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MASTER

VOLUME I

PRELIMINARY REPORT

BUDGETARY STUDY FOR ENGINE/STAGE TEST STAND 2-3

NUCLEAR ROCKET DEVELOPMENT STATION

JACKASS FLATS, NEVADA

PREPARED FOR

THE SPACE NUCLEAR PROPULSION OFFICE

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February 1966

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KAISER ENGINEERS

In Association With

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Prepared for
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Kaiser Engineers
Oakland, California

In Association With
The Marquardt Corporation
and
Hofman-Paul Cryogenic Division,
Air Reduction Company, Incorporated

Approved by:

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J. S. Ritchie,
Project Manager

SELECTED PRELIMINARY TEST STAND CONCEPT

FOR E/STS 2-3

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SECTION 1

INTRODUCTION

This report is a further step in the efforts of the AEC NASA Space Nuclear Propulsion Office (SNPO) for the construction of a nuclear rocket propulsion module test complex at the Nuclear Rocket Development Station (NRDS) Jackass Flats, Nevada. The test complex has been identified as Engine/Stage Test Stand 2-3 (E/STS 2-3). The purpose of the test complex is to provide the capability for testing of large NERVA engine systems and complete nuclear propulsion modules.

Kaiser Engineers was awarded contract SNPN-19 to prepare a Budgetary Study which develops facility concepts and cost estimates for the facility. Kaiser Engineers is in association with The Marquardt Corporation and with Hofman-Paul Cryogenic Division, Air Reduction Company Incorporated, who are studying the exhaust system and cryogenic systems, respectively.

The Budgetary Study began about the first of December, 1965, and is scheduled for completion in April, 1966. The study is being performed in two phases:

- a. Phase I to include sufficient engineering to establish preliminary concepts, to include trade-off studies and at least partial optimization of the larger facility elements, and to produce a facility cost estimate with an expected accuracy of ± 15 percent.
- b. Phase II to include further optimization or cost reduction, continuing study of alternate concepts where Phase I has apparently not yielded the best solution and, finally, a facility estimate with an expected accuracy of ± 10 percent.

The Budgetary Study effort to date has been of a dynamic nature due to the multitude of paths which must be explored in order to converge on most appropriate solutions and concepts. The test complex developed in Phase I is the result of constant inquiry and progressive definition of detailed requirements and their satisfaction.

While there are seemingly unlimited possibilities as to concept, site, etc., the study effort in Phase I has been concentrated on the review and modification of preliminary concepts and conclusions resulting from prior programmatic planning and presented in the aforementioned

Criteria document and other studies received from SNPO. Specifically, the Budgetary Study is being performed using, as a guide, the document titled "Criteria for Budgetary Study for Engine/Stage Test Stand 2-3" dated August 25, 1965, prepared by the Space Nuclear Propulsion Office, U.S. Atomic Energy Commission, Washington, D. C., Harold B. Finger, Manager.*

The Budgetary Study effort is being monitored continuously by an SNPO task force consisting of W. R. Slivka, Chief, NERVA Branch SNPO, as Technical Director assisted by a staff of specialists representing various Space Nuclear Propulsion Offices, Marshall Space Flight Center, Los Alamos Scientific Laboratory and Aerojet General Corporation. The SNPO Director and his staff have been providing continuous technical review and evaluation, have been suggesting various approaches which they feel should be investigated and have been readily providing necessary information about other facilities and equipment pertinent to this program. The task force members are further supported by their respective organizations for greater depth in guidance, study, and evaluation.

This Preliminary Report presents the results of the Phase I work and the resultant test complex concept as it was envisaged as of approximately the end of January, 1966. This is an interim document and the test complex described herein constitutes the first complete stage in the evolution of the final E/STS 2-3 facility concept which will result at the end of Phase II. The Phase I facility concept reported herein represents a conservative approach, one which is feasible but not necessarily resulting in the lowest possible facility cost.

Volume I of this report includes the results of a site evaluation, development of the facility layout, safety and integrity considerations and describes the presently selected concepts for the various elements of the facility. It also discusses the alternate concepts which were considered in trade-offs which led to the present concepts.

Volume II of the report presents an estimate of construction and engineering costs and a schedule for the facility which is described.

The Phase I work reported upon herein provides a reference design concept from which alternates can be compared during Phase II effort with the ultimate goal of continuing to meet the basic criteria while reducing the overall facility costs to a minimum.

*This document is frequently referred to in this report as the Criteria document.

SECTION 2

SUMMARY

2.1 General

The concepts presented in this report are based on trade-off studies performed for various facility elements. In general, SNPO Design Criteria and Siting Studies Documents were used to form the initial bases for selected trade-off studies to reduce these approaches to first-order conceptual designs. The trade-offs were generally cost oriented to select between major alternatives. In some instances this meant developing technical trade-offs between alternative concepts. Further cost reduction studies for each element will occur under Phase II.

The designs, materials and components selected have been based on standard construction methods using off-the-shelf type equipment wherever possible. Whenever the requirements dictated nonstandard equipment, fabricators have been contacted relative to the practicality of the proposed equipment.

A test facility complex has been conceived which meets the Design Criteria. Two test stands provide altitude simulation prior to, during and after engine operation by steam driven ejector and supplementary exhaust driven diffusers. The stands are separated to preclude damage from each other, and a retractable facility shield reduces the nuclear radiation to the various elements of the facility to acceptable limits. Retraction of the shield provides access to the tank bottom for engine installation and removal; with the present NRDS remote handling equipment (EIV). Common support facilities, e. g. cryogenic fluids, gasses, water and steam are available for connection to either stand. Similarly, a single control center can be connected to either stand for test operations. Some services, e. g. engine/module setup, are duplicated for parallel efforts on both stands.

2.2 Siting

Four general areas were investigated for the location of the test complex; i. e. , Fortymile Canyon, ETS-1, 5,000 ft West, ETS-1 Vicinity 10,000 ft West and Kiwi Mesa.

The Fortymile Canyon site was selected by SNPO on the basis of safety considerations.

Separation distances between facility elements used in the site layout are based on the nuclear requirements for access and/or on DOD Tables of Separation Distance for the storage of liquid hydrogen where applicable. The plot plan shown in this preliminary report will be re-examined for possible further economies in the layout during Phase II.

The location of the support buildings and the general areas of support equipment have been arranged in a triangular shape with test stands located at two of the corners of the triangle and the support equipment and control room at the other. This provides for convenient access to the areas and short runs for cabling and process piping.

2.3 Test Stand

The test stand concept presented in this report has evolved from examination of 22 studies and has been based on the requirement of having access to the work platform by the Engine Installation Vehicle. The height of the test stand structure has been established to accommodate the dry exhaust* diffuser/ejector duct. The vertical height of the diffuser/ejector system to be accommodated in the test stands is 170 ft. Refinements to the radius of the elbow have indicated that a dry exhaust diffuser/ejector system can be accommodated in 155 ft with an L/D of 8:1 for the diffuser. In this concept, it is assumed that a diffuser L/D of 4:1 for the 10,000 mw growth engine can be accommodated in the same height.

Studies indicate that the nuclear radiation created by plate-out on the interior of the diffuser will be sufficiently intense as to require permanent shielding so that access to the stand is possible. Concrete was selected for the shield since it would also serve as a retaining wall for the earth fill and structural supports for the umbilical tower and work area.

The umbilical tower, as shown on Drawing 6552-4-M1 is constructed of concrete to provide protection for personnel and equipment against radiation. Most radiation attenuation requirements

*Dry-exhaust vs water injected into rocket exhaust for cooling.

were satisfied by a cylindrical shield enclosing the engine. For access, including engine installation and removal, the shield was made retractable into the stand base with hydraulic jacks serving to raise and lower the shield.

Trade-off studies indicated that large cost savings associated with the diffuser/ejector and overall height of the stand could be obtained by having the engine nozzle protruding slightly into the diffuser entrance during tests. This necessitated lowering the propulsion module after the engine mating operation. Hence the propulsion module is attached to the main shield just prior to and during test firing.

Umbilical assemblies are provided with flexible gimbal joints to allow a vertical movement of 45 in. for the stage, and to provide an 8° horizontal swing which allows for a clearance of approximately 5 ft for installation and removal of the stage. A structural assembly is used to support the umbilical head, cabling and piping and provides for man access to the instrumentation unit.

2.4 Diffuser/Ejector Systems

The basic system analysed for this report is a dry exhaust water cooled tube bundle configuration similar to ETS-1 system. Saturation cooling of the test gas ahead of the elbow (wet exhaust) was considered, but deferred until further analysis of radioactive rain-out and coolant diffusion and mixing could be made. Steam was selected as the diffusion pumping fluid for the secondary ejector. Preliminary trade-offs indicated that hot gas used as pumping fluids would be more expensive. Continued effort will be made to investigate other fluids, or combination for the ejector drive system. The L/D of 8:1 used for the diffuser was selected on the basis of existing heat transfer data. It was assumed that future research would provide data on lower L/D diffusers and duct elbows such that a diffuser configuration for the 10,000 mw growth engine would be of the same vertical height as the current 5,000 mw diffuser.

It is anticipated that the diffuser will be constructed and installed at the site from shop fabricated assemblies. In the event the diffuser and ejector assemblies must be removed from the test stand, the diffuser section will be uncoupled from the elbow and lifted vertically. The ejector and elbow will be removed by man operated

shielded vehicles. Wheel assemblies will be located on the structural support frame of the assemblies so that the entire assembly can be rolled horizontally from the test stand vault.

2.5 Cryogenic and Gas Supply Systems

To accomplish the specified total run times, it is necessary to replenish the liquid hydrogen during the run. This is accomplished by a pressure system to the storage dewars. Regulation of the flows will be accomplished by varying storage tank pressure using electro-hydraulic flow control system. Replenishment requirements will be based upon liquid level control in the module tank.

Due to the large quantity of gas required for the facility, continuous vaporization from liquid storage has been shown to be the most practical. Where mechanical equipment is required for pumps, back-up equipment will be at standby through the test period. Emergency systems are provided which use high pressure gas storage in the event the continuous vaporization system fails.

Helium for the emergency cooldown system will be stored in high pressure receivers.

2.6 Shielding

The basic nuclear attenuation for the facility is provided by a cylindrical facility shield close to the radiation source, i. e. around each engine. Since this facility shield encloses the engine it also serves as an environmental chamber and supporting structure for the module. Other shields are incorporated into the test stand to provide nuclear protection to equipment and for personnel access.

The upper shield, as shown on Drawing 6552-4-ML-26, is used to accomplish the radiation simulation of the module tank bottom and is used to control radiation to the umbilical tower. The lower engine compartment shield is permanently installed to protect the test stand concrete. A removable lead shield is used to cover the diffuser to provide access to the work level of the test stand for personnel. A water shield enclosing the upper divergent section of the diffuser is provided to eliminate gamma heating of concrete in the test stand vault. Thermal protection of the test stand is required because of radiant heat generated by the exhaust flame.

Preliminarily the shields have been considered as tanks filled with water. Concrete has been used for shielding where it can also serve as a structural member. The control room is shielded by an earth cover. Subsequent studies will investigate alternate shielding methods and materials.

2.7 Instrumentation and Control Systems

The system or design concept for the instrumentation and control systems was developed from past experience, current practices and technological advances to meet the requirements of measurement, documentation, control and operational flexibility. Accordingly, many standard components or characteristics of the system concept are not detailed in this report. Rather, emphasis is placed on basic philosophies as they affect design, problem areas, system trade-offs, including controversial and alternative approaches, and areas involved with changing technology.

The data acquisition signal transmission concept, for example, is based on the technical performance requirements stipulated in the Criteria document. Cost trade-offs were made for six transmission concepts to permit evaluation of cost versus performance. Three concepts were considered technically feasible. A cost analysis indicated a narrow cost differential between acceptable systems. The concept selected has the greatest technical advantage and is the only concept that unconditionally meets the Criteria requirements.

2.8 Power and Utilities

New substations and power distribution systems have been planned for this complex using a commercial power supply from the NRDS, 69 kv system and a diesel generator for essential and emergency electrical back-up. Controlled voltage for instrumentation and control systems will be provided by regulators located in the control room. Water requirements, established by the needs of diffuser cooling and fire deluge water, will be fed through a gravity system from a storage tank located on the hill northeast of the test complex. Water will be supplied from existing wells. However, it is possible that a new well will be required.

2.9 Control and Miscellaneous Support Buildings

The control center is shown for this study as a rectangular, concrete, single story building which is divided into areas for electronics, control, mechanical, electrical and office space. Tunnels will provide for access from the control center to the electronics room at the test stand and emergency egress from the control center. At each of the test stands these tunnels will provide space for data acquisition cables and electrical conduits.

A rigid frame 100 ft x 40 ft shop building is located on the main access road to the test complex. This building is located at a safe distance from the test stand and will provide storage and maintenance work areas for the test stand operations.

Other support facilities include a camera bunker; also equipment sheds and guard shacks which have been located at pertinent locations to provide for normal needs of the facility.

2.10 Estimates and Schedules

The estimate presented for the preliminary report has been based on the drawings enclosed in this report. Particular emphasis was given to reflecting cost conditions as they exist at NRDS; including escalation of cost based on present annual trends.

The estimates and schedules are enclosed in Volume 2 of the preliminary report and are marked for "Official Use Only".

The estimates have been based on standard quality control for facility equipment; an outline of the quality control document is presented in Section 17.

It is not anticipated that major research and development will be required for facility items used in the complex and no research and development costs are included except for some items such as the steam generator system which will require nominal development and testing. Scale model testing program for the diffuser/ejector system has not been included in the cost back-up.

SECTION 3

DESIGN CONSIDERATIONS

The general design criteria for the E/STS 2-3 test complex are listed below, followed by general design assumptions and basic design considerations.

3.1 General Design Criteria

The following items represent a summary of the basic design criteria for E/STS 2-3 as required by the Criteria document:

1. Provide two test stands to accommodate a complete nuclear propulsion module.
2. Provide capability for vertical down-firing engines.
3. Provide capability for 30-minute run time at 5,000 mw using make-up propellant from storage during run.
4. Provide capability for 30-day test intervals for 5,000 mw 30-minute tests.
5. Provide altitude simulation consisting of engine back-pressure no greater than 2 psia during engine start, run, and shutdown.
6. Provide for 40:1 engine nozzle area ratio and for engine gimbaling of 30° solid angle.
7. Provide for manual installation and remote removal of exhaust duct.
8. Provide for capability of remote mate and demate of the engine on the test stand with the stage in place.
9. Provide capability of space radiation environment simulation to the engine and propulsion module tank bottom.
10. Meet safety and access requirements as outlined in Criteria document.

11. Provide capability of future facility modification to accommodate 10,000 mw engine configuration and 45-minute runs.
12. Facility design shall not preclude future modification for accommodation of module clusters.
13. Space shall be provided for possible future installation of an exhaust scrubber for each test stand.

3.2 General Design Assumptions and Basic Design Considerations

The assumptions and considerations used to develop the test complex for Phase I are itemized below:

1. Dry, water-cooled diffuser and ejector selected for Phase I design.
2. Design is based on a convergent diffuser using an L/D of 8:1 for the 5,000 mw engine.
3. Assume that the 10,000 mw diffuser with a shorter L/D can be developed to fit in the same test stand diffuser vault.
4. Provide steam generator capable of maintaining a 2 psia pressure in the altitude simulation chamber during startup and shutdown phases. Also provide enough flow at the end of the ejector to prevent the possibility of air entering the system with an assumed wind velocity of 35 mph.
5. Provide for the capability of erecting and removing the module tank and its instrumentation and equipment bays by using a 200-ton crawler-type crane.
6. Provide for manual installation of module and manual removal except for remote connect and disconnect of stage clamps and umbilical assembly.
7. Provide for the installation and removal of the engine by using the existing Engine Installation Vehicle modified as required.
8. Provide 20 ft of access room around engine for remote servicing equipment such as existing Beetle.

9. Provide capability of replenishing the module tank during test operations and maintaining a set pressure within 3/4 psi in stage.
10. Provide necessary gas, cryogenic liquids and controls as required for purging, cooldown, pressurization, and valve actuation.
11. Provide the interconnection capability for supplemental control of the module.
12. Provide necessary facility controls for remote operations.
13. Provide data acquisition, calibration and checkout systems, safety monitoring and communications as outlined in Criteria document.

SECTION 4

SITE

The Phase I site for E/STS 2-3 is shown on Drawing 6552-2-C1, Plot Plan and Figure 4.0-1.

4.1 Objective

The objective of the Phase I site study is to compare several available sites at NRDS.

4.2 Comparison with Alternative Sites

Of the three sites described in the "Siting and Facility Configuration" Document, only two were studied:

ETS-1 Vicinity - 5,000 ft West
Fortymile Canyon

By direction of SNPO the third site, Kiwi Mesa, was not studied but a fourth site, ETS-1 Vicinity - 10,000 West, was studied in its place.

The major items of difference of the three sites studied were evaluated. These major items were earthwork, water supply, storm drainage, pavement, railroads, telephone trunk, transmission line and substation, cryogenic piping, control center and access tunnels. The comparative costs of these items were:

ETS-1 5,000 ft West	Base cost
ETS-1 10,000 ft West	\$ 200,000 higher than base cost
Fortymile Canyon	\$1,300,000 higher than base cost

Safety considerations at the Fortymile Canyon site, were considered by SNPO to overshadow the \$1,300,000 cost penalty.

4.3 Location and Description

The E/STS 2-3 site is located on the east bank of Fortymile Canyon at north coordinate 760,000, approximately five miles west of ETS-1. This site, selected by SNPO, provides satisfactory soils conditions and is a relatively remote location on the western side of the NRDS. This remote location provides for increased NRDS safety by minimizing contamination from the wind-borne plume to other areas of the NRDS.

4.4 Soils Conditions

Two sets of preliminary subsurface borings at the Fortymile Canyon site have established the general nature of the soils as being sand, gravel and cobbles in various relative proportions. Although tests have not yet been performed on the accumulated samples, it is believed probable that soil conditions requiring abnormal types of foundations do not exist. From the blow counts of the standard penetration tests the majority of the soils strata are in the dense to very dense condition indicating the probability of good bearing values. Several zones of high permeability were encountered as evidenced by loss of drilling mud. A soft zone of probable low bearing value about 6 ft thick was discovered 138 ft below the surface at the center of stand No. 3. Safe embankment side slopes have been estimated at 2:1 based on the type of material at the Fortymile Canyon site and on the recommendation for Test Cell "D" for similar material contained in the Cooper and Clark Report. It is expected that all embankments will be compacted to 90 percent of maximum density at optimum moisture content as determined by the modified AASHO method. A complete soils investigation program will be necessary for detail design.

4.5 Meteorology

In general, daytime winds are southerly in summer and northerly in winter. Wind reversal occurs at early evening and late morning. Daytime winds at the 9 ft level at Alice, 40 Mile Wash and Top Wash towers, all within 2 miles of the Fortymile Canyon site of E/STS 2-3, averaged 180° azimuth in the daytime and 300° to 360° azimuth at night.

Since stand No. 2 is northerly from stand No. 3, the fallout from the wind-borne plume during a test at No. 3 is a potential hazard. The hazard from the plume will be more fully treated in the Phase II report.

4.6 Effect of Topography

As compared with the mildly rolling foothill region at the ETS-1 Vicinity site, the Fortymile Canyon site roads and railroads are more costly. Gravity drainage for sanitary and radioactive waste and for LH_2 and LOX spills is simpler at the Fortymile Canyon site. A flatter site such as areas south of the Canyon site would probably require greater earthwork since advantage could not be gained by using knolls to reduce fill on the long stand approach ramps.

4.7 Future Phase II Work

Additional sites at the general canyon area will be examined in Phase II for possible savings in total facility cost over the site presented in Phase I. The ETS-1 10,000 ft West site will be re-estimated on the basis of the Phase II layout. If decided economic advantages are discovered at the ETS-1 site SNPO may wish to reconsider the E/STS 2-3 site location.

4.8 Accessibility to Roads, Railroads, Water and Power

The Canyon site is served by a 2 mile extension of existing road "H", a new 4.5 mile railroad connection to the existing rail system at ETS-1, a new 2-mile water supply line from existing Well J-13 and a new 4.5 mile 69 kv power transmission line from existing transmission line "T" at ETS-1.

SECTION 5FACILITY LAYOUT

The Phase I Plot Plan for the E/STS 2-3 Facility is shown on Drawing 6552-2-C1.

The objective of the layout effort is to satisfy the following requirements and objectives:

1. The functional requirements of the Criteria document.
2. The requirements and geometry of the facility elements developed during Phase I.
3. Maximum economy of piping, tunnels, power supply, earthwork, roads and railroads.
4. The nuclear access requirements contained in the Criteria document.
5. Explosion-fire hazards requirements of DOD Instruction 4145.21.

Arrangements other than that shown on the Plot Plan, which were considered but not used were:

1. Diffuser water drained directly to the floor of Fortymile Canyon without excavation. It is considered more economical to sink the stands below the natural channel thereby lowering the approach fills to arrive at a balance between channel excavation and approach fill.
2. Taking the EIV railroad out at the north side of the site. This would have required the EIV track from stand No. 3 to be brought north to join the stand No. 2 track. Realizing that the nearest rail connection at ETS-1 is south of stand No. 3, it was found to be more economical to direct the road and railroad connections southwesterly from stand No. 2, in the most direct route.
3. The early site arrangement concepts envisioned the Module Assembly and Maintenance building (MAM) to the east of the two test stands rather than southeast as shown on the Phase I Plot

Plan. It was quickly realized that such an arrangement routed the module transporter road into the rising topography of the Calico Hills. It became apparent that the Phase I Plot Plan arrangement with the transporter road parallel to the contour lines was more economical and gave sufficient separation between MAM and the potential wind-borne contamination from the stands.

4. Individual access roads to many of the facility components were eliminated as increasing shrinking of the site area made possible the servicing of more components directly from the main transporter road.
5. An early decision was made not to apply the DOD separation distances to road and railroad locations. This was considered justified in view of the short period of exposure experienced by a vehicle passing a potential hazard.

The stands are located at the east side of Fortymile Canyon to minimize excavation for the diffuser cooling water discharge channel. The steam generator, the cryogenic storage area and the control center are located on the perpendicular bisector of the line joining the test stands. The centerline location of these facilities minimizes the total lengths of the steam piping, cryogenic piping and access tunnels.

The LH₂ storage area is 550 ft from test stand No. 2. This DOD distance for protected facilities is in accordance with the total stored volume of all four LH₂ tanks. The control center is 300 ft from the nearest LH₂ tank. This distance, although less than the minimum DOD separation of 550 ft is considered acceptable since the control center is buried beneath approximately 5 ft of earth for nuclear shielding. The control center exit to the parking lot is 550 ft from the nearest LH₂ tank. The cryogenic area is at the edge of the bluff, avoiding deep fills to the floor of the canyon. Stand No. 3 is located 380 ft from the southerly perimeter road of the cryogenic area since this road is used for access to the steam generator, the separation distance for which is 380 ft from the stand according to the nuclear access requirements in the Criteria document. This distance gives unlimited access after 12 days. (L 2, defined in Section 6, after one hour is also satisfied since this access requires a separation of only 100 ft). The nuclear separation of 700 ft between the nearest test

stand and the LH₂ fill area for unlimited access after three hours is also satisfied since stand No. 3 is 770 ft from the fill area as a result of the DOD and nuclear separations cited previously. The liquid hydrogen storage required for the growth module test program can be accommodated by additional storage dewars placed to the northeast of the existing storage area. Total liquid hydrogen storage required for the growth module test program will require approximately four million gallons. This quantity of liquid hydrogen requires a separation distance of approximately 610 ft for protected areas.

The burn pond is 400 ft from the steam generator and from stand No. 3 based on experience with a similar burn pond at Aerojet's Sacramento facility. The LOX storage tank is 410 ft from stand No. 2 and 330 ft from the steam generator. Propane is stored at the southwesterly corner of the cryogenic area, providing a reasonable separation distance from stand No. 3, and the steam generator. Borate mixing and diesel storage are provided at the top of the bluff to provide an optimum combination of truck access and short piping runs. The camera bunker is on line and halfway between the two stands to provide a side view of the stands during firing. The bunker is close to a plant road for easy vehicular access.

The water pump house and facility substation are 1,800 ft from the nearest LH₂ tank, the required DOD distance for unprotected facilities. The end of the control center emergency exit tunnel, the support shop, the gatehouse and the vehicle decontamination area are 3,400 ft from the nearest test stand satisfying the nuclear criteria requirement of L 2 after 1 hour. A location for the future module assembly and maintenance building is shown 5,200 ft from the nearest test stand to satisfy the criteria requirement of L 2 following an MCA.

The radioactive waste leaching pond is 1,000 ft from the nearest stand based on estimated activity levels in the pond as a result of decontamination fluid activity. The sanitary sewage lagoon is located to provide gravity drainage from stand No. 3 and the control center. Sanitary sewage from stand No. 2 is treated in a local septic tank and drain field. The water storage tank for diffuser cooling and stand and cryogenic deluge is located in the hills behind the facility at an elevation sufficient to provide the operating head required during a test.

Roads and railroads are located for minimum length at the governing grades for the Engine Installation Vehicle and the Module Transporter. A rough balance has been achieved between the excavation for the

diffuser water discharge channel at the bottom of the channel and the road and railroad embankment in the facility area.

Possible future cluster capability is not prohibited by the above plant arrangement. The additional space requirement could be attained on the north side of stand No. 2 and the south side of stand No. 3.

Installation of a possible future scrubber 200 ft in length for each test stand may be accommodated in this layout.

During Phase II the plot plan will be re-examined for possible further economies in layout and the elevation of the test stands will be re-evaluated for a closer balance between the channel excavation and the plant site embankment.

SECTION 6

SAFETY AND FACILITY INTEGRITY

The following sections describe the means incorporated in the proposed facility concept to ensure personnel safety and facility integrity based on analyses of the nuclear and industrial hazards associated with the operation of the test complex.

6.1 Credible Accidents

The design considerations which have been incorporated into the proposed facility concept to accommodate credible accidents associated with the use of the facility are discussed in this section.

The various credible accidents which can be postulated could result in fire, explosion, and radiation dose rates in excess of those associated with normal operation. For purposes of Phase I, an attempt has been made to predict the maximum fire, maximum explosion, and maximum dose rate which may result from any accident.

6.1.1 Maximum Fire

As already discussed in Section 5, the separation distances used for the accommodation of liquid propellants and liquid hydrogen at the proposed facility concept have been based on Department of Defense Instruction No. 4145-21 dated March 26, 1964. In that document liquid hydrogen is listed in hazard group III. Separation distances between facility locations have been selected with the assumption that the test stand and support equipment areas can be classified as protected areas.

The above criteria then specify a separation distance based on burning of the available hydrogen at any E/STS 2-3 location. This gives a separation distance of 550 ft, which will produce two cal/cm^2 on the 1 percent water vapor curve.

This separation distance is considered safe for equipment and personnel in the event of a major tank rupture and hydrogen fire.

6.1.2 Maximum Explosion

Hydrogen explosions have not been considered because the liquid hydrogen storage area is provided with ground level dikes and drainage to prevent surface contact of liquid hydrogen and LOX. Nitrogen purge will be used in electrical boxes that are located in areas that could be contaminated with hydrogen gas.

Hazards associated with the liquid oxygen and propane system consist of an explosion danger caused by potential mixing of liquid oxygen and propane at the gas generator. Phase II of this study will evaluate potential peak overpressure based on the amount of propellants that could mix after a malfunction has occurred and before valves can be closed. Normally the Five Second Rule would apply. It is not visualized that possible LOX propane hazards will affect the siting arrangement as shown in this study.

TNT equivalent of 110 lb was used for the nuclear energy excursion explosion as presented in the KIWI "TNT" Evaluation of Environmental Effects. Curves were plotted showing direct and reflected overpressure as a function of TNT quantity and distance.

In the event of an excursion that develops an explosive kinetic energy equivalent of 110 lb of TNT, calculations show that major damage would occur to the module tank and to the environmental chamber. Little or no damage would occur to the test stand structure from the explosion. However, major fire would develop if the module tank contained a large quantity of liquid hydrogen. No attempt will be made to design the environmental chamber to withstand the anticipated peak overpressure.

6.1.3 Summary of Above Separation Distances

For the purposes of the Phase I work, the foregoing paragraphs give the bases for the minimum separation distances between facility areas, exclusive of radiation dose rate consideration. These distances are tabulated below where, because a full module tank has approximately as much liquid hydrogen as do the liquid hydrogen storage tanks, a test stand is treated as a liquid hydrogen storage area.

