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PRELIMINARY ETS-1 DESIGN SAFETY EVALUATION

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PRELIMINARY

ETS-1 DESIGN SAFETY EVALUATION

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1. INTRODUCTION

The initial safety evaluation of the ETS-1 Complex was completed in October of 1962(21). This previous evaluation was based upon utilization of the facility for flight engine development and, to a large extent, upon facility systems which were in a state of preliminary or conceptual design. Since that time, many of the early utilization requirements imposed on the facility by the engine development program have changed, and the final designs for most of the systems which comprise the test complex have been completed. Consequently, this present evaluation is intended to upgrade the results of previous safety evaluation efforts. It has been based upon the current status of the facility design and construction, and upon utilization of the facility for X-Engine tests.

The primary objectives of this study have been (1) to review and evaluate the design safety aspects of the ETS-1 Complex as related to its supporting the X-Engine test program, (2) to identify major safety deficiencies or problems in the ETS-1 system designs in time to allow for corrective action prior to completion of facility activation, (3) to provide information upon which to base safety criteria and requirements needed during facility checkout and the detailed planning of the engine tests, and (4) to provide information upon which to base safety approvals for facility test operations. This evaluation is preliminary in that the evaluation of the safety aspects of the ETS-1 design and operation cannot be completed until all facility and engine system designs are finalized, and the facility activation and checkout is complete.

Sections 2 through 6 of this report evaluate the major systems which comprise the engine test complex, i.e., the Process and Fluid Systems, the Nuclear Exhaust System, the Facility Instrumentation and Control Systems, the Test Stand and

Engine Control Systems, and the Engine Compartment Shield System. Each of the sections which cover these systems is divided into three parts: (1) a description which reviews the salient features of the system design and operation, (2) an evaluation which discusses the major safety aspects of the design and any safety problems or deficiencies noted, and (3) conclusions which summarize the important conclusions reached in the evaluation. Section 7 is devoted to the radiation environment associated with test operations and to the related problems of decontamination and waste disposal. Section 8 reviews various emergency situations which could arise during test operations and discusses the types of corrective action that may be required. An overall summary of the significant recommendations resulting from the evaluation is included in the last section of the report. Many of the recommendations noted have already been brought to the attention of the cognizant engineering groups as a result of the continual safety evaluation that has taken place during the facility development and during the conduct of this study. As a consequence, it is expected that many of the deficiencies identified herein will have been resolved or will be in the process of resolution by the time this report is issued. For those remaining, expeditious action is required to preclude possible delays in either the facility activation schedule or the engine development program.

2. PROCESS AND FLUID SYSTEMS

2.1 Description

2.1.1 General

The ETS-1 Complex Process Systems were initially designed and installed only up to the test stand area. Subsequently, as the test fluid requirements at the engine interface were defined, the facility-to-thrust-structure interface system design was completed. References (1) and (2) are composite flow diagrams of the process and utility systems up to the facility-to-thrust-structure interface, and Reference (3) is the composite flow diagram of the interface system. The Reference (1) and (3) drawings are currently being revised and integrated into a single composite flow diagram, References (4) through (8). The specifications for the fluid and process systems are given by References (9) through (11). A brief description of these systems follows:

2.1.2 Liquid Hydrogen System

The Liquid Hydrogen System consists of an unloading station, a 250,000-gallon 100-psig storage Dewar, a 500-gallon 1500-psig high-pressure Dewar, a 77,000-gallon 50-psig run tank, distribution piping (vacuum jacketed), engine propellant supply line, control valves, and instrumentation. Liquid hydrogen flows from the LH_2 unloading station to the LH_2 storage vessel through a 2-inch stainless-steel 150-psig vacuum jacketed line. From the storage Dewar, LH_2 flows through a 6-inch stainless-steel 150-psig vacuum-jacketed line to the high pressure LH_2 Dewar and to the run tank. LH_2 for both normal cooldown and emergency cooling is supplied to the test article from the high-pressure Dewar through a 6-inch invar 1500-psig vacuum-jacketed line.

2.1.3 Gaseous Hydrogen System

The Gaseous Hydrogen System consists of an LH_2 vaporizer, first and second stage compressors with aftercoolers, three 2500-psig 2409-cu-ft gas storage bottles, distribution piping, control valves, and instrumentation. Hydrogen is fed from the LH_2 storage vessel through the hydrogen vaporizer to the first and second stage hydrogen compressors and from there to the high-pressure storage bottles. The GH_2 boiloff from the Dewar can also be fed through the compressors to the storage bottles. The gas from these bottles is used for pressurizing the LH_2 storage vessels and run tank, for engine control-drum and TPCV actuation, and for engine cooldown. Stainless-steel piping is used in the test stand area. Carbon-steel piping is used elsewhere. Line filters (10 micron) are installed at the carbon-to-stainless steel interfaces to assure that particles produced by erosion of the carbon-steel piping do not reach the test article, Reference (12).

2.1.4 Helium System

The Helium System consists of an unloading station, compressor with aftercooler, six 2500-psig 1770-cu-ft gas storage bottles (same as used in gaseous nitrogen system), distribution piping, control valves, and instrumentation. Helium flows from the unloading station, through the compressor to the storage bottles from which it is distributed throughout the complex as required. The system provides GHe for purging the cryogenic system and process piping, and for cooling the engine. The system also provides helium for block and bleed of the LH_2 Dewars.

2.1.5 Liquid Nitrogen System

The Liquid Nitrogen System consists of an unloading station, a 31,000-gallon 250-psig LN_2 storage Dewar, distribution piping, and instrumentation.

The liquid/gas nitrogen mixers originally installed in the LN_2 system have been removed. Liquid nitrogen is used primarily for cooling the engine; however, the boiloff from the LN_2 storage vessel can be fed through the helium compressor to recharge the high-pressure GN_2 storage bottles. A small LN_2 vaporizer is being added to the facility to provide an additional source of GN_2 for recharge of the GN_2 storage bottles.

2.1.6 Gaseous Nitrogen System

The Gaseous Nitrogen System consists of an unloading station, LN_2 vaporizer (currently not installed), compressor with aftercooler (same as used in helium system), six 2500-psig 1770-cu-ft gas storage bottles (same as used in helium system), distribution piping, control valves, and instrumentation. The system provides inert gas for purging air or hydrogen from GH_2 lines, purging of the Steam Generator System, and inerting the Engine Test Compartment, Engine Test Compartment seals, and duct seals. In addition, the system provides actuation gas to the solenoid valve boxes located throughout the facility. GN_2 cylinders provide a backup supply to all critical valves in the event of a loss of GN_2 from the main system. Gas bottles are recharged either directly from the unloading station or by using vaporized LN_2 or boiloff from the LN_2 storage Dewar.

2.1.7 Liquid Oxygen System

The Liquid Oxygen System consists of an unloading station, a 22,000-gal 400-psig storage Dewar, a 400-psig LO_2 knockout surge pot, distribution piping, control valves, and instrumentation. Liquid oxygen flows from the LO_2 unloading station to the storage Dewar through a 3-inch insulated stainless-steel line. The Dewar is pressurized to 400 psig with gaseous nitrogen. From the storage

Dewar, the LO_2 flows to the Steam Generator System through a 6-inch insulated stainless-steel line. The surge pot, which is used to remove gaseous oxygen from the fluid, is located a short distance upstream of the steam generators.

2.1.8 Propane System

The Propane System consists of a fill station, a 16,425-gal 400-psig storage tank, distribution piping, control valves, and instrumentation. Liquid propane flows from the storage tank to the Steam Generator System through a 4-inch insulated carbon-steel line. Propane is also piped to the flare stacks and to the NES duct exhaust for pilot operation.

2.1.9 Process Water System

The Process Water System consists of a pumping station, demineralizer plant (rated at 167,000 gallons per day), pumps, a 2-3/4-million gallon demineralized-water storage tank, distribution piping, control valves, and instrumentation. The storage tank is located about 7000 feet north of the test stand and is elevated approximately 464 feet above the test stand elevation. It is connected to the test stand area by a 42-inch epoxy-lined carbon-steel pipe. The epoxy resin is applied to resist attack of the carbon steel by the demineralized water. Water from this system is used for cooling of the NES duct (33,400 gpm, full flow), as shielding and coolant for the Engine Test Compartment shields (~ 6000 gpm), as makeup and cooling water for the Steam Generator System (~ 1800 gpm), and for augmenting the Fire Protection System through the facility deluge system (18,700 gpm max.). A flow schematic of the system and its sequence of operation is given in Reference (13).

Several flow tests of the Process Water System have been conducted. During the early tests performed in September and October 1964, severe vibrations were noted in the process water piping, Reference (14). These vibrations were suspected to be caused by cavitation in the flow control valves due to lack of sufficient back pressure and, also, to natural frequency vibration of the piping system due to insufficient support. For the latest series of tests conducted o 23 and 24 June 1965, Reference (15), the flow control valves were relocated and the piping was more adequately supported. However, results from these tests indicate that an appreciable amount of vibration is still present in the system during full flow conditions. Additional testing and modifications to the system are planned.

2.1.10 Miscellaneous Process Systems

In addition to the systems already described, the following process systems are included in the ETS-1 Complex:

Flare System - consisting of the run-tank flare stack and knockout drum, the LH_2 storage flare stack, and the steam generator flare stack.

Vacuum System - consisting of vacuum pumps, connecting piping, control valves, and instrumentation. The system is used to evacuate certain process piping and storage vessels, and the annular spaces of the Dewars and vacuum-jacketed lines.

Utility Water System - consisting of a 150,000-gal storage tank, cooling tower, distribution piping, fire hydrants and sprinklers, control valves, and instrumentation.

Diesel Fuel System - consisting of a storage tank, distribution piping, control valves, and instrumentation.

Plant Air System - consisting of an air intake filter, compressors, receiver, prefilter, air drier, distribution piping, valves, controllers, and instrumentation.

2.2 Evaluation

2.2.1 Vessels

The liquid and high-pressure gas storage vessels utilized at ETS-1 are listed in Table I. The safety evaluation of these vessels has been based upon the information provided by References (1) to (17) and upon discussions with NTO personnel. Physical inspection of all the vessels was not accomplished, nor were test and inspection records for the vessels reviewed.

2.2.1.1 Dewars

The six Dewar vessels located at ETS-1 are fabricated with an inner tank suspended concentrically within an outer tank by a low heat transmitting suspension system. The annular space between the two shells will be evacuated to a pressure of 10 microns Hg, or less, at ambient conditions, to minimize the evaporation loss of the stored liquified gas. With the exception of the run tank (V-5001), the annular space between the shells is filled with perlite, a powdered-type insulating material.

The inner vessels have been designed, fabricated, inspected, and tested in strict accordance with American Society of Mechanical Engineers (ASME) "Boiler and Pressure Vessel Code, Section VIII, Rules for Construction of Unfired Pressure Vessels," for the internal operating vapor-space pressures indicated in Table I, together with a full vacuum externally. The inner shells are equipped with pressure-relief valves and rupture discs and with manual and remote operated boiloff vent valves. Hydrogen boiloff is vented to one of the flare stacks. *Inner vessel of run tank is not designed for full vacuum unless full vacuum exists in vacuum space between inner & outer vessels.*

TABLE I

ETS-1 STORAGE & PROCESS VESSELS

Vessel	Service	Capacity	Pressure	Ref.	Comments
V-5001 LH_2 Run Tank (Dewar)	LH_2	77,000 gal	50 psig	9	ASME coded, certified and stamped. Rupture disc and relief valve on inner vessel.
V-5002 LH_2 High Pressure Dewar	LH_2	4,400 gal	~~1500~~ 1800 psig	10	ASME coded, certified and stamped. Relief valve on inner vessel, rupture disc on outer vessel.
V-3801 LH_2 Storage Dewar	LH_2	250,000 gal	100 psig	16	ASME coded, certified and stamped. Multiple rupture discs and relief valve on inner vessel.
V-5003 LO_2 High Pressure Dewar	LO_2	550 gal	~~1500~~ 1800 psig	10	Currently not planned for use.
V-2801 LO_2 Storage Dewar	LO_2	22,000 gal	400 psig	10	ASME coded, certified and stamped. Relief valve on inner vessel, rupture disc on outer vessel.
V-3601 LH_2 (LN_2) Storage Dewar	LH_2 (LN_2)	31,000 gal	250 psig	10	ASME coded, certified and stamped. Relief valve on inner vessel, rupture disc on outer vessel.
V-3401 Propane Storage Tank	LP	16,425 gal	400 psig	9	ASME coded, certified and stamped.
V-3201 to 3206 High Pressure Gas Bottles (6)	GN_2, GH_e	1,770 cu ft	2500 psig	none	Built to ASME code(17).
V-3207 to 3209 High Pressure Gas Bottles (3)	GH_2, GN_2, GH_e	2,409 cu ft	2500 psig	none	Built to ASME code. ASME certification and stamping of these vessels is anticipated(17).

TABLE I (Continued)

Vessel	Service	Capacity	Pressure	Ref.	Comments
V-3001 Surge Tank	GH_2	--	230 psig	9	Code requirements not specified by Ref. 9
V-3003 & 3004 Oil Traps	GH_2	--	3600 psig	9	Built to ASME code.
V-3005 Air Receiver	Air	--	100 psig	9	Built to ASME code.
V-3006 Expansion Tank	Water	--	--	9	Built to ASME code.
V-2401 Diesel Oil Storage Tank	Oil	--	--	9	Built to ASME code.

The outer vessels have also been designed, fabricated, inspected, and tested in accordance with ASME "Boiler and Pressure Vessel Code, Section VIII, Rules for Construction of Unfired Pressure Vessels," for an external atmosphere pressure and internal vacuum. With the exception of the run tank the LH_2 storage Dewar, each of the outer vessels is equipped with a 4-inch sa head and rupture disc which is designed to rupture at an internal pressure of 15 psig. The outer vessels of the LH_2 run tank and storage Dewar are equipped with pressure-relief flanges which separate when the internal pressure in the annular space increases to atmospheric pressure.

The inner shell of the LH_2 run tank is supported from the outer shell by a weight-cell system, complete with calibration and readout equipment. The weight cell has been designed to weigh the inner tank assembly with a repeatable accuracy of 0.1 percent. This capability provides a separate and independent check on the quantity of LH_2 coolant remaining in the run tank and, thus, reduces the risk of inadvertently running out of reactor coolant as a result of a faulty instrument reading (liquid level indicator).

A dike has been installed beneath the LH_2 storage Dewar to contain, within a confined area, liquid hydrogen from a major spill or vessel rupture. The surface of the dike has been spread with gravel to increase the LH_2 evaporation rate.

No deficiencies have been noted in the design of the ETS-1 Dewars which could adversely affect the safety of ETS-1 operations. It is concluded that the design of these Dewars is adequate from the safety standpoint.

2.2.1.2 Gas Bottles

The documented information available within REON and NTO on the gas storage bottles at ETS-1 is limited; however, the following information was obtained through discussions with NTO personnel. The six 1770-cu-ft inert-gas bottles have been enclosed within a shed which is temperature controlled to 100 ± 20°F in order to maintain the temperature of the vessels above the Nil Ductility Transition (NDT) temperature for carbon steel (~ 70°F) and to reduce deleterious effects to the vessels from work hardening. These bottles have been downgraded by direction of SNPO-C from their design pressure rating of 3600 psig to 2500 psig. The bottles have been hydrostatically tested by the manufacturer to 5400 psig and pneumatically proof tested at the site to 3750 psig, Reference (17). The remaining three gas bottles which are intended for hydrogen gas storage were received at the site in June 1965 and are currently being installed. NTO plans to have these bottles ASME certified and stamped before use.[17]

Two pressure relief valves and a remote-shutoff valve are located on each of the six installed H.P. bottles to prevent overpressurization. The relief valves were designed for system operation at 3600 psig with a factory set relieving pressure of 4000 psig and a reseat pressure of 3200 psig. Since the gas bottles have been downgraded to 2500 psig these valves have been reset to relieve at 2750 psig.

On the basis of the above information, it would appear that the ETS-1 gas storage bottles can be utilized safely up to the planned operating pressures of 2500 psig.

2.2.1.3 Miscellaneous Vessels

The remaining vessels listed in Table I have been built and tested to ASME Code requirements and, as a result, should be adequate from the safety standpoint for their intended utilization at ETS-1.

2.2.2 Piping and Valves

2.2.2.1 Vacuum Jacketed Lines

The inner pipes have been designed in accordance with American Standard Association (ASA) Standard B31.3-59, "Petroleum Refinery Piping," for internal maximum line pressures at -423°F for LH_2 service together with full vacuum externally. Jackets have been designed in accordance with the ASME "Boiler and Pressure Vessel Code, Rules for Construction of Unfired Pressure Vessels, Section VIII" for an external atmosphere pressure and internal vacuum with pipe at ambient temperature.

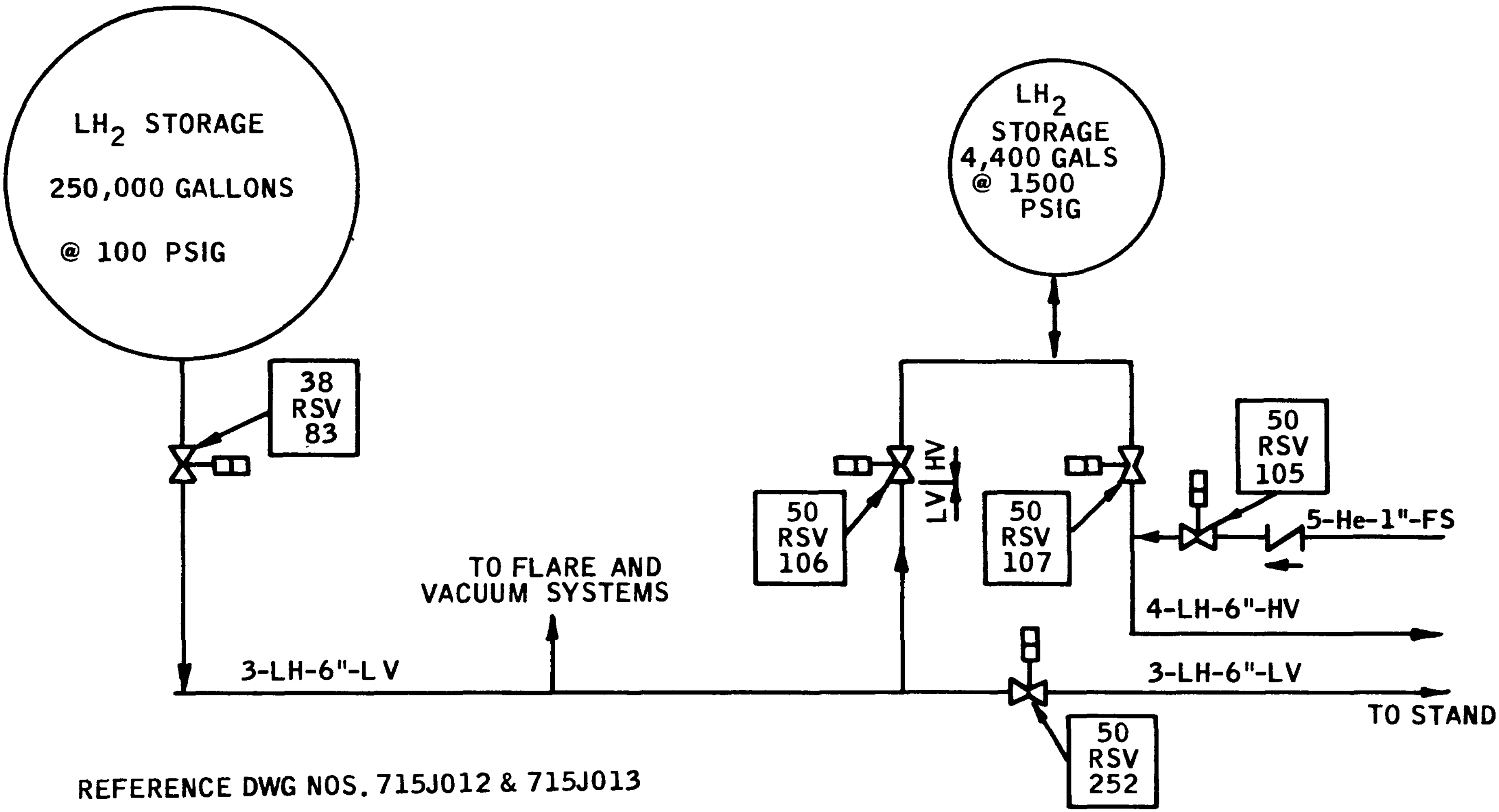
Since it is possible that cryogenic fluids can be trapped in a line between block valves which have been closed inadvertently, pressure-relief valves have been provided to the inner-pipe segments between shutoff valves. The relief valves have been sized to be capable of relieving at least 150 percent of the calculated bare-pipe volume of LH_2 boiloff at the normal summer ambient temperature which may be expected at the site, Reference (9). The relief valves are set to relieve line pressures in excess of 110 percent of maximum design pressure. The pressure-relief systems for these lines appear to be adequate from the safety standpoint.

The specifications for the vacuum jacketed lines, Reference (9), require that each vacuum-insulated section shall be equipped with a safety head and rupture disc with special vacuum support designed to rupture at [illegible] internal pressure of 30 ± 2 psig in the annular space. The purpose of this requirement is to reduce the damaging effects to the system and the hazards to personnel associated with pressure buildup and rupture of the annular jacket. Due to excessive leakage, the rupture discs provided on the jacketed lines at ETS-1 have been found to be unsatisfactory. As a result, the rupture discs on each section of line have been replaced by relief valves which have been set to relieve at approximately 9 psig.[89] This protection against over-pressurization of the jackets appears to be adequate from the safety standpoint.

2.2.2.2 Block and Bleed

Double block valves are commonly used to prevent leakage of Dewar hydrogen to transfer lines downstream of the storage system. The double-block setup consists of two closed blocking valves in series with the line between the valves vented to the atmosphere or other low-pressure system. The low-pressure venting insures that a leak in the first block valve (i.e., the Dewar shutoff valve) does not result in over-pressurization of the transfer lines or unduely restrict maintenance operations downstream of the storage vessel.

A simplified schematic of the ETS-1 LH_2 storage system[4-7] is shown in Figure 1. As can be seen, a double block and bleed cannot be used on the downstream side of the large LH_2 storage Dewar or on either the upstream or downstream sides of the high-pressure storage Dewar. Thus, in order to safely perform many of the maintenance operations which may be required on the system, one or both of the LH_2 storage Dewars must be drained, brought to ambient temperature, and purged. For example, in order to effect repair of leaks in valves RSV-106 or RSV-252, or in Line 3-LH-6"-LV upstream of RSV-252, without endangering maintenance personnel, it would be necessary to dump the entire contents of the large LH_2 storage Dewar to the atmosphere. To preclude or lessen the necessity for this very costly and time consuming operation,



REFERENCE DWG NOS. 715J012 & 715J013

FIGURE 1

SIMPLIFIED SCHEMATIC OF ETS-1

LH_2 STORAGE SYSTEM

it is recommended that modifications to the LH_2 storage system be made to allow for double block and bleed setups on both of the LH_2 storage Dewars. These modifications will also prevent over-pressurization and interruption of fluid flow in Line 3-LH-6"-LV should RSV-106 leak high-pressure fluid from the small Dewar during operations involving transfer of LH_2 to the run tank.

2.2.2.3 Pressure Relief Valves

Pressure-relief valves are installed at ETS-1 in connection with all pressure-reducing valves which separate high and low pressure lines to prevent excessive pressure on the low-pressure side of the regulator. Relief valves are also used on cryogenic lines between blocking valves, in all high-pressure systems, and on liquid and gaseous storage vessels to prevent pressures from exceeding design limits. Relief valves are of the automatic closing type and have been designed to meet the requirements of ASME "Boiler and Pressure Vessel Code, Section I, Power Boilers."

The discharge of all relief valves in the hydrogen systems must be piped to safe disposal points such as to the flare stacks or to local vent stacks. This practice has been followed at ETS-1 with the exception of the pressure-relief valves in the high-pressure gaseous-hydrogen storage system, namely RV-604 through RV-609, RV-278, RV-337, RSV-193 and RSV-194 (Reference Dwg No. 715J014). The discharge from these valves should be piped to local vent stacks instead of directly to the atmosphere as is indicated on the drawings. Each vent stack should be terminated with a tee to equalize line forces produced by high-pressure discharge from the system.

Throughout the ETS-1 Complex, manually operated globe valves are placed directly upstream of pressure-relief valves. The globe valves are sealed in their open position with lightweight wire and a soft metal clamp. Since these valves may be inadvertently left in a closed position during system operation, this feature in the design is highly undesirable from a safety standpoint. It is recommended, therefore, that wherever globe valves are used in connection with pressure-relief valves on high-pressure lines or on pressurized storage vessels, the system configuration be modified in one of the following manners:

(1) remove the globe valve from the system,

(2) physically lock the valve in its open position so that it cannot be closed without following a specified and approved procedure,

(3) tack-weld or otherwise fix the valve in its open position, or

(4) provide dual relief valves which are connected to a common three-way two-position valve in such a manner that one of the valves will always be directly connected into the high-pressure system.

This latter modification is particularly desirable on the pressurized storage system, since it allows for safe removal and repair of one of the relief valves without depressurizing and completely emptying the storage vessel. It should be noted that a duel relief-valve configuration has been provided for the high-pressure gas bottles at ETS-1; however, a common three-way two-position valve has not been used.(7)

2.2.2.4 Check Valves and Blind Flanges

Check valves are installed in lines at ETS-1 to prevent inadvertent over-pressurization of lines and vessels, undesirable backflow through piping, and inadvertent mixing of air with combustible fluids. These valves are also used to maintain the desired direction of flow under variable operating conditions. A review of the check valve utilization in the ETS-1 process systems References (4) to (7), revealed only one location where it would appear that an additional check valve should be provided, viz., in the inlet line to the run-tank flare stack, Line 20-GH-12"-AS, to prevent the entry of air into the flare-system piping when the nitrogen purge system is not operating.

