hydrogen introduced directly into the compartment as the result of a rupture in the propellant feed system.

The design and operation of the duct assembly and the SGS and the ability of these systems to perform the above functions during engine testing are discussed in the sections that follow.

4.2.1 Duct Assembly

4.2.1.1 Design

An artist's concept of the duct assembly is shown in Figure 4.2.1. The assembly is located in a concrete vault directly below the engine test position (see Figure 2.9). One end of the duct vault

Figure 4.2.1 - Artist's Concept of NES Duct Assembly

is open to permit installation and removal of the duct and to provide ventilation of this area during engine tests. The vault area is subjected to a water spray during test operations to cool both the duct support structure and the concrete surfaces of the vault. At the conclusion of testing, an aluminum-covered concrete door can be moved across the opening of the vault to shield personnel from any residual fission-product activity in the duct and from induced radioactivity of the duct or vault structure. The aluminum covering protects the door from the intense heat of the burning hydrogen exhausted from the duct. The concrete walls of the vault provide radiation shielding to the adjacent pipe chase and equipment vaults so personnel can have access to these areas after removal of a fired engine from the stand.

The duct configuration is shown in Figure 4.2.2. The primary section of the duct has been designed as a second-throat supersonic diffuser, the first throat being that of the engine nozzle. To minimize the heat flux on the elbow section, the supersonic exhaust stream that enters the duct is shocked down to a subsonic stream in the cylindrical or second-throat portion of the duct (Stations 52.3 to 364.3). The diffusion process in this section is sufficient to provide an engine-compartment pressure of approximately 1 psia. The inlet area of the duct was made as large as possible without interfering with the diffuser action. The conical section downstream of the supersonic diffuser (Stations 364.3 to 468.1) is a subsonic diffuser to further reduce the gas velocity before entering the elbow.

Downstream of the elbow, an offset conical section is provided to stabilize flow within the elbow. The purpose of the offset configuration of the transition cone and of the drain at the low point of the 45° exit elbow is to prevent the accumulation of water in the secondary section if a coolant-passage wall on the inside of the duct is ruptured during an engine test. By preventing the accumulation of water in the secondary section, the possibility of a nuclear excursion is reduced to a minimum if pieces of the reactor core become dislodged during an engine

NOTES.

- 1. DIMENSIONS ARE IN INCHES.
- 2. DIAMETERS ARE INTERNAL

Figure 4.2.2 - NES Duct Configuration

test run and are carried downstream through the primary duct section into the secondary section. The exit elbow deflects the exhaust gases at a 45° angle to minimize thermal heating of the drainage ditch and test stand.

Steam is introduced into the duct through sonic nozzles encircling the duct at the inlet of the secondary duct section (Station 716.8). The steam acts as a check valve to prevent air from flowing back into the duct and mixing with hydrogen during engine startup and shutdown or during a sudden loss of coolant to the engine. The steam also creates a partial vacuum in the duct and engine compartment prior to engine firing and during engine bootstrapping.

The steam ejector consists of a series of two-dimensional nozzles attached to an uncooled torus. The nozzles discharge 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 steam-supply-line connection between the duct and the steam generator is secured by a remotely controlled, pneumatically actuated, Marman-type clamp.

The duct is fabricated from Type-347 stainless steel and uses two types of double-wall construction to provide longitudinal channels for the flow of cooling water between the inner and outer walls. The 90° elbow section is constructed of round tubes that are welded together, and the primary and secondary duct sections are constructed of sheet and angle sections that are welded together to provide rectangular channels. The two configurations of the duct coolant passages are shown in Figure 4.2.3.

The elbow section is provided with an additional water jacket to prevent entrance of air into the duct or leakage of hydrogen into the vault in the event of penetration or other failure of the tubular

TYPICAL ELBOW SECTION 2

TYPICAL STRAIGHT SECTION 1 & 3

Figure 4.2.3 - NES Duct Coolant-Passage Configurations

wall construction of the elbow. If such a failure occurs, the water flow rate through the elbow jacket changes because of a change in pressure within the jacket due to water leakage between the elbow coolant tubes and the jacket. Instrumentation is provided to measure this change in flow rate and thus detect any sizeable penetration of the elbow wall (see Section 4.2.3).

A water-filled radiation shield surrounds the upper portion of the primary duct section (see Figure 4.2.1) to absorb the high-level neutron and gamma radiation from the engine and thereby prevent structural damage to the facility walls and reduce the residual neutron-induced activity in the vault area. The shield comprises an upper and lower section. The upper section, located at the duct inlet, discharges water into the lower section immediately below, which in turn discharges into the elbow jacket. The lower section is open at the top and thereby permits overflow of excess water to the vault floor. A flexible seal is located between the bottom of the shield and the outer wall of the primary duct section to accommodate relative thermal expansion.

The duct is supported in a truss assembly that permits thermal expansion, both circumferentially and longitudinally, from a hinged support at the elbow. The truss is supported at both sides of the vault by front and rear trunnions. Four jacking plates on the truss permit the duct-truss assembly to be elevated or lowered during installation and removal. The complete duct-truss assembly consists of an upper and lower assembly joined by Marman clamps at a severance plane between the top of the 90° elbow section and the bottom of the primary vertical section.

To allow for thermal expansion of the duct during engine testing, a nitrogen-filled double-walled bellows assembly is provided between the primary duct section and the test stand. The nitrogen in the bellows cavity is maintained at a pressure higher than that on either side of the duct wall to prevent air leakage into the duct or hydrogen leakage to the vault. Because of this pressure differential, a leak in the bellows

assembly causes nitrogen to flow out of the bellows cavity, either into the duct or the vault. The connection between the duct and the test stand is secured by a remotely controlled, pneumatically actuated, Marman-type clamp.

The severance-plane flanges between the upper and lower sections of the duct are protected against leakage in a similar manner. In this case, each flange has an annular buffer zone between two metallic gaskets. The buffer zone is supplied with gaseous nitrogen above atmospheric pressure and above the internal duct pressure. The flow and pressure of nitrogen in both the duct-to-stand seal and in the severance-plane seal are monitored during operation to detect leaks.

4.2.1.2 Performance Characteristics

Upon completion of the NES design and development program, the selected duct configuration was subjected to a series of scale-model system-performance tests to provide an operational map, as well as a high level of confidence in the prediction of system operation at ETS-1. Ejector-system performance tests were first conducted with a 1/8-scale model from which full-scale predictions of performance were made. A 1/4-scale model ejector system was subsequently built and tested to verify the scaling parameters used and to further increase the confidence of performance predictions for the full-scale system. As indicated by AGC Report RN-S-0099* (Revised), agreement between the 1/8-scale and 1/4-scale data was found to be very good in all areas. The more significant performance data for the full-scale NES duct, based on the scale-model test results, are presented below.

The extent to which the duct is expected to develop and maintain the environment desired in the ETC for expansion and flow of the engine exhaust gases is indicated by the relationship between the engine-compartment pressure and the nozzle chamber pressure (Figure 4.2.4).

*Performance Characteristics of ETS-1 Nuclear Exhaust System, October, 1964.

NOTES:

1. TURBINE EXHAUST FLOW AT DESIGN VALUE
2. STEAM FLOW CONDITIONS - $P_{sc} = 100 - 115$ PSIA, $T_{sc} = 1600 - 1700^{\circ}\text{R}$,
 $\dot{W}_s = 115 - 130$ LB/SEC
3. SEAL LEAKAGE FLOW = 0 - 2 LB/SEC AMBIENT N_2
4. $P_a = 12.8$ PSIA

Figure 4.2.4 - Engine-Compartment Pressure vs Nozzle Chamber Pressure

The discontinuity in the curve at the point where chamber pressure is approximately 140 psia is known as the duct pull-in point and represents the conditions at which flow through the duct becomes sonic. At higher values of chamber pressure, the ETC pressure is no longer affected by the steam flow through the duct.

The effects of GN_2 flow into the engine compartment during full-power testing as a result of seal leakage or operation of the ETC purge system are shown in Figure 4.2.5. As indicated by the figure, relatively high rates of nitrogen flow into the compartment during high-power testing have relatively little effect on compartment pressure.

The predicted pressure profile along the internal wall of the duct during full-power testing is shown in Figure 4.2.6, and the internal Mach numbers based on this profile are shown in Figure 4.2.7.

4.2.2 Steam-Generator System (SGS)

The SGS is housed in a reinforced concrete enclosure at the base of the ETS-1 superstructure, above the pipe-chase vault and immediately behind the concrete shadow-shield wall. The enclosure is open to the northeast.

The SGS consists of three steam-generator subunits or modules, which are connected to a common steam-collection and -discharge plenum. Each generator module comprises a steam generator with control, safety and sequence equipment that renders it capable of operating both independently of the other generator modules and as an integrated unit of the entire steam-generator system. The three identical generator modules are skid-mounted on a common mounting base to form a main assembly (Figure 4.2.8). In addition to a support frame and the steam-collection and -discharge plenum, the common mounting base includes inlet and distribution manifolds, gas regulators, and a common control system for integrating the control and sequencing equipment of the individual modules.

NOTES:

1. P_e = NOZZLE EXIT PRESSURE, P_v = ENGINE COMPARTMENT PRESSURE
2. TURBINE EXHAUST FLOW AT DESIGN VALUE
3. SGS STEAM FLOW AT DESIGN VALUE
4. P_a = 12.8 PSIA

Figure 4.2.5 - Nozzle-Exit and Engine-Compartment Pressure vs N₂ Leakage into ETC at 100% Power

Figure 4.2.6 - Duct Wall Pressure Profile when Testing at 100% Power

Figure 4.2.7 - Mach-Number Profile when Testing at 100% Power

Figure 4.2.8 - Steam-Generator System

The SGS is designed to produce a normal output of superheated steam in accordance with the following specifications:

Steam temperature	1000°F $\pm$ 50°F
Steam pressure	130 psia
Weight flow rate (minimum)	120 lb/sec

With no flow through the engine, operation of the system at these conditions results in the engine test compartment being pumped down to approximately 7.6 psia (see Figure 4.2.4). After duct pull-in, which occurs at an engine chamber pressure of approximately 140 psia (see Figure 4.2.4), the steam flow through the duct no longer affects the test-compartment pressure.

The specified weight flow rate of 120 lb/sec is the quantity of steam necessary for choked flow through the supersonic-diffuser section of the duct (97 lb/sec) plus the flow (23 lb/sec) necessary to prevent any penetration of air into the system by a 35-mph wind directed at the duct exit. This requirement is derived by considering the following accident possibility. It is assumed that an instantaneous loss of coolant to the engine occurs while operating the engine at rated conditions. As a result of the pressure differential between the ETC and the secondary ejector, steam flows up through the supersonic-diffuser section of the duct at a maximum choked-flow rate of 97 lb/sec while 23 lb/sec continues to flow to the duct exit to prevent any entry of air into the system. After the compartment has reached its equilibrium pressure (7.6 psia), the full flow of steam is again directed to the duct exit. Hydrogen diverted from the engine into the compartment through a ruptured coolant line or other opening into the propellant feed system is removed by the pumping action of the steam as it continues to flow through the secondary section of the duct.

The capability of the system for removing hydrogen from the engine test compartment to prevent overpressurization of the compartment if a

main propellant line ruptures is illustrated in Figure 4.2.9. This figure presents an estimate of the maximum hydrogen flow rate possible without exceeding ambient pressure within the compartment.* It is based on the steam-generator system operating at design conditions and no fluid passing through the engine nozzle. No attempt was made to estimate the hydrogen temperature, but, with none of the gas passing through the reactor, it is felt that the gas temperature will be reasonably low.

Each steam generator has been designed to produce steam at a rate in excess of 65 lb/sec; thus, the specified 120-lb/sec output of the system is obtained by the simultaneous operation of two modules. The third module is operated at idle (producing approximately 6 lb/sec of steam), from which it can be brought quickly to rated capacity when one of the other modules malfunction.

The heat energy required to produce the steam is generated by burning propane in oxygen. The combustion element of each module uses approximately 8 lb/sec of propane and 18 lb/sec of oxygen to produce gas at about 5100°F. Steam is generated, and its temperature is controlled to 1000°F, by the injection of water into the combustion chamber.

The combustion element (Figure 4.2.10) consists of a first-stage igniter, second-stage igniter, main-stage injector, main combustion chamber, and a water injection and cooling system. Propane is supplied to the first-stage igniter in the liquid state, atomized into the combustion chamber, and mixed with gaseous oxygen. The mixture is ignited with a spark provided by a 10,000-v transformer. The second-stage igniter is concentric with the first stage, is ignited by a jet of flame produced by the first stage, and is operated with liquid oxygen and propane drawn from the main manifolds at constant flow. After ignition, the second-stage igniter is independent of the transformer spark and first-stage combustion. The final and major combustion process takes place in the main combustion chamber, which

*Maximum H₂ Flow into Engine Compartment, AGC Memo 790:MD385, 28 October 1964.

Figure 4.2.9 - Maximum H_2 Flow into Engine Compartment Without Exceeding Ambient Pressure

Figure 4.2.10 - Steam-Generator Combustion Element

provides for water injection to control the gas temperature to design conditions. All three stages of the combustion element are cooled by water circulating through an external jacket.

The control system for the steam-generator system controls the steam-generating process, provides for system checkout by using simulated signals that operate all components in sequence, and automatically protects the system from damage due to malfunction. The system is set up to command each module to generate steam at full flow (65 lb/sec) or to operate at idle standby (6 lb/sec). Any two units can be operated at full flow. Under normal operation, two units operate at full flow, with the third unit at idle standby. If a malfunction causes one of the units to be shut down, the idling unit is automatically brought to full-flow output in approximately 2 sec.

A safety interlock system that monitors the operation of the steam-generator system prevents system startup, or causes system shutdown, as appropriate, if an unsafe condition develops.

The steam-generator system is operated entirely from a 28-vdc system. The electrical power is derived from rectifiers that operate off of the essential load bus (see Section 4.9). An emergency battery supply floats on this system so that, if primary power is lost, emergency power is available either to continue or safely terminate the operation.

4.2.3 NES Instrumentation

Instrumentation for the NES has been provided to measure the parameters required for both operational control and diagnostic evaluation.

Water flow through the three coolant sections of the duct is measured to verify that adequate cooling is available and to obtain

diagnostic data for heat-transfer evaluation. The primary elements used for the flow measurements are flow tubes located at both inlets to each section of the duct. Flow measurements are verified by measuring the differential pressures across the flow-balancing orifices at the outlets of each section. In addition, coolant-water pressures are measured at both the inlet and outlet of each section.

Small leaks, such as those that might result from rupture of a single duct-wall channel or tube, cannot be detected by the above measurements. However, thermocouples located in a number of tubes in the elbow should aid in detecting such failures by indicating abnormal temperature rises.

The temperature of the water supply is measured at four points on the truss-assembly water headers. The temperature of the discharge water is measured at each outlet section by multiple thermocouples in parallel. Temperature and pressure of the steam safety purge are measured in the steam supply line as well as within the combustion element of each steam module.

During engine testing, the elbow section of the duct is the location most vulnerable to damage by particle penetration. If such damage occurs, the water flow rate through the water jacket surrounding the elbow changes because of a change in pressure within the jacket. This change in jacket flow, and hence the occurrence of a duct-wall penetration, is indicated by a flow tube in the water supply line to the jacket. This flow tube measures both the direction and the rate of water flow between the duct water shield and the jacket.

Leakage past the seals at the interface of the duct and the facility bottom shield, as well as at the severance plane of the duct, is monitored by measuring the pressure and flow of the nitrogen supply to the gasketed buffer zones at these seals.

Strain gages at critical points on the duct and its support truss indicate the duct wall stresses. Vibration of the duct is indicated by strategically located transducers that measure vibration along the x, y, and z axes.

4.2.4 Duct Purge Requirements Under Low Hydrogen Flow Rates

One of the planned modes of engine cooldown is with hydrogen pulsed from the run tank at flow rates varying between zero and approximately 5 lb/sec. If the steam-generator system is shut down at these relatively low flow rates, there is a possibility of air entering the duct either by diffusion through the gas interface at the duct exit or as the result of adverse static-pressure gradients. Unless a combustible mixture of hydrogen and air can be excluded from the duct during this type of flow condition, ignition of the gas mixture by flash-back of the exit flame could result in damage to the system. The general problem of achieving low hydrogen flow rates without the steam-generator system in operation is discussed in this section, and the minimum requirements for protection of the NES system under these conditions are established.

4.2.4.1 Steady-State Condition

During pulse cooldown, the temperature of the hydrogen leaving the duct exit is estimated to range from 540 to 800°R. With a mass flow rate of 5 lb/sec assumed, the first question to be answered is whether or not a significant quantity of air can back-mix in counterflow to the mass of hydrogen flowing from the duct. Molecular diffusion velocities (i.e., mass transport on a molecular level with a concentration gradient as the driving force) were determined and found to be several orders of magnitude below the mean boundary-layer velocity. Formation of a combustible mixture by the diffusion mechanism is therefore concluded to be impossible.

Next, the in-flow of air resulting from adverse static-pressure gradients is considered. At low hydrogen flow rates, the static pressure in the duct upstream of the 45° exit elbow is less than the atmospheric pressure at the drain-pipe exit. This condition exists because the elevation head of the relatively cold and dense ambient air between the duct exit and the drain-pipe exit is greater than the total equivalent elevation head for the less dense hydrogen and the static-pressure drop between the drain-pipe inlet plane and the duct exit plane. For example, with 100% hydrogen at 800°R flowing at 5 lb/sec under the conditions at NRDS ($T = 60^{\circ}\text{F}$, $P = 12.7$ psia), the static-pressure differential between the opposite ends of the drain pipe is 0.36 lb/sq ft. This differential is sufficient to cause air to flow into the drain pipe and then into the duct, where it can mix with the hydrogen to form a combustible mixture.

One way of preventing this entry of air is to increase mass flow through the duct during the cooldown pulse, thus increasing the static pressure within the duct. Additional nitrogen flow increases the static head by decreasing the density difference between the duct gas and air, increasing the frictional and bend resistance in the exit elbow, and reducing the flammability limits of the mixed gas stream. Calculations were therefore made to determine the nitrogen mass flow rate required to increase the static head to a level that would preclude backflow through the drain pipe into the duct. Frictional losses were shown to be negligible compared with bend-discharge effects. Two approaches to the calculation of bend-discharge effects were taken: (1) conventional flow coefficient for a pipe bend followed by piping and (2) the Madison-Parker flow coefficient for a bend exhausting directly to the atmosphere. The conventional calculation gave a lower flow resistance and thus required the higher added mass. With a 5-lb/sec hydrogen flow rate, the results indicated that exit-gas temperatures of 800 and 540°R would require nitrogen flow rates of 19.6 and 21.9 lb/sec, respectively. The higher flow resistance obtained by using the more applicable Madison-Parker approach results in nitrogen flow rates of 4.05 and 6.87 lb/sec being required for the same exit-gas temperatures. Because small

changes in atmospheric pressure significantly affect the duct static-pressure differential and, thus, the mass of nitrogen required, and because the empirical data of Madison and Parker were extrapolated to the present case, it was concluded that a minimum nitrogen purge rate of approximately 10 lb/sec is sufficient during a hydrogen pulse at 5 lb/sec.

For respective hydrogen and nitrogen mass flow rates of 5 and 10 lb/sec, the quantity of air that must flow into the duct to produce a combustible mixture (6 vol% oxygen in the hydrogen-nitrogen mixture) is approximately 36 lb/sec if the gases are assumed to mix uniformly within the duct. Since the choked flow rate of air through the 8-in. drain pipe is approximately 12 lb/sec, a combustible mixture cannot develop as the result of air entering through the drain pipe when the above hydrogen-nitrogen flow rates are used. For hydrogen flow rates less than 1.2 lb/sec with a nitrogen flow rate of 10 lb/sec, a combustible mixture can develop with air intrusion at the choked flow rate; however, as indicated in Appendix C, the flame velocity for such a mixture is well below the gas velocity in the duct, so the duct exit flame cannot flash back into the duct even though the combustible mixture is present. Finally, Appendix C indicates that some burning of hydrogen and air in the duct can be tolerated since calculations have shown that combustion of up to 36 lb/sec of oxygen with hydrogen increases the enthalpy of the gas in the duct by less than 20% of that occurring during full-power testing. Consequently, it is evident that, even with reduced water flow rates through the duct coolant channels (as will exist during pulse cooldown of the engine), some hydrogen-air combustion can be tolerated in the duct without damaging the duct wall. On the basis of the above information, the specified minimum nitrogen flow rate of 10 lb/sec through the duct during periods of low hydrogen flow rate should be more than adequate to protect the system from damage due to hydrogen-air combustion inside the duct.

4.2.4.2 Transient Conditions After Steady-State Flow

At the end of the steady-state portion of a cool-down pulse, the duct is filled with a mixture of hydrogen and nitrogen having a density less than that of the atmosphere. As flow decreases, this lighter fluid will be displaced by decantation; i.e., the lower-density duct gases will flow out of the duct while the higher-density air flows in through the drain pipe and over the lower lip of the duct exit. By assuming a mixing coefficient of 0.16 (typical for air entrainment in buoyant gas plumes) and that the volume of duct gas flowing out equals the volume of air flowing in, duct gas velocities of 8.5 and 1.85 ft/sec were respectively computed for pure hydrogen flow and for the mixed flow of 5 lb/sec of hydrogen and 10 lb/sec of nitrogen. These calculations were based on equations developed from data on the buoyant flow of hydrogen and its combustion in air. For the volume of the secondary duct and 90° elbow (1335 cu ft), pure hydrogen would be displaced in 10 sec, whereas the 87.5% hydrogen-nitrogen mixture would be replaced with air in about 11 min. Oxygen can be excluded from the duct during the shutdown period and between pulses by continuing the nitrogen purge after cutting off hydrogen flow to ensure that the duct is filled with noncombustible nitrogen of essentially the same density as that of the atmosphere. If the same nitrogen flow rate is used as during the pulse (10 lb/sec), a nitrogen purge of approximately 16-sec duration is required after the pulse.

4.2.4.3 Conditions Between Pulses

Between cooldown pulses it is advisable to ensure against the intrusion of air into the duct either through leaks or through the discharge openings. Calculations on the molecular diffusion of air into nitrogen when a continuous purge of nitrogen at 1.0 lb/sec is used in the engine test component show that a purge velocity of about 1 ft/sec is approximately eight orders of magnitude greater than the counterflow diffusional velocity. Turbulent mixing would reduce this margin, though the extent of this reduction was not calculated.

The effect of an on-stand wind on the purge gas flow is to slightly pressurize the duct gases. For example, a head-on wind at 30 mph would increase the duct static pressure by about 0.08 psi. Here again, local turbulent mixing, a function very sensitive to local pressure and temperature fluctuations, would be the primary mechanism for air entry into the duct.

4.2.4.4 Conclusions

On the basis of the preceding discussion of the requirements for duct purge during engine operations at low hydrogen flow rates, the following conclusions have been drawn:

a. Any time the hydrogen flow rate through the duct is between approximately 0.1 lb/sec and 5 lb/sec, either the steam flow rate to the secondary ejector or the nitrogen flow rate to the engine test compartment should be no less than 10 lb/sec.

b. During pulse cooldown operations, a nitrogen purge flow of 10 lb/sec should be initiated approximately 8 sec before initiating the hydrogen pulse to ensure the exclusion of air in the duct as hydrogen enters. The nitrogen purge flow should be continued for approximately 16 sec after hydrogen cutoff to sweep all hydrogen out of the duct. At all other times between hydrogen cooldown pulses, a continuous nitrogen purge flow of approximately 1 lb/sec should be introduced into the ETC to minimize air entry into the duct.

c. If hydrogen flow rates are much above 5 lb/sec, the steam-generator system should be used to provide a minimum steam flow of 10 lb/sec to the duct. Should this capability be lost while testing the engine at significant power (e.g., above the duct pull-in point), the ETC purge system should be used to provide nitrogen to the ETC at a minimum

flow rate of 10 lb/sec before initiating engine shutdown. Should both the steam-generator system and the ETC purge system be lost during an engine power test, immediate shutdown should be initiated with switchover to inert fluids for reactor cooldown before the hydrogen flow rate decreases below 5 lb/sec.

4.2.5 Thermal Effects of the Exhaust Plume

The heating effects of the exhaust plume from the duct on the ETS-1 facility during both cold-flow and high-power tests and for both low and high hydrogen flow rates have been analyzed.* A brief summary of these results and of the conclusions drawn is presented below.

4.2.5.1 Plume Size

Photographic data obtained in the subscale tests of the NES duct were analyzed to develop an experimental representation of the exhaust. This model was then compared with theoretical predictions for the length of a thrust-controlled flame to generate a correction factor to relate experimental and theoretical data. The subscale correction factor was then used to modify the theoretical flame lengths predicted for the full-scale system for both the full-power engine test (77 lb/sec of hot hydrogen gas) and for the NES design demonstration test (100 lb/sec of ambient hydrogen gas). For no-wind daylight testing of the system, the plume for the full-power engine test case has a predicted flame length of 169 ft and, for the design-demonstration case, has a flame length of 396 ft. A comparison of the configurations anticipated for these thrust-controlled plumes is shown in Figure 4.2.11.

The thrust-controlled plume at high hydrogen flow rates is not appreciably affected by on-stand winds below the top of the test

*NES Exhaust Plume Scale-Model Measurements and Full Scale Predictions, RN-S-0168, November 1964. W. R. Thompson, Predicted Size and Geometry for the NES Effluent Plume for Normal Reactor and Design Demonstration Tests at ETS-1, RN-TM-0394, 5 October 1966.

NOMINAL REACTOR FLOW TEST
 $\dot{W}_{H_2} = 77 \text{ LBM/SEC}$

DESIGN DEMONSTRATION TEST
 $\dot{W}_{GH_2} = 100 \text{ LBM/SEC}$

Figure 4.2.11 - Predicted Plume Size and Shape

stand. However, for flow ramps involving low hydrogen flow rates during periods with an on-stand wind, some hot-gas impingement on the stand is anticipated, with a severity depending on the wind velocity and the time at this condition.

During extended pulse cooldown of the engine with LH_2 coolant from the run tank, the steam-generator system will normally be shut down and the duct system will have a mixture of gaseous hydrogen and nitrogen flowing at rates of 5 and 10 lb/sec, respectively. Under these conditions, the exit gas velocity is expected to range from 50 to 100 ft/sec and result in a "buoyant-flame" plume. On the basis of laboratory-scale experiments conducted at Battelle Memorial Institute with methane and ethane as fuel gases, the still-air flame height for the pulse-cooldown plume was calculated to be 92 ft. The tilting effect of wind on buoyant flames was determined experimentally at Battelle for wind velocities up to 13 ft/sec (9 mph). A balance between force of the crosswind on the flame and buoyant force of the flame was developed to give two equations relating the horizontal and vertical projections of the tilted flame height to the still-air flame height and the wind velocity. By following this approach, the effects of wind were calculated. The results are shown in Figure 4.2.12 for on-stand wind velocities of 0, 5, 20, and 40 mph.