TABLE 6.1-1

MINIMUM SEPARATION DISTANCES
EXCLUSIVE OF NUCLEAR DOSE RATE CONSIDERATIONS

<u>Items</u>	<u>Minimum Separation Distance in Ft</u>
Test stand to test stand	485 (based on 500,000 lb LH ₂ growth module tank capacity)
Test stand to LH ₂ storage	550
LH ₂ storage to closest point of earth shielded control center	300
LH ₂ storage to control center ground level exit to parking lot	550
LH ₂ storage to ejector fluid generator	550

6.1.4 Maximum Dose Rate

For the purposes of the Phase I work, the maximum credible accident (MCA) has been assumed to result in a shutdown reactor with no facility shield, where the reactor has previously operated at 10,000 mw for 45 min. It also has been assumed that:

1. Debris from the MCA would be removed by 16 days after the accident,
2. A 100 second decay time is associated with the post MCA allowable dose rates: at existing facilities at MAM (inside), and at the main electrical substation.

6.1.5 Future Work

Various credible accidents, including the six credible accidents postulated in the Criteria for Budgetary Study for Engine/Stage Test Stand 2-3, will be evaluated in Phase II with respect to the suitability of these choices of maximum consequences.

6.2 Separation Distances Based on Nuclear Considerations for Regions Without Local Shielding

6.2.1 Introduction

The E/STS 2-3 facility has inherent facility safety problems because of the potentially flammable and explosive material such as LH₂ at the site, and because of the potentially biologically dangerous nuclear radiation at the site. As previously discussed in Section 6.1, a separation distance of 550 ft is being used between large LH₂ containers and other regions to provide safety from fire and explosion. The means used to provide safety from nuclear radiation are discussed in this section.

Shielding and separation distance both are used in the conceptual facility design to provide safety from nuclear radiation. A single facility shield, in the form of a 7 ft thick water annulus around the engine, is used in conjunction with minimum separation distances to reduce the nuclear radiation dose rates to acceptable values, as established by the intended facility use pattern. The required dose rate values were provided as input in the Criteria document. The facility shield and minimum separation distances which provide the desired dose rates were then established. Local shielding to control nuclear radiation is specified for some regions. Regions which require local shielding are discussed in Section 6.3. Considerations which establish the facility shield and the separation distances for regions without local shielding are discussed herein.

The formulation of the intended facility use pattern recognized four zones with respect to personnel access where the radiation dose rate ranged from U, where no control of personnel would be required, i. e. unlimited access, to R, from which personnel would be restricted. Thus the zones refer to projected personnel use. The dose rates associated with the four zones as specified in the Criteria document are given in Table 6.2-1.

TABLE 6.2-1DEFINITION OF ZONES

<u>Zone</u>	<u>Dose Rate</u>
Unlimited Zone (U)	$< 2.5 \text{ mr/hr}$
Limited Zone 1 (L 1)	$2.5 - 100 \text{ mr/hr}$
Limited Zone 2 (L 2)	$100 \text{ mr/hr} - 3 \text{ r/hr}$
Restricted Zone (R)	$> 3 \text{ r/hr}$

In accordance with the criteria document uncertainties in the dose rate calculations were accommodated by applying a factor of 3 conservatism to the dose rates during operation, and a factor of 5 conservatism to the post operational dose rates.

Each facility region was examined for four operating conditions:

1. Maximum credible nuclear accident (MCA, the shut-down core without facility shield as discussed in Section 6.1),
2. During 10,000 mw operation,
3. With facility shield in place after a 2 minute run at 2,500 mw,
4. With the facility shield in place after a single 45 min. run at 10,000 mw.

Where appropriate, the time by which each region must decay to the upper limit zone condition was specified for each of the above four conditions. The post operational U zone conditions specified for MAM (inside), for the main electrical substation, and for the existing facilities were considered to apply after 1 hour. Such an interpretation seems consistent with the projected facility use pattern, has only a slight effect on the results, and simplifies the calculation a great deal. The dose rate limitations associated with each of the four operating conditions at each region, from the Criteria document, is shown in Table 6.2-1.

TABLE 6.2-2

UNSHIELDED FACILITY REGION - ZONE RELATIONS

<u>Region</u>	<u>Maximum credible accident (MCA)</u>	<u>During 10,000 mw op- eration</u>	<u>With facility shield in place after 2 min run at 2,500 mw</u>	<u>With facility shield in place after either 45 min run at 10,000 mw (this controlled) or 2 separate 30 min 5,000 mw runs within 30 days</u>
Access to Control Center (Ground Level)	R	R	L 1 after 3 hours	L 1 after 1 day
Access to Control Center (Tunnel Entrance)	L 2 after 1 hour	R	U after 1 hour	L 1 U after after 1 hour 1 day
Fill (LH ₂ , etc.)	R	R	U after 3 hours	U after 3 days
Adjacent Stand (Pad)	L 1 U after after 16 30 days days	R	U after 3 hours	U after 3 days
MAM (Inside)	L 2	L 1	U	U
Main Electrical Substation	L 2	L 1	U	U
Complex Substation	R	R	L 1 after 3 hours	L 1 after 1 day
Existing Facilities	L 1	U	U	U
Fluid Storage	R	R	L 1 after 3 hours	L 1 after 3 days
Ejector Fluid Generator	R	R	L 2 after 1 hour	U after 12 days

6.2.1 Cont'd

Water was chosen as the Phase I facility shielding material. The choice of water was made to simplify the initial calculations --water has no cracks, and lends itself to fairly simple calculations. Although some composite facility shield may later be found to have advantages over water, that composite facility shield probably would have a weight comparable to the water facility shield.

Calculations of dose rate versus distance were made for each appropriate time (100 seconds, 1 hour, 3 hours, 1 day, 3 days, and 12 days) for each of the aforementioned four operating conditions using various facility shield thicknesses. The dose rate contributions of direct gamma radiation, air scatter, neutrons, and exhaust gas plume were considered when formulating the dose rate versus distance information. From these data the distance at which the desired zone dose rate would exist was found for each facility shield thickness considered. The facility shield thickness (7 ft) which gave dose-rate-based separation distances which approximated the separation distances based on LH_2 storage volumes (stated in Table 6.1-1) was selected for the conceptual design. The separation distances summarized in Table 6.2-3 give safe dose rate values (those specified in Table 6.2-2) for the facility regions specified.

The Criteria document asks that the feasibility of providing in the future capability of testing clusters be examined. For cluster operation, a new umbilical tower would be used, and the test stand would be extensively reworked. However, the separation distances are to be compatible with possible future cluster operation. Cluster operation has been defined as two nuclear engines simultaneously operating at 10,000 mw per engine for 15 min. The operating cluster, with its total 20,000 mw output, gives twice the dose rate of that from a single 10,000 mw engine. Nevertheless, since the cluster dose rates remain within the factor of conservatism used to establish the separation distances, the separation distances were not increased for and not governed by cluster operation. Further, since the post operation dose rates for 15 min. of 20,000 mw operation are less than for 45 min. of 10,000 mw operation, the separation distances were not governed by the post operational cluster conditions. The calculations whose results are summarized in Table 6.2-2 are described in the succeeding portions of this section.

TABLE 6.2-3
REGION - DISTANCE - CRITERIA RELATIONS
WITH 7 FT WATER FACILITY SHIELD

(Showing distances in ft required to satisfy conditions other than R)

Region	MCA taken as bare core shutdown after 10,000 45 min of 10,000 mw operation	During mw operation	Shutdown after 2 min run at 2,500 mw	Shutdown af- ter 45 min run at 10,000 mw
Access to con- trol center (ground level entrance door- way)	R	R	L 1 after 3 hr 170	L 1 after 1 day 325*
Access to con- trol center (tun- nel entrance)	L 2 after 1 hr 3,400*	R	U after 1 hr 1,150	L 1 af- U after ter 1 hr 1 day 1,400 1,300
-Fill (LH ₂ and H. P. gas)	R	R	U after 3 hr 700*	U after 3 days 520
Adjacent stand (pad)	L 1 U after after 30 days 16 days 2,550*** 4,000***	R	U after 3 hr 700*	U after 3 days 520
MAM (inside)	L 2 after 100 sec** 5,200*	L 1 5,900	U After 1 hr 1,400	U After 1 hr 3,200
Main electrical substation	L 2 after 100 sec** 5,200*	L 1 5,900	U After 1 hr 1,400	U After 1 hr 3,200
Complex substation	R	R	L 1 after 3 hr 170	L 1 after 1 day 325*
Existing Facilities	L 1 after 100 sec** 7,700*	U 11,000	U After 1 hr 1,400	U After 1 hr 3,200
Fluid storage	R	R	L 1 after 3 hrs - 170*	L 1 after 3 days - 100
Ejector fluid generator	R	R	L 2 after 1 hr - 100	U after 12 days - 380*

* Design distance.

** No times were associated with these values in the original criteria. The 100 second value was used in the design both because it is considered not to be a biological problem and because of restriction on data availability.

*** It was assumed that the debris from an accident would be removed by 16 days after the accident, and hence the MCA cases do not govern this separation distance.

6.2.2 Calculations

The calculations to define shield thickness and minimum separation distances considered four separate contributions to the total radiation dose. In addition to the direct gamma and neutron radiation transmitted through the shield, contributions from gamma rays scattered through the air and from fission products in the exhaust plume were evaluated.

6.2.2.1 Direct Gamma Radiation

The transmission of gamma rays through the shield was calculated using a point source approximation. This calculation uses the basic equation

$$D = \frac{1}{4\pi d^2} \sum \frac{SfB' B(b) e^{-b}}{k} \quad (\text{Eq 6.2.1})$$

Where

D = dose (r/hr)

d = horizontal distance from reactor (cm)

k = conversion factor $\left(\frac{\text{Mev/cm}^2/\text{sec}}{\text{r/hr}}\right)$ - see Rockwell,

Reactor Shielding Manual, page 20

$B(b)$ = dose buildup factor in water (dimensionless) - see Rockwell, Reactor Shielding Manual, page 434

$b = \sum \mu_t t$ = number of e-folding thicknesses (dimensionless)

μ_t = gamma attenuation factor (cm^{-1}) - see ANL 5800

t = thickness of shielding (cm) medium

S = source (Mev/sec)

f = core self-shielding factor (dimensionless)

B = effective core build-up factor (dimensionless)

The source terms and related data used in conjunction with equation 6.2.1 for calculating direct gamma rays are contained in Table 6.2-4. These sources are extended to other decay times using Figure 8.11 from Second Edition of The Reactor Handbook. The results in terms of radiation levels as a function of distance are shown in Figures 6.2-1, 6.2-2 and 6.2-3 for full power operation, following a 2 min. run at 2,500 mw and following 45 min. at 10,000 mw respectively.

The data in Figures 6.2-1, 6.2-2, and 6.2-3 are for a 7 ft facility shield. Similar data were produced for other shield thicknesses to identify a facility shield which would not impose limitations on the plot plan. In Table 6.2-5 a comparison is made between separation distances imposed by a 5 ft thick facility shield and a 7 ft shield. It is evident that the choice of a 7 ft thickness produces a fair approximation to the separation distances required by non-nuclear considerations discussed in Section 6.1 and that less shielding produces unreasonable separation distances.

6.2.2.2 Air Scatter

The air scatter gamma dose levels in the vicinity of E/STS 2-3 were calculated using the GGG single scatter digital computer program developed by R. Malenfant of LASL. As can be seen on Figure 6.2-4, the air scatter contribution to the total dose during operation is appreciably less than the cloud or direct gamma contribution. It was similarly shown that the contribution of air scatter was appreciably less than that from direct gammas after operation. Therefore, the contribution of air scattering was neglected when establishing the facility shield thickness and the separation distances.

6.2.2.3 Neutrons

The neutron dose rate, in neutrons/cm²/second, was calculated from the relation

$$\phi = \frac{S_e - \Sigma_n t}{4\pi d^2} \quad (\text{Eq 6.2.2})$$

where $\Sigma_n = 0.1$: removal cross section in water (cm⁻¹)

Figure 6.2-1

Dose Rate vs Distance
During Operation at 10,000 MW
Direct Gamma Contribution

Figure 6.2-2

2 Min. Run at 2,500 MW
7 Ft Water Shield

TABLE 6.2-4GAMMA SOURCE INFORMATIONDuring 10,000 mw operation

E Mev	0.5	2.0	4.0	6.0
S Mev/sec	1.36×10^{21}	2.72×10^{21}	8.59×10^{20}	1.514×10^{20}
f	5.74×10^{-3}	4.11×10^{-2}	9.45×10^{-2}	1.37×10^{-1}
B'	13.2	3.55	2.18	1.78
k Mev hr/r cm ² sec	4.7×10^5	6.2×10^5	7.8×10^5	8.8×10^5
μ_t water cm ⁻¹	0.0966	0.0493	0.0339	0.0275
μ_t air cm ⁻¹	8.68×10^{-5}	4.45×10^{-5}	3.07×10^{-5}	2.5×10^{-5}

1 hour after 10,000 mw operation

E Mev	0.1 - 0.9	0.9 - 1.8	>1.8
S Mev/sec	2.77×10^{19}	3.2×10^{19}	1.75×10^{19}
t	5.74×10^{-3}	2.58×10^{-2}	5.64×10^{-2}
B'	13.2	4.26	2.83
k Mev hr/r cm ² sec	5×10^5	5.5×10^5	6×10^5
μ_t water cm ⁻¹	0.0966	0.0493	0.0420
μ_t air cm ⁻¹	8.68×10^{-5}	4.45×10^{-5}	3.80×10^{-5}

TABLE 6.2-5

DESIGN SEPARATION DISTANCES FROM REACTOR

<u>Area</u>	<u>5 ft Water Shield Distance in ft for test and post-test</u>	<u>7 ft Water Shield Distance in ft for test and post-test</u>
Access to control center (ground level entrance doorway)	770	325*
Access to control center (tunnel entrance)	2,500	1,400
Fill (LH ₂ and H. P. gas)	1,540	700*
Adjacent stand (pad)	1,540	700* **
MAM (inside)	7,600	5,900
Main electrical substation	7,600	5,900
Complex substation	770	325*
Existing facilities	> 11,000	11,000
Fluid storage	450	170*
Ejector fluid generator	960	380*

* Design separation distances from reactor.

** During the period of engine removal 16 days after use, the adjacent stand will briefly see 3 r/hr while the engine is not behind the facility shield.

Conversion to biological dose rate (rem/hr) was made using data from Rockwell, Reactor Shielding Design Manual. The results are given in Table 6.2-6. It is evident that the neutron contribution to the total dose rate is much less than the direct gamma contribution for a 7 ft shield configuration. Therefore, the neutron contribution was neglected when establishing the facility shield thickness and the separation distances.

TABLE 6.2-6

FAST NEUTRON (ABOVE 0.8 MEV) CONTRIBUTION
TO DOSE RATE DURING 10,000 MW OPERATION
WITH 7 FT FACILITY SHIELD

<u>Horizontal distance</u> <u>from reactor, ft</u>	<u>Direct neutron</u> <u>rem/hr</u>	<u>Direct gamma</u> <u>r/hr</u>
500	7.14×10^{-4}	3×10^2
1,000	1.79×10^{-4}	5.9×10^{-1}

6.2.2.4 Exhaust Plume

A limiting case was calculated assuming that the discharge gases rise at a rate of 10 fps. Since the velocity of the gases at the discharge point is about 400 fps, and since the dose rate from the exhaust varies inversely with velocity, these calculations provide a conservative limit for test stand design.

The equation used for calculating the nuclear radiation from the exhaust is:

$$Q = \frac{Q_0 e^{-t/\lambda}}{4\pi t^2 k} \quad ; \quad (\text{Eq 6.2.3})$$

Where

t : distance in air, ft

$\lambda = 600$: mean free path in air, ft

Q_0 : source strength, mev/sec

k : conversion factor, $\frac{\text{Mev/ft}^2/\text{sec}}{r/\text{hr}}$

$Q = r/\text{hr}$ (dose rate)

To evaluate Q_0 it was assumed that 6 percent of the fission products are in the exhaust stream. At steady state the density of products in the exhaust stream is uniform. There is, nevertheless, a variation in intensity with height because of differences in the transit time in which the fission products decay. This variation in intensity was evaluated from data on page 27 APEX 448 and the integration over all heights performed numerically. The results as a function of distance from the plume are shown in Figure 6.2-4.

6.2.2.5 Maximum Credible Accident

The maximum credible nuclear accident to be considered for the Phase I effort is defined in Section 6.1 as a shutdown core without facility shield subsequent to 45 min. of operation at 10,000 mw. The radiation from this configuration was evaluated using equation 6.2.1 with the parameters modified as appropriate for a case with air as the only shielding medium.

Sources for this calculation are given in Table 6.2-7 and the results are given in Figures 6.2-5, 6.2-6 and 6.2-7. The implications of these results regarding separation distances are summarized in Table 6.2-3.

Figure 6.2-4

Dose Rate vs Distance
During 45 Min. Run at 10,000 MW Operation
Direct Gamma and Cloud Contribution

TABLE 6.2-7

SHUTDOWN GAMMA SPECTRUM
24 HOURS AFTER 30 MIN. OPERATION AT 5,000 MW
 (Data was Later Extrapolated to 10,000 MW Operation)

<u>E Mev</u>	<u>SfB' Mev/Sec*</u>
3-4	3.15×10^5
2.6-3	7.05×10^{13}
2.2-2.6	2.33×10^{14}
1.8-2.2	1.61×10^{14}
1.35-1.8	2.55×10^{14}
0.9-1.35	1.98×10^{14}
0.4-0.9	2.25×10^{14}
0.26-0.4	1.25×10^{12}

TABLE 6.2-8GAMMA ATTENUATION FACTORS, μ_t

<u>E Mev</u>	0.5	2.0	4.0	6.0
μ_t water	0.0966	0.0493	0.0339	0.0275
μ_t air	8.68×10^{-5}	4.45×10^{-5}	3.07×10^{-5}	2.5×10^{-5}

6.2.2.6 Future Work

The analyses reported in this section were of a preliminary character to provide a basis for initiating facility layout and test stand design. Continuation of related activity is considered more in the area of facility shield design and will therefore be discussed with other Phase II shield design activities.

*Source strengths are in horizontal direction from core.

6.3 Regions Which Require Local Shielding

6.3.1 Introduction

The radiation dose rate at several regions is influenced by local shielding as well as by the 7 ft facility water shield and the separation distances specified in Section 6.2 which are needed to satisfy the zone relations for the specific locally shielded region. The local shielding is described in this section.

First, the facility shield and then each locally shielded region -- facility shield, umbilical tower, regions protected by ground cover, and regions governing pad access -- is discussed individually. The permissible radiation dose rate is indicated where appropriate. The calculations are described and the results are indicated in terms of the required local shielding. Associated nuclear information, such as activation, is also given where appropriate.

6.3.2 Facility Shielding

6.3.2.1 General

Specification of a facility shield consisting of 7 ft of water has been covered in the discussion of separation distances in Section 6.2. This shield has a further requirement that reactivity perturbations to the engine will be minimized. Although some consideration has been given to the use of boral liners to accomplish this requirement, analytical and experimental data from the NERVA and PHOEBUS programs suggest that the desired reactivity perturbations can be adequately met by borating the water in the facility shield. Homogeneous dispersal of boron in the facility shield has the added advantage of decreasing neutron activation of the test pad and umbilical tower areas external to the facility shield.

Mechanical design of the facility shield is described in Section 7.3 of this report. In the following paragraphs, the nuclear heating of the facility shield is described. Thermal contributions from gamma radiation, slowing down of neutrons, and neutron absorptions are considered.

6.3.2.2 Gamma Heating

The heat deposition in the water of the facility shield was calculated using Equation 6.2.1 with conversion constants giving Btu/cu ft/hr in water instead of r/hr. Using the data given in Table 6.3-1, the distribution of heat generation rates was calculated for the shield. These distributions were integrated numerically across the 7 ft thickness, yielding a total heating rate from this source of 1.72×10^8 Btu/hr.

TABLE 6.3-1

NUCLEAR DATA FOR GAMMA HEATING OF FACILITY
SHIELD DURING 10,000 MW OPERATION

<u>E MEV</u>	<u>S MEV/SEC-WATT</u>	<u>μ_t</u>	<u>μ_e</u>
0.5	1.36×10^{11}	0.0966	0.0330
1.5	1.67×10^{11}	0.0575	0.0285
2.5	1.05×10^{11}	0.0437	0.0270
3.5	6.08×10^{10}	0.0370	0.0222
4.5	2.51×10^{10}	0.0317	0.0205
5.5	1.08×10^{10}	0.0287	0.0193
6.5	4.34×10^9	0.0263	0.0185

6.3.2.3 Heat Deposition From Neutrons

The thermal load on the facility shield resulting from the incident neutrons results from their loss of kinetic energy, Q_k and from neutron absorptions Q_r . Using the neutron distributions in Figure 6.3.1 and the neutron spectra in Table 6.3-2, the number of neutrons incident on the shield was calculated. The deposition of kinetic energy of neutrons was evaluated assuming that all incident neutrons were thermalized in the shield. The thermal load on the facility shield from this source, Q_k is 0.59×10^8 Btu/hr.

Neutron reactions which contribute to Q_r result primarily from hydrogen absorption yielding a 2.23 Mev gamma ray, and from absorption in boron yielding 2.29 Mev and a particle and a 0.5 Mev gamma ray. A modest conservatism is introduced by assuming that all neutrons incident on the shield are absorbed,

TABLE 6.3-2

LEAKAGE SPECTRUM
(n/cm²-sec)
10,000 MW

Group	E_i^* ev	** $\alpha = 0$	$\alpha = 90^\circ$	$\alpha = 180^\circ$
1	6.00×10^6	4.616×10^{12}	2.142×10^{13}	3.478×10^{13}
2	2.80×10^0	1.795×10^{13}	8.870×10^{13}	8.876×10^{14}
3	1.80×10^6	1.630×10^{13}	4.864×10^{13}	3.298×10^{14}
4	8.00×10^5	2.836×10^{13}	7.844×10^{13}	3.080×10^{14}
5	2.00×10^5	3.136×10^{13}	1.107×10^{14}	6.948×10^{14}
6	3.40×10^4	2.838×10^{13}	1.091×10^{14}	6.478×10^{14}
7	6.00×10^3	2.990×10^{13}	1.197×10^{14}	5.292×10^{14}
8	8.90×10^2	3.390×10^{13}	1.074×10^{14}	4.730×10^{14}
9	1.228×10^2	3.298×10^{13}	1.072×10^{14}	3.918×10^{14}
10	4.52×10^1	1.600×10^{13}	6.546×10^{13}	2.316×10^{14}
11	1.664×10^1	1.530×10^{13}	6.558×10^{13}	1.683×10^{14}
12	6.12×10^0	1.443×10^{13}	4.332×10^{13}	1.355×10^{14}
13	2.26×10^0	1.338×10^{13}	6.074×10^{13}	9.728×10^{13}
14	8.28×10^{-1}	1.212×10^{13}	5.666×10^{13}	6.510×10^{13}
15	3.04×10^{-1}	1.073×10^{13}	5.196×10^{13}	1.450×10^{13}
16	1.12×10^{-1}	1.476×10^{13}	5.210×10^{13}	1.681×10^{13}
17	5.00×10^{-2}	6.938×10^{12}	3.632×10^{13}	1.087×10^{13}
18	Thermal	5.582×10^{13}	2.354×10^{14}	8.874×10^{13}

* E_i is the lower boundary of the energy group.

** $\alpha = 0$ is along the reactor axis in the upward (going towards the sky) direction.

$\uparrow \alpha = 0^\circ$

$\alpha = 90^\circ$

$\downarrow \alpha = 180^\circ$

and that such absorption deposits 2.29 Mev of energy in the shield. The thermal load on the facility shield from this source, Q_R , was calculated to be 3.73×10^8 Btu/hr.

6.3.2.4 Temperature Rise

The nuclear heating from the three sources described above is 6.04×10^8 Btu/hr at 10,000 mw. For a shield containing 3×10^6 lb of water with a heat capacity of 1 Btu/lb, this results in an adiabatic temperature rise of 150 F in 45 minutes with no conservatism other than that implied by the calculational method. For 30 minutes at 5,000 mw the corresponding temperature rise is 50 F.

It is clear that some cooling is required for the 10,000 mw case. The subject of cooling for the 5,000 mw case is discussed in Section 7.3. Provisions for temperature control will depend on modifications to the shield concept and the degree of conservation required.

6.3.3 Umbilical Tower

Radiation dose rate limitations apply to three regions of the umbilical tower: the connections, the general interior and the termination rooms.

6.3.3.1 Umbilical Connections

The criteria for access to the umbilical connections with the facility shield in place are:

1. After a 2 min. run at 2,500 mw

L 2 after 1 day

2. After a 45 min. run at 10,000 mw ;

L 2 after 3 days

U after 12 days with the engine removed

The method of satisfying the umbilical connection criteria such as shielding configuration and material selection for minimum activation, will be established in Phase II. However, Phase I calculations have established that direct gamma radiation from the shutdown reactor together with concrete activation severely limit access to the umbilical connections if no local shielding is provided.

6.3.3.2 Inside Umbilical Tower (All Levels)

The criteria for access to the inside of the umbilical tower, with the facility shield in place, are:

1. After 2 min. run at 2,500 mw

L 2 after 1 hr

L 1 after 1 day

2. After a 45 min. run at 10,000 mw

L 2 after 1 day

L 1 after 12 days with engine removed

It was estimated that the following umbilical tower concrete thicknesses satisfy this access criteria:

For the wall facing the engine:

<u>Elevation in Ft From</u> <u>Test Stand Pad</u>	<u>Ft of Concrete</u>
0-40	2.5
40-80	3.5
80-120	2.5

2 ft of concrete for the back wall (the wall facing the duct exhaust), and

1.5 ft of concrete for the side walls (for scatter and airborne activity).

6.3.3.3 Test Stand Electronics Rooms (Called Termination Room in Criteria Document)

The electronics rooms are located in the umbilical tower at the level of the facility shield. The electronics room shielding is to satisfy the following zone requirements:

<u>Condition</u>	<u>Zone</u>
MCA	R
During 10,000 mw operation	L 2
With facility shield in place after 2 min. run at 2,500 mw	L 1 after 3 hours
With facility shield in place after either 45 min. run at 10,000 mw (this controlled) or 2 separate 30 min. 5,000 mw runs within 30 days	L 1 after 1 day

The calculations for the electronics room concrete used Equation 6.2.1 and Table 6.2-4 for gamma source information, page 469 ANL-5800 for concrete attenuation coefficients, and ANL-6443 for concrete build-up factors. For general convenience, the information on required concrete thickness in the absence of a facility shield as a function of dose rate and distance was developed as shown in Figures 6.3-2 and 6.3-3. The use of these figures can be illustrated as follows:

During 10,000 mw operation, a 1 r/hr dose rate is wanted inside the electronics room, which is 40 ft away ($1.6 \times 10^3 \text{ ft}^2$) from the reactor, with the 7 ft thick facility shield in place. Then $r\text{-ft}^2/\text{hr} = 1.6 \times 10^3$, and from Figure 6.3-2 the equivalent of 8.9 ft of concrete are required for the termination room wall facing the engine. Since the 7 ft thick facility shield is the equivalent of $7 \times 60/150 = 2.8 \text{ ft}$ of concrete, the termination room wall facing the engine must be faced with $8.9 - 2.8 = 6.1 \text{ ft}$ of concrete.

Figure 6.3-3

Dose Rate vs Concrete
During 10,000 mw Operation

6.3.3.4 Regions Protected by Ground Cover

The control center and the tunnels are protected by ground cover i. e., backfill on the roof. The tunnel shielding requirements follow from those at the termination of the tunnels and those at the control room which is the origin of the tunnels.

6.3.3.5 Control Center

The control center shall be so shielded that it satisfies the criteria:

MCA	L 1
During 10,000 mw Operation	U
With facility shield in place after 2 min. run at 2,500 mw	U
With facility shield in place after either 45 min. run at 10,000 mw (this controlled) or 2 separate 30 min. 5,000 mw runs within 30 days	U

As discussed in Section 6.2, the radiation dose rate during operation (10,000 mw operation was found to be the governing condition for the control room) at distances less than 5,000 ft from the reactor comes primarily from the exhaust gas plume (see Figure 6.2-4). The following control room roof shielding thicknesses, which were found by using dose rate data from Figure 6.2-4 in calculations like those previously described for the electronics room, were found to satisfy the criteria for the control room:

<u>Distance In Ft Between Reactor & Control Center</u>	<u>Ft of Concrete Required Over Control Room</u>	<u>Equivalent Thickness of Earth in Ft</u>
500	7.0	10.5
1,000	5.5	8.3

6.3.3.6 Tunnels to Test Stands

The tunnel from the control room to the termination room is uniformly covered with the equivalent of 6 ft of concrete (or 9 ft of earth) facing the reactor. Using this shielding, the dose rate inside the tunnel is somewhat less than that in the termination room (L 2) during 10,000 mw operation.