The high-pressure gas storage system is equipped with blind-flange-type blanks which can be positioned so as to completely isolate the high-pressure gas bottles from the gas headers and thus prevent improper utilization and mixing of high-pressure gases, and exclude inadvertent pressurization of systems during non-test periods. This feature has been adequately provided for in the ETS-1 process system design, as indicated by Reference (7).

2.3 Conclusions

On the basis of the information reviewed, it is concluded that the design of the Process and Fluid Systems for ETS-1 is adequate from the safety standpoint with the following exceptions:

(1) Modifications to the LH_2 Storage System should be made to allow for double block and bleed setups on both the LH_2 storage Dewar and the LH_2 high-pressure Dewar. (See Section 2.2.2.2)

(2) The discharge from the relief valves in the high-pressure gaseous hydrogen storage system, namely RV-604 through RV-609, RV-278, RV-337, RSV-193, and RSV-194, should be piped to local vent stacks instead of directly to the atmosphere as indicated on Dwg No. 715J014. (See Section 2.2.2.3)

(3) Wherever globe valves are used in series with pressure-relief valves on high-pressure lines or on pressurized storage vessels, the globe valves should either be removed from the system or be physically locked in their open position, or dual relief valves which are connected to a common three-way two-position valve should be provided so that with one of the valves removed, the other valve will always be directly connected into the high-pressure system. (See Section 2.2.2.3)

(4) A check valve should be added to the inlet line to the run-tank flare stack, Line 20-GH-12"-AS, to prevent the entry of air into the flare system piping when the nitrogen purge system is not operating. (See Section 2.2.2.4)

3. NUCLEAR EXHAUST SYSTEM

3.1 Description

The purpose of the Nuclear Exhaust System (NES) is to direct the hot nuclear exhaust gases and fission products away from the test stand during an engine firing and to provide a steam safety purge. The system is composed of two major subsystems; namely, the Duct System and the Steam Generator System. These systems include their respective piping, valving, instrumentation, and controls. Documentation of the design and of supporting analytical and experimental studies is given in References (51) through (61).

3.1.1 Duct System

The ETS-1 NES duct is a welded, stainless steel (Type 347), double-walled heat exchanger. It is divided into three cooling sections. Coolant is provided during duct operation by a one-pass, gravity-fed water system. An artist's conception of the duct and support structure is shown in Figure 2. All major duct-to-facility interface points are noted. The duct geometry is shown in Figure 3.

A severance plane is located between the top of the 90° elbow section and the bottom of the primary straight section. This is provided so that the entire duct-truss assembly can be shipped in two sections. When the duct assembly is to be removed from the test stand after a series of firings, it must be done remotely and as a single unit. Upon removal, the duct can then be separated at the severance plane for ease of transport.

The duct is supported in the truss assembly by hinged supports located in the 90° elbow section. These supports are capable of carrying both vertical and horizontal loads. Four roller supports located on each side of the

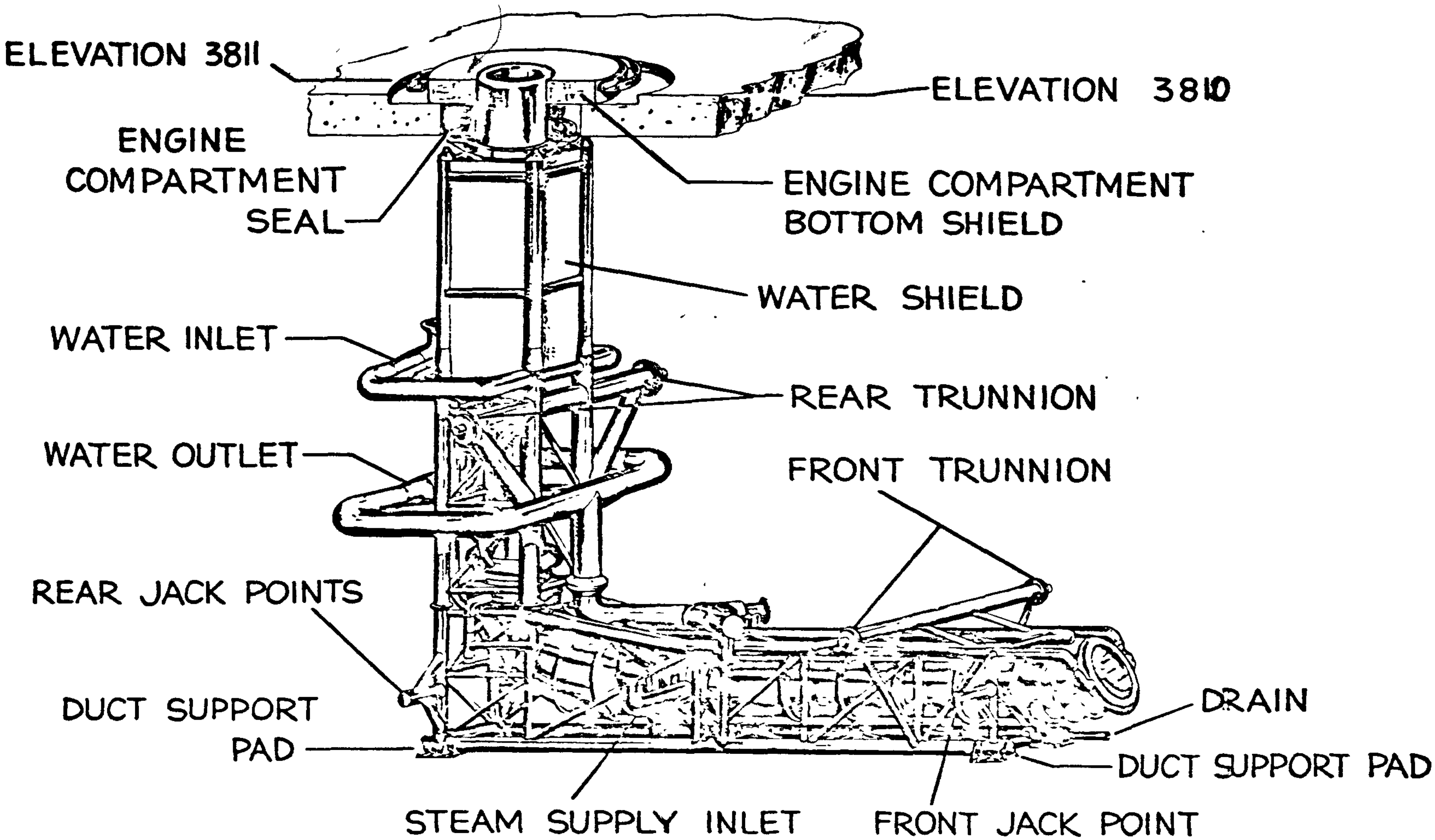


Figure 2

ETS-1 NES Duct

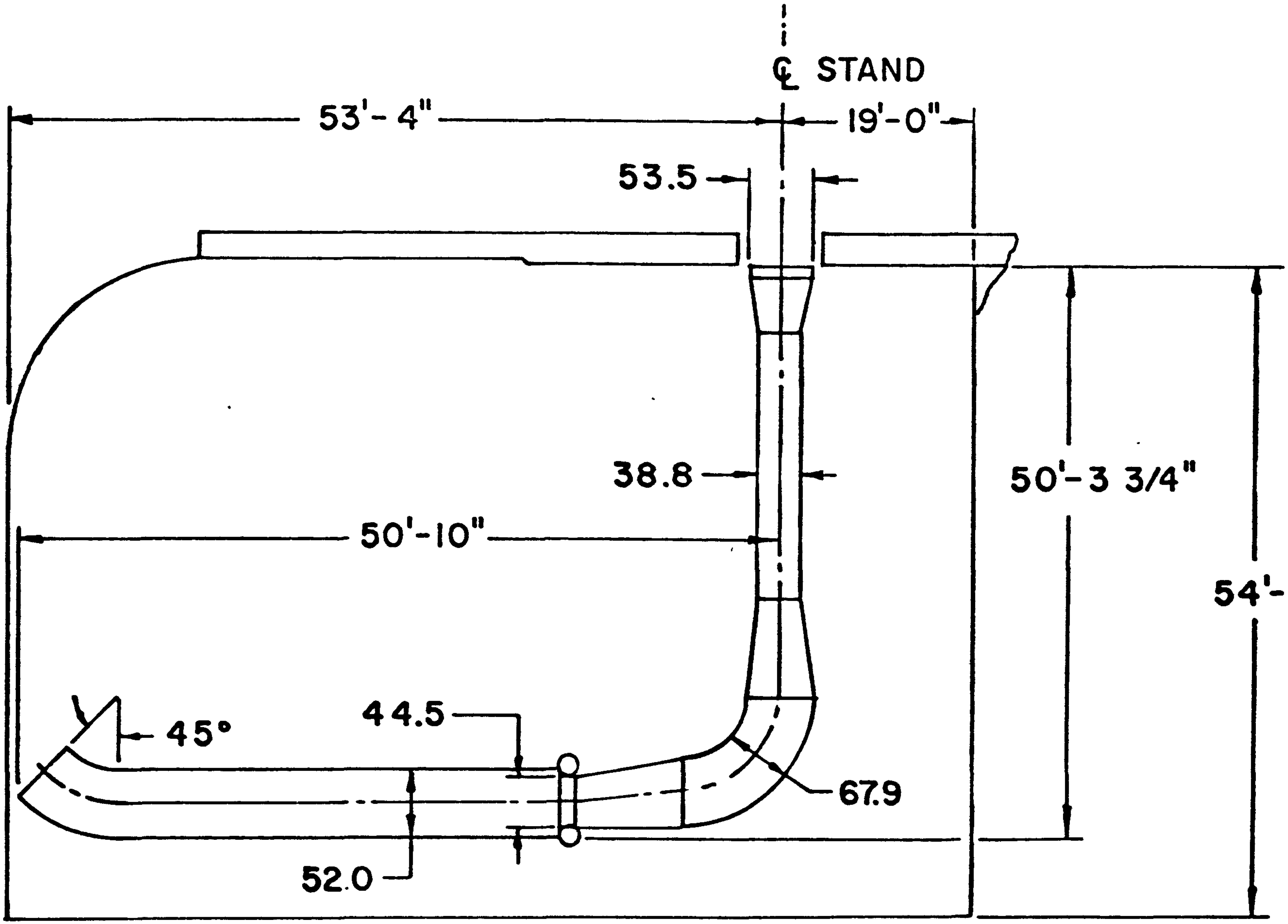


Figure 3

NES Duct Geometry

duct are capable of carrying lateral loads. In this manner, the duct is permitted to expand circumferentially and longitudinally from the hinged support.

The primary section of the duct was designed to operate as a s d throat supersonic diffuser. In the operation of this type of diffuser the supe stream shocks down to a subsonic stream, with a commensurate increase in pressure This process occurs in the cylindrical portion of the duct The diffusion process is sufficient to provide an engine compartment pressure of 1 psia The inlet area was made as large as possible without interfering with the diffuser action. The conical section downstream of the supersonic diffuser is a subsonic diffuser to further reduce the velocity before entering the elbow. Downstream of the elbow an offset conical section is used to act as a flow stabilizer within the elbow The cone is offset to make the duct self-draining.

The secondary ejector is the location at which the steam is intro-duced to provide some pumping and also to provide an inert atmosphere within the duct in the event of a nuclear engine malfunction. The secondary ejector is the larg diameter section because of the requirement to handle the engine flow plus the steam flow. A flow of 130 lb/sec of steam reduces the engine compartment pressure to abo 8 psia with no engine flow.

The drain tube located at the 45° exit elbow is installed t prev water accumulation within the duct The 45° exit elbow deflects the exit gases r-wards to minimize the thermal heating of the drainage ditch and test stand

One of the primary considerations in the design of the duct was the proper cooling of the system during operation. St dy findings dictated that duct had to be divided into three separate cooling sections These are 1 the primary or supersonic duct section, (2) the 90° elbow and offset cone, and (3 th secondary duct or subsonic section, including the 45° exit elbow and low-point drain. A double-wall, smooth-inter-surface configuration, constructed from an inner shell and a series of angles welded to the periphery of the inner surface, form the coolant passage configuration in the primary and secondary sections of the duct. The 90° elbow and off-set-cone coolant passage was designed as a tubular bundle, formed to the proper contour and welded both internally and externally. Each of the three principal sections have separate coolant-water manifolds. Water is delivered at one end of the section through a ring manifold circling the duct. The water makes a single pass through the cooling channels and then exits through the discharge manifold. Because of thermal expansion, water lines connecting to the ring manifolds have expansion joints to provide freedom of movement between the duct and supporting truss. The total duct coolant water flow rate is 33,400 gpm. The heat flux varies from 0.5 to 2.6 Btu/in.^{2}-sec. The total heat transfer is approximately 125,000 kw.

During NES duct operation, remote monitoring of events is provided to the test stand operations personnel by means of instrumentation. The two major functional divisions of this instrumentation are control and diagnostic. In order to simplify the design, the duct coolant system was designed as an on-off or go-no-go operation. The water supply and discharge valving can be cycled but only in two positions: full open or full closed. All remote interface connections are controlled in order to accomplish the remote removal of the ETS-1 NES duct. (The duct will be removed only after it has been damaged and requires replacement.) Diagnostic instrumentation for measuring such parameters as temperature, pressure, flow, strain and vibration, is provided to the test stand operator to assist him in determining or predicting a system malfunction.

3.1.2 Steam Generator System

3.1.2.1 General

The steam generators and associated components are lo at ETS-1 on the south side and near the east end of the test-stand shadow shi . They are contained within a reinforced-concrete blast enclosure which is open to the northeast. The enclosure has wall and roof thicknesses of approximately 15 inches. As protection against fire, 10 spray nozzles are located inside the enclosure and 6 are located outside. The deluge system is activated by heat activated devices (HADs), 4 inside the enclosure and 2 outside. In addition the enclosure is ventilated in compliance with National Fire Protection Association Pamphlets #68 and #91. The ventilation system is connected to the deluge system such that in the event of a deluge the ventilators are automatically shut down.

An artists conception of the Steam Generator System (SG is shown in Figure (4). The system is a three-module unit, two of which when running at full flow produce sufficient quantity of steam to prevent air back-flow into the duct and engine compartment. The third module is a back-up spare and is operated at full capacity only when a malfunction has occurred to one of the other modules. The required energy for steam production is provided by the combustion of propane with oxygen. Steam output is increased in mass flow and the temperature controlled by the injection of water into the third stage or main combustion chamber.

The three steam modules, which are mounted on a common base assembly, feed into a single steam plenum output chamber. Each mod is up of a steam generator with control, safety, and sequence equipment that is capable of operating independently of the other modules. The base assembly contains th

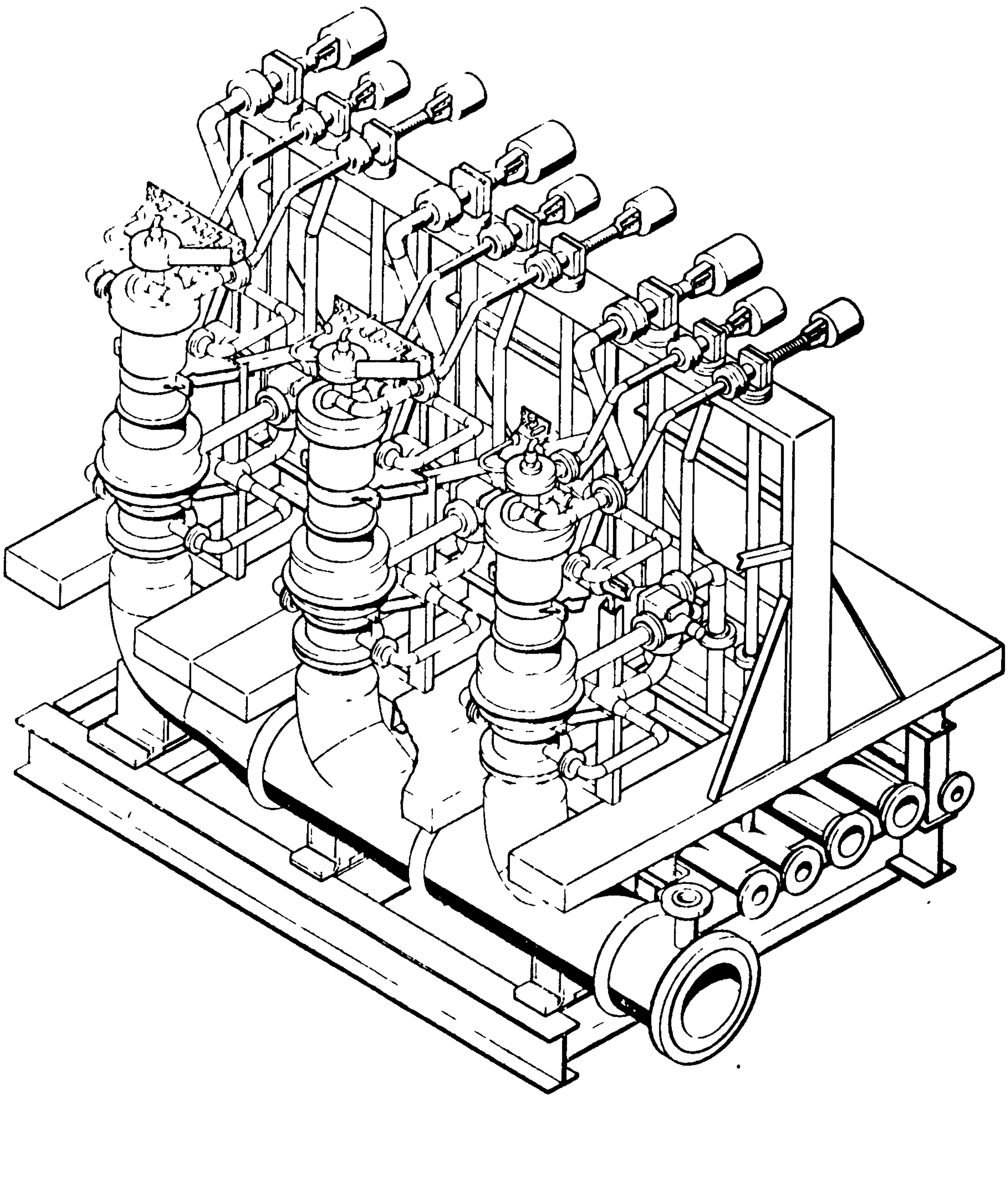


Figure 4

Steam Generator System

equipment common to all modules. This equipment includes common control, inlet and distribution manifolds, and a steam collection and discharge duct.

The SGS system is designed to product a normal output o super-heated steam in accordance with the following specifications:

a. Steam temperature 1300°F ± 100 F

b. Minimum steam pressure 130 psia

c. Weight flow (nominal) 130 lb/sec

Each generator is capable of producing 65 lb/sec, thus the required 130 lb/sec output can be delivered by two of the modules. The third module, if in standby, will automatically come to full output if required.

The combustion element of each module is a pressure vessel which contains and controls the combustion process. Each will utilize approximately 8 lb/sec of propane to produce gas at a temperature of about 5100°F. Steam is generated and the temperature controlled to 1300°F by the water injection system. The fuel is burned at a nominal mixture ratio of 2.6 in the main chambers and igniters. The combustion element consists primarily of:

a. First stage igniter

b. Second stage igniter

c. Main stage injector

d. Main combustion chamber

e. Water injection and cooling system

Ignition of the SGS is accomplished by a two-stage spark-initiated igniter. Propane is supplied to the first stage in the liquid state, atomized into the combustion chamber and mixed with gaseous oxygen (GO_2). Ignition is accomplished by a continuous spark provided by a 10,000 volt transformer. The spark plug is cooled by GO_2 flowing across the spark gap. The rate of flow of propellants to this stage is controlled by a cavitating venturi in the propane side and an orifice in the liquid oxygen (LO_2) side of the system. The LO_2 is converted to the gaseous phase by passing through a heat exchanger. The first stage is cooled by water flow through a concentric jacket.

The second-stage igniter is concentric with the first stage. It is ignited by a spear of flame produced by the first stage and is operated with liquid propellants which are drawn from the main manifolds at a constant flow controlled by cavitating venturis. This igniter is cooled by water circulating through a jacket. The second-stage igniter is designed for continuous duty and is independent of the spark and first-stage combustion after achieving ignition.

The combustion chamber contains the final and major combustion process and provides water injection to reduce the gas temperature to design conditions. The main chamber is cooled by external circulation of water through a jacket.

The steam plenum is a water cooled header which ducts the steam discharge of each of the three modules into the exhaust system. The plenum is water cooled, and has one inlet manifold adjacent to each steam inlet to provide even cooling-water distribution.

3.1.2.2 Control System

The control system for the Steam Generator System controls the steam generating process, permits step variation by command, and automatically protects the system from damage due to malfunction. A control console, remotely located, is the sole operating point. All operations except "propellant fill" are automatic. Checkout of components is accomplished with simulated signals which operate all of the components in sequence.

The control system is set up to command each module either generate steam at full flow or to operate at igniter idle. The capabil. exists to operate any combination of units. Normal operation comprises two of the three units to be "on-the-line" with the third unit on automatic standby and operating at igniter idle. The required capacity of steam is obtained when two modules are "on-the-line" and the third is at igniter idle. In the event that a malfunction should require that one of the units be shut down, the standby unit is automatically brought to full-flow output in approximately two seconds.

The control system is built to National Electrical Code, Class I, Group D Standards. All electrical inter-connections on the skid are conduit enclosed, and where required, the components are protected by a continuous purge.

A master sequencing unit in the control system provides (1) a readiness signal when the main manifolds are pressurized (water, N_2, LO_2, C_3H_8), and (2) automatic full flow on a standby idling unit when plenum steam pressure drops to a pre-set value Operation of the individual generator modules is controlled by separate sequence circuits in each generator module and coordinated by the master sequence unit.

3.1.2.3 Sutdown Safety System

The SGS is provided with several safety circuits, both pre- and post-start, which function to provide an automatic safety system for the steam generator. In addition to the safety circuits, all operations must be performed in proper sequence, i.e., each step must be successfully completed before subsequent steps can be accomplished. Thus, the overall system, independent of the added safety circuits, has been designed to be inherently safe.

The following is a listing of the safety interlocks, the system functions that are monitored, and the item which supplies the input signal:

a. Start-up is prevented if:

(1) The liquid oxygen, propane, and water manifolds are not pressurized to the minimum prescribed values (pressure switch).

(2) The gaseous nitrogen purge and valve actuation pressures are not at prescribed minimum values (pressure switch).

(3) The propellant lines have not been bled within 60 seconds prior to initiating the start command (timer).

b. First-stage ignition is prevented if:

(1) Nitrogen purge is not available (pressure switch).

c. Second-stage ignition is prevented if:

(1) The first-stage chamber pressure is below the prescribed minimum at the end of 6 seconds (pressure switch and timer).

(2) Nitrogen purge is not available.

d. Main-stage combustion is prevented if:

(1) The second-stage chamber pressure is below the prescribed minimum at the end of 6 seconds (pressure switch and timer).

(2) The injection water is not flowing into the main chamber (pressure switch).

e. System shutdown is initiated if:

(1) The plenum chamber is not to the prescribed pressure in a given time interval after the main-chamber fuel valves are open (pressure switch and timer).

(2) Either cooling or injector water flow falls below the prescribed minimum (pressure switch).

(3) The steam temperature exceeds 1800°F (temp - switch).

(4 The manual shutdown signal is given by the operator (console shutdown button

Under normal SGS operation all safety circuits are bypassed at 5 seconds after full-steam command, except high steam temperature combined with either loss of injection water or jacket coolant-water pressure

In addition to the automatic safety inputs, the Test Engineer has a number of readouts on the control console which independently monitor pressure and/or temperature at critical locations. These are:

a. First-stage chamber pressure

b Second-stage chamber pressure

c. Main-stage chamber pressure

d. Propane manifold pressure

e. Water injection pressure

f. Steam outlet temperature and pressure

This permits the Test Engineer to manually command a system shutdown if any of the above items do not appear normal. It also permits shutdown before automatic initiation if the Test Engineer, by observation, decides that it is advisable

3.1.2.4 System Power Supply

The steam generator system is operated entirely from a 28 volt dc system. This system is derived from commercial power. The ETS-1 facility has an emergency battery supply which floats on this 28 volt dc system

Thus, in the event of loss of the primary power system, operation of the steam generator would not be affected and the emergency power system would be used to safely shut down and secure the Steam Generator System.

3.1.2.5 Cold Checkout System

The cold checkout system is utilized to check all pre-start and post-start safety circuits. This checkout confirms the functioning of all shut-down inputs from pre-start, to and including full-steam flow.

The system consists of a group of three-way solenoid valves which transfers the steam-generator pressure switches from the operating source to a cold-checkout GN_2 manifold. This transfer permits the actual operation of the pressure switches and valves to produce a simulated startup during which malfunctions are introduced to confirm proper response of the safety circuits.

In order to ensure that no LO_2 or propane is released from the storage tanks during the cold checkout, an arm switch (key operated) on the console is placed in "OFF" to prevent operation of the main propellant valves

It is to be noted that the cold checkout system does not provide for confirming the pressures at which the switches actually trip The check-out only confirms that the switch functions, and does not confirm that the switch has tripped at the prescribed pressure.