4.2.5.2 Temperature Rise of Test-Stand Components

Local heat fluxes resulting from the X-engine full-power plume were calculated for six stations on the front of the test stand, located as shown in Figure 4.2.13. The calculations were performed for flame temperatures of 4600 and 4000°R, which respectively represent the expected upper limit and the best estimate. The upper limit corresponds to the adiabatic flame temperature for a stoichiometric mixture of hydrogen and oxygen, and the best estimate is based on extrapolation of subscale data.

Figure 4.2.12 - Predicted Time-Average Plume Envelopes for Pulse Cooldown as Affected by On-Stand Winds

Figure 4.2.13 - Representative Stand Areas Selected for Analysis

Because the highest temperatures will occur in the thinnest materials, the test-stand components expected to have the greatest temperature rise are the tank weather doors (Stations 2 and 3) and the aluminum cover on the duct-shield door (Stations 5 and 6). The thicknesses of these components are 0.032 and 0.064 in., respectively. The temperature rise in each of these components for the two assumed flame temperatures is given in Figure 4.2.14.

The thinnest structural members on the test stand are the angles, flanges, and channels, which are nominally 1/4 in. thick. The maximum heat flux calculated for the stations shown in Figure 4.2.13 occurs at Station 5, which is located on the duct-vault door. This heat flux was determined to be $1.20 \text{ Btu/ft}^2\text{-sec}$ for a 4600°R flame temperature with allowance for heat loss by convection. The heat flux on the substructure members, such as the stairway next to the duct vault, will be similar to the vault-door heat flux. The maximum heat flux on the superstructure was found at Station 4, opposite the intermediate shield. The heat flux at this point was calculated to be $0.62 \text{ Btu/ft}^2\text{-sec}$, again for a 4600°R flame temperature. From direct-line-exposure considerations, no other locations on the test stand will be subjected to heat fluxes greater than $1.20 \text{ Btu/ft}^2\text{-sec}$, and most areas will have heat fluxes less than $0.62 \text{ Btu/ft}^2\text{-sec}$. The temperature rises of 1/4-in.-thick structural members subjected to these heat fluxes are shown in Figure 4.2.15.

To aid in the interpretation of the potential effects indicated by the temperature-rise data, the structural strength of aluminum at various temperatures is presented in Table 4.2.1.

Figure 4.2.14 - Temperature Rise of Tank Weather Door and Vault Door Cover during Full-Power Engine Test

Figure 4.2.15 - Temperature Rise for 1/4-in.-Thick Structural Members Nearest Plume During Full-Power Engine Test

TABLE 4.2.1
TENSILE STRENGTH OF 6063-T42 ALUMINUM
AS A FUNCTION OF TEMPERATURE

<u>Temperature, °F</u>	<u>Tensile Strength, % of Room- Temperature Value</u>
75	100%
212	99
300	95
400	42
500	21
600	14
700	10

If the design margin of the test-stand aluminum components is two, the maximum temperature that can be tolerated in these components is approximately 400°F (860°R). The results given in Figure 4.2.15 show that the maximum full-flow run times that can be tolerated in the absence of structural cooling are 4.5 and 9 min for the substructure and superstructure members, respectively, when strength of the structural members is the criterion.

4.2.5.3 Conclusions

On the basis of the preceding information, the following conclusions are drawn.

Under high hydrogen flow rates, additional cooling (water spray) is needed for the tank weather doors and the vault-shield door. In addition, cooling or other protection against plume thermal radiation is necessary for structural members during test runs exceeding approximately 5-min duration. Although not specifically considered, all other hardware on the test stand constructed of thin aluminum sheet (conduits, junction boxes, lighting fixtures) will need cooling or other protection.

Because of a number of uncertainties in the analysis, the nature and extent of the additional protection to be provided to the facilities will not be decided until heat-flux data have been collected during facility activation tests and the NES design-demonstration program. The test stand will be instrumented for measuring temperatures and heat fluxes during these test programs. If the data obtained show that additional protection is needed on the test stand, the existing fire-protection system (see Section 4.13) can be used and, if necessary, can be easily modified to provide additional cooling for the tank weather doors and the duct-shield door

Pulse cooldown with hydrogen can apparently be accomplished safely when the wind is directed away from the facility. However, the possibility of local air recirculation carrying flaming gas back into the stand or vault for off-stand or cross-stand wind conditions requires further evaluation. The presence of eddy currents in the air as a result of turbulence caused by wind-stand interaction will be determined experimentally prior to X-engine testing. If an on-stand wind develops during a low-flow condition, such as during pulse cooldown of the engine, the steam generators can be started, if not already operating, to produce a jet-controlled (high-flow) condition at the duct exit. In addition, hydrogen flow can be terminated.

During tests involving high hydrogen flow rates through the duct, moderate winds in any direction are not expected to affect the temperature rise of test-stand components.

4.2.6 Malfunction Considerations

The types of malfunctions that have been considered in the NES design and the consequences of these malfunctions in terms of their effects on the facility and test article are discussed further in this section.

4.2.6.1 Loss-of-Coolant Accident

With two of the steam-generator modules operating at rated conditions, a complete and instantaneous loss of coolant to the engine during a power test results in steam flowing from the steam ejector up through the supersonic-diffuser section of the duct and into the test compartment. Steam flow to the compartment continues at a maximum flow rate of 97 lb/sec (choked flow) until the compartment equilibrium pressure of approximately 7.6 psia (see Figure 4.2.4 for P_c equals zero) has been achieved. If only one of the steam modules is operating at the instant of loss of coolant, some air may also backflow through the duct into the ETC. However, if the worst-case condition of choked (maximum) flow through the supersonic diffuser is assumed (approximately 65 lb/sec of steam with 35 lb/sec of air), the maximum oxygen concentration in the steam-air mixture will be less than 5% which is insufficient to support combustion with any hydrogen that may be present in the ETC. With all of the steam modules shut down and with an instantaneous loss of coolant to the engine, sufficient air can backflow through the duct to the compartment to produce a combustible or explosive mixture.

An additional consequence of a loss-of-coolant accident is the possibility of introducing a large quantity of hydrogen into the compartment as the result of a rupture in the propellant feed system. Figure 4.2.9 shows the results of an analysis made to determine the maximum rate at which hydrogen can flow into the ETC without overpressurizing the compartment when two steam modules are operating. The analytical model used for this analysis was somewhat oversimplified in that, first, only a single compartment volume was considered and, second, it was conservatively assumed that all hydrogen entering the compartment would be instantaneously flashed to gas in the temperature range indicated in Figure 4.2.9. In reality, the compartment

consists of two distinct volumes connected by the annular opening formed by the compartment intermediate shields and the engine external shield (see Figure 4.1.1). Consequently, if the propellant feed system ruptures, the extent of pressure buildup in the ETC depends not only on the steam flow rate through the duct but also on the location of the line rupture, the rate of temperature rise after hydrogen enters the compartment, and how quickly after rupture the hydrogen flow to the compartment can be terminated. For these reasons, the minimum steam-flow requirements to the duct to protect the compartment against overpressurization due to a rupture in the propellant feed system have not yet been established; however, since the flow area around the intermediate shields between the upper and lower volumes of the ETC is greater than the minimum flow area through the duct, the results given in Figure 4.2.9 should be applicable to the double-volume ETC configuration. Consequently, the steam output of two steam modules is considered adequate to protect the ETC against overpressurization.

4.2.6.2 Steam-Generator Malfunctions

a. Loss of Steam

The preceding discussion indicates that, if less than two steam modules are operating while the engine is being tested at high power, protection of the compartment against overpressurization in the event of a rupture in the propellant feed system cannot be assured. Consequently, if a single steam generator fails and the standby generator cannot be brought to full power, the ETC purge system is used to provide a minimum nitrogen flow of 10 lb/sec to the compartment before engine shutdown is initiated. The nitrogen purge flow is initiated to minimize the possibility of air entering the duct in the event of a hydrogen flow failure during the shutdown sequence (see Section 4.2.4.1).

Experimental data from the 1/8-scale model tests⁽¹⁾ and from full-scale duct tests in ETS-1⁽²⁾ show that, at low engine flow rates (i.e., below duct pull-in), total loss of steam resulting from a malfunction of the steam generator system can cause air backflow into the duct. In order to better understand the conditions under which air backflow can occur, a simplified analytical model was developed.⁽³⁾ The model assumes that if the rate of change of mass in the test compartment is greater than the combined flow rates of primary fluid (GH_2), steam, and purge gas, then air must enter the system based on the principle of conservation of mass. Thus, from a simple mass balance it can be determined qualitatively whether air will enter the duct under a given set of operating conditions.

To verify the soundness of this approach, analytical results obtained using the model were compared with full-scale duct test data.⁽³⁾ In all cases, the analytical results were found to be in good agreement with the experimental observations. Specifically, the analysis predicted air intrusion for all runs where backflow was detected by the oxygen analyzers during the NEPN-1 tests.⁽²⁾

The analytical model described above shows that the controlling factor for the air-backflow condition is the rate-of-decay of steam-line pressure. If this rate is reduced sufficiently, the compartment repressurization rate is reduced and air backflow does not occur. The steam-pressure decay rate following a malfunction of the steam generator system can be reduced by use of a large steam reservoir (accumulator) connected to the steam line. Calculations which take into account both a 35 mph head-on wind on the duct opening and condensation of steam in the duct and the test compartment show that an on-line steam accumulator with a volume of 2000 ft³ is adequate to prevent air backflow.

(1) ETS-1 Scale Model Testing, AGC Memo 7860:0467M, 6 June 1967

(2) SPEAR Report NEPN-1, 24 June 1967

(3) Analysis of Flow Transients and Air Backflow in ETS-1 Duct, AGC Memo 7830:M3339, 11 July 1967

A steam accumulator system which satisfies the above requirement is currently being designed and will be fabricated, installed and checked out at ETS-1 prior to XE testing. With the addition of this system, a total loss of steam flow from the steam generator system during low-flow engine testing will not result in air backflow into the duct.

b. Introduction of Oxygen from the Steam Generator System Into the Duct

An evaluation of potential malfunctions in the steam-generator system indicates that oxygen-rich steam may be introduced into the duct during hydrogen flow tests by any of the following mechanisms:

- (1) Loss of propane to an operating steam module or to the steam-generator system.
- (2) Excessive time delay between termination of propane and oxygen flow should a premature SGS shutdown occur.
- (3) Excessive time delay between initiation of oxygen flow and initiation of propane flow during startup of a standby steam module.

The consequences of introducing oxygen from the steam generator system into the hydrogen environment of the duct have been analyzed. The results are reported in Appendix C. The analysis is based on the assumption that the malfunction which causes the introduction of oxygen does not allow air to penetrate the duct exit. For the case of a malfunction shutdown of the steam generator system, the backflow of air into the duct is precluded by the addition of the accumulator system described above. The accumulator also serves to delay the entry of oxygen into the duct until repressurization of the compartment has occurred and equilibrium flow from the compartment through the duct has been re-established. Under these conditions,

Appendix C shows that an explosion within the duct cannot occur and that when operating at low hydrogen temperatures there is only a remote possibility of hydrogen/oxygen combustion in the duct. Furthermore, for those cases where combustion can occur, the added heat which results from the combustion does not cause thermal overload to the duct cooling system.

4.2.6.3 Duct-Wall Penetration

An analysis of the problem of core particulates damaging the walls of the duct reveals that potential penetration and impact damage is maximum at the 90° elbow. Recent analysis for the E/STS 2-3 revealed that damage is not severe even in the elbow. The small particles have high impact velocity but cause little damage because of their low mass; conversely, though the large particles have a high mass, they cause little damage because of their low velocity. The possibility of particles penetrating the inner or outer wall is therefore considered rather remote.

The elbow is composed of 0.095-in.-thick stainless steel tubing with circumferential support rings interspaced behind the tubes to make the elbow rigid and to support the 1/4-in.-thick backup jacket. This backup jacket surrounds the outside of the 90° elbow section to prevent the flow of outside air into the duct or the flow of hydrogen into the vault if the elbow surface or cooling tubes should be damaged during a test firing. Water is supplied to the jacket and a pressure head is maintained by a direct gravity connection between the jacket and the shield water tank. The jacket pressure is maintained above that expected on either side of the duct wall.

Penetration damage to the inner elbow surface of the duct results in (1) water flowing into the duct interior or (2) water flowing both into the duct and through the jacket up to the shield tank. In both cases, air is prevented from mixing with the hydrogen. The water line between the jacket and the shield tank is instrumented to detect duct damage (see Section 4.2.3).

4.2.6.4 Fuel Deposition in the Duct

If the engine is damaged to the extent that fuel is deposited in the duct, 1.5% of the core would have to accumulate under optimum spacing conditions and would have to become fully flooded to attain criticality. Assuming that this amount of fuel accumulates in the duct under optimum spacing conditions, to achieve criticality it is also necessary to assume that an additional failure occurs that allows water to enter the duct and completely flood the accumulated fuel mass. However, the duct is designed with an offset transition cone immediately downstream of the 90° elbow to eliminate the formation of a pocket in which water can accumulate and a drain is provided at the low point of the 45° exit elbow to carry off any water that might enter the duct. Although these design features may be inadequate to prevent criticality in the duct under some unforeseen conditions, they are sufficient to ensure that a sustained criticality condition cannot exist for an extensive period of time inasmuch as the water source can be shut off by means of valves (as described in Section 4.3) to allow the accumulated water to drain.

Before a "hot" engine is removed from the test stand, criticality in the duct does not significantly increase the posttest radiation environment on the stand because the integrated power of a criticality excursion in the duct is much less than that for the core during engine testing.

For the above reasons, the problem of fuel deposition in the duct is primarily one of allowing a sufficient radioactive decay period to facilitate cleanup of the duct under radiation conditions caused by the presence of irradiated fuel. If, for example, it is assumed that an amount of fuel equivalent to four elements having a full-power, full-duration operation history is deposited in the duct, the dose rate one week after the accident is approximately 10 r/hr 10 ft from the fuel; after a 2-mo

decay, the radiation dose rate drops to approximately 1 r/hr at the same distance. Under these conditions, cleanup operations can be accomplished by controlling personnel access and using semiremote handling techniques. Other test-stand activities can be accomplished during the period of radioactive decay because the engine can be removed from the test stand and the duct-vault door shield and the duct cover shield can be moved into place to reduce the radiation environment at the test pad to acceptable working levels.

4.2.7 Evaluation Summary

As indicated at the beginning of Section 4.2, the basic safety functions of the NES are: (1) to direct the hydrogen exhaust gases from the engine away from the test stand so they can be safely burned; (2) to provide an effective purge capability when the ETC purge system is not operating and the hydrogen flow through the duct is insufficient by itself to exclude air from entering the system; and (3) under accident conditions involving sudden termination of hydrogen flow to the engine, to prevent the backflow of air into the system and to ensure that the engine test compartment is not overpressurized by introduction of hydrogen directly into the compartment as the result of a rupture in the propellant feed system.

The evaluation in Section 4.2.5 shows that the duct carries the engine exhaust gases away from the stand so that thermal effects of the exhaust plume do not jeopardize the facility. However, the analysis also indicates that some additional cooling of facility components may be required during extended high-power testing and that testing under low hydrogen flow should not be performed with an on-stand wind. Heat-flux data to verify the plume heating analysis will be collected during facility activation tests and during the NES design-demonstration program. If the data obtained show that additional protection is needed for the test stand during engine tests, the existing fire-protection system can be readily modified to satisfy this requirement.

With respect to the second of the basic safety functions of the NES, Section 4.2.4 shows that the NES prevents the backflow of hazardous quantities of air into the system under all hydrogen flow conditions if the steam-generator system is operating at rated flow. An accumulator system is being added to the steam line to prevent air backflow into the duct upon total loss of steam from the steam generator system during low-flow engine tests. During pulse cooldown of the engine with LH_2 , a nitrogen flow rate of 10 lb/sec to the engine test compartment appears adequate to prevent the entry of air into the duct system.

Finally, the capability of the NES to remove hydrogen from the engine test compartment to prevent overpressurization of the compartment if a main propellant line ruptures is discussed in Section 4.2.2 and 4.2.6.1. From the results of analyses presented, it is concluded that the steam output of two steam modules is adequate to provide the necessary protection against compartment overpressurization during full-power engine testing.

Other features of the NES relating to its design and operational safety, and which tend to enhance the overall safety of the engine test program, are:

a. The steam-generator system provides a backup steam module for immediate use during engine testing if one of the two operating modules fails.

b. Two steam generators operating at idle conditions provide an effective backup to the ETC purge system should it fail during pulse cooldown operations.

c. Accumulation of water in the duct is protected against by a drain at the low point in the duct. This feature protects against a nuclear excursion in the event pieces of the reactor core become dislodged during a test and are deposited in the duct.

d. The elbow section of the duct has an additional water jacket to prevent entrance of air into the duct or leakage of hydrogen into the vault if penetration or other failure occurs in the tubular wall construction of the elbow.

e. Nitrogen-filled double-walled seals are used at the severance plane between the upper and lower sections of the duct and at the connection between the duct and the test stand. Nitrogen pressure and flow to the seals will be monitored during a test to detect any leaks.

On the basis of the above considerations, the modes of operation discussed, the analyses that support this evaluation, and the addition of a steam accumulator system on the SGS steam line, the NES is considered adequate from the safety standpoint to support the X-engine test program.

4.3 PROCESS WATER SYSTEM

The process water system at ETS-1 provides cooling for the exhaust duct, makeup (injection) water and cooling for the steam generators, shielding and coolant for the ETC shields, and deluge water for Areas 1 and 2 of the fire-protection system. For full-power engine testing, the system provides approximately 38,000 gpm for exhaust-duct cooling, 2200 gpm for the steam generators, and 3700 gpm for the ETC shields. Details on the use of process water for fire protection are discussed in Section 4.13.

The process water system comprises a well pumping station, a demineralizer plant, a 2.5 million gallon demineralized-water storage tank, distribution piping, control valves, and instrumentation. The storage tank is located approximately 700 ft north of the test stand at an elevation approximately 460 ft above the test stand. A 42-in. epoxy-resin-lined carbon-steel pipe with a storage capacity of approximately 250,000 gal connects the storage tank to headers at the test stand, which in turn supply the systems that use process water. Because the difference in elevation between the storage tank and the test stand makes gravity feed adequate for supplying the system headers at design pressures, pumping is not required. A simplified flow schematic of the process water system is shown in Figure 4.3.1.

4.3.1 Water Storage and Distribution

Demineralized water is pumped from the demineralizer plant (D-2001) to the 2.5-million-gallon storage tank (T-3302), from which it is gravity-fed to the exhaust duct, steam generators, ETC shields, and fire-protection system. The main supply valve downstream of the storage tank is a manually operated butterfly valve, BFV-661, located near the tank. This valve is normally open to ensure that water is available for fire protection. Motorized valve BFV-666, located in the pipe chase, is the main water supply valve for the duct, steam generators, and engine shields. A pressure transmitter, PT-168, with remote readout at the control-point building, serves to

4.3-2

Figure 4.3.1 - Flow Schematic of Process Water System

indicate water supply pressure in the main supply line upstream of BFV-666. Two 6-in. drain lines, with gate valves GAV-665 and 669, provide a means for draining the main supply line on either side of BFV-666.

A remote readout of water level in the storage tank (LI-15) is provided on the Lead Facility Engineer Console in the control room. In addition, a local liquid-level indicator (LT-07) is provided on the storage tank. As discussed in Section 4.13, a minimum reserve of 500,000 gal of process water is required for fire protection. This quantity corresponds to a storage-tank level of approximately 10 ft.

4.3.2 Steam-Generator System

Process water for operating and cooling the steam-generator system is provided through gate valve GAV-1781, located near the steam-generator enclosure behind the shadow-shield wall. Water is initially supplied to the steam generators through a bypass valve, RSV-434, at a relatively low flow rate to minimize shock to the system during initial fill operations. Flow through the bypass line is restricted by a 2-in. crossover line that connects the 4-in. fill line to the 6-in. main supply header. During SGS operation, plenum cooling water and injection water are supplied through RSV-433. The flow rate of injection water to each of the steam-generator combustion chambers is controlled remotely by flow-control valves FCV-423-1, -2, and -3. The plenum cooling water is routed directly from the steam-generator system to the main facility drain line, which empties into the open drainage ditch.

To increase the reliability of SGS operation during engine test periods, RSV-433 and FCV-423 (-1, -2, and -3) are designed to fail in the open position upon loss of their electrical or pneumatic supply. Thus, failure of these valves to their normal position during engine test periods does not result in a premature SGS shutdown since water flow to the system is maintained during such a failure. If water flow to the steam generators is interrupted

for some other reason, an automatic shutdown signal is generated by differential pressure switches that monitor plenum-cooling water flow (PDS-404), injection water flow (PDS-406-1, -2, and -3), and combustion-chamber pressure (PDS-405-1, -2 and -3).

If RSV-433 fails open during engine shutdown periods, GAV-1781 can be used to prevent excessive water loss (approximately 1000 gpm) from the storage tank through the steam-generator system. Current estimates of posttest radiation levels at the GAV-1781 location indicate that controlled personnel access to this valve should be permissible within approximately an hour after engine shutdown from a full-power full-duration test. However, even if the local radiation level exceeds current estimates and thus precludes such access, a backup to closing GAV-1781 is available by using BFV-666, which can be partially closed from the control point to reduce water flow to the steam generators and, at the same time, maintain sufficient water flow to the duct for cooling during the remainder of the engine cooldown period.

4.3.3 Exhaust-Duct System

Process water is supplied as coolant to the exhaust duct during test operations to prevent overheating of the duct inner wall. Except for the elbow, this system is designed so the maximum duct inner-wall temperature does not exceed 1000°F under normal operations. At the elbow, the maximum inner-wall design temperature is approximately 1180°F. These design temperatures are based on both theoretical and experimental scale-model determinations of heat transfer from the hot gas to the coolant water. The design bulk temperature of the outlet water is 140°F. Inner-wall temperatures are maintained by the exchange of heat between the duct inner wall and the coolant water flowing in parallel rectangular or circular tubes that form the duct periphery.

Water flow rates are preset by means of orifice plates in the outlet line from each duct section and at the end of the drain line. The orifices at the duct outlets control the flow through each duct section while the orifice in the drain line controls total flow as well as maintaining a back pressure on the system. Normal operation of the duct cooling system during engine startup, firing, and shutdown is with all control valves in the system in an open pre-calibrated position. After engine power testing, water flow through the duct is reduced and subsequently maintained at some low rate until cooldown is complete. Flow is reduced during this period by throttling FCV's 30, 31, and 32.

The system flow-control and shutoff valves, which are located in the pipe chase, are remotely operated with solenoid pilot valves and hydraulic (water) operators. Flow through the system is initiated by sequentially opening RSV-296, -297, and -298. After the duct coolant system is charged, full flow through the system is accomplished by sequentially opening FCV-30, -31, and -32. Water from the 42-in. supply main flows into a 36-in. branch supply header in the test-stand pipe chase and then into the duct vault, where it branches into two 20-in. supply headers parallel to the exhaust duct. These headers supply the truss headers that supply the primary, secondary, and elbow sections of the duct. The effluent water discharges from the jackets into two drain headers, also parallel to the duct, and then flows into a common 36-in. discharge main that connects to the existing facility main drain in the pipe chase. The water flows into an open ditch adjacent to the test stand. The elbow water jacket and water-shield tank are supplied with water at approximately 100 gpm from the duct-system drain headers. Water overflows from the duct water-shield tank and elbow buffer-zone water jacket onto the duct-vault floor to supplement the spray water from the duct vault deluge system (see Section 4.3.4), which cools the concrete surfaces of the duct vault.

A 1/4-in.-mesh strainer (ST-35) is located in the 36-in. supply header to the duct to prevent foreign matter or objects large enough to plug the duct coolant channels from entering the duct coolant system. This strainer has been in the system since the time of duct installation at ETS-1.

As noted in Figure 4.3.1, each control valve in the duct coolant system fails in whatever position it has at the time its electrical or hydraulic actuation supply is lost. In addition, since these valves are supplied from a common 28-vdc power source (see Section 4.9), a single failure in the electrical system can result in all of these valves failing in their full-open position during test operations. If such a failure occurs, the valve failure modes are such that coolant flow to the duct is maintained; and, during the subsequent cooldown periods when water flow through the system must be reduced to conserve water for duct cooling and fire-protection reserve, BFV-666 can be throttled remotely from the control point to reduce coolant flow as necessary. Furthermore, to ensure that a single electrical-system failure cannot result in simultaneous loss of control over both the flow-control valves in the duct coolant system and BFV-666, this latter valve is operated from an ac power source that is independent of the dc source used for actuation and control of RSV's 296, 297, and 298, and FCV's 30, 31, and 32.

In addition to the extensive instrumentation provided for monitoring the water flow and temperatures in each individual duct section, instrumentation is also provided to indicate gross inlet flow rate to the duct and the duct-coolant inlet and outlet temperatures. Signals are transmitted by this instrumentation to the control-point building so appropriate corrective action can be taken if abnormal temperatures or flow rates are indicated. The relative locations of duct flow transducers FT 30, 31, and 32 and of the duct inlet and outlet temperature indicators, TI-47 and 48, are shown in Figure 4.3.1.

4.3.4 ETC Shield System

The flow of water to the ETC shields is controlled from the control point by operation of RSV's 303, 304, 305, and 306. The shields may also be filled by using hand-operated valves GLV-1222, 1223, 1224, and 1225, which are located in the valve pit near the steam-generator enclosure. Flow to the side shields (including the intermediate shield) enters at the top of the shields, circulates through them, and discharges through an overflow manifold at the top of the shields to the duct-vault deluge system. The vault deluge system consists of a series of nozzles in the duct-vault ceiling that disperse the discharged water over the concrete surfaces of the duct vault for cooling during test operations. Remotely operated valves RSV-355 and -356, which remain closed during test operations, are used to drain the side shields before transfer to their storage locations. Water circulated through the top shield also flows to the duct-vault deluge system. Water circulated through the bottom shield flows to an open drain in the duct vault. All water discharged from the shields ultimately flows to the open drainage ditch adjacent to the test stand.

Remote disconnects are provided for the process water piping to the side shields so the shields can be separated and moved without exposing personnel to the test-stand radiation environment.

As indicated on Figure 4.3.1, loss of electrical power or gas actuation pressure causes the remotely operated inlet flow-control valves, RSV-303, and -304, -305, and -306, to fail in the open position. Thus, loss of electrical or actuation supply to these valves during test periods does not result in loss of shield-water flow. Furthermore, if for some other reason water flow to one or more of these shields is interrupted, the mechanical design of the shields precludes the loss of water within the shields. In addition, adequate instrumentation is available to monitor shield water temperature; and, if this temperature becomes excessive, appropriate action can be taken to preclude shield damage.