The shielding requirements for the tunnel access to the control center have been assumed to be L 1, 1 hour after the MCA. This is the criteria for the control center, so the tunnel is as safe as the control center after the MCA. However, it is assumed that there is no traffic in this tunnel during normal operation. The shielding over this tunnel varies with distance away from the control center:

<u>Distance From Control Center in Ft</u>	<u>Thickness of Con- crete in Ft</u>	<u>Equivalent Thickness of Earth in Ft</u>
0-700	2.5	3.8
700-1400	2.0	3.0
1400-2100	1.5	2.3

6.3.3.7 Regions Governing Pad Access

The post test access to the pad is primarily influenced by the activation of the concrete and the radiation from the exhaust duct and exhaust duct vault. The summary investigation of pad and umbilical tower concrete activation made in Phase I suggested that concrete activation will only be a localized problem. For example, at the level of the upper umbilical assemblies where the umbilical tower is subjected to reactor radiation attenuated only by several ft of LH_2 in the run tank, concrete activation and concrete heated by nuclear radiation may require special local treatment. The somewhat more protracted Phase I investigation of radiation from the exhaust duct, which is outlined in the following paragraphs, established that the equivalent of 6 in. of lead shielding would be needed over the vertical section of the exhaust duct to provide the desired post test access to the pad. Incidental to that exhaust duct calculation, the required post test exclusion distances from the bare exhaust duct, which are of interest to the mechanical designer of the duct handling equipment, were estimated.

6.3.3.8 Neutron Activation Source Strength

The neutron activation of a particular material is directly proportional to the neutron flux. The neutron flux at various locations on the exhaust duct was established by applying the inverse distance square law to the neutron data given on Figure 6.3-1 and in Table 6.3-2.

The same irradiation history was assumed for the neutron activation analysis and the plate-out analysis: irradiation time per 10,000 mw test of 45 min., 180 days between each of 10 tests at 10,000 mw, and a decay time of 12 days after the tenth test.

The neutron activation analysis was based on 304 stainless steel (304-SS) whose activities originated from thermal and from fast neutrons: intermediate neutron activation was found to be comparatively unimportant.

The thermal neutron activation calculations were based on data from Bopp and Sisman (page 46, January 1956 Nucleonics). Since the components having a half-life of less than 1 day were excluded because they are comparatively unimportant, the thermal neutron calculations was based on the three 304-SS constituents of 25 day, 45 day, and 5.3 year half-life.

The fast neutron activation calculations were based on the following three (N, P) reactions:

After calculating the total (thermal and fast) neutron activation volume source strength, it was approximated by a total neutron activation line source strength, assuming an average diffuser wall thickness of one centimeter.

6.3.3.9 Fission Product Plate-Out Source Strength

The fission product plate out was assumed to take place uniformly throughout the inner surface of the ejector duct. The plate-out source strength data was taken from Figure 8.11 of the second edition of The Reactor Handbook for the case of 12 day decay time after 1 hr of reactor operation at 10,000 mw. (Data was not readily available for 45 min. of operation. The plate-out source strength from the runs prior to the tenth test were found to be negligible in comparison to those from the tenth and last test.)

The fission product plate-out source strength was estimated as follows where, as in the 6.2 section on the exhaust plume, it was assumed that 6 percent of the fission products are in the exhaust stream:

Equivalent power corresponding to 0.01 percent release = 1.0×10^6 watts

Gamma strength after 12 days following 1 hr run = 1.04×10^{13} Mev/sec

Surface area of duct = 4.08×10^3 ft²

Plate out surface source strength = 2.74×10^6 Mev/cm²-sec

Total length of duct = 366 ft

Plate out line source strength = 9.37×10^8 Mev/cm-sec

6.3.3.10 Total Ejector Duct Activation and Plate-Out Source Strength

The total ejector duct activation (from thermal and fast neutrons) and plate-out line source strength as a function of distance from the core center is shown below in Table 6.3-3. Note that as one precedes away from the reactor, the initially dominant activation line source becomes subordinate to the plate-out line source.

TABLE 6. 3-3
LINE SOURCE STRENGTH AS FUNCTION OF DISTANCE

<u>Distance From Core Center (ft)</u>	<u>Distance Correction Factor</u>	<u>Activation Source (Mev/Cm-sec)</u>	<u>Plate-Out Source (Mev/Cm-sec)</u>	<u>Total Strength (Mev/Cm-sec)</u>
10	1	6.63×10^{10}		
20	1/4	1.66×10^{10}	9.37×10^8	1.75×10^{10}
40	1/16	4.15×10^9	9.37×10^8	5.10×10^9
60	1/36	1.84×10^9	9.37×10^8	2.78×10^9
80	1/64	1.04×10^9	9.37×10^8	1.98×10^9
100	1/100	6.64×10^8	9.37×10^8	1.60×10^9
120	1/144	4.61×10^8	9.37×10^8	1.40×10^9
140	1/196	3.39×10^8	9.37×10^8	1.28×10^9
160	1/256	2.60×10^8	9.37×10^8	1.20×10^9

6. 3. 3. 11 Shielding for Pad Access

Since the line source strength from the diffuser duct to the pad falls off as the square of the separation distance, the activation at the top of the diffuser duct governs the shielding requirements needed for pad access. The 6 in. lead shielding required over the diffuser to provide a Zone U radiation dose rate at the pad 12 days after 45 min. operation at 10,000 mw was calculated by approximating the line sources at the top of the diffuser as disc sources.

6. 3. 3. 12 Duct Exclusion Distances

The information presented in Table 6. 3-3 was used to find the dose rate versus distance from the diffuser when it is removed

from its vault. Selected values are given in Table 6.3-4. Keeping in mind that the radiation dose rate varies directly as the square of the separation distance, and that a dose rate of less than 3 r/hr is required for even very limited personnel exposure, one sees that direct work on a used ejector duct is precluded for years.

6.3.3.13 Future Work

The bulk of the Phase II nuclear engineering work will be devoted to a more comprehensive examination of shielding requirements. The highlights of the Phase II shielding work are indicated in the following paragraphs.

The gamma source information given on Table 6.2-4, which is the basis for most of the nuclear governed separation distance work, has been found to be overly conservative. Some of the separation distances developed for non-nuclear reasons for the conceptual design are so large that reduction of the facility shield thickness on the basis of actual separation distances is possible. Thus the first task will be to recalculate the facility shield thickness -- separation distance for regions without local shielding -- facility shielding heating relationships.

The second task will be the investigation of the desirability of using a composite facility shield. The intermediate shield must be investigated.

The exhaust plume calculation, whose results govern the control center shielding and may also govern the integrated dose to the back of the termination room, will be expanded and checked against experimental data.

The nuclear heating of the umbilical tower and the nuclear heating of the duct vault will be calculated.

The activation calculations will be extended; the umbilical tower and pad activation will be calculated in some detail.

Shielding and activation calculations for the umbilical assemblies will be accomplished.

TABLE 6.3-4

DUCT DOSE RELATIONS

<u>Duct Section</u>		<u>Dose Rate</u>	<u>Notes on Handling</u>
100 ft from top of V (vertical) section*	10 cycles (1 every 6 months) of 10,000 mw 45 min operation - 12 days after last operation	5 r/hr	
100 ft from top of V section	12 days after a single 10,000 mw 45 min operation	3.3 r/hr	
100 ft from top of V section	10 cycles (1 every 6 months) of 10,000 mw 45 min operation - 280 days after last operation	1.2 r/hr	
2,000 ft from top of V section	10 cycles (1 every 6 months) of 10,000 mw 45 min operation - 12 days after last operation	10 mr/hr	When V section is removed it must be taken 2,000 ft from inhabited area (such as the steam generator location)
100 ft from top of V section	12 days after a single 5,000 mw 45 min operation	800 mr/hr	
100 ft from horizontal section of highest activity	10 cycles (1 every 6 months) of 10,000 mw 45 min operation - 12 days after last operation	25 mr/hr	This is mostly from plate out; might be able to wash off deposit and then work on directly

*Top of V section is the most active part of the duct.

6.4 Thermal Radiation From Exhaust Plume

The purpose of this investigation was to evaluate the effects of the plume on the test stand with regards to the radiation heat fluxes and local surface temperature rises, as functions of position.

In the absence of specifically available data, an analysis was adopted for this investigation and checked with related experience. The results allowed a recommendation for specific thermal protection of the candidate test stand concept. The various simplifications that were adopted reflect the preliminary nature of the concepts which define the exhaust gas condition and the system geometry. Some of the parameters have a major effect on the results, and therefore on the conclusion pertaining to the need for special protection of the exposed faces of the test stand. These parameters (e. g. flame temperature, emissivity and the view factors) had to be evaluated in some detail. The adopted method of analysis was checked using the plume measurements obtained by Aerojet General Corporation during their scale tests of the ETS-1 ejector system and reported in their report No. 2679. Good agreement was found in all the important parameters, thus raising the confidence level of our approach.

6.4.1 Summary of the Method of Analysis

Reference: G. N. Abramovich, The Theory of Turbulent Jets, MIT Press, 1963. Equations of energy and of the component concentration within a turbulent boundary layer of a jet, were stated for the case when chemical reaction (burning) is taking place. Besides these equations the use was made of the equation for the conservation of mass (before and after the chemical reaction), and of the stoichiometric relationship between the amounts of substances consumed, to show that there is a similarity between the enthalpy distribution and the concentration differences in the reacting substances.

As a consequence of this similarity, it was possible to write a nondimensional distribution function, θ , which is equal to both the normalized local enthalpy relation and the normalized local concentration relation. This distribution function depends on the local axial and radial coordinates of the jet.

6.4.1 (Cont'd)

In reality, the flame boundary could only be found by solving simultaneously the equations of motion, energy, state and the conservation of mass. However, in the case of the diffusion flame (i. e. where the oxidant is not present within the exhaust gases before their exit), approximate coordinates of the flame boundaries could be obtained by specifying relationships for the axial and the radial enthalpy distribution within the jet, normalizing the enthalpy, and equating it with the above mentioned nondimensional distribution function, θ , evaluated at the diffusion flame front. Along the flame front this function depends only on the fuel concentration and on the stoichiometric relationships.

While the sketch in the AGC report, which was based on the photograph of the test plume, shows a conical flame shape, Kaiser's calculations give a shape which resembles a candle flame. It could be argued that the sketch encompasses the hot turbulent gases which emanate from the flame, persisting in the direction of their original momentum, thus forming a cone. The flame lengths are in satisfactory agreement.

Since E/STS 2-3 tests could be conducted in the presence of a 35 mph wind, it became important to find the degree to which the flame boundary would be distorted should the wind blow towards the umbilical tower. The radiation heat transfer would increase if the flame is shifted closer to the tower. An empirical equation was used to evaluate the coordinates of the bent jet axis. This correlation applies to jets which do not contain the flame front. However, since the flame contours were derived with the help of the nonburning jet gas dynamics, the bent jet correlation could provide a first-cut approximation. It was found that the wind effect on the flame boundaries was small where the gas velocities in the vicinity of the axial flame boundary are still much higher than the incident wind velocity.

Accuracy of the flame temperature is important since it enters the fourth power relationship for the evaluation of heat flux.

Therefore, the adopted method for evaluation of the flame temperature utilizes enthalpies (rather than specific heats) of the constituent gases. This method has been programmed for use on Quicktran, a time-sharing digital computer.

6.4.1 (Cont'd)

In the AGC report, arguments were presented to support their assumption that only 70 percent of hydrogen in the hydrogen-air mixture participates in the reaction. This led to the agreement between their flame temperature measurement and the result of their analysis. Using the same assumption for the amount of the participating hydrogen, Kaiser's method of analysis predicted the flame temperature which was within 40 F of their measurement. However, if it is assumed that all hydrogen participates, in stoichiometric proportion, the calculated flame temperature is appreciably higher. Consequently, for the purpose of thermal radiation analysis, it was decided to adopt the arithmetic mean of the calculated temperatures based on the 70 percent and the 100 percent hydrogen participation.

Only the hot water vapor and carbon dioxide were assumed to contribute to thermal radiation. While in reality the contribution of each (volume) portion of the plume to the thermal radiation which reaches the test stand, depends on the view factor and attenuation due to passage through hot gases, the evaluation of the incident thermal radiation was simplified by assuming that radiation emanates only from the surface of the plume (i. e. from the flame boundary). This called for evaluation of an equivalent emissivity of that surface, which was performed by calculating the emissivity of the hot gases for radiation to their boundary which in this case happens to be the flame boundary. This emissivity, together with the flame temperature and the view factor between the flame surface and the selected location on the test stand, defined the amount of the incident thermal radiation.

In the AGC tests, measurements were made of thermal radiation reaching the probe which was located very close to the flame. Since the flame temperature is also known, this allows computation of the equivalent emissivity of the flame surface. This turned out to be of the order of 0.38, very close to the result of Kaiser's computation method.

To find the view factor, the flame boundary was approximated by an inclined cylinder and the view factor computed by numerical integration utilizing Quicktran.

Preliminary results have shown that large rises in the test stand surface temperature can be expected if the flame sees the bare concrete surface. As a consequence it became necessary to evaluate the effects of painting the concrete surface with aluminum paint, or of placing a thermal shield ahead of the surface. Free convection air cooling of the aluminum sheet shield was considered in this analysis.

6.4.2 Results

The plume (flame) size, temperature, view factors and heat fluxes were evaluated for the ejector exit condition which consisted of 325 lb/sec of H_2 , 482 lb/sec of CO_2 , and 1,480 lb/sec of H_2O , the gas mixture exit velocity 4,700 ft/sec, and the ambient air temperature of 560 R. This exit condition corresponds to the dry, subsonic elbow diffuser, with $L/D = 8$, attached to the ejector which uses steam as the ejecting fluid. Some CO_2 also is present because propane is burned in the presence of oxygen to provide the heat of vaporization of water, the combustion products being injected in water.

For this condition the flame length was found to be about 250 ft, its largest diameter 50 ft and the flame temperature about 4,340 R.

The maximum local surface temperature of the concrete wall belonging to the umbilical tower was found for the following three cases, assuming the flame duration of $3/4$ hours:

1. Bare, unshielded concrete
2. Concrete painted with aluminum paint
3. Aluminum shield placed 6 in. away from concrete wall.

The table below summarizes results for two test stand schemes. Plume effects at the ejector exit also were investigated for test stand scheme No. 21, which is the configuration described in this report.

<u>Condition</u>	Maximum Surface Temperature Of The Concrete Wall	
	<u>Test Stand Scheme No. 17</u>	<u>Test Stand Scheme No. 21</u>
Unshielded, bare concrete wall	780 F	1,000 F
Unshielded concrete wall, painted with aluminum paint	510 F	665 F
Shielded concrete wall; shield consists of an aluminum sheet which is exposed to air on both sides	116 F Maximum tem- perature of alu- minum shield 395 F	132 F Maximum tem- perature of alu- minum shield 522 F

6.4.3 Conclusions

An aluminum shield, spaced at least 6 in. from the wall, should cover all the surfaces of the umbilical tower which see the flame. Refractory brick, about 6 in. thick, should cover all the exposed concrete surfaces around the ejector exit, except for the concrete floor. Water sprays must be employed at the exhaust end of the vault to form a water-mist curtain to protect the steel structure that sees the flame. The spray design should accommodate the heat removal (by evaporation of spray) of about 55,000 Btu/hr/sq ft, where the surface refers to the cross-section area of the vault.

In the future, when more accurate evaluation will be of interest, improvements in the analysis should be sought in the area of definition of the plume (flame) shape and size, and of the radiation incident on the test stand as contributed by each (volume) portion of the plume rather than by the plume surface. The effect of the wind on the plume shape also should be examined in more detail.

SECTION 7TEST STAND7.1 Test Stand Configuration7.1.1 Basic Criteria

The basic objective of this effort was to develop a configuration of the test stand which would satisfy the following basic requirements:

1. Support 5,000 mw propulsion module in a vertical down-firing position.
2. Shield the stand and other facility elements from engine nuclear radiation.
3. Shield propulsion module from exhaust plume thermal radiation.
4. Provide environmental enclosure around engine for altitude simulation.
5. Provide for accessibility of the EIV units and the Beetle.
6. Provide for handling of module tank, instrument unit, subsystem equipment bay and environmental enclosure; on and off the stand.
7. Provide umbilical tower to accommodate the umbilical assembly, cryogenic piping and other supporting services and required electronic equipment.
8. Provide for the diffuser/ejector configuration.
9. Provide the capability of accommodating an approximate 55 ft high growth module tank.
10. Provide growth capability for accommodating a 10,000 mw propulsion module.

11. Provide growth capability for accommodating a 10,000 mw diffuser/ejector configuration.
12. Provide nuclear shielding and handling systems where required.
13. Provide thermal shielding or protection where required.
14. Provide access to all levels of the umbilical tower.
15. Provide for control and instrumentation systems, propellant and inert fluid systems and air conditioning systems.
16. Provide necessary purges and safety systems to eliminate hazards associated with trapped hydrogen.

7.1.2 Concepts Considered and Rejected

There were 21 different schemes considered. Of these, eight were discarded as not feasible due either to excessive earth fill requirements, excessive elevator heights, or excessive retaining wall heights; heights of about 180 ft.

Seven schemes were studied in more detail using dry exhaust of 8:1 ratio for the diffuser for the 5,000 mw and 10,000 mw engines, and using the vertical stage transporter concept. These seven schemes were reduced to four separate concepts based upon the concept of using a dry exhaust 8:1 ratio diffuser for the 5,000 mw engine and about a 4:1 ratio for the 10,000 mw engine. Two of these schemes required no fill, but used 111 ft high elevators for raising the EIV units up to pad level for engine installation and removal. These schemes were rejected on a cost and impracticability basis of the elevators. The best features of the remaining two schemes were combined into an additional scheme. This scheme was used as the basis for the final concept selection.

Two additional schemes were studied having a minimum umbilical tower, with most of the electrical and electronic equipment located either in a room separate from the test stand or in the control center. It became apparent from trade-off studies that the electronics and equipment rooms could best be accommodated in the test stand structure because the umbilical tower provided this space and is necessary for other reasons. One of these schemes

also had the ejector duct in the open with no concrete cover. This scheme required an extensive bridge approach to the pad level and was rejected because of excessive costs.

Three other schemes were made with changes to the overall stand height due to diffuser modifications.

7.1.3 Selected Concept

The selected concept is as shown on the following drawings:

- Drawing 6552-4-M1 - Test Stands - General Arrangement - Elevations
- Drawing 6552-4-M2 - Test Stands - General Arrangement - Plans & Sections
- Drawing 6552-4-A1 - Test Stand - Perspective

The final configuration and location at the Fortymile Canyon site requires 40 ft of excavation for the ejector discharge duct in the canyon bottom, and 35 ft of fill at the stand for access to pad level for E/STS-2, and 57 ft of fill for E/STS-3.

Concrete was selected as a basic construction material for the following reasons:

1. It provides for nuclear shielding which is necessary for the safety of personnel due to excessive radiation created by activation of the diffuser.
2. It provides an integral retaining system for the earth fill.
3. It provides the required structural support of the test hardware and facility equipment.

A cylindrical configuration for the test stand was selected because it combined shielding, structural support, and earth retaining capabilities in the smallest area, is easily constructed using a continuous pour slip form method, and is compatible with the cylindrical engine shield tank.

Features of the selected concept are described on the pages following.

7.1.3.1 Propulsion Module Support

The module tank is supported initially from the lower tank skirt using adjustable support trunnions on an aluminum support structure, as shown on Drawing 6552-4-ML-26, and held in place while the engine is installed by the EIV units. This structure is supported by two columns at the pad level and from the umbilical tower. Personnel access is provided on this framework which also contains the lower instrumentation and process piping umbilical assembly units.

The diameter of the engine shield tank is established to provide clearances for the diffuser. This diameter will accommodate the 10,000 mw growth module configuration by changes to the upper section of the engine shield tank which supports the 5,000 mw module and is shown on the Drawing 6552-4-ML-26.

After all installations and set-ups have been made and a test is to be run, the engine shield tank is raised to interface with the lower skirt of the stage. After this attachment has been made, the connection of the module tank to the support structure will be disconnected and the entire propulsion module will be lowered to place the bottom of the engine nozzle approximately 6 in. inside of the diffuser. This will require the umbilical connections to be capable of a vertical movement of the module of 3 to 4 ft. This movement can be readily attained.

7.1.3.2 Facility Shield and Environmental Enclosure

A cylindrical water filled shield which raises above pad level and lowers to a position flush with pad level, serves as a nuclear radiation shield around the engine. This shield also serves as an environmental enclosure around the engine for altitude simulation when sealed to the stage and diffuser system; and also supports the propulsion module.

7.1.3.3 Propulsion Module Thermal Protection

The propulsion module and the umbilical tower are protected from thermal radiation from the exhaust plume by a vertical aluminum shield mounted on the exhaust side of the umbilical tower. The concrete at the ejector duct discharge is protected by a water fog spray system.

7.1.3.4 Pad Level Area

A concrete apron 125 ft long is provided at the approach to the stand which has the EIV tracks centered on the test stand, and enlarged areas to the side for location of the module tank handling crane and movement of the prime mover for the horizontal module tank transporter.

7.1.3.5 Umbilical Tower

The umbilical tower is a reinforced concrete structure, 40 ft by 40 ft on the outside, 135 ft high above the pad level, and is supported by a 105 ft high concrete substructure.

A concrete structure was selected to provide nuclear radiation shielding of equipment, cable and pipe chases and areas for personnel access.

The tower supports the propulsion module support frame, the upper umbilical assembly and the aluminum thermal shield. Housed in this portion of the tower are three electronic equipment rooms, one opposite each umbilical assembly and one at pad level. For purposes of the estimate and determination of amount of concrete required for the tower, the electronics room number 4 at the upper umbilical assembly as shown on Drawing 6552-4-M1 has been considered to be lowered to the third position above the pad level area.

Cryogenic piping is located on the outside along one vertical side wall to provide for complete ventilation and is protected from nuclear radiation from the engine by a concrete wing wall.

The space beneath the tower below pad level contains the decontamination room with toilet facilities, the air conditioning room, an electronic equipment room and an electrical equipment room. The access tunnel from the control center enters the test stand structure at the lower electronic equipment room.

A 4-ton freight elevator and a stairwell service all levels of the tower and the rooms below pad level.

The tower is designed so the height can be extended approximately 55 ft to accommodate either the growth tank of the 5,000 mw propulsion module or the 10,000 mw propulsion module.

7.1.3.6 Diffuser/Ejector Vault

A 55 ft inside diameter cylindrical reinforced concrete structure below pad level encloses the engine shield tank in its lowered position, and the diffuser and elbow.

This cylindrical structure extends 170 ft below pad level to the bottom of the discharge duct vault.

The ejector is housed in a reinforced concrete arch section vault which daylights 173 ft-6 in. from the centerline of the stand into the canyon with the bottom of the vault 40 ft below the canyon floor. A weather door is provided over the ejector discharge duct.

During operation of the cooling water system for the diffuser/ejector, approximately 400,000 gpm of cooling water is discharged into the diffuser/ejector vault. This water will be about 3 ft deep and will then flow out of the end of the vault and down the waste water channel.

7.1.3.7 Nuclear Shielding

The wall thicknesses of the test stand are sized to provide nuclear shielding where required. The prime shielding is the umbilical tower walls which are sized to protect equipment in the tower and to allow personnel access, in accordance with the Criteria document. Shield thicknesses are discussed in Section 6.

The diffuser inlet has a remotely operable shield door which protects the area above the diffuser from nuclear radiation during the periods between test runs. This is discussed further in Section 7.2.

7.1.3.8 Water Deluge System

A water deluge system is provided to protect the module tank, instrument unit, environmental enclosure, equipment bay, water shield tank, the module face of the umbilical tower and associated structures in this area.

The piping system around the module tank and water shield tank are movable so that they can be moved to a position that will clear the work area at pad level and allow the module tank to be removed.

7.1.4 Phase II Work

During Phase II, the overall configuration of the test stand will be refined based on further design and trade-off studies.

Other feasible concepts also will be considered during the early period of Phase II.

7.2 Handling Systems

Handling procedures involving equipment that is not radioactive are considered routine manual operations and are not discussed here. However, the presence of an operating nuclear reactor causes certain components of the facility to become radioactive, thus restricting personnel approach. In addition, the engine itself, being a primary source of radiation after initial operation precludes the use of personnel for routine maintenance and demating. As a result, remote handling is a requirement in the maintenance of the facility and would also be required if clean up of a credible accident were necessary. Consistent with the criteria as set forth in Section 3, handling concepts are developed for each item which requires remote handling. Accidents which may cause the distribution of concentrated quantities of fissionable material, or physical disarrangement of the equipment, are not specifically provided for. Although the techniques discussed here will aid in a clean up operation, supplemental equipment would be needed, which is not included as part of the facility.

7.2.1 Module Tank Handling

The objective is to provide for the transportation, erection and removal capability of the module tank at the test stand. This is essentially a manual operation, except for the locking of the tank to the stand and connection and disconnection of the umbilical assemblies which are remote operations.

Manual operations consist of installation and removal of all lifting fixtures, which are GFE, and are bolted in place. The erection and removal of all upper equipment bays and modules also are accomplished manually.

Concepts for module tank transport and erection that were examined and discarded by Marshall Space Flight Center included

7.2.1 (Cont'd)

a railroad mounted vehicle carrying the tank vertically at a minimum height and a similar vehicle incorporating a hoist to raise the tank to the stand position.

For maximum flexibility, and in keeping with previously established methods of tank handling, it was decided to use the concept of carrying the tank to the stand in a horizontal position on a Saturn type transporter. Both the transporter and the tractor are considered to be GFE.

A crawler equipped crane of about 100,000 lb capacity at 76 ft radius, was suggested by MSFC as part of their overall planning to obtain maximum utilization around the entire facility. This crane also serves to fulfill other lifting requirements at the test stand. This approach eliminates the need for hoists on the umbilical tower.

The general concept as shown in Drawing 6552-6-ML-25 resulted from utilizing the equipment described above. The procedure shown is for installation. Removal is the reverse process with the added precautions of minimizing personnel contact with the tank bottom due to radioactivity.

Operational details are not shown, however, it is necessary to consider that the act of suspending the module tank from a crane will require tie-offs and tag lines handled by personnel in order to prevent the wind from swinging the tank.

The selected concept assumes no restraints imposed by residual radioactivity of the tank or the stand since detailed activation analyses are not currently available.

If the tank can be left in the stand until the level of radioactivity at the support structure has decreased sufficiently to permit personnel to guide the tank manually out of the structure, then the method as presented is satisfactory. If the time for activity decay is excessively long and interferes with the test program, then a system of mechanical guidance in and out of the stand is required. This aspect will be pursued and a recommendation made in the final report.

The handling crane as shown on Drawing 6552-6-ML-25 must be pre-positioned so it can reach the forward portion of the tank, perform the lift, and then swing the tank to the test stand position without shifting its base position. Outriggers are required, hence the crane cannot move when these are in use.

The tank is brought to the test stand and positioned so the trunnion end of the module faces toward the stand. The upper handling ring is bolted to the stage and the crane is attached to the stage as soon as the transporter is backed sufficiently to allow the jib boom to extend to the 75 ft radius required to perform the entire lifting operation without shifting position.

By simultaneously driving the transporter away from the stand, and performing a straight lift using the crane, the module tank is pivoted to an upright position on the trunnion equipped transporter (refer to Step 1 on the drawing).

The crane lifts the module tank high enough to clear the test module support structure and swings the tank into alignment with the support structure. At this point, numerous tag lines and manual handling will be needed to guide the tank into the structure. Large fixed guides will guide the tank skirt into contact with the skirt retaining devices.

The four aft support skirt retaining devices are moved into position remotely to support and lock the tank temporarily prior to engine mate or demate. After the locking operation, the module tank lifting fixture is manually unbolted and removed (refer to Step 2 in the drawing).

The IU and the environmental unit are brought on separate transporters and positioned on top of the tank by the stage handling crane. The upper and lower umbilical connections are mated to the tank remotely. A manual alignment check is made to establish the coincidence of the centerlines of the engine mate flange with the vertical axis of the diffuser inlet. The tank is now ready for the engine mating operation.

7.2.2 Engine Handling

The engine is a major source of radioactivity after operation at full power and it, therefore, requires complete remote handling during removal. Reinstallation of a fired engine also would require remote handling.

The concept of engine handling has been established by Aerojet-General under contract to SNPO and has been reviewed for adaptability to the test stand configuration. The equipment consists of the Engine Installation Vehicle (EIV) and its associated Manned Control Car (MCC) which are both GFE.