3.1.3 NES Operation

3.1.3.1 Required Flow Into Engine Compartment

The expected engine compartment pressure during X-Engine tests is shown in Figure 5[52] To eliminate inherent instability in the engine-compartment pressure just prior to pull-in, it is necessary that some gas be introduced into the engine compartment during a test firing. If the amount of side-

NOTES. 1. TURBINE EXHAUST FLOW AT DESIGN VALUE
2. SAFETY PURGE - P_{sc} = 100-115 psia, T_{sc} = 1600-1700 °R, $\dot{W}_s$ = 115-130 lb/sec, $\dot{m}_s$ = 18-2
3. SEAL LEAKAGE FLOW = 0-2 lb/sec AMBIENT N_2
4. P_a = 12.8 psia

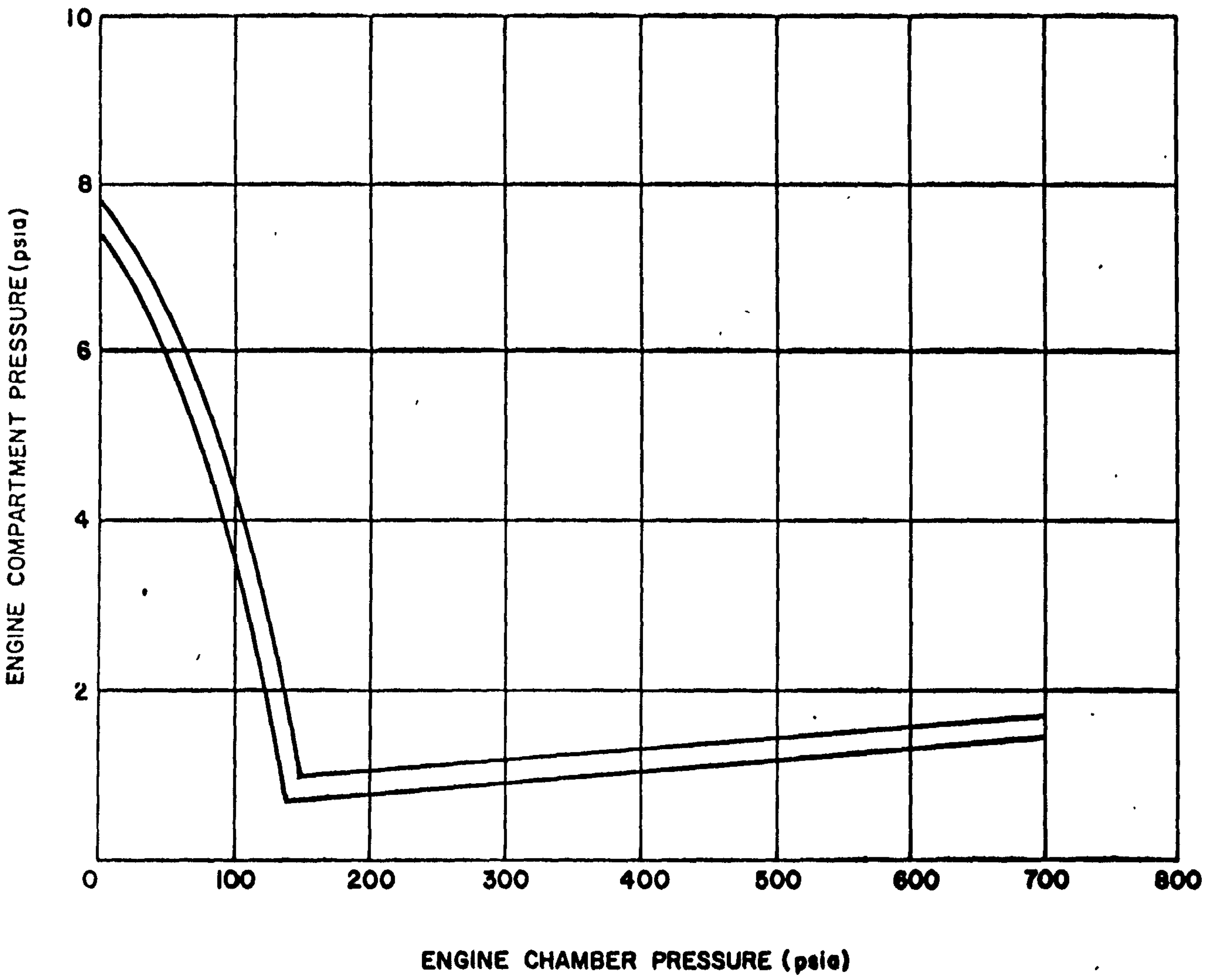


Figure 5

Engine Compartment Pressure vs 10:1 Conical NERVA Nozzle Chamber Pressure

shield seal leakage and actuator bleed is as expected (1.5 lb/sec of N_2), there is no problem. However, there is a possibility of no side-shield seal leakage in which case it will be necessary to add nitrogen to the engine compartment to make the total flow rate of nitrogen at least 1 lb/sec. Since the system can adequately handle this flow plus the expected seal leakage, it has been recommended by NES Project Personnel that this gas flow be added[52].

3.1.3.2 Maximum H_2 Flow Into Engine Compartment

A rupture in the main propellant feed line could result in a large volume of cold hydrogen entering the Engine Test Compartment. This would cause an increase in the engine-compartment pressure. Figure 6 illustrates the results of a study[54] made to determine the maximum flow rate permissible commensurate with not overpressurizing the engine compartment. It was assumed that the steam safety purge system was operating at design conditions and that no fluid was passing through the nozzle. No attempt was made to estimate the hydrogen temperature but it was felt that if none of the gas passes through the reactor that the temperature will be reasonable low.

3.1.3.3 Heat Transfer

The design condition for the hot side of the duct was assumed to be NERVA engine full-power operating conditions. In addition, an engine malfunction condition was considered. This condition results from reactor core "break-up," with resulting small particles of hot, solid material transversing the duct. This added heat flux (in addition to convection from the hot gases) was assumed to be the maximum obtainable, i.e., black-body radiation and all radiant energy emitted falling on the inside surface of the duct.

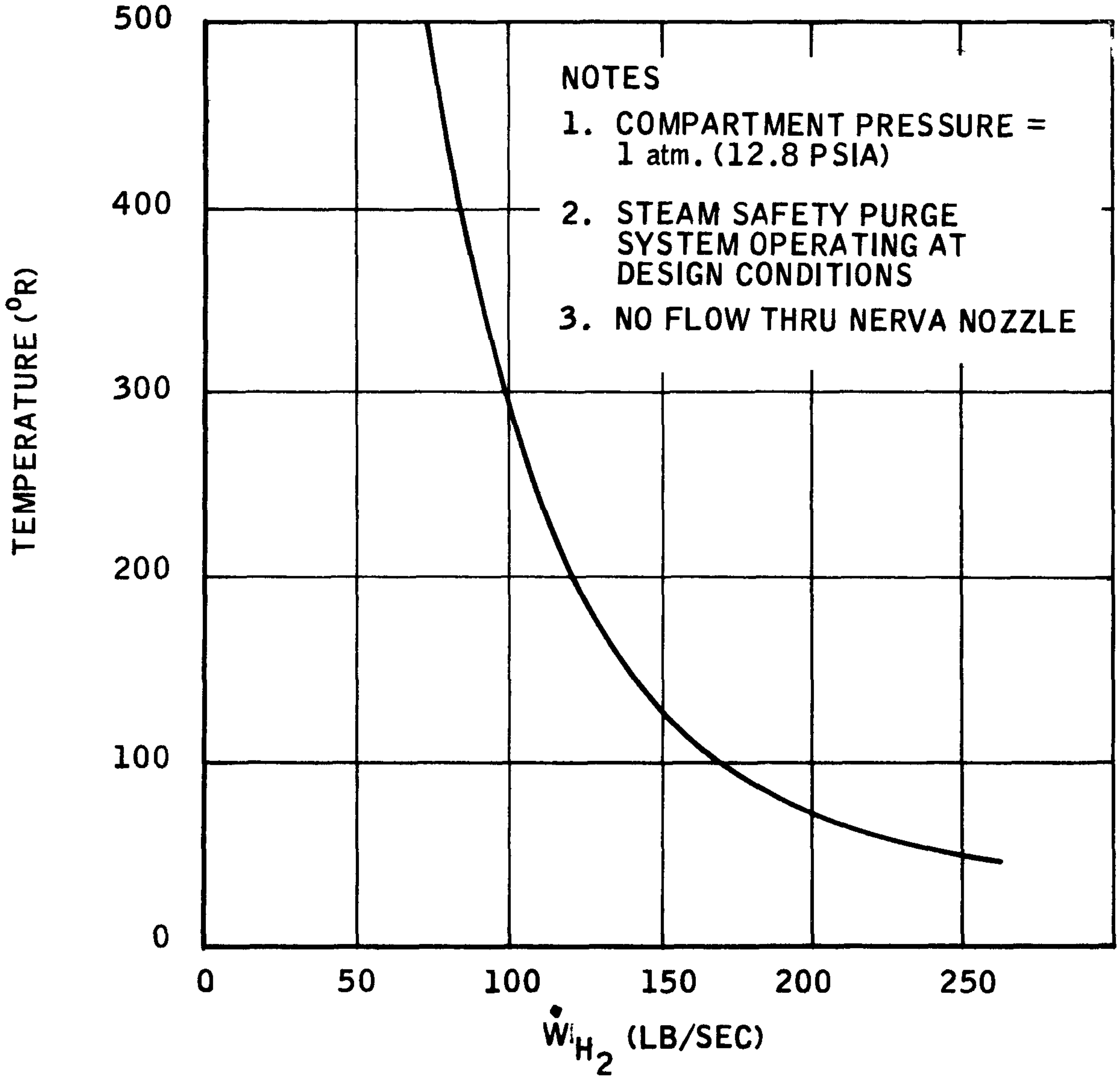


FIGURE 6

MAXIMUM H_2 FLOW INTO ENGINE COMPARTMENT WITHOUT EXCEEDING 1 PSIG

The following design limits were used in the heat-balance calculations for the coolant-passage design:

1. Maximum wall temperature not to exceed 1150°F during normal operation (stress limit).

2. Maximum design coolant-side wall temperature = 320°F This insures no nucleate boiling in the coolant passage at design pressure under normal conditions. During the malfunction condition, the majority of the duct cooling surface will operate in the nucleate boiling regime.

3. Maximum outlet bulk temperature at malfunction conditions = 180°F. This restriction prevents "flashing" at the outlet.

The burn-out flux was computed to be a factor of two higher than the maximum flux calculated for the assumed malfunction operation The condition of minimum velocity and subcooling were used in the calculation. Thus, from a thermal standpoint, the duct should operate satisfactorily during the assumed malfunction condition.

3.1.3.4 Safety Purge

The ejector system must, at all times, exhaust the hydrogen gas so that it can be safely disposed of by burning. Air must not be allowed to mix with the hydrogen inside the duct. While the engine is running, the primary ejector accomplishes this separation of air and hydrogen. Prior to start-up, the air in the Engine Test Compartment is replaced by nitrogen using the ETC purge system. During engine cooldown with hydrogen, steam flow in the duct is maintained to preclude entry of air.

A major malfunction (e.g., rupture of the main prop[illegible]ant line or seizure of the turbi[illegible]) ca[illegible]s [illegible] instantaneous cessation [illegible] flow to the engine and, in turn, collapse the established shock structure in the duct. Upon collapse of the shock structure, a large pressure differential exists between the engine compartment ($P_v \leq 2$ psia) and the atmosphere (P_a - 12.8 psia at NRDS). This pres gradient would force in air, mix it with the residual hydrogen in the duct, and create an explosive mixture. This surge of gas would also cause overpressurization of the engine compartment and separate the side shields A secondary purge system is located aft of the elbow to introduce the safety purge fluid. This inert fluid will fill the engine compartment and prevent air from entering the ejector and will prevent overpressurization in the event of a malfunction, as described

The required secondary safety-purge fluid for the ejector system is primarily steam, with the following properties:

Ratio of specific heats	1 25
Molecular weight	18-21
Nozzle stagnation pressure	100-115 psia
Nozzle stagnation temperature	1600-1700°R
Flow rate	115-130 lb/sec
Nozzle throat area	119 in.^{2}

The secondary safety purge flow rate is equal to the sum of the choked flow rate (97 lb/sec) required to fill the engine compartment without allowing air to enter the ejector in the event of an instantaneous termination of the reactor working fluid, and the flow rate (23 lb/sec required to prevent penetration of 35-mph air into the ejector.

3.1.3.5 Exhaust Plume

The predicted exhaust-plume size and shape, based on test data as well as analysis, and the predicted thermal radiation from the exhaust plume to proximate surfaces is given in Reference (55). Temperature-rise time data were calculated for the concrete drainage ditch floor, test stand walls, and the aluminum radiation shields. Results indicate that extremely high temperatures (on the order of 1000 to 2000°F) may be expected at certain points on the concrete surfaces which are not cooled. Appreciable surface damage in these areas is expected.[55]

3.2 Evaluation

Considerable care has been taken during the NES design and development to provide the system with a high degree of reliability and safety. The system incorporates a wide range of sequence and safety circuits, which, if properly functioning, will automatically protect the system from damage and assure its proper performance and continuous operation during engine tests. Furthermore, extensive checkout and demonstration tests are planned[57] for the system prior to its utilization during XE and XECF test operations. These tests should verify its predicted performance and result in the identification and elimination of any "bugs" or deficiencies in the design. However, as a result of the present review and evaluation of NES, two potentially serious safety problems inherent to its utilization at ETS-1 have been identified; specifically, (1) the introduction of oxygen-rich steam into the hydrogen environment of the duct during engine test operations, and (2) the formation of explosive oxygen/propane mixtures in the Steam Generator System. Each of these problems is discussed below.

3.2.1 Introduction of Oxygen-Rich Steam Into the Secondary Duct

The introduction of excess oxygen into the hydrogen environment of the duct during engine operation represents a potential explosion hazard to the NES system. In general, oxygen/hydrogen explosions result from two distinct modes of reaction - deflagration and detonation. Under initially ambient temperature and pressure conditions in air, deflagration can occur over a hydrogen concentration range of 4-74 volume percent while detonation can occur over a range of 18-59 volume percent(62). These concentrations correspond to minimum oxygen/hydrogen ratios in air of 0.07 for deflagration and 0.15 for detonation. Explosive limits for oxygen/hydrogen mixtures in the NES duct under various operating conditions are not known, nor is it apparent that they can be reliably predicted from information contained in the literature. However, it can be inferred from experience gained with oxygen/hydrogen mixtures in air, that a serious problem may exist under certain flow and temperature conditions if the volumetric concentration of oxygen in the duct during operation exceeds approximately 5 percent.

The specification for the Steam Generator System(58) requires that the exhaust gas from the oxygen/propane combustion shall contain less than 4.0 volume percent free oxygen. For the optimum SGS oxidizer/fuel mixture ratio of 2.6, Reference (16) reports the free oxygen content of the exhaust gas to be 2.76 percent The normal oxygen content of the steam entering the duct will be considerably less than this value due to the large quantity of water mixed with the exhaust gas following combustion. However, there are several situations which can arise during NES operations that may increase to a hazardous level the free oxygen content of the steam reaching the secondary duct. These situations are particularly hazardous during engine cold-flow experiments (when hydrogen temperatures in the duct are within the range of 200-300°R) for the following reason. During hot tests, the hydrogen/oxygen mixture will be considerably above the auto-ignition temperature (~1100°F) so that burning may be expected to occur as the oxygen contacts the hot hydrogen gas. Under these conditions, it is expected that the free oxygen in the duct will be consumed before an explosive mixture can be formed. However, during cold flow experiments the hydrogen/oxygen mixture will be well below the auto-ignition temperature so that an explosive mixture may be formed if sufficient quantities of oxygen are introduced into the system.

The types of system malfunctions which may lead to a condition of oxygen-rich steam are discussed below.

a. <u>Loss or reduction of Propane Flow to Main Combustion Chamber</u>

A line rupture, filter plugging, inadvertent valve closure, or loss of system pressurization can result in partial or total loss of propane flow to one or more of the steam modules. Should the failure affect only one of the two operating modules, automatic startup of the standby module from its idle condition to full steam will result upon receipt of a signal indicating low steam pressure from the failed module; however, automatic shutdown of oxygen flow to the failed module will not occur since automatic shutdown of a steam module results only when both conditions of high steam temperature and low water flow are indicated. Consequently, oxygen will continue to flow into the steam plenum (at a rate of approximately 23 lb/sec) and from there into the duct until such time as manual shutdown of the failed module is initiated. Should the failure in the propane system cause loss of propane flow to the entire SGS unit, both of the operating modules will fail and a total of 46 lb/sec of oxygen will be fed into the system. Furthermore, the loss in steam pressure will signal the standby generator to full steam, with the possibility of introducing an additional 23 lb/sec of oxygen into the system. The standby module will automatically shut down within 3 seconds due to either a signal indicating low steam pressure or a signal indicating low pressure in the second stage; however, the originally operating modules will continue to flow oxygen until manually signaled to shutdown. Should one of these conditions arise when the duct is flowing cold hydrogen, a damaging explosion may result.

As an example, consider the situation where either propane is lost to one of the operating modules or one of the operating modules shuts down and the propance valve on the standby module fails to open when signaled to full steam. Under these conditions steam and oxygen will flow to the duct at rates of 65 and 23 lb/sec, respectively. The estimated hydrogen content of the secondary duct as a function of hydrogen gas temperature is shown in Figure 7. Assuming the hydrogen in the secondary duct is at a temperature of 300°R and at a pressure close to ambient, then from Figure 7, this portion of the duct will contain approximately 3.6 pounds of hydrogen flowing at a velocity of 640 ft/sec. If it is also assumed that the oxygen and steam are swept through the duct at the hydrogen velocity, then the oxygen and steam content of the duct will be approximately 1.1 and 3.1 pounds, respectively. Using a TNT equivalent ratio of 3.5 for stoichiometric mixtures of H_2/O_2 (63) and assuming that 60 percent of this mixture is ignited to react in a detonation, the blast will be equal to 2.5 pounds of TNT. Based on the criterion contained in Section 11.4 of Reference (64), major structural damage to the secondary ejector portion of the duct from the resulting blast waves may be expected.

b. Premature Shutdown of a Steam Module

Automatic shutdown of a steam module results when both conditions of high steam temperature and low water flow (either cooling water or feed water) occur. When these conditions are indicated, the main oxygen valve and the main propane valve are signaled to close concurrently. (Closure requires approximately 0.5 second.) Due to dissimilarities in circuit response times and valve operating characteristics, some excess oxygen may be fed to the steam plenum during the shutdown transient.

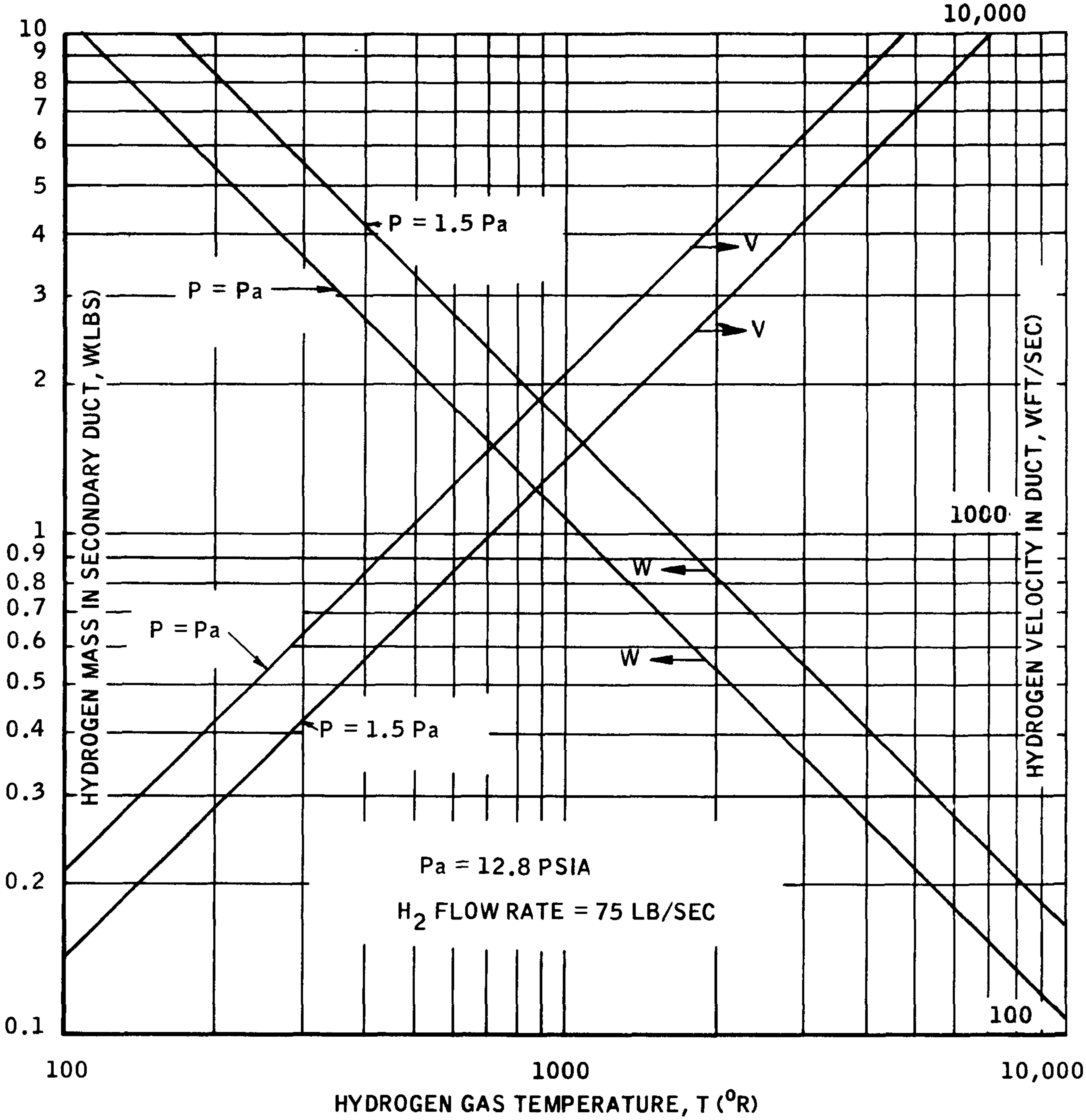


FIGURE 7

HYDROGEN MASS AND VELOCITY IN SECONDARY DUCT AS A FUNCTION OF H_2 TEMPERATURE

Automatic startup of the standby module from idle to full steam occurs when a condition of low steam pressure is indicated (which results when the operating module is shut down). A propane lag of approximately 0.5 to 1.0 second occurs as a result of the lag between the signal for the main oxygen valve and the main propane valve to the standby module to open. Consequently, excess quantities of oxygen will be fed to the duct during a portion of the startup sequence for the standby module.

In conclusion, oxygen-rich steam, and the concomitant explosion hazard to the duct during test operations, may result from premature shutdown of an operating module accompanied by automatic startup from idle to full steam of the standby module.

3.2.2 Formation of Explosive Oxygen/Propane Mixtures

As was indicated by the pressure-rise measurements made during the LOX lead tests reported in Reference (61), a potentially unsafe condition exists when propane leads LOX to the main combustion chamber by as little as 20 to 40 milliseconds. In order to reduce the probability of accumulating an explosive mixture of oxygen and propane in the main combustion chamber, the normal startup sequence for the individual steam modules incorporates a 0.5 to 1.0 second signal lead to open the main oxygen valve. Though this is intended to provide a desirable margin of safety during startup of an individual module, it can result in a hazardous condition when operating two modules at full steam and one module on idle. Under these conditions, should a malfunction occur which causes a loss or significant reduction of oxygen flow to one of the two operating modules, automatic startup of the standby module from idle to full steam will result upon indication of low steam pressure from the failed module. Since propane will continue to flow from the failed module and since startup of the standby module is accompanied by an oxygen lead, non-combusted oxygen and propane may combine in the steam plenum to produce an explosion.

3.3 Conclusions

On the basis of the above considerations, it is concluded that, during the conduct of both XE and XECF test operations, certain malfunctions within the NES system can occur which will result in severe damage to NES and, under some conditions, to other portions of the engine test facility. Specifically, these malfunctions are: (1) loss of propane to one or more of the steam modules, (2) loss of oxygen to one or both of the operating steam modules, and (3) malfunctions causing startup of the standby module from idle to full steam during engine test operations.

The potential consequences associated with these malfunctions and the methods which can be used to reduce the probability of their occurrence should be evaluated during the SGS and NES demonstration test programs. The oxygen content of the steam under various malfunction conditions should be measured and the response times for opening and closing of the main propellant valves should be determined. The necessity for automatic and rapid startup of the standby module following a failure of an operating module should also be examined. In addition, various system modifications should be considered. For example, a fast acting valve may be placed in the oxygen line which will rapidly and automatically stop oxygen flow to the steam generator upon indication of low propane flow. Secondly, excess oxygen fed to the duct may be eliminated during startup and shutdown transients by operating all three modules simultaneously so that in the event of a failure of one module, startup of a standby module is not required. (In conjunction with this latter mode of operation, automatic shutdown of a steam module can be most safety accomplished by initiating closure of the oxygen valve before initiating closure of the propane valve. This sequence of events will not produce an oxygen/propane explosion hazard in the steam plenum since the third module would already be at full steam condition.) Finally, simultaneous operation of the three modules should be considered as a means of reducing the probability of an oxygen/propane explosion in the steam plenum as a result of a loss or reduction in oxygen flow to one or both of the two operating modules followed by automatic startup of the standby module.

4. FACILITY INSTRUMENTATION AND CONTROL SYSTEM

4.1 Description

The Facility Instrumentation and Control System consists of the Facilities Control System, Data Acquisition System, Safety System, and Communications and Television. The Electrical Power Generation and Distribution System, although not part of the Facility I&C System, is also included in this section.

4.1.1 Facilities Control System

The Facilities Control System provides equipment to control, indicate, condition, and buffer signals for the test stand support equipment and the six fluid process subsystems. The test stand support equipment includes such items as duct, shields, and steam generator. The six fluid process systems include hydrogen, helium, oxygen, nitrogen, propane, and process water. In addition, the Facilities Control System, as a whole, conditions and buffers system signals to be recorded by the Data Acquisition System.

Inputs to the Facilities Control System are from transducers, valve indicators, commands, and time codes. The outputs are status indications on consoles, graphic displays, and feed-back commands. In addition to status indications and graphic displays in the control room, the Facilities Control System provides buffered analog signals and isolated binary signals to the Data Acquisition System.