The side-shield remotely operated drain valves, RSV-355 and -356, fail closed on loss of electrical power or actuation gas pressure. Since the side shields cannot be moved to their storage position without being drained, manually operated emergency drain valves that discharge water locally are provided in the drain lines. Thus, if the remotely operated drain valves fail, the S-1 and S-2 shields can be drained and removed from the test position to provide access for removing the engine from the stand.

The possibilities of plugging the shield drain lines are considered because complete stoppage of flow through any one of the shields may cause overpressurization and rupture of that shield. This possibility is precluded in each shield by multiple discharge lines of large diameter that feed a common large-diameter drain line. For example, the water drain line for each side shield is a 10-in. pipe fed by four 6-in. discharge lines. Thus, to overpressurize a side shield, all four discharge lines would have to become plugged. This possibility is too remote to warrant concern.

4.3.5 Disposal of Process Water

Process water discharged from the steam generators, exhaust duct, and engine shield system during test operations (approximately 1.5 million gallons maximum) is emptied into the drainage ditch adjacent to the exhaust-duct vault. Since fission products are released into the drainage ditch during engine testing and cooldown, this effluent water stream may become highly contaminated. For this reason, a holdup reservoir of approximately six-million-gallon capacity is provided downstream of the drainage ditch for containment and holdup of the released effluent water. On the basis of results of sampling, the water is either retained in the reservoir for decay and settling of fission products or released in a controlled manner if fission-product concentrations are sufficiently low. By this means, contamination of roads or other accessible

areas beyond the holdup reservoir is minimized. The location and relative size of the effluent-water drainage ditch and holdup reservoir at ETS-1 are shown in Figure 4.3.2.

4.3.6 Evaluation Summary

Because coolant water for the duct and injection and coolant water for the steam generators must be available for the safe conduct of engine test operations, the process water system is designed to provide this water with a maximum degree of reliability. The system uses gravity feed from the storage tank. All valves in the system are designed to fail in a position that does not jeopardize facility components by loss of coolant if the electrical or actuation supplies for the system valves are lost during full-power engine testing. Furthermore, during engine cooldown, redundant control of the flow of water to the duct and the steam generators is provided so that a single failure cannot result in inability of the system to provide the necessary coolant. This redundant control ensures that, under malfunction conditions, the flow of process water can be terminated if necessary to conserve water for fire protection. A remote readout of the water level in the storage tank is provided at the control point so appropriate corrective action can be taken against inadvertent depletion of water for the fire-protection reserve. As additional protection against partial loss of water to the duct cooling system due to blockage of the duct coolant channels, a strainer in the water feed line upstream of the duct prevents foreign material from entering the duct coolant system.

The ETC shields are protected against overpressurization and possible rupture due to plugging of the shield-water discharge lines by providing multiple discharge lines of large diameter that in turn feed a large-diameter drain line. Complete plugging of these lines is not considered a credible situation. To preclude loss of water from the ETC shields during test, the water inlet and outlet lines are connected to the shields above the full

Figure 4.3.2 - Relative Location of ETS-1 Holdup Reservoir

water level. In this manner, a failure of the inlet or outlet lines cannot cause a loss of shield water. In addition, the remotely operated drain valves for the side shields fail to the open position upon failure of an electrical or pneumatic supply so that they cannot inadvertently terminate shield-water flow. Emergency drain provisions are incorporated so that, if the remotely operated drain valves cannot be opened, the side shields can be drained and removed from the test position to provide access for removing the engine from the stand.

On the basis of this evaluation, and for the reasons stated above, the process water system is considered adequate from the safety standpoint to support the X-engine test program.

4.4 ENGINE-SHIELD FILL-AND-DRAIN SYSTEM

The engine-shield fill-and-drain system is used to fill the X-engine external shield with borated water (1 wt% ammonium pentaborate) after installing the engine on the test stand and to drain the shield prior to engine removal. In addition, in order to maintain the bulk shield water temperature below 180°F, the system can provide continuous water flow through the shield at approximately 60 gpm during long-duration full-power engine tests.

The system is designed to limit the engine-shield pressure to 30 psia during normal engine test periods and to prevent shield pressures from exceeding 36 psia under malfunction conditions. The engine shield has been hydrostatically proof-tested to 38 psig.

The fill-and-drain system consists of an insulated mix tank with agitator and heater, a transfer pump, supply and drain lines with associated valves, a GN_2 pressurization system, and appropriate instrumentation and controls. The system is operated remotely from the RIC console in the control-point building. A simplified flow schematic of the system is shown in Figure 4.4.1.

The mix tank holds approximately 2000 gal of a 1-wt% water solution of ammonium pentaborate ($\text{NH}_4\text{B}_5\text{O}_8 \cdot 4\text{H}_2\text{O}$). An agitator helps dissolve and maintain the chemical in solution. The temperature of the solution is controlled between 80°F and 100°F by an electric resistance-type immersion heater and a thermostatic temperature controller. A low-liquid-level controller protects system components against damage by terminating pump operation and cutting off power to the heater coil when low liquid level is indicated.

The supply line to the engine shield contains a centrifugal-type pump rated to deliver 60 gpm with flooded suction against a 130-ft water head. A strainer installed immediately upstream of the pump prevents passage of all particles that are 0.1 in. or larger in size. The supply-line pressure downstream of the pump (PI-62) is established by setting the position of GLV-2693

Figure 4.4.1 - Flow Schematic of XE External-Shield Fill-and-Drain System

so that the shield pressure (PT-800) is approximately 30 psia during pump operation with water flowing through the shield at a rate of 60 gpm. For these conditions, the pressure at PI-62 is expected to be approximately 56 psia. The position of GLV-2693 can be mechanically locked to ensure that a preset position is maintained during test periods.

After the engine is installed on the stand and before the shield is filled, the remote couplers at the engine-adapter interface can be leak-checked by closing RSV-703, RSV-854, and GLV-2693 and then opening RSV-705 to pressurize the system to 12 psig with GN_2 . After closing RSV-705, a drop in system pressure indicates a leak.

To fill the shield, the system is operated as follows. The pump is started with GLV-2693 locked in its preset position and with RSV's 703 and 854 open and RSV's 705, 718, and 712 closed. The time required to fill the shield is estimated to be 5 min. To empty the shield, the pump is shut down, RSV's 703 and 854 are closed, and RSV's 712 and 705 are opened. The borate solution is displaced with nitrogen flowing at 12 psig through PRR-486. A sudden drop in system pressure shows when the shield is empty. PRR is equipped with an internal pressure relief set at 15 psig so a malfunction in this valve or in the upstream pressurization system does not result in excessive downstream pressures.

During engine test operations, the system can be operated in either of two modes. During relatively short-duration tests (less than 5 min at full power), the total radiation heat input to the shield is sufficiently low that water need not be circulated through the shield. For this case, the shield is filled, the pump is shut down, and RSV's 703 and 854 are closed. RSV's 712 and 705 are then opened. When the engine-shield level probes (LT-001 and LT-002) indicate that the level in the shield has been reduced by 1 in., RSV-712 is closed, RSV-718 is opened, and the pressurization gas system remains in operation throughout the test. Shield-water temperatures (TE-868 and TE-870) are monitored to ensure that the bulk shield temperature does not

exceed 180°F. A relief valve, RV-2730, in the shield drain line protects against overpressurization of the system. This protection is provided in the event of malfunctions, such as the temperature elements indicating low, and as a result thereof, the shield water temperature being inadvertently permitted to increase to a point where the vapor pressure in the shield becomes excessive. Excessive pressures due to disassociation of the water by radiation are also precluded by this relief valve.

During long-duration tests, water flow through the shield is required to prevent the shield water temperature from exceeding 180°F. This flow is maintained by using the pump and the preset position of GLV-2693 to obtain a 60-gpm flow through the shield and drain line to the duct vault, at which point it is discharged into the drainage ditch.

Because the pressure downstream of the pump during operation is considerably greater than that permissible in the shield, a number of safety features are incorporated in the system to protect the shield from overpressurization in the event of a malfunction. First, each of the remote shutoff valves in the system has been designed to fail to its normal position when operating with flow in the shield. For example, RSV-703 is spring-loaded to its open position so that, upon loss of its pneumatic or electrical actuation supply, the valve will remain open and thereby not block flow through the system which would increase the shield pressure. Second, if an operator error results in closure of either RSV-703, which blocks flow through the system, or RSV-854, which removes the low-pressure relief from the system, signals from position switches on these valves result in automatic shutdown of the pump. Finally, if some other event, such as blockage in the shield drain line, causes the shield pressure to start increasing significantly above its normal operating pressure of 30 psia, RV-2225 relieves the drain-line pressure to prevent a pressure increase of more than 3 to 5 psi in the shield. If the section of drain line between the shield and the relief valve becomes blocked, a signal from a pressure switch results in automatic shutdown of the pump. The pressure switch is normally set to signal pump shutdown at a shield pressure of 36 psia.

In summary, the engine-shield fill-and-drain system provides the capability to fill and drain the external engine shield and to maintain water flow through the shield during test periods without the possibility of damaging the system by overpressurization. Under normal operating conditions, the maximum shield pressure is 30 psia. Under credible malfunction conditions, the pressure-relief valves in the system and the various devices for automatic shutdown of the pump limit the maximum pressure that can develop in the shield to 36 psia. The shield has been hydrostatically proof-tested to 38 psig, which is equivalent to an internal shield pressure of 39 psia when the engine test compartment is at its lowest expected operating pressure of 1 psia. Thus, under credible malfunction conditions, the shield pressure is limited to a value 3 psi below the pressure at which the shield has been hydrostatically proof-tested. It is therefore concluded that the engine-shield fill-and-drain system is adequate from the safety standpoint to support the X-engine test program.

4.5 X-ENGINE ACTUATION GAS SYSTEM

The actuation gas system for the X-engine supplies the actuation gas to the servicing actuators for the reactor control drums and for all pneumatically operated engine valves. The system, which consists of four separate supplies to the engine, provides: (1) regulated GH_2 or GHe to the pneumatic actuators for the 12 reactor control drums; (2) regulated GH_2 or GHe to the pneumatic actuator for the TPCV; (3) regulated GHe to the pneumatic actuators for the six on-off engine valves (PDSV, CSV, PDVV, CVV, PSV, and TBV); and (4) regulated GN_2 to the coupling drive motors at the TSA-UTS interface and to the remote-disconnect clamps for the pump inlet line, emergency cool-down line, and common LH_2 vent line. Each of these supplies originates at the facility gas-storage tanks and is filtered and reduced in pressure before entering the engine. A simplified flow schematic of the actuation gas system is shown in Figure 4.5.1.

4.5.1 Control-Drum Actuator Supply

The control-drum actuation gas system supplies either GH_2 or GHe at 215 ± 10 psia to the 12 control-drum actuators. The GHe supply is used during system checkouts and low-power tests when the engine test compartment is not closed and the compartment is not purged. The GH_2 supply is used during engine power tests. Both of these supplies enter the engine through a common line that contains a key-operated double block and bleed to prevent inadvertent pressurization of the drum actuators during nonoperating periods (see Section 4.6). The keys are captive in the locks when the blocking valves (RSV-2334 and RSV-444) are in their open position and when the bleed valve (BV-2332) is in its closed position. This key provision ensures that when the keys are removed from the locks the double block and bleed is in effect.

The primary control valves in the system are RSV-868, -867, -880, -2334 and -444. Except for RSV-867, these valves fail open upon loss of actuation supply so that pneumatic pressure to the control drums can be

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maintained during engine test operations if either the electrical or pneumatic supply to these valves is lost. RSV-867 fails closed so as to prevent the GHe from entering the system if its electric power or valve actuator pressure fails during a test.

The pressure for both the GH_2 and GHe supplies is reduced from the facility supply pressure of 2500 psig to 1500 psig by two pressure-regulating valves (PRV-402 and -403) with associated remote loaders. The line pressure is further reduced to system operating pressure by PRV-200, which is also controlled by a remote loader. PRV-403 and -200 fail open upon loss of electrical power so that pneumatic pressure to the control drums is maintained if this failure occurs during engine test operations. (The mechanical construction of the pressure regulators precludes their failure to the open position upon loss of their pneumatic actuation supplies.)

The portion of the system downstream of PRV-200 is protected from over-pressurization by a dual pressure relief system. RV-2848 acts as a back-pressure regulator to control the actuation pressure to 237 psig if PRV-200 fails full open. The regulation pressure of 237 psig is based on the nominal pressure rating of the engine components. RV- which is set at 250 psig provides additional assurance that, even under multiple failure conditions, the gas pressure in the actuation line never exceeds a maximum pressure of approximately 250 psig. This redundancy in the relief system is considered necessary since an abnormally high gas pressure to the control drum actuators can cause failure of the bellows assembly in the servo valve of each actuator. Such a failure on the "drum-out" side of the servo-valve torque motor could cause the drums to run out at speeds considerably greater than $100^\circ/\text{sec}$ which, in turn, could result in an unacceptable nuclear excursion.

The remote shutoff valves and the remote loaders for PRV-402, -403 and -200 are manually and individually controlled from the ASE Console at the control-point building. Indicators for pressure transducers,

pressure switches, and RSV valve positions (open or closed) are also provided on the console. In addition, the signal from a pressure switch is transmitted to the engine safety system to produce a reactor scram on low-pressure indication.

To protect the control drum actuators from detrimental effects produced by condensible impurities in the gas stream during actuator operation at cryogenic temperatures, an LN₂ cryotrap is provided in the actuation gas line upstream of PRV-200. The system cools the actuation gas, either hydrogen or helium, to below 175°R and then passes it through a 20-micron filter to remove the condensibles. The gas is subsequently passed through two 10-micron filters to prevent other foreign particles from entering the actuators. The discharge gas from the actuators is vented through a common open line to the engine test compartment.

4.5.2 TPCV Pneumatic Supply

The pneumatic supply system for the TPCV is identical to the control-drum-actuator supply up to the key-operated double-block and bleed valves. From this point to the engine, the line contains one hand-operated valve, GLV-2337, which is in its open position during engine tests, and two filters to prevent foreign particles from entering the TPCV actuator.

4.5.3 Engine-Valve Pneumatic Supply

The six on-off engine valves are operated from a common pneumatic line that supplies helium gas at 500 psig. The engine valves are the PSV (propellant shutoff valve), PDSV (pump-discharge shutoff valve), CSV (cooldown shutoff valve), PDVV (pump-discharge vent valve), CVV (cooldown vent valve), and TBV (turbine block valve). The pressure to the valves is reduced from the facility supply pressure of 2500 psig to 500 psig by pressure-regulator valve PRV-485 with associated remote loader and pressure switch.

A relief valve set at 550 psig is located downstream of the regulator valve to protect this portion of the system from overpressurization if the regulator valve fails in the full-open position.

The primary control valve in the system is RSV-702. This valve is spring-loaded to fail open upon loss of electrical power or pneumatic supply and PRV-485 fails open upon loss of electrical power in order to prevent loss of helium flow to the engine valves in the event pneumatic actuation pressure to these valves is lost. However, if for some other reason system pressure is lost during a test, the engine valves fail to positions which minimize the potential for engine or facility damage. Specifically, loss of engine-valve pneumatic-supply pressure has the following consequences:

a. PSV - Loss of pneumatic supply pressure to the PSV causes valve closure and emergency shutdown due to loss of flow through the main propellant feed system. During emergency cooldown, coolant is supplied to the reactor through the emergency cooldown line (see Section 4.8).

b. PDSV and CSV - Both the PDSV and the CSV fail in the open position. Because this is their normal position during engine power testing, loss of pneumatic pressure to these valves during engine testing does not jeopardize the test operation.

c. TBV - Loss of pneumatic supply pressure to the TBV causes valve closure and an emergency shutdown due to reduced flow through the main propellant feed system. During emergency shutdown, coolant is supplied to the reactor through the emergency cooldown line. (The fact that this valve closes in conjunction with PSV closure upon loss of pneumatic supply pressure results in protection of the turbine against overspeed by removing the drive force on the turbine when the pump is unloaded.)

d. PDVV and CVV - Both the PDVV and the CVV fail in the closed position. Because this is their normal position during engine power testing, loss of pneumatic pressure to these valves during engine testing does not jeopardize the test operation.

4.5.4 GN₂ Pneumatic Supply

The GN₂ pneumatic supply system provides actuation gas at 85 psig both to the 12 TSA-UTS-interface remote-coupling drive motors at engine Station 42.89 and to the remote-disconnect Marman clamps at Station 41.40 for the pump inlet line, emergency cooldown line, and common LH₂ vent line. The system consists of the components shown in Figure 4.5.1. The supply pressure is reduced from 2500 down to 500 psig by PRV-416 and is then further reduced to 85 psig by PRV-405. A relief valve set at 100 psig is located downstream of PRV-405. The flow from the facility to the actuators is controlled by solenoid valve SV-464. After passing through the ETC top shield, the pneumatic supply line divides into two lines in which the pressures are reduced to 37 psig. Gas in one branch flows to the 12 structural-connector actuator control valves. Gas in the other branch flows to the three remote Marman actuator control valves.

The TSA-UTS interface connection is designed so that, if the GN₂ pneumatic system fails before or during removal of a "hot" engine from the test stand, the EIV manipulators can be used to release the engine. Thus, failure of the GN₂ system does not jeopardize the engine test program.

4.5.5 Evaluation Summary

The X-engine actuation gas system incorporates the following features relating to its safety of design and operation.

a. Either the TPCV or the control-drum actuators can be operated with inert gas so that they can be operated safely when the ETC is not both mated and purged.

b. The failure modes of valves in the system are such that loss of their electrical or pneumatic supplies during engine test operations does not cause loss of actuation gas to the engine valves or the control-drum actuators.

c. A key-operated double block and bleed is provided in the pneumatic supply line to the control-drum actuators as additional protection against inadvertent rotation of the control drums during nonrun periods.

d. A separate pneumatic supply line that bypasses the double block and bleed is provided to the TPCV to allow checkout of this component without concurrent pressurization of the pneumatic supply to the control-drum actuators.

e. The pneumatic lines in the system have pressure reliefs that are adequate to prevent overpressurization and damage to the system or to the engine if a regulator valve fails to its full-open position.

Because of the above features and the fact that suitable countermeasures are provided for protection of the engine if any one of the pneumatic supplies to the engine fails, the X-engine actuation gas system is considered adequate from the safety standpoint to support the X-engine test program.

4.6 X-ENGINE CONTROL-DRUM LOCKOUT SYSTEM

The control-drum lockout system is designed to ensure that the X-engine control drums are not inadvertently rotated during nonrun periods at ETS-1 when the X-engine is installed on the test stand and the manual key locks on the individual control-drum actuators are disengaged. This capability is needed both before and after engine testing because of inaccessibility of the control-drum actuator keys. Access to the actuator keys before engine testing is restricted by space limitations within the upper-thrust-structure module. After engine testing, access to the actuator keys is further restricted because of high radiation levels in the vicinity of the engine.

For the purposes of the description that follows, the term lock, as applied to the X-engine control drums, is used to connote a mechanism that is operated with a key and which, when engaged, either directly or indirectly prevents rotation of the drums. The control-drum locking mechanisms are categorized as either mechanical, pneumatic, or electrical. Mechanical locks are defined as those that prevent rotation of the drums by physically restricting their movement, even when the actuator mechanism is energized. Pneumatic locks are defined as those that physically prevent pressurization of the pneumatic actuator system within the engine and thus preclude the possibility of the actuators producing drum rotation. Electrical locks are defined as those that prevent electrical signals required for actuator operation from reaching the actuator.

Because it is extremely difficult to preclude the possibility of spurious signals being generated within the ETS-1 control system, mechanical or pneumatic locks are expected to provide a greater degree of protection against inadvertent drum rotation than electrical locks. Thus, wherever possible, mechanical or pneumatic locks are used in preference to electrical locks for the control-drum lockout system.

4.6.1 Requirements for Control-Drum Lockout at ETS-1

The operational and safety requirements for control-drum lockout at ETS-1, along with the reasons for each, are listed below:

a. The keys for all control-drum locking mechanisms shall be captive when the locking mechanism is deactivated or disengaged. This requirement is imposed to provide an effective means for administrative control over the keys for the locking mechanisms and, hence, over the rotation of the drums. With the keys in the possession of the Test Director or other authorized personnel, proper locking of the control-drums is ensured.

b. The capability shall exist to either mechanically or pneumatically lock the X-engine control drums during nonrun periods both before and after engine testing. This capability should neither unduly restrict nor hinder run-simulation or checkout operations not requiring drum rotation during nonrun periods. The basis for this requirement is that, during certain nonrun periods, a considerable number of maintenance and checkout operations may be going on concurrently at ETS-1; and, as a result, personnel will be allowed considerable freedom of movement within the test complex. Under these conditions, electrical locks to prevent control-drum motion are not considered adequate as sole protection against drum rotation because they can be readily defeated by a simple short in the actuator control circuitry.

c. An electrical lock shall be provided at the control point to allow the CTO to unlock all of the pneumatic locking pins in the drum actuators and, hence, move the drums. Without the key for this lock, rotation of more than a single drum will not be possible. This lock is required to maintain positive control over drum-rotation capability until such time as final approval for conduct of the test is received and multiple drum rotation is required. Administrative control over the key for this lock will be maintained until the run day arrives and final approval for testing has been granted.

d. The electrical circuits for the pneumatic locking pins shall be electrically isolated from each other so that (1) a separate and distinct manual action is required to withdraw the locking pin for each drum and (2) a single electrical malfunction cannot cause more than a single pneumatic locking pin to be withdrawn. This requirement is imposed to prevent a single inadvertent action by an operator or a simple short circuit within the system from causing more than a single locking pin to be withdrawn when both the mechanical and pneumatic locks on the drums have been defeated.

e. The capability shall be provided to individually unlock the pneumatic locking pin and rotate a single drum from either the test-cell building or the control point while the pneumatic locking pins for the remaining 11 drums are engaged and electrically locked. Selection of the drum to be rotated shall be at the discretion of the operator. This capability is required during countdown and during certain maintenance periods to allow individual checkout of each drum-actuator system while still maintaining the necessary control over inadvertent drum motion prior to receiving final test approval.

f. An electrical lock shall be provided at the test-cell building that can be used to prevent drum rotation from the control point. This lock provides additional protection against inadvertent drum rotation during certain maintenance and checkout periods involving the control consoles at the CP when both the mechanical and pneumatic control-drum locks have been defeated.

4.6.2 Drum-Lockout Capability at ETS-1

The capability of the control-drum lockout system at ETS-1 to protect against inadvertent drum rotation during nonrun periods when the engine is installed at the test stand is described below. This capability, in conjunction with appropriate procedural controls, is sufficient to satisfy all of the requirements identified in Section 4.6.1 above.

4.6.2.1 Mechanical Locks

Each of the 12 control-drum actuators on the X-engine is provided with a mechanical key lock which, with the key withdrawn, physically prevents retraction of the pneumatic locking pin, which in turn mechanically restricts drum motion. With the key inserted and rotated in the lock, the key is captured and the pneumatic locking pin is free to retract if an appropriate electrical signal is received and if the pneumatic supply system is pressurized.

4.6.2.2 Pneumatic Locks

The pneumatic supply system for the X-engine control-drum actuators consists of a single pneumatic supply line to the engine that provides the pneumatic fluid for the 12 control-drum actuators and their pneumatic locking pins (see Section 4.5 for a schematic of the system). On the opposite side of the shadow-shield wall from the engine (i.e., on the south side), this line is divided into two separate lines, one for hydrogen and one for helium. A key-operated double block and bleed is installed in the common line downstream of the junction of the two supply lines at a location that is accessible during nonrun periods when a "hot" engine is on the stand. The keys are captive in the locks when the blocking valves are in their open positions and when the bleed valve is in its closed position. The pneumatic supply line to the TPCV actuator joins the common line at a point upstream of the double block and bleed so the TPCV can be operated for engine-checkout purposes during nonrun periods without defeating the pneumatic locks on the control-drum actuators.

4.6.2.3 Electrical Locks

The TSCS-ECS is provided with four key-operated switches that can electrically lock the control drums. The functions of these switches are shown schematically in Figure 4.6.1.

Figure 4.6.1 - Simplified Schematic of Electrical Drum-Lock System

Switch No. 1 is a three-position switch on the electronics equipment rack in the test-cell building. The first position (OFF) prevents drum unlocking and rotation from either the control point or the test-cell building. The second position (TCB) prevents drum unlocking and rotation from the control point but allows a single drum to be selected, unlocked, and rotated from the test-cell building. The third position (CP) prevents drum unlocking and rotation from the test-cell building but allows the drums to be unlocked and rotated from the control point. The key for Switch No. 1 is captive in the TCB and CP positions.

Switch No. 2 is a two-position switch on the ATE Console at the control point. With the switch in the ENABLE position, a single drum may be unlocked and rotated provided Switch No. 1 is in the CP position. Thus, a single drum can be rotated from the control point by using only the keys to Switches No. 1 and 2. End-to-end checkout of the control system during nonrun periods is thereby possible while rotation of more than a single drum is precluded. The key to Switch No. 2 is captive in the ENABLE position.

Switch No. 3 is a two-position switch on the ATE Console at the control point. The first position (DISABLE) prevents unlocking of more than a single drum (retraction of the pneumatic locking pins) from the control point. The second position (ENABLE) allows selection and individual withdrawal of each of the 12 pneumatic locking pins, provided Switch No. 1 in the test-cell building is in the CP position and Switch No. 4 (see below) is in either the OPERATE or SIM/OPR position. The key to Switch No. 3 is captive in the ENABLE position.

Switch No. 4 is a three-position switch on the CTE Console at the control point. The first position (SIMULATE) prevents unlocking and rotating more than a single drum from the control point. The second and third positions (SIM/OPR and OPERATE) allow ganged drum rotation if Switch No. 3 is in the ENABLE position (and the drums to be rotated have been unlocked) and Switch No. 1 is in the CP position. The key to Switch No. 4 is captive in the OPERATE and SIM/OPR positions.

In summary, the key to Switch No. 1 is required to unlock and rotate a single drum from the test-cell building, the keys to Switches No. 1 and 2 are required to unlock and rotate a single drum from the control point, and the keys to Switches No. 1, 3, and 4 are required to unlock and rotate more than a single drum from the control point. Because it is planned, during pretest checkout operations, to operate the control system in the SIM/OPR mode with only a single drum unlocked, the key to Switch No. 3 becomes the master key that is retained by the proper authority until final test approval is received.

4.6.3 Evaluation Summary

With the control-drum lockout provisions described in the preceding section, all requirements specified in Section 4.6.1 for the X-engine control-drum lockout system are satisfied. Furthermore, the system incorporates all the basic safety features and capabilities inherent to the NRX control-drum lockout system as defined in NTO-SOP-0015, Revision 2, dated 6 December 1965. For these reasons, the control-drum lockout system at ETS-1 is considered adequate to support the X-engine test program.