7.2.2 (Cont'd)

Referring to Drawing 6552-4-ML-30, it is apparent that two alternative positions for the EIV with respect to the test position centerline are possible. Studies were made to determine the feasibility of driving the EIV into the test area and maintaining a short reach on the engine adapter fixture, or keeping the EIV wheels on the concrete surface and extending the reach of the engine adapter. Placing rails across the test area is not desirable due to high concentrated loads on the top of the facility shield and the presence of an environment seal on the shield tank which must not be interrupted.

On this basis, the concept of running the EIV close into the test position was discarded in favor of the extended reach on the vehicle.

The approach direction of the EIV track to the stand was dictated by site location and fill considerations, and does not enter into the engine handling consideration. Studies were made to determine the usefulness of this track for diffuser duct removal and it was concluded that the position selected allows the most flexibility for handling the duct. This is discussed in more detail in the next section.

Drawing 6225-6-ML-25, Step 3, illustrates the procedure adapted for this study. The engine is assumed to be carried into the stand with the nozzle clearing the pad surface by three in. A 9 in. vertical upward movement of the EIV serves to mate the engine and all of its connections. All motions to obtain alignment and positioning are controlled by the operator in the shielded MCC. The bottom of the mate/demate flange on the module tank is positioned to allow a 12 in. total clearance between the engine and the test pad top. After the engine is installed the EIV is removed. The diffuser inlet shield door is remotely moved into place to cover the duct opening and allow manual checkout of a cold, clean engine. It should be noted that engine mate/demate can be performed whether or not the shield is in place.

After the engine is checked out, the upper intermediate shielding is put in place around the engine and connected to the water system. This operation is designed to be performed remotely, if the level of radioactivity around the engine requires it.

Referring to Drawing 6225-6-ML-25, Step 4 consists of raising the facility shield up around the engine. This shield contacts the stage skirt and transfers the weight of the test module from the support structure to the facility shield. At this point the module clamps on the shield tank are actuated to lock the stage skirt to the shield tank. The four skirt retaining devices on the support structure are unclamped and retracted into the support structure and the radial shield tank is lowered, thus moving the propulsion module into firing position. At this point the nozzle exit plane is located approximately 3 in. below the diffuser inlet (refer to Steps 5 and 6 on the drawing).

Total movement of the test module is about 45 in., which must be accommodated by the umbilical connections.

This movement is governed by the thickness of the lower intermediate shielding which surrounds the diffuser as shown on Drawing 6552-4-ML-26. As part of the Phase II work, the shield requirement in this area will be studied to see if the shield thickness can be reduced, thus reducing the total module movement. It probably cannot be reduced to less than 24 in. since a shield door over the duct opening must be provided for.

In the event that a malfunction of the facility shield raising/lowering system occurred, it would not be possible to remove the engine from the test position. Therefore, an auxiliary lifting system is connected to the stage skirt from the support structure to allow raising the propulsion module up to the normal demate position. This action is independent of the shield tank mechanism.

7.2.3 Diffuser and Ejector Handling

The engine exhaust system may require removal as a result of three different actions:

1. Replacement of the growth configuration
2. Removal for maintenance due to duct malfunction
3. Removal due to accident

Since the system will be radioactive due to a combination of plate-out and activation, it has been assumed that the ducts must be handled remotely. The vertical or diffuser portion will be highly activated to the extent that remote operations

7.2.3 (Cont'd)

are necessary. Similarly, the horizontal or ejector portion may be beyond the personnel access limits so provisions are made for remote handling.

Studies were performed to evaluate the size and weight of individual pieces of the system in order to determine the method of removal. By increasing the number of pieces, the weight of each piece is reduced thus allowing the use of smaller cranes and transportation devices. However, each additional duct joint is estimated to cost \$100,000. A trade-off showed that it was more economical and resulted in increased reliability to establish three major pieces; namely the diffuser, the 90° elbow and the ejector. Each piece is estimated to weigh 350,000 to 400,000 lb.

After establishing the number of pieces and their geometry, it was decided that the vertical section would most easily be withdrawn vertically while the elbow and the horizontal section would be removed horizontally. Removing the elbow vertically was abandoned since it would have increased the diameter of the vertical concrete tube and engine shield. Rotation of the elbow to reduce its overall height was considered in order to reduce the horizontal tunnel height. It was abandoned since it contributes to mechanical complexity of the elbow handling and support structure.

A study of three basic types of vehicle for ejector duct and elbow removal was conducted. A rubber tired vehicle, fixed crawler treads and a method employing standard railroad freight car tracks and rails was evaluated for function and cost. The rubber tired vehicle was found to result in ground pressures in excess of the 2,500 psf loading which is considered maximum on the unimproved areas in the canyon bottom. To reduce this loading, the vehicle required many wheels which made it more costly than crawler treads which can distribute the load and have the advantage of not requiring a track or prepared roadway.

Draw bar pull required on level ground varies as follows:

7.2.3 (Cont'd)

<u>Duct Vehicle</u>	<u>Draw Bar Pull/Ton</u>	<u>Tractor Vehicle Total Pull Requirement</u>
Rubber tire trailer	75 lb/ton	15,000 lb
Crawler	200 lb/ton	40,000 lb
Railroad car trucks	20 lb/ton	4,000 lb

On this basis, it was decided that the Beetle with its 80,000 lb draw bar pull would be a satisfactory tractor whichever vehicle was selected.

The concept selected for the preliminary report utilizes crawler treads since they offer high load carrying capacity over unprepared ground and maximum operational flexibility and compatibility with the existing Beetle.

Concepts for handling the vertical diffuser consisted of rubber-tired vehicles, crawler transporters and railroad cars. Railroad cars offered the lowest cost with very high carrying capacity and they could be used with the existing EIV track, the MCC and the booster locomotive, all of which would be available. On this basis, other concepts were abandoned. Due to the 369,000 lb weight of the diffuser, it was decided that two cranes of 100 ton capacity would be more readily obtainable than a single 200-ton crane with the required boom length. A 200-ton railroad locomotive crane was considered, but was found unsuitable due to the limited boom length available.

Drawing 6552-6-ML-21 illustrates the concept selected for this report.

For the removal of the diffuser, two mobile cranes of 100 ton capacity each with about 140-ft booms are required. These cranes are GFE. A separation distance of 50 ft between the operators and the duct is planned. This results in radiation exposure to the operators which will require shielding. This problem will be resolved in the final report.

7.2.3 (Cont'd)

Before the vertical diffuser section can be removed, a portion of the upper support structure is removed along with the lower neutron shields and the diffuser inlet shield. This work may be carried out by controlled personnel exposure using long-handled tools and temporary shielding.

The piping and instrumentation connections to the facilities are separated and the main support structure is unbolted from the test stand by long-handled tools. Expedient shielding will be used where required to limit personnel exposure. Special hand tools and equipment are not included in the Cost Estimate.

The diffuser is lifted vertically from the vault using the two cranes attached to an equalizer beam. Two specially equipped railroad flat cars, not included in the facility cost, are prepositioned at the edge of the test stand under the control of the MCC. The car closest to the MCC is equipped with a winch capable of swinging the duct bottom sideways on to the support frame. As the MCC moves the car away from the stand, the cranes lower the duct section into place on the second car, which has remained in position. The crane slings are removed and the duct is transported to the forward decontamination area. No additional fixtures are required since the duct is designed to be self-supporting in the horizontal position. It is assumed that the Beetle or a similar shielded vehicle with manipulator capability is available to perform tasks requiring manual dexterity.

During initial construction, this equipment and handling method will be used to transport and erect the diffuser section.

The ejector section is supported at four trunnion points which are remotely released. All water and instrumentation is disconnected at the uncoupling station. Jack-equipped crawler treads are pushed into place along a treadway on either side of the duct. This is done by a shielded vehicle such as the Beetle. The jacks raise the duct from the supports and the Beetle pulls the assembly from the vault to the decontamination area situated in the canyon.

By a similar process, the elbow section is raised from its supports and then removed to the same decontamination area by the Beetle.

Since water to a depth of 3 ft will cover the floor of the tunnel, the duct moving vehicles will be in place only during removal operations. All fixed mechanical equipment is placed above the anticipated water level to prevent rusting.

Facility connections for cooling water, ejector fluid and instrumentation will be grouped in an adjacent room at the junction of the vertical and horizontal tunnels. All connectors will be of the quick make/break type that can be operated remotely.

The decontamination area for the horizontal duct and elbow is located in the canyon at a distance from the stand consistent with shutdown activity levels, and is used as the initial fabrication area.

For the final report another study will be made to evaluate the use of railroad car trucks on the horizontal duct sections if the size and weight of the duct increases.

7.3 Engine Shield Tank

The shield tank surrounding the engine serves three purposes:

1. A radiation shield
2. Support for the test module when it is in firing position
3. Environment simulation chamber

Two configuration concepts were studied along with a choice of two shielding materials and three methods for obtaining shield movement. Of the two configurations, i. e., vertically split halves moving laterally, and a one piece design moving vertically, it was decided that the technical difficulties of sealing the split shield made it undesirable.

Nuclear requirements which are covered elsewhere dictated a preliminary choice of water instead of concrete for shielding. Therefore, the concept evolved into a water filled tank. Methods for raising the tank which were investigated included a mechanical hoist system, hydraulic jacks and water flotation. Mechanical hoists were discarded due to problems of hoist synchronization and load sharing and the fact that lifting forces would be applied eccentrically thus introducing torsional moments in the tank. Flotation is reliable, but problems of maintaining shield levelness

7.3 (Cont'd)

exist when loading is unsymmetrical. Also, this method is slow considering that two 500 gpm pumps would require about six to seven hours to raise the empty tank. At this point another six to seven hours would be required to fill the tank. On this basis the concept selected which appeared to offer the best speed, maximum reliability and simplification of the problems of load sharing and tank levelness was hydraulic jacks.

Two systems of test module support that were evaluated were:

1. Support of the module from an independent support structure.
2. Support of the module from the shield tank itself.

In order to reduce the number of seals required and to provide vertical movement of the module, the concept of using the shield tank as the main support during firing with the independent support structure used during mate/demate was adopted.

Altitude simulation concepts included the use of a separate inner pressure chamber surrounding the engine, and the use of the shield tank itself as the pressure chamber. Difficulties of obtaining radiation resistant seals and the fact that water cooling would be required for the inner chamber caused it to be discarded in favor of using the shield tank.

Environment seals may be grouped into inflatable, barometric and freeze seals. Each was evaluated, but state-of-the-art dictated that inflatable types appeared to be least costly and offer good reliability particularly if they are used in series with a nitrogen purge between them.

The general configuration adopted for this report is shown on Drawing 6552-4-ML-26. All shield geometries shown are "first-cuts" and will be studied for cost reduction during Phase II.

The entire engine shield structure is aluminum in order to reduce nuclear heating and activation, and contains the equivalent of 84 in. thickness of borated water. This amount of shielding is calculated to be adequate for the 10,000 mw engine, as is the ID of the shield tank, therefore, this shield may be used for the growth configuration by modifying the upper portion where the stage is attached.

7.3 (Cont'd)

Connections are provided to circulate the water for heat removal purposes, however, no cooling system is provided for the 5,000 mw engine as discussed in Section 6.

When access to the engine is required, the shield is lowered into the stand surrounding the diffuser duct as shown in Drawing 6552-4-ML-26. The raising and lowering is accomplished at a rate of 1/2 foot per minute by six 600 ton hydraulic jacks of a type used on offshore drilling barges.

The entire load of the module including the atmospheric load, wind and seismic loads, is carried down through six equally spaced columns which are integral with the shield tank. These transmit the load in turn to the six 42 inch diameter steel columns to which the jacks are attached. Since the jacks have built-in mechanical stops, no other method of locking the system in the firing position is provided.

Hydraulic fluid is selected to be compatible with the radiation dose encountered during the equipment lifetime.

For rapid access to the test area when the shield is extended, a manway is provided which may be flooded and emptied independently of the remainder of the tank.

Leakage into the engine compartment will be controlled by means of two circular seals; one at the stage support skirt, and the other between the tank ID and the diffuser support structure. These are located to minimize exposure to irradiation.

For this report, inflatable seals with a nitrogen purge are shown. The final report will include a trade-off study with the mercury barometric seal, which has the advantage of simplicity and absolute leak tightness without special fit up tolerances. Mercury has such drawbacks as toxicity, high cost and neutron activation, however.

An intermediate shield tank inside the engine compartment (shield) at approximately the height of the engine internal shield is supported from hollow tubular columns which serve to provide circulating boric water for cooling. The tank is split into two semicircular parts

to allow for engine removal. The two halves of this intermediate shield are removed remotely. At this time, the overall size and weight of this shield is not known, therefore the specific method used for removal cannot be described. During Phase II, a study will be conducted to establish the size of this shield and the removal method. If it becomes small enough, it may be possible to incorporate it into the main facility shields and eliminate the need for separate handling.

A study of the shielding requirement around the diffuser inlet and support structure was conducted in keeping with the criteria of unlimited access to the test area 12 days after engine removal. In addition, it is necessary to provide sufficient structural strength in the area around the diffuser to allow access for a Beetle type vehicle.

The studies included a movable concrete floor slab which could be slid in place over the entire operating area, and the fixed aluminum water tank with provisions for a smaller movable shield over the diffuser opening. The movable slab concept was discarded due to its large mass, the multiplicity of support tracks required and the fact that a depression in the test pad was required to accommodate it.

The concept selected consists of a fixed aluminum water tank surrounding the diffuser inlet. The top surface serves as the operating floor within the test area. The tank is removable to permit access for seal maintenance and permit access to the main bolting ring which secures the diffuser to the test stand.

Additional work which remains to be done consists of optimizing the vertical thickness, determination of the need for cooling and a material trade-off to reduce activation and heating of the concrete structure.

7.4 Diffuser Inlet Shield Door

The diffuser inlet will have a sufficiently high level of radioactivity after operation to require a shutdown shield to permit manual servicing of a cold, clean engine.

Studies were conducted for both lead and depleted uranium shields, of one piece and split half geometries. The means of inserting the

shield consisted of lift-in and slide-in devices. Due to the operational requirement of having the engine in place during shield installation and removal, all ideas using external lifting and insertion devices were abandoned. These methods used equipment which was bulky and interfered with the engine nozzle. Since the surrounding shielding is the governing factor in test module overall movement, the depleted uranium shield was discarded as its smaller thickness was of no advantage and its cost of fabrication is very high.

The concept adopted for this report is shown on Drawings 6552-4-ML-26 and ML-30, and may be described as follows:

The door is of aluminum construction and contains the equivalent of 6 in. of lead. It is approximately 158 in. in diameter, weighs about 50,000 lb, and is by-parting with a center lap joint to reduce streaming. The door halves ride on rails, and are retracted remotely by fluid driven actuators buried in the neutron shield tank.

When the engine is in operating position, the door halves are withdrawn into pockets built into the neutron shield tank. A study of the gamma heating of the shield will be performed for the final report. Water cooling will be provided if shown to be necessary.

The diffuser shield door is not designed to accommodate any added live loads, therefore, if it is necessary to work over this area, a structural cover is needed.

7.5 Exhaust Duct Outlet Door

The exit of the ejector section of the exhaust duct is exposed to the weather and requires a protective cover to prevent intrusion of foreign matter during periods of non-operation. In addition, strong winds and/or the chimney effect in the vertical duct would cause drafts that may carry radioactive particulate back up into the test pad area. Twelve days after shutdown from full power operation the level of radiation due to duct activation is not expected to exceed 25 mr/hr at a distance of 100 ft from the 90° elbow. It is apparent, therefore, that built-in shielding is not a requirement, and that no shield door is required at the exhaust end of the duct vault.

Three concepts of unshielded doors were considered:

1. Applying a small cover to the end of the duct opening.
2. Employing a large by-parting horizontal sliding door covering the entire vault.
3. A horizontal roll-up door covering the entire end of the vault.

All of these concepts use remote means to move them since it is necessary to close the door as soon as firing is completed. The roll-up door was discarded as it appeared that it would be extremely bulky since it must span 55 ft unsupported and resist 100 mph winds. The by-parting horizontal sliding door concept, whether shielded or unshielded, was discarded due to the large size requirements of approximately 70 ft high by 60 ft wide, with the associated mechanical operators. With the bottom of the ejector vault 40 ft below the canyon floor, additional earth retaining wall construction would be required to accommodate these doors. Also these doors would have to be protected from the thermal radiation of the exhaust plume. As the main requirement is to protect the ejector exhaust duct from foreign materials, the concept chosen utilizes a small hinged cover over the duct discharge, remotely operated from the main control room.

The work remaining will be to determine the materials of construction and the need for cooling due to the radiant heat flux from the exhaust plume.

7.6 Module Tank Mounting Clamps

The module tank is equipped with an aft skirt which serves three purposes:

1. Provide a sealing surface for altitude simulation.
2. Provide a handling and clamping structure.
3. Provide a mounting space for the engine umbilical connection.

This skirt and its special attachments are considered the interface between the facility designer and the module tank designer, and are capable of transmitting 20×10^6 in.-lb of moment to the supporting structure.

Concepts which were studied included various wedge locks, ball, pin and trunnion locks. Pull-down hooks and cams were also examined. The guidelines which governed the degree of acceptance of each method are as follows:

7.6 (Cont'd)

1. Simple geometric shapes
2. Minimize fabrication tolerance requirements
3. Reduce stresses on the skirt
4. Not require close alignment of skirt and holding devices
5. Minimize scuffing and galling at sliding surfaces
6. Limit the need for large amounts of materials which would be activated
7. Provide for the secondary hoist as mentioned under Section 7.2.2.
8. Maintain a secured condition without the application of power

In addition to the above, the clamps must provide a temporary locking function at the support structure during engine mate/demate and release to allow the module to be clamped to the shield tank during firing.

For this study, the concepts that appear to meet the requirements most satisfactorily are, six pull-down hooks which will secure the module skirt to the shield tank, and four trunnion locks which will hold the module tank temporarily to the support structure.

The shield tank clamp system selected for detailed consideration consists of a multiple number of hooks which swing in to engage the lower flange of the module tank skirt. A second independent motion is employed to pull the hooks down and clamp the skirt flange securely against the structure of the shield tank. All motions are powered by gaseous nitrogen driven air motors to minimize explosion hazard in the area of the skirt juncture where H_2 is likely to collect.

The reference design accommodates a module tank flange which is out-of-round as well as improperly centered on the stand, and still provides maximum flange engagement. This is essential since the narrow surface provided on the module skirt is subject to high stresses. The number of clamps is tentatively established at six, but this is subject to change depending on resulting flange stresses. This will be subject to review and approval.

The hook element selected is designed to apply its clamping force evenly without sliding over the aluminum flange and scuffing it. All load carrying elements are designed to carry the maximum overturning moment of 20×10^6 in.-lb in addition to 250×10^3 lb of engine thrust acting simultaneously. Since the clamps are located external to the neutron shield, it is not anticipated that radiation hardened materials will be necessary.

The four trunnion locks which secure the module tank to the support structure require the addition of four pins mounted at 90° spacing and permanently attached to the module tank skirt. These pins are engaged and held by power driven cams located on the support structure and utilize a toggle bar mechanism for locking. In this manner, each pin is held in a slotted cam which permits differential radial expansion without imposing stresses on the module tank skirt. The pin-in-a-slot concept also permits minimum tolerances on the location of each pin with respect to the tank center, but permits tight tolerances to be maintained between each pin and its mating slot.

All mounting clamps are arranged to perform their functions remotely from the main control console and are designed to maintain a secured condition without the application of power. In case of mechanical or power failure, they are operated manually by extension handles applied from outside of the shielded area.

Time will be spent in Phase II evaluating the secondary lifting method and other means of securing the module tank.

7.7 Flight Radiation Simulation Shield

A variable attenuation shield assembly will be designed and furnished as a part of the test item, not as part of the facility.

The variable shield is assumed to fit within the tank and/or engine envelope. The following assumptions regarding the variable shield were used:

1. Cooling either will not be employed. or it will be separate from the facility shield system.
2. It may be supported from the intermediate shield tank (called "upper shield" on Drawing 6552-4-ML-26) but not permanently attached to it.
3. Shielding may have to be remotely removed when the facility shield is retracted in order to obtain engine access.

In order to provide a support structure on the intermediate shield adequate for the variable shield, it will be necessary to assume a weight and volume envelope for the variable shield. This will be done during the remaining phase of the report period and will be subject to the review and approval of the engine and module tank contractors.

7.8 Umbilical Assemblies

The test module requires the connection of umbilical assemblies at the upper level as follows:

1. Instrument unit umbilical assembly
2. Module operations umbilical assembly
3. Service umbilical assembly

At the lower end of the module the connections consist of:

1. Lower tank umbilical assembly
2. Lower tank skirt umbilical assembly
3. Engine support umbilical assembly

Consistent with the Criteria document these connections must all be arranged for remote connection and disconnect. Personnel access is required at the point of umbilical connection to the test module to meet the L 2 exposure Criteria three days after shutdown. It is also required to maintain all umbilical connections during the interval when the module is either raised or lowered between firing position and engine mate/demate position. The interface between the test module and the facility occurs at the mounting surface for the umbilical connector plug half which mates to the test module, but does not include the plug.

Two umbilical assembly concepts were examined during the preliminary study. One concept employed a telescoping assembly which bridged the gap between the face of the test stand tower and the tank diameter at the point where it is closest to the tower face. The other concept employed an assembly which contacted the module tank at an angular position rotated 90° from the previous concept. This scheme required that the assembly pivot in a horizontal plane to clear the test module.

The telescoping assembly had two disadvantages:

1. It did not provide sufficient distance between the tower and the module to accommodate 4 ft of vertical movement of the connecting piping.
2. The telescoping walkway is more complex and expensive in comparison to the fixed length pivoting walkway.

On this basis, the telescoping assembly concept was discarded in favor of the pivoting design.

The concept selected has the following general characteristics:

Horizontal Swing:	8° (5-1/2 ft clearance to module)
Length:	40 ft
Height:	20 ft
Width:	7 ft
Approximate Weight:	35,000 lb, not including piping or shielding

The umbilical connections have an angular orientation 90° from the tower face.

The umbilical assembly provides a personnel walkway as well as provisions to carry all services to the module. The swing mechanism utilizes fluid power actuators located in enclosures on the tower face.

The lower umbilical connections do not require an arm since the support structure in this area can fulfill the function of providing a personnel walkway and support for the facilities. The umbilical head and its retraction mechanism is supported from the structure and access is gained by a ladder and platform allowing personnel to climb down from the support structure which is located above the umbilical area. The lower connections have the same angular orientation as the upper umbilical assemblies.

The stainless steel pipe lines in both umbilical assembly areas are subject to activation during engine operation. This problem coupled with the L 2 personnel access requirement will require additional study in order to establish the need for, and the extent of, neutron and gamma shielding along the arm. Additional trade-off studies will be needed in order to minimize shield weight which is particularly important on the upper umbilical assembly.

7.9 Electronics Rooms

The basic function of the Test Stand Electronics Room is to provide a terminal area to permit instrumentation and control interconnection between the module and the central control center. Other considerations, discussed in Section 14 of this report, were transposed into equipment space requirements (about 1,500 sq ft). However,

7.9 (Cont'd)

the structural concept made it feasible to subdivide the I & C equipment functionally assigned to a test stand into four separate electronics rooms. It should be emphasized that the utilization of these areas was the resultant and not the basis for the umbilical tower configuration.

The four electronics rooms are situated at four levels within each test stand. The lowest, the termination and battery room, is located at the tunnel entry; the pad level station provides a distribution point for test stand safety and facility systems; the engine level station provides for the connection of both the engine and lower tank umbilical assemblies; and the stage level station accommodates the connection of the equipment bay umbilical assembly and eventually, the instrument unit umbilical assembly.

The pad level, engine level and module level stations contain termination, patching, signal conditioning, amplifiers, multiplexers and digitizing equipment for the instrumentation and control system.

To reduce response time, the analog controllers are located at the appropriate electronics room. Controller set-point adjustments are provided by electrical signals hard lined to the control center.

The digital signals from the three upper levels of the umbilical tower are high level multiplexed in the termination room resulting in a single data transmission line to the control center. The cabling running from each tower level to the termination room is encased in shielded chase ways. Each tower level is equipped with a raised floor system to facilitate electrical interconnection of equipment. Positive pressure air conditioning provides both assurance against gaseous hydrogen encroachment and increased operational reliability of the electronic devices. The space requirements for the terminal station is 500 sq ft, the pad level station 200 sq ft, the engine level station 500 sq ft and the module level station 300 sq ft.

Nuclear shielding is provided to meet a 100 r total integrated dose during the anticipated testing program at E/STS 2-3. The amount of signal degradation anticipated by component damage is minimized provided this criteria is adhered to. Since most components have radiation tolerances in excess of 10^3 rads, it is anticipated that there will be no loss of test data even if the number of anticipated tests is greatly increased. There is no attempt in the present

7.9 (Cont'd)

concept to use radiation hardened components, and since all equipment will be of solid state design, it is deemed advisable that a conservative dose factor be used to ensure that all tests can be compared on a common basis without the effects of component degradation from radiation influencing the correlation of test data. All stations are provided with communication, oxygen detection, combustible gas detection, gamma radiation detection, and fire detection systems.

SECTION 8

EXHAUST SYSTEM

8.1 Diffuser and Ejector

The primary purpose of the exhaust system is to control the removal of effluent (hot gaseous hydrogen) from the engine and turbine and to preclude the entrance of air into the reactor after firing or sudden cessation of rocket exhaust. Secondly the exhaust system will provide altitude simulation for the nozzle and turbine exhaust during firing.

A series of diffuser/ejector combinations were evaluated to meet the design criteria. The diffuser/ejector system is intended to provide altitude simulation corresponding to a pressure of 2 psia or less at the engine exit with engine gimbaling and turbine exhaust discharge. This diffuser/ejector ducting system must operate safely with up to 35 mph winds by precluding the mixing of hydrogen and air in the system even with the sudden termination of engine flow. It must also be structurally adequate to operate maintenance-free through 100 cycles. Based on the literature survey, six basic combinations were considered as noted on Figure 8.1-1, to meet this Criteria.

Due to the complex flow structure and the varying gas state properties and gas composition (which is even complex in chemical rocket engines), an analytical solution for the design of diffusers supported by experimental data has not been developed. Simple one-dimensional analyses of diffuser designs require experimental substantiation since a comprehensive three-dimensional analytical solution has yet to be developed.

Diffuser designs should be based on similar configurations proved in operation or on experimental data obtained from accurate models. Therefore, for this program extrapolations have been restricted to size since scalability is one parameter that most experimenters accept as reasonable.

The fluid jet diffuser noted on Figure 8.1-1 falls in the future research category as an untried concept. Center body diffusers take advantage of a short second throat height and fixed length/diameter

POTENTIAL DIFFUSER / EJECTOR EXHAUST SYSTEM

SECOND THROAT DIFFUSER
SUBSONIC ELBOW
ANNULAR EJECTOR

CENTER BODY DIFFUSER
SUBSONIC ELBOW
ANNULAR EJECTOR

BENT TUBE DIFFUSER
SUPERSONIC ELBOW
ANNULAR EJECTOR

CENTER BODY DIFFUSER
DIRECT SPRAY COOLING
CENTER BODY STEAM EJECTOR

SECOND THROAT DIFFUSER
DIRECT SPRAY COOLING
CENTER BODY STEAM EJECTOR

FUTURE / RESEARCH
FLUID JET DIFFUSERS

FIGURE 8.1-1

ratio to obtain short diffuser lengths. However, for E/STS 2-3, heat transfer in the diffuser is the critical parameter. Existing data on stagnation point heat transfer and elbow heat transfer is meager and conflicting and does not at this time provide suitable basis for design of the system. Therefore, further consideration of center body diffusers is deferred until such data is available.

The three basic diffuser configurations analyzed are:

1. The straight second throat diffuser with a 90° subsonic elbow, all water jacketed.
2. The curved second throat diffuser (bent tube diffuser), all water jacketed.
3. The straight second throat diffuser water jacketed to the end of the second throat at which point the gas is cooled by direct water injection.

Configurations 1 and 2 which do not spray water into the engine exhaust gas but cool the walls by water jackets are referred to as dry systems. Configuration 3 which sprays water directly into the engine exhaust gas is referred to as a wet system.

Each of these configurations was analyzed to determine approximate dimensions, diffuser performance, water cooling requirements and secondary ejector requirements. A tube wall water jacket configuration was developed in order to better evaluate the fabrication costs associated with each configuration.