The Facilities Control System includes five consoles:

1) Assistant Facilities Engineer Left (AFEL)

2) Assistant Facilities Engineer Right (AFER)

3) Lead Facilities Engineer (LFE)

4) Gas Fill and Service (GFS)

5) Test Director (TD)

The following controllers are used in the Facilities Control System:

1) Nitrogen Flow (50-FC-50)
2) Nitrogen Coolant Temperature (50-TC-53)
3) Liquid Hydrogen Storage Dewar Pressure (38-PC-68)
4) Engine Run Tank Pressure (50-PC-99)
5) High-Pressure Liquid Oxygen Run Tank Pressure (50-PC-249)
6) High-Pressure Liquid Hydrogen Run Tank Pressure (50-PC-250)
7) Gaseous Hydrogen Coolant Flow Control (50-PC-251)

The controllers, on the respective panels, are provided with switches for manual and automatic (closed loop) control. Demand potentiometers and manual switching facilities are located on the appropriate consoles. The controllers have three major functions in the automatic control system. The first is to provide an error signal. The controller circuitry compares the magnitude of the measured variable with that of a "demanded" value. The resulting error, if any, can then be used by the controller to correct the measured variable so as to reduce the error. The second function is to correct the system response to various inputs and feedback signals so that the system is stable. The third function is to provide switching, metering, data output, etc., as may be required to properly operate and control the system.

4.1.2 Data Acquisition System

The purpose of the Data Acquisition System (DAS) is to accept electrical signals from various transducers within the ETS-1 Complex, condition these signals for both analog and digital recording, and finally to convert the recorded data into usable engineering units. Most of the signals entering the system emanate from diagnostic type transducers, control loops, and other measurement sources within the Test Stand Control System (TSCS), Engine Control System (ECS), and Facilities Control System (FCS).

The ~~overall~~ Data Acquisition System is subdivided into three identical subsystems. The primary purpose of the subdivision is to prevent a catastrophic loss of data within the Digital Data System in the event of a major equipment failure. Entrance into each identical subsystem is through either a low or high level programmable patch board. Within each subsystem, signal amplification is accomplished and those signals entering the Digital Data System are multiplexed and digitized. Therefore, the signals emanating from each of the three subsystems are either high level analog signals to be recorded within the Analog Recording System or digitized signals to be recorded within the Digital Data System. Considerable flexibility has been built into the Data Acquisition System by the use of effective patching. Any channel from diagnostic sources or control loops may be fed into any one of the three subsystems and then recorded ~~graphically and/or~~ digitally.

4.1.3 Safety System

The purpose of the Safety System is to provide warning of impending or existing hazardous conditions so that appropiate corrective action may be taken to protect both personnel and facilities. The system is divided into six subsystems covering (1) Fire Protection, (2) Oxygen Detection, (3) Combustible Gas Detection, (4) Area Surveillance and Warning, (5) Radiation Monitoring, and (6) Meteorological (31, 36). An additional system, a proposed Criticality Alarm System, is also included in this evaluation.

Quantitative information from these subsystems is transmitted to the Lead Safety Engineer (LSE) Console at the Control Point Building along with appropriate visual and audible alarms if pre-set levels are exceeded. A communications panel is also located at the LSE Console to allow for local and area wide emergency communications to personnel.

A Safety System Graphic Display Panel is located above the LSE Console. The panel will display a map of ETS-1 showing the alarm status of the detectors and emergency switches located throughout the ETS-1 Complex. The map will also display the purge status of facility components, door closure indications, and the status of area warning devices used to control personnel and vehicular traffic throughout the facility.

A description of the major subsystems which comprise the ETS-1 Safety System follows:

4.1.3.1 <u>Fire Protection System</u>

The Fire Protection System, designed under separate contract from the other safety subsystems, provides water deluge and carbon dioxide (CO_2) flooding to three principal areas in the ETS-1 Complex:

1) Test Stand Area (includes superstructure, substructure and steam generator areas).
2) Storage Area (includes LH_2 Dewar, high pressure gas storage, and liquid oxygen storage Dewar)
3) Fill Station Area (includes truck unloading station, propane storage, propane vaporizer, gas compressor room and hand-hose lines at the truck unloading area).

The Test Stand Area is provided with water deluge flooding to 14 zones (Zones 1 through 14), 8 of which are now active. The systems are operated automatically by heat-responsive devices to start deluge of the particular zone in which they are located. Provisions are also made for local and remote ON and OFF manual activation. The heat responsive devices initiate deluge when the temperature approaches 225°F.

The Storage Area is provided with water deluge flooding to 6 zones (Zones 15 through 20), 2 of which are presently active. Heat responsive devices, local control, and supervisory systems are the same as those provided for Test Stand Area coverage.

The Fill Station Area is provided with water deluge and CO_2 flooding. This area is divided into 7 zones (Zones 21 through 27), 3 of which are presently active. Water deluge controls are similar to those provided for test stand and storage areas. The CO_2 system can be activated by a local switch or from the fire protection console at the Control Point Building.

As specified by Reference (48), the water deluge systems are designed in accordance with requirements outlined in National Board of Fire Underwriters (NFBU) Pamphlet No. 15, "Standards for Water Spray System," Pamphlet No. 13, "Standards for Installation of Sprinkler Systems," and Pamphlet No. 72 "Standards for the Installation, Maintenance and Use of Proprietary Signaling Systems." Design and installation of the CO_2 system is in accordance with NFBU Pamphlet No. 12, "Carbon Dioxide Extinguishing Systems."

Utility water for fire protection at the truck unloading station, the propane storage area, and the vaporizer area is available through an 8-inch pipeline by gravity flow from a 150,000 gallon storage tank. Demineralized water is available to zones where high flow rates are required and is supplied through a 24-inch welded branch connection installed in the 42-inch gravity flow line from the 2,750,000-gallon storage tank. The Aetron specifications(48) specify the flow rates to be used in the design for fire suppression in critical areas.

A control console at the Control Point Building is furnished with controls and indication lights for the fire protection systems. Activation of the heat responsive devices causes console audible alarm and area sirens to sound. (Aetron design provided capability for a flashing red light at the console for an abnormal condition with acknowledge switch to silence the audible alarm and change the flashing red light to steady. However, this specification was not complied with during installation (87). The only way to silence the area sirens is from the individual ac distribution panels in remote areas other than the Control Point Building.)

4.1.3.2 Oxygen Detection Subsystem

The Oxygen Detection Subsystem provides for monitoring of oxygen concentrations at ETS-1 locations where oxygen deficiency may pose a personnel hazard and where concentrations may be sufficient in combining with combustible gases to cause an explosion. These locations are:

1) LH_2 Storage Flare Stack
2) Test Stand Building
3) Test Stand Valve Pit
4) Run Tank Flare Stack
5) Engine Compartment (4 units)

The analyzers for the engine compartment and flare stacks are used to detect the presence of oxygen before flow of hydrogen is initiated. The valve pit and test stand building analyzers are used to detect a deficiency of oxygen.

The four engine compartment analyzer outputs are displayed on the TSE Console by one meter and selector switch, and signals are recorded. Each analyzer has a red, yellow, and green light on the TSE Console to show status of oxygen conditions within the compartment. Other oxygen analyzer outputs are displayed on the LSE Console by a meter and selector switch and if analyzer output exceeds a pre-set level, the Area Surveillance and Warning Subsystem is activated.

All of the detector signals are displayed by a flashing red light on either the LSE or TSE Consoles and on the Safety Graphic Display should pre-set levels be exceeded. The flashing red light will change to steady red when the acknowledge button on the LSE Console is pushed. A summary warning light is provided at the LSE Console to indicate the failure of a part of the system.

4.1.3.3 Combustible Gas Detection Subsystem

The Combustible Gas Detection Subsystem provides for detection of explosive concentrations of hydrogen and propane at ETS-1 locations where the potential for these gases to accumulate is highest. These locations are

1) Valve Pit
2) Test Stand Building
3) Run Tank Flare Stack
4) Fill Station
5) LH_2 Storage Flare Stack
6) GSA Revetment
7) Engine Compartment (4 units)

The combustible gas analyzers detect the presence of combustible gas (within the range of 0% to 100% of the lower explosive limit of either hydrogen or hydrogen-propane mixtures in air) and are designed to activate the Area Surveillance and Warning Subsystem should the concentration exceed a pre-set level.

The signals from the four detectors of the engine compartment are displayed on the TSE Console by a meter and selector switch and are recorded on the Safety System recorders. Three colored lights (red, yellow and green) on the TSE Console are used to indicate safe, marginal or unsafe conditions within the engine compartment. All other detector signals are displayed on the LSE Console by meter and selector switch.

All detectors (other than in engine compartment) will activate sirens and door lights of the Area Surveillance and Warning Subsystem. All of the detector signals are displayed by a flashing red light on the consoles (TSE or LSE) and the Safety Graphic Display should a pre-set level be exceeded. The flashing red light will change to a steady red when the acknowledge button is pushed on the LSE Console. A summary warning light is provided at the LSE Console to indicate failure of a part of the system.

4.1.3.4 Area Surveillance and Warning Subsystem

This subsystem is comprised of visual and audible warnings throughout ETS-1 for alerting personnel of an abnormal or emergency condition, directing these personnel to safe locations, and alerting Control Point personnel so appropriate corrective action may be taken as early as possible. The subsystem components include sirens, klaxons, beacons, door lights, and traffic lights.

The subsystem is activated by a trip signal from one or more of various detectors (radiation, oxygen, and combustible gas) located throughout ETS-1. The siren and klaxon audible alarms can be activated and silenced manually at the LSE Console.

Sirens are utilized as aural warning for any unsafe condition other than radiation. Radiation warning is provided by a klaxon. Activation of a siren or klaxon is displayed by a flashing red light on the LSE Console and Safety Graphic Display. Acknowledgement of the flashing red light, by depressing the acknowledge button, changes, for a pre-set interval of time, the light to steady red and silences the LSE Console audible alarm. The area beacons and door lights continue to present alarm conditions until the system detector is manually re-set by the LSE. Re-set will not occur unless the detector senses a safe condition.

Color coding of beacons and door lights is as follows: green (safe condition), yellow (controlled access), and red (no access). Appropriate beacons will light with color coding dependent upon the condition in the area. Door lights indicate the condition on the opposite side of the door from which it is viewed indicating direction of safe travel. Each door which exits from the tunnel is equipped with an open/close position microswitch; the closed position indication for each door is displayed on the Safety Graphic Display.

Six emergency switches throughout the complex provide a means for personnel to inform the Lead Safety Engineer at the LSF Console that a hazardous condition, undetected by sensors, exists. The LSE can then take appropriate action.

4.1.3.5 Radiation Monitoring Subsystem

This subsystem is comprised of radiation detectors located throughout ETS-1 for monitoring environmental neutron and gamma radiation intensities both during engine operation and after shutdown and also for monitoring concentrations of airborne radioactivity.

These detector systems are designed to warn personnel of abnormal environmental radiation conditions by activating audible and visual alarms of the Area Surveillance and Warning Subsystem in addition to establishing radiation intensities for personnel re-entry to radiation areas after test firing. Both local and remote (LSE Console) readout are provided. Capability is also provided near the LSE Console for recording the readings. The subsystem consists of the following detectors:

Area gamma monitors	15 ea
Mobile radioactive airborne particulate monitors	4 ea
Mobile radioactive gas monitors	4 ea
Neutron monitors	2 ea

All below-ground gamma monitors have sensitivity ranges of 0.1 mr/hr to 100 mr/hr. Above-ground detectors with exception of 2 units have ranges of 1 mr/hr to 1000 mr/hr. The 2 additional units (at the test stand) have ranges of 1r/hr to 10^6 r/hr. Airborne particulate detectors are designated for below-ground and are sensitive to beta-gamma with a sensitivity range of 10^{-11} to 10^{-6} microcuries per cubic centimeter ($\mu c/cc$) referenced to I^{131}. The four radioactive gas detectors are designated for below-ground and are sensitive also to beta-gamma with sensitivity range of 10^{-6} to 10^{-1} $\mu c/cc$ referenced to A^{41}. The 2 neutron detectors are boron-lined thermal neutron (gamma compensated) types with sensitivity range of 10^1 to 10^5 n/cm^2-sec.

4.1.3.6 Meteorological Subsystem

The Meteorological Subsystem monitors wind direction, wind velocity, barometric pressure, and ambient temperature. The subsystem is a supplement to existing NTS observation facilities used for evaluating weather conditions for engine testing.

Sensing elements are located on a twenty-foot pipe stand above the Control Point Building. Wind direction and velocity are displayed on the LSE Console, and temperature and barometric pressure readings are displayed in a panel to be located adjacent to the LSE Console. All four readings are recorded.

There are no alarms or controls for this subsystem.

4.1.3.7 Criticality Alarm System

During development of the ETS-1 Safety System provided through the EG&G contract, no provisions were made for a Criticality Alarm System capable of monitoring the engine on the test stand before startup and after shutdown.

Per Reference (34), the following criticality monitoring requirements were established:

"A Criticality Alarm System must be available at ETS-1 which is capable of continuous operation during all engine shutdown periods when the engine is installed in the test stand. The system must be capable of detecting criticality in the engine without regard to the position of the side shields or other test stand equipment. It must also be capable of detecting criticality both before and after engine operation. In the event of inadvertent criticality, the system shall energize an alarm which is audible throughout the entire ETS-1 Complex. In addition, it must provide an audible and visual alarm plus a meter readout of the criticality signal at the LSE Console in the Control Point Building."

A preliminary equipment specification was subsequently developed by NTO for a Criticality Alarm System. This specification is similar to that developed for Criticality Monitoring at Test Cell A. The system utilizes 3 neutron detectors with a logic circuit common to all three channels for monitoring the condition of meter contacts to provide a criticality alarm indication in the event of 2 or 3 simultaneous high level trips. The neutron detectors are proportional BF_3-filled sensors with sensitivity of 40 cps/nv.

A remote panel up to 2000 feet distance from count rate electronics is utilized. The remote panel contains count rate meters, alarm continuity, and klaxon controls.

4.1.4 Communications and Closed Circuit Television

4.1.4.1 Communications

The Communications System is comprised of three major subsystems: (1) inter-phone, (2) public address, and (3) RF (radio frequency).

Three general types of communication panels are used:

(1) Inter-Phone Communications Panel

(2) Inter-Phone/PA Communications Panel

(3) Special Communications Panel

Use of the inter-phone, RF, or PA subsystems, individually or simultaneously, will be possible from these panels and at various consoles (including the LSE Console) in the Control Point Building.

The inter-phone subsystem consists of a system of 26 trunklines routed throughout the complex to self-operated inter-phone stations.

The public address (PA) subsystem has three modes of operation: Local-area, Universal, and Emergency. Local-area operation means that only those speakers in a selected area will be activated. Universal operation shall cause all speakers to be operated throughout the complex. Emergency operation means operation of the Universal PA from the Assistant Test Director's Console where a special switch allows all other PA conversation to be overridden.

The RF subsystem provides communication links between a fixed station at the Control Point Building and personnel situated in remote areas. The three RF nets are used as follows:

(1) One net is used for safety communications between the Control Point Building and NRDS safety personnel.

(2) Two general communications nets are provided to permit conversation between the Control Point Building and personnel situated in remote areas, using handy-talkys. These nets include stations at the engine prime mover (PM/MCC) and the E-MAD building.

4.1.4.2 Closed Circuit Television

The Television System provides visual observation from within the Control Point Building of activities in the test stand area and immediate surroundings. There are 18 different camera locations and capability of viewing 8 different scenes on the monitors. The 21-inch monitors in the Control Room and the 8-inch monitors in the Electronics Maintenance Room display eight scenes simultaneously while the Test Director selects two of these eight to be displayed on the 8-inch monitors.

Each of the two monitors at the Test Director's Console is capable of presenting any one of the eight video channels simultaneously with the monitor at the TV console. A monitor is provided at the LSE Console for use by the Lead Safety Engineer. Should either the Test Director or Lead Safety Engineer desire a change in the accessory control setting on the camera being monitored, they may accomplish this by calling the TV Console on the inter-phone to request the operator to change the settings for that channel.

4.1.5 Electrical Power Generation and Distribution System

The Electrical Power System for ETS-1 is described in Reference (27). Reference (28) is a schematic of the system. As is shown by this drawing, electrical power for ETS-1 is distributed by three separate buses: (1) The Utility Load Bus, (2) the Essential Load Bus, and (3) the Instrument Load Bus. A simplified schematic of the system is shown in Figure 8.

The Utility Load Bus supplies power to the complete ETS-1 Complex during periods of non-testing. During test periods, the Utility Power System supplies only facility support items such as motors, fans, lighting, etc. It is also used as a backup to the other two buses. The system receives power from the Nevada Power and Light Company. Power enters the ETS-1 Substation on a 69 kv line where it is stepped down to 4160 volts by a 2500 kva transformer and then enters the switchgear through a main breaker. The breaker is protected by an over-current relay which will cause the breaker to open in the event of high current flow through the bus. Power passes through the closed breaker to the Utility Bus where it is then distributed to the loads through four feeder breakers which are also protected by over-current relays. The protective relays will be calibrated to afford selective tripping, i.e., tripping nearest the fault. Furthermore, each relay trip circuit will have its own dc battery power supply.

The Essential Load Bus supplies power to control circuits, vital motor loads, and any load which requires a high degree of reliability but which is not necessarily sensitive to harmonic transients or minor voltage fluctuations. During non-testing periods, power is supplied from the Utility Bus through a tie breaker which can be activated by either of two over-current relays or by high speed under-voltage and reverse-power relays. During test periods, power is supplied from

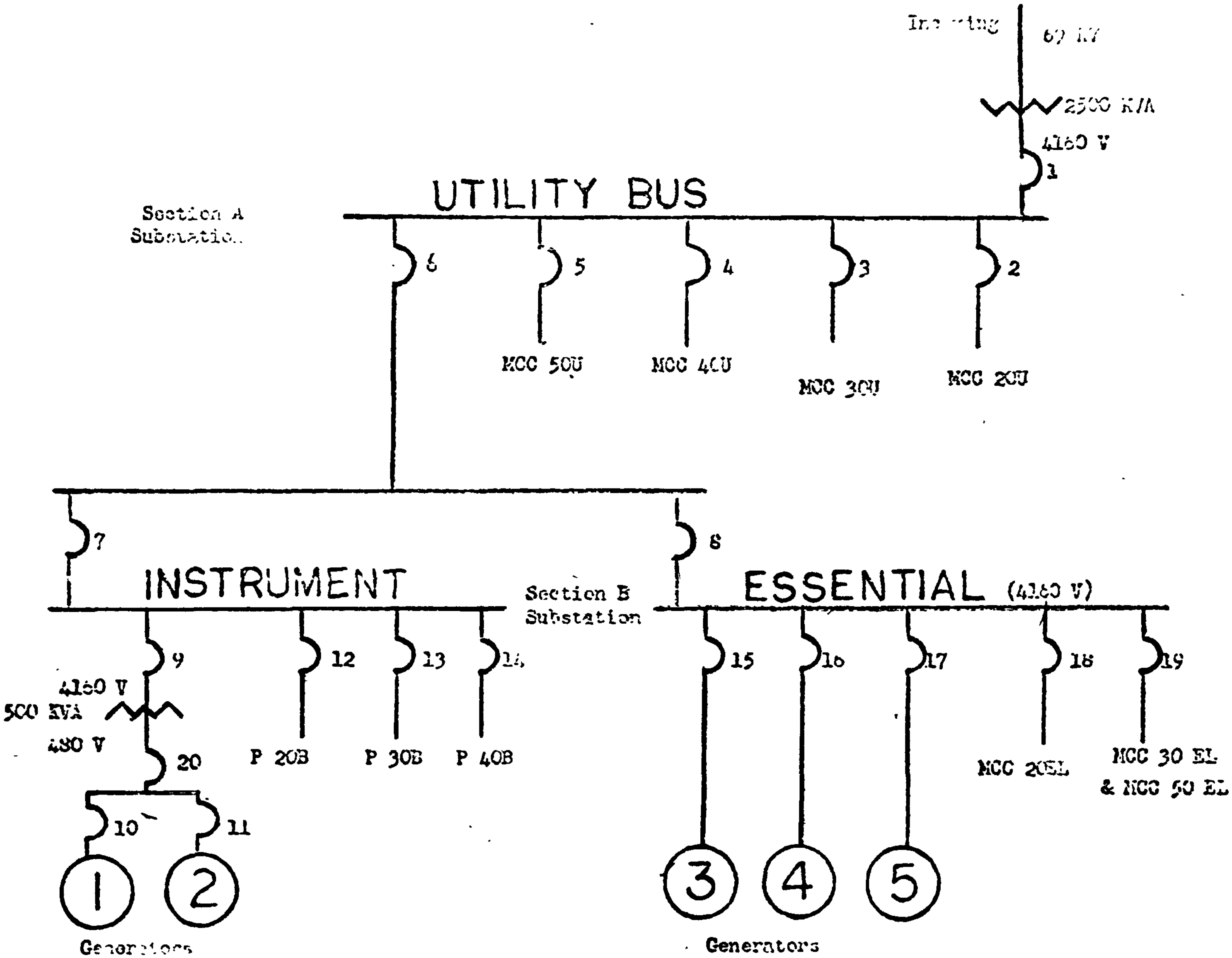


Figure 8
Simplified Schematic of Electrical
Power System

three 200 hp Caterpillar diesels, each driving a 150 kw (187.5 kva) Allis Chalmers generator. Power from the generators to the bus passes through individual output breakers which are protected by over-current and reverse power relays. Power from this bus is routed to the loads through two feeder breakers which are also protected by over-current relays.

The Instrument Load Bus supplies power to loads such as data acquisition and signal conditioning equipment or vital loads which are sensitive to transient harmonics or voltage fluctuation. During periods of non-testing the Instrument Bus is fed by the Utility Bus through a tie breaker which is protected by over-current relays. During test periods, power is supplied by two 250 kw Commins diesels through the generator output breakers which are protected by series over-current devices and by reverse power relays. Power from these breakers passes through an output breaker to a 500 kva transformer which steps up the generator output voltage from 480 volts to 4160 volts. At this point, the power is impressed on the Instrument Bus through an output breaker. This breaker is also protected by over-current relays. Four feeder breakers with protection relays distribute the power to the various loads.

The electrical power grounding system consists of 11 ground rods, each 10 feet long, driven in the ground around the substation and connected by means of an underground bare copper bus to ground grids at each building. All electrical equipment, motors, terminal boxes, raceways, transformer neutrals, and reinforcing steel are grounded to these grids. A single point ground system is used for the instrumentation ground and for interconnections made by insulated cable.

4.2 Evaluation

4.2.1 Facilities Control System

An evaluation of the Facilities Control System has shown there are no significant safety deficiencies inherent to the system design. As a result, the system was found to be adequate from a safety standpoint.

4.2.2 Data Acquisition Syst m

An evaluation of the Data Acquisition System has shown there are no significant safety implications inherent to the system design. As a result, the system was found to be adequate from a safety standpoint.

4.2.3 Safety System

4.2.3.1 Fire Protection System

A significant portion of the Fire Protection System (including water deluge and CO_2) has been installed and activated in various area zones at ETS-1, and remote control and readout capability has been provided to a master console at the Control Point Building. However, Reference (84) indicates that a significant amount of work is still required on the CO_2 system, both to make the system operational and to improve on its operational capability. Early attention to this problem by NTO is expected.

The water deluge and CO_2 fire suppression systems cover critical areas where overheating may occur (including those areas exposed to nuclear heating) and where leakage of gaseous or liquid hydrogen from piping or tankage systems poses a fire hazard.

As noted in the description of the Fire Protection System (Section 4.1.3.1), Aetron specifications specified system design (both water deluge and CO_2) in accordance with National Board of Fire Underwriters' standards

(References (67) through (70)). These standards cover the pertinent needs for fire suppression in addition to requirements for remote and local signaling (alarms). Further, the Aetron specifications established requirements for minimum flow-rate coverage in specific zones. No attempt was made during this evaluation to evaluate the Fire Protection System as to consistency with National Board of Fire Underwriters' standards in terms of water and CO_2 supply requirements, flow rates, nozzle sizing, piping, etc. It is assumed these details will be reviewed by NTO during system acceptance tests. However, it does appear that the basic requirements of the NBFU standards have been fulfilled.

As stated in Section 2.1.9, the maximum water flow-rate capability of the Fire Protection System (all deluge systems activated) is 18,700 gpm[13]. Assuming that full water flow for 30 minutes will be required in the event of a major fire, approximately 560,000 gallons of process water must be available for this purpose. Based upon the 2-3/4-million gallon capacity of the process water storage system, upon an estimated[13] 842,000 gallons required for a 5-minute engine test (1,460,000 gallons for a 20-minute test), and upon 440 gallons/minute for NES duct cooling[13] during the 24-hour engine cooldown period (634,000 gallons total), it appears that sufficient supply of water will be available for utilization by the Fire Protection System.

Of major concern is the fact that the Fire Protection System, including CO_2 fire suppression systems, has not been interfaced with the Area Surveillance and Warning Subsystem. This has also been noted in Section 4.2.3.4. In contrast to other safety systems interfaced with the Area Surveillance and Warning Subsystem, no provisions exist at the fire-protection master console in the Control Point Building for acknowledging and silencing alarms. This capability is necessary to allow emergency instructions from the Lead Safety Engineer to be heard through the

Public Address System. In areas where total flooding CO_2 systems are used, public address communications are especially vital in warning personnel to evacuate flooded areas and to avoid re-entry until conditions permit. It should also be pointed out that the Fire Protection System must be properly interfaced with the Area Surveillance and Warning Subsystem for activation of appropriate visual warnings, i.e., beacons and door lights.

It is understood, through discussions with NTO, that SNPO-C has approved interfacing of the Fire Protection System with Area Surveillance and Warning Subsystem and that the design changes necessary to accomplish this interfacing are almost complete. It is further understood that one of the NTO design changes consists of relocating readouts and controls, presently on the fire protection console, to the Lead Safety Engineer Console and of providing alarm acknowledging and silencing capabilities. The effects of these design changes to the Fire Protection System will be further evaluated from the safety standpoint as additional information becomes available.