4.7 RUN-TANK SYSTEM

The run-tank system supplies LH_2 to the engine pump inlet during normal engine operating periods and during pulse cooldown periods after reactor shutdown. The system consists of a 77,000-gal LH_2 storage tank, a tank pressurization and vent system, and a propellant feed line to the engine. A simplified flow schematic of the run-tank system is shown in Figure 4.7.1. The failure mode of critical valves upon loss of electrical or pneumatic actuation supply is indicated in the figure.

The run tank consists of an inner vessel suspended within an outer vessel by a low-heat-transmitting suspension system. The annular space between the inner and outer vessels is evacuated to minimize evaporation loss of the stored liquefied gas. The inner vessel is designed for operation at a maximum working pressure of 65 psia. The outer vessel is designed to withstand external atmospheric pressure under internal vacuum and is equipped with pressure-relief flanges that separate to relieve the pressure in the annular space if it exceeds atmospheric pressure.

Several different types of sensors are provided for measuring the quality of LH_2 in the run tank. The specific sensors that are available to measure the volume or level of LH_2 in the lowest 10% of the run-tank volume are listed in Table 4.7.1.

Figure 4.7.1 - Flow Schematic of Run-Tank System

TABLE 4.7.1

RUN-TANK VOLUME-LEVEL SENSORS

<u>Type</u>	<u>Volume-Level</u>	<u>Indication</u>	<u>Display</u>
Resistance	10% volume	Point	Yes
	10% volume	Point	No
	8% volume	Point	Yes
	6% volume	Point	Yes
	4% volume	Point	Yes
	2% volume	Point	Yes
	1% volume	Point	Yes
Capacitance	100-0% level	Continuous	Yes
	10% volume	Point	Yes
RTT	10% volume (4)	Point	Yes
	5% volume (1)	Point	Yes

The run tank is filled before engine testing by establishing a pressure differential between the LH₂ storage Dewar, V-3801, and the run tank, V-5001. The fluid is transferred through a 6-in. vacuum-jacketed line, with binary control by RSV-128 and RSV-129 (see Figure 4.7.1). When the desired tank level is established, pressure control is provided by PCV's 165 and 180, which may be operated either manually (position demand) or automatically (pressure feedback) to maintain a constant run-tank pressure. The pressure-feedback signal used during automatic control of run-tank pressure is derived from PT-99. If this signal is lost or RSV-186 fails closed while operating in the automatic control mode, a relief system in the pressurization line downstream of PCV-165 protects this portion of the line from overpressurization (i.e., from pressures greater than 230 psig after a failure that introduces 2500-psig gas). The run tank, which is designed to operate at a maximum working pressure of 65 psia, is protected against overpressurization by relief valve RV-66, which is set at 55 psia, and by burst disk BD-11, which is set to rupture at 65 psia. Additional protection against overpressurization is provided by the run-tank control system. When the run tank pressure as indicated by PT-99 exceeds a preset value, the vent valve, PCV-180, is opened and the pressurization valve, PCV-165, is closed. In addition, a red lamp is illuminated on the ASE Console to notify the operator.

After engine testing, the run tank is emptied by reducing the pressure in V-3801 to approximately 5 psig, placing the V-3801 pressurization system in automatic control to maintain this reduced pressure, and opening RSV-128 and RSV-129. When the run-tank liquid level reaches a predetermined value, RSV's 128 and 129 are closed and the remainder of the run-tank LH_2 is vented through RSV-455 and PCV-579. After the tank is emptied of LH_2 , it is depressurized by closing RSV-186 and opening PCV-180.

The propellant feed line immediately downstream of the run tank has a vent valve (PCV-579) and two shutoff valves (RSV-132 and PSV) that are used to establish a double block and bleed on the propellant feed system as protection against inadvertent flow of LH_2 to the engine during shutdown periods. The vent valve also provides for control of LH_2 flow in the propellant feed line during chilldown operations and thus can be used to control the chilldown rate and to prevent overspeed of the turbine flowmeter (FE-14) downstream of RSV-132. A pressure-relief system located between the two shutoff valves prevents the pressure in the propellant feed line from exceeding its maximum working pressure of 100 psig. Helium for purging the run tank, the propellant feed line, and the engine is supplied through RSV-142. A cross-over line from the emergency-cooldown supply system enters the propellant feed line downstream of RSV-132. As discussed in Section 4.8, this line provides an alternate path to the reactor that can be used for introduction of inert coolants if the CSV fails in the closed position at any time before the engine cooldown cycle is completed.

It is also planned to use the run tank to provide coolant to the engine during the initial phases of normal reactor cooldown. Initial studies of a long-term LH_2 pulse cooldown method for the X-engine indicate that the reactor can be pulse-cooled with the run-tank pressure set at 35 psia and the TPCV closed. A typical sequence for this operation is as follows:

During the normal engine shutdown sequence and at a predetermined point on the engine operating map, the control drums are scrambled and the TPCV

is scheduled closed. Coolant flow to the engine is allowed to continue until some lower chamber-temperature limit is achieved, at which time flow is terminated by closing the PSV. Pulse cooling at a flow rate of approximately 5 lb/sec is initiated when the chamber temperature increases to a predetermined value and is terminated by closing the PSV when the chamber temperature decreases to the lower temperature limit. Between pulses, line chill is maintained by venting through the PCV-579. This procedure is continued until either reactor cooldown is complete or switchover to other coolant sources is accomplished by using the emergency cooldown line as the flow path to the reactor.

If the PSV fails to close during pulse cooldown, the PDSV or RSV-132 can be used as alternate shutoff valves. If PCV-579 fails to close, shutdown cooling can be continued by either increasing the run-tank pressure or initiating flow of alternate coolants through the CSV. In the event of a failure of the run-tank pressurization system or a failure to the closed position of one of the two shutoff valves (RSV-132 or PSV) in the propellant feed line, shutdown coolant can be provided by initiating flow of alternate coolants through the CSV. In the event of a failure of the ETC purge system (see Section 4.1) resulting in a loss of capability to purge the compartment during pulsing with LH_2 , or, as discussed in Section 4.2, a change in local wind direction to an on-stand condition, the pulse-cooldown mode with LH_2 can be terminated and inert coolants can be supplied through the cooldown line.

Evaluation of the run-tank system reveals no major defects, omissions, or discrepancies in the design that might affect the safety of X-engine operations. For this reason, and in view of the preceding discussion, it is concluded that from the standpoint of safety the design of the run-tank system is adequate to support the X-engine program.

4.8 XE COOLDOWN SYSTEM

The XE cooldown system is designed to maintain engine-system components within acceptable temperature limits should an engine shutdown be initiated at any time during a test. Three types of engine shutdown can be initiated: normal shutdown, scram shutdown, and emergency shutdown. For each of these shutdown modes and during the subsequent cooldown period, the cooldown system provides appropriate fluids in a controlled manner to the pump discharge line of the engine. In addition to the run-tank system discussed in Section 4.7, the cooldown system consists of a high-pressure liquid-hydrogen Dewar, a liquid-nitrogen Dewar, Dewar pressurization systems, high-pressure storage vessels for helium and gaseous hydrogen, transfer lines and valves, and components to measure and control coolant flow. A simplified flow diagram of the XE cooldown system is shown in Figure 4.8.1.

For the purposes of this discussion, the following definitions apply. Shutdown corresponds to the time interval from the final steady-state condition of the engine power schedule to the time the control drums are rotated to their minimum-reactivity position and the TPCV is closed. Cooldown begins immediately at the end of shutdown and is the process of initiating and controlling the flow of facility fluids for cooling the reactor. Scram corresponds to the rotation of the control drums to their minimum-reactivity position at maximum rate. Pump tailoff connotes controlled shutdown of the turbopump after the reactor has been scrammed, with the TPCV position controlled by the temperature-control loop of the engine-control system.

4.8.1 Engine Shutdown and Cooldown Modes

The normal engine shutdown mode is used to shut down the engine system when a test is completed or when a shutdown is required and abnormal or hazardous conditions do not exist. In this mode, the engine-control system automatically decreases reactor power from the power region

- NOTES
- (1) SYMBOLS USED FOR INDICATING VALVE POSITIONS UPON LOSS OF ELECTRICAL OF PNEUMATIC ACTUATION SUPPLY ARE
(C) CLOSED (O) OPEN
 - (2) ASTERISK (*) INDICATES VALVE IS MECHANICALLY BLOCKED IN OPEN POSITION DURING ENGINE TEST OPERATIONS
 - (3) DOUBLE ASTERISK (**) INDICATES REDUNDANT ELECTRICAL AND/OR ACTUATION SUPPLIES ARE PROVIDED TO MAINTAIN VALVE OPERATIONAL UNDER SINGLE-FAILURE CONDITIONS

Figure 4.8.1 - Flow Schematic of XE Cooldown System

of engine operation at a preselected, negative, temperature ramp rate. When a predetermined temperature is reached, the negative temperature ramp is terminated, the temperature loop is opened, and the drums are rotated full in. Temperature is further decreased by the pump-tailoff controller which positions the TPCV so that chamber temperature is placed on a decreasing temperature ramp. When chamber pressure decreases below a preset level, the pressure-control loop is automatically opened and the TPCV is closed.

The scram shutdown mode is used to protect against malfunctions in the reactor control system, or for other cases where an abnormal condition requires immediate shutdown and the propellant feed system is functioning properly. In this mode, the reactor control drums are scrambled immediately from their operating position and pump tailoff is initiated. When chamber pressure decreases below a preset level, the pressure-control loop is automatically opened and the TPCV is closed.

For both the normal and scram shutdown modes, wherein the cause for shutdown does not involve a loss of propellant flow or require the immediate initiation of an inert coolant, cooldown of the engine continues with LH_2 flow from the run tank in a pulsed manner. The use of the run tank for this mode of cooldown is discussed in Section 4.7. At the option of the Test Director, pulse cooling from the run tank is terminated, and coolant flow to the engine is continued through the cooldown line that feeds into the pump discharge line downstream of the pump-discharge check valve (PDKV). Initially the fluid supplied to the cooldown line is either LH_2 , GH_2 , or He. After the flow of either GH_2 or He (for system warm-up to prevent freezing of nitrogen coolant), LN_2 can be used as required to complete the engine cooldown cycle.

The emergency shutdown mode is used for immediate shutdown and introduction of coolant through the cooldown line when the main propellant flow through the pump discharge line is lost or when initiation of inert coolant

flow is required in a minimum time after shutdown as protection against fire or explosion. Upon receipt of an emergency shutdown signal, the following events occur. The drums are scrambled and the electrical signal to the drum locking pins is removed, causing the drums to be locked when returned to their zero position. The TPCV is commanded to close at its maximum velocity, and the TBV is commanded closed. PSV closure occurs after an electronic time delay that is provided to ensure continuous LH_2 supply to the turbopump until rotation has ceased as a result of closing the TPCV and TBV. Uninterrupted coolant flow is provided to the engine through the cooldown line. Initially, the flow of coolant is controlled by PCV-472 (see Figure 4.8.1). Helium may be introduced into the system through PCV-471 if necessitated by a fire or explosion hazard at any time during the initial cooldown period. The cooldown cycle is completed by pulse cooling with LN_2 in a manner similar to that used for the normal and scram cases.

The emergency cooldown system is operated as follows. Prior to starting an engine power program, the liquid hydrogen line from the high pressure LH_2 Dewar (V-5002) to the cooldown shutoff valve (CSV) is chilled by venting through the cooldown vent valve (CVV) located just upstream of the CSV. The GH_2 - and GHe -pressure control valves, PCV-251 and -471, are placed in manual control and the lines upstream of these valves are pressurized from the storage tank. RSV-875, which is located between the gas branch of the cooldown line and relief valve RV-2974, is opened to provide a low-pressure relief on the system. This is required to maintain the cooldown-line pressure below approximately 500 psig during low-power engine operation to prevent an unacceptable nuclear excursion resulting from LH_2 insertion into the reactor if either PCV-251 or -471 fail to their open position.* During high-power operation, this protection is not required and RSV-875 is closed to allow sufficient pressure for providing gaseous coolants to the engine during emergency shutdown. The LN_2 system is chilled from the LN_2 Dewar (V-3601) to RSV-545 located downstream of PCV-517 and the LN_2 -Dewar pressure control is set in automatic at 250 psig. At the

*Safety Analysis Report for X-Engine Testing, AGC/WANL Report NJD-9 (CRD).

start of the power program, PCV-472 is closed and placed in the automatic cooldown mode, the CVV is closed, and the pressure in V-5002 is increased to approximately 500 psig in automatic control. When the chamber temperature reaches approximately 1100°R, the CSV is opened allowing the cooldown line between PCV-472 and the engine to be pressurized near pump discharge pressure. The line is pressurized through an orificed line that bypasses the CKV. When a predetermined chamber pressure is reached, approximately 200 to 250 psig, RSV-875 is closed and the V-5002 pressure is increased to approximately 1250 psia. Upon appropriate reduction of engine power, the V-5002 pressure is reduced to approximately 500 psig and RSV-875 is again opened.

Initiation of an emergency shutdown by the engine safety system causes PCV-472 to automatically open allowing LH₂ to flow from V-5002 to the engine. The chamber temperature is then automatically programmed down by the PCV-472 controller to 1000°R. Though the flow of GH₂ or GHe may be manually initiated at any point during the cooldown period, normally these gases are not used until approximately 150 sec after shutdown, at which time either GH₂ or GHe is manually introduced into the system to warm up the lines and further cool the engine. Once gaseous flow has been established, PCV-472 is closed and all remaining LH₂ downstream of PCV-472 is vented. After the system warms up, RSV-545 is opened and either PCV-251 or -471 (whichever is being used) is closed allowing LN₂ to flow from V-3601 to the engine. LN₂ is manually controlled as required using PCV-517 to maintain the chamber temperature between 800°R and 1200°R.

4.8.2 Safety Considerations

To protect against loss of capability to provide emergency coolant to the test article under credible malfunction conditions, the cooldown system is designed to satisfy the following criteria.

a. Any single failure in either the electrical power system or the valve actuation systems is not to result in both an emergency shutdown condition and a loss of capability to flow LH_2 to the engine from the high-pressure LH_2 Dewar.

b. Any single failure in either the electrical power system or the valve actuation systems is not to result in both the loss of capability to supply GH_2 and the loss of capability to supply GHe to the cooldown system.

c. Any single failure in either the electrical power system or the valve actuation system is not to result in loss of capability for LN_2 to flow to the engine for cooldown.

The approaches taken to ensure that these criteria are satisfied are discussed below.

4.8.2.1 Remote Shutoff Valves

Each of the remote shutoff valves in the cooldown system is pressure-actuated by a piston that travels in a cylinder. Each piston is biased by a spring that causes the valve to be either open or closed when no pressure is applied. When actuation pressure (GN_2) is applied to the top or bottom of the piston, the valve moves against the spring force to either the closed or open position. Pressure to the valve is controlled by a solenoid valve located in a solenoid-valve box. This solenoid is controlled remotely from the control-point building.

The principal pneumatic supply (GN_2) for the RSV's is from the high-pressure nitrogen tanks in the high-pressure-gas storage area (see Section 4.10). If the main supply fails, the solenoid-valve boxes in each area are served from an emergency source that consists of several high-pressure gas cylinders feeding a common manifold. The emergency supply is initiated via a main supply-pressure sensing switch that energizes the emergency-supply solenoid valve open.

No absolute safeguard can be provided against mechanical failure in the solenoid or the valve proper. However, certain steps can be taken to provide directional failure, such as blocking some valves open or mechanically locating a spring to ensure valve closure. In addition, electrical power can be so distributed that a single electrical failure cannot result in a loss of cooldown-system capability to provide emergency coolant to the engine. Electrical power distribution as it relates to the cooldown system is more fully discussed in Section 4.9, Electrical Power Generation and Distribution System.

The mechanical-failure mode of all critical valves in the cooldown system is indicated in Figure 4.8.1. Certain valves in the system, such as the main block valves in the CH_2 system, fail in a direction that would compromise the operational capability of the cooldown system if the failure were to occur during engine testing. Consequently, these valves are equipped with a mechanical locking device that, when installed, prevents movement of the valve to its normal failure position upon loss of actuation pressure. The valves so equipped are identified by asterisks in Figure 4.8.1.

Several of the binary valves in the cooldown system must be capable of movement to both their open and closed positions during engine testing. Consequently, performance of their functions must be ensured by some form of redundancy. The methods of failure protection for these valves are discussed below.

a. Cooldown Shutoff Valve

The cooldown shutoff valve (CSV) is a normally open-type butterfly valve that is held in the open position by a spring until both an electrical signal and pneumatic pressure are supplied. The valve is closed by applying pressure at one port of the actuator. The valve is opened both by spring load and by pressure applied at a second port of the actuator.

The actuator is pneumatically controlled by two solenoid valves. With no electrical signal, both solenoid valves go to the vent position and the valve goes to its normal (open) position. Closing the valve requires application of 28 vdc, which pressurizes the actuator against the spring load. Application of the voltage to the other solenoid valve applies pressure to assist the spring in opening the valve.

To protect against failure, each solenoid has two independent voltage supplies so that one failure does not cause interruption of electrical power. In addition, redundant valve controls are provided. The valve position is controlled automatically by both the engine control system and the engine safety system and is controlled manually by a switch on the TSE Console.

Finally, if the CSV is closed and later fails to reopen during engine cooldown, an alternate cooldown path for LN_2 between the cooldown line and the pump inlet line is provided through PCV-576 and RSV-721 (see Figure 4.8.1). PCV-576 is a spring-loaded normally-closed valve such that depressurization of the cooldown line is prevented if electrical power or actuation pressure for PCV-576 is lost during engine testing.

b. RSV-545

RSV-545 is the flow shutoff valve in the LN_2 cooldown line. Since this valve must remain closed during engine operations and must open for LN_2 pulse cooling, it is provided both with a redundant actuation gas system that utilizes an independent K-bottle gas supply and with redundant control circuits that are powered from separate rectifier-battery units (see Figure 4.9.2 of Section 4.9). Thus, RSV-545 remains operational after any single failure in the facility actuation gas system or the electrical power system. It should be noted that RSV-545 is also a suitable backup to PCV-517 for the control of fluid to the engine during LN_2 pulse cooling.

c. RSV-107

Since the high pressure Dewar shutoff valve (RSV-107) must be maintained open during engine operating periods and closed at appropriate times after engine shutdown, it is also provided with redundant actuation gas supplies and with redundant control circuits in a manner similar to that employed for RSV-545. Thus, single electrical or actuation system failures will not cause this valve to move to its closed position during critical phases of engine testing.

4.8.2.2 Pressure-Control Valves

Pressure-control valves (PCV) can be positioned from full open to full closed, in accordance with a demand signal. The PCV consists of three main units: (1) a converter that changes an electrical-signal demand into a proportional pressure signal, (2) a valve positioner that receives the pressure signal and translates it into actuation pressure to move the actuator piston and valve stem, and (3) the control valve.

The critical PCV's in the cooldown system are PCV-251, which controls GH_2 flow; PCV-471, which controls GHe flow; PCV-472, which controls LH_2 flow; and PCV-517, which controls the flow of LN_2 . Except for PCV-517, which is pneumatically operated, these valves are controlled by hydraulic actuators. The hydraulic system that serves these valves is provided with individual accumulator systems for each PCV. These accumulators have sufficient reserve capacity for about 6 valve cycles, which is expected to be more than adequate to execute a cooldown operation. Thus, a failure within the hydraulic actuation system cannot critically affect the operation of more than a single valve, and such a single failure does not, in itself, preclude a safe shutdown of the engine. However, if a fire or explosion hazard exists during emergency cooldown, a failure in the hydraulic supply system for PCV-471 could delay the time at which transfer to an inert coolant can be accomplished,

since GH_2 (as opposed to GHe) would have to be used for system warmup before switching to LN_2 .

PCV-517 is designed as a fail-open valve if pneumatic supply pressure to the valve is lost, in which case RSV-545 provides an acceptable backup for the control of LN_2 flow to the engine during cooldown. Thus, a redundant actuation supply for PCV-517 is not required for continued operation of the LN_2 system upon failure of PCV-517.

The PCV controllers receive electrical power from common ± 15 - and ± 24 -vdc power supplies, which are provided with redundant ac power by utilizing power from both the instrument bus and the essential bus. In addition, redundant power supplies and crossover networks are so utilized that redundant dc power is supplied to each controller. The system not only guards against external power failures, but also provides protection against internal diode failures.

4.8.2.3 LN_2 Dewar Pressurization

During LN_2 pulse cooling, continuous pressurization of the LN_2 storage Dewar is required. The primary method of providing this pressurization is with PRV-108 (see Figure 4.8.1). The valve acts essentially as a variable line orifice that changes area by changing the position of a sliding plug that has a hole in it. As the plug is withdrawn, the hole in the valve body is partially closed to decrease the area; in turn, the flow and downstream pressure are decreased. The position of the sliding plug is controlled by the position of a diaphragm in the valve dome. The diaphragm position is controlled by the pressure on the bottom of the diaphragm, which is the downstream line pressure, balanced against the pressure on the top of the diaphragm, which is set by a pressure regulator (loader). The positions of the diaphragm and line plug are remotely controlled from the control-point building by utilizing two solenoids to pressurize or vent the top of the diaphragm (dome). One solenoid admits pressure to the dome and the other permits venting. If power

to the solenoids is lost, the dome of the valve is vented. The downstream pressure forces the diaphragm upward and pulls the plug out to the point where flow through the valve ceases.

If, due to loss of electrical power or actuation gas pressure, PRV-108 fails to its closed position during engine testing, the stored energy in the LN₂-Dewar system is sufficient to maintain adequate Dewar pressurization for accomplishing the LN₂ pulse cooldown cycle. Thus, a backup pressurization system for the LN₂ Dewar is not required. Furthermore, the LN₂-system vent valves (RSV-327, -392, -393 and PCV-754) fail closed so that failure of these valves to their normal position do not compromise use of the system.

4.8.3 Evaluation Summary

The XE cooldown system is designed with the capability to provide coolant to the engine as required for safe termination of engine testing under both normal and credible accident conditions. By appropriate selection of valves and their corresponding failure modes, by use of valve blocks and backup valve-actuation and control systems, and by incorporating suitable system redundancy, the cooldown system is protected against failure as the result of single malfunctions of facility components or subsystems. On this basis, the XE cooldown system is considered adequate from the design safety standpoint to support the XE test program. Evaluation of the capability of the cooldown system to maintain engine test parameters within acceptable limits during cooldown will be documented in the XE-1 Safety Evaluation Report, Phase II*.

*To be issued.

4.9 ELECTRICAL-POWER GENERATION AND DISTRIBUTION SYSTEM

The ETS-1 electrical-power generation and distribution system provides electrical power, as required, to all facility systems and to the test article during both test and nontest periods and under both normal and emergency conditions. Redundancy is incorporated into the system design to ensure a highly reliable source of continuous power during engine test periods and an emergency source of power for safe termination of engine testing under credible accident situations.

Electrical power is supplied to, and distributed from, three separate buses: the utility bus, the essential bus, and the instrument bus. The generation and distribution system is shown schematically in Figures 4.9.1 and 4.9.2. A brief description of this system, its utilization, and the inter-relationship of its major components follows.

4.9.1 Utility-Bus Power and Distribution

The utility-bus power and distribution system supplies power to the ETS-1 complex during nontest periods. During test periods, the utility system supplies facility support items such as motors, fans, and lighting; however, it also provides a backup source of power to the essential bus should other sources of power to this bus fail. This aspect of the system utilization is discussed further in Section 4.9.3.

The utility power system receives power through separate 138-kv transmission lines from Nevada Power Company and Valley Electric Association. The power is stepped down to 69 kv at the Jackass Flats Substation. Should either of these power sources fail, the other is available to supply power to NRDS, though several minutes are required for switching. Power enters the ETS-1 substation at 69 kv and is stepped down to 4160 v by a 250-kva transformer before it is fed to the utility bus through a main

4.9-2

Figure 4.9.1 - ETS-1 Power Generation System

Figure 4.9.2 - ETS-1 Power Distribution System

breaker. This breaker is protected by two overcurrent relays that cause the breaker to open if excessive current flows through the bus. Power is then distributed to loads through five feeder breakers, which are also protected by overcurrent relays. These relays are calibrated to afford selective tripping (tripping nearest the fault). Furthermore, each relay trip circuit is provided with its own dc battery power supply for added reliability.

4.9.2 Instrument-Bus Power and Distribution

The instrument-bus power and distribution system supplies power to loads such as data-acquisition and signal-conditioning equipment, pressure and flow controllers, and vital loads that are sensitive to transient harmonics or voltage fluctuations. During nontest periods, the instrument bus is fed by the utility bus through a tie breaker that is protected by overcurrent relays. During test periods, this breaker is open and power is supplied by two 250-kw diesel generators. The two output breakers from the diesel generators are protected by overcurrent and reverse-power relays. (The reverse-power relays prevent one generator from drawing power from the other if one of the generators malfunctions.) Power from these breakers passes through an input breaker to a 500-kva transformer that steps up the generator output voltage to 4160 v from 480 v. The tripping capability of the input breaker to the transformer is deactivated during test periods because operation of this breaker is not necessary for protection of the instrument bus during test periods, and its failure could result in an unnecessary loss of instrument-bus power. The output voltage of the 500-kva transformer is applied to the instrument bus through an output breaker that is protected by overcurrent relays. Three feeder breakers with protective relays distribute the power to various facility loads.

The two diesel generators operate in parallel. Either generator is capable of assuming the total instrument-bus load if one generator malfunctions. If both generators or their circuit breakers fail, the instrument bus becomes inoperative; however, the capability exists to manually

transfer the instrument-bus load to the essential bus. This transfer can be accomplished remotely from the recorder room of the control-point building and requires only a few seconds.

4.9.3 Essential-Bus Power and Distribution

The essential-bus power and distribution system supplies power to control circuits, vital motor loads, and any load that requires a high degree of reliability but which is not necessarily sensitive to harmonic transients or minor voltage fluctuations. During nontest periods, power is supplied from the utility bus through a tie breaker that is actuated either by operation of overcurrent relays or by concurrent operation of high-speed undervoltage and reverse-power relays. During test periods, power is supplied from three 308-hp diesels, each driving a 150-kw (187.5-kva) generator. Power from the generators to the bus passes through individual output breakers that are protected by overcurrent and reverse-power relays. Power from this bus is routed to the loads through two feeder breakers that are also protected by overcurrent relays. The undervoltage and reverse-power relays, which are used to trip the tie breaker between the utility bus and the essential bus, act to protect the essential bus during test operations if a power failure drops the voltage on the utility bus. Under these conditions the utility bus attempts to draw power from the essential bus, causing the relays to open the breaker. The overcurrent relay protects the utility bus from a similar-type failure affecting the voltage on the essential bus.