8.1.1 Diffuser Sizing

The diffuser inlet diameter was sized to accommodate a 112 in. inside diameter nozzle exit with a 40:1 area ratio, conical from the 25:1 area to the exit, the nozzle exit located slightly below the diffuser inlet, $\pm 1-1/2^\circ$ gimbaling with the rotational center 30 ft above the engine nozzle exit plane. The second throat diameter, conical contraction angle, and second throat length/diameter ratio (L/D) are empirically related to the inlet diameter. The basic diffuser configuration is shown on Drawing 6552-5-ML-27.

8.1.2 Diffuser Performance

The diffuser, as sized above, was analyzed to determine starting pressure ratio and cell pressure ratio. Figure 8.1-3 shows the diffuser performance with an atmospheric discharge. The engine to diffuser discharge pressure ratio, $P_t/P_e = 28$ would "start" or "pull-in" the diffuser when the engine pressure reached 358 psia and remain started during operation at higher pressures. This condition would not meet the criteria of maintaining a maximum cell pressure of 2 psia during startup and shutdown and of permitting engine operation at engine pressures down to 100 psia.

Figure 8.1-4 shows the effect on diffuser performance of adding a secondary ejector. The ejector shown would have the capacity of holding a pressure at the diffuser discharge of 2 psia with an engine weight flow of 52 pps. This would start the diffuser when the engine pressure reached 56 psia ($2 \text{ psia} \times 28$). In the range of engine pressures between 56 psia and 358 psia, the secondary ejector must operate to maintain a subambient discharge pressure at the diffuser exit.

The effect of turbine exhaust and seal leakage flow and varying second throat L/D on diffuser performance was predicted from data from Aerojet tests with similar systems. Figure 8.1-5 shows the estimated effect of turbine flow and seal leakage on diffuser performance for configuration 1 with a second throat $L/D = 8$. The effect of turbine exhaust flow, at 5 percent of engine flow discharged randomly into the cell, is to increase the cell vacuum pressure by a factor of about 4. Diffuser starting pressure ratio is also increased by leakage of low energy flow into the vacuum chamber. From Figure 8.1-5 it can be noted that the test cell pressure, although higher, has not exceeded the allowable 2 psia. The engine pressure at diffuser start is now 67 psia based on a corrected pressure ratio, $P_t/P_e = 33.5$ and the engine pressure at which the diffuser may discharge to ambient is now 429 psia.

The required ejector capacity to maintain the diffuser in the started condition during the engine transient is shown on Figure 8.1-6. The secondary ejector must be sized to have at least the pressure ratio shown. When the engine pressure reaches 429 psia as noted above, at which point the engine weight flow is 265 pps, the ejector flow can be reduced to idling. The performance of the diffuser/ejector system is shown on Figure 8.1-7.

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DIFFUSER PERFORMANCE

Figure 8.1-3

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DIFFUSER PERFORMANCE

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DIFFUSER PERFORMANCE

Figure 8.1-5

Figure 8.1-6

Figure 8.1-6

EXHAUST SYSTEM PERFORMANCE

FIGURE 8 1 - 7

Decreasing the L/D of the second throat has the effect of increasing the starting pressure ratio. A decrease from L/D = 8 to L/D = 4 raises the starting pressure ratio by 30 percent (Ref. Aerojet Report RN-S-0242, Figure 38). If an L/D of 4 in the second throat is used with configuration 1, the starting pressure would be 87 psia and require a larger secondary ejector capable of maintaining 2 psia at the diffuser exit with an engine flow of 70 lb/sec. This is about a 17 percent increase in required secondary ejector capacity. This ejector must maintain a pressure ratio across the diffuser of 43.6 or greater up to the diffuser atmospheric discharge condition at an engine pressure of 557 psia. This means the secondary ejector pumping would be required to within about 10 percent of maximum engine power.

Therefore, to minimize ejector size and hot gas generator capacity required a second throat L/D = 8 must be used. This conclusion also applies to configurations 2 and 3.

8.1.3 Diffuser Cooling

The maximum gas side heat transfer coefficients were computed for each section of the three diffuser configurations. The method of Aerojet Report No. RN-NR-0038 was used to compute these coefficients. It was found that the following metal wall thicknesses could be cooled within reasonable design limits:

- a. Inlet cylindrical section - all configurations = .095 in.
- b. Second throat-straight - configurations 1 and 3 = .095 in.
- c. Second throat-curved - configuration 2 = .025 in. ✓
- d. Subsonic elbow - configuration 1 = .060 in. ✓

From the above tabulated wall thicknesses it is obvious that in order to build a diffuser as large as the one shown in Drawing 6552-5-ML-27, the walls which are water cooled must be made of a special structure such as tubes to accommodate the thin walls required. The wall thickness in the curved second throat, configuration 2, are too thin to be handled and fabricated with any degree of reliability. Therefore, configuration 2 was dropped from further analysis.

The wet system, configuration 3, was an outgrowth of the thin wall elbow configurations as a way to add reliability to the structure. It consists of spraying water into the exhaust stream at the

exit of the second throat in sufficient quantity to saturate the hot hydrogen. This permits conventional, low temperature duct design in the subsonic expansion, elbow and secondary ejector. The water required to accomplish this cooling can be obtained from the cooling water jacket exit from the diffuser inlet and second throat sections. The main consideration here is atomizing and mixing the cooling water with the engine exhaust gas. The consequences of discharging a saturated, low energy exhaust into the atmosphere with the subsequent possible radioactive rain-out are uncertain. Therefore, further consideration of the wet system, configuration 3, was deferred until Phase II studies.

8.1.4 Secondary Ejector Requirements

As noted above, the secondary ejector must be capable of maintaining the required pressure ratio across the diffuser during operation of the engine. It must also evacuate the exhaust system during startup and shutdown maintaining a pressure not to exceed 2 psia and preclude the possibility of air entering the exhaust system during an abrupt stoppage of engine gas flow or purge conditions with a 35 mph wind into the end of the duct.

The diffuser discharge pressure which is also the secondary ejector inlet or suction pressure at varying engine gas flows required to maintain the correct pressure ratio across the diffuser is shown on Figure 8.1-6. As noted above, for weight flows in excess of about 265 lb/sec the diffuser discharge pressure is ambient (12.8 psia) and secondary pumping is not required to operate the diffuser. The ejector flow required during engine operation to preclude air entering the diffuser in the event of an abrupt stoppage of hydrogen flow with a 35 mph wind is about 1,350 pps. The required secondary ejector operating cycle is shown on Figure 8.1-8.

8.1.5 Basis for Design

Due to the high heat transfer rate in the ducting, an annular ejector was selected. The design procedure for annular secondary ejectors outlined in Aerojet Report No. RN-S-0242 was used with the following assumptions:

- a. Secondary ejector $L/D = 8$.
- b. $A_{sd}/A_{pe} = 1.62$ (per Aerojet Report No. RN-S-0242, pg. 74).
- c. Ejector manifold pressure $P_{sc} = 150$ psia.

FULL POWER OPERATING CYCLE

FIGURE 8.1 - 8

The secondary ejector configuration is shown on Drawing 6552-5-ML-27. Four ejector fluids were evaluated:

- a. Hydrogen - vaporized and heated in indirect heat exchangers.
- b. Hydrogen - vaporized and heated by a direct firing oxygen-hydrogen combustor.
- c. Hydrogen - vaporized and heated by a direct firing oxygen-propane combustor.
- d. Water - vaporized and heated by a direct firing oxygen-propane combustor.

Propane was selected only as a typical hydrocarbon fuel. The results of this evaluation would be applicable to other hydrocarbon fuels.

Ejector fluids a., b. and c. were selected to obtain a high temperature/molecular weight ratio (T/MW). For a. and b. T/MW is 400. For c. it was not possible to attain a T/MW of 400 with combustion, therefore, a $T/MW = 280$ was selected. For d. a $T/MW = 80$ was selected resulting in correspondingly higher secondary ejector mass flows.

8.1.6 Secondary Ejector Sizing

The effect of varying ejector inlet diameter on ejector flow rate and available diffuser pressure ratio was determined for a range of inlet diameters. Figures 8.1-9 through 8.1-12 present the available diffuser pressure ratio (P_t/P_e) as a function of secondary flow rate for a range of engine pressures (P_t). From these curves the secondary ejector size and flow rate can be determined to operate the diffuser down to the minimum required engine pressure.

Figures 8.1-9 through 8.1-12 can be read by entering the compression ratio of the diffuser on the ordinate of the upper chart, then proceeding horizontally to the line illustrating the minimum desired engine pressure (P_t), then dropping vertically to the abscissa where the quantity of secondary ejector flow is indicated. The same flow is then read on the abscissa of the chart below. The secondary ejector inlet diameter is obtained from the bottom chart.

Referring to Figure 8.1-12, it can be seen that for oxygen-propane with water dilution fluid, higher engine pressures size

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Figure 8.1-12

the inlet diameter. This is not the case for the low molecular weight fluids. For these an engine pressure of about 100 psia sizes the inlet diameter. Therefore, if a low molecular weight fluid is selected, a saving in required secondary flow rate can be realized if the engine can be started at a pressure of 150 psia instead of 100 psia. For all fluids, a slight decrease in required diffuser starting pressure ratio has an appreciable effect on secondary weight flow requirements. For example, reducing the pressure ratio from 46.5 to 33.5 reduces the secondary weight flow of the oxygen-propane with water addition fluid from 3,430 pps to 2,100 pps and this reduces the ejector inlet diameter from 175 in. to 135 in.

The effect of generator gas temperature on secondary ejector weight flow and pressure ratio was also evaluated for all four fluid combinations. In the case of heated H_2 , the weight flow increases as the square root of the temperature ratio,

$$\frac{W_2}{W_1} = \sqrt{\frac{T_1}{T_2}}$$

Figures 8.1-13 through 8.1-15 show the variation in gas flow rate with temperature for the other fluid combinations.

Referring to Figure 8.1-15, any decreases in temperature for the oxygen-propane with H_2O dilution fluid requires both a larger inlet diameter ejector and an increase in secondary weight flow. The other fluids can be reduced in temperature and only increase the weight flow requirements and not the ejector size. There probably is a limit in temperature reduction for a given ejector diameter, but this was not evaluated at this time.

The performance of the selected annular secondary ejector is shown on Figure 8.1-16 for the propane-oxygen water system in comparison to the pressure required to keep the diffuser started at a constant pressure ratio $(P_t/P_e) = 33.5$. The dotted curve is the same as shown on Figure 8.1-6. The actual performance using the above secondary ejector is the solid curve.

8.1.7 Ejector Cooling

The most severe heat transfer case was the ejector operating at the purge flow rate of 1,350 pps with an oxygen-propane, water

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Figure 8.1-13

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Figure 8.1-14

Figure 8.1-15

fluid at 1,680 R and a primary flow rate of hydrogen of 325 pps at 5,000 R. This condition can be handled with 2-1/2 in. diameter, 321 stainless steel tubes approximately .065 in. thick. Approximately 93,500 gpm of cooling water are required.

8.1.8 Ejector Safety Purge Requirements

The secondary safety purge flow rate is equal to the sum of the choked flow rate 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 required to prevent penetration of 35 mph air into the ejector. The purge flow for all fluid combinations is approximately 1,350 lb.

8.1.9 Diffuser/Ejector Configuration Revisions

During a review of the 5,000 mw dry diffuser, configuration 1, it became apparent that there was a significant difference in the proportions of the elbow compared to ETS-1. The elbow configuration was designed on the basis of allowable heat transfer rates. Therefore, an extensive review was made. Based on this review it was determined that a correction factor could be applied to the heat transfer coefficient which should result in significant differences in the allowable wall thickness and elbow radius. In Phase II, the changes will be evaluated.

8.1.10 Materials Selection

The materials for the exhaust system were based on the following considerations:

1. Heat transfer
2. Structural strength
3. Radiation activity
4. Corrosion
5. Cost

The high heat transfer conditions result in the need for a material with structural strength at high temperatures. This resulted in the selection of 321 stainless steel tubes for duct surfaces in contact with the hot test gas. The heat load is absorbed by coolant water flowing through the stainless tubes. The external surfaces, therefore, are cool. Mild steel was chosen for the external

cooling, water piping and the structural support members. The selection of mild steel was based on good low temperature structural strength, radiation activity substantially less than stainless steel, low cost and ease of fabrication. The reduced radiation activity (compared to 321 stainless steel and other 18-8 stainless steels) is due to reduced cobalt (impurities) and a smaller activation cross section.

Aluminum was considered as a possible structural material. In the ducting in contact with the high temperature gases, aluminum could not carry the high heat load. For cooler external structure, the higher cost of aluminum compared to mild steel was not warranted since the radiation from the stainless steel duct will be dominant.

One consideration in the design of the external water piping using mild steel is corrosion. This would tend to be inhibited by the relatively dry atmosphere at the site. Corrosion products in the piping are not particularly critical since no small openings which could clog are planned. To further reduce the corrosion between runs, consideration will be given to purging and filling the water piping with dry nitrogen gas.

8.1.11 Structural Design

The 5,000 mw diffuser-ejector exhaust system is physically divided into three major equipment items:

1. Diffuser
2. Elbow
3. Ejector

It is anticipated that the 10,000 mw growth system will be similarly divided. However, for installation and removal the growth equipment may be divided into subsections.

The three major equipment items are joined together forming a large single duct. The internal shape of the 5,000 mw system duct is defined on Drawing 6552-5-ML-27. Drawing 6552-5-ML-33 shows an exterior view of the "base configuration" as defined on Drawing 6552-5-ML-27 (5,000 mw engine at the diffuser inlet). The diffuser and elbow and the elbow and ejector are joined together with a remotely actuated clamping mechanism similar to the Aeroquip Corporation, Marman Division

8.1.11 (Cont'd)

"Conoseal" joint, Figure 8.1-18 (Aeroquip Drawing No. MJH 61048). Due to the large size of the joint, six to eight segments may be used in lieu of the four shown. The segments may be remotely actuated by high pressure nitrogen gas. The mechanisms may be made of stainless steel with non-gumming graphite type lubrication. The joint, once made, is not subject to axial loads as the vacuum in the duct puts the joint into compression.

The three major equipment items may be removed by remote operators. Actuation of the nitrogen cylinders (hydraulic shown in Figure 8.1-18) retracts the wedge clamps permitting the joints to separate in an axial direction. The diffuser can be raised vertically clearing the diffuser-elbow joint. The ejector can be moved horizontally clearing the elbow-ejector joint.

Remote actuation of the water and steam joints can be done in a similar manner. Close accuracy in handling is not required once the joints are cleared by a 3 to 6 in. movement and the equipment can be moved to a remote location as described under Section 7.2.3, Diffuser and Ejector Handling.

The initial alternative exhaust system configuration is illustrated by Figure 8.1-9 and Drawing 6552-5-ML-28. This configuration requires a 190 ft deep vault as compared to the 170 ft deep vault required for the base configuration. The equipment design and removal method is similar to that of the base configuration.

A configuration for a "growth" duct of 10,000 mw size is shown in Drawing 6552-5-ML-29. This design was generated for the vault space allocation only. It is based on an expansion of the base configuration modified by having a shorter radius, larger diameter elbow and a second throat $L/D = 4$. Preliminary critical diametric dimensions are shown. To permit minimum cost, it has been assumed that further design refinements will be available at the time the growth duct is designed.

Consequently, the diameters given in Table 8.1-1 for equipment size were established and used to size the concrete vault width and diameter. The vault height was established as 170 ft to match the current requirement for the 5,000 mw exhaust system.

8.1.11 (Cont'd)

TABLE 8.1-1SPACE ALLOCATION - EXTERNAL DIAMETER

5,000 mw diffuser	28 ft
10,000 mw diffuser expansion section	32 ft
Elbow	32 ft
Ejector	32 ft

The duct structure for the three equipment items is very similar. It consists of a bundle of small 321 stainless steel tubes welded longitudinally to adjacent tubes forming the circular interior wall of the duct. These tubes are cooled with water flowing at a high velocity through the tubes. As explained earlier in Section 8.1.3, the tube walls must be very thin to withstand the high heat flux. Consequently, the tubes must be held in the required position and the pressure loads taken by circumferential rings of carbon steel. On the elbow and the ejector where the bundle is subject to bending loads, the circumferential rings are supported by a longitudinal beam, see Section A-A of Drawing 6552-5-ML-33. The rings are supported by lugs at the horizontal centerline, riding in a channel groove which permits longitudinal temperature expansion and some differential expansion between the bottom and top of the duct. The longitudinal beams and their stiffening crosses and diagonal beams are designed for four points of support, two on each side, for both the ejector and the elbow, as shown on Drawing 6552-5-ML-33. These supports may be either rigid supports to the foundation or temporary supports to the removal transport equipment. Loading diagram for these supports are shown on Figure 8.1-22.

The order of magnitude oscillatory loads were calculated for the diffuser. The maximum pressure fluctuation of approximately 1 psi is expected to be in the middle portion of the diffuser second throat, see Figure 8.1-23. The loading change on the diffuser with an amplification factor of 2 will be about 16,000 lb or 4 percent of the diffuser weight. Figure 8.1-24 shows that the frequency of the maximum vibrating load is about 800 cycles/sec. The frequency-pressure relationship is shown in Figure 8.1-25.

The vibration loading in the ejector was not calculated since it is expected to be substantially smaller than the diffuser loading.

DIFFUSER DUCT
OSCILLATING PRESSURE VARIATION

FIG. 8.1-23

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DIFFUSER DUCT
PRESSURE AMPLITUDE VS. FREQUENCY (f_0)

FIG. 8.1-25

KAISER ENGINEERS
OAKLAND, CALIFORNIA

DIFFUSER DUCT
PRESSURE VARIATION FREQUENCY

FIG. 8.1-24

KAISER ENGINEERS
OAKLAND, CALIFORNIA

8.1.11 (Cont'd)

The vibration loadings are relatively noncritical unless structural resonance develops. The difference between the speed of sound in the cooling water and in the steel results in vibration damping. The cooling water tube local radial flexibility and the relative stiffness of tube bundle and the structural steel should also provide damping for the high velocity pressure fluctuations in the gas stream. It is expected that the actual amplification factor would be less than the factor of 2 used above.

A key detail design area is the assembly of the tube bundle and the support rings. Typical sections are shown on Drawing 6552-5-ML-33. Table 8.1-2 shows the tube diameter and wall thickness and ring spacing for the various portions of the duct. Joining of the tubes to form a tight pressure shell is a major fabrication activity. Both welding and brazing have been considered. Very precise temperature control is required when welding the thin tubes to prevent burning into the wall.

TABLE 8.1-2

DIFFUSER-EJECTOR TUBE SIZES
BASE CONFIGURATION

	Outside Diameter (Inches)	Wall Thickness (Inches)	Ring Spacing (Inches)
Diffuser Inlet	4 - ?	.095	48
Diffuser Convergent Section	4 to 3 - ?	.095	48 to 30
Diffuser Second Throat	3 - ?	.095	30
Diffuser Expansion Section	2-1/4 to 4 - ?	.095	24 to 48
Elbow Bend Section	1-3/8	.065	18
Elbow Taper Section	1-3/8 to 1-1/8	.065	12
Ejector Inlet Section - Exterior	4 - ?	.095	48
- Interior	3 - ?	.095	--
Ejector Main Section	2-1/2	.065 - ?	30

The Air Preheater Company has developed techniques for welding tubes with .095 in. walls and believe they can make a satisfactory weld with .065 in. wall tubes. However, the welds are limited to a size approximately the same as the wall thickness. The resulting

8.1.11 (Cont'd)

small weld while appearing satisfactory for the pressure seal and the circumferential restraint needed between rings, does appear to be somewhat vulnerable to tube flexing which may be caused by vibration and temperature growth. The complex analysis of this detail has not been completed.

Brazing of similar tube wall ducts has been satisfactory. Conseco, Inc. fabricated a tube wall diffuser for Aerojet-General Corporation with a 1/4 in. braze on .02 in. wall tubes of 1/2 in. diameter. Silicon bronze, .030 diameter wire was used as supplied by Western Welding. The weld has a 35-40,000 lb tensile strength. Welding is at 1,800 F, substantially lower than the melting point of 321 stainless steel tube. Consequently, a substantial juncture between the tubes can be made without risk of tube damage. The braze, or weld, will be placed on the back side, or outside, of the tube bundle where the braze or weld is protected from the hot gas, and therefore, unaffected by heat transfer size limitations. The braze alternative was used in the estimate.

The tubes will be butt welded into full length tubes. These butt welds must be very carefully controlled to obtain precise wall thickness without sharp protrusions. The tube wall thickness on the duct side, including the butt weld, is the major area where close tolerances will have to be maintained. The diffuser has conical sections. The number of tubes is kept constant throughout the diffuser inlet and throat. Consequently, the tube diameter must change. The diameter change may be accomplished by flattening the tube. It also may be accomplished by fabricating a tapered tube. The taper tubes (also the round tubes) may be made of butt welded rolled sheet. These longitudinal welds may be oversized with loose tolerances as the weld can be placed on the backside of the tube where wall thickness is not critical.

The spacing between ring supports, Table 8.1-2, was determined by the ability of each individual tube to withstand the pressure load as a beam between rings. The rather stiff junction between tubes may somewhat reduce the individual beam loading but no allowance for this effect was made at this time. The ring detail used for the estimate consists of two 1/4 in. mild steel plate rings brazed or welded to the tubes. A mild steel 8 in. x 5-1/4 in. wide flange beam rolled to diameter is welded to the plates (see Drawing 6552-5-ML-33). The structural steel, neutron shield, cooling water manifolds and headers will be of mild steel.

8.1.11 (Cont'd)

Consideration is being given to filling the water system with nitrogen between runs in order to reduce the corrosion to a minimum. The water manifold connections will be "Conoseal" or equal (see Figure 8.1-18). These connections will be operated remotely with nitrogen gas. The flexible joints in the connecting piping required for temperature expansion changes will permit withdrawing the piping and freeing the joints. It is anticipated that the water piping will be moved with nitrogen actuated cylinders. The water system piping required for the exhaust system is shown on Drawing 6552-5-P1.

The steam system manifold and piping on the ejector is similar to that of the cooling water except the material is 304 stainless steel.

The three major equipment items are too large to be shipped in one piece by railroad. A review of the RIFT Route Survey indicates a possibility of trucking the units from an Oceanside, California dock to the site. The loads would be overweight, overlength, and overheight. Their shipment as single units would entail highway widening and power line raising. Consequently, it is currently planned to assemble the units on site.

They can be installed in the vault in a manner similar to their removal. The removal transport equipment can be used for installation.

The long tubes and structural support members may be factory fabricated, partly assembled, and shipped to the site as segments. These can be shipped by rail or truck provided width and height are not excessive. The segments could be assembled in the field using large jigs. Tolerance on the duct diameter and out-of-round are very loose except at the joints and at the diffuser inlet. At these places the large flange and manifold sections can be used as jigs to hold the required tolerances, about $\pm 1/2$ in. In other portions of the duct, the diameter and out-of-roundness can vary several inches without affecting the function, thus permitting use of moderate cost (and tolerance) assembly fixtures.

8.2 Hot Gas Generator System

The oxygen-propane steam system was selected due to its lower installation cost and lower operating cost. Experience would indicate that a 300 lb/sec unit is about as large a unit as would be built. This would result in 7 units rated to generate 1,680 R steam at 200 psig. The molecular weight of the steam hot gas mixture is 21.

The generators operate on liquid propane and vaporized oxygen. In order to avoid the large cost of a conventional vaporizer a bootstrap method is utilized. Referring to Drawing 6552-7-P5, a small quantity of oxygen (roughly 0.5 percent of the total required) is vaporized in a conventional vaporizer and transferred to Preheater No. 1 where it is burned with propane. The hot gas products enter Preheater No. 2 and vaporize injected liquid oxygen. The mixed hot combustion gases containing excess vaporized oxygen then complete their combustion in Preheater No. 2. The volume and heat content of the gas is then sufficient to vaporize the remainder of the LOX feed in the LO₂ vaporizer.

It is anticipated that the generators would operate at two conditions, full on and standby. To reduce flow to idle flow, just sufficient to prevent introduction of a 35 mph wind into the duct, complete units would be turned off. The oxygen vaporizer system would of course modulate as the load varied.

A cost trade-off showed that a single hot gas generator system to feed both stands results in the minimum cost installation. The cost of steam generators at each stand would be about 50 percent higher than one generator with piping to both stands.

Figure 8.2-1 illustrates a typical test run based on a straight tube diffuser with $L/D = 8$, with a tube wall elbow and an ejector utilizing oxygen propane and steam as the hot gas driving fluid. Prior to engine start the ejector is placed on full flow. When chamber pressure reaches approximately 67 psia the diffuser starts and reduces the vacuum pressure at the engine discharge to approximately 0.2 psi. This pressure then rises in direct proportion to the engine chamber pressure to a maximum of approximately 1.5 psia with the engine chamber at 600 psia.

After the chamber pressure has reached the level at which it can hold the diffuser in operation without operation of the ejector,

(i. e., 33.5×12.8 psia atmospheric pressure = 429 psia), the ejector flow can be reduced to standby flow. Standby flow is sufficient to choke the second throat and prevent a 35 mph wind from entering axially into the exhaust duct if the engine flow were instantaneously cutoff. Standby flow is increased to full flow again one to two minutes before engine shutdown. After shutdown the generator flow is reduced to standby flow, 260 pps, sufficient to prevent wind entry, and held at this rate until completion of the 10 minute post-run period of liquid and gaseous hydrogen engine cooldown.

SECTION 9

CRYOGENIC FLUIDS

9.1 Introduction

Several concepts for the storage and transfer of cryogenic fluids were evaluated to meet the requirements of the design criteria. Drawings 6552-7-P1 through -P7 show the liquid storage and transfer piping required for the facility.

9.2 Requirements for Cryogenic Fluids

Liquid hydrogen is required for transfer piping and propulsion module cooldown, module fill, module topping, module connecting mode simulation and engine aftercooling. Liquid nitrogen is required for engine aftercooling and liquid oxygen and liquid propane are required for the gas generators that support the altitude simulation system. Small quantities of liquid propane are required for vaporizer firing. In addition to these propulsion module and facility liquid requirements, economic studies have indicated that facility and propulsion module gas requirements can, in general, be accommodated at lowest cost by the continuous conversion of liquid to gas. The facility liquid storage complex, shown on Drawing 6552-7-P7, accommodates the facility and propulsion module liquid requirements and the majority of the facility and propulsion module gas requirements. The gas conversion systems are described in Section 10, High Pressure Gas Systems; the liquid requirements are summarized in Table 9-1.

9.3 Storage and Transfer Concepts

The several concepts developed to satisfy each cryogenic liquid requirement are presented in Table 9-2; advantages and disadvantages are included under appropriate remarks.