4.2.3.2 Oxygen Detection Subsystem

All detectors have been procured for this subsystem. Cabling and conduit have been installed; however, no detectors have been installed.

There appear to be no significant safety problems or deficiencies inherent to this subsystem design. However, as noted in the evaluation of the Area Surveillance and Warning Subsystem (Section 4.2.3.4), additional oxygen analyzer units have been purchased and will be installed in the High Pressure Gas Storage Area. This action is considered necessary since an enclosure was recently provided for this area and a potential oxygen deficiency hazard exists. Significant effort remains to interface the outputs of these analyzers with the Area Surveillance and Warning Subsystem (see evaluation, Section 4.2.3.4 of Area Surveillance and Warning Subsystem, for recommended interfacing).

4.2.3.3 Combustible Gas Detection Subsystem

All combustible gas detectors, with the exception of those used for the engine compartment, have been procured. Cabling and conduit for the subsystem has been installed; however no detectors have been installed. Procurement of detectors for the engine compartment has been deferred since they are not required as early in the ETS-1 activation schedule as other facility area detectors.

There are no apparent safety problems or deficiencies inherent to this subsystem design. However, some significant modifications regarding audible and visual alarms for this subsystem are recommended in the evaluation of the Area Surveillance and Warning Subsystem (see Section 4.2.3.4.).

4.2.3.4 Area Surveillance and Warning Subsystem

The Area Surveillance and Warning Subsystem, as designed, provides numerous warning media sufficient to blanket the entire ETS-1 Complex. However, in view of the complexity of alarm logic of this subsystem, personnel could misinterpret certain signals; therefore there appears to be a need to simplify the logic. In addition, several perturbations have occurred since customer approval of the EG&G Design Data documents [31,36] that have significant effects on design of the Area Surveillance and Warning Subsystem, namely:

a. It is specifically stated in the NRDS Emergency Alarm Criteria[47] that a klaxon horn will be used only to denote an inadvertent criticality accident. Therefore, present subsystem design, which provides for klaxon warning for all radiation hazards, is inconsistent with NRDS standards.

b. The Fire Protection System is equipped with area sirens; however, it has not been interfaced with the Area Surveillance and Warning Subsystem. Present design of the Fire Protection System does not allow acknowledgement and silencing of alarms from the Control Point Building as do other warning systems.

c. The Fire Station CO_2 System is being modified for integration with the Fire Protection System(32). This system also requires interfacing with the Area Surveillance and Warning Subsystem.

d. The requirement for a Criticality Alarm System for ETS-1 has been established(34). Interfacing of this proposed system with the Area Surveillance and Warning Subsystem must also be accomplished.

e. Joint evaluation of the Area Surveillance and Warning Subsystem by NTO Health and Safety and REON Safety resulted in certain recommended changes to provide more effective control of personnel(37).

As a result of these perturbations and their effects on the design of the Area Surveillance and Warning Subsystem, it is recommended that the following changes or additions be made to assure an effective warning system and to provide consistency with the NRDS Emergency Alarm Criteria. (These changes and/or additions are reflected in the proposed alarm logic chart, Table II. Locations of the stations for the logic chart are outlined in Table III.)

a. Gamma and particulate radiation detectors should not be connected to area klaxons or activate warning beacons or door lights. There is no conceivable case where it would be necessary to cause widespread area alarm and evacuation of personnel upon activation of one of these detectors. Therefore, alarm logic should be limited to local audible and visual signals with visual and audible indication at the LSE Console. The local audible alarm should be sounded for

TABLE II

RECOMMENDED ALARM LOGIC FOR ETS-1(1)

STATION \ ACTION	SIREN	KLAXON	BEACONS			SAFETY GRAPHIC	LSE CONSOLE		LOCAL SIGNAL		DOOR LIGHTS
			TEST STAND	FILL STA.	CONT. POINT		AUD.	VIS.	AUD.	VIS.	
A-1, 2U, 3, 4U, 5, 6U, 7, 8U, 9U, 10U, 11, 12, 13, 14, 15						Red	Yes	Yes	Yes	Yes	
P-1, 2U, 3U						Red	Yes	Yes	Yes	Yes	
CG-1	Yes		Red	Yel	Yel	Red	Yes	Yes			Note(2)
CG-5, 6A, 6B	Yes		Yel	Red	Yel	Red	Yes	Yes			Note(2)
CG-7, B						Red	Yes	Yes			
CG-10U	Yes		Red	Yel	Yel	Red	Yes	Yes			Note(3)
CG-2, 3, 4, 9						Red					
O_2-1, 8						Red	Yes	Yes			
O_2-2, 12U						Red	Yes	Yes	Yes		
O_2-(Gas storage)							Yes	Yes	Yes	Yes	
O_2-4, 5, 6, 10						Red					
SW-1, 2, 3, 4	Yes		Red	Yel	Yel	Red	Yes	Yes			Note(2)
SW-5, 6	Yes		Yel	Red	Yel	Red	Yes	Yes			Note(2)
Criticality Alarm Sys.		Yes	Red	Red	Red	Red	Yes	Yes			Note(2)

TABLE II (cont.)

STATION	SIREN	KLAXON	BEACONS TEST STAND	BEACONS FILL STA.	BEACONS CONT. POINT	SAFETY GRAPHIC	LSE CONSOLE AUD.	LSE CONSOLE VIS.	LOCAL SIGNAL AUD.	LOCAL SIGNAL VIS.	DOOR LIGHTS
FPS Deluge Zones-1,2,3,6, 7,8,9,10	Yes		Red	Yel	Yel		Yes	Yes			Note(2)
FPS Deluge Zones-15,17, 21,22	Yes		Yel	Red	Yel		Yes	Yes			Note(2)
CO_2-Compressor Room	Yes		Yel	Red	Yel		Yes	Yes			Note(2)
CO_2-Fill Sta. Reels							Yes	Yes			

NOTES:
(1) A blank in table indicates detector cannot affect condition or status of warning device.
(2) Lights at locations 1 and 2 turn green. Outside lights at locations 3 through 9 turn green. Inside lights at locations 3 through 9 turn red. (See Table III for door light locations.)
(3) Same as for Note (2) except that door light at location 1 turns red.

TABLE III

LOCATION KEY FOR ALARM LOGIC CHART

DOOR LIGHT LOCATIONS

1. Tunnel exit/entrance at Test Stand Building on stairway.
2. Tunnel entrance from Test Stand Building.
3. Tunnel exit/entrance at Test Cell Building.
4. Tunnel exit/entrance at LH_2 Dewar.
5. Tunnel exit/entrance at Gas Storage Area.
6. Tunnel exit/entrance at Forward Control Room.
7. Tunnel exit/entrance at Utility Equipment Building.
8. Tunnel exit/entrance at Control Point.
9. Main tunnel exit/entrance.

REMOTE AREA GAMMA MONITORS*

A-1	Outside tunnel main entrance.
A-2U	In tunnel at Control Point Building.
A-3	In Utility Equipment Building.
A-4U	In tunnel near bend at knock-out plug.
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.

TABLE III (cont.)

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.

PARTICULATE MONITORS*

P-1	Near air intake filters in Utility Equipment Building.
P-2U	Inside Forward Control Room.
P-3U	Inside Test Cell Building.

COMBUSTIBLE GAS DETECTORS*

CG-1	Inside steam generator enclosure.
CG-5	Inside Valve House in H.P. gas storage area.
DG-6A) DG-6B)	Inside Compressor Room of Fill Station Building.
CG-7	On top of Test Stand inside base of flare stack.
CG-8	In line between check valve and LH_2 storage flare stack.
CG-10U	Inside Test Stand Building.
CG-2,3, 4,9	Inside Engine Test Compartment.

OXYGEN DETECTORS*

O_2-1	In top of Test Stand in base of flare stack
O_2-2	In Test Stand Valve Pit
O_2-8	In line between check valve and LH_2 storage flare stack
O_2-12U	Inside the Test Stand Building
O_2-4,5, 6,10	Inside Engine Test Compartment

TABLE III (cont.)

EMERGENCY SWITCHES

SW-1	At southwest end of shadow shield.
SW-2	At top of the Test Stand by stairs.
SW-3	At intermediate level on Test Stand by stairs.
SW-4	Between elevator and shadow shield at pad level.
SW-5	Inside Valve House in H.P. Gas Storage Area.
SW-6	Outside north wall of Compressor Room in Fill Station Building.

* U designates underground location

warning personnel in the immediate area and should be very distinguishable from area sirens and klaxons.

b. Neutron detectors N_1 and N_2 of the EG&G design data package(31,36) should be utilized solely for neutron dosimetry purposes and not connected to any visual or audible alarm so that the effectiveness of the Criticality Alarm System is not impaired. Therefore, these detectors should be deleted from the alarm logic chart.

c. A requirement for a Criticality Alarm System has been established and a study is underway by LASL to determine the optimum locations of the detectors. The system must be interfaced with the Area Surveillance and Warning Subsystem, including activation of area klaxons (to maintain consistency with NRDS Emergency Alarm Criteria) and other appropriate visual and audible indications.

d. All indoor and outdoor sirens and klaxons should operate as an entire group: klaxons for accidental criticality, sirens for other unsafe conditions. This is to assure all personnel in the facility (whether above or below ground) hear the signal and are immediately made aware that an emergency condition exists.

e. Yellow door lights should be deactivated from the door lighting alarm logic for entry to or exit from tunnel areas. Only red and green lights should be used. The yellow light, per EG&G specifications, was considered as an indication of a potentially hazardous (or limited access) condition preceding a red signal. This could cause some hesitation or indecision on the individual's part; therefore, a go, no-go red and green indication is considered much more effective in the event of an emergency. It is recommended that the yellow light be considered for use on a manual activation basis for alert during countdown or during shutdown periods when the engine is on the test stand (see k below).

f. Combustible-gas and oxygen detectors used at the flare stacks should not be connected to area sirens, sound local alarms, or activate beacons or door lights. It is not considered necessary to require complete evacuation of personnel on activation of these detectors. The audible and visual alarm should be retained at the LSE Console so appropriate corrective action can be taken.

g. The Fire Protection System including the CO_2 system should be interfaced with the Area Surveillance and Warning Subsystem. This should include connection with appropriate visual and audible alarms with provision for acknowledgment and alarm silencing at the LSE Console in order that emergency instructions can be heard through the Public Address System.

h. The Safety System Graphic Display at the Control Point Building should include a closure light signal for the blast door at the forward end of the tunnel in addition to the closure signals for the tunnel exit doors.

i. In addition to the O_2 analyzer systems provided by the EG&G package, additional units are being installed in the High Pressure Gas Storage Area. The requirement for these units was established when an enclosure for the gas storage bottles was provided, resulting in a potential oxygen-deficiency hazard. This system should be provided only with local audible and visual alarms and audible and visual indication at the LSE Console, since widespread areas at ETS-1 are not affected.

j. Green beacons should be eliminated from logic associated with activation of emergency switches. Only red and yellow should be used. If a hazardous condition exists where it is considered necessary to activate an emergency switch, it is probable the entire above ground area at ETS-1 may be affected, in which case a green beacon is not appropriate. In addition, evacuation to tunnel areas will be required. Therefore, door lights should be activated on activation of emergency switches for guidance of personnel. These changes are reflected in Table II.

k. With a no-alarm (normal) condition, all door lights (both above and below ground) and beacons at ETS-1 are continuous green. With an alarm condition, the subsystem is designed to automatically change colors of door lights and beacons to direct personnel to safe areas. In view of the need to control personnel during countdown, test, and post shutdown periods with the engine at the test stand, it appears the door lights and beacons could be used to good advantage as alert signals to supplement other means in directing personnel to allowable occupancy areas. Therefore, it is recommended that capability be provided at the LSE Console for manual activation of each beacon and each set of door lights to effect change to red, yellow, or green color. These capabilities do not exist with the current design.

It should be emphasized that installation of the Area Surveillance and Warning Subsystem is proceeding on the basis of EG&G design. The major portion of cabling, conduit, and visual and audible alarm components have been installed; however wiring of terminal connections has not been completed.

It is considered that the changes and/or additions to the alarm logic, as outlined above, will provide a more effective warning system than with the present design and also will afford consistency with NRDS Emergency Alarm Criteria.

4.2.3.5 Radiation Monitoring Subsystem

There currently appear to be no major problems or deficiencies with this subsystem.

There is need to relocate area gamma monitor A7. This channel location, per EG&G package[31,36], is designated for installation at the change house. However, the change house was deleted from ETS-1 facilities due to budget limitations; therefore, relocation is necessary. It appears that the optimum location for an additional area gamma monitor is at the 2nd level of the test stand since personnel access will probably be required to this area during shutdown periods and no monitors were provided for this area in the EG&G package. Therefore, it is recommended area gamma monitor A7 be installed at this test stand location.

In addition, it is considered that radioactive gas monitoring capability is not necessary. The potential for release of gaseous activity to below-ground areas is very minimal since this activity will be highly dispersed before it can reach the tunnel air intake near the Control Point Building. The airborne particulate monitors will readily indicate whether any airborne activity is present. Therefore, it is recommended the gaseous monitoring units be deleted. If it is shown later that a specific need for gaseous monitoring exists, a small portable inexpensive sampling unit containing activated charcoal can be procured for use at the tunnel air intake location.

All detector units, with exception of airborne (particulate and gaseous) activity monitors, have been procured. Procurement of the airborne activity monitors is currently scheduled for CY 1966. The two neutron detectors and all but three of the area gamma detectors have been installed. EG&G is currently preparing checkout procedures for this subsystem, the procedures to be submitted to NTO for review and approval.

With regard to interfacing of the radiation monitoring subsystem with visual and audible alarms of the Area Surveillance and Warning Subsystem, attention is directed to Section 4.2.3.4 since significant changes from EG&G design have been recommended.

4.2.3.6 Meteorological Subsystem

Sensing elements have been installed on the twenty-foot pipe stand above the Control Point Building. Wind direction and speed displays have been mounted on the LSE Console. Temperature and barometric pressure displays have been mounted in a separate panel near the LSE Console.

This subsystem has not been checked out. EG&G has, however, prepared checkout procedures and NTO is reviewing for comment.

It appears that present subsystem design is adequate and that no major modifications will be required. The subsystem, as designed, fulfills ETS-1 supplementary weather monitoring needs.

4.2.3.7 Criticality Alarm System

As noted in the description of this system (Section 4.1.3.7), an equipment specification for such a system has been developed by NTO. The specification has not been submitted for review and approval.

On request from NTO, effort is presently being expended by LASL to determine optimum locations for the neutron detector units. In determining these locations, consideration must be given to analysis of NERVA engine neutron flux, interposed shielding between engine and detectors, and avoiding interference with other installed instrumentation. Based on past discussions with cognizant engineers, it does not appear feasible to locate the detectors in contact with or within the Engine Test Compartment.

Although the criticality monitoring instrumentation is not required in the near future, there remains considerable effort in providing this capability. This effort includes finalizing equipment specifications, establishing system component locations, obtaining necessary approvals, and procuring and installing equipment. In addition, visual and audible outputs of this system must be properly interfaced with the Area Surveillance and Warning Subsystem as discussed in Section 4.2.3.4.

Based on the aforementioned current status of this system and on the considerable additional effort required, it is recommended that emphasis be placed on finalizing design and obtaining necessary approval for this system as early as possible. Special attention should also be given to determining optimum locations for system components to assure highest efficiency.

4.2.4 Communications and Closed Circuit Television

4.2.4.1 Communications

Portions of the Communications System have been installed and activated to meet current needs. Cabling has been completed to the LSE Console and the panel is completely fabricated and ready for connection to the LSE Console.

No significant problems have arisen to date with activated portions of this system. It appears the system design is adequate for communications throughout the complex and no problems are anticipated through completed installation and activation.

4.2.4.2 Closed Circuit Television

Installation of the system is in progress. It appears the system, as designed, is adequate to meet remote viewing requirements for ETS-1 operations. Although the LSE Console will be equipped with only a single monitor, the capability exists for the Lead Safety Engineer to be provided with presentation of any single channel upon request to the TV Console operator. This capability is considered adequate from a safety standpoint.

4.2.5 Electrical Power Generation and Distribution

The Electrical Power Generation and Distribution System for ETS-1 appears to be adequately designed to provide continuous electrical power with a high degree of reliability during critical test and non-test periods.

Power for the Electrical Power System during non-testing periods originates from the Nevada Power and Light Company. Power is provided to the Essential and Instrument Buses through tie breakers from the Utility Bus. The diesel generators will be available in the event of failure of Nevada Power.

During test periods, it is planned to operate the Electrical Power System as follows. The Utility Bus will be supplied from Nevada Power. All breakers on the bus will be closed including the tie breakers. The Essential Bus loads will be supplied with power from the three Caterpillar diesels and will be parallel to the Utility Bus through its tie breaker. Operation in this manner affords high reliability by having the diesels carrying the essential loads with Nevada Power tied in as a backup. In the event of a fault on the Navada Power System the high speed under-voltage and reverse-power relays will open the tie breaker protecting the Essential Load Bus. The diesel generators will see a minimum load transient as they had already been carrying the essential loads. On the other hand, if the diesels should fail, Nevada Power will assume the essential loads. The Instrument Load Bus has been designed to supply power loads which are sensitive to transients. Due to the nature of these loads (i.e., low power consumption, no large inductive circuits, etc.), this bus will be divorced from Nevada Power during testing. If either of the diesel generators fail, its protective circuits will remove it from the line. Should this occur, the running diesel generator can be manually paralleled back with Nevada Power; however, there would be no high-speed relays to protect this bus if Nevada Power should fault. Upon completion of testing, Nevada Power will be paralleled to the Instrument Bus and the diesels will be removed from the bus one at a time by reducing their loads and opening their output breakers. Current estimates of Instrument Bus loads indicate that either of the diesel generators is capable of carrying the bus. This essentially gives the system 100% backup without switching to Nevada Power in the event of a single generator failure.

In addition to the backup provided within the normal power distribution system, +28 vdc emergency power is provided by batteries as backup to the dc rectifiers which operate off of the Essential Load Bus and supply dc power for critical pilot valves, relays, instrumentation and control circuits.

The specifications and drawings for the electrical systems at ETS-1 require that the wiring and components used in these systems conform with the National Electric Code (NEC). Each area within the test complex has been classified as either Class 1, Division 1, Group B; Class 1, Division 2, Group B; Class 1, Division 2, Group D; or General Purpose in accordance with the hazardous area definitions given in Reference (29). For a number of areas it has been noted that all of the installed equipment does not meet the requirements associated with the established area classifications[(65)] (e.g., General Purpose lighting has been installed in some Class 1 areas[(66)]). Furthermore, off-the-shelf equipment which satisfies the Class 1, Group B requirements is frequently not available, so that in areas with this classification, compromises in the selection and installation of the electrical equipment have been made. Finally, it is expected that some of the areas within the ETS-1

Complex may have been over-classified and, as a result, should be downgraded to effect a reduction in future installation costs. For the above reasons, NTO is currently reviewing the hazardous area classifications at ETS-1 and is establishing the minimum equipment requirements which must be satisfied within each area[65]. It is recommended that this effort be incorporated into an integrated Hazardous Area Classification Plan for the ETS-1 Complex. The plan should specify the classifications recommended for each area within the ETS-1 Complex, the justification for these classifications, and the recommended means by which the classification requirements can be satisfied by code or through the establishment of suitable design and installation standards. Upon completion of this effort, the REON Safety Division will review the classification and installation of electrical equipment at ETS-1 and forward their recommendations to NTO. Subsequent approval of the plan by SNPO-C must then be requested.

4.3 Conclusions

4.3.1 Safety System

There are no apparent significant problems or deficiencies regarding the Oxygen, Combustible Gas and Radiation-Detector Sybsystems or the Meteorological Subsystem of the Safety System provided by the EG&G subcontract. However, as described in the evaluation of the Safety System (Section 4.2.1), a number of changes and/or additions to the alarm logic of the Area Surveillance and Warning Subsystem are required to provide effective control of personnel and consistency with the NRDS Emergency Alarm Criteria. This is a comprehensive effort and early attention is necessary.

The Fire Protection System provides water deluge and CO_2 fire suppression capability for critical areas where leakage of gaseous or liquid hydrogen from piping or tankage systems poses a fire hazard. In addition, the system covers areas where overheating may occur (including nuclear heating). It is concluded that the basic requirements of the National Board of Fire Underwriters' standards, specified by the Aetron specifications, are satisfactory for the Fire Protection System installation (both water deluge and CO_2) at ETS-1. However, this system has not been interfaced with the Area Surveillance and Warning Subsystem as have other safety systems. This interfacing should be effected to provide alarm acknowledging and silencing capabilities at the Control Point Building in addition to providing activation of door lights and area beacons to guide personnel to safe areas when a fire alarm is sounded.

As discussed in Section 4.1.3.7, criticality alarm capability is required for ETS-1 operation. The only significant progress, to date, in providing this capability has been preparation by NTO of preliminary specifications for a proposed Criticality Alarm System. Therefore, since considerable effort remains to provide an operable system, early attention is necessary. This effort should include assurance that this system is appropriately interfaced with the Area Surveillance and Warning Subsystem.

4.3.2 Communications and Closed Circuit Television

These systems provide optimum control capability at ETS-1 including viewing and communications provisions at the LSE Console in the Control Point Building. There are no unique safety problems or deficiencies evident.

4.3.3 Electrical Power Generation and Distribution

The Electrical Power Generation and Distribution System for ETS-1 appears to be adequately designed to provide continuous electrical power with a high degree of reliability during critical test and non-test periods. No design deficiencies in the system were noted during this evaluation which could seriously compromise the safety of ETS-1 operations.

The hazardous area classifications and associated electrical equipment requirements for ETS-1 need to be reviewed, and in some instances revised, to assure that classifications are adequate, yet not overly restrictive, and that installed electrical wiring and equipment satisfy appropriate safety criteria. NTO is currently performing this review. It is recommended that the results of this effort be incorporated into an integrated Hazardous Area Classification Plan for ETS-1. Following REON Safety Division review, the plan should be submitted to SNPO-C for approval.

5. TEST STAND AND ENGINE CONTROL SYSTEMS

5.1 Description

5.1.1 Test Stand Control System

The primary purpose of the Test Stand Control System (TSCS) is to operate the ETS-1 facilities that interface directly with the X-Engine. The system is comprised of the following major units:

a. Chief Test Engineer (CTE) Console

The CTE Console provides the controls that initiate engine operation and contains displays of various parameters required to monitor engine operation. Included on the console are controls and set points to allow the operator to initiate such functions as Start Reactor, Start Engine Run, Hold, Shutdown, Period Set, Pressure Trim, etc. The CTE also has the controls necessary to switch from an automatic to a manual mode of operation. Provisions are made for the manual control demand signal to track the demand or measured Engine Control System (ECS) signal in order to accomplish a "bumpless" transfer during switching between the operating modes. To facilitate manual operation, the CTE can manually control the drum position, log power, temperature, pressure and TPCV position demands. In emergency situations the CTE can initiate a scram or an emergency shutdown. When the console is ready for operation, a signal is sent to the Test Director Console.

b. Assistant Test Engineer (ATE) Console

The ATE Console in conjunction with the CTE Console provides individual, ganged or combinations of drum control for physics tests. The console contains a key switch to activate the drum control circuitry and meters to monitor drum position. The ATE Console also monitors chamber temperature, and two in-core temperature stations, and selects the temperature feedback signal to be provided to the Engine Control System temperature control circuit. Meters and indicators are provided to monitor period, average drum position, log count rate, reactor temperatures and computed temperature. When the console is ready for operation, a signal is sent to the Test Director Console.

c. Lead Reactor Engineer (LRE) Console

The LRE Console contains the displays and controls necessary to monitor both the neutronic parameters as generated by the 3 log power nuclear instrument channels of the Engine Control System, and the 3 log power, 3 linear and 3 log count rate nuclear instrument channels of the TSCS. The log power signal from the TSCS nuclear channels may be selected by the LRE for engine control and for CTE monitoring in the event the ECS nuclear channels malfunction. The LRE Console also contains variable controls for setting exponential and ramp signals to the auto startup circuit of the ECS, and for establishing floating power, fixed power, and period trip setpoints for the Engine Safety System (ESS). When the console is ready for operation, a signal is sent to the Test Director Console.

d. Test Stand Engineer (TSE) and Assistant Stand Engineer (ASE) Consoles

The TSE and ASE Consoles contain the controls and displays which are necessary to operate the test stand process systems in conjunction with the Process System Controller. Indicators are provided to accept 0-5 volt analog signals received from pressure, temperature, flow, level and valve position potentiometer transducers. Other indicators are provided to accept +28 vdc signals received from pressure switches, level transducers, position switches for remote shut-off valves, and selection of AUTO/MANUAL/PROGRAM modes. Two potentiometers are provided for each process system analog valve; one used as the automatic demand and

and the other for manual demand. The manual potentiometer assembly includes a servo motor driven by the demand setting to "track" when operation is not in the manual mode. Switches are provided for initiating 28 vdc binary signals to remote shutoff valves (RSV), heater on circuits (HT), pressurization and vent solenoids (RL), etc.

e. Engine Safety System (ESS)

The ESS monitors critical engine parameters comparing the measured values against the setpoint values to detect malfunctions and, in the event of a malfunction, initiates control signals to the ECS for emergency action. The two types of emergency action which can be taken are defined as follows:

(1) Scram - The reactor drums are returned to zero at their maximum rate and a normal controlled flow shutdown is initiated.

(2) Emergency Shutdown - The drums are returned to zero at their maximum rate, the turbine power control valve (TPCV) is closed, and the reduction in pressure in the pump discharge line allows coolant to enter the nozzle through the cooldown shutoff valve (CSV) and the cooldown check valve (CKV).