Any two of the three diesel generators that supply the essential bus are capable of supplying the essential-bus load during test periods. If, because of some malfunction, two of the three diesel generators are rendered inoperable, manual adjustments can be made so that utility power assumes the total essential-bus load. The possibility that failure of any one diesel generator may cause the other generators to malfunction is virtually eliminated by the use of the reverse-power relays on the circuit breakers.

To ensure that a single failure does not cause loss of power to both the instrument bus and the essential bus, separate fuel-supply lines are provided from the common fuel-storage tank to each of the five diesel generators. Thus, a fuel-line blockage, line rupture, or excessive water content in the line does not result in loss of generator power from more than one diesel. In addition, each of the diesels is provided with a separate day tank. The fuel capability of the day tanks for the two instrument-bus diesels is sufficient for approximately 2-1/2 hr of continuous diesel-engine operation. The fuel capacity of the day tanks for the three essential-bus diesels is sufficient for approximately 8 hr of continuous diesel-engine operation. Thus, even a tank rupture accompanied by total loss of fuel from the main storage tank does not result in concurrent loss of power to both the instrument bus and the essential bus.

4.9.4 28-vdc System

The 28-vdc system, shown schematically in Figure 4.9.2, provides dc power to all binary valves at ETS-1 as well as to certain critical instrumentation and control circuits. It consists of three 400-amp rectifier units that operate from essential-bus power and supply 28-vdc power to the control-point area, the forward control-room area and the test-cell-building area, respectively. Floating on line with the output of each rectifier unit is a 28-v 400-amp-hr battery bank. If the rectifier unit or the essential bus fails, the battery bank automatically assumes the 28-vdc bus load. The battery bank is capable of supplying the required load for periods of time well exceeding that required for engine shutdown in the event of a power-system emergency. Furthermore, the circuitry permits switching of any one rectifier-battery combination to either of the other two system loads.

4.9.5 System Control

Control of the electrical-power generation and distribution system requires a combination of remote and local operations. The diesel

generators cannot be started remotely, but are started locally. 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 control-point building. 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 are synchronized either locally or remotely and are regulated according to voltage, frequency, or load.

The power-control panel in the recorder room of the control-point building is provided with controls and indicators for: (1) the utility tie breaker, (2) the bus tie breakers feeding the essential and instrument buses, (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 also provides indication and control of the three 400-amp rectifiers and their associated battery banks. 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 is closed from the power panel only after the respective rectifier is started. The internal temperatures of the rectifiers, as well as the dc-bus voltages, are displayed on the power panel. The output voltages of the rectifiers are adjusted locally with a potentiometer.

4.9.6 Operating Philosophy

Power for the electrical power system during nontest periods originates from either the Nevada Power Company or the Valley Electric Association. Power is provided to the essential and instrument buses through

tie breakers from the utility bus. The diesel generators are available for backup if commercial power fails.

During test periods, the electrical power system is operated as follows. The utility bus is supplied from one of the two commercial power sources. All breakers on the bus are closed, including the tie breakers. The essential-bus loads are supplied with power from the three diesels and are paralleled to the utility bus through its tie breaker. Operation in this manner affords high reliability by having the diesels carrying the essential loads with commercial power tied in as a backup. In the event of a fault on the commercial power system, the high-speed undervoltage and reverse-power relays (2- to 4-cycle operating time) open the tie breaker protecting the essential bus. The diesel generators see a minimum-load transient because they are already carrying the essential loads. On the other hand, if the diesels fail, commercial power assumes the essential-bus load.

The instrument bus is designed to supply power loads that are sensitive to transients. Because of the nature of these loads (e.g., low power consumption, no large inductive circuits), this bus is divorced from commercial power during testing. If one of the diesel generators fails, its protective circuits remove it from the line, and the running diesel generator supplies the total load. If both diesel generators fail, the instrument bus is manually paralleled back to the utility bus; however, under these conditions there is no high-speed relay to protect the instrument bus if the commercial power faults.

4.9.7 Emergency Shutdown Provisions

The foregoing discussion shows that, during engine test periods, no single failure in the electrical power system can result in the loss of power to more than one bus. Furthermore, should primary power to any

one bus be lost, backup power to that bus is available, either immediately or within a relatively short time after the failure. However, depending on the nature of the failure, it may not be possible in all cases to route the backup power to the critical loads supplied by the failed bus. Consequently, if any one bus fails during engine testing, the required instrumentation and control capability for safe engine shutdown and cooldown must be available; and adequate provisions must be made to ensure that functions that must be performed by the test operators are not unduly impaired.

The minimum facility functions, instrumentation readouts, and control capabilities required for safe emergency shutdown and cooldown of the engine are summarized in Table 4.9.1. Described below are the methods of ensuring adequate power for each of these critical items if a power bus fails during engine testing.

4.9.7.1 Binary-Valve Control

Power from each of the three 28-vdc buses is fed through main feeder breakers to separate distribution panels from which power is then distributed to individual components. This power is used to activate and control all binary valves at ETS-1 as well as to power certain critical instrumentation and control circuits. Thus, a loss of output from any one of these buses results in loss of control over all binary valves and circuits supplied by that bus. Since certain failures within the dc power system can result in component failures that cause automatic initiation of emergency shutdown of the engine, these failures must not also cause simultaneous or sequential loss of 28 v to critical valves in the fluid systems that supply the emergency coolants; i.e., the LH_2 , GH_2 , He, and LN_2 supply systems. It is also highly desirable that the emergency shutdown condition not be accompanied by simultaneous shutdown of the steam-generator system.

TABLE 4.9.1

INSTRUMENTATION AND CONTROL CAPABILITY REQUIRED OF
CRITICAL FACILITY FUNCTIONS DURING EMERGENCY SHUTDOWN AND COOLDOWN

<u>Critical Item</u>	<u>Purpose</u>
1. Control of remote shutoff valves in fluid supply systems	To ensure the availability of sufficient cooldown fluids for the engine and continued operation of the steam-generator system.
2. Flow control of water through the duct cooling system. (Discussed in Section 4.3.)	To ensure that water supply for duct cooling and fire protection is not depleted prior to completion of cooldown period.
3. Control of emergency-cooldown-line pressures.	To provide control of LH ₂ , GH ₂ , GHe, and LN ₂ flow rates through the emergency cooldown system.
4. Indication of engine chamber pressure and temperature	To ensure that critical temperature and pressure limits are not exceeded.
5. Indication of Station 0.5 + 1.0 core temperature.	To ensure that critical temperature limits are not exceeded.
6. Indication of average nozzle torus pressure.	To ensure that the maximum pressure of 1100 psi at the nozzle torus is not exceeded.
7. Indication of GH ₂ and GHe bank pressures.	To indicate quantity of cooldown fluid remaining.
8. Indication of GH ₂ bank pressure, LN ₂ Dewar pressure, and LH ₂ HP Dewar pressure.	To indicate driving pressure for cooldown fluid.
9. Indication of steam-generator output.	To establish requirement for switchover to inert cooling of the engine.
10. Operation of engine safety system.	To ensure that appropriate shutdown actions are taken in the event of a power failure.
11. Control-point lighting.	To ensure adequate illumination of controls for the operating personnel.
12. Ventilation system.	To provide adequate cooling for instrumentation and control systems.

Consequently, to preclude this type of simultaneous loss of power, the distribution of power from the dc power system is routed so that power for critical components that can cause emergency shutdown is supplied from portions of the dc power system other than those used to supply critical valves in the fluid supply systems. (Binary valves at ETS-1 generally require two separate sources of dc power, one to supply the electrical actuation power required for valve operation and the other to supply the control or command signal. Loss of either supply causes the valve to fail.)

The components that result in initiation of emergency or scram shutdown upon loss of their 28-v signal or supply power are:

<u>Component</u>	<u>Shutdown Mode Resulting from Loss of 28-v Signal</u>
Turbine block valve	Emergency shutdown
Propellant shutoff valve	Emergency shutdown
Tank safety valve (RSV-132)	Emergency shutdown
Run-tank vent valve (RSV-390)	Emergency shutdown
Engine control system (ECS)	Emergency shutdown
Engine safety system (ESS)	Scram shutdown
Control-drum amplifiers	Scram shutdown
ECS consoles	Emergency shutdown

Except for the ECS consoles, which derive their power from rectifier-battery unit No. 1, the above components receive their electrical power from rectifier-battery unit No. 3, which is the source of all 28-vdc power in the test-cell-building area. In addition, the control signals required to operate the valves listed above derive their power from rectifier-battery unit No. 1, which supplies the 28-vdc power to the control-point area. Thus, a loss of power from either of these dc buses (i.e., units No. 1 or 3) results in emergency shutdown.

Therefore, the division of dc power to critical engine components and valves has been accomplished at ETS-1 so that the components that can result in emergency shutdown if dc power fails are supplied by different "power sources" from those that supply critical valves in the emergency-cooldown and steam-generator systems. For the purpose of this discussion, power sources are considered to be separate if their power is not derived from the rectifier-battery units through a common main feeder breaker directly downstream of a rectifier-battery unit. For example, consider the power distribution scheme illustrated in Figure 4.9.3. If power required for the operation and control of the run-tank shutoff valve, RSV-132, is derived from rectifier-battery unit No. 1 through feeder breaker No. 1 and from rectifier-battery unit No. 3 through feeder breaker No. 5, power for the high-pressure-Dewar shutoff valve, RSV-107, (through which emergency coolant is provided to the engine upon loss of primary coolant flow from the run tank) is considered to have a separate dc power source from RSV-132 if its power is derived from rectifier-battery unit No. 1 through feeder breaker No. 2 and from rectifier-battery unit No. 3 through feeder breaker No. 6. Figure 4.9.3 shows that a single power failure downstream of any one of the main feeder breakers is isolated automatically by the feeder breaker, and the failure does not affect more than one of the two valves. Furthermore, a failure at any point upstream of the rectifier output breakers is isolated automatically by the output breaker, and power continues to be supplied by the battery units that float on the line. With this distribution scheme, the only type of single failure that can cause both valves to fail is a short circuit in the "hard-wired" line between the rectifier output breakers and the main feeder breakers. Such a failure is considered to have an acceptably low probability of occurrence.

4.9.7.2 Control of Emergency-Cooldown-Line Pressures

The primary source of power for all pressure controllers (PCV's) is derived from a central power supply that receives its ac power from the instrument bus. To ensure that a failure of the instrument

Figure 4.9.3 - Simplified Schematic Illustrating Division of Power for RSV-132 and RSV-107 Utilizing Separate dc Power Sources

bus does not preclude the operation of controllers necessary for emergency cooldown of the engine, an additional power supply for critical valve controllers is installed and connected to the essential bus. The outputs of both the primary supply from the instrument bus and the backup supply from the essential bus are distributed to the critical valve controllers through a conventional crossover network. Both the instrument bus and the essential bus must thus be lost before valve-controller power is interrupted. The critical valve controllers that have been provided with this redundant source of power are: PCV-472 in the high-pressure LH_2 supply system, PCV-251 in the GH_2 supply system, PCV-471 in the helium supply system, and PCV-517 in the LN_2 supply system.

4.9.7.3 Critical Instrumentation Readouts

The critical instrumentation readouts required for emergency cooldown operations and the purpose for each are presented in Table 4.9.1. The methods used to ensure the availability of power for these readouts if an electrical system fails are discussed below and are summarized in Table 4.9.2.

a. Engine Chamber Pressure

Three pressure transducers are used to measure average chamber pressure. Two of these transducers and associated equipment are supplied power from the instrument bus. The remaining transducer and associated equipment are supplied power from the essential bus. The averaging circuits differentiate between transducer failure and power failure to prevent rejection of valid signals. Thus, with all three instrument channels operational, both buses must fail to lose chamber-pressure indication.

TABLE 4.9.2

CRITICAL COOLDOWN PARAMETERS

<u>Parameter</u>	<u>Instrument Bus (Primary)</u>	<u>Essential Bus (Backup)</u>
GH ₂ Bank Pressure	PT-3	PT-587
GHe Bank Pressure	PT-5	PT-586
GN ₂ Bank Pressure	PT-2	PT-1
LH ₂ HP Dewar Pressure	PT-97	PT-101
LN ₂ Dewar Pressure	PT-181	PT-194
Chamber Pressure ⁽¹⁾	PT-148 PT-149	PT-151
Nozzle Torus Pressure	PT-124 ⁽²⁾	PT-891
Chamber Temperature ⁽¹⁾	TE-138 TE-139 TE-140	TE-141 TE-144
Station 0.5 + 1.0 Temperature ⁽¹⁾	TE-601 TE-602 TE-603	TE-611 TE-612 TE-613
Average Cooldown Temperature Chamber Temperature Average Station 0.5 + 1.0 Temperature Average	T-158	T-600
Steam Generator Injection Water	FT-406-1, -2, -3	FCV-423-1, -2, -3
Steam Temperature	TE-159	TE-534

(1) To prevent rejection of valid signals, averaging networks differentiate between transducer failure and power bus failure.

(2) Three additional sensors will be added.

b. Engine Chamber Temperature

Five thermocouples are used to obtain average chamber temperature. Three of these thermocouples and associated equipment are supplied power from the instrument bus. The remaining thermocouples are supplied power from the essential bus. The averaging circuits differentiate between transducer failure and power failure to prevent rejection of valid signals. The averaging circuit is provided with power from the instrument bus.

c. Station 0.5 + 1.0 Temperature

Six thermocouples are used to derive the average temperature at Station 0.5 + 1.0. Three of the thermocouples and associated equipment are assigned to the instrument bus. The other three thermocouples and associated equipment are assigned to the essential bus. The averaging circuits differentiate between transducer failure and power failure to prevent rejection of valid signals. The averaging circuit is provided with power from the essential bus.

d. Nozzle Torus Pressure

All pressure transducers and their associated equipment used to derive average nozzle torus pressure are assigned to the instrument bus. Pressure transducer PT-891, which is located upstream of the CSV in the emergency cooldown line, is assigned to the essential bus. The pressure indication at this location serves as a suitable backup if indication of torus pressure is lost.

e. GH_2 , He, and GN_2 Bank Pressures

Redundant pressure transducers are used to measure pressures of the GH_2 , He, and GN_2 banks. One of the transducers on

each bank is assigned to the instrument bus and one is assigned to the essential bus.

f. LN_2 and High-Pressure LH_2 Dewar Pressures

The same type of redundancy is provided here as described above for the gas bank pressures. Again, one of the transducers on each Dewar is assigned to the instrument bus and one is assigned to the essential bus.

g. Steam-Generator Output

During shutdowns and cooldowns, the differential pressure measured across the water-supply venturi and the steam temperature measured for each steam-generator module are sufficient critical data for determining system operation. The differential-pressure parameters (FT-406-1, FT-406-2, and FT-406-3) are assigned to the instrument bus. To provide backup information, the associated flow-control-valve positions are assigned to the essential bus. These position indications are from FCV-423-1, FCV-423-2, and FCV-423-3. Two redundant temperature transducers for measuring steam temperature are located in the steam header. One of these transducers and associated equipment are assigned to the instrument bus, and the other is assigned to the essential bus.

4.9.7.4 Operation of the Engine Safety System

The engine safety system that provides the signals to the engine for scram and emergency shutdown is powered by 28 v from rectifier-battery unit No. 3. This unit also supplies power to the engine binary valves. Consequently, since a loss of dc power to the engine results in essentially the same actions as are commanded by the engine safety system for emergency shutdown, concurrent loss of dc power to the engine and the

engine safety system does not, in itself, compromise a safe emergency shutdown. If, on the other hand, the engine safety system were supplied from a different dc bus than supplies the engine, a failure of this bus (which would cause a scram shutdown) followed by a condition warranting emergency shutdown could jeopardize the safety of the engine through inability of the safety system to provide the required emergency shutdown signals.

4.9.7.5 Control-Point Lighting

Power for control-point lighting is supplied from the essential bus. If this power is lost, emergency battery-powered lights automatically switch on. These emergency lights provide sufficient illumination for test personnel to continue with test operations.

4.9.7.6 Ventilation System

Ventilation fans that circulate air for cooling critical instrumentation and controls needed during emergency shutdown are provided with power from the essential bus. The remaining less-critical components of the ventilation system are provided with power from the utility bus. (See Section 4.15.)

4.9.8 Evaluation Summary

The electrical-power generation and distribution system provides the necessary redundancy to ensure a highly reliable source of continuous power during engine operating periods and an emergency source of power for the safe termination of engine testing under all credible accident situations. In addition to supplying redundant source power to each of the main distribution points, protective relays that afford selective tripping are provided to isolate faults in the system and thus minimize the spread of component failures due to loss of electrical power. Though single failures

in the power system can result in emergency shutdown of the engine, the redundant features of the system have been so utilized that no single failure can compromise safe termination of engine test operations. On this basis, the electrical-power generation and distribution system at ETS-1 is considered adequate from the safety standpoint to support the X-engine test program.

4.10 FACILITY ACTUATION GAS SYSTEM

The facility actuation gas system supplies GN_2 for actuation of all pneumatically operated binary valves in the facility, and GN_2 or GHe for all pressure regulators in the facility that are equipped with remote loaders. Engine valves are supplied by a separate actuation system (see Section 4.5). The facility actuation gas system provides regulated gas to eight solenoid-valve boxes (SVB's) from which the gas is further distributed to individual valves. Each of the gas supplies originates from the facility gas-storage tanks and is filtered and regulated in pressure before entering the valve boxes. A simplified flow schematic of the facility actuation gas system is shown in Figure 4.10.1. The pressure settings for pressure regulators and relief valves are indicated on the figure.

In the event of failure of the main actuation gas supplies, the solenoid valve boxes in each area are served with an emergency supply, which consists of several high-pressure gas cylinders (K-bottles) feeding a common manifold. The emergency supply is initiated via a main-supply pressure-sensing switch that energizes the emergency-supply solenoid "open."

Though emergency actuation-gas supplies are provided to each solenoid-valve box, one or more of the following techniques are used to provide additional protection to the test article and critical facility systems and components against loss of valve-actuation pressure during engine test operations: (1) valves are designed to fail in a safe direction upon loss of actuation pressure, (2) valve blocks are used to prevent valve movement to an unsafe position, and (3) redundant valve-actuation supply systems are provided. Examples of these techniques to protect against failure of critical valves are discussed in Section 4.8, XE Emergency Cooldown System.

Figure 4.10.1 - Simplified Flow Schematic of Facility Actuation Gas System

4.11 RADIATION MONITORING SYSTEM

The radiation monitoring system comprises fifteen gamma detectors, two neutron detectors, and three airborne particulate-gas monitors, with appurtenances for continuous remote monitoring of the environmental radiation background during both engine operation and shutdown periods. The detector units are strategically located throughout the ETS-1 complex above and below ground in the areas indicated by Figure 4.11.1. The ranges of detection of the radiation monitors are given in Table 4.11.1.

Alarm outputs from the gamma detectors and airborne particulate-gas monitors are interconnected with the area surveillance and warning system, as described in Section 4.14. These output signals activate local audible and visual alarms to alert personnel to evacuate the immediate area when abnormal radiation levels exist. In addition, audible and visual alarms are annunciated at the LSE Console, and a visual alarm is annunciated on the safety-system graphic-display panel to aid the Lead Safety Engineer in immediate identification of the affected area. An alarm-acknowledgment capability is provided at the LSE Console.

Outputs of the gamma detectors and airborne particulate-gas monitors are not connected to area visual (door lights) and audible (Klaxon or siren) alarms because it is highly improbable that any abnormal radiation hazard could arise that would necessitate area-wide evacuation of personnel, except for the radiation hazard associated with accidental criticality, which is covered separately by the criticality monitoring system described in Section 4.12 of this report. Certain aboveground detectors, as identified in Table 4.14.1 of Section 4.14, automatically activate area beacons because these beacons alert personnel outside the boundaries of the affected area not to enter the area.

The outputs of the two neutron detectors (N_1 and N_2), located on the shadow-shield wall, are not interconnected with the area surveillance and

TABLE 4.11.1

RANGES OF RADIATION DETECTORS

<u>Detector</u>	<u>Range</u>
<u>Gamma Detectors</u>	
Below Ground:	
A-2U, 4U, 6U, 8U, 9U, 10U	$10^{-1} - 10^2$ mr/hr
Above Ground:	
A-1, 3, 5, 7, 11, 12, 15	$10^0 - 10^3$ mr/hr
A-13, 14	$10^0 - 10^6$ r/hr
<u>Neutron Detectors</u>	
N-1, 2	$10^1 - 10^5$ cpm ($10^3 - 10^7$ n/cm ² -sec)
<u>Particulate and Gas Monitors</u>	
P-1U, 2U, 3U	
Particulate	$10^{-11} - 10^{-6}$ μ c/cc
Gas	$10^{-6} - 10^{-2}$ μ c/cc

warning system. These detectors are designed to aid in determining neutron dose to personnel in the event of an accidental reactor criticality and to measure the environmental neutron flux during engine test operations. Separate neutron detectors of the criticality monitoring system are used to activate alarms in the event of inadvertent criticality.

The detectors of the radiation monitoring system further serve to provide remote indication of radiation intensities at facility locations in advance of personnel re-entry. These indications provide a backup to measurements taken with portable instruments by rad-safe personnel. Readout meters and recorders indicating the intensities measured by the radiation-monitoring-system detectors are provided at the LSE Console for use by the Lead Safety Engineer in coordinating personnel re-entry to radiation areas. Local readouts are also provided at the detector units.

The radiation monitoring system, as described above, fulfills all of the radiation monitoring requirements for such a system as identified by the ETS-1 Personnel Safety Control Plan given in Appendix A.

4.12 CRITICALITY MONITORING SYSTEM

The criticality monitoring system provides continuous monitoring to detect an accidental criticality of the nuclear engine while it is at the test stand. This system, disarmed during engine testing, is capable of detecting an accidental criticality with and without the engine side shields in position and before and after engine operation.

The criticality monitoring system is interfaced with the area surveillance and warning system (see Section 4.14) to immediately warn personnel of an accidental criticality condition. Area audible and visual alarms are automatically energized upon activation of the criticality monitoring system. As indicated in Section 4.14, in order that personnel can clearly distinguish accidental criticality from other hazards, Klaxons are used as the area audible alarm and all three area beacons automatically turn to red. Thus, personnel are immediately alerted to evacuate to below-ground protected areas. Visual and audible alarms and meter readouts are provided at the LSE Console in the control-point building. Alarm-acknowledgement capability is also provided at this console.

The criticality monitoring system comprises three identical neutron-monitoring channels. Each channel consists of a highly sensitive BF_3 thermal-neutron detector ($40 \text{ cps/n/cm}^2\text{-sec}$) with preamplifier, scaler, timer, high-voltage supply, linear count-rate circuit, and meter indication. The detectors are located on the hot side of the shadow-shield wall approximately 22 ft from the engine pressure vessel. The detectors have a flux-detection range of 0.025 to $2.5 \times 10^3 \text{ n/cm}^2\text{-sec}$. The alarm setting is adjustable over this detector flux range. Because of their location and sensitivity, the detectors are capable of sensing a nuclear excursion in the power range of 0.0016 to 160 w without the side shields in position around the engine. With the engine shields in position, the neutron flux is attenuated by a factor of approximately 10^4 ; thus, for this case, the detector sensing range for a nuclear excursion is 16 w to 1.6 Mw.

The ETS-1 Personnel Safety Control Plan (Appendix A) states that the capability of criticality monitors shall be based on appropriate criteria established by 10 CFR 70.24; i.e., the monitoring system shall energize the alarm system when the radiation level resulting from a nuclear excursion is 300 rem/hr at a distance of 1 ft from the source of the radiation. When applied to ETS-1 operations, this criterion is interpreted as 1 ft from the reactor pressure vessel when the side shields are not in place, and 1 ft from the outside surface of the side shields when the shields are in position around the engine. On the basis of the sensitivity range of the neutron detectors discussed above, the monitoring system meets the 300-rem/hr criterion with and without the side shields in place.

Pertinent reliability features of the criticality monitoring system include two-out-of-three neutron-channel alarm logic to minimize false alarms, and automatic switchover to battery power (28 vdc) in the event of loss of main-line power. Failure of any one neutron channel does not interfere with continued operation of the remaining channels. Continuity lights are provided to serve as failure indicators for each channel.

4.13 FIRE-PROTECTION SYSTEM

The ETS-1 fire-protection system is designed to protect facility structures and equipment from thermal radiation heating produced either by the engine exhaust plume during normal test operation or by fire under accident conditions. To do this effectively, the system provides for rapid detection, automatic action, and application of water with minimum time lag at densities up to 1 gpm per square foot of surface area.

A plot plan of the ETS-1 area showing the location of the principal components of the fire-protection system is given in Figure 4.13.1.

4.13.1 Zone Coverage

Coverage by the system is divided into three principal areas: (1) the test-stand area, including the test-stand substructure and superstructure, the high-pressure LH_2 Dewar, and the steam-generator system; (2) the fluid-storage area, including the LH_2 storage Dewar and the high-pressure gas-storage bottles; and (3) the fill-station area, including the truck unloading station, the propane storage vessel, and the propane vaporizer.

Water deluge flooding within these areas is further divided into zones where overheating might occur and where potential leakage of combustible gases and liquids from the piping or storage system poses a substantial fire hazard. Zones 1 through 14 are in the test-stand area; zones 15 through 20 are in the fluid-storage area; and zones 21 and 22 are in the fill-station area.

Water is dispersed through a number of high-velocity center-jet spray nozzles located in each zone so as to blanket all structural and component surfaces with a continuous deluge of water. Table 4.13.1 identifies the specific zone locations. This table shows that certain zones

Figure 4.13.1 - ETS-1 Fire-Protection-System Plot Plan

TABLE 4.13.1

FIRE PROTECTION ZONE DESIGNATIONS

AREA 1 - TEST STAND AREA

Zone 1 - Test stand structure and process area under test stand superstructure between elevations 3810 and 3849 feet.

Zone 2 - The bottom of run tank, run tank outlet piping, test stand aluminum superstructure, upper side of top shield, process piping, and instrumentation leads, between elevations 3849 and 3866 feet.

Zone 3 - The sides of run tank and aluminum test stand superstructure between elevations 3866 and 3886 feet.

Zone 6 - The sides of run tank and aluminum test stand superstructure between elevations 3886 and 3901 feet.

Zone 7 - The top of run tank, piping to the top of run tank and aluminum superstructure between elevations 3901 and 3916 feet.

Zone 8 - The bottom 20 feet of flare stack, relief valve manifold, control valve manifold, piping, and equipment above top platform at elevation 3916 feet.