9.3.1 Liquid Transfer

Liquid transfer by gas pressurization generally has been selected rather than transfer by pumping because of the greater inherent reliability of this type of system. Also because of the relatively short duration of operation, gas pressurization generally can be

TABLE 9-1

FACILITY AND PROPULSION MODULE LIQUID REQUIREMENTS

<u>Fluid</u>	<u>Requirement</u>	<u>Stored In</u>	<u>Total Quant.</u> <u>lb</u>	<u>Flow</u>
LH	Transfer Piping & Module Cooldown	V-LH-1 & V-LH-2	80,000	20-40 lb/sec @ 35 psia
LH	Module Fill	V-LH-1 & V-LH-2	240,000	100 lb/sec @ 24 psia
LH	Module Topping (Replace Boil-off)	V-LH-1 & V-LH-2	40,000	0.5-1.5 lb/sec @ 44 psia
LH	Module Connecting Mode Simulation	V-LH-1 & V-LH-2	355,000	300-330 lb/sec @ 44 psia
LH	Module Residuals	V-LH-1 & V-LH-2	12,000	-
LH	"Fast" Engine Cooldown	V-LH-4	10,000	90 lb/sec @ 250 psia
LH	Fill V-LH-4	V-LH-1 & V-LH-2	10,000	-
LH	"Emergency" Engine Cooldown	V-LH-9 (E/STS-2) V-LH-10 (E/STS-3)	800	140 lb/sec @ 600 psia
GH	Module Pressurization	V-LH-3	15,000	6 lb/sec GH @ 49 psia & 190 R

TABLE 9-1
(Cont'd)

<u>Fluid</u>	<u>Requirement</u>	<u>Stored In</u>	<u>Total Quant.</u> <u>lb</u>	<u>Flow</u>
GH	V-LH-1 & V-LH-2 Pressurization	V-LH-3	26,000	10.5 lb/sec GH @ 90 psia & 190 R
GH	V-LH-4 Pressurization	V-LH-3	2,000	10.0 lb/sec GH @ 315 psia & 190 R
GH	Module Purge	V-LH-3	7,000	0.5 lb/sec GH @ 25 psia & 530 R
GH	V-LH-3 Pressurization	V-LH-3	77,000	1.5 lb/sec GH @ 340 psia 190 R
GH	Engine Controls	V-LH-5	2,500	1.2 lb/sec GH @ 700 psia 530 R
LN	Engine Cooldown	V-LN-11	550,000	105 lb/sec @ 250 psia
LN	"Emergency" Engine Cooldown	V-LN-12	70,000	230 lb/sec @ 500 psia
GN	Altitude Sim. Sys., Equipment & Piping Purge	V-LN-11	51,000	95 lb/sec GN @ 50 psia 530 R
GN	Module Tank —Purge	V-LN-11	25,000	5 lb/sec GN @ 25 psia 530 R

TABLE 9-1
(Cont'd)

<u>Fluid</u>	<u>Requirement</u>	<u>Stored In</u>	<u>Total Quant.</u> <u>lb</u>	<u>Flow</u>
GN	Module Environmental Enclosure Purge	V-LN-11	5,000	2 lb/sec GN @ 16 psia 530 R
LN	Fill V-LN-12	V-LN-11	70,000	-
LO	Hot Gas Generators	V-LO-22	1,250,000	600 lb/sec @ 365 psia
LP	Hot Gas	V-LP-23	320,000	165 lb/sec @ 365 psia
GN	V-LN-11 Pressurization	V-LN-11	92,000	10.6 lb/sec @ 415 psia 530 R
GN	V-LO-22 Pressurization	V-LN-11	75,500	40 lb/sec @ 365 psia 530 R
GN	V-LP-23 Pressurization	V-LN-11	21,500	5 lb/sec @ 365 psia 530 R

TABLE 9-2
CONCEPT SUMMARY
LIQUID STORAGE AND TRANSFER

<u>Requirement</u>	<u>Concepts</u>	<u>Remarks</u>
Module Cooldown, Fill, Top, & Connecting Mode Simulation (Liquid Hydrogen)	Low Press Storage Pumped Transfer	Pump Costs High, Re- liability Questionable
	<u>Pressurized Transfer</u>	Selected Concept, In- crease in Dewar Costs Less Than Pump Costs, Reliability is High
	Single Large Dewar	Lowest Cost But Larger Than Fabricated to Date
	<u>Two 1/2 Capacity Dewars</u>	Selected Concept, Pro- vides Operational Advan- tages; Well Within State- of-the-Art
"Fast" Engine Cool Down (Liquid Hydrogen)	Low Press Storage Pumped Transfer	Pump Costs High, Re- liability Questionable
	<u>Pressurized Transfer</u>	Selected Concept, In- crease in Dewar Cost Much Less Than Pump Costs, Reliability is High
	<u>Common Dewar vs Separate Dewars for E/STS 2-3</u>	Common Dewar Selected, Extra Piping Cost Less Than Second Dewar Cost

TABLE 9-2
(Cont'd)

<u>Requirement</u>	<u>Concepts</u>	<u>Remarks</u>
Engine Cooldown (Liquid Nitrogen)	Low Press Storage Pumped Transfer	Lower Cost But Reliability Questionable For Critical Operation
	<u>Pressurized Transfer</u>	Selected Concept To Ensure Reliability For Critical Operation
	<u>Common 400 psi Dewar vs (1) 400 psi Dewar & (1) 100 psi Dewar</u>	Single Dewar Selected Since Incremental Cost Increase is Less Than 2nd Dewar Cost
"Emergency" Engine Cooldown (Liquid Nitrogen)	Low Press Storage Pumped Transfer	Higher Cost, Reliability Questionable
	<u>Pressurized Transfer</u>	Selected Concept, Lower Cost, Reliability is High
	<u>Common Dewar vs Separate Dewars For E/STS 2-3</u>	Common Dewar Selected. Extra Piping Cost Much Less Than Second Dewar Cost
Gas Generator Supply (Liquid Oxygen)	<u>Pressurized Transfer</u>	Preliminary Selection Of Pressurized Transfer Because of High Reliability
	Low Pressure Storage, Pumped Transfer	Requires Future Cost Trade-Off Study

provided at a lower cost than transfer pumping stations. The long duration 250 psi liquid nitrogen required for engine aftercooling and the liquid oxygen required for the gas generators can be accommodated at a lower cost by pumping. Further trade-offs between reliability and cost for each system are required before a final selection of liquid nitrogen and liquid oxygen transfer is made.

9.3.2 External Versus Self-Pressurization

External pressurization of the dewars has been selected rather than self-pressurization (gravity fed pressure building coils) because the liquid expulsion rates are such that high gas flow rates are required and gravity flow pressure building is impractical and uneconomical.

9.3.3 Dewar Capacity and Pressure Rating

The facility storage dewar sizes were based on given and calculated fluid usage quantities. The dewar pressure ratings were established by the maximum required end use pressure plus the system pressure losses. Since fluids are required at varying pressure levels, trade-off studies were conducted to determine the optimum break point between a dewar rated at a given pressure and other dewars rated at higher or lower pressures. Future detailed optimization studies may show that further economies can be achieved by shifting dewar pressure ratings and adjusting capacities.

9.3.4 Line Loss Trade-Offs

In general, major line sizes have been established as a trade-off between piping costs and dewar costs as a function of pressure rating. Future detailed optimization studies may indicate minor shifts in dewar pressure ratings and/or major transfer line sizes. The large dewars are particularly cost sensitive to small changes in pressure rating.

9.3.5 Dewar Insulation

Vacuum Perlite insulation has been selected for all cryogenic liquid storage dewars although a strict economic evaluation between equipment and operating costs can justify more sophisticated insulation. The selection represents a compromise

between less efficient and lower cost insulation that would materially increase operating costs. Operational procedures will be established and/or design features incorporated to avoid potential Perlite compaction problems.

9.4 System Description

9.4.1 Primary Liquid Hydrogen Storage (V-LH-1 and V-LH-2)

9.4.1.1 Dewar Configuration

The liquid hydrogen required for stage and transfer piping cooldown, module fill, module topping (boil-off make-up) and module connecting mode simulation is stored in two 650,000 gal, 75 psig, vacuum Perlite insulated, spherical dewars that are common to E/STS 2-3. The use of two dewars rather than one larger dewar provides operational advantages in that early generation tests that do not require connecting mode simulation can be accommodated by a single dewar. Furthermore, shorter duration tests can be accommodated at any time in the program with one dewar out of service for maintenance and/or repair.

A single dewar is adequate for module cooldown, fill and topping while the second dewar is adequate for module connecting mode simulation. These operational advantages will be evaluated in more detail to determine if the additional cost of approximately \$500,000 required to provide two dewars is warranted.

9.4.1.2 Dewar Piping

Each dewar is provided with a common connection for gas pressurization and venting. Gas pressurization is provided through a block valve and a pressure control valve. Venting is provided through a pair of block valves appropriately actuated by pressure switches sensing dewar ullage pressure; the vent manifolds are provided with parallel relief valves and rupture discs. Each dewar is provided with a common liquid withdrawal and fill connection. Withdrawal is accomplished through a 16 in. block valve and fill is accomplished through a 4 in. block valve.

9.4.1.3 Dewar Vacuum System

Each dewar is provided with a nominal 300 cfm, 15 hp vacuum pump (P-VA-3 and P-VA-4) connected to the dewar insulation space through a block valve.

9.4.1.4 Dewar Pressure Control System

Prior to the initiation of module fill, the dewars will be maintained at a slight positive pressure by the periodic venting of the gas generated by heat in leakage through the walls of the dewar. Upon initiation of module fill, the dewar pressure in a single selected dewar will be programmed to a nominal 60 psig by the admission of gas through the dewar pressure control valve. This pressure will be maintained until the module is full as sensed by a module tank high level control system. At this time, the dewar pressure will be reduced and maintained at a pressure sufficient to provide topping flow to the module. Upon initiation of rapid flow for connecting mode simulation, the dewar pressure in the second dewar will be gradually increased by a stage level control system until the liquid flow to the stage balances the liquid flow from the module. At the conclusion of a run, the pressure in the dewars will be released to permit the return to storage (V-LH-1 or V-LH-2) of any residual liquid in the module tank.

9.4.2 Other Liquid Hydrogen Storage (V-LH-3, 4, 5, 9, 10)

9.4.2.1 Dewar Configuration

All liquid hydrogen requirements other than the primary propellant requirement are serviced by vacuum Perlite insulated dewars as listed below:

<u>Use</u>	<u>Net Capacity</u>	<u>Working Pressure</u>
"Fast" Engine Cooldown (V-LH-4)	24,000 gal.	300 psig
"Emergency" Engine Cooldown (V-LH-9 & V-LH-10)	1,500 gal.	650 psig
Facility and Propulsion Module Gas (V-LH-3)	100,000 gal.	325 psig
Gas For Engine Controls (V-LH-5)	5,000 gal.	750 psig

Each dewar serves both E/STS 2-3, except the emergency engine cooldown dewars. One dewar is provided for each stand since the cost of the second dewar is less than the cost of the additional piping required if a common dewar was used to serve E/STS 2-3.

9.4.2.2 Dewar Piping

Each dewar is provided with pressurization, vent, and liquid fill and withdrawal piping and valving similar to that described for the primary liquid hydrogen storage dewars.

9.4.2.3 Dewar Evacuation System

Each dewar is evacuated through a block valve that connects to a manifold evacuated by a vacuum system (P-VA-5) common to all hydrogen dewars but the primary hydrogen storage dewars.

9.4.2.4 Dewar Pressure Control System

Prior to preparation for test, the dewars will be maintained at a slight positive pressure by the periodic venting of the gas generated due to heat in leakage through the walls of the dewars. Prior to test, the pressure will be increased to the required operating pressure by admitting gas through the pressure control valves.

9.4.3 Primary Liquid Nitrogen Storage (V-LN-11 and V-LN-12)

9.4.3.1 Dewar Configuration

The lower pressure liquid nitrogen required for engine cooldown is stored in a 150,000 gal., 400 psig, vacuum Perlite insulated spherical dewar common to E/STS 2-3. Economic studies have also indicated that the gaseous nitrogen required for facility pressurization and for facility and propulsion module purge can be accommodated with the lowest cost by storage in this dewar with conversion to gas as required. The dewar is sized to provide sufficient nitrogen gas for all requirements under 400 psig. The liquid nitrogen required for "emergency" engine cooldown is stored in a 12,000 gal., 550 psig vacuum Perlite insulated dewar common to E/STS 2-3.

9.4.3.2 Dewar Piping

Each dewar is provided with pressurization, vent, liquid fill and withdrawal piping similar to that described for the liquid hydrogen dewars.

9.4.3.3 Dewar Evacuation System

Each dewar is evacuated through a block valve that connects to a manifold evacuated by a vacuum system (P-VA-8) common to all liquid nitrogen dewars.

9.4.3.4 Dewar Pressure Control System

Prior to preparation for test, the dewars will be maintained at a slight positive pressure by the periodic venting of the gas generated due to heat in leakage through the walls of the dewars. Prior to test, the pressure will be increased to the required operating pressure by admitting gas through the pressure control valve.

9.4.4 Liquid Oxygen Storage (V-LO-22)

9.4.4.1 Dewar Configuration

The liquid oxygen required to support the gas generator system (see Section 8 - Altitude Simulation System) is stored in a 140,000 gal., 350 psig, vacuum Perlite insulated, spherical dewar common to E/STS 2-3.

9.4.4.2 Dewar Piping

The dewar is provided with pressurization, vent, liquid fill and withdrawal piping similar to that described for the liquid hydrogen dewars.

9.4.4.3 Dewar Evacuation System

The dewar is provided with a nominal 140 cfm, 5 hp vacuum pump (P-VA-10) connected to the dewar insulation space through a block valve.

9.4.4.4 Dewar Pressure Control System

The dewar pressure control system will operate as described for the liquid nitrogen storage dewars (V-LN-11 and V-LN-12).

9.4.5 Transfer Piping

9.4.5.1 Liquid Hydrogen

All liquid hydrogen piping to the propulsion module and all pump section piping is vacuum insulated to ensure high quality liquid at the use point. Vent valves are provided as required for pipe cooldown and to maintain liquid at the final block valve upstream of the use point. Noncritical liquid hydrogen piping is sufficiently insulated to preclude the formation of liquid air. Shut off valves up to 8 in. are of the Y-globe type; shut off valves over 8 in. are of the ball or butterfly type.

9.4.5.2 Liquid Oxygen and Liquid Nitrogen

All liquid nitrogen piping to the propulsion module will be adequately insulated to ensure high quality liquid at the use point. Vent valves are provided as required for pipe cooldown and to maintain liquid at the final block valve upstream of the use point. Noncritical liquid nitrogen and liquid oxygen piping is sufficiently insulated to avoid vapor choking of the lines. Shut off valves up to 8 in. are of the Y-globe type; shut off valves over 8 in. are of the ball or butterfly type.

9.4.5.3 Test Stand Isolation

Each liquid line that serves both test stands is isolated by double block valves connected in series with an intermediate bleed to prohibit accidental flow to an idle test stand.

9.5 Materials of Construction

9.5.1 Dewars

The dewar inner vessels are constructed of stainless steel and the outer vessels are constructed of carbon steel. Aluminum inner vessels could be provided with a cost savings of approximately \$400,000. However, recent experiences with aluminum

inner vessels indicate that operational problems may arise due to leakage in piping transition joints (aluminum to stainless steel) and therefore aluminum is not selected for the inner vessel material at this time. Further investigation may show that the operational problems have been eliminated, thus warranting the selection of the lower cost aluminum.

9. 5. 2 Piping

All vacuum jacketed piping is constructed with invar or stainless steel inner piping and stainless steel outer piping. All non-vacuum jacketed liquid piping will be stainless steel or aluminum.

9. 5. 3 Valves

All cryogenic valves will be constructed of aluminum or stainless steel.

9. 5. 4 Filters

All cryogenic filters will be constructed of aluminum or stainless steel.

9. 5. 5 Vacuum Pumps

All vacuum pumps will be standard commercially available units.

9. 6 Cryogenic Fluid Unloading

9. 6. 1 Liquid Hydrogen

An unloading station for the simultaneous transfer of liquid hydrogen from six trailers to the storage dewars is provided. Transfer by self-pressurization of the supply trailers is assumed.

9. 6. 2 Liquid Nitrogen

An unloading station for the simultaneous transfer of liquid nitrogen from two trailers to the storage dewar is provided. Transfer by self-pressurization of the supply trailers is assumed although future consideration will be given to providing facility pumps for unloading.

9. 6. 3 Liquid Nitrogen

An unloading station for the simultaneous transfer of liquid oxygen from two trailers to the storage dewar is provided. Transfer by

self-pressurization of the supply trailers is assumed although future consideration will be given to providing facility pumps for unloading.

9.7 Phase II Work

9.7.1 General

Phase II studies will be oriented towards reducing cost and improving operation and reliability.

9.7.2 Equipment Arrangement

Particular emphasis will be placed on studying alternative equipment arrangements that are consistent with the siting criteria but reduce the length of major piping runs and, therefore, also reduce the piping costs.

9.7.3 Single Versus Dual Primary Liquid Hydrogen Dewars

The operational advantages of the dual primary hydrogen dewars (V-LH-1 and V-LH-2) will be evaluated in detail to determine if the increased cost over a single larger dewar is warranted.

9.7.4 Common Versus Separate Dewars

The selection of common versus separate dewars in the similar capacities (V-LH-4 and V-LN-12) will be evaluated in detail with regard to equipment and piping costs.

9.7.5 Dewar Material

The use of lower cost aluminum for the dewar inner vessels will be investigated in detail.

9.7.6 Line Loss Versus Dewar Pressure Rating

Further detailed trade-off studies will be conducted to determine if increased dewar operating pressures coupled with reduced transfer line sizes will result in overall cost savings.

9.7.7 Transfer By Pumping

Detailed consideration will be given to the transfer of liquid oxygen and liquid nitrogen by pumping rather than by gas pressurization.

SECTION 10

HIGH PRESSURE GAS SYSTEMS

10.1 Introduction

Several concepts for the storage and transfer of purge, pressurization and cooling gases were evaluated to meet the requirements of the Design Criteria. Drawings 6552-7-P1 through P-7 show the gas systems and indicate the flows and pressures required.

10.2 Gas Requirements

Moderate to high pressure gaseous hydrogen, helium and nitrogen are required for propulsion module and facility use. Gaseous hydrogen is required for module purge and pressurization, for module and engine controls, for engine cooldown and for facility dewar pressurization. Gaseous nitrogen is required for module tank and environmental enclosure purge, for altitude chamber and diffuser purge, for facility piping and equipment purging and inerting, for facility dewar pressurization and for instrumentation and valve actuation. Gaseous helium is required for engine and insulation purge and for emergency engine cooldown. The facility and propulsion module gas requirements are summarized in Table 10-1.

10.3 Storage and Transfer Concepts

10.3.1 General

Economic studies have indicated that substantial savings in equipment costs can be effected by storing the fluid required in liquid rather than gaseous form with conversion to gas by heated vaporizer assemblies upon demand. This concept has generally been applied in the design of the facility. Where mechanical equipment is required, redundancy has been included in the design to ensure uninterrupted operation in the event of a malfunction. The several concepts developed to satisfy each gas requirement together with advantages and disadvantages and appropriate remarks are presented in Table 10-2.

TABLE 10-1
FACILITY AND PROPULSION MODULE
GAS REQUIREMENTS

<u>Fluid</u>	<u>Requirement</u>	<u>Produced By</u>	<u>Total Quant.</u> <u>lb</u>	<u>Flow</u>
GH	Stage Pressurization	C-LH-1 or C-LH-2	15,000	6 lb/sec @ 49 psia & 190 R
GH	Stage Purge	C-LH-1 or C-LH-2	7,000	0.5 lb/sec @ 25 psia & 530 R
GH	Engine Controls	C-LH-4	2,500	1.2 lb/sec @ 700 psia & 530 R
GH	Stage Controls	V-GH-8 (Stored as Gas)	600	0.5 lb/sec @ 500 psia & 530 R
GH	"Fast & Normal" Engine Cooldown	V-GH-8 (Stored as Gas)	200	20 lb/sec @ 250 psia & 530 R
GN	Stage Tank Purge	C-LN-6 or C-LN-7	25,000	5 lb/sec @ 25 psia & 530 R
GN	Stage Environmental Enclosure Purge	C-LN-6 or C-LN-7	5,000	2 lb/sec @ 16 psia & 530 R
GHe	Engine Purge	V-GHe-16 through V-GHe-21 (Stored as Gas)	1,000	1 lb/sec @ 65 psia & 530 R
GHe	Insulation Purge	V-GHe-16 through V-GHe-21 (Stored as Gas)	600	1 lb/sec @ 15 psia & 530 R
GHe	"Emergency" Engine Cooldown	V-GHe-16 through V-GHe-21 (Stored as Gas)	20,000	165 lb/sec @ 1250 psia 530 R

TABLE 10-1
-- (Cont'd)

<u>Fluid</u>	<u>Requirement</u>	<u>Produced By</u>	<u>Total Quant.</u> <u>lb</u>	<u>Flow</u>
GH	V-LH-1 & V-LH-2 Pressurization	C-LH-1 or C-LH-2	26,000	10.5 lb/sect @ 90 psia & 190 R
GH	V-LH-4 Pressurization	C-LH-1 or C-LH-2	2,000	10.0 lb/sec @ 315 psia & 190 R
GH	V-LH-3 Pressurization	C-LH-3 & P-LH-1 or P-LH-2	7,700	1.5 lb/sec @ 340 psia & 190 R
GN	V-LN-12 Pressurization	V-GN-14 & V-GN-15 (Stored as Gas)	12,000	28 lb/sec @ 565 psia & 530 R
GH	V-LH-5 Pressurization	V-GH-8 (Stored as Gas)	500	0.2 lb/sec @ 765 psia & 530 R
GN	V-LN-11 Pressurization	C-LN-8 or C-LN-9 & P-LN-6 or P-LN-7	92,000	10.6 lb/sec @ 415 psia & 530 R
GN	V-LO-22 Pressurization	C-LN-6 or C-LN-7	75,500	40 lb/sec @ 365 psia & 530 R
GN	V-LP-23 Pressurization	C-LN-6 or C-LN-7	21,500	5 lb. sec @ 365 psia & 530 R
GN	Alt. Sim. Sys. Equipment and Piping Purge	C-LN-6 or C-LN-7	51,000	95 lb/sec @ 50 psia & 530 R
GN	Valve Act. Misc. Purge Contingency	V-GN-14 & V-GN-15 (Stored as Gas)	38,000	-
GHe	V-LH-6 & V-LH-7 Pressurization	V-GHe-16 through V-GHe-17 (Stored as Gas)		-

TABLE 10-2CONCEPT SUMMARY GAS STORAGE AND TRANSFER

<u>Requirement</u>	<u>Concept</u>	<u>Remarks</u>
Stage Press. (Gaseous Hydrogen)	High Press. Gas Storage, Cool W/LN ₂	High Storage Cost, High Operating Cost
	<u>Liquid Storage and Vaporization</u>	Low Cost Storage
	<u>Separate Low Press Storage vs Combining with other Higher Pressure Require- ments</u>	Combined Concept Selected since Incre- mental Dewar Cost is Less than Separate Dewar. Also Higher Pressure Reduces Pipe Size
Stage Purge (Gaseous Hydrogen)	Same as Stage Pressurization	
Engine Controls (Gaseous Hydrogen)	Continuous Pumping and Vaporization	Requires Two Units with High Cost Reli- ability Questionable
	High Press. Gas Storage	Highest Cost
	<u>High Press. Liquid Storage and Vaporization</u>	Selected Concept Be- cause of Lowest Cost
Stage Controls (Gaseous Hydrogen)	Continuous Pumping and Vaporization	High Cost, Reliability Questionable
	<u>High Press. Gas Storage</u>	Quantity Small; there- fore Cost is Nominal. Selected Concept
	High Press. Liquid Storage and Vaporization	Could Reduce Cost if Combined with Engine Controls. Requires Further Investigation

TABLE 10-2
(Cont'd)

<u>Requirement</u>	<u>Concept</u>	<u>Remarks</u>
"Fast & Normal" Engine Cooldown (Gaseous Hydrogen)	Continuous Pumping and Vaporization	High Cost, Reliability Questionable
	<u>High Press. Gas Storage</u>	Selected Concept Quantity is Small; therefore Cost is Nominal, Most Reliable for Critical Operation
V-LH-1, V-LH-2 Pressurization (Gaseous Hydrogen)	High Press. Liquid Storage and Vaporization	High Cost Due to High Flow Rate
	Gravity Fed Vaporizer (Press. Bldg Coil)	Vap. Cost High Due to Low ΔP & High Flow Required
	High Press. Gas Storage	Very High Cost Due to Large Quantity Req'd
	<u>Separate Higher Press. Liquid Storage and Vaporization</u>	Selected Concept Because of Significant Cost Savings
V-LH-4 Pressurization (Gaseous Hydrogen)	Gravity Fed Vaporizer (Press. Bldg Coil)	Vap. Cost High Due to Low ΔP & High Flow Req'd
	High Press. Gas Storage	High Cost Due to Significant Quantity Req'd
	<u>Separate Higher Press. Liquid Storage & Vap.</u>	Selected Concept Because of Significant Cost Savings
	<u>Combine Liquid Storage W/Liquid Storage & Vap. for V-LH-1 & 2 Press. & Stage Pressurization</u>	Preliminary Selection Although Cost Penalty is Incurred due to Increasing Press. Beyond that Req'd. for V-LH-1 & 2 and Stage Req't's. Further Investigation Req'd.

TABLE 10-2
(Cont'd)

<u>Requirement</u>	<u>Concept</u>	<u>Remarks</u>
V-LH-3, Pressurization (Gaseous Hydrogen)	Gravity Fed Vaporizer (Press. Bldg. Coil)	Flow Might be Low Enough to be Feasible. Requires Further In- vestigation.
	High Press. Gas Storage	High Cost Due to Sig- nificant Quantity Req'd.
	Separate Higher Press. Liquid Storage & Vaporizer	High Cost Although Might be Combined with Engine Controls. Re- quires Further Investi- gation.
	<u>Self Pressurization by Booster Pumping & Vap.</u>	Selected Concept. Low Vaporizer Cost Be- cause Pumps Provide Adequate ΔP .
V-LH-5 Pressurization (Gaseous Hydrogen)	Gravity Fed Vaporizer (Press. Bldg. Coil)	High Cost
	<u>High Press. Gas Storage</u>	Selected Concept. Cost is Nominal Due to Small Quantity Req'd
	Separate Higher Press. Liquid Storage & Vaporizer	High Cost for Low Quantity Required
V-LH-6 & V-LH-7 Pressurization (Gaseous Helium)	High Press. Gas H ₂ Storage	Line Not Available Cost Increases to Run Line
	<u>High Press. GHe Storage</u>	Line Available as Part of Same "Emergency" Cooldown Req't. Selected Concept

TABLE 10-2
(Cont'd)

<u>Requirement</u>	<u>Concept</u>	<u>Remarks</u>
	Gravity Fed Vaporizer	High Cost Due to High Flow
	Separate Higher Press. Liquid Storage & Vap.	High Cost for Small Quant. Req'd. Not as Reliable for Critical Operation
Facility, Stage, Environmental Enclosure, Alt. Simulation System Purge (Gaseous Nitrogen)	High Press. Gas Storage	High Cost Due to Large Quantities Required
	<u>Liquid Storage & Vaporization</u>	Selected Concept Due to Significant Cost Savings
	<u>Combine with Engine Cool-down Storage</u>	Selected Because of Least Cost.
V-LO-22 & V-LO-23 Pressurization (Gaseous Nitrogen)	High Press. Gas Storage	High Cost Due to Large Quantities Required.
	<u>Liquid Storage & Vaporization</u>	Selected Concept Due to Significant Cost Savings
	Combine with Engine Cool-down Storage	Preliminary Selection Although Cost Penalty is Incurred Due to Higher Press. Required for this Use. Requires Further Investigation.
V-LN-11 Pressurization	Gravity Fed Vaporizer (Pressure Bldg Coil)	Might be Feasible Due to Higher Density of LN. Requires Further Investigation

TABLE 10-2
(Cont'd)

<u>Requirement</u>	<u>Concept</u>	<u>Remarks</u>
	High Press. Gas Storage	High Cost Due to Large Quantities Required
	Separate Higher Press. Liquid Storage & Vaporizer	High Cost
	<u>Self Press. By Booster Pumps and Vaporizer</u>	Preliminary Selection Because Pumps Provide Adequate ΔP Through Vaporizer
V-LN-12 Pressurization	- Gravity Fed Vaporizer (Pressure Bldg Coil)	High Cost Due to High Flow Required
	<u>High Press. Gas Storage</u>	Selected Concept Since Costs are Nominal Due to Small Quantities Required
	Separate Higher Press. Liquid Storage and Vap.	Higher Cost for Small Quantities Required

10.3.2 Storage Concept

The concept of liquid storage with conversion to gas upon demand was selected over conventional high pressure storage for economic reasons. A cost savings in excess of \$3,000,000 is indicated.

10.3.3 Line Loss Trade-Offs

In general, major line sizes have been established as a trade-off between piping costs and dewar costs as a function of pressure rating. Future detailed optimization studies may indicate minor shifts in dewar pressure ratings and/or major transfer line sizes. The large dewar (V-LH-3) is particularly cost sensitive to small changes in pressure rating.

10.3.4 Booster Pumping Versus Gravity Flow

Booster pumping prior to vaporization has been selected rather than gravity flow through the vaporizer to generate gas flow for the self-pressurization of the secondary liquid hydrogen dewar (V-LH-3) and the primary liquid nitrogen dewar (V-LN-11).

Economic studies have shown vaporizer cost increases substantially exceed the cost of the booster pumping systems when designed for low pressure loss. Future emphasis will be placed on investigating alternative concepts that do not depend on booster pumping.

10.4 System Description

10.4.1 Hydrogen Gas Distribution Systems

10.4.1.1 325 psi Distribution System

Hydrogen gas at 325 psi is provided for pressurization of the primary liquid hydrogen (V-LH-1 and V-LH-2) and "fast" engine cooldown liquid hydrogen (V-LH-4) dewars, for stage pressurization and for stage purge. The gas is stored at 325 psi liquid in the 100,000 gal. secondary liquid hydrogen storage dewar (V-LH-3) and supplied to a pair of redundant 25,000,000 Btu/hr propane fired vaporizers (C-LH-1 and C-LH-2). The gas is distributed through control valves to the various use points.

10.4.1.2 325 psi Secondary Dewar Pressurization

A portion of the liquid withdrawn from the secondary dewar (V-LH-3) is boosted in pressure by a pair of redundant (one operating) circulating pumps (P-LH-1 and P-LH-2), vaporized in a 5,000,000 Btu/hr propane fired vaporizer (C-LH-3), and returned through a control valve to the dewar to maintain the required pressure in the dewar ullage. The pumps provide pressure head through the vaporizer and gas piping. Surge tanks (V-GH-6 and V-GH-7) sized to provide a one-minute transition from the operating to the standby pump are provided. The gas pressure upstream of the dewar pressure flow control valve is maintained by bleeding liquid from the pump discharge back to the storage dewar.