Each of the items monitored for malfunction by the ESS are provided with a bypass circuit which, when activated, prevents the ESS from initiating emergency action in the event of a malfunction of the particular item bypassed. The bypass switches are located on the LRE Console and the Setup Panel.

f. Test Stand Nuclear Instrumentation

The test stand nuclear instrumentation is provided to monitor the reactor flux over the complete range of operation and is comprised of:

(1) Three startup channels utilizing BF_3 proportional counters to cover the source-level and low-power range over five decades.

The signals from each of the startup channels are sent to the LRE Console and are not tied into the engine safety logic. The power supplies for these channels are remotely controlled from the LRE Console.

(2) Three linear channels to monitor the power level from 9.5 decades below full power to 500-percent full power. These channels are not tied into the engine safety logic. The linear channels utilize WX-5362 compensated ion chambers as detectors and send their signals to the LRE Console.

(3) Three logarithmic channels to monitor the power level from 7.5 decades below full power to 500-percent full power on single-range 8-decade log meters at the LRE Console. WX-5362 compensated ion chambers are used as detectors and send signals to individual display meters on the LRE Console and an average/reject circuit. The average signal is provided to the CTE Console for display and can be sent to the ESS for malfunction detection. A period signal generated from the average log signal is provided to the LRE and ATE Consoles for display. In the event of malfunction of the log channels in the Engine Control System, the 3 TSCS log channels are available as backup for control and malfunction detection.

g. Process System Controller (PSC)

The PSC includes control amplifiers, servo amplifiers, detector amplifiers, setpoints, and the logic required for operation of the process control systems. Signals to initiate action by the PSC are received from the TSE and ASE Consoles which may demand MANUAL, AUTOMATIC or PROGRAM modes of operation.

h. Setup Panel Rack

The Setup Panel Rack provides the capability to perform override bypass commands, override level settings, non-neutronic scram bypass

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commands, simulation control, and transfer function measurement controls. The rack contains a power supply monitoring panel and a display to indicate whether the various override and scram bypass circuits are activated or deactivated.

i. Test Simulation System (TSS)

The TSS is provided to simulate the critical engine and test stand functions necessary to aid in establishing the readiness of the control systems to perform the test operations. The system will be capable of simulating selected control components to permit exercising of control loops with response provided to an associated control console. Hence, the simulator provides both a checkout and training capability.

j. Checkout System

The Checkout System includes the measuring, recording, and signal-generating equipment necessary to determine, locate, and isolate a malfunction in a control system module within the TSCS/ECS control complex in order to facilitate calibration and repair. The connection of checkout equipment into the control system is facilitated by means of the Checkout Test Point Panel which contains jacks or connectors for the tie-in of such items as recorder binary inputs and oscilloscope horizontal amplifier inputs.

k. Recorders

The ETS-1 Control Room is provided with four 8-channel strip chart recorders having seven bi-polar event markers per recorder. Control "trend-type" information as selected prior to a test run can be patched into the recorders and monitored by an operator.

5.1.2 Engine Control System (ECS)

The Engine Control System for the X-Engine test program is comprised of circuits and control loops which will enable the engine system to accomplish startup, bootstrap, power operation, and shutdown in a programmed manner. The major circuits and control loops comprising this system include an auto start circuit, sequence controller, manual power controller, temperature control loop. pressure control loop, and TPCV scheduler which operate in the manner described in the following paragraphs.

Upon receipt of a reactor start signal from the CTE the Engine Control System is placed in a start condition by the sequence controller. For an auto start, the drums are commanded out by the auto-start circuit in a manner dictated by exponential and ramp settings made by the LRE. When the power has risen to a level corresponding to a value preset on the manual power controller, the auto start circuit closes the power loop to maintain the preset power level.

The Engine Control System can be operated through the reactor start phase by manual control of both drum position and the power controller from signals initiated by the CTE Console. A start engine signal from the CTE causes the sequence controller to establish conditions necessary for the bootstrap and power rise to the hold point. When the start engine signal is received, the PDSV is opened, pump chilldown is completed, and a log power ramp is initiated.

As the power increases and the flow and temperature increase. the measured temperature will become equal to the temperature demand signal and the sequence controller will close the temperature loop. In conjunction with this sequence of operations, and at the end of the chilldown operation, a signal is sent to the "TPCV Scheduler" and the TPCV is opened over the preselected profile.

When the measured pressure equals the pressure demand signal, the pressure loop is closed. The pressure demand signal which is generated by the temperature-to-pressure function generator will rise with temperature to the predetermined hold point.

Upon receipt of a "shutdown" signal, the temperature is ramped down causing the pressure to reduce according to the relation established by the "temperature-pressure" function generator. When the temperature reaches a preset minimum value the sequence controller opens the temperature loop and commands a rapid power decrease thereby causing the drums to rotate into their minimum reactivity position. At this point, the TPCV is switched from pressure control to a pump tail-off control which adjusts the TPCV so that constant temperature is maintained as flow decays. A level detector in the sequence controller senses when a minimum pressure is reached and initiates a signal to command the TPCV and PSV closed and informs the operator that shutdown is complete.

The ECS also includes "override" or "limiter" circuits as a first step in developing engine malfunction compensation. Three "override" circuits presently included in the system are Core Temperature, Log Power and Δ Pressure. Also under consideration for inclusion in the ECS are Turbine Speed, Period, and Tie-Rod Temperature overrides. The override signals act to reduce drum position in proportion to the amount the particular signal exceeds the set point value.

5.2 Evaluation

This preliminary safety evaluation of the Test Stand Control System and the Engine Control System is based on the information contained in References (71) to (73) and on discussions with cognizant AGC personnel. The TSCS is in the initial stages of final design and fabrication. The preliminary design of the ECS is complete and a "bread board" model is presently being tested. The equipment for both systems is being designed to utilize modules and parts that have been standardized to provide maximum interchangeability and to be compatible with equipment already in use at ETS-1.

The multiplicity of controls and displays are arranged in logical groupings on the various control consoles utilizing human engineering practices and operating experience to enhance the operators control ability. Since the test operations are under control of the Test Director, a status of readiness signal is provided for information to the TD Console from each operator console of the TSCS. In each case where a control function can be selected to operate in a MANUAL, AUTOMATIC or PROGRAM mode, the manual control demand signal will track the ECS demand or measured signal in order to permit a "bumpless" transfer during the switching between modes, thereby enhancing the safety of such operations. The control arrangements included in the design are considered to be adequate for their intended purpose.

Key-operated switches are utilized on the CTE and ATE Consoles and the forward drum-control unit of the ECS to provide operational control. When the keys are removed from the switches, power to the valve solenoid relays is off, the control drums cannot be operated from the Control Point either individually or ganged, and the drums cannot be moved at the Forward Control Point. The combinations of possible switch positions is designed to prevent inadvertent control drum movement and is considered an important safety feature.

The Engine Safety System (ESS) portion of the TSCS monitors critical engine parameters and, upon detection of a malfunction, provides a signal to the Engine Control System (ECS) to initiate emergency action. Bypass switches, located on the LRE Console and the TSCS Setup Panel, are provided for each parameter monitored. The fixed-power, floating-power, and period signal inputs to the ESS are normally derived from the three redundant log-power channels of the ECS; however, signals from the three log-power channels of the TSCS may be utilized in the event of malfunction. In addition to the log-power channels incorporated in the TSCS, three linear-power channels and three BF_3 startup channels are included in the system. The signals from the linear and startup channels are not used for malfunction monitoring but are directed to the LRE Console for operator information.

Power to the TSCS is supplied from the Instrument Load Bus of the facility electrical distribution system. The 115 vac supplied from this distribution is converted to $\pm$ 24 vdc and utilized for normal operation of the process system analog control valve amplifiers. The $\pm$ 15 vdc required for operation of the process system controller is derived from the $\pm$ 24 vdc supply through a zener diode shunt regulator. The 115 vac from the Instrument Load Bus is also converted to $\pm$ 12 and $\pm$ 15 vdc by the power supplied of both the reactor parameter and engine parameter circuits of the Engine Safety System. The power supplies of these two circuits will incorporate automatic redundancy by interconnection through a diode network. Critical power supplies will be monitored so that the operator can take corrective action upon loss of one of the redundant supplies. However, the power to all of these circuits is actually derived from the Instrument Load Bus and a single malfunction in the distribution network between this power bus and the TSCS will cause the loss of $\pm$ 24, $\pm$ 15 and $\pm$ 12 vdc power sources. Therefore, the control circuits in this supply network which are required to accomplish a safe shutdown of the facility and engine should be identified and some method of supplying a redundant voltage to these critical circuits in the event of an Instrument Load Bus failure should be incorporated into the TSCS.

The integrated TSCS/ECS system has several methods for checking the operability of the control circuits and equipment including lamp verify circuits, checkout test point panels, and the Test Simulation System, all of which appear to be adequate. The latter system provides a means for conducting a simulator run of a complete operating procedure which verifies proper sequence of functions and system readiness prior to an actual test run.

To assure that the control systems are designed, fabricated, and installed in accordance with the highest possible standards, a detailed Product Assurance Plan, Reference (74), has been established which follows the control systems through each phase of the program including the final system checkout at NRDS by trained NTO technical personnel. Satisfactory implementation of the Product Assurance Plan should enhance the overall reliability of the system.

5.3 Conclusions

The information contained in References (71) to (75) indicates that the designs of the Test Stand Control System and the Engine Control System are proceeding in a logical manner utilizing past experience to improve the overall reliability of the systems. However, on the basis of this evaluation, it is concluded that a study should be made to determine which control circuits of the TSCS and ECS are necessary to accomplish a safe facility shutdown in the event of a facility power failure. The circuits determined to be critical should then be provided with an additional source of power independent of the Instrument Load Bus supply.

With the exception of the deficiency noted above, the evaluation of the TSCS and ECS indicates that adequate safety considerations are being incorporated into the system designs. The evaluation of system parameters to be monitored for malfunction and utilized to activate scram and emergency shutdown action is continuing. There is also a continuing effort to develop override (limiter) circuits for power, period, temperature, pressure, and turbine speed malfunction compensation. The results of these efforts to improve system reliability through the development of malfunction compensation and circuit simplifications will be further analyzed from a safety standpoint as additional information becomes available.

6. ENGINE COMPARTMENT RADIATION SHIELDS

6.1 Description

The engine compartment 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 ambient atmospheric pressure around the engine in order to partially simulate space environmental conditions, (3) to reduce the deleterious effects of radiation on engine components located above the engine external shield and on facility components located outside the engine compartment, and (4) to allow greater personnel access to facility areas following engine shutdown.

6.1.1 Basic Criteria

During the initiation and development of the shield design, certain criteria were established which formed the basis for the design. Most of these criteria were never fully documented nor was a design report assembled to summarize the design requirements and operational philosophies which evolved. However, some of the basic <u>radiation</u> criteria which were used in the design were compiled and are reported in Reference (18). The more significant of these are summarized below:

a. The shield will be designed for use with a 3.5 NERVA engine operated to 2.0×10^6 Mw-sec per run. In addition, an interval of 30 days between runs and no more than 10 runs per year will be assumed.

b. The integrated dose to personnel located in the Control Point Building will not exceed 100 mr from a 2×10^6 Mw-sec run.

c. At one hour after shutdown, the radiation levels in the Test Cell Building and at the facility entrance in the Control Point Area will not exceed 10 mr/hr.

d. Twenty-four hours after shutdown the does rate in the Storage Farm Area will be less than 2.5 mr/hr.

e. Five days after shutdown with the engine and side shields removed and with the duct cover shield and duct vault door shield in place, the dose rate on the test stand and in front of the duct vault door will be less than 2.5 mr/hr.

With the exception of the latter, the above criteria have been met as is shown by Reference (21). Whether the five-day criterion has been satisfied will depend upon the amount of effluent fallout in the test stand area and the amount of fission-product contamination of the NES duct. However, the residual activity levels at the test stand resulting from materials activation satisfy the stated criterion.

6.1.2 Design

The engine compartment radiation shields consist of a top shield, two semi-cylindrical 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 designated the Engine Test Compartment (ETC). A half-donut-shaped intermediate shield is attached to each of the side shields which mate with an engine shield located at the upper end of the thrust chamber when the two side shields are engaged in the test position. The bottom shield contains a nozzle penetration for the NES duct. The duct penetration can be covered by a portable duct cover shield when the side shields are not in the sealed position. The side shields and the duct cover shield are remotely placed into position. Penetrations into the compartment for the fuel line, purge line, thrust measuring components, electrical lines, and instrumentation leads are in the top shield. An air-tight seal of the ETC is required and is accomplished by employing an eutectic seal between the top shield and the side shields and between the bottom shield and the side shields. Sealing between the vertical faces of the side shields is accomplished by pressurizing a convolute metal seal system with inert gas. Each of these compartment seals is a double seal with an inert gas pressurized buffer zone between seals. The shield design and supporting analysis is documented in References (19) through (24).

6.1.2.1 Top Shield (S5)

The engine compartment top shield consists of a circular tank of aluminum construction approximately 17.5 feet outside diameter and 30 inches deep. The tank is filled with circulating demineralized water for thermal cooling and neutron attenuation. Two 1-inch lead plates are located near the top of the shield to provide additional gamma-ray attenuation. The layers are separated to allow cooling water flow between the layers during engine test operations. The shield has cylindrical openings extending through the shield for thrust measuring, for piping of fluids required in the compartment during test, and for electrical and instrumentation connections to the engine and thrust ring. The top shield provides support for the top seal ring and seal mechanism, and for cooling water supply and return manifolds.

6.1.2.2 Side Shields (S1, S2 and S6)

The two side shields are in the form of right circular semi-cylinders, 22.5 feet outside diameter, 17.5 feet inside diameter and approximately 31 feet in overall height. The 30-inch cavity in each shield is filled with circulating demineralized water for thermal cooling and neutron attenuation. Located near the inside surface of these shields is a cellular extrusion of aluminum alloy which supports a 1/4-inch boral plate. The purpose of the boral is to minimize possible reactor perturbations which might result from reflected neutrons. A 1/4-inch water cooling passage is located on each side of the boral plate to provide forced convection cooling in this region. A 2-inch lead plate is located near the bottom of the shield to provide additional shielding for the seal components and structural members located below the shield.

The two intermediate shield segments (S6) are suspended by fourteen 3-inch pipes from the top of the shields to a position about half way down the inner surface of the shields. The pipes, which are connected to a water manifold at the top, provide the water flow paths to and from the segments. The segment shields have an inner diameter of 8.73 feet, an outer diameter of 17.21 feet, and are 3.33 feet thick. A 1/4-inch boral plate is located near the bottom surface of each segment shield and lead plates, 1-1/2 inches thick and 1 inch thick, are positioned in the shield near the inner and top surfaces, respectively. When the engine and side shields are in test position, the intermediate shield mates with the external engine shield above the pressure vessel.

The outer surface of each side shield contains 5 penetrations (total of 10 for the compartment) for neutron detectors (Ref. Dwg No. 3350-S118); one of the penetrations is located 5-1/8 inches from the bottom of the shield, three of the penetrations are located 10 ft 4-1/4 inches from the bottom of the shield, and the fifth penetration is located 12 ft 10 inches from the bottom of the shield.

The side shields will be stored during non-test periods at a point 200 feet away from the test stand centerline and locked at this point to prevent damage from winds up to 70 mph. Positioning of the shields at the test stand will occur only at those times immediately prior to tests. The shields are capable of remote operation for accurate alignment as they approach the test stand centerline to form the Engine Test Compartment. Each of the shields is supported on a transfer car which travels on rails to and from the test stand. The mechanical drive for this system is an endless steel cable and drum unit driven by an electric motor with fluid coupling. Smooth acceleration, constant travel speed of approximately 15 fpm, and smooth deceleration is provided. The power sheaves of each unit near the test stand incorporate a positive tension device so that cable tension on the drive side of the cable is uniform at all times. A slow-speed motor and controls are incorporated with the main drive system for "inching" during the last 12 inches of travel at the test stand end. All fluid and electrical connections are made and interlocks are activated at a station 8 inches from the test position. Water fill and drain is accomplished at a station approximately 1 inch from the test position. Continuous water flow is maintained during test operations by opening the fill valves and allowing water to overflow 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 sealing purge gas pressure. The locking mechanism uses an "over-center" cam principle so as to prevent accidental opening of the lock upon loss of pneumatic actuation pressure. The locking mechanism consists of a total of 24 latches (12 on each side) operated in sets of four by 6 pneumatic cylinders.

6.1.2.3 Bottom Shield (S4)

The bottom shield consists of a cylindrical tank, 16.21 feet in diameter, 30 inches deep, and with a central opening 6.83 feet in diameter to accommodate the exhaust duct penetration. The top surface of the shield is comprised of a cellular extrusion of aluminum which contains a 1/4-inch boral plate. A 1/4-inch water cooling passage is located on each side of the boral to provide forced convection cooling in this area. A 2-inch lead plate is positioned inside the shield near the bottom surface. The bottom shield provides support for the bottom seal ring and seal mechanisms, cooling water supply and return manifolds, and internal piping. In addition, the bottom shield provides for attachment of the exhaust duct seal mechanism.

6.1.2.4 Engine Compartment Seals

a. Top Eutectic Seal - The top eutectic seal 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 which contains a eutectic mixture of lead (45 percent) and bismuth (55 percent). The bellows and double plate seal blades are supported from the top shield, and the trough is supported by the side shields. The eutectic is normally melted by electric heating coils located near the bottom of the troughs. Pressurizing the bellows with GN_2 displaces the double-plate blades downward into the molten eutectic. The blades are sealed as the eutectic solidifies. Further sealing protection against air leakage into the ETC is obtained by pressurizing the space between the seal blades with an inert buffer gas (GN_2).

Pressurization of the bellows is remotely controlled by a solenoid valve to a design working pressure of 18 psig. The buffer-gas pressurization is remotely controlled by a solenoid valve to a design working pressure of 2 psig.

The eutectic trough is also equipped with water cooling coils which prevent melting of the eutectic during test operations. Cooling water flow to the side-shield troughs is controlled with two solenoid valves. The cooling coils may be manually connected to the Steam Generator System to melt the eutectic in event of electric heater malfunctions.

b. 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. The trough is raised by hydraulic cylinders which rotate the trough through an arc of 8° - 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 pressurized with a buffer gas (GN_2). Buffer gas pressure to the blades is controlled by solenoid valves.

c. Convolute Seals - The convolute seals seal the ETC along the vertical longitudinal seam between the side shields. The convolute seal consists of a metallic, inflatable seal with two convolutions. When pressurized, the convolutions expand and form a seal with an adjoining seal surface. The side shields are held together by the latch mechanisms described in Section 6.1.2.2 above. To further ensure against leakage of air into the ETC, the space between the two convolutions and the adjoining seal surface is pressurized with an inert buffer gas (GN_2). The convolute seal pressure is controlled by a solenoid valve to a design working pressure of 5 psig, and the buffer-gas pressure is controlled by a solenoid valve to a design working pressure of 2 psig.

6.1.2.5 Duct Cover Shield (S3) 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 following engine removal from the stand. The shield is supported on a transfer car which is driven and positioned in a manner similar to that described for the side shields, except that its position-accuracy capabilities are not as great.

The shield is constructed of lead and is in two sections, both of which are three inches thick. The bottom section of the shield is fixed to the transfer car. The top section is on rollers which allows it to slide over the top of the bottom section. Thus, either three or six inches of lead can be positioned over the duct with the engine removed. The duct cover shield was fabricated in two sections so that, as required by the criteria[18], shielding can be provided for the duct during the engine removal operations. Had the shield been fabricated in a single 6-inch thickness, it was felt that the clearance between the top of the duct cover shield and the bottom of the nozzle might be insufficient to allow for engine removal with the cover shield in place.

6.1.2.6 Control and Instrumentation

The required Engine Test Compartment operations are controlled from either the local control panels or from the remote control consoles in the Control Point Building. There are two local control panels. One panel controls the operations for Side Shield S1 and the pump, seals, and latch operations. The other panel controls the operations for Side Shield S2 and

Duct Cover Shield S3. These local control panels also include the necessary indicator lights for each of the control functions. There are no pressure, temperature, flow rate, etc., readouts on the local panels.

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

The remote control consoles in the Control Point Building enable all necessary operations to be performed remotely to transfer the shields, to establish seals, and to fill and drain water from the shields. The remote control consoles also contain indicator lights for pressure, temperature, and flow indications required to monitor these operations.

6.2 Evaluation

6.2.1 Structural and Mechanical Design

a. Examination of the structural and mechanical aspects of the engine compartment shield design has revealed no major defects, omissions, or discrepancies in the design which might affect the safety of ETS-1 operations. The calculations which support the design, Reference (23), were reviewed and found to be thorough and well documented. A more detailed evaluation to determine the validity of these calculations is currently being performed by REON Department 7421, Structures - Staff Engineering.

b. The water distribution system for the shields has been designed such that loss of inlet water will result in loss of flow through the shields but not loss of water in the shields. Thus, barring a major structural failure, loss of shield water is considered to be highly improbable.

c. The engine compartment is completely sealed with double seals buffered with a nitrogen purge. A seal failure resulting in significant air leakage into the compartment appears to be highly improbable providing the seals are properly mated during side-shield installation.

d. The cable-drawn side-shield transfer cars will be unable to separate the side shields following an engine test should one of the following malfunctions occur[25]: (1) loss of capability to melt the eutectic alloy in the top and bottom seals, (2) loss of capability to lower the bottom shield trough, or (3) loss of capability to deactivate the side shield locking mechanism. There are three separate resistor heating units in both the top and bottom eutectic seals, any one of which is expected to be capable of melting the eutectic alloy[25]. In addition, steam can be passed through the water cooling lines located in the eutectic to accomplish the same purpose. Thus, there appears to be adequate provisions in the design to assure that the eutectic seals can be melted. However, in order to separate the bottom-shield seal trough from the side shield, a rotating ring assembly must be rotated by four hydraulic (oil) cylinders. Failure of this subsystem would prevent separation of the side shields. Finally, failure of the pneumatic cylinders to disengage the side-shield locks would also prevent side-shield separation. Thus, it is concluded that means of separating the side shields in the event of failure of the locking or sealing mechanisms should be considered and any special GSE capability which might be required for this purpose should be provided (see Section 8).

6.2.2 Nuclear Design

a. The radiation criteria used for the shield design appear to provide for adequate protection of personnel during test operations as currently contemplated for ETS-1. As has been shown in Reference (21), the radiation criteria utilized in the design have been satisfied.

b. The effects of radiation on the shield components are not covered by the available documentation though it is understood that radiation damage effects were given detailed consideration by Aetron during final design[25,26]. Aetron has stated,[25] however, that there could be some problem with valve seals located in the instrument boxes on the transfer cars. There is also some question about the ability of certain components of the ETC shield system (e.g., the pneumatic and hydraulic actuators which operate the sealing and locking mechanisms on the side shields) to withstand the radiation environment which is present during operation. It is concluded, therefore, that the effects of radiation heating and damage to shield components be further examined by cognizant REON personnel.

6.3 Conclusions

On the basis of the information which was available and used for this evaluation, it is concluded that the design of the engine compartment radiation shields is satisfactory from the safety standpoint. In addition, it is recommended that

(1) the effects of radiation heating and damage on shield components be examined by cognizant REON personnel, and

(2) means of separating the side shields in the event of failure of the locking or sealing mechanisms be considered and that the GSE capability required for this purpose be provided.

7. RADIATION

7.1 Environment

The environmental radiation intensities expected at ETS-1 following an X-Engine test are presented below[49,50]. The situations covered are limited primarily to those which govern personnel access to various areas of the facility following normal test operations. For each case described, an engine operating history of 300 seconds at a power level of 1100 Mw was assumed. The results presented are preliminary; however, with the exception of the isodose levels in the facility areas located behind the shadow shield (Figures 13 to 15), the results are based on more exact geometric representations of the engine and facility components than were used previously for calculating the radiation data reported in Reference (21).

7.1.1 Dose Rates from X-Engine After Shutdown

The build-up and decay of the fission-product activity in the X-Engine core was calculated with FPIP[22] assuming 100% retention of the fission product inventory. The shutdown gamma-ray dose rates one day after shutdown were calculated with QAD using, as input, the FPIP results. The results of the QAD calculation are shown in Figure 9 as a function of distance from the axial centerline of the core. The two cases considered include side enclosure shields in-place, and side enclosure shields either removed or in-place but drained. As can be seen, the dose rate at the surface of the side shields one day after shutdown from a 300-second full-power run is about 110 r/hr.