Zone 9 - Includes the horizontal piping valve manifold and vertical piping between elevations 3840 and 3916 feet; the platforms, stairways, and elevator; the process valve manifold area at elevation 3810 feet; vessels V-5002 and V-5003 and associated piping; and the instrumentation and control terminal box structure, and terminal boxes and ducts mounted on the concrete shield wall.

Zone 10 - The area surrounding the steam generator, including valving and piping adjacent to the steam generator building.

Zones 4, 5, 11, 12, 13 and 14 - For future expansion or spares.

AREA 2 - STORAGE AREA

Zone 15 - The 250,000 gallon capacity liquid hydrogen storage Dewar, V-3801, and associated piping manifolds adjacent thereto.

Table 4.13.1 (cont.)

AREA 2 - STORAGE AREA (cont.)

Zone 17 - Protection of the piping connections to the high pressure gas vessels and for coverage of all the piping and valve manifolds between the vessels and the radiation shield wall.

Zones 16, 18, 19 and 20 - Spares.

AREA 3 - FILL STATION AREA

Zones 21 and 22 - Zone 21 covers the truck unloading station and Zone 22 covers the propane storage vessel V-3401 and the propane vaporizer VR-3401, including piping manifolds at these facilities. Fire protection for the truck unloading station consists of a fixed-spray system covering the area between the concrete safety wall and the truck bumpers and extends the entire length of the safety wall. A separate fixed-spray system is provided for the propane storage vessel V-3401 and propane vaporizer VR-3401 and the piping manifolds at each of these facilities.

are not presently activated but are available for future expansion of the system. Figure 4.13.2 shows the locations of the various zones in the test-stand area.

4.13.2 Water Distribution

A simplified flow schematic of the water distribution system for the ETS-1 fire-protection system is given in Figure 4.13.3. This schematic shows the water storage tanks, main piping, headers, valves, and valve pits through which water is distributed to each zone.

The water supply for Areas 1 and 2 is provided by the 2-1/2-million-gallon demineralized-process-water storage tank that also supplies the process water for the steam generators, exhaust duct, and engine-compartment shields (see Section 4.3). An additional 250,000 gal is available from the stored capacity of the 42-in. supply line connected to the storage tank. The process-water supply for fire protection is gravity-fed to valve pits in the test-stand area and the fluid-storage area (valve pits No. 1 and 2). These valve pits are provided with gate valves, subheaders, remote shutoff valves, and solenoid-operated deluge valves for controlling the flow of water to each zone. Strainers, which can be flushed during full flow, are provided for removing solids that might obstruct the spray nozzles. Water from the deluge valves feeds into each zone feed main, which in turn supplies the spray nozzles. Low-point drains with drain valves are provided in the pits for drainage of water from both the zone and actuation water-line piping.

The actuation supply for both the RSV's and the deluge valves are taken off the main area headers. The actuation lines feeding the deluge valves are at line pressure, whereas pressure in the lines to the RSV valves is reduced to 70 to 80 psig. Pressure-relief valves set at 90 psig protect the RSV actuation cylinders which have a 100-psig maximum operating pressure.

Figure 4.13.2 - Test-Stand Deluge System

Figure 4.13.3 - Water Flow Schematic for Fire-Protection System

To ensure the availability of deluge water within a minimum time period after system actuation, each zone riser can be primed to the high point of its vertical run, where a "tell-tale" valve is installed to indicate a fully primed system. To protect against freezing, all above-ground piping that requires priming is insulated and heat-traced.

Deluge water for zones in Area 3 is supplied by the 150,000-gal utility-water storage tank. Water is gravity-fed from the tank to valve pit No. 3, which has a valve arrangement and safety features similar to those provided for valve pits No. 1 and 2. The utility-water storage tank also supplies water to seven fire hydrants for use in suppressing fires in areas not covered by the deluge system.

4.13.3 Water Utilization

The fire protection system for Areas 1 and 2 is designed to deliver water at a pressure of 123 psi with full demand on the process water system (including flow to steam generators, exhaust duct, and engine compartment shields). This includes all present flow plus estimated future flow for fire protection. Flow tests show that a static pressure of 210 psig is maintained in the pipe chase with full process water demand. During fire protection system checkout, pressures in excess of 200 psig have occurred. These tests indicate fire protection system design pressures can be maintained or exceeded during all test and nontest conditions. Line pressure on utility water piping is 90 psig. Flow testing and line pressures discussed above for both process and utility water for fire protection, meet the applicable criteria of NBFU No. 15.*

*Standard of the National Board of Fire Underwriters for Water Spray Systems for Fire Protection, NBFU No. 15.

Design water flow rates for all active zones of the fire protection system are summarized in Table 4.13.2. For the zones supplied with process water (i.e., zones 1 through 17), the total design flow rate is approximately 15,000 gpm. Thus, since 30 min of deluge protection in the event of a major fire appears to be a reasonable time requirement based on the standards of NBFU No. 15, a minimum quantity of approximately 450,000 gal of process water is allotted for fire protection reserve during engine test operations and at all other times when the run tank contains liquid hydrogen. A minimum of 50,000 gal is maintained in the process water storage tank for fire protection reserve for Area 3. This provides for approximately 60 min of deluge protection at design flow rates.

The water discharge rates into each zone have also been considered in terms of the surface areas that require protection. For example, utilizing surface areas of approximately 3.4×10^3 sq ft for the LH₂ run tank and 6.4×10^3 sq ft for the LH₂ storage Dewar, and assuming uniform spray coverage, the design flow rates given in Table 4.13.2 result in water application densities on the surfaces of these vessels in the range of 0.65 to 1.25 gpm/sq ft. These values are consistent with the applicable criteria of NBFU No. 13* and No. 15. Photographs showing the deluge system in operation at both the test stand and the LH₂ storage Dewar are presented as Figures 4.13.4 and 4.13.5, respectively.

4.13.4 Fire Detection, Actuation and Supervisory Provisions

The fire-protection system has both manual and automatic actuation capability. The deluge valves that control the flow of water to each zone are actuated automatically by thermopneumatic rate-of-temperature-change equipment. Compared with fixed-temperature detectors, the detection signals from these heat-actuated devices, or HAD's, are not delayed until air

*Standard of the National Board of Fire Underwriters for Installation of Sprinkler Systems, NBFU No. 13.

TABLE 4.13.2

FIRE PROTECTION SYSTEM FLOW RATES

<u>ZONE</u>	<u>NO. OF NOZZLES</u>	<u>NO. OF HAD's*</u>	<u>DESIGN FLOW RATE, gpm</u>
1	102	8	1,763
2	120	8	1,736
3	112	8	1,802
6	39	8	1,018
7	31	12	652
8	33	12	522
9	121	22	2,489
10	16	6	246
15	175	31	3,994
17	32	13	760
21	12	7	307
22	29	10	532
Totals:	<u>822</u>	<u>145</u>	<u>15,821</u>

*Heat-actuated devices

Figure 4.13.4 - Test-Stand Deluge During System Activation Tests

Figure 4.13.5 - LH₂ Storage-Dewar Deluge During System Activation Tests

temperature reaches a certain preset value; instead signal indication is provided as soon as the rate-of-temperature-change is faster than normal for the environment. When an abnormal rise occurs, the pressure of expanding or contracting air through a pneumatic tubing system acts against a sensitive diaphragm, which in turn trips a relay for a solenoid valve that controls the operation of the deluge valve. This relay can be tripped by an increase or a decrease in the normal tube pressure (24 oz), so that the fire protection system fails safe in the event of accidental breakage of any portion of the detection equipment. The number of HAD's located in each of the fire protection zones are given in Table 4.13.2.

Manual capability for actuation and reset of the fire-protection system is provided at local control panels in each of the three fire protection areas and at remote control and annunciator panels on the LSE Console in the control room. By depressing the zone deluge switch at one of these locations, 28 vdc power on the deluge-valve solenoid is removed, and the deluge valve is opened by water pressure in the water actuation system.

After the system (zone) deluge has been started, there are two ways to stop it. Depressing the reset switch energizes the deluge solenoid, closing the deluge valve. If the condition (fire) still exists, after the reset switch button is released the deluge valve is again opened by removal of 28 vdc from the solenoid. Failure of a system to reset indicates that a fire still exists or that the relay has failed to relatch. The deluge can also be stopped by closing the RSV (remote shutoff valve) for that zone. The RSV is not closed until it is visually determined that fire does not exist.

The annunciator and the control panel at the LSE Console in the control point building have additional supervisory and signaling provisions that are incorporated with the area surveillance and warning system discussed in Section 4.14. Activation of a deluge system, whether by manual or automatic means, energizes a blinking red light and audible alarm for warning

to the LSE Console operator (a signal is also transmitted to the NRDS fire station). Acknowledgement of this signal changes the blinking red light to steady red, a condition maintained for approximately 3 min. after which the light returns to blinking if the system has not been reset or if the condition has not been cleared. Red and green annunciator lights are also provided to indicate open and closed positions of the remote shutoff valves. Visual indications of feed water pressure, gate valve positions, and 28 vdc power are also provided.

The fire-protection system is also integrated with the area surveillance and warning system to alert all personnel at ETS-1 to a fire condition and direct these personnel to a safe environment. Activation of a water deluge system in any zone automatically energizes area sirens, beacons, and door lights. As discussed in Section 4.14, these visual and audible alarms can also be energized manually, as required, from the LSE Console.

A remote readout indicating the water level of the demineralized water storage tank is provided at the LFE Console in the control-point building. This feature indicates to control point personnel when additional demineralized water is needed to maintain minimum supply level in the storage tank.

The preceding supervisory and signaling provisions meet or exceed standard requirements outlined in NBFU No. 13, 15, and 72.* In addition, the audible and visual alarm devices for warning personnel fulfill all applicable requirements of the ETS-1 Personnel Safety Control Plan (Appendix A).

*Standard of the National Board of Fire Underwriters for Proprietary, Auxiliary and Local Protective Signaling Systems, NBFU No. 72.

4.13.5 Electrical Power Supplies

Electrical power for the fire-protection system is provided by 28 vdc power fed from the essential bus through three 400 amp rectifiers. The essential bus is fed power from the utility bus and, during periods of testing, is supplemented by three diesel generators synchronized with the commercial power source. If these ac sources (rectifiers or ac sources supplying the rectifiers) fail, the dc system load demand is met by three 400 amp-hr batteries hard-wired on the dc buses.

Failure of dc power to a fire-protection zone causes deluge in that zone. As already indicated, this is due to removal of 28 vdc from the deluge solenoid which causes the deluge valve to open. Design of electrical power circuitry for the fire-protection system fulfills applicable requirements of NBFU No. 72.

4.13.6 TSER CO₂ System

The test stand equipment room (TSER) contains considerable mechanical and electrical equipment used for the operation and maintenance of the test stand. Equipment in this area which is particularly vulnerable to fire includes: the cable runs, termination and control distribution boxes, the hydraulic system for operating the eutectic-seal trough of the ETC, and vacuum pump VP-5001. Since damage by fire to this equipment could seriously affect test operations and since the area will be unmanned during test periods, an automatic fire suppression system is installed to protect the critical equipment in this area. The system is capable of providing CO₂ deluge spray at full capacity for ten minutes. The system is automatically activated by area sensors and can be manually activated by controls at the LSE Console.

4.13.7 Evaluation Summary

Since the ETS-1 facility is constructed primarily of noncombustible materials, the main sources of potential fire are hydrogen and other inflammable fluids stored and used in the facility. For this reason, the primary purpose of the fire-protection system is to safeguard facility structures and equipment from the intense combustion heat of one of these fluids. Protection is provided by the use throughout the facility of high-velocity water spray nozzles that discharge water on vulnerable structural components, storage vessels, and equipment at high application densities. All areas within the facility requiring such protection are adequately covered. Other features of the fire-protection system that relate to the safety of its design and operation are summarized below.

To minimize the time between initiation of a fire and the actuation of the deluge systems, the valves that control the flow of water to each zone are actuated automatically by thermopneumatic rate-of-temperature-change equipment. Furthermore, to assure the availability of deluge water in a minimum time following system actuation, each zone riser can be primed to the high point of its vertical run. Sufficient water for fire protection is assured at all times by maintaining a minimum level in the water storage tanks.

Other features of the system which improve its overall safety and reliability are:

- a. Strainers are located in the main feeder lines to remove solids that could obstruct the spray nozzles.

- b. Visual indications of feed water pressure, gate valve positions, and 28 vdc power are provided at the LSE Console.

c. Local control panels with capability for manual actuation and reset are located in each of the three fire protection areas.

d. A failure in either the detection system or the electrical supplies for the deluge valves causes actuation of the system. A complete loss of electrical power causes all deluge and shutoff valves to fail open.

Finally, the supervisory and signaling provisions of the fire-protection system conform with applicable requirements and standards of the National Board of Fire Underwriters. In addition, the alarm devices fulfill all of the applicable requirements of the ETS-1 Personnel Safety Control Plan, Appendix A.

4.14 AREA SURVEILLANCE AND WARNING SYSTEM

The area surveillance and warning system consists of audible and visual alarms strategically located throughout the ETS-1 complex. The system is designed to alert personnel to hazards associated with either normal or emergency conditions and to guide personnel to a safe environment.

The system is activated automatically by sensor outputs of the fire protection, oxygen detection, combustible gas detection, radiation monitoring, and criticality monitoring systems when unsafe conditions are detected. The capability for manual activation of the area surveillance and warning system includes emergency switches at six above-ground locations and at the safety console. These are for use if a hazardous condition not detected by the sensors is discovered. Table 4.14.1 identifies the audible and visual alarm logic used by the system when it is activated by the various hazard sensors and emergency switches. Table 4.14.2 identifies the location of hazard sensors, emergency switches, and tunnel door lights. The locations of the emergency switches and the audible and visual alarms (as shown by the LSE safety graphic display) are shown in Figure 4.14.1.

Manual activation of the area surveillance and warning system is also utilized to alert personnel of exclusion areas during countdown operations, system checkouts, or other normal operating periods when exclusion areas or control of personnel access are required.

The area surveillance and warning system incorporates all of the necessary features of design to satisfy the basic safety principles defined in the ETS-1 Personnel Safety Control Plan (Appendix A). These principles, together with a brief description of the system design features that show how these principles are satisfied, are summarized below:

TABLE 4.14.1 - - ASWS ALARM LOGIC

ACTION STATION	SIREN	KLAXON	BEACONS				LSE CONSOLE		LOCAL SIGNAL		DOOR LIGHTS	NRDS FIRE DEPT
			TEST STAND	FILL STA.	CONT. POINT	SAFETY GRAPHIC	AUD.	VIS.	AUD.	VIS.		
A - 2U, 4U, 6U, 7, 8U, 9U, 10U, 13, 14, 15						Red	Yes	Yes	Yes	Yes		
A - 1, 3			Yel.	Yel.	Red	Red	Yes	Yes	Yes	Yes		
A - 5			Yel.	Red	Yel.	Red	Yes	Yes	Yes	Yes		
A - 7, 11, 12			Red	Yel.	Yel.	Red	Yes	Yes	Yes	Yes		
G - 1U, 2U, 3U P - 1U, 2U, 3U						Red	Yes	Yes	Yes	Yes		
CG - 1,	Yes		Red	Yel.	Yel.	Red	Yes	Yes			Note (2)	
CG - 5, 6	Yes		Yel.	Red	Yel.	Red	Yes	Yes			Note (2)	Yes
CG - 7, 8						Red	Yes	FER*				
CG - 10U	Yes		Red	Yel.	Yel.	Red	Yes	Yes			Note (3)	
O ₂ - 1, 8						Red	Yes	FER*				
O ₂ - 2, 12U						Red	Yes	Yes	Yes			
O ₂ - 11						Red	Yes	Yes	Yes	Yes		
SW - 1, 2, 3	Yes		Red	Yel.	Yel.	Red	Yes	Yes			Note (2)	
SW - 4, 5, 6	Yes		Yel.	Red	Yel.	Red	Yes	Yes			Note (2)	
Critically Alarm System		Yes	Red	Red	Red	Red	Yes	Yes			Note (2)	Yes
FPS Deluge Zones - 1, 2, 3, 6, 7, 8, 9, 10	Yes		Red	Yel.	Yel.		Yes	Yes			Note (2)	Yes
FPS Deluge Zones - 15, 17, 21, 22	Yes		Yel.	Red	Yel.		Yes	Yes			Note (2)	Yes
CG - 13							Yes	Yes				

*Facility Engineer Right Console

- NOTES: (1) A blank in the table indicates the detector cannot affect the condition or the status of warning devices.
 (2) Lights at locations 8 and 9 turn green. Outside lights at locations 1 through 7 turn green. Inside lights at locations 1 through 7 turn red. (Table 4.14.2 shows door light locations).
 (3) Same as for note (2) except that door light at location 9 turns red.

TABLE 4.14.2
LOCATION KEY FOR ALARM LOGIC CHART

DOOR LIGHT LOCATIONS

1	Main tunnel exit/entrance at control point building.
2	Side tunnel exit/entrance at control point.
3	Tunnel exit/entrance at utility equipment building.
4	Tunnel exit/entrance at fill station.
5	Tunnel exit/entrance at gas storage area.
6	Tunnel exit/entrance at LH ₂ Dewar.
7	Tunnel exit/entrance at test cell building.
8	Tunnel entrance from test stand building.
9	Entrance to test stand building on stairway.

REMOTE AREA GAMMA MONITORS

A-1	Outside main entrance to tunnel.
A-2U	In tunnel at control point building.
A-3	In utility equipment building.
A-4U	In tunnel near bend.
A-5	Inside mechanical equipment room at fill station building.
A-6U	In tunnel outside forward control room.
A-7	On test stand at level of top of shadow shield.
A-8U	In mechanical and electrical equipment room of test cell building.
A-9U	In electronics room of the test cell building.
A-10U	In test stand building.
A-11	At northeast end of the shadow shield.
A-12	At southwest end of the shadow shield.
A-13	On test stand at head of stairs.
A-14	On test stand above duct vault door.
A-15	At bottom of stairs outside of exhaust duct vault.

Table 4.14.2 (cont.)

PARTICULATE AND GAS MONITORS

P-1U	Near air intake filters in utility equipment building (air to control point building, lower level fill station building, and test cell building).
P-2U	Near air intake filters in utility equipment building (air to tunnel).
P-3U	Inside test stand building.

COMBUSTIBLE GAS DETECTORS

CG-1	Inside steam generator enclosure (C_3H_8).
CG-5	Inside valve house in gas storage area (H_2).
CG-6	In LH_2 Dewar revetment area (H_2).
CG-7	On top of test stand inside base of flare stack (H_2).
CG-8	In line between check valve and LH_2 storage flare stack (H_2).
GC-10U	Inside test stand building (one each H_2 and C_3H_8).
CG-13	Air intake for control point building in utility equipment building (C_3H_8).

OXYGEN DETECTORS

O_2 -1	On top of test stand in base of flare stack.
O_2 -2	In steam generator enclosure.
O_2 -8	In line between check valve and LH_2 storage flare stack.
O_2 -11	In high pressure gas storage building.
O_2 -12U	Inside test stand building.

EMERGENCY SWITCHES

SW-1	At top of the test stand near elevator.
SW-2	At intermediate level on test stand near stairs.
SW-3	Between elevator and shadow shield at ground level.
SW-4	At tunnel entrance to LH_2 Dewar area.
SW-5	At tunnel entrance to valve house in gas storage area.
SW-6	On outside north wall of compressor room of fill station building.

Figure 4.14.1 - Location Plan for ASWS Audible and Visual Alarms

a. Control of Personnel Through a Centralized Location

Outputs from visual and audible alarms are transmitted to the LSE Console in the control point building for acknowledgement. In addition, alarm signals are transmitted to the NRDS fire department in the event of high hydrogen concentrations in the gas or LH_2 storage areas, activation of the fire protection deluge system, or activation of the criticality alarm system. Visual alarm signals and door-closure indications are also provided by the safety system graphic display panel. Manual controls are provided at the LSE Console for activating visual and audible alarms and the site traffic lights. From this console the lead safety engineer can assist other key personnel at the control point in coordinating the location and movement of personnel.

b. Continuous Awareness by Personnel of Access Restrictions to Areas During Normal Operations and the Location of Hazardous Conditions during Emergencies

This system consists of audible area klaxons and sirens, and visual tunnel door lights, area beacons, and site traffic lights. Local audible and visual alarms are also provided as necessary. The system can be placed in continuous operation, with capability for automatic and manual activation of these audible and visual alarms. Audible alarms immediately alert personnel of a hazardous condition. Rotating area beacons alert personnel of the condition in a particular area: green (safe condition); yellow (hazardous condition with entry by permission only); red (test in progress or hazardous condition with no entry except by direct authorization of the test director). Tunnel door lights indicate the condition on the opposite side of the door, indicating direction of safe travel. Each door has a set of green, amber, and red lights. Green indicates a safe condition; amber indicates a hazardous condition; travel past an amber light is allowed only with permission of the test director during testing, the facility manager, or their designated alternates; and red indicates no travel past a

designated door because a test is in progress or a hazardous condition exists. During a test the test director may direct specific personnel through these doors to accomplish specific operations.

c. Capability for Personnel to Clearly Distinguish an
Accidental Criticality from all other Hazards

Klaxons are used exclusively as the audible alarm for accidental criticality and sirens are used to indicate other hazards affecting widespread areas. These alarms, which are audible throughout the complex, fulfill the requirements of the NRDS emergency alarm criteria.* In addition, all three area beacons become red in the event of accidental criticality.

d. Control and Evacuation of Personnel Relative to the
Safest Direction of Travel

The area beacons and tunnel door lights already described are clearly visible to personnel and provide visual indication of safe direction of travel and areas to be avoided during emergency evacuation.

e. Unnecessary Area-Wide Evacuation of Personnel
to Distant Areas to be Minimized

The system alarm logic is designed to initiate movement of personnel depending on whether the hazard is localized or widespread. This is accomplished by interconnecting the outputs of only the sensors that monitor a widespread hazardous condition to area visual and audible alarms. Activation of these area alarms requires evacuation of all personnel to protected areas. Other hazard sensors activate only local visual and audible alarms that are located in the immediate vicinity of the sensor. Activation of local alarms requires evacuation from the immediately affected area only.

*NRDS Emergency Alarm Criteria, SNPO-N Memo S: J. W. Lilly, 18 March 1965
NERVA Test Operations Emergency Plan - ETS-1, NTO-A-0030, Section 018,
26 September 1966

4.15 VENTILATION SYSTEM

The ventilation system at ETS-1 provides conditioned air to the below-ground areas of the facility for tunnel pressurization, instrumentation cooling, and personnel comfort. The system consists of air-intake and exhaust units, filter units, control fans with associated ductwork, and controls and instrumentation. Air is cooled and heated as necessary to maintain suitable environmental conditions within the facility. Figure 4.15.1 is a simplified flow schematic of the forced air ventilation system.

4.15.1 Air Supply and Distribution

Outside (fresh) air is supplied through two air intakes at the utility equipment building, which is located near the main entrance to the tunnel leading to the control point building (Figure 4.15.2). This location is remote from the test stand and cryogenic storage tanks; therefore, the potential for intake of hazardous airborne materials is minimized.

One intake unit supplies fresh air at a rate of 13,000 cfm, through air intake fan F-4, for instrumentation conditioning at all tunnel locations and for positive tunnel pressurization in the direction of the test stand. This positive pressure prevents outside air from leaking in through cracks or openings in tunnel entrances or through other penetrations. Pneumatically operated louvers are provided at the air intake to reduce flow of air; however, the intake fan must be shut down to completely stop the flow. The intake air is temperature-controlled and filtered. The filtering system has an efficiency of 99.97% for removal of particles of 0.3 micron size or greater; however, it does not effectively remove gaseous contaminants. Air is exhausted at the end of the tunnel near the test stand area around an open 60-in. circular blast door. The blast door, which acts as an air-flow check valve between the test cell building and the test stand equipment room (Figure 4.15.1), is mounted on ball bearings in a spiral raceway and is counterweighted so that the pressure exerted on the door by the air exhausting from the tunnel is sufficient to keep the door open. If the pressure within

4.15-2

Figure 4.15.1 - Flow Schematic of ETS-1 Ventilation System

Figure 4.15.2 - Ventilation-System Plot Plan

the facility drops, the counterweights pull the door closed. For ease of personnel access the door can be locked in an open position. A visual signal is provided at the LSE Console in the control point building to indicate when the blast door is closed. The door is designed to prevent overpressure in the tunnel from a shock wave resulting from an explosion or blast occurring in the vicinity of the test stand building. With the door in the normal operating position (open), outside pressure forces the door to close, thereby precluding entrance of the blast air that may be contaminated, or of the shock wave that may have sufficient force to injure personnel.

The other air intake unit, equipped with louvers and a filtering system similar to those described for the tunnel air intake, provides fresh air at a flow rate of 13,500 cfm, through air intake fan F-1, to the control point building, lower-level fill station building, and test cell building. The air is humidity-conditioned by unit HU-1 and distributed to the below-ground areas in the following proportions: 10,000 cfm to the control point building and 3500 cfm (boosted by fan F-3) to the lower-level fill station building and test cell building. This fresh air is mixed with recirculated air by air handling units at these locations, and is then circulated for room ventilation (heated and cooled as necessary) and instrumentation cooling. Portions of the recirculated air are exhausted to the tunnel to maintain system balancing and to supplement tunnel pressurization.

Electrical power for the operation of the ventilation system is supplied from the utility bus and the essential bus. Since the essential-bus is considered the more reliable of these two power sources (see Section 4.9), essential-bus power is used for the critical ventilation-system components which maintain positive tunnel pressurization and circulate air for cooling critical control racks and instrumentation. The critical components of the ventilation system which are supplied from the essential bus are: fresh-air makeup fans F-1 and F-4, recirculation fan F-3 which circulates air to the forward control room, control room fan F-9, and air handling units AH-3, -4

and -5. With this power distribution scheme, loss of utility power during test periods does not adversely affect the critical functions provided by the ventilation system, though continued test operations may be curtailed since facility air under this malfunction condition is not cooled or humidity controlled.

If essential bus power to the ventilation system is lost or if for some other reason the ventilation system is shutdown, the probability of hazardous airborne materials entering the facility is very small since all conduit leading to the below-ground areas of the facility are sealed and entry doors to these areas are weather stripped. Furthermore, the status of the facility entry doors (either open or closed) is visually indicated on the Safety Graphic Display Panel so that operating personnel may be continuously alerted to potential entry paths for hazardous airborne materials into the facility.

As further protection against accumulation of hazardous airborne materials in the below-ground areas of the facility, combustible gas detectors and particulate/gas radioactive air monitors are located in the air intakes of the ventilation system and in proximity to the test stand terminus of the tunnel. Hydrogen, propane and radioactive air monitors are located in the ceiling of the test stand equipment room and in the ventilation system down-stream of fans F-1 and F-4. An additional hydrogen detector is located in the tunnel of the test cell building near the blast door. Readouts from each detector and alarms are provided at the LSE Console. Thus, if airborne contaminants enter the personnel-occupied areas of the facility, their presence will be detected so that appropriate action for the protection of personnel can be taken.