10.4.1.3 750 psi Gas Distribution System

Hydrogen gas at 750 psi is provided for open loop supply to the engine control system. The gas is stored as 750 psi liquid in the 5,000 gal. secondary liquid hydrogen storage dewar (V-LH-5) and supplied to a 10,000,000 Btu/hr propane fired vaporizer (C-LH-4). The gas is supplied to the propulsion module umbilical interface through a flow control valve.

10.4.1.4 750 psi Dewar Pressurization

The 750 psi secondary liquid hydrogen storage dewar (V-LH-5) is pressurized by gas supplied through a flow control valve from a 240,000 SCF, 3,500 psi, gaseous hydrogen storage tank (V-GH-8).

10.4.1.5 3,500 psi Gas Distribution System

Hydrogen gas for engine cooldown, open loop stage controls, and 750 psi secondary storage dewar pressurization is stored as gas at 3,500 psi (V-GH-8). The gas is distributed through flow control valves to the various use points.

10.4.1.6 3,500 psi Gas Storage Fill

The 3,500 psi storage tank (V-GH-8) is filled by a 10,000 SCFH converter assembly (C-LH-5) (recharger) that draws liquid from the 300 psi secondary liquid hydrogen storage dewar (V-LH-3).

10.4.2 Nitrogen Gas Distribution Systems

10.4.2.1 400 psi Gas Distribution System

Nitrogen gas at 400 psi is provided for stage, environmental enclosure, altitude simulation system and miscellaneous facility purge, and for pressurization of the liquid oxygen and liquid propane storage tanks. The gas is stored as 400 psi liquid in the primary liquid nitrogen storage dewar (V-LN-11) and supplied to a pair of redundant 37,000,000 Btu/hr propane fired vaporizer (C-LN-6 and C-LN-7). The gas is distributed through control valves to the various use points.

10.4.2.2 400 psi Primary Dewar Pressurization

A portion of the liquid withdrawn from the primary dewar is boosted in pressure by a pair of redundant (one operating) booster pumps (P-LN-6 and P-LN-7), vaporized in a pair of redundant 5,000,000 Btu/hr propane fired vaporizer (C-LN-8 and C-LN-9) and returned through a control valve to the dewar to maintain the required pressure in the dewar ullage. The pumps provide pressure head through the vaporizer and gas piping. A surge tank (V-GN-13) sized to provide a one-minute transition from the operating to the standby pump are provided. The gas pressure upstream of the dewar pressure flow control valve is maintained by bleeding liquid from the pump discharge back to the dewar.

10.4.2.3 6,000 psi Gas Distribution System

Nitrogen gas for engine cooldown dewar pressurization and for miscellaneous purge and valve actuation is stored as gas at 6,000 psi (V-GN-14 and V-GN-15). The gas is distributed through flow control valves to the various use points.

10.4.2.4 6,000 psi Gas Storage Fill

The 6,000 psi storage tank is filled by a 72,000 SCFH converter assembly (C-LN-10) (recharger) that draws liquid from the 400 psi primary liquid nitrogen storage dewar (V-LN-11).

10.4.3 Helium Gas Distribution System

10.4.3.1 5,000 psi Gas Distribution System

Helium gas for emergency engine cooldown, 600 psi emergency LH_2 dewar pressurization and engine and insulation purge is stored as gas at 5,000 psi (V-GHe-16 through V-GHe-21). The gas is distributed through flow control valves to the various use points.

10.4.3.2 5,000 psi Gas Storage Fill

The 5,000 psi storage tank is filled by a pair of high pressure diaphragm compressors (P-GHe-8 and P-GHe-9) that take suction from commercial delivery trailers through a purifier assembly (F-GHe-1). The compressor inlet pressure is maintained constant by a control valve. Provision to bypass the compressors for initial pressure equalization between the supply trailers and the storage tanks (V-GHe-16 through V-GHe-21) is incorporated in the design.

10.5 Test Stand Isolation

Each gas line that serves both test stands is isolated by double block valves connected in series with an intermediate bleed to prohibit accidental flow to an idle stand.

10.6 Hydrogen Gas Disposal

10.6.1 Burn Pond

All hydrogen gas is collected and transferred to a common burn pond for safe disposal. The burn pond is sized for a minimum disposal rate of 150 lb/sec. The pond is fired with diesel oil with a propane gas pilot.

10.6.2 Storage Complex Disposal

Hydrogen vent gas in the storage complex area is collected in a 12-in. line and transferred to the burn pond.

10.6.3 Test Stand Disposal

Hydrogen vent gas at each test stand is collected and transferred in a 36-in. line to the burn pond. The 36-in. line also serves to drain liquid hydrogen under emergency conditions from the stage at an average rate of 6,670 gpm.

10.7 Materials of Construction

10.7.1 High Pressure Storage Vessels

The high pressure gas storage vessels are of multi-layer carbon steel construction. Storage vessels operating at temperatures below -20 F are of aluminum or stainless steel construction.

10.7.2 Piping

Gas piping that operates at normal temperatures is carbon steel. Gas piping exposed to temperatures below -20 F is stainless steel or aluminum. All piping downstream of the filter regulator stations to the test stands are stainless steel.

10.7.3 Valves

Valves that operate at normal temperatures are carbon steel. Valves exposed to temperatures below -20 F are stainless steel or aluminum. All valves downstream of the filter regulator station are stainless steel.

10.7.4 Filters

All filters are stainless steel body with sintered cloth elements.

10.8 Gaseous Helium Unloading

An unloading station for the simultaneous transfer of gaseous helium from four tube trailers to the storage vessels and/or the compressors is provided.

10.9 Phase II Work

10.9.1 General

Phase II studies will be oriented towards reducing cost and improving operability and reliability.

10.9.2 Elimination of Booster Pumping

Alternative concepts for the pressurization of the main hydrogen gas storage dewar (V-LH-3) that eliminate the booster pumps (P-LH-1 and P-LH-2) will be evaluated.

10.9.3 Fast Engine Cooldown Dewar (V-LH-4) Pressurization

Alternative concepts for the pressurization of the Fast (LH₂) engine cooldown dewar will be evaluated. The elimination of this pressurization requirement by the conversion of liquid stored in the main gas storage dewar (V-LH-3) would permit a reduction in the design operating pressure of this dewar with a resultant decrease in cost.

10.9.4 Equipment Arrangement

Particular emphasis will be placed on studying alternative equipment arrangements that are consistent with the siting criteria but reduce the length of major piping runs and, therefore, reduce the piping costs.

SECTION 11PROCESS WATER SUPPLY SYSTEM

The objective of this system is to supply cooling water for the diffuser and other equipment and deluge water for the stand and cryogenic storage area at the pressures and in the quantities developed during Phase I design.

Among the system arrangements considered were:

1. Use of one storage tank for deluge storage and one for cooling water as opposed to a single larger tank. The two tank scheme was found to be \$136,000 greater in first cost and was therefore rejected.
2. Using a common tank for deluge and cooling water, two discharge systems were considered:
 - a. A single line supplying both deluge and cooling water to the facility site.
 - b. Separate lines for deluge and cooling water. Under system b. the cooling water line would have its intake set at such a distance above the bottom of the storage tank that it would be impossible to withdraw cooling water from the fire protection reserve. The decision was made, however, that fire reserve could be maintained by proper operational procedure, i. e. valving the cooling flow at the end of a test so the fire reserve is not jeopardized. A single line (scheme a.) withdrawing water from the tank bottom was therefore used in the Phase I design.
3. Consideration was given to providing elevated storage at the plant site as opposed to a hillside tank with a long connecting pipe line. An elevated tank of 22,000,000 gallon capacity on 300 ft steel legs was determined to be impractical and was therefore rejected.
4. A plant site ground level tank supplying gravity feed to the suction of large booster pumps was considered. Since emergency electrical power for these units was out of the question, diesel

engine drive was investigated. The pumped scheme was found to be \$2,700,000 greater in first cost than the scheme using the hillside tanks and was rejected.

5. A once-through scheme from wells was considered to be impractical because of the large quantities of water required (390,000 gpm) and the relatively small capacity of the two existing wells (800 to 1,000 gpm).

The system under consideration at the end of Phase I provides gravity flow through a 102 in. diameter pipe from a 22,000,000 gallon hillside storage tank set at an elevation sufficient to provide gravity supply at the required operating water pressure at the test stands. The tank is filled from existing water Well J-13 by a new booster pump at the well and a new surge tank and booster pump at the facility site pumphouse fed by a new 10 in. water line. The new surge tank also serves as a storage tank for the pumped domestic water system complete with its own distribution system. The booster pumps are sized to fill the hillside tank in 22 days, satisfying the criteria turnaround time of 30 days with an eight day allowance for possible down time of the booster pumps. The 22,000,000 gallon tank is sized as shown in the following table:

		<u>gal.</u>
Fog (vault exit)	3,500 gpm x 45 min =	157,500
Diffuser ejector cooling	390,500 gpm x 45 min =	17,572,500
Alum. shields (vault exit walls)	8,500 gpm x 45 min =	382,500
Test stand deluge	26,400 gpm x 30 min =	792,500
Storage area deluge	24,250 gpm x 10 min =	242,500
Steam generator cooling	14,000 gpm x 58 min =	812,000
Steam generator injection water	10,780 gpm x 30 min =	323,400
Diffuser cooldown (post test)	-	<u>1,600,000</u>
Storage Capacity Total		21,882,900

The stored test water is undesirable for drinking because it is dead storage, permitting growth of organisms, and also because it chlorinated at a higher rate than drinking water to avoid slime growth in the test water systems. Domestic water is therefore supplied separately as described above.

It is possible that a new well may be required if the continuous plant air conditioning load plus storage tank refill rate exceeds existing well

capacity. This is being investigated in Phase II. (The estimate includes the capital costs of a new well and booster pumps to supply once-through air conditioning cooling water.)

During Phase II the following features of the process water system storage tank will be investigated:

1. Optimization of the line size from the tank to the site. This involves costs of pipe line, road to water tank, and control wiring to water tank as the tank location varies in response to varying line diameter.
2. Investigation of possible economy in the pumped scheme by use of geared jet engines as drivers.
3. Investigation of requirement for new well.

SECTION 12MISCELLANEOUS FACILITY SUPPORT AND UTILITY SYSTEMS

The nature of the tests, development activities, normal operations, and maintenance performed at the E/STS 2-3 complex requires augmentation of the process systems with a net of support and utility systems. Sketches of these systems that include equipment requirements, materials, and major line sizes were developed to use as the basis of the preliminary cost estimate. Outline specifications will be included in the final report. These support and utility systems are defined in the following paragraphs.

12.1 Cooling Water

Cooling water systems are required to remove heat from the various items of operating equipment. Once-through, recirculation, and recovery systems were considered for this service. A recirculation system was discarded because of the reduced reliability and the extremely high cost of pumps, power, and cooling tower for such a large system. A recovery system was discarded because the cost of the water clean-up equipment, piping, and pumps, which in part would duplicate the necessary facility supply pumps, would more than offset the incremental cost increase for larger facility supply pumps and piping for once-through cooling systems. The once-through systems are selected on the basis of cost, simplicity, and reliability. A distinction is made here to differentiate the cooling water systems from the deluge systems which incorporate both cooling and fire protection features and are defined separately. Water is supplied to the cooling water systems from the facility process water supply system, which is discussed in Section 11, and is routed within the local areas to points of use. Each area is supplied with cooling water to meet the following requirements.

1. Diffuser/ejector cooling - 390,500 gpm. Storage allocation - 30 minutes during test plus 15 minute post-test cooldown.
2. Steam generator cooling - 14,000 gpm. Storage allocation - 15 minutes pre-test, 30 minute test run, and 13 minute post-test cooldown.

3. Equipment bay service umbilical connection - 0.6 gpm.
(Criteria document requirement).
4. Concrete cooling (subjected to nuclear radiation) - none.
Storage allocation - none.
5. Engine shield tank cooling - none for 5,000 mw engine.
Storage allocation - none.
6. Air conditioning units - 900 gpm, continuous demand.
7. Mechanical equipment (i. e. , compressors, etc.) - 50 gpm,
intermittent demand.

The cooling water flows to those items associated with a test run are controlled by the test programmer. Flows required by other facility equipment are regulated by the associated equipment requirements.

Work in Phase II will include studies to reduce the continuous demands on the cooling systems including the cost and suitability of cooling towers, and further investigation of the 10,000 mw engine requirements which may affect the initial design.

12.2 Deluge Water

Deluge water systems are required to provide external cooling and fire protection to several areas of the test complex. Water is supplied to the deluge systems from the facility process water distribution system as discussed in Section 11. The deluge systems are designed on the basis of three rates of coverage and for the areas of coverage as shown below:

1. 5 gpm per sq ft for LH₂ and LOX unloading stations. The area sprayed is the plan area of the unloading manifolds from the delivery vehicles to the facility piping.
2. 1 gpm per sq ft for the following:
 - a. The module supporting structure - envelope surface.
 - b. Test stand surfaces exposed to the test module.

- c. Test module umbilical assemblies - envelope surface.
 - d. Diffuser vault exit and surrounding walls - cross-sectional area.
3. 0.5 gpm per sq ft for the following:
- a. LH_2 storage tanks - total surface area.
 - b. LH_2 vaporizers and converters - total surface area.
 - c. GH_2 storage - total surface area.
 - d. LOX storage - total surface area.
 - e. Module propellant tank - total surface area.

The activation of all deluge systems is either automatic (by sensors) or manual from local or remote control stations.

For the purpose of sizing the water storage tanks and supply piping, it is predicted that the deluge systems may be activated for the following periods:

- 1. Test stand area systems - 30 min. (simultaneous with test).
Storage allocation of 792,500 gal.
- 2. LH_2 and LOX areas - 10 min. (after a test).
Storage allocation of 242,500 gal.
- 3. Vault exit and surrounding walls (fog spray) - 45 min. (simultaneous with test and H_2 cooldown).
Storage allocation of 157,500 gal.

Work in Phase II will include further investigation of methods of application of deluge water to the module propellant tank.

12.3 Fire Protection Water

A fire protection water system is required to provide hose stations for the local application of water to small fires within areas of the facility. Water is supplied to the fire protection system from the facility process water distribution system. Each hose station is designed to handle a flow of 100 gpm and is provided with 50 ft of 1-1/2 in. hose, hose rack, and a 1-1/2 in. combination nozzle which delivers either a straight stream jet or a fog blanket. These stations are provided at each level in the test stand areas and throughout the control center. Adequate water storage allocation for fire protection is included for the deluge of the cryogenic storage area and no additional storage is required for intermittent small fires.

12.4 Steam Generator Injection Water

The operation of the steam generator requires injection water. The maximum supply rate is 9,800 gpm at 350 psig.

Water storage is allocated for the following operations:

1. Start-up period - 5 min. at average of 1/2 maximum flow.
2. Start-up period - 10 min. at maximum flow.
3. Test period - 30 min. at 1/2 maximum flow.
4. Cooldown period - 3 min. at maximum flow.
5. Cooldown period - 10 min. at average of 1/4 maximum flow.

This requirement is met by boosting the pressure of the facility water (100 psig) by means of three diesel engine driven booster pumps. Diesel engine drives were selected for reasons of economy. Electric drives would require power from the essential and critical power systems and would more than double the cost of the emergency generator station plus considerably higher costs for the main complex substation, for the required switchgear, and for the electrical distribution system.

The pumps are sized so that each can handle 50 percent of the maximum load (900 hp each). During normal operation each pump will be operating at 66 percent of its required capacity. If one pump fails the other two will operate at their full required capacity.

Work in Phase II will include the investigation of gas turbine drives for the booster pumps.

12.5 Shield Water System

A shield water system is required for the preparation and transfer of a borated solution to the engine shield. Raw water from the facility process water mains will be mixed with boron chemicals in a batch type operation. Two 1,000 gal. mixing tanks are furnished to provide a continuous flow of solution to the shield. A 150 kw electric water heater is furnished in the water supply to warm the water sufficiently for rapid and continuous solubility of the boron chemicals. One 50 gpm transfer pump and a stand-by complete the mixing facility which is located to serve both test stand shield tanks. A piping system distributes the borated solution to the two radiation shields which are connected to the piping by means of flexible connections capable of taking up the vertical movement of the shields. Vent and overflow piping is provided to ensure the complete filling and make-up for the shields. Preliminary calculations show that the shield tank will not cool down between 30 day tests in its retracted position so provision is made to drain the shields between tests and refill with fresh solution. The cost of chemicals only for refilling the shield tank is approximately \$4,000.

Work in Phase II will include investigation of liquid boron solutions that can be introduced into the water by eductors or metering pumps in lieu of batch mixing, and trade-off studies for cooling the borated water in lieu of replacing the inventory.

12.6 Domestic Water

Domestic water is required for the control center, test stands, storage area, gas generation area, support shop building, and gate house. It is supplied from the facility distribution system. This water is routed within these areas to serve the drinking fountains, toilets, showers, and safety showers. The safety

showers are located in the cryogenic storage areas, cryogenic unloading stations, gas generation area, test stands, and at the chlorination equipment. The estimated peak demand is 120 gpm and the daytime normal is 30 gpm. This system design is in accordance with Chapter 5, Interior Utilities, of NASA Facility Publication - NPC 325-1, April 1965, Design Criteria and Construction Standards.

12.7 Plant Air

A plant air system is required to provide service air for maintenance tools and for instrument air service in the control center. It is estimated that 500 scfm of 100 psig air is needed to supply the facility requirements. Two compressors are sized to handle 250 scfm each, their operation is fully automatic with provisions for three step unloading. Each compressor is furnished with an aftercooler. The system includes an air receiver and a control panel common to both compressors.

Of the service air, 50 scfm is diverted to dual absorption filters and dual tower dryers for use in controllers and operators located within the control center. The outgoing instrument air will have a dew point of -20 F at pressure. The plant air is distributed to hose stations in the control center, service tunnels, test stands, electronic rooms, steam generation plant, cryogenic storage area, support shop, and the water pumping station. This system design is in accordance with Chapter 4, Exterior Utilities, of NASA Facility Publication - NPC 325-1, April 1965, Design Criteria and Construction Standards.

Work in Phase II will include a more accurate determination of the air system requirements.

12.8 Gaseous Nitrogen for Facility Use

Gaseous nitrogen is required for two facility uses in addition to the test process. These uses are for the control systems and for the inert gas purging and pressurizing of sparking devices in hazardous areas. The control systems gas operates at two pressure levels: 500 psig and 100 psig. The inert purge and pressurization gas systems operate at 0.5 psig. The supply of all gaseous nitrogen for these systems is from the 1,000 psig test process system. Distribution of the gases to the areas of use is as described below.

1. The 500 psig nitrogen systems are supplied directly from the 1,000 psig test process nitrogen gas systems through pressure reducing valves. These systems are routed throughout the process areas to supply operating gas to the large or high pressure valve operators and to remote disconnect operators.
2. The 100 psig nitrogen systems are supplied from the 500 psig nitrogen systems through pressure reducing valves. These systems are routed throughout the process areas to supply operating gas to the small or low pressure valve operators and where required for pneumatic signals.
3. The 0.5 psig nitrogen systems are supplied from the 100 psig nitrogen systems where available or from the 500 psig nitrogen systems through pressure reducing valves. These systems are routed throughout the hazardous (H_2) areas to supply inert purge and pressurizing gas to the enclosures of sparking devices.

In order to ensure the maximum degree of system reliability, all pressure reducing stations consist of redundant parallel valving.

Work in Phase II will include further investigation of the requirements and sizing of these systems.

12.9 Fuels

There are three separate fuel systems required for the facility support operations:

1. The propane gas system for the cryogenic fluid vaporizers which is defined elsewhere in this report.
2. The diesel fuel system for the emergency power system.
3. The diesel fuel system for the hydrogen burn pond igniters and the diesel engine drives for the gas generator injection water pumps.

The diesel fuel system for the emergency power generator consists of a 42,000 gal. underground storage tank with a gravity fill station and piping to the generator set. This capacity is based on a 10-day supply at a 2.9 gpm use rate. Transfer pumps are included as part of the generator package.

The diesel fuel system for the burn pond igniters and the gas generator injection water pump drives consists of a 15,000 gal. underground storage tank with a gravity fill station, transfer pumps, and distribution piping to the points of use. This capacity is based on a 10-day supply at a normal continuous use rate of 1 gpm for the burn pond igniters (14,400 gal.), plus 2 gpm for 70 min. of additional igniter flow during an emergency hydrogen dump period (140 gal.), plus 5 gpm for the water injection pump drives for 45 minutes during a test period (225 gal.). The transfer pumps, one operating and one standby, are sized for 10 gpm at 150 psig to satisfy the combined requirements of the igniters and the injection pump drives.

Work in Phase II will include a review of these systems to confirm consistency with the equipment served.

12.10 Carbon Dioxide

Fire protection is required for the electronic rooms in the test stands. This protection is provided by total CO₂ flooding of the enclosed area. The CO₂ system is sized to provide 1 lb of CO₂ per 12 cu ft of space to be protected. The system is provided with all standard accessories required for fully automatic or manual operation and with the delay and alarm devices required to ensure complete personnel protection, all in accordance with Chapter 5, Interior Utilities, NASA Facility Publication - NPC 325-1, April 1965, Design Criteria and Construction Standards and NEFU Pamphlet No. 12.

Consideration was given to the use of CO₂ flooding of the electronic equipment room in the control center. This concept was discarded because of the personnel hazard of releasing such a large quantity of CO₂ in building occupied by so many people, especially during a test when access is limited and the presence of personnel is mandatory. Portable CO₂ extinguishers, not included in facility cost estimate, will be used for fire protection in the control center electronic equipment and control rooms.

Work in Phase II will include further study of the CO₂ storage and distribution systems at the test stands to satisfy the needs of the selected test stand arrangement.

12.11 Sanitary Sewers

Sanitary sewers are required in the inhabited structures within the facility. The sanitary sewage from the control center and from test stand 3 is collected in a gravity system that flows to the facility lagoon which is defined elsewhere in this report. The sanitary sewage from test stand 2, the support shop building, and the gate house flows by gravity to individual septic tanks. The sewers within each building are designed in accordance with Chapter 5, Interior Utilities, NASA Facility Publication - NPC 325-1, April 1965, Design Criteria and Construction Standards. Effluents from the test stand decontamination operations are collected in separate systems and flow by gravity to a retention pond for decay of radioactivity and controlled release to the natural drainage channels.

12.12 Heating and Ventilating

All facility buildings require heating, ventilating, or air conditioning systems to ensure safe, clean, and appropriate comfort or process environment with controlled air flow during all phases of facility operation. These systems are designed to satisfy three conditions of facility operation:

1. Normal conditions when no testing or emergency exists.
2. Testing period.
3. Emergency periods when a nuclear or combustible gas incident has occurred which would create a hazardous condition to personnel or equipment.

These systems, equipment, and controls, where applicable, conform to the requirements of Chapter 5, Interior Utilities, NASA Facility Publication - NPC 325-1, April 1965, Design Criteria and Construction Standards.

12.12.1 Control Center Air Flow

During normal operations and test periods, outside make-up air is drawn through a filter plenum located at the mouth of the control center emergency exit tunnel by two 6,000 cfm air handling units that are located in the control center equipment room. These blowers supply make-up air to the air conditioning systems to maintain the control center at a positive pressure to prevent the infiltration of radioactive particles or combustible gases. Exhaust air from the control center is allowed to exfiltrate into and pressurize the tunnels leading to the test stands where it is relieved to atmosphere through relief dampers except during test or emergency periods.

During emergency conditions when sensors detect nuclear activity or combustible gases in the air supply, intake dampers and relief dampers close automatically and the make-up air handling units stop. The air conditioning units continue to operate and recirculate air in the control center for equipment cooling and personnel comfort. Limited make-up air at the rate of 700 cfm is then introduced from 300 psig air storage to supply the minimum ventilation need for 100 people for one hour (sufficient to permit evacuation of unnecessary personnel), plus 35 cfm to supply five people for two days (minimum crew to operate the facility for reactor cooldown or until the emergency is over). Trade-off studies of air storage at 100, 300, and 2,000 psig indicate that the equipment costs (compressor and receivers) for 300 psig storage is \$40,000 less than 100 psig storage and \$25,000 less than for 2,000 psig storage. Two 350 cfm booster fans are provided at the control center to supply pressurization air through the tunnel air locks to the test stand areas during test and emergency periods.

Air conditioning of the control center is provided in the following manner. One outside air unit conditions 6,000 cfm of make-up air to take care of lighting and personnel loads in the instrumentation equipment and control rooms. This air is supplied to the rooms through a low velocity duct system and ceiling diffusers. The equipment in these rooms is cooled by two 16,000 cfm air handling units supplying air through a pressurized underfloor plenum. This air is withdrawn through the ceiling return plenum, along with the make-up air, for recirculation by the air handling units. The second outside air handling

unit conditions 6,000 cfm of make-up air for two 10,000 cfm air circulation units serving all other areas of the control center through low velocity ducts to ceiling diffusers. Air is returned from these areas via the ceiling return air plenum for mixing with make-up air and recirculation.

All air handling units are the draw-through type, single zone units consisting of a filter section, an electric heating unit, a chilled water coil section, and a fan section. In addition, the outside air units are provided with a humidifier section of the water spray type. Two 100-ton standard water chillers, factory assembled, reciprocating compressors, shell and tube water cooled condensers, and direct expansion type coolers plus two 250 gpm chilled water circulation pumps are provided to satisfy the present capacity requirements. All equipment is located in the control center mechanical equipment room. Space is allowed in the equipment room for a future 30-ton chiller, a future 16,000 cfm air handling unit, and a future 75 gpm chilled water circulation pump to accommodate a 50 percent load growth factor for the electronic equipment and control rooms. The air ducting is sized to accommodate the future loads.

12.12.2 Test Stand Air Flow

During normal maintenance and preparation periods for testing, outside make-up air is ducted through dampers to mix with recirculation air to the air handling units located in the equipment rooms of the test stands. Exhaust air is allowed to exit through relief dampers to atmosphere.

During test periods or when sensors detect nuclear activity or combustible gases in the air supply, intake dampers and relief dampers close automatically. The air handling units continue to run and recirculate air to cool the operating equipment. Pressurization of the equipment rooms is maintained by blowers located in the control center with air flowing through the tunnels to the stands and through connecting ducts within the stands.

Air conditioning (equipment cooling) for the equipment rooms in the test stands and for the Instrument, Equipment, and Environmental Bay on the propulsion module is provided in the following manner. Two 25-ton water chillers and two 65 gpm chilled water circulation pumps are located in the test stand

mechanical equipment room. These units supply chilled water to all air handling units in the test stand. The air handling units for the electronic equipment are separate units for each room and are located at the tunnel level, at the pad level, at the engine umbilical level, and at the upper umbilical level. These units are sized at 960 cfm, 1,900 cfm, 5,700 cfm, and 2,600 cfm respectively. The air handling unit for the decontamination (health physics) room is located in the mechanical equipment room and is sized for 900 cfm. The air handling unit for the mechanical equipment room and the electrical equipment room is a single unit located in the mechanical equipment room and is sized for 5,000 cfm. The air handling unit for the Instrument, Equipment, and Environmental Bay is located at the upper umbilical level and is sized for 1,200 cfm. The discharge of this last unit is ducted directly to the umbilical connection on the Environmental Bay and does not operate during test periods but is purged with gaseous nitrogen at this time.

All air handling units are the draw-through type, single zone units consisting of a filter section, an electric heating unit, a chilled water coil section, and a fan section. The chillers are standard factory assembled, reciprocating compressors, shell and tube water cooled condensers, and direct expansion type coolers. Space is allowed in the mechanical equipment room for a future 15-ton chiller and a future 40 gpm chilled water circulation pump to accommodate a 50 percent load growth factor for the electronic equipment.

12.12.3 Miscellaneous Buildings

Air conditioning, heating, and ventilation are supplied for miscellaneous facility buildings as shown below:

1. Gate House - 2.5-ton, packaged heat pump air conditioning unit, and electric heaters.
2. Support Shop - 2.5-ton packaged heat pump air conditioning unit, and electric heaters for the office and toilet area, gravity ventilation in the remainder of the building.
3. Cryogenic Area Office - electric heater and gravity ventilation.

4. Cryogenic Area Substation - forced ventilation.
5. Camera Bunker - forced ventilation during periods of occupancy, sealed at all other times.