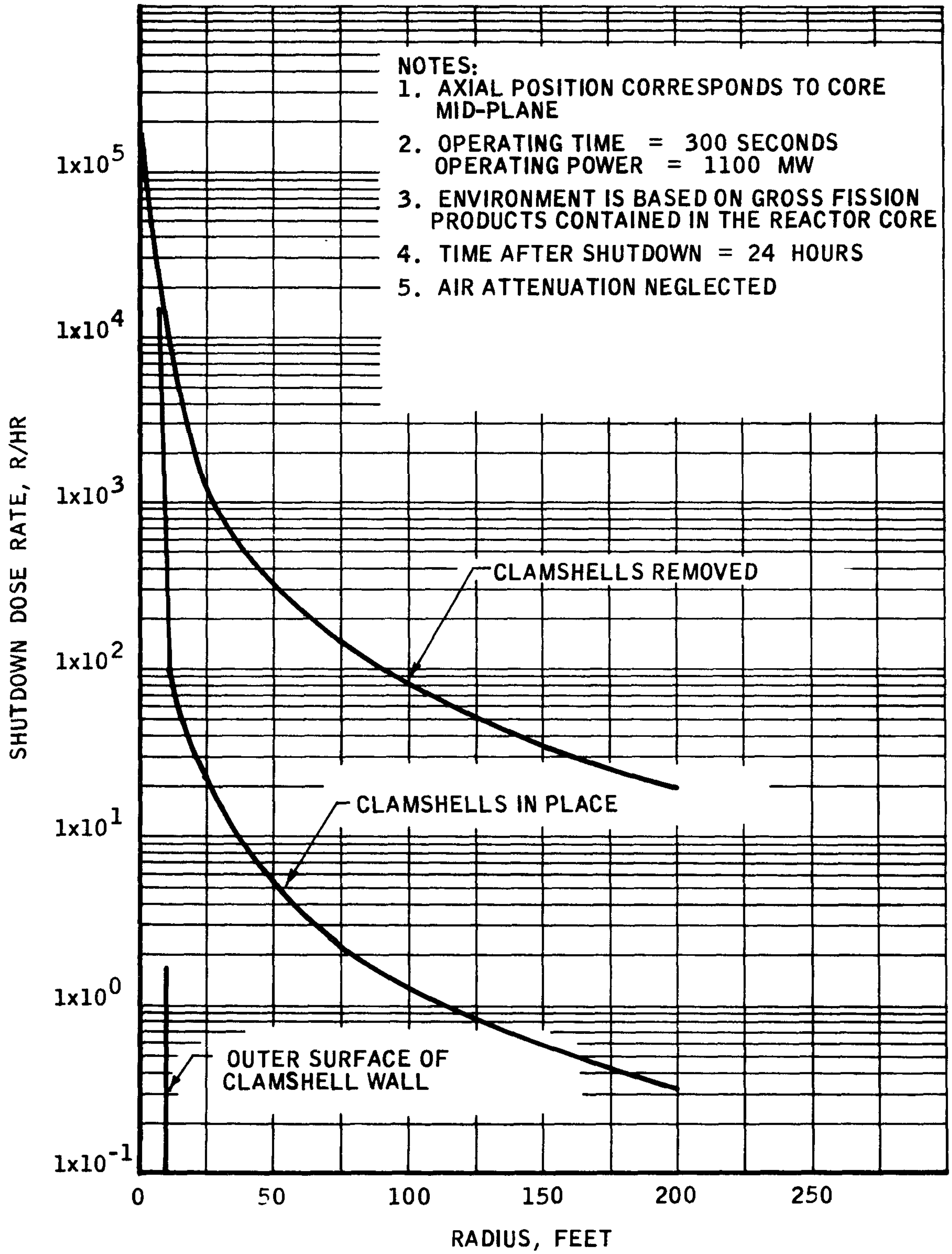

FIGURE 9
GAMMA DOSE RATE FROM ENGINE
ONE DAY AFTER SHUTDOWN

7.1.2 Time Decay of Fission Product Activity

An important consideration in evaluating facility accessibility is the variation of fission product activity with time after engine shutdown. This variation, as predicted with the FPIP Code between 0.3 days and 60 days following a 300-second run, is shown in Figure 10. The fission product activity has been normalized to unity at one day after shutdown to facilitate its use in extrapolating the radiation data presented in this section to various shutdown times

7.1.3 On-Stand Dose Rates Due to Duct and Ditch Contamination

Operation of the X-Engine at ETS-1 will result in fission product deposition in the NES duct and along the drainage ditch. Due to the complexities of the mechanisms for fission product release and deposition, accurate predictions of the resulting radiation environment cannot be made. However, conservative estimates can be made which should be helpful in the assessment of potential safety problems deriving from the X-Engine tests. For this preliminary evaluation the following assumptions were used

(1) 5% of the gross fission product inventory generated in the core during operation is released to the exhaust stream.

(2) 0.5% of the core inventory is uniformly deposited within the NES duct.

(3) 0.5% of the core inventory is logarithmically deposited along the drainage ditch with the concentration at the upstream end a factor of 12.4 times the concentration of a downstream point located 2000 ft from the duct exit.

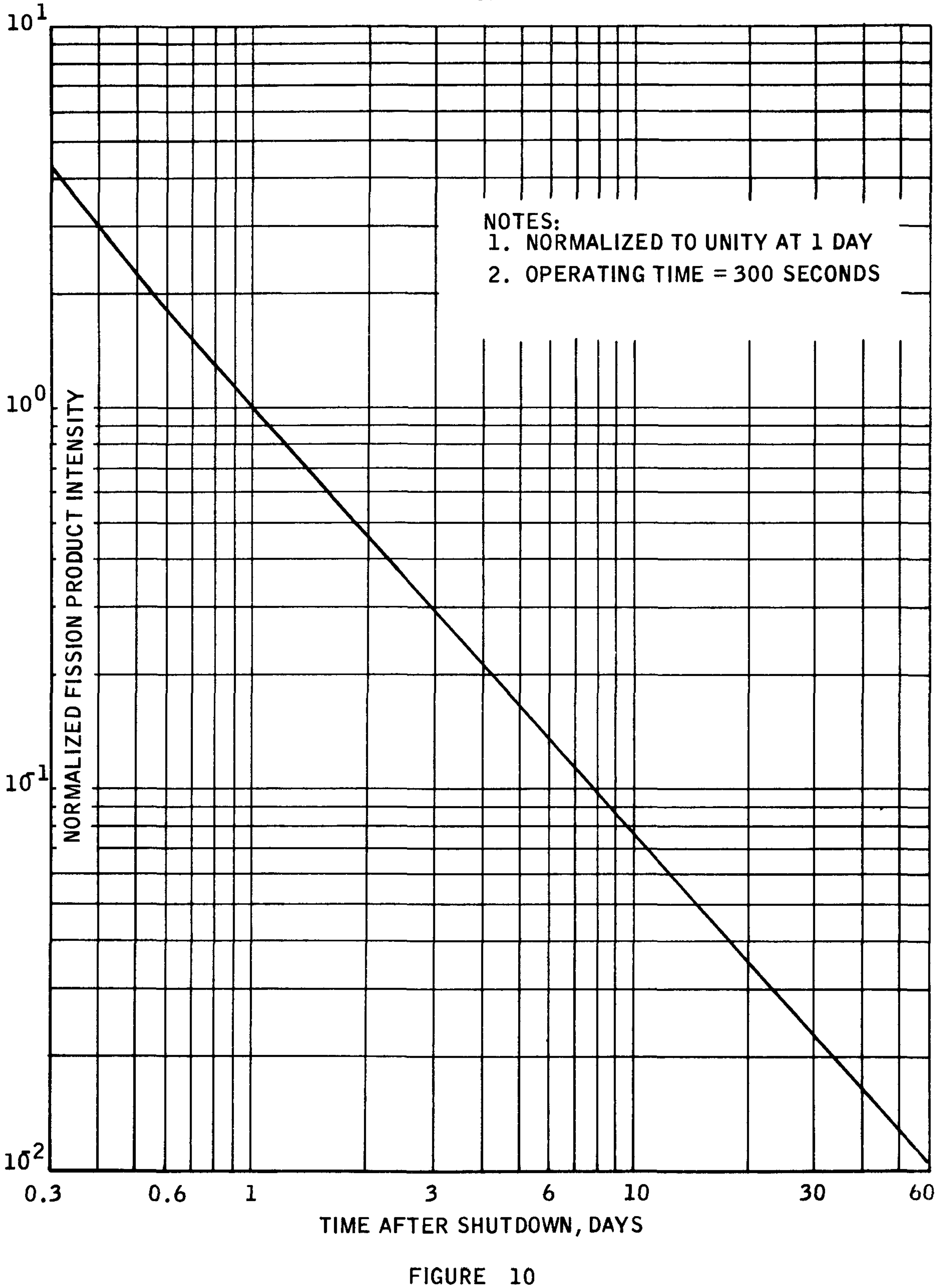

FIGURE 10
NORMALIZED FISSION PRODUCT DECAY CURVE

The resulting gamma-ray dose rates in the duct vault area one day after shutdown vary between 20 r/hr and 50 r/hr depending upon proximity to the NES duct elbow. These dose rates can be extrapolated to other shutdown times by use of the time-decay curve in Figure 10.

The dose rate on the test stand one day after shutdown with the engine and the side shields removed and with the duct cover shield (6 inches of lead) in place above the duct is shown in Figure 11. This figure gives the dose rate as a function of height above the test pad. The minimum indicated by the curve results from the transition between predominance by NES duct contamination and predominance by drainage ditch contamination. As shown, the nominal environment on the stand one day after shutdown varies between 160 and 400 mr/hr.

7.1.4 Activation of Side Enclosure Shields

Neutron activation of the side enclosure shields during XE operation will also contribute to the radiation environment in the test stand area following engine removal from the stand. An activation analysis[50] of these shields was performed using the TDC, DSN, QAD and ACT-II computer programs. The four-group neutron fluxes needed for input to ACT-II were calculated from 16-group fluxes obtained with TDC and DSN. (The surface fluxes produced by TDC along the clamshell interior were attenuated through the shields with the DSN program.) The specific activities resulting from the ACT-II calculations were then used as input to a QAD distributed-source calculation. The results of the above calculations as a function of time after shutdown are shown in Figure 12. Note that the dose rate from the enclosure shields will exceed the on-stand dose rate with the engine removed (Figure 11) until a time about 6 days after engine shutdown.

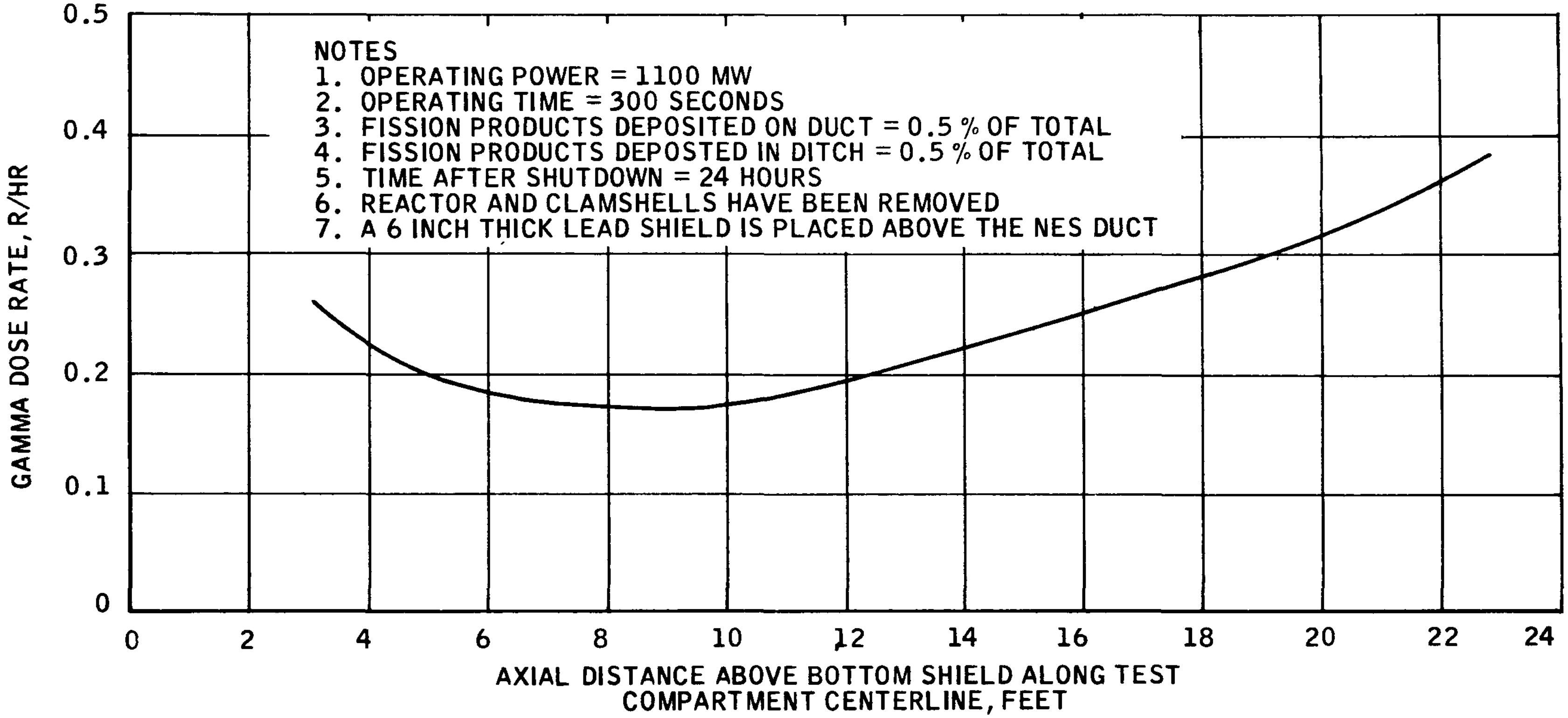

FIGURE 11

ON STAND DOSE RATE ONE DAY AFTER SHUTDOWN
FROM DUCT AND DITCH CONTAMINATION

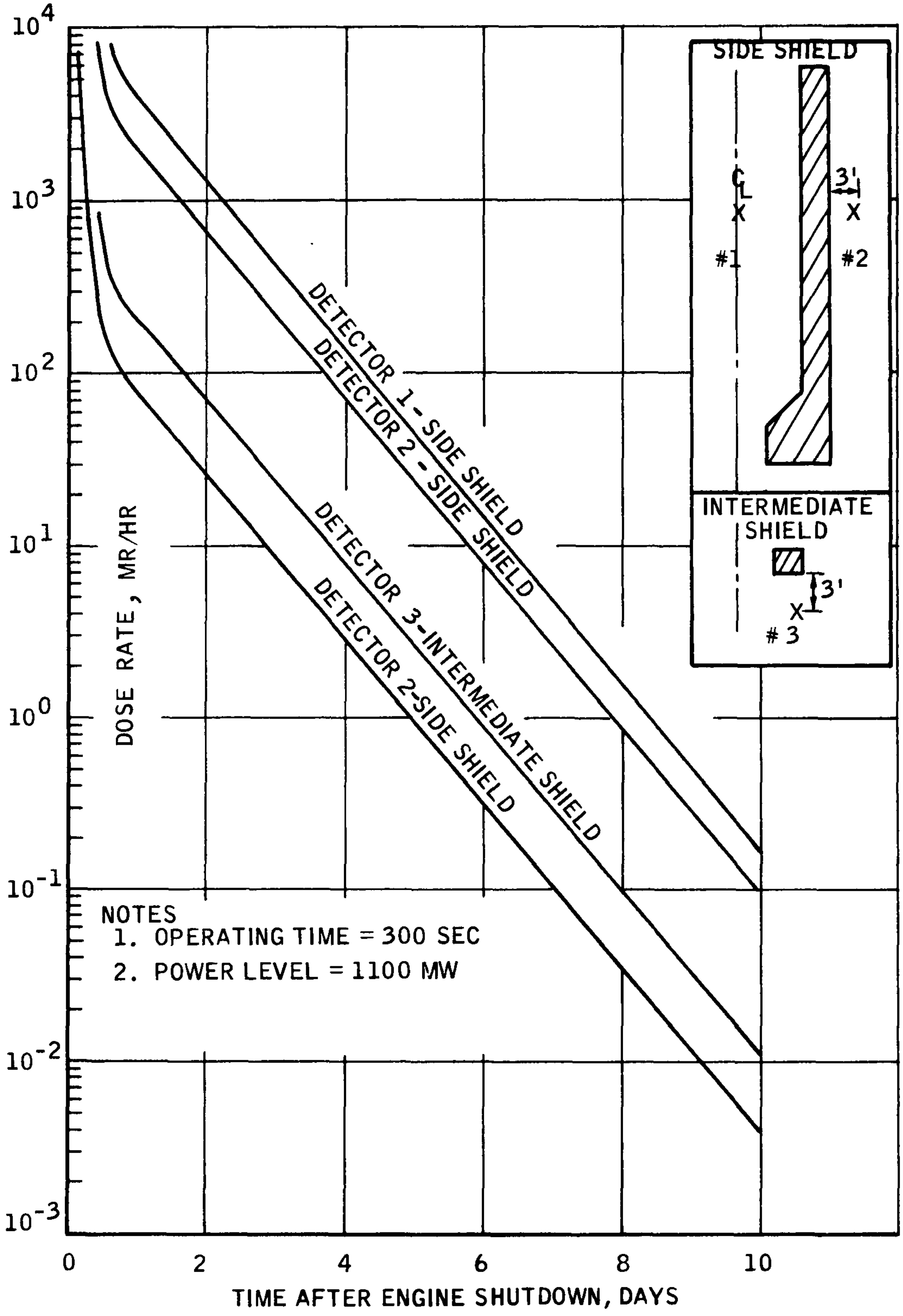

FIGURE 12

NEUTRON ACTIVATION OF SIDE AND INTERMEDIATE SHIELDS FROM XE - 1 OPERATION

7.1.5 Isodose Maps of the ETS-1 Area

Isodose maps of the test stand area and the facility areas behind the 3-foot concrete shadow shield are presented in Figures 13 to 15. The dose rates are shown for the periods: during engine operation, one hour after shutdown, and one day after shutdown. The radiation levels were extrapolated from the data given in Figure 9 and from the results of the GAS-6 calculations reported in Reference (21). The radiation levels directly behind the shadow shield are expected to be somewhat higher than those indicated in Figures 13 to 15 due to effects of radiation scattering off the test stand superstructure which were not considered in the GAS-6 analysis.

7.1.6 Miscellaneous Contributions to the Radiation Environment

Several additional situations have been postulated which may increase the radiation environment at ETS-1. The radiation level resulting from a single fuel element is interesting in terms of what would be expected should fuel be inadvertently ejected from the core during operation. Extrapolation to fractional or multiple elements can be made by mass proportion of the fuel. Assuming there are 1500 fuel elements in the reactor operating with a peak-to-average power ratio of 1.3, the one-day dose rate 3 feet from a single centrally located element is 250 r/hr. Thus, personnel access to areas contaminated by an ejected fuel element, or any significant fraction thereof, will be severely limited.

Another situation examined is the dose rate 3 feet above the ground plane when the surface is contaminated by fission product fallout. The fallout density was calculated assuming that 1% of the gross fission product

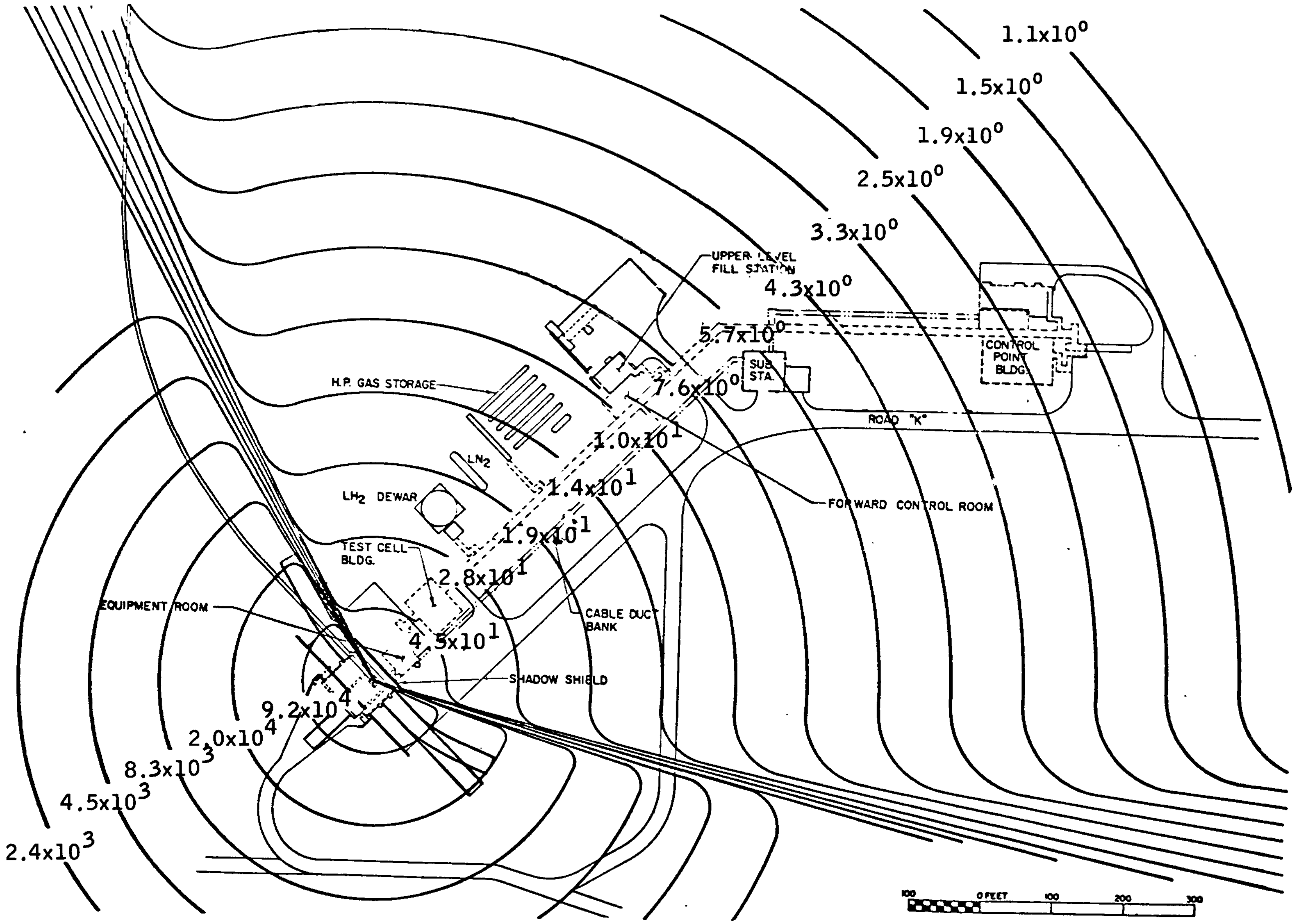

FIGURE 13

ISODOSE MAP FOR ETS-1 DURING XE-1 OPERATION (R/HR)

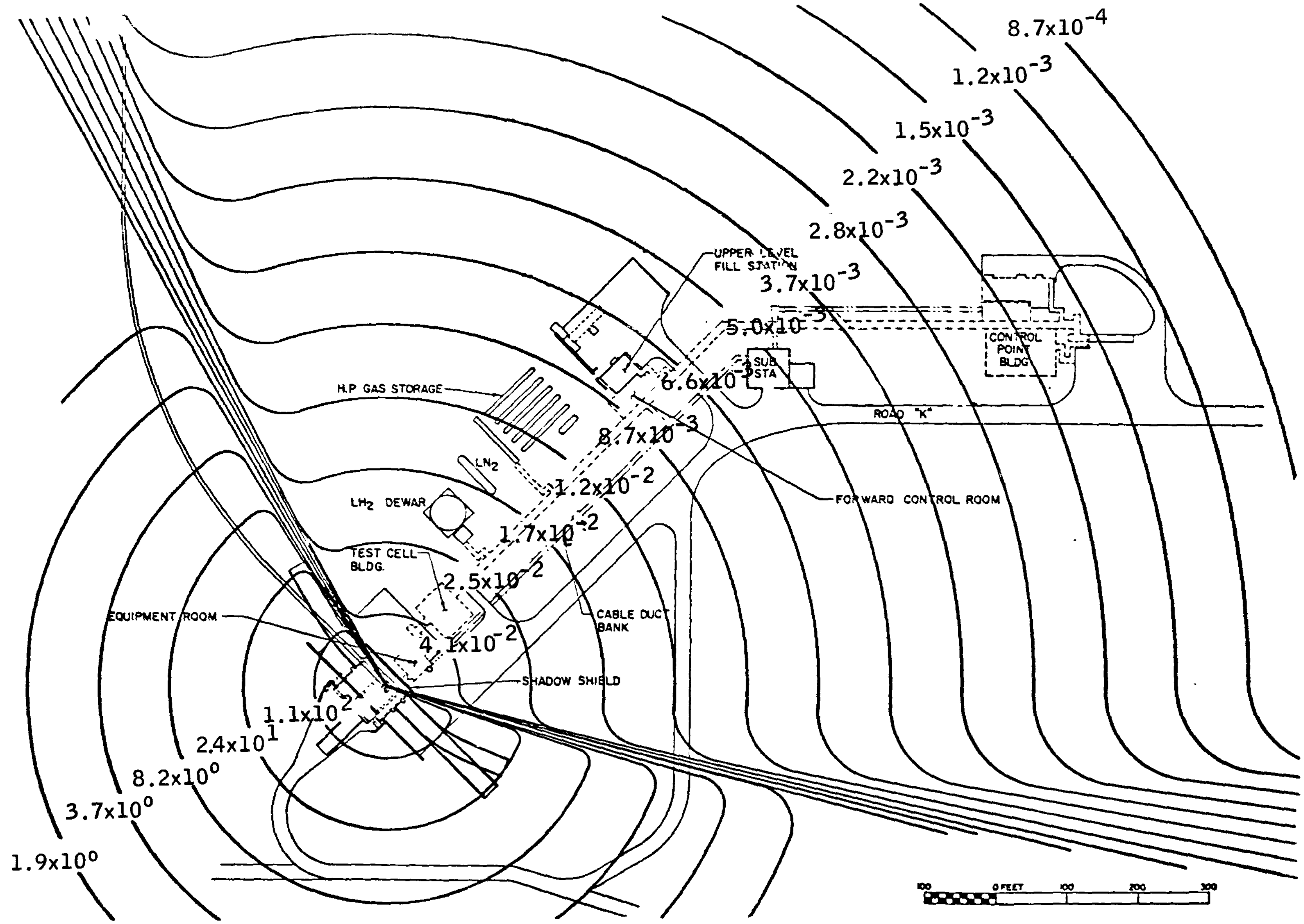

FIGURE 14

ISODOSE MAP FOR ETS-1 ONE HOUR AFTER XE-1 SHUTDOWN (R/HR)

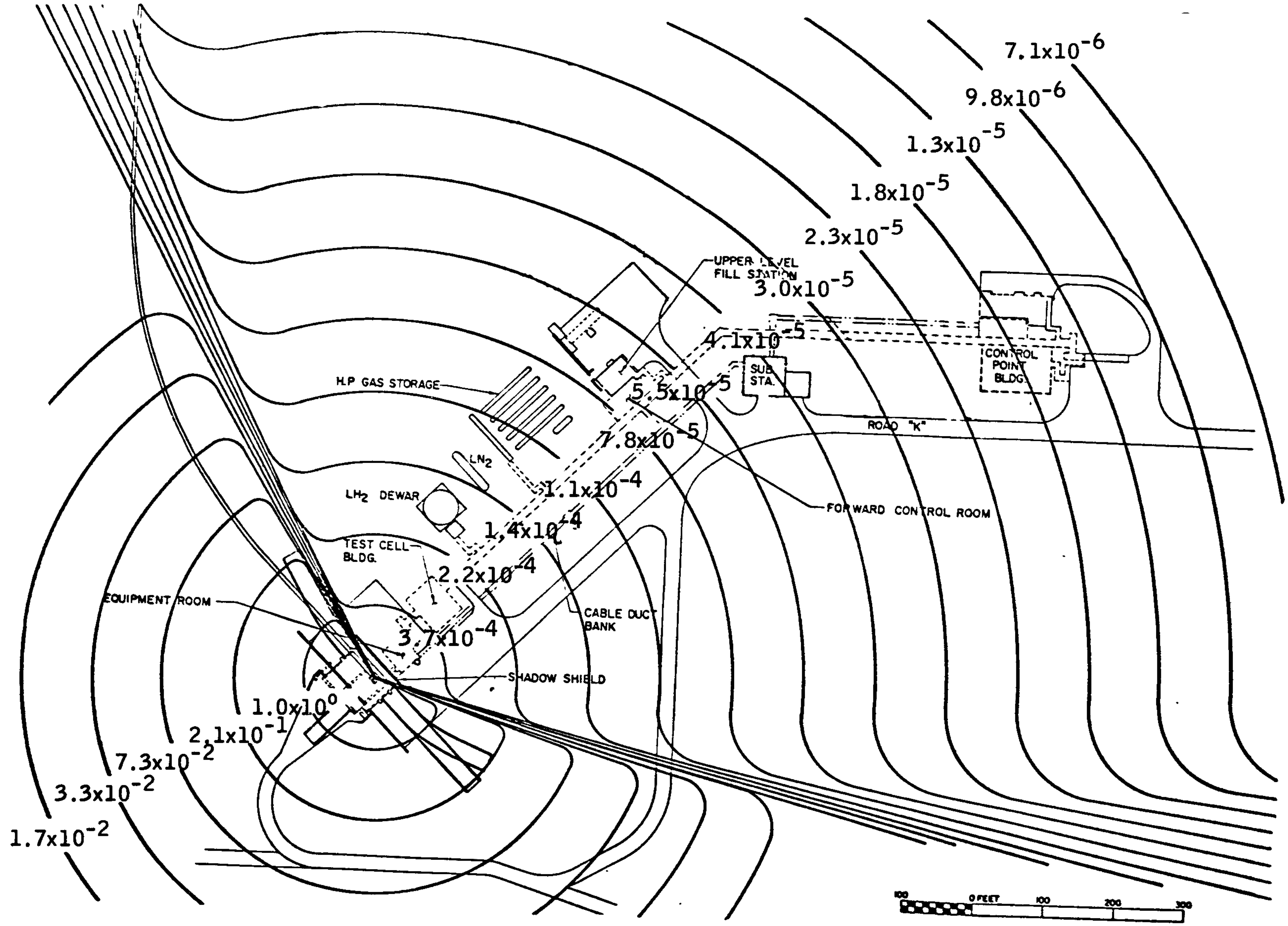

FIGURE 15

ISODOSE MAP FOR ETS-1 ONE DAY AFTER XE-1 SHUTDOWN (R/HR) inventory is distributed uniformly over a disk 100 meters in diameter. The resulting dose rate one day after shutdown was found to be 11 r/hr at a point 3 feet above the center of the fallout pattern.