4.15.2 System Operation

During routine operations, when the engine is not on the test stand or tests or checkouts are not in progress, release of hazardous materials to the environment is not a major problem. During these periods,

personnel are normally allowed unrestricted access to above- and below-ground areas (Appendix A). The ventilation system is placed in operation with the air intakes and recirculating units operating and with the blast shield door locked open.*

During engine test operations, significant amounts of fission products may be released. At these times, personnel are normally restricted to the control point building or immediate vicinity. As previously indicated, the filtering system of the air intake units effectively removes particulates but not gaseous contaminants. Therefore, unless the air intakes are shut down under unfavorable meteorological conditions (i.e., with the wind direction from the test stand back over the facility), these gaseous contaminants could be introduced into the ventilation system, with resultant exposure of personnel. (Shutdown of the air intakes means shutdown of air-intake fans F-1, and F-4, and closure of the air-intake louvers.) If a nuclear accident occurs during test operations, fission product release may be increased several orders of magnitude. Consequently, excessive exposure to personnel is highly probable if these contaminants enter the ventilation system.

Appendix B is a study of the radiation exposures to personnel in the control point building from a maximum ground-level release of fission products as a result of a loss of coolant to the engine. This study assumed "worst-case" conditions, which includes passage of the cloud directly over the air intakes of the ventilation system. The study concludes that when the air intakes are in operation, such an accident results in excessive exposure to personnel in a short period of time; the controlling dose factor being intake of gaseous iodine by the thyroid. The study also shows that with the air intakes shut down and with air leakage into below-ground areas restricted to openings around doors or through other small

*The blast shield door is locked open to enable unlimited personnel access to and from the tunnel and to prevent the counterweights from suddenly closing the door if the tunnel pressurization is disrupted.

apertures, personnel do not receive more than maximum permissible exposure limits for emergency conditions. Based on a referenced study of limited occupancy in an unventilated enclosure, Appendix B also shows that the air volume of the control-point building is adequate to provide life support to 146 people for a period of 8 hr after closure of the air intakes. On this basis, it is concluded that an emergency air supply for life support in the control-point building is not needed.

Introduction of fission products into the ventilation system is precluded by the use of instrumentation and warning devices to inform control point personnel about the potential for fission product intake, and by provisions for prompt shutdown of the air intake units if fission product intake appears imminent. During nontest periods when the engine is on the test stand, the criticality alarm system is in operation to detect accidental criticality and alert personnel to the possibility of fission product release. During test operations the potential for fission product release is continuously monitored by observation of key reactor parameters. Wind-speed and direction indicators are provided at the LSE Console in the control room, so that the direction of fission-product transport can be determined. Particulate/gas radioactive air monitors are provided for continuous monitoring of air downstream of the filters at the air intakes and in the test stand building (Section 4.11). These units are equipped with local audible and visual alarms and provide a remote readout and alarm at the LSE Console to warn operating personnel of the presence of any airborne contamination at the detector locations. Prompt shutdown of the air intake units, the need for which may be indicated by any of the preceding instrumentation or warning devices, can be accomplished by switches (for operating the air intake louvers and fans) located at the LSE Console. Controls for other components of the ventilation system are located on a panel in the utility equipment control room, which is located directly across the tunnel from the control point building.

Consideration has also been given to leakage of hydrogen or propane to occupied below-ground areas through the ventilation system, or other openings, following a major rupture of either the LH_2 or propane containment vessels. The 77,000-gal LH_2 run tank is located a considerable distance from the air intakes at the utility equipment building and is on the opposite side of the shadow shield wall from below-ground personnel-occupied areas. If the run tank ruptures it is highly improbable that there would be significant spillage of liquid on the opposite side of the wall due to the solid support provided by superstructure members and the offset position of the tank relative to the shield wall (Figure 2.7). Furthermore, since the run tank is filled only during engine test periods when personnel are restricted to the control point building and the blast shield door is counterbalanced against the tunnel pressure (air intakes operating), penetration of hydrogen into the tunnel area is precluded even if hydrogen gas penetrated and became trapped in the below-ground test stand equipment room.

The 250,000-gal LH_2 storage Dewar is also remote from the air intakes; however, it is adjacent to a tunnel entrance (Figure 4.15.1). A dike, with an enclosed capacity approximately 15% greater than that of the Dewar, is provided for containment of LH_2 spills. The diked area is covered with crushed rock to increase boil-off of LH_2 . A large deflector shield, installed between the Dewar and adjacent tunnel entrance, is designed to deflect spilled LH_2 back into the dike. Therefore, because of these design features, the rapid boil-off characteristics of LH_2 and the diffusion properties of hydrogen, entry of hydrogen to below-ground areas is highly unlikely.

The 16,000-gal liquid propane storage tank is also located a considerable distance from the air intakes. This minimizes the possibility of drawing propane gas into the facility in the event of tank rupture. However, since propane gas is heavier than air, under unfavorable meteorological conditions this gas could drift to the vicinity of either the

air intakes or the test stand equipment room. Sensitive propane gas detectors with remote readout and alarm at the LSE Console are provided in the test stand equipment room and in the air intakes to alert operating personnel to the presence of propane. In the event of such a condition, the air intakes can be promptly shut down from the LSE Console as a precautionary measure.

APPENDIX A

ETS-1 PERSONNEL SAFETY CONTROL PLAN

Because of the potentially hazardous nature of ETS-1 operations, special precautions must be taken to control personnel within the ETS-1 complex under both normal and emergency operating conditions. The purpose of this plan is to establish a basis for personnel control at ETS-1 and to identify the requirements for a safety system that will adequately support this control. The personnel control measures identified herein are implemented by NTO procedures A-0030-018 and -019.^(1,2)

A.1 SAFETY PRINCIPLES FOR PERSONNEL CONTROL

The basic safety principles that will be followed to control personnel at ETS-1 are:

a. Primary control of personnel will be coordinated through a centralized facility location where information on the status of environmental conditions within the complex will be continuously available and where the capability for manual control of audible and visual signals and a means for communicating with facility personnel will be provided.

b. Personnel will be made continuously aware of access restrictions to areas during normal operations and of hazardous conditions and their locations during emergencies. A visual indication and audible alarm system designed for both automatic and manual activation will be provided for this purpose.

- (1) NERVA Test Operations Emergency Plan - ETS-1, NTO-A-0030, Section 018, 26 September 1966.
- (2) Area Surveillance and Warning System at ETS-1, NTO-A-0030, Section 019, 27 September 1966.

c. Personnel will be able to clearly distinguish an accidental criticality from all other hazards. Klaxons will be used as the audible indication for an accidental criticality condition. Sirens will be utilized for audible indication of all other hazards requiring area-wide evacuation. These alarms will be audible throughout the test complex.

d. Evacuation of personnel will always be effected by the safest direction of travel. Visual indicators that clearly show the direction of safe travel will be provided.

e. Unnecessary area-wide evacuation of all personnel to distant protected areas will be minimized. As a result, alarm logic of the audible and visual warning system will be designed for movement of personnel based on the presence of localized or widespread hazard effects. Further control will be coordinated through voice communications from the control point building.

A.2 PERSONNEL CONTROL AT ETS-1

A.2.1 Normal Conditions

The procedural controls that will be used for the protection of personnel at ETS-1 during normal operating periods are:

a. Routine Maintenance Periods

During periods involving routine facility maintenance when the engine is not on the stand, establishment of specific exclusion areas will not normally be required. Therefore, personnel access to the various areas, both above and below ground, will be permissible. However, some localized controls on entry to areas in the vicinity of the test stand may be necessary due to chemical hazards or to residual radiation from previous testing.

b. Countdown Operations

During countdown operations involving either the installation of the engine at the stand or checkout of the engine or facility systems, the area of personnel exclusion areas will depend on the hazards involved. During these periods, personnel authorized for access to ETS-1 will be restricted to the immediate area of the control point building unless specifically authorized access to other areas by the test director.

c. Engine Test Periods

Entry to the ETS-1 complex and access to aboveground areas will not be permitted during engine testing. Personnel at the facility will be restricted to the control point building or other protected locations as approved by the test director.

d. Posttest Operations

Exclusion areas will remain in effect at all aboveground areas following a test run shutdown. Due to the possibility of either high gamma radiation from the engine following shutdown or fission product contamination in aboveground areas, personnel will not be allowed to exit to aboveground areas until clearance is given by the test director after environmental surveys by RAD/SAFE personnel. After clearance is given, reentry personnel who are on authorized access lists and are properly clothed and monitored, will be permitted to enter exclusion areas to perform posttest maintenance and securing of systems as required. During removal and transport of the hot engine, all personnel will be evacuated to protected areas where adequate shielding exists.

A.2.2 Emergency Conditions

Hazards associated with high-pressure gas systems, combustible gases, and cryogenics can result in both localized and widespread emergency conditions. Residual radiation levels from previous testing may also be hazardous; however, precautions against this condition can be readily established. Hazards such as oxygen deficiency in personnel-occupied areas and combustible-gas accumulation in areas isolated from cryogenic storage vessels and connecting lines will affect only localized areas. Widespread areas will probably be affected only if fire or explosion were to occur after formation and ignition of combustible gases in close proximity to storage vessels or connecting lines.

If only a localized area is affected, personnel will be evacuated only from the immediate area. If widespread areas are or might be affected, personnel will be evacuated to designated below-ground areas. Thereafter, personnel will follow instructions of the facility manager or the test director given through the communications system at the control point building.

With an engine on the test stand, radiation hazards of unpredictable magnitude will exist if accidental criticality occurs. Since this condition could potentially affect an extensive area, all personnel will be immediately evacuated to designated tunnel areas, avoiding the test stand area enroute. Personnel will, thereafter, await further instructions from the facility manager or test director through the communications system at the control point building. During a test run, all personnel will be located in the control point building or in other protected locations. If an emergency occurs, personnel will remain in these areas pending further instructions from the test director.

A.3 SAFETY SYSTEM REQUIREMENTS

Based on the preceding safety principles and methods for personnel control, the requirements for the design and use of a safety system at ETS-1 have been established. The purpose of the safety system will be to provide warning of impending or existing hazardous conditions at ETS-1, so that appropriate corrective action may be taken to protect both personnel and facilities. The system will have seven subsystems: (1) fire protection, (2) oxygen detection, (3) combustible gas detection, (4) radiation monitoring, (5) criticality monitoring, (6) meteorological, and (7) area surveillance and warning. The basic requirements for these subsystems are:

A.3.1 Fire Protection

Water deluge capability will be provided at ETS-1 for three principal areas: (1) test stand, (2) hydrogen and propane storage, and (3) fill station. Automatic heat-responsive devices will activate area audible and visual alarms of the area surveillance and warning system.

A.3.2 Oxygen Detection

Detectors will monitor concentrations of oxygen at strategic locations where oxygen deficiency can be a personnel hazard or in areas where concentrations may be high enough, in combination with combustible gases, to cause an explosion. Output signals from these detectors will activate local alarms of the area surveillance and warning system when conditions are outside safe limits.

A.3.3 Combustible Gas Detection

A system will be provided for the detection of explosive concentrations of hydrogen and propane at critical locations where the accumu-

lation potential for these gases is highest. Output signals from the detectors will activate local or area alarms of the area surveillance and warning system when safe limits are exceeded.

A.3.4 Radiation Monitoring

Radiation detectors will be provided at strategic locations for monitoring gamma radiation intensities. Output signals from the gamma detectors will activate local audible and visual alarms of the area surveillance and warning system when preset levels are exceeded. Detectors will be equipped with local and remote readout meters. The remote readouts will provide an immediate indication of residual radiation levels in various areas prior to personnel reentry; however, these readouts will not be utilized as the primary indication for permitting personnel to enter radiation areas. RAD/SAFE monitoring personnel equipped with portable radiation survey meters will determine the specific reentry environment and coordinate the reentry requirements for operations personnel with the lead safety engineer.

A.3.5 Criticality Monitoring

Three highly sensitive neutron detectors, with two-out-of-three alarm logic, will be provided to continuously monitor the nuclear engine for accidental criticality during non-run periods when the engine is at the test stand. The capability of the criticality monitors will be based on the criteria established by AEC Manual Chapter 8401 and 10 CFR 70.24. The alarm output signal will activate the audible klaxons and visual alarms of the area surveillance and warning system. The criticality monitoring system will be disarmed during the engine test.

A.3.6 Meteorological

A meteorological subsystem will be provided to monitor wind direction and speed. Readouts from the sensors that will be located

above the control point building will be displayed at the LSE Console and utilized to evaluate local meteorological conditions for engine testing and to assist the facility manager or test director in directing personnel during emergencies.

A.3.7 Area Surveillance and Warning

A system that consists of audible and visual signals and alarms located strategically throughout ETS-1 will be activated automatically by the sensor outputs of the fire protection, oxygen detection, combustible gas, radiation monitoring, and criticality monitoring systems when unsafe conditions exist. In addition, the area surveillance and warning system will have the capability of being activated manually by emergency switches at above-ground areas or at the Lead Safety Engineer (LSE) Console at the control point building if a hazardous condition, undetected by sensors, is discovered. The audible and visual alarms will have the capability of being activated manually to alert personnel of countdown operations, system checkouts, or other normal operating conditions where exclusion areas are required and personnel access is controlled. Since the lead safety engineer must be aware of the status of all visual and audible alarm signals, these signals will be transmitted to the LSE Console at the control point building.

A.4 SAFETY SYSTEM UTILIZATION

Components of the area surveillance and warning system will be used as follows:

a. Sirens will provide an aural warning for any unsafe condition, other than an accidental criticality, and will be audible throughout the ETS-1 complex. Klaxon audible alarms will be used for accidental criticality and will also be audible throughout the complex. These two audible alarms, which are consistent with standard NRDS alarm criteria, will alert personnel that a

hazardous condition exists and evacuation of personnel to a safe environment is necessary. Direction of safe travel will be provided by visual indicating lights.

b. Rotating beacons will serve to alert personnel of the condition in a particular area of the facility. The meaning of these beacons will be as follows:

(1) A green beacon will indicate area conditions are safe.

(2) An amber beacon will indicate a hazardous condition in the area. Entry to such an area will be by permission only.

(3) A red beacon will indicate a test is in progress with no entry into the designated area, except as specifically directed by the test director for the performance of specific functions within the red-light area.

c. Sets of door lights will be placed at each entrance and exit to the tunnel area. Each set of lights will consist of three lights: green, amber, and red. A green light will indicate a safe condition beyond the designated door. An amber light will indicate a hazardous condition beyond the designated door. Travel past an amber light will require permission of the test director (during testing), the facility manager, or their designated alternates. A red light will indicate no travel through a designated door because a test is in progress or a hazardous condition exists; except that during the conduct of a test the test director may direct specific personnel through these doors to accomplish specific operations.

d. Traffic lights will be placed at the gate entry to ETS-1 to indicate status of access to the complex. The meanings of the lights will be as follows:

(1) Green - site conditions are safe. Vehicles may proceed to designated parking areas; however, all visitors must register with the facility operations manager.

(2) Amber - a hazardous condition exists or a test is in progress. Entrance will require permission. A security roadblock will be established at the site entrance. Personnel allowed on site must follow the instructions of the security officer on duty.

(3) Red - a hazardous condition exists or a test is in progress. In either case, no entrance to the site is permitted, and a security roadblock will be established at the site entrance.

During periods involving only routine maintenance with no area-wide exclusion areas in effect, the area beacons, tunnel door lights, and traffic lights of the area surveillance and warning system will be green to indicate access is permissible. Green tunnel door lights, both inside and outside, will indicate travel is safe in either direction.

If a local exclusion area is required, the beacon in the affected area will be switched manually to yellow (limited access) or to red (no access); outside door lights will be green to indicate safe direction of travel to tunnel areas; inside door lights will be switched to red or yellow depending on whether the adjacent area outside is limited or a no access area. The traffic warning light will be switched to yellow indicating access to the ETS-1 complex is controlled.

During engine testing or other tests of general hazard, area beacons will be manually activated to red to indicate no access. Outside door lights will be green and inside door lights will be red to maintain personnel within designated tunnel areas. The traffic warning light will be changed to red to indicate no access to the ETS-1 complex.

Automatic activation of sensors of the fire protection and criticality monitoring systems, certain sensors of the combustible gas detection system, and manual activation of emergency switches, indicate hazards that may affect widespread aboveground areas. Therefore, when these sensors are activated, area audible alarms (klaxons or sirens) will be sounded to direct personnel to evacuate to designated tunnel areas. Except for a criticality alarm condition where all beacons become red, the beacon in the affected area will automatically change to red and the other beacons will change to yellow. Outside door lights will remain green to indicate safe direction of travel and inside door lights will change to red to warn personnel to remain in tunnel areas. The traffic warning light will change to yellow to serve as a warning for limited-access or red for no-access to the ETS-1 complex. The red traffic signal will be supplemented with a roadblock. All alarm signals will be transmitted to the LSE Console at the control point building for local acknowledgment.

Due to the widespread hazards that can result from accidental criticality, when the area klaxons are activated all beacons will change to red. Thus, these beacons in conjunction with the klaxon sound (which is clearly distinguishable from the sound used to denote other types of hazards) will serve as an immediate warning to personnel of an accidental criticality.

As already indicated, hazards such as (1) oxygen deficiency in areas where personnel may be located or (2) combustible-gas accumulation in isolated areas will affect the localized area only. Therefore, sensors for indication of these hazards will be provided with local visual and audible alarms only and will not be connected to area alarms (including sirens, beacons and door lights) to preclude unnecessary facility-wide evacuation of personnel.

Activation of radiation detectors of the radiation monitoring system will automatically initiate local audible and visual alarms and transmit an audible and visual signal to the LSE Console. These detector

alarms will not be connected to area audible alarms or to door lights, since it is improbable that any abnormal radiation hazard could occur other than that originating from an inadvertent criticality which would necessitate complete evacuation of personnel to below-ground areas. As already indicated, the criticality monitoring system will detect and warn personnel of inadvertent criticality. Certain aboveground radiation detectors, however, will automatically activate beacons since the beacons can serve to good advantage in alerting distant personnel to a hazardous condition in the affected area.

APPENDIX B

PROTECTION OF ETS-1 PERSONNEL FROM A MAXIMUM GROUND LEVEL RELEASE OF FISSION PRODUCTS

B.1 INTRODUCTION AND SUMMARY

A loss of coolant to the XE reactor while the engine is operating at full power results in the release of a large fraction of the total fission-product inventory contained in the core. This appendix deals with the adequacy of radiation protection afforded to personnel in the control-point building if such an accident occurs.

The control-point building, in which all personnel are confined during engine testing, is located below ground about 1000 ft from the test stand. The building is adequately shielded to protect personnel from direct fission-product radiation from all external sources; however, under adverse wind conditions; i.e., with the control-point building located downwind of the test stand, volatile fission products released during an accident can enter the facility either through the ventilation system or through small openings or cracks around such objects as doors and conduits. In addition, ground-level contamination by fission products released during an accident can preclude safe evacuation of personnel from the facility if prompt evacuation is necessitated by a below-ground emergency such as a fire. In the following sections, the potential radiation hazards to control-point personnel after a loss-of-coolant accident are examined.

Inhalation hazards to personnel in the control-point building are considered for two cases: first, the inhalation dose received by personnel with the air intakes to the facility ventilation system open, and, second, the inhalation dose received by personnel with the air intakes to the facility ventilation system closed. The estimated radiation exposures under the

assumed worst-case conditions, which involve ground-level release of fission products with the wind directed toward the control-point building, are as follows:

<u>Atmospheric Condition</u>	<u>Total Integrated Dose (Rad)</u>	
	<u>Air Intakes Open</u>	<u>Air Intakes Closed</u>
Lapse	6,350	1.17
Moderate inversion	56,300	10.4
Inversion	1,180,000	218.

For the case of the air intakes closed, the values obtained are below the maximum levels permissible under emergency conditions.

This appendix also shows that the air volume of the control-point building is adequate to provide life support to 146 people for a period of 8 hr after closure of the air intakes. On this basis, it is concluded that an emergency air supply for life support in the control-point building is not needed.

The maximum radiation levels that can occur in the vicinity of the ETS-1 control-point exits were estimated by direct extrapolation of Kiwi transient-nuclear-test (TNT) data. From these data, and by assuming the control point is located downwind of the test stand at the time of the accident, the upper-limit dose rates in the control-point area due to ground-level contamination by fission products released during a maximum accident are:

<u>Time After Accident, (hr)</u>	<u>Downwind Dose Rate 1000 ft from Stand, (r/hr)</u>
0.1	10,000
1.0	510
8.0	34

For this case (which assumes the control-point building is located downwind of the test stand), it cannot be concluded that adequate personnel protection is provided since, for the maximum accident condition assumed, safe evacuation of the control point is not possible until several hours after the accident. This restriction on the egress of personnel from the facility is intolerable if a below ground emergency necessitating prompt evacuation develops. For example, failure to close the ventilation system before fission products enter the facility or existence of an electrical fire in the control-point building are situations that could require immediate evacuation of the control-point area after a maximum aboveground accident.

Crosswind data derived from the TNT experiment indicate that, if the wind is not blowing toward the control point when the accident occurs, the upper-limit dose rates at the control-point exits are lower than the above values by approximately two orders of magnitude. Such a reduction in the aboveground radiation environment at these exits allows prompt evacuation of control-point personnel if necessitated by a below-ground emergency. Further, since the maximum fission-product inventory that can be released by accidents during nonrun periods is orders of magnitude below that for the assumed loss-of-coolant accident, Reference (2), prompt evacuation of personnel from the facility is not precluded for these nonrun accidents even if they occur under adverse wind conditions.

From the results of this study, it is concluded that the facility affords adequate protection against excessive radiation exposures to personnel if wind direction is such that the control-point building is upwind of the test stand during engine power testing. However, this does not preclude power testing under less favorable conditions if additional data or refinement of potential accident situations in conjunction with supporting analyses show that adequate protection is provided under the less favorable conditions.

B.2 SOURCE TERM

For the specific conditions considered in this evaluation, thyroid dose due to inhalation of iodine is the controlling factor. Most of the iodine isotopes are formed from the decay of antimony and tellurium. The actual formation is of the type $A \rightarrow B \rightarrow C$ rather than the formation of C directly. When the half lives of the precursors are short compared with the half life of iodine, the effect of the precursors may be ignored, and the maximum iodine inventory in the core after reactor shutdown may be calculated on the basis of maximum effective yield, which is the combined fission yield of the iodine isotope and its precursors. Iodine 131, 133, and 135 are in this category. In the case of I-132 and I-134, however, the half lives of the precursors are a controlling factor in the determination of the maximum effective yields or inventories after shutdown. On the basis of Reference (1), the 132 and 134 decay chains and half lives involved are:

where the values in parenthesis are the fission yields. By excluding the relatively fast decay of the antimony isotopes, the amounts of iodine as a function of time after fission can be determined from the expression

$$I(t) = \frac{\lambda_{\text{Te}} \text{Te}(0)}{\lambda_{\text{I}} - \lambda_{\text{Te}}} (e^{-\lambda_{\text{Te}} t} - e^{-\lambda_{\text{I}} t}) + I(0)e^{-\lambda_{\text{I}} t}, \tag{3}$$

where λ is the decay constant. The maximum effective yields of I^{132} and I^{134} based on this expression, together with the maximum effective yields for the remaining iodines, are given in Table B-1.

TABLE B-1
MAXIMUM EFFECTIVE YIELDS
OF IODINE ISOTOPES AFTER FISSION

<u>Isotope</u>	<u>Half Life</u>	<u>λ (sec⁻¹)</u>	<u>Maximum Effective Yield</u>
I-131	8.05D	9.97×10^{-7}	2.9×10^{-2}
I-132	2.3 H	8.37×10^{-5}	1.7×10^{-3}
I-133	20.8 H	9.26×10^{-6}	6.5×10^{-2}
I-134	53 M	2.18×10^{-4}	3.5×10^{-2}
I-135	6.68H	2.88×10^{-5}	5.5×10^{-2}

For 20 min at 100% power, the total number of fissions is

$$\begin{aligned} \text{Fissions} &= 1200 \times 1100 \times 3.1 \times 10^{16} \\ &= 4.08 \times 10^{22}. \end{aligned} \tag{4}$$

Thus, the maximum inventory of the iodines in the core after shutdown is

$$\begin{aligned} Q_i &= \frac{4.08 \times 10^{22} \times Y_i \times \lambda_i}{3.7 \times 10^{10}} \\ &= 1.10 \times 10^{12} Y_i \lambda_i \text{ curies,} \end{aligned} \tag{5}$$

where Q_i is the maximum inventory of iodine isotope i in the reactor after shutdown, Y_i is the maximum effective yield of isotope i and λ_i is its decay constant in sec⁻¹. The maximum inventories of the iodines after shutdown from a 20-min full-power run as calculated by substitution of the yields and decay constants from Table B-1 into Equation (5), together with the conversion factors for dose to the thyroid per iodine curie inhaled, from Reference (2), are given in Table B-2.

TABLE B-2

MAXIMUM IODINE INVENTORIES
FOLLOWING 20-MINUTE FULL-POWER RUN

Isotope	Maximum Inventory, Q_i (curies)	Dose Conversion, C_i (rad/curie)	$Q_i C_i$ (rad)
I-131	3.18×10^4	1.46×10^6	0.46×10^{11}
I-132	1.56×10^5	5.35×10^4	0.08×10^{11}
I-133	6.62×10^5	4.0×10^5	2.65×10^{11}
I-134	8.39×10^6	2.5×10^4	2.10×10^{11}
I-135	1.74×10^6	1.24×10^5	2.16×10^{11}
Total =			7.45×10^{11}

The last column in Table B-2 represents the source term and gives a measure of the relative dose contribution from each iodine isotope. As indicated, the contributions from I-133, I-134, and I-135 predominate. Though the total shown is never achieved because the inventory of each isotope is maximum at different times after shutdown, it is only slightly greater than the actual value achieved about 1 hr after shutdown. Furthermore, the summation of $Q_i C_i$ does not vary by more than about a factor of 2 for the 8-hr period following shutdown; consequently, for the purposes of this evaluation, it can be assumed to be constant without introducing appreciable error.

The remainder of this analysis is based on the assumption that 50% of the iodine inventory in the core is released as the result of a loss-of-coolant accident. Thus, the source used in the subsequent analysis becomes

$$S = 1/2 \sum_i Q_i C_i = 3.7 \times 10^{11} \text{ rad.} \quad (6)$$

The 50% release fraction assumed corresponds to the value used in the X-engine safety analysis, Reference (2).