12.12.4 Phase II Work

Work in Phase II will include reevaluation of the proposed schemes to satisfy the needs of the selected control center and test stand arrangements, investigations of alternatives for air supply during emergencies such as GFE air packs or supply from a safe distant source, and a cooling tower for cooling the air conditioning units.

SECTION 13POWER DISTRIBUTION SYSTEM13.1 Functional Requirements

The electrical power system for the E/STS 2-3 complex is required to supply the connected loads with the quantity and quality of power required and with a degree of reliability consistent with the operations being performed to meet the objectives outlined in the E/STS 2-3 Criteria document.

The degree of reliability required for the electrical loads varies according to their functions and the loads can generally be divided into the following classes:

a. Essential Loads

Those loads which, if interrupted, would cause shutdown of a test in progress with a subsequent loss of test data and objectives.

b. Critical Loads

Those loads which, if interrupted, would create a hazard to life or property by preventing safe shutdown and/or cooldown of the propulsion module under test.

c. Nonessential Loads

Those loads which, if interrupted, would result only in minor inconvenience or delay.

To meet the requirements of the Criteria document, the electrical power system shall:

a. Be connected to existing systems at NRDS

b. Have provisions for electrically independent emergency power

- c. Have provisions for regulated essential power, electrically independent of the utility power system
- d. Be equipped with necessary monitoring, grounding, switching, and operating instrumentation and controls.

13.2 System Arrangement

Alternative arrangements of power supplies and distribution have been evaluated to establish the optimum system which will meet the functional requirements and criteria for the complex and which will conform to NASA Design Criteria and Construction Standards NPC 325-1.

The selected system consists of a commercial power supply from the NRDS system; an emergency, or backup, diesel engine-driven generator arranged to operate in parallel with, or independent of, the commercial power supply; distribution switchgear and feeders segregated into "essential" and "non-essential" systems; load-center substations and low voltage distribution for the various facilities; all necessary supplemental equipment, devices and circuits required to complete the systems; and critical power supplies for critical loads.

The power distribution system is arranged as shown on the Normal and Emergency Power One-Line Diagram, Drawing 6552-8-E1. Critical power supplies are not shown on this diagram but are described in paragraph 13.2.4 Critical Power, page 13-5.

Ratings of equipment and circuits are based on preliminary calculations of electrical loads including allowances for load growth. In general, capacity is included for approximately 50 percent load growth in all areas, with additional allowances where necessary to provide standby, or backup.

13.2.1 Commercial Power Supply

Commercial power for the NRDS area is supplied at 138 kv, 3 phase, 60 cycles to the Jackass Flats Substation where it is stepped down to 69 kv and 12.5 kv for transmission to the NRDS facilities.

Commercial power for the E/STS 2-3 complex at the Fortymile Canyon site will be supplied from existing 69 kv line "T" by tapping this line near the ETS-1 site and constructing a new line to a substation for E/STS 2-3.

Consideration was given to tapping the 138 kv transmission line scheduled for construction by AEC-NVOO to run from the Jackass Flats Substation, passing near the Fortymile Canyon Site and continuing to the Nevada Test Site north of NRDS. A 138-69-12.5 kv substation would be constructed at the point of the line tap, a 69 kv line would be provided to the substation for E/STS 2-3, and a 69 kv line would be constructed to tie into existing 69 kv line "T" near ETS-1 to form a 69 kv loop circuit back to Jackass Flats Substation. The 12.5 kv service would be available to provide a tie-in to the existing 12.5 kv line to Well J-13 to convert this circuit to a loop back to Jackass Flats Substation.

This arrangement of substations and circuits would improve the reliability of service to existing NRDS facilities as well as to E/STS 2-3, but the cost would be on the order of \$400,000 more than the cost of extending the 69 kv service for E/STS 2-3 from the ETS-1 area. It was considered that this excess cost is not applicable to the E/STS 2-3 project alone and further consideration of this arrangement was abandoned. It should be noted, however, that the 69 kv line extension from ETS-1 can be used for the loop circuit in the future if a 138-69-12.5 kv or 138-69 kv substation is ever installed.

Consideration was also given to tapping the 138 kv line and providing a substation to supply E/STS 2-3 only. The cost of this installation would be comparable to extending the 69 kv line from ETS-1. The capacity of the transformer and the arrangement of this installation would not be suitable for conversion to looped circuits for the NRDS system in the future. Further consideration of this arrangement was, therefore, abandoned.

13.2.2 E/STS 2-3 Complex Substation

The substation is of the primary unit type comprising a steel structure for dead-ending the 69 kv line; a line disconnect switch; primary fuses; lightning arrestors; a 5,000-1,750-3,750 kva, 69-12.5-4.16 kv, 3 winding, Class OA, transformer with automatic load-tap-changer (LTC) on the 4.16 kv winding and provision

for future fan cooling; 4. 16 kv metal-clad outdoor switchgear throat-connected to the transformer and a single unit of 12.5 kv metal-clad outdoor switchgear with cable connection to the transformer.

The substation is located as shown on the Plot Plan, Drawing 6552-2-C1. The location was selected to avoid the 69 kv line crossing the module transporter road and the EIV railroad track and to conform to the unprotected safety separation distance from the cryogenic storage area. Additional studies of the location will be made in Phase II to determine access requirements in relation to nuclear safety parameters.

13.2.3 Emergency Power

The commercial power supply for the NRDS area in general, and for E/STS 2-3 in particular, consists of relatively long, single-circuit transmission lines which are susceptible to outages mainly due to storms and lightning, but also possibly due to malfunctions and operating errors. An alternative source of power is, therefore, required to provide the degree of reliability and continuity needed for the power loads at the complex.

A 2,000 kw diesel-engine driven generator will be installed at the complex substation to provide a second source of power supply for essential loads during tests and to serve as standby for the commercial power supply for normal operating loads when a test is not being performed.

The generator is rated 4.16 kv, 3 phase, 60 cycles and is arranged to operate in parallel with the commercial power supply as shown on the Normal and Emergency Power One-Line Diagram, 6552-8-E1.

The 4.16 kv power distribution system for the complex is a dual radial system with "essential" loads segregated on one part of the system and "nonessential" loads segregated on the other part. The 4.16 kv bus-tie circuit breaker is provided between the two parts of the system at the complex substation.

For back-up of essential test loads, the emergency generator will be started prior to the test. It will then be paralleled with commercial power and loaded equivalent to the anticipated essential

test load. Failure of commercial power will open the 4.16 kv tie circuit breaker to isolate the nonessential loads and permit the test to continue on emergency power. Failure of the engine or generator will open the generator breaker and permit the test to continue on commercial power.

When a test is not in progress, the emergency generator will be on standby. Failure of commercial power will open the 4.16 kv tie circuit breaker, start the emergency generator and close the generator circuit breaker to pick up the loads on the essential power system. The nonessential power system can then be energized by operator action after sufficient nonessential loads have been dropped to prevent overloading the generator.

The emergency generator is a standard "packaged" unit mounted on skids with a weather-protective and sound insulated metal enclosure. The engine-generator unit contains all necessary engine accessories. A separate unit of similar construction houses the generator switchgear and electrical controls.

13.2.4 Critical Power

In the event of complete failure of both the commercial and emergency power supplies, certain "critical" loads will be required for protection of personnel and for safe shutdown and/or cooldown of the test engine.

Battery operated emergency lights are provided in all facilities to permit minimum operations and safe egress.

Instrumentation and control systems, signals and alarms have battery back-up as described in Section 14.

The horsepower required for the water injection pumps for the steam generator is large in relation to the capacity of the power system for the complex. Electric motor drives for these pumps would require a major increase in capacity of the main transformer, emergency generator, and distribution equipment and would be uneconomic. The motors would create operating problems for the diesel engine/s on the emergency generator/s and would cause large voltage drops on the system during starting. These

pumps are, therefore, equipped with direct diesel engine drives which meet the requirements for both "essential" and "critical" power.

In the cryogenic area the LH₂ pumps, LH₂ vaporizer fans, LN₂ pumps and LN₂ vaporizer fans are provided with engine driven standbys to meet the requirements for "critical" power. Additional studies of these drives will be made in Phase II to consider alternative arrangements or installation of motor drives with a common standby engine driven generator.

13.2.5 Power Distribution

Power distribution within the complex site is at 4.16 kv as being the optimum voltage level for the loads and distances involved. All 4.16 kv distribution feeders are installed in underground ducts.

A distribution voltage level of 12.5 kv is provided to supply the new booster pump at existing Well J-13 and the possible new well to be located between Well J-13 and Well J-12. A single circuit overhead line is provided to tie into the existing 12.5 kv line at Well J-13. The new well will be connected to the existing line between Wells J-13 and J-12.

A short line is tapped from the new 12.5 kv line to supply a transformer for the gate house and support shop.

13.2.6 Distribution Substations

Load-center substations for the principal facilities of the complex comprise double-ended indoor type substations, each with two ventilated, dry-type transformers and 480 v switchgear. One transformer is supplied from the "essential" power system and the other is supplied from the "nonessential" system. A key interlocked bus-tie circuit breaker is provided for each substation so that either transformer can serve as standby for the other.

The pump house, gate house and support shop, new well and booster pump at Well J-13 have single distribution transformers.

13.2.7 Low-voltage Distribution

Low-voltage distribution is 480 v to motor control centers and to 208Y/120 v transformers for lighting and instrumentation and control. All distribution circuits are underground or in trays or conduits in buildings and tunnels.

13.3 Further Considerations and Evaluations

In addition to the studies to be made in Phase II to establish the location of the complex substation and consider the critical power supplies in the cryogenic area, further considerations and evaluations will be made for the following:

- a. Review the selected system to meet the requirements for alternative site locations or configurations which are to be considered.
- b. Reassess the selected system to assure its adequacy to meet the functional requirements and criteria for the complex.
- c. Recalculate electrical load requirements for revised and updated facilities to establish optimum ratings and capacities of the power system components.
- d. Establish conceptual requirements for lightning protection and grounding for the systems.

SECTION 14

INSTRUMENTATION AND CONTROL SYSTEMS

14.1 Basic SNPO Criteria

The objectives of the Instrumentation and Control (I&C) System are to provide an efficient and reliable means of acquiring the data necessary to the development and testing of nuclear rocket engines and modules and associated equipments in an economical and straightforward manner. In order to accomplish these objectives, the I&C System must be of high stability, repeatability and dependability while maintaining the high order of accuracy and flexibility for application essential to such a system. These criteria dictate the use of field and time-proven techniques that have previously demonstrated performance capabilities in similar applications.

The conceptual development should provide common instrumentation and control and support systems wherever consistent with program requirements, safety and economy of original construction and operating costs.

14.2 System Concept Philosophy

The system concept for the instrumentation and control systems evolved from past experience, current practices and recent technological advances. This proposed conceptual design meets the requirements of measurement, documentation, control and operational flexibility as specified by the Criteria document. Certain components and/or subsystems of the overall system concept will not be completely explained or justified; in this preliminary report, emphasis is placed on basic philosophies as they affect design, problem areas and system trade-offs, including controversial and alternative approaches.

14.3 Data Acquisition Concepts

14.3.1 Input/Output Requirements

The input/output requirements of the data acquisition system form the basis of the system concept. The nominal 1,500 measurement channels listed in the Criteria document were

evaluated and further divided in that document into signal type and accuracy class. System accuracies are defined as follows:

Class A - $\pm$ 0.1 to 0.2 percent of full scale

Class B - $\pm$ 1.0 percent

Class C - $\pm$ 5 percent

Priority diagnostic and control channels fall within the Class A classification. Figure 14-1 is a representation of the conceptual signal quality and quantity allocation. The allocation was based on total test stand complex requirements and engineering judgment. However, not represented in Figure 14-1 are 300 Class B measurement channels for console and/or strip chart display.

14.3.2 Data Storage Requirements

Presently available devices used for the direct recording of analog voltages, coupled to long transmission lines, are generally incapable of maintaining the accuracy assigned diagnostic and control channels (0.1 to 0.2 percent). It is necessary, therefore, to amplify and digitize the analog voltages before recording, which makes system accuracy independent of the recording medium. Digital signal transmission transfers the burden of overall accuracy to the analog portion of the system. The bulk of the test data reduction, processing and printout will be accomplished in the central NRDS data processing facility with an existing general purpose computer. This factor requires that all test data be tape recorded digitally compatible with the data processing computer. Digital magnetic tape becomes the recommended real time master tape data recording technique.

14.3.3 Data System Concept Evolution

On the basis of digital recording, an overall data system concept starts to evolve. Digital data is time-sequential, and from this factor, time-sharing of equipment (time multiplexing) develops. Analog-to-digital measurement and conversion techniques are time proven, widely used techniques. Amplification of low level inputs into levels suitable to analog-to-digital converters as close as practicable to the measurement transducer will minimize the probability of noise injection.

INSTRUMENTATION & CONTROL

DATA CHANNELS SIGNAL QUALITY & QUANTITY

E/STS - 2

TOTALS

E/STS	2		1395
E/STS	3		1395
CRYOGENIC & GASEOUS			360
	2	<u>3150</u>	
		1575	

CRYOGENIC & GASEOUS

LEGEND

	<u>MEASUREMENT</u>	<u>CONTROL</u>
CLASS A
CLASS B
CLASS C

FIGURE 14-1

14.3.4 Data Transmission

The various methods of signal transmission from the test stand to the control center required examination to establish the point of signal transformation. Several factors influence this decision. These factors consist essentially of the following:

1. Signal Types and Quantities
2. Transmission Distance (Location of Signal Source)
3. Signal Quality
4. Operational Flexibility

Of these factors, transmission distance of low level signals (0 to $\pm$ 100 millivolts or less) is of immediate concern. Signal degradation (attenuation) and electrical "noise" (signal-to-noise ratio) are directly related to transmission distance and transmission environment. Noise reduction is the primary problem in the design of high speed and accurate data gathering systems. The analog portion of this system cannot be designed to a specific signal-to-noise ratio. However, certain engineering practices are incorporated to reduce signal-to-noise ratio to below 60 db. Shielding techniques and spatial isolation are utilized to diminish the electromagnetic and electrostatic coupling effects and system grounding techniques are incorporated to reduce the effects of resistive coupling. Noise induction is not necessarily linearly related to transmission distance; however, noise induction is always positive within any transmission line increment and is cumulative for the total transmission line distance. What constitutes the maximum allowable transmission distance is controversial.

The conceptual development of the data transmission from the test stands to the control center is illustrated in Figure 14-2. The signal quality range figures listed are determined primarily by the anticipated signal-to-noise ratios and signal degradation during transmission. The basis of these values are engineering judgment and experience with other data acquisition systems.

Concept 1 employs direct low level analog transmission from the test stands to the control center. Patching, signal conditioning, multiplexing and A/D conversion is accomplished in the control center. As a consequence of the transmission distance (1,000 ft) in conjunction with anticipated high ambient electromagnetic and electrostatic fields, this concept is deemed unacceptable. The relative cost factor for Scheme 1 is 0.49 (A cost factor of unity assigned to the selected concept forms the basis of the cost evaluation).

14.3.4 (Cont'd)

Concept 2 improves the signal quality by about a factor of two. The improvement is accomplished by reducing the bridge completion and thermocouple extension distances by placing the signal conditioning equipment at each test stand. The cost factor for Concept 2 is 0.70.

Concept 3 improves the signal quality further by moving the amplifiers to the test stands. The large (five order) improvement is attributed to the change from low level analog transmission (5 millivolts full scale) to high level analog transmission (10 volts full scale). The cost factor for Concept 3 is 1.08.

Concept 4 is an economic improvement of Concept 3. The cost reduction is effected by inserting the low level multiplexers in the test stands, reducing the amplifier requirements. The cost factor for Concept 4 is 0.97.

A PAM-FM system is incorporated in Concept 5. The conversion of analog data to the frequency mode for transmission to the control center offers an improvement in signal quality over Concept 4 by a factor of 2 to 5 times. However, this improvement in transmission is not completely realized as a consequence of the degradation that occurs in the frequency-to-analog conversion required at the control center. The cost factor of Concept 5 is 1.02.

Digital signal transmission to the control center, with analog signal transmission within the test stands minimized, is incorporated in Concept 6. The signal quality of this concept is limited only by the signal-to-noise ratio and signal attenuation occurring within the analog portion of the system. The chief advantage of the digital concept is that no data degradation occurs during data transmission, data storage or data handling. As a consequence of the on-off nature of digital signals, the data accuracy is essentially absolute* and is limited only by bit error rate for a given design. The value of this concept is further enhanced by computer compatibility. The data quality of Concept 6 is 0.1 percent to 0.2 percent, and the cost factor is 1.0.

*Digital devices can recognize signals with signal-to-noise ratios of 6 db down (50 percent noise) or a 50 percent attenuation of the pedestal amplitude.

14.3.4 (Cont'd)

Thus, on the basis of technical and cost considerations, Concept 6 is recommended. Drawing 6552-9-11 reflects the integration of Concept 6 into the overall data transmission concept.

A major factor influencing cost estimating concerns a novel multiplexer-amplifier combination recently marketed. The functional duality of this equipment at a unit cost of \$500 per channel is approximately half the combined costs for a low level multiplexer and amplifier purchased separately.

The test stand portion of the instrumentation and control system is illustrated on Drawing 6552-9-11. From the test article connector, cables are routed through the umbilical assembly to the station termination and patching located within the umbilical tower.

Control and measurement channel isolation is maintained to reduce channel interaction. Hard wire transmission is provided for discrete control circuits from the control patcher to the control center termination. Analog measurement signals are taken from the measurement patcher to signal conditioning while discrete measurement channels are hard wired to the control center termination. From the signal conditioner low level analog measurement channels are routed to the low level amplifier-multiplexers; high level analog measurement channels are fed to the high level multiplexer; the wide band channels are hard wired to the control center termination; and the analog measurement channels for console display are first amplified, isolated, and then hard wired to the control center termination area. From the amplifier-multiplexer, the analog measurement channels are digitized and routed to the high level multiplexer. All amplifiers and multiplexers provide differential inputs, high common mode noise rejection, low drift and high linearity. A redundant parallel A/D converter is activated automatically. The high level multiplexer, located in the test stand terminal room, is hard wired through the tunnel to the control center.

The analog controllers are activated by analog measurement signals from the signal conditioners and the analog error signal is routed to the appropriate umbilical tower termination. The controller set-point adjustment is provided by hard wire signals from the control center. A 28 volt d-c power supply, with two-day emergency battery backup, is located in the termination room.

This power supply energizes the discrete control and discrete measurement channels. The facility support and safety systems are tied in at the three stations and the terminal room terminations.

The transmission lines are tray supported along the two sides of the test stand access tunnels. Analog control and measurement circuits are mounted on opposite sides of the tunnel from discrete control and discrete measurement circuits. Shielded twisted pair cables are utilized for narrow band channels and coaxial cables are provided for the wide band channels.

14.3.5 Control Center Instrumentation

The control center portion of the instrumentation and control system is functionally illustrated on Drawing 6552-9-12.

14.3.5.1 Channel Distribution

Data signals entering the control center are first terminated to facilitate channel identification and location and then routed to patching to provide flexibility in channel distribution within the center. Physical separation providing electrical isolation at the analog control and measurement channels from the discrete control and measurement channels is provided in both termination and patching areas to improve the signal-to-noise ratio. Both raw data recording signals and wide band channel recording are taken from the measurement patcher.

From the measurement patcher the digital channels are routed to the digital computer; the discrete measurement channels are directed to a priority interrupt selector through an accumulator (buffer); analog channels are fed into a calculator; and the analog channels are routed to the console analog recorders and indicators.

14.3.5.2 Computer

The on line digital computer is utilized to:

1. Gather and store the test data
2. Provide a continuous real time system status indication regarding both the test article and instrumentation and control channel conditions for before, during and after test operations

3. Provide test article simulation for operational checkout of the instrumentation and control system
4. Provide real time discrete control functions as a consequence of off normal behavior
5. Provide limited real time data display in engineering units (Class B accuracy)

Entry to the computer is accomplished by the conventional programmer's data injection techniques (card reader, typewriter and magnetic tape) and by a manual override feature. The manual override allows complete operational access to control functions. To simplify programming and to reduce computer size, process mathematical computations are performed by analog calculators composed of analog functional modules. Answers from these analog calculators are available to the computer by A/D conversion.

The high speed memory (core) under consideration consists of 32,000 24-bit words. The low speed memory (disc) can accommodate 16,000 24-bit words.

The selection of operational subroutines is accomplished by 32 priority interrupts which are actuated by selected discrete measurements.

In any system employing a digital computer, the degree of success achieved is highly dependent upon the programming effort. The formulation and use of programming assemblers or compilers will greatly simplify the programming chores and will permit test oriented personnel to write programs without a detailed knowledge of the computer language. It is highly recommended that effort be devoted early in the design phase to an appropriate assembler program.

Simplified programming software packages are currently available, an outgrowth of recent developments in the area of real time computer software. It is estimated that an operational engineer, after exposure to about three weeks of specialized programming training, will then be capable of preparing, over a four or five month period, the original programs necessary for the computer.

The Phase II Budgetary Study report will include a discussion and listing of the various computer program routines and sub-routines required for the data acquisition and checkout system.

The improved operational flexibility of the instrumentation and control system, utilizing simultaneous operation of the computer for both test stands, was investigated. This is possible by expanding the computer capabilities. The relative cost factor providing computer operational duality is 1.5 of the basic computer price. This dual capability is not included in the Phase I design or cost estimate.

14.3.5.3 Display

Data presentation is provided by console mounted bar chart displays, X/Y plotters, console meters and graphic displays. Limited on-line real time data presentation is provided by console mounted digital displays and a line printer.

14.3.5.4 Timing

A time code generator compatible with the one at ETS-1 is supplied, which provides time references throughout the test complex instrumentation and control systems, and for computer activation. Coded time is recorded on strip charts, magnetic tape, photographic film and oscillograms. Eight pulse rates are simultaneously available from the timing system varying from one pulse per minute to 1,000,000 pulses per second. Remote displays of the day number, hours, minutes, and seconds are provided in the control room on large size indicator panels. External frequency standards are available for use with Station WWV to calibrate the system and for synchronism with other time code generators and the ETS-1 site. These standards have not been included as part of the facility cost.

14.3.5.5 Multiplexer

The entire analog multiplexing is under the control of a multiplexer programming and control unit contained within the computer block. It contains the storage, logic and drive circuitry to produce the necessary digital drive signals for cyclic operation of the low-level and high-level multiplexers. The proper timing signals for synchronization of multiplexers are generated from the timing subsystem.

Emphasis is placed on the flexibility afforded by such programming and control. By means of a stored program, it is possible to scan inputs in any desired order, with selected sampling rates. The system accepts and stores a program from the computer and automatically determines the properly timed drives for the multiplexers to accomplish the desired sequence. In normal operation, the multiplexing program which is supplied initially by the computer is modified as changes are indicated. These changes may be the result of a time-sequenced prepared program, a program decision (subroutine), or a manual entry via the computer override.

The control unit is capable of addressing in the selected low-level multiplexer channels so that they are sampled at an increased rate without interruption of the then existing sampling program for the nonselected channels.

14. 3. 5. 6 Signal Conditioning

The signal conditioning equipment provides excitation, bridge completion, thermocouple reference junctions, scaling, zero offsetting and calibration insertion.

Excitation for each transducer is provided on an individual channel basis as a part of the signal conditioning equipment. For example, the study of bridge conditioning equipment (bridge completion circuitry, power excitation, nulling, and calibration circuits) considered the choice between a common excitation power supply for all the bridge circuits and individual excitation power supplies. The merits and disadvantages of these two equipment configurations are discussed below.

A common excitation supply provides power for more than one bridge circuit at a lesser cost. Maintenance and wiring of the common excitation system are simplified. On the other hand, the common supply requires isolation of the signal output of each bridge. Furthermore, there is no flexibility in coarse adjustment of individual bridge excitations.

Individual excitation power supplies provide channel scaling capability (within the adjustable voltage range). Voltage offset adjustments permit channel zero level standardization out of the signal conditioner.

14.3.5.7 Operational Checkout

A system is provided, integrated within the overall data acquisition system, to perform preprogrammed automatic or manually selected equipment and/or system checkout tests. Switching capability permits generalized control and simulation of module systems and related ground support equipment. However, the system permits the application of manual calibration and checkout, particularly during the pretest operational checkout phase. Individual circuit elements and/or loops can be isolated for manual checkout independent of total system operation. Also, at any time, adjustment and calibration settings can be frozen to prevent tampering.

14.4 Process and Utility Systems

Industrial "process type" instrumentation is applied to the cryogenic and gaseous storage area, utility systems, and steam generator. Analog measurement and control channels associated with these areas are of the high level current type. Discrete measurement and control channels are activated from a 28 volt d-c power supply. All instrumentation housings are environmentally protected and inerted with gaseous nitrogen where required. The Phase II report will contain a full discussion of the I&C concepts supplemented by logic diagrams for selected systems.

14.5 Safety Subsystem

The design objective of the safety subsystem is to provide an adequate means to monitor and control personnel and equipment from hazards inherent to E/STS 2-3 operations. Detectors for fire, oxygen concentration and explosive mixtures and radiation are mounted at strategic locations within the test complex where a potential safety hazard could exist.

The design approach to meet these objectives is to use systems that have been proved at other test locations. All components and/or subsystems are "off the shelf" and have a long history of reliability and stability. There is no necessity in the present design concept to use other than standardized components and/or systems since those that are available are applicable to the system without modification and at a minimal price.

A safety annunciation board, mounted at the entrance gate house of the site, pinpoints the location of malfunctions.

14.5.1 Fire Detection

The fire detection system consists of air ionization chambers to detect the products of combustion prior to the evolution of smoke or fire. The detector head contains an extremely sensitive cold cathode gas discharge tube which is controlled by two ionization chambers. The "open chamber" is exposed to the atmosphere while the "closed chamber" is virtually sealed from the atmosphere. Each chamber contains minute sources of alpha emitting material which ionize the air in their respective chambers, making the air electrically conductive. When no smoke or combustion gases are present, the chambers are electrically balanced and the tube is nonconductive.

Detection locations were chosen to be in areas where the probabilities of fire are high, which include the electronics rooms, steam generator, umbilical towers, cryogenic area, propane area, diesel fuel tank, underfloor plenums, air conditioning system, and control room. When an alarm condition has been sensed, the detector will transmit a signal to a central control panel on the safety console pinpointing the exact location of the combustion gases and an alarm will be sounded in the area affected. At the discretion of the safety control console operator, appropriate fire-smothering gases can be released to halt the spread of combustion. If within a designated period of time after the alarm no action is taken, an automatic release of fire extinguishing fluid will take place. All sensors, circuits, and alarm lights can readily be checked to determine validity of alarm conditions and status of operation. Any alarm condition can be transmitted automatically to the central fire station at NRDS.

14.5.2 Oxygen Detection

As shown on Drawing 6552-9-16, oxygen level analyzers are located throughout the test complex. These analyzers are of the paramagnetic type and are capable of determining oxygen concentration in the range of zero to 100 percent. When an undesirable oxygen concentration is reached, a distinctive alarm will be sounded locally. The specific location of improper O₂ level will be pinpointed on a safety display panel. Oxygen levels at each detection point will be recorded, both on a strip chart and data acquisition tape recorder. Sensors will be capable of being cleaned if contaminated by radiation fallout.

14.5.3 Combustible Gas Detection

Combustible gas or explosive gas mixtures are detected by two elements of a Wheatstone bridge in a sintered metal housing. Analyzer locations are as stipulated on Drawing 6552-9-13 and have the same annunciation and recording as the oxygen detection system. The analyzers are operational from zero to 100 percent of the lower explosive limit of hydrogen mixtures at corresponding pressures. Each alarm corresponding to a hazardous explosive mixture actuates the klaxon horn in the area, to notify personnel of a potentially dangerous situation.

14.5.4 Radiation Hazards

Radiation detection and monitoring fall into four categories:

- 1.. Gaseous and particulate detection.
2. Gross gamma detection.
- 3.. Neutron detection.
- 4.. Portable personnel monitoring.

The gaseous and particulate monitoring detectors and amplifiers are located as shown on Drawing 6552-9-17. A single channel consists of an isokinetic nozzle connected to a vacuum pump into which gases in the immediate area of the detection are pumped through a porous moveable filter tape which is run adjacent to a beta-gamma probe. Any particulate entrained within the gas is trapped on the filter, and the radiation is detected by an ionization chamber whose signal is amplified and transmitted back to the control room. For Gaseous radiation detection, the gas is brought to a lead lined pig where the radioactivity is detected by another ionization chamber. This detector signal is amplified and transmitted back to the control room. The particulate and gas monitors have sensitivities of 1×10^{-6} to 1×10^{-1} microcuries per cubic centimeter of gas. Remote calibration and on-off controls are