Finally, the gamma-ray dose rate that may exist near the downstream end of the drainage ditch was estimated. Fission products deposited in the drainage ditch will be washed towards a single collection area near the end of the paved section of the ditch. Assuming that 0.1% of the fission products can accumulate in this area, radiation levels in the range between 0.1 and 1.0 r/hr one day after shutdown can result. However, since the necessity for access to this area soon after engine shutdown is not anticipated, no significant safety problems resulting from this contamination are expected.

7.2 Decontamination

7.2.1 Facility Areas

Normal testing of the nuclear engine will result in the release of fission products to the ETS-1 environs. As stated in Section 7.1.3, it has been assumed for this study that, during a full-power full-duration run, 5% of the total fission product inventory will be released from the core, 0.5% of the total inventory will plate out in the exhaust duct, and 0.5% of the total inventory will be deposited in the drainage ditch. Although facility areas other than the drainage ditch may be affected by fission product deposition, it is expected that the local fallout will be concentrated in the ditch. In addition, activation of structures, foreign particles, etc. which are located in the vicinity of the engine during test will add to the radioactive contamination of the facility.

Figure 11 shows that the gamma-ray dose rate on the test stand, as a result of fission product deposition in the duct and drainage ditch one day after shutdown, is in the range between 160 and 400 mr/hr. Since these radiation levels are probably higher than will actually exist due to the conservative assumptions used in the calculations, and also since it is expected that unlimited personnel access to the test stand area will not be required until at least a week after the engine is removed from the stand, a requirement to decontaminate the duct and drainage ditch will probably not develop. For example, the above dose rates will decrease to a range between 8 and 20 mr/hr after fifteen days, based upon the fission product decay curve of Figure 10. However, it is possible that either the above dose rates are not conservative, or an abnormality during the test operation will significantly increase the fission product release and the concomitant duct and ditch contamination. Under these conditions, at least partial decontamination of the ditch may be desirable. It is expected that a simple, yet effective, means for partial decontamination of the drainage ditch area will be by high pressure water spray. This can be accomplished by using a high-pressure fire hose operated at a sufficient distance from the radioactive debris so as not to over-expose personnel. Some difficulties may be encountered in decontaminating the sloping walls of the ditch due to the existing porous and cracked condition of the gunite surfaces. It is recommended, therefore, that consideration be given to refinishing these surfaces to enhance the effectiveness of possible decontamination operations.

Decontamination requirements and methods applicable to other ETS-1 facility areas are largely dependent upon such factors as personnel access requirements, specific location, accessibility and surface characteristics. Water spray may also be effective on the test stand; however, methods such as vacuuming or scrubbing may be more effective. NTO Health and Safety personnel should continue to maintain cognizance of decontamination activities at Test Cells A and C, and utilize the information obtained for developing appropriate decontamination techniques and procedures for ETS-1.

A discussion concerning decontamination of ETS-1 areas for abnormal (accident) conditions is presented in Section 8, Emergency Requirements.

7.2.2 Equipment

No provision was made in the ETS-1 design for decontamination of components or equipment within the test complex area. It is currently planned that contaminated equipment will be packaged, as required to prevent the spread of radioactivity, and transported to a remote decontamination facility. Present capability for decontamination is provided in an area adjacent to R-MAD. However, it is expected that with increased activity at NRDS, additional facilities will be made available at E-MAD. No significant problems are anticipated at ETS-1 in packaging or transporting equipment for decontamination.

Major attention in the past has been centered on decontamination of the exhaust duct since it is expected that a significant amount of fission product activity will plate out on its inner wall surfaces. However, based on the following considerations, it appears neither practical nor desirable to attempt duct decontamination.

(1) The effectiveness of decontamination is questionable. A considerable amount of effort has been spent in the past relative to studies of appropriate duct decontamination methods[85,86,88]. These efforts have included discussions with decontamination consultants, from which no specific conclusions could be drawn. Experience to date on decontamination of the duct material (stainless steel) subjected to plate-out under conditions similar to those which will exist during engine testing is very minimal. Significant radioactivity was removed from KIWI nozzles after implementation of rigorous methods; however, the applicability of these methods to duct decontamination is questionable since the environment to which the KIWI nozzles were exposed differs considerably from that expected within the NES duct during test operations.

(2) The accessibility to the inner duct walls for application of decontaminants is impaired due to the size and shape of the duct.

(3) There exists a potential radiation exposure problem for personnel involved with the decontamination operation.

(4) The exhaust duct is contained within a heavily shielded vault to provide protection to personnel from plate-out activity. Consequently, unless frequent access to, or access for extended periods within the vault is required, no significant personnel exposure problems exist. For example, if personnel access to the vault area is not required for several weeks to several months after shutdown, limited personnel access to the vault area will be feasible based upon the possible utilization of supplementary shielding and upon the estimated dose rates of 20 to 50 r/hr in the vault one day after engine shutdown (see Section 7.1.3).

7.2.3 Personnel

During re-entry to test stand areas and areas adjacent to the test stand subsequent to engine testing, personnel may come in contact with significant amounts of radioactive contamination. Transporting these personnel to remote locations for decontamination is not only time-consuming but also increases the potential for spread of radioactivity. Therefore, it is desirable to provide a personnel decontamination capability at a strategic location within the ETS-1 Complex.

A change house to be utilized for clothing change and personnel decontamination purposes, and located above ground near the test stand building, was factored into ETS-1 facility design during CY 1964(77); however, it was subsequently deleted. As a result, it is recommended that alternate accommodations be provided in the forward area of ETS-1 for personnel change of anti-contamination clothing and for shower facilities to be used for personnel decontamination. A trailer with these accommodations should suffice. The trailer should be located so as to provide positive control of personnel entering and exiting the test stand and adjacent areas, thereby minimizing the spread of contamination.

7.3 Radioactive Waste Disposal

7.3.1 Solid Waste

Solid radioactive waste at ETS-1 may be generated from materials or equipment used for decontamination or from activated or contaminated components or equipment not considered reusable. Disposal of all solid waste at NRDS is currently accomplished at the burial grounds adjacent to the

R-MAD Building. Waste is packaged, as required, to prevent the spread of contamination during transport to the disposal area. This method is considered satisfactory for waste generated at ETS-1.

Design criteria for an additional disposal facility adjacent to the spent fuel storage facility currently under construction is presented in Reference (78). However, construction effort on this additional disposal facility has been deferred indefinitely.

7.3.2 Liquid Waste

A large volume of process water (in excess of a million gallons) will flow from the duct vault into the drainage ditch during engine testing. The drainage ditch directs the flow of this water to ground areas remote from the ETS-1 Complex. Some of the fission product activity deposited in the drainage ditch during test operations will be picked up by the water; however, due to the frequency of tests planned for ETS-1 and in view of the widespread and remote ground areas to which this effluent will be carried, it is not expected that localized deposition of the radioactive contamination in the effluent water will pose a significant safety problem. (See Section 7.1.6 for estimates of potential radiation levels from this source.) Furthermore, it is probable that fallout of airborne activity in certain localized areas will result in significantly higher ground concentrations than those resulting from water transport.

Some consideration has been given in the past to construction of a hold-up basin downstream from the drainage ditch to contain the effluent water[76]. However, construction of such a basin does not currently appear justified for the purpose of containing the fission product activity transported by liquid waste from the facility.

7.4 Portable and Semi-Portable Radiation Monitoring Equipment

In addition to the radiation monitoring subsystem provided through the EG&G subcontract, certain types of portable and semi-portable radiation monitoring equipment should be provided in support of the ETS-1 operations. It is recognized that portable instruments, currently being utilized by the Support Services Contractor (PAN AM) for other NRDS operations, can be used by the SSC at ETS-1 for performing radiation surveys since such equipment is normally provided based on area coverage needs. Therefore, specific recommendations for this type of equipment are not being made.

There does, however, appear to be a definite need to evaluate the requirements for semi-portable equipment, such as personnel contamination monitors, to be provided at strategic ETS-1 locations. It is understood, through discussions with NTO Health and Safety, that no requirements have been established to date for such instrumentation. Since there are many tunnel entrances to below ground areas, and since radioactive fallout or spread of activated material is not confined to any specific ETS-1 location, some means to monitor personnel to supplement surveys by Rad/Safe personnel should be provided. These personnel monitoring instruments should be provided in low radiation background areas (below ground). One strategic area is near the Control Point Building where personnel traffic is heavy and personnel can conveniently monitor themselves. Therefore, it is recommended that a monitor be placed near the main tunnel entrance for monitoring personnel entering and exiting the tunnel and that "frisker" type units be provided at other convenient below-ground locations. This arrangement will serve to minimize spread of contamination to below-ground occupied areas, and also will provide better assurance that personnel will not spread contamination to off-site locations. Attention should be given to this matter in sufficient time to establish specific needs, procure equipment, and effect installation prior to engine testing.

8. EMERGENCY REQUIREMENTS

Abnormal or emergency conditions may arise at ETS-1 that will impair operations and pose a hazard to personnel involved in correcting or recovering from these conditions. It is the intent of this section to discuss a cross-section of emergency conditions considered most likely to pose significant hazards to personnel and constraints on operation. Of special concern are problems associated with correction of abnormal conditions or recovering from emergencies in a radiation environment. The following evaluation places special emphasis on minimizing radiation exposure to personnel at ETS-1. Recognition is given to the possibility that correction of hazardous radiation conditions can be effected by use of existing equipment with only minor modifications, and can be delayed to allow sufficient radioactive decay to preclude need for costly shielded or remote handling equipment.

8.1 Maintenance

8.1.1 Cold Engine on Stand

It is anticipated that certain emergency maintenance functions may be required in the vicinity of the test stand before testing commences. Such maintenance may include but not be limited to:

(a) side shield drive malfunctions

(b) replacement or repair of engine instrumentation, valves, nozzle, etc.

(c) EIV, PM or MCC vehicle malfunction

(d) Engine Test Compartment (ETC) shield failures

(e) weather door failures

(f) remote TV failures

With a cold (unfired) engine installed at the test stand, the primary limiting factor regarding personnel occupancy involves residual radiation resulting from activation of test stand structures and from fission product deposition during previous testing. With regard to this residual radiation, Figure 11 shows gamma dose rates near the axial centerline of the test stand to be in the 200-300 mr/hr range at one day after shutdown resulting from fission product deposition in the exhaust duct and drainage ditch. Allowing as short a time interval as 20-25 days between tests and based on the fission product decay curve of Figure 10, the aforementioned dose-rate range will decay to approximately 5-7 mr/hr. Further, assuming decay of activated structures is similar to that for the clamshell and intermediate shields (Figure 12), dose rates from activation will be negligible. Therefore, it is concluded that direct personnel access will be permissible and no significant safety problems will exist.

8.1.2 Hot Engine on Stand

Certain emergency maintenance requirements, similar to those anticipated for the cold engine case, may occur with a hot (fired) engine on the test stand. Based on the radiation environment one day after shutdown (Figure 9), it is apparent that dose rates (with or without clamshells in place) pose a definite maintenance problem in the test stand vicinity since personnel access cannot be permitted. For example, radiation intensities of 1200 r/hr without clamshells and 25 r/hr with clamshells at 25 feet from the axial center of the core are shown. Additional contributions to these dose rates will result from structural activation and fission product deposition; however, these contributions will be masked by the high radiation environment produced by the reactor.

In the past, a shielded vehicle, the "Beetle," has generally been regarded as a vehicle potentially capable of performing emergency tasks in high radiation fields at ETS-1. However, these capabilities have not been demonstrated and, in view of the size, weight, and limitations of maneuverability of this vehicle, and the demand for precision control, it is very questionable that the "Beetle", or any similar shielded vehicle will suffice for such maintenance functions. In addition, a considerable amount of time has been devoted to maintenance of the "Beetle", and it is understood that the vehicle is presently inoperative. Finally, use of such remote handling equipment is not considered feasible due to viewing limitations and to the excessive distances from which the equipment must be operated. Therefore, it is concluded that it is not feasible to attempt on-stand precision maintenance in the vicinity of a hot engine. However, assuming the emergency maintenance requirement involves a problem such as inability to separate the side enclosure shields, some means should be available to correct the problem in order to effect removal of the hot engine from the stand. It is recommended, therefore, that some type of remote maintenance capability be provided for ETS-1 such as could be obtained with a manipulator attached to the forward end of the MCC/EIV.

For emergency maintenance at distances beyond approximately 150 feet from the engine with the clamshells in place, personnel access is feasible for limited periods. For example, Figure 9 shows the dose rate at 150 feet one day after shutdown to be approximately 1 r/hr. Emergency personnel access for a limited time in this environment is considered feasible.

8.2 Hot Engine Transport

Based on the discussion of emergency maintenance in Section 8.1.2 for a hot engine, it appears that direct personnel access cannot be permitted for corrective action relative to connecting and disconnecting the engine at the test stand or a dropped or toppled engine. Therefore, other means for recovery from these emergencies must be provided.

Shielded vehicles, such as the "Beetle", appear to be somewhat more adaptable for these emergency conditions than for maintenance. However, as noted in Section 8.1.2, due to the present status of this vehicle and lack of proven worth, its adequacy is questionable here also. Furthermore, it is considered impractical to design and procure costly shielded or remote handling equipment for this purpose. Therefore, it is recommended that an attachment for the MCC/EIV be considered to provide the capability required for recovery from these types of hot-engine transport emergencies.

8.3 Fires

Primary corrective or recovery capability regarding fires at ETS-1 is provided by the Fire Protection System (including appropriate warning signals) discussed in Section 4. However, fires in the vicinity of the test stand may involve release of radioactive materials. Therefore, portable radiation monitors should be provided at ETS-1 for these emergencies in order to readily determine radiation hazards affecting fire fighting personnel who may be needed to supplement the fire suppression systems.

Removal or recovery of highly radioactive debris spread by fires in ETS-1 areas is covered subsequently in Section 8.5.

8.4 NES Damage

Damage to or failure of the exhaust duct is of major concern during engine testing. Assuming the most pessimistic case, that is duct failure or damage at the end of the test run, and based on the fission product deposition of 0.5% of the total fission product inventory in both the drainage ditch and duct, direct personnel access to the vault area one day after shutdown will not be permissible. (Section 7.1.3 indicates the gamma dose rate adjacent to the duct one day after shutdown to be of the order of 20-50 r/hr.) As for the case of hot maintenance with the engine on the stand, it is felt that use of remote handling equipment or shielded vehicles is not feasible to facilitate duct repair or removal from the vault. It is concluded, therefore, that if major damage to or failure of the exhaust duct does occur, it will be necessary to delay corrective action until radiation levels have undergone significant decay. Assuming a delay period of one to two months for this purpose, fission product decay should result in reduction of the aforementioned dose rates (20-50 r/hr) to a level where limited personnel access will be permissible and duct removal or repair can be accomplished.

8.5 Dispersal of Fuel

It is possible that highly radioactive portions of the core will be dispersed throughout the test stand area in the event of an accidental reactor excursion, or reactor breakup resulting from fire, hydrogen detonation, etc. Based on the dose rate of 250 r/hr at three feet from a fuel element after one day decay (see Section 7.1.6), recovery of fuel elements or portions thereof spread over a wide area poses a major problem. Allowing for an extended decay period of from 30 to 60 days, dose rates will still be sufficiently high to pose personnel exposure problems. For example, based on the normalized fission product decay curve of Figure 10, the fuel element dose rate of 250 r/hr at three feet will decrease to approximately 5 r/hr at the same position after 30 days decay.

Recovery of highly radioactive core parts dispersed during operations at Test Cells A and C has been accomplished primarily by personnel using long-handled tongs for transferring fuel debris to lead shields. Although no excessive personnel exposures have resulted from this practice, a certain amount of risk is involved. Exposure probabilities could be significantly reduced if some shielding protection were provided; however, for reasons similar to those discussed in Section 8.1.2, the use of shielded vehicles or remote handling equipment is not felt to be a realistic solution to this problem. Consequently, it is concluded that continued reliance must be placed upon (1) the use of long-handled tools, (2) allowance for significant radioactive decay, and (3) limitations on personnel exposure times, to provide the necessary protection to personnel during accident-recovery operations.

8.6 Emergency Plan

All personnel at ETS-1 must be made aware of action to be taken in the event of emergency conditions. The ETS-1 Safety Standard #1[82] provides instructions to personnel for evacuation and take-cover action during the current construction and activation phase. Although the potential for any major emergency condition arising at ETS-1 currently is minimal and no nuclear hazards exist, operation at Test Cells A and C may pose a hazard to ETS-1 personnel. Consequently, an ETS-1 Emergency Plan should be prepared in advance of use of nuclear materials in this area. Special emphasis should be placed on preparation of procedures relative to action to be taken by personnel in event of activation of the Area Surveillance and Warning Subsystem described in Section 4.1.3.4. The effectiveness of this warning subsystem is primarily dependent on proper personnel interpretation of the various audible and visual alarms.

8.7 Conclusions

Based on the discussion presented herein, it is concluded that design and procurement of shielded vehicles or remote handling equipment for use in recovering from or correcting emergency conditions involving high radiation fields at ETS-1 is impractical. It is concluded that the most reasonable means for recovery from emergency conditions is through

(1) minor modifications to existing equipment such as the EIV which will allow for limited on-stand maintenance to be performed under emergency conditions, and

(2) allowance for significant radioactive decay to permit limited personnel access to contaminated areas.

9. SUMMARY AND CONCLUSIONS

The safety aspects associated with the systems currently comprising the ETS-1 Complex have been evaluated. Basically, the designs of these systems have been found to be adequate to support the X-Engine test program. All of the safety deficiencies noted in the preceding sections of this report can be corrected with nominal effort and expense, either through the procurement of additional, relatively low-cost equipment, or by relatively minor modifications to existing designs and/or operating procedures.

It is emphasized again that this evaluation is neither final nor all inclusive. It is planned that the design safety evaluation of the ETS-1 Complex will continue until all facility and engine system designs are finalized, and the facility activation and checkout is complete. Though, in this sense, the present evaluation is preliminary, it is felt that all major safety deficiencies and/or problems inherent to the current ETS-1 system designs have been identified.

The significant recommendations resulting from this evaluation are summarized below:

(1) Modifications to the LH_2 Storage System should be made to allow for double block and bleed setups on both the LH_2 storage Dewar and the LH_2 high-pressure Dewar. (Section 2.2.2.2)

(2) The discharge from the relief valves in the high-pressure gaseous-hydrogen storage system, namely RV-604 through RV-609, RV-278, RV-337, RSV-193, and RSV-194, should be piped to local vent stacks instead of directly to the atmosphere as indicated by Reference (7). (Section 2.2.2.3)

(3) Wherever globe valves are used in series with pressure-relief valves on high-pressure lines or on pressurized storage vessels, the globe valves should either be removed from the system or be physically locked in their open position, or dual

relief valves which are connected to a common three-way two-position valve should be provided so that, with one of the valves removed, the other valve will always be directly connected into the high-pressure system. (Section 2.2.2.3)

(4) A check valve should be added to the inlet line to the run-tank flare stack, Line 20-GH-12"-AS, to prevent the entry of air into the flare system piping when the nitrogen purge system is not operating. A check valve should also be added to the inlet line of the high-pressure LH_2 Dewar, Line 5-LH-2"-LV, to prevent over-pressurization and interruption of fluid flow in Line 3-LH-6"-LV should RSV-106 leak during operations involving transfer of LH_2 to the run tank. (Section 2.2.2.4)

(5) System modifications and modes of operation for NES should be further evaluated in terms of reducing the probability of, or the consequences resulting from (1) the introduction of oxygen-rich steam into the hydrogen environment of the duct during XE or XECF test operations, and (2) the formation of explosive oxygen/propane mixtures in the Steam Generator System. The malfunctions identified which are potentially capable of producing at least one of these conditions are: (1) loss of propane to one or more of the steam modules, (2) loss of oxygen to one or more of the operating modules, and (3) malfunctions causing startup of the standby module from idle to full steam during engine test operations. (Section 3.2)

(6) A number of changes and/or additions to the alarm logic of the Area Surveillance and Warning Subsystem are required to provide effective control of personnel and consistency with the NRDS Emergency Alarm Criteria. The alarm logic recommended for this system is presented in Table II of Section 4. (Section 4.2.3.4)

(7) The Fire Protection System must be interfaced with the Area Survillance and Warning Subsystem to provide alarm acknowledging and silencing capabilities and to provide for activation of door lights and area beacons when a fire alarm is sounded. (Section 4.2.3.1)

(8) Early attention is required on finalization of the design of a Criticality Alarm System for ETS-1. The system must be appropriately interfaced with the Area Surveillance and Warning Subsystem. (Section 4.2.3.7)

(9) Upon completion of the NTO review of hazardous area classifications at ETS-1, the results of this review should be incorporated into an integrated Hazardous Area Classification Plan for ETS-1. Following Safety Division review, the plan should be submitted to SNPO-C for approval. (Section 4.2.5)

(10) A study should be made to determine which control circuits of the TSCS and ECS are necessary to accomplish a safe shutdown of the facility and engine in the event of a facility power failure. The circuits determined to be critical should then be provided with an additional source of power independent of the Instrument Load Bus supply. (Section 5.2)

(11) Analyses of radiation heating and damage effects on the ETC shield components were not documented during the shield design. Consequently, this aspect of the design should be reviewed by cognizant REON personnel to assure that the design is adequate from a radiation effects standpoint. (Section 6.6.2)

(12) Consideration should be given to refinishing the cracked and porous surfaces of the drainage ditch walls in order to enhance the effectiveness of possible decontamination procedures. (Section 7.2.1)

(13) NTO Health and Safety should continue to maintain cognizance of decontamination activities at Test Cells A and C, and utilize the information obtained for developing appropriate decontamination techniques and procedures for ETS-1. (Section 7.2.1)

(14) Temporary accommodations should be provided in a forward area of ETS-1 for personnel change of anti-contamination clothing and for shower facilities to be used for personnel decontamination. A trailer with these accommodations should suffice. (Section 7.2.3)

(15) In order to minimize the spread of radioactive contamination at ETS-1, personnel radiation monitoring instruments should be placed at convenient ETS-1 locations for monitoring personnel entering and exiting low contamination areas. (Section 7.4)

(16) Remote maintenance capability such as could be obtained with a manipulator attached to the MCC/EIV should be provided for performing limited on-stand maintenance functions which may be required in the presence of a "hot" engine. (Section 8.1.2)

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