B.3 ATMOSPHERIC DIFFUSION

Since the value of the source term, S, is assumed constant over the 8-hr period after shutdown, the predicted dose to a downwind receptor during the cloud passage is essentially independent of the time interval over which the iodine is released. Thus, a simple instantaneous point-source release of the total iodine inventory is assumed (as opposed to a more realistic continuous release type model) without introducing a significant error into the calculation of total integrated exposure to personnel during cloud passage. This, of course, is based on the assumption that the receptor is immobile and that the atmospheric conditions do not change during the release interval.

From Reference (3), Sutton's Equation for downwind concentration along the cloud centerline from an instantaneous ground level release of a source Q is

$$X(x,t) = 2Q \left[\pi C^2 (\overline{ut})^2 - n \right]^{-3/2} \exp \left[- \frac{x^2}{C^2 (\overline{ut})^2 - n} \right] \quad (7)$$

where:

$X(x,t)$ = concentration, curies/m³

Q = source strength, curies

C = generalized diffusion coefficient, m^{n/2}

n = nondimensional parameter associated with stability

$\overline{u}$ = mean wind speed, meters/sec

t = time, sec

x = receptor location, meters.

The values of the diffusion parameters recommended by the USWB, Las Vegas, for use at NRDS, Reference (2), are:

<u>Parameter</u>	<u>Lapse</u>	<u>Moderate Inversion</u>	<u>Inversion</u>
c^2	0.1	0.04	0.01
n	0.23	0.33	0.50
$\bar{u}$	5.36	2.68	1.34
	(12 mph)	(6 mph)	(3 mph)

The preceding values in conjunction with Equation (7) are used throughout the remainder of this analysis to calculate radiation exposures to personnel.

B.4 INHALATION DOSE

References (2) and (5) give a breathing rate of $3.5 \times 10^{-4} \text{ m}^3/\text{sec}$. Thus, the total integrated dose (TID) in rads to a receptor located on the cloud centerline at a distance x from the release point is:

$$\text{TID} = 3.5 \times 10^{-4} \frac{S}{Q} \int_0^{\infty} X(x,t) dt \quad (8)$$

where S/Q represents the conversion factor for dose to the thyroid per curie of iodine inhaled. Substituting Equation (7) into Equation (8) and integrating gives

$$\text{TID} = \frac{7.0 \times 10^{-4} S}{\pi C^2 \bar{u}(x)^2 - n} \quad (9)$$

During test operations of the X-engine, personnel are located in the ETS-1 control point at approximately 1000 ft or 300 meters from the test stand. For a ground level release of the source S , i.e., 3.7×10^{11} rad, the doses for lapse, moderate inversion, and inversion conditions to a receptor located on the cloud centerline at 300 meters from the release point as determined using the diffusion parameters given in Section B.3, are:

$$\begin{aligned} \text{TID(L)} &= 6350 \text{ rad} \\ \text{TID(MI)} &= 56,300 \text{ rad} \\ \text{TID(I)} &= 1,180,000 \text{ rad} \end{aligned}$$

The preceding values represent the thyroid dose received by personnel at 300 meters from the release point if they are not protected in an underground sheltered area, but are above ground on the cloud centerline during the entire passage of the cloud.

The exposure to iodine of personnel located inside the control point at ETS-1 is examined below for two conditions: first, with the ventilation system operating normally, i.e., with an air intake of 10,000 cfm into the control point building, Reference (4); and second, with the air intake fans shut down and the air intake louvers closed.

For the first case, it is shown that the total integrated exposure of personnel located inside the control point building is essentially the same as the exposure they receive if they are outside the building. First, assuming that the iodine is released from the engine at a very slow rate so that the iodine concentration at the air intake is a slowly varying function of time, the model can be represented by the simple diagram shown below

where X_o is the outside concentration which is assumed constant; $X_i(t)$ is the concentration inside the Control Point; F is the air-flow rate into and out of the CP (equal to $4.73 \text{ m}^3/\text{sec}$); and V is the volume of the CP (equal to approximately $2 \times 10^3 \text{ m}^3$). Thus, the change of concentration in the CP with time is represented by the expression

$$\frac{d X_i}{dt} = \frac{F}{V} (X_o - X_i) \quad (10)$$

which has the solution

$$X_i = X_o \left(1 - e^{-\frac{E}{V} t}\right). \quad (11)$$

Substitution of appropriate values in this equation shows that 50% of the air in the CP is changed every 4.9 min and after 10 to 15 min the iodine concentration inside the CP is essentially equal to the concentration at the air intake. Thus, when the iodine is released at a very slow and constant rate such that the concentration at the air intake is relatively constant over time intervals $\gg 5$ min, personnel inside the CP are subjected to approximately the same iodine concentrations as are outside, and consequently the TID's are approximately the same as given on page B-8.

On the other hand, if the iodine release is very rapid, so that the cloud passage occurs in a time interval $\ll 5$ min, it can be assumed that

$$X_i(t) = X_i(o) e^{-\frac{E}{V} t} \quad (12)$$

where $X_i(o)$ represents the concentration in the CP if all of the iodine brought into the CP is present at time zero, i.e.,

$$X_i(o) = \frac{E}{V} \int_0^{\infty} X_o(t) dt, \quad (13)$$

which has the solution

$$X_i(o) = \frac{2 F Q}{V C^2 \bar{u} (x)^2 - n}.$$

By combining Equations (12) and (14), and substituting into Equation (8), the total integrated dose becomes

$$\begin{aligned}
TID &= \frac{7.0 \times 10^{-4} \text{ FS}}{\pi V C^2 \bar{u}(x)^{2-n}} \int_0^{\infty} e^{-\frac{E}{V} t} dt \\
&= \frac{7.0 \times 10^{-4} S}{\pi C^2 \bar{u}(x)^{2-n}},
\end{aligned} \tag{15}$$

which is the same as Equation (9).

Thus, for the limiting cases of a very slow iodine release and a very rapid iodine release, with the ventilation system operating, the exposure of personnel inside the CP is approximately the same as they would receive if located outside.

Next, consider the case where the ventilation system is turned off and all personnel are located inside the control point building during the cloud passage. This case is illustrated by the following diagram

where L_f is the leakage rate into the facility tunnel areas and test cell building through the exterior openings to the facility such as the facility exit doors, and L_i is the leakage rate into the control point through the control point doors and any other openings from the tunnel area. Assuming the outside concentration, X_o , is constant, then

$$V_f \frac{dX_f(t)}{dt} = L_f X_o - L_i X_f(t) + L_i X_i(t) - L_f X_f(t) \tag{16}$$

$$V_i \frac{dX_i(t)}{dt} = L_i X_f(t) - L_i X_i(t). \tag{17}$$

If it is now assumed that the fractional leakage per unit time through both the tunnel and control point volumes are equal, i.e.,

$$k = \frac{L_f}{V_f} = \frac{L_i}{V_i}, \quad (18)$$

and also that the times at which we are concerned are such that $kt \ll 1$, then

$$X_i \ll X_f < X_o$$

and Equations (16) and (17) simplify to

$$\frac{dX_f(t)}{dt} = k X_o - \left(1 + \frac{V_i}{V_t}\right) k X_f(t) \quad (19)$$

$$\frac{dX_i(t)}{dt} = k X_f(t). \quad (20)$$

Letting $b = \left(1 + \frac{V_i}{V_f}\right) k$ and solving for $X_i(t)$ gives

$$X_i(t) = \frac{k^2 X_o}{b} \left[t - \frac{1}{b} (1 - e^{-bt}) \right]. \quad (21)$$

The total integrated dose to personnel located inside the control point then becomes

$$(TID)_i = B \frac{S}{Q} \int_0^t X_i(t) dt \quad (22)$$

where B is the breathing rate and $\frac{S}{Q}$ is the conversion between curies inhaled and dose. Integration gives

$$(TID)_i = \frac{B S X_o k^2}{2 b^3 Q} \left[b^2 t^2 - 2bt + 2 - 2e^{-bt} \right]. \quad (23)$$

If X_o is constant over the time interval, t , and has a value so that personnel located outside the building during this time interval receive the exposures given on page B-8, then

$$X_o = \frac{(TID)_o Q}{B S t} \quad (24)$$

so that

$$\frac{(TID)_i}{(TID)_o} = \frac{k^2}{2 b^3 t} \left[b^2 t^2 - 2 b t + 2 - 2 e^{-bt} \right]. \quad (25)$$

Since, as stated previously, we are concerned only with those times when $kt \ll 1$, and since for ETS-1 $V_i \cong V_f$, then $bt \cong 2 kt$ so that $bt \ll 1$. Thus, for bt small,

$$-2e^{-bt} = -2 + 2 bt - (bt)^2 + \frac{(bt)^3}{e} - \dots \quad (26)$$

which upon substitution into Equation (25) gives

$$\frac{(TID)_i}{(TID)_o} \cong \frac{k^2 t^2}{6}, \text{ for } kt \ll 1. \quad (27)$$

Equation (27) is used to calculate the dose, as a function of time, received by personnel located inside the control point given the value for the leak-rate constant, k . For example, assuming the leakages through the facility and through the control point are 10% per day, and also that the iodine inventory is released at a uniform rate over an 8-hr period, then

$$\frac{(TID)_i}{(TID)_o} = \frac{(0.1)^2 (1/3)^2}{6} = 1.85 \times 10^{-4}$$

so that the total integrated dose received by personnel located inside the control point during the 8-hr period is

TID(L) = 1.17 rad,
TID(MI) = 10.4 rad,
TID(I) = 218. rad.

It is assumed that, at the end of this period, the iodine release is complete and the ventilation system can be used to clear the control point of iodine and thus terminate the exposure of personnel.

B.5 DISCUSSION OF INHALATION-DOSE CALCULATIONS

It has been show that, after a nuclear accident, prompt shutdown of the air intakes to the facility ventilation system may be required to prevent excessive below-ground contamination by airborne fission products. As described in Section 4.15, there are three radioactive air-particulate gas monitors at ETS-1, each of which has remote readout capability at the LSE console. Two of these monitors are in the air inlets for the utility-equipment building, downstream of the absolute filters. The third monitor is in the test-stand building for sampling of ambient air. A manual-control capability exists at the LSE console to close the air-intake louvers and shut down the air-intake fans if monitored radioactive airborne particulate or gas cencentrations exceed acceptable limits. The air radioactivity monitors, plus the meteorological instrumentation provided at the LSE console, provide adequate warning to operators to permit closure of the intake air vents and shutdown of the air-intake fans before radioactive concentrations in the below-ground areas of ETS-1 become excessive.

Determining leakage of radioactivity into the building when the air-intake vents are closed and the ventilation system is shut down is more difficult. As shown by Equation (27), the analysis of this condition requires knowledge of the air leakage rates into the facility. These rates depend on wind velocity and the air currents around the facility. With no wind, the leakage rate should be negligible because internal and external pressures will be equal and radioactive material can enter only by diffusion through small

openings into the facility. As the wind velocity increases, the leakage rate also increases; however, as was shown, predicted doses decrease significantly as the wind velocity increases (e.g., in going from inversion to lapse conditions). Therefore, the highest leak rates will occur under conditions that tend to minimize exposure levels.

In attempting to estimate the leakage rate for ETS-1, an effort was made to obtain information about the leakage rates associated with standard building construction. Reference (5) indicates that a well-constructed building may have a leakage rate of less than 1% per day; in addition, reactor-containment buildings are designed for leakage rates of less than 0.1% per day when pressurized to 50 psi. Therefore, since all doors and openings leading into ETS-1 are weather stripped for the blast door and conduit openings in the test-cell building, the assumptions in Section B.4 (i.e., that the leakage rates into the ETS-1 facility and from the tunnel area into the control-point area are less than 10% per day) are believed to be conservative. The analysis in Section B.4 is based on the conservative assumption that the "hot line" is directly over the facility during the entire release period. Further, a release period of 8 hr was assumed. If the release occurs over a 1-hr period rather than an 8-hr period, the predicted dose is lower by a factor of approximately 1/64, since, as shown by Equation (27), the total exposure is directly proportional to the square of the release time.

On the basis of the preceding information, it is concluded that the TID values given on page B-14 for exposure of personnel inside the control point at ETS-1 after a loss-of-coolant accident represent upper limits because of the conservatism of the assumptions used. Furthermore, these "worst-case" exposures are below the thyroid dose of 300 rad for the public that is used by Reference (4) and in 10 CFR 100 as criteria for reactor siting.

B.6 AIR-SUPPLY REQUIREMENTS FOR CONTROL POINT PERSONNEL

As indicated in Section B.4, the air intakes to the ETS-1 ventilation system must be closed and the intake fans must be shut down either before

or immediately after any substantial ground-level release of fission products from the engine when the wind is directed from the test stand toward the control-point building. Current estimates indicate that approximately 146 people will be at the control point during X-engine testing. Therefore, an analysis of the length of time this number of people can safely remain in the control-point building without replenishing the building air supply is pertinent to an accident at ETS-1 that requires the ventilation system to be closed or shut down for an extended period.

The Reference (6) study deals with this problem and specifically evaluates the time limits of occupancy in an unventilated enclosure in terms of:

- a. Decrease in oxygen level to a minimum concentration without harmful effects.
- b. Increase in carbon-dioxide level to a concentration that has no harmful effects.
- c. Increase in shelter temperature to the upper limit of tolerance for man as a result of body heat production exceeding the heat-removal capabilities of the shelter wall at underground temperatures.

The study indicates that the upper limit of human tolerance to heat in an unventilated, gasproof enclosure is approximately 88°F at 100% relative humidity. Oxygen concentrations of down to 14% and carbon-dioxide concentrations of up to 2% can be tolerated without harmful effects and with only moderate discomfort. The study shows that, for atmospheric conditions not harmful to man, the 2% CO₂ concentration is the critical index for time limits of occupancy in unventilated enclosures when the wall temperatures are less than 74°F.

The air requirements to maintain the CO₂ concentration at less than 2% for a relatively inactive man is given by Reference (6) as 57.9 cu ft/hr. Since the air volume of the control-point building is approximately 7 x 10⁴ cu ft, the time that 146 people can remain in this location with no outside air and with the CO₂ concentration maintained at less than 2% is

$$\text{Time} = \frac{7 \times 10^4}{146 \times 57.9} \approx 8 \text{ hr.}$$

This 8-hr period is more than adequate to allow for passage of the radioactive cloud, after which operation of the ventilation system can be resumed. Therefore, no special provisions are needed for an emergency air supply to provide life support to personnel in the control point.

B.7 EGRESS OF PERSONNEL FROM ETS-1 AFTER AN ACCIDENT

After a maximum aboveground accident and passage of the effluent cloud, the sources of radiation exposure that can affect egress of personnel from the facility are: (1) direct radiation originating from the reactor located at the test stand with the side enclosure shields withdrawn and (2) fuel-fragment and fallout contamination of the ground plane near the exits from the below-ground areas.

Reference (7) indicates that direct radiation from the reactor core with the side enclosure shields in place 1 hr after a 5-min full-power test yields a dose rate of 1.5 mr/hr at the exit to the control-point building. Based on this value and upon an enclosure-shield attenuation factor of 200 for fission-product decay gammas, the dose rates at the exit to the control-point building with and without the enclosure shields in place and at times of 0.1, 1.0, and 8.0 hr after a 20-min full-power test are:

<u>Time After Shutdown (hr)</u>	<u>Dose Rate at CP Exits After 20-min Full-Power Test (r/hr)</u>	
	<u>Enclosure Shields in Place</u>	<u>Enclosure Shields Withdrawn</u>
0.1	0.10	20.
1.0	0.006	1.2
8.0	0.0006	0.12

As may be seen from these values, even for the most severe case where the enclosure shields are withdrawn (as the possible result of an accident), prompt facility evacuation of control-point personnel can be accomplished at any time after engine shutdown without undue hazard from direct radiation from the engine.

The maximum radiation levels that can occur in the vicinity of the ETS-1 control-point exits as a result of ground-level contamination by fission products released during a maximum accident cannot be determined analytically with any degree of precision because of the complexities of the mechanisms involved. However, it is presumed that an upper-limit estimate to these levels can be established by applying experimental data derived from the Kiwi transient nuclear test (TNT). This test was a deliberate nuclear-destruction experiment of a prototype nuclear rocket engine. The experiment involved inducing a nuclear transient in an XE-type reactor that was modified for test by deleting its coolant system and changing its control-drum drive mechanism to allow an extremely rapid insertion of reactivity. The transient produced 10^4 Mw-sec before the associated temperatures and pressures pulverized or volatilized most of the core and destroyed the reactor. Reactor components and core fragments were dispersed in the test area, with most of the material being deposited within a few hundred feet of the test point. Approximately two-thirds of the fission-product activity produced was transported away from the test point by the effluent cloud.

The reasons for expecting the TNT data to provide an upper-limit estimate to the potential contamination problem at ETS-1 are twofold: first,

a mechanism for reactivity insertion comparable to that used in the TNT experiment does not exist for the XE core, and, consequently, the maximum kinetic-energy release from an XE reactor excursion will be substantially less than that produced by TNT; and second, for a comparable excursion at ETS-1, the ETC shields and the shadow-shield wall will significantly restrict the distribution of fuel fragments in facility areas where tunnel exits are located. Thus, it is felt that some degree of conservatism is inherent in the following discussion of the ETS-1 contamination levels, which are extrapolated directly from the TNT results.

The results of the TNT experiment reported in Reference (8) indicate that the maximum deposition of U-235 beyond the immediate throw-out area of 500 ft occurred along the "hot line" (downwind direction) at a distance of approximately 1000 ft from the test position. The U-235 concentration at this location was approximately $10^{-4}\%$ of the uranium content of the core per square meter of ground surface area, which, if uniformly distributed, corresponds to 1% of the core per 10^4 square meters. Reference (9) shows that the maximum measured dose rate beyond the 500-ft throw-out area also occurred at this location. From the posttest data collected, the dose rate 30 in. above the ground plane at the 1000-ft downwind location was found to fit a decay extrapolation equation of the form

$$D(t) = 3.90t^{-1.3},$$

where D is the dose rate in r/hr at a time t hr after the event. For times of 0.1, 1.0, and 8 hr, the dose rates obtained from this expression are 78, 3.9, and 0.25 r/hr, respectively. By scaling these values from the energy produced by the TNT experiment (10^4 Mw-sec) to that produced during a 20-min full-power test of the X-engine (1.3×10^6 Mw-sec), the upper-limit dose rates in the CP area of ETS-1 for the assumed accident condition become:

$$\begin{aligned} D(0.1) &= 10,000 \text{ r/hr,} \\ D(1.0) &= 510 \text{ r/hr,} \\ D(8.0) &= 34 \text{ r/hr.} \end{aligned}$$

Clearly, under these conditions, facility evacuation of personnel cannot be accomplished safely during the first few hours after the accident.

Crosswind data presented in Reference (9) indicate that, if the control-point building is not located downwind of the test stand when the accident occurs, the upper-limit dose rates at the control-point exits are lower than the above values by approximately two orders of magnitude. Such a reduction in the aboveground radiation environment at these exits allows prompt evacuation of control-point personnel if necessitated by a below-ground emergency. It is thus concluded that, if XE power testing is limited to periods when the control-point building is not downwind of the test stand, radiation levels at the facility exits resulting from ground-level fission-product contamination will not preclude safe evacuation of control-point personnel immediately after a maximum accident.

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APPENDIX C
CONSEQUENCES OF INTRODUCING O₂
FROM THE STEAM GENERATOR SYSTEM
INTO A COLD HYDROGEN ENVIRONMENT IN THE DUCT

During XE test operations involving the flow of hydrogen through the duct, the possibility of introducing oxygen-rich steam into the duct has been of concern due to the potential explosion hazard. An evaluation of steam generator operations has shown that oxygen-rich steam may be introduced during hydrogen flow tests by any one of the following mechanisms:

1. Loss of propane to any operating steam module or to the steam generator system.
2. Excessive delay time between termination of propane and oxygen flow if a premature SGS shutdown occurs.
3. Excessive delay time between initiation of oxygen and propane flow during startup of a standby steam module.

If oxygen is introduced when the hydrogen is above the autoignition temperature (~1100°F), burning will occur immediately downstream from the steam injector; however, the only consequence will be an increase in temperature of the flowing gas. For this case, calculations have shown that combustion of 36 lb of oxygen/sec (all the oxygen from two modules) increases the enthalpy of the gas in the duct by less than 20% of that occurring during full-power testing. This increase is well within the capability limits of the system.

The potentially most serious condition involving introduction of oxygen into the duct occurs during startup or cold-flow tests, and possibly during the last stages of engine shutdown, when the hydrogen and the duct are

relatively cold, so that automatic ignition does not necessarily occur. The possibilities resulting from this situation are as follows:

C.1 ASSUMED CONDITIONS FOR ANALYSIS

The analysis of the potential hazards associated with introduction of oxygen into the hydrogen environment of the duct has been predicated on the following assumptions.

- a. The hydrogen in the duct is below the autoignition temperature ($\sim 1100^{\circ}\text{F}$).
- b. The maximum flow rate of oxygen to the duct under credible failure conditions is 36 lb/sec (based on design flow rate from two modules).
- c. A pilot flame or other ignition source is always present at the duct exit.
- d. Quenching effects of nitrogen from the engine compartment, and water or combustion products from the steam generator are ignored.

C.2 SUMMARY OF AVAILABLE DATA

No experimental data for the conditions occurring in the NES duct under the assumed failure conditions have been found. However, data are available for flammability, flame speed, and explosive characteristics, References (1) and (2). The conditions under which these data are obtained are similar

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- (1) B. Lewis and G. von Elbe, "Combustion Flames and Explosions of Gases," Second Edition, New York: Academic Press, 1961.
 - (2) Symposia (International) on Combustion, Vols 3-10, various sponsors and publishers 1949-1965. Volumes 6-10 have been published under the auspices of Combustion Institute.

in one or more respects to conditions in the duct. The applicable data from these references are summarized below.

1. Limits of Combustion and Explosion

Figure C.1 shows flame speeds in mixtures of $2\text{H}_2 + \text{O}_2$ diluted with H_2 , O_2 , N_2 and CO_2 . Concentrations at which flame speeds reach zero are the combustion limits. Thus, 4% H_2 in O_2 (6% combustible mixture) and 6% O_2 in H_2 (18% combustible mixture) are the combustion limits in gas mixtures containing H_2 and O_2 only. If a stoichiometric mixture ($2\text{H}_2 + \text{O}_2$) is diluted with nitrogen, the combustion limit is the same as if the mixture were diluted with hydrogen, although flame speeds are much lower with nitrogen. Carbon dioxide has a more pronounced effect on combustion limits and flame speeds.

Also shown in Figure C.1 are detonation limits for H_2 - O_2 mixtures. These limits are defined as being below the level at which a detonation will propagate. Mixtures containing less than 15% H_2 in O_2 (22.5% combustible mixture) or 10% O_2 in H_2 (30% combustible mixture) cannot be detonated.

2. Flame Speeds

The flame velocities shown in Figure C.1 are for laminar flow. Velocities in turbulent flow are less well documented. Flame velocity increases with turbulence (gas velocity) but only up to a value about three to four times of the laminar flame velocity. Some available data show slightly higher velocity ratios at high gas flows. The conditions that determine whether increased flame velocity or flame-out occurs appear to vary from experiment to experiment.

3. Transition of Flame Wave to Detonation

If a gas mixture which is within the detonation limits and which is at rest or flowing slowly in a long tube is ignited at or near the

Figure C.1 - Flame Speeds in $\text{H}_2\text{-O}_2$ Mixtures

closed end, the combustion initially travels along the tube with the velocity shown in Figure C.1. After traveling approximately 60 pipe diameters, the combustion changes to detonation, which is initiated by the gradual buildup of a shock wave ahead of the combustion zone. If the gas is flowing fast enough to generate turbulence, the distance the flame travels before detonation may be shortened to some 12 to 15 pipe diameters. In comparison, the distance from the ejector to the exit of the duct is equivalent to 8 pipe diameters.

If the preceding mixture is ignited at or near the open end of the tube, detonation will not occur. If the flow velocity is less than the flame velocity, the flame will travel up the tube to the end or to the gas source. If the gas velocity is greater than the flame velocity, the flame will stabilize at the end of the tube; with high gas velocities, the flame may be blown away from the end of the tube.

C.3 APPLICATION TO NES DUCT OPERATION

Figure C.2 shows gas velocity, Reynolds number, and laminar flame velocity as functions of hydrogen flow in the duct, with a flow of oxygen from the steam injector amounting of 36 lb/sec. This oxygen corresponds to the full flow from two steam generator modules with complete loss of fuel (propane) flow.

A stoichiometric mixture is reached at a hydrogen flow rate of 4.5 lb/sec. For hydrogen flows about 35 lb/sec, the mixture is not inflammable; for flows about 20 lb/sec the mixture cannot be detonated even by a high explosive. For flows above approximately 10 lb/sec, gas velocity is so much higher than any possible flame velocity that ignition at the duct exit or in the duct from the steam injector downwards merely results in a flame at the exit.

For hydrogen flows giving nearly stoichiometric mixtures, gas velocity is close to and may be even slightly less than three times the laminar flame velocity. The factor of three has been used to account for the increase

Figure C.2 - Gas Velocity and Flame Velocity in Duct vs Hydrogen Flow Rate for Oxygen Flow Rate of 36 lb/sec

in flame velocity due to turbulent flow of the gas. Ignition at the duct exit or between the duct exit and the steam injector could conceivably result in a combustion wave that could travel upstream and give a flame stabilized at the steam injector (oxygen source). Apparently, however, there are no conditions that could result in explosion.

On startup, with ignition at the duct exit, the flame may travel up the duct to the steam injector when the hydrogen flow reaches about 3 to 4 lb/sec. As the hydrogen flow increases, the flame would remain at the steam injector up to some higher rate, probably about 10 lb/sec, when it would be blown downstream to the duct exit. If the fuel failure in the steam generator system did not occur until the hydrogen flow in the duct had reached approximately 10 lb/sec, the flame would not travel upstream from the duct exit.

On shutdown, a flame would remain at the duct exit until the hydrogen flow had decreased to approximately 10 lb/sec, depending on hydrogen or steam injector temperature. The flame could then conceivably travel up the duct to the steam injector and remain there until the hydrogen flow had decreased to some lower value. By this time, the nitrogen purge used on shutdown would probably give a noninflammable mixture.

C.4 CONCLUSIONS

Based on the preceding analysis and discussion, the following conclusions have been drawn:

1. Apparently there are no operating or malfunction conditions of NES that would enable an explosion in the duct due to the introduction of excess oxygen from the steam generator system.

2. With introduction into the duct of all the oxygen from two steam generator modules, there is only a remote possibility that a flame

could travel from the duct exit to the steam injector when the cold hydrogen flow rate is within a fairly narrow range. However, since such combustion in the duct can only occur at low hydrogen flow rates and low hydrogen temperatures, the added heat from combustion is not expected to cause thermal overload of the duct cooling system.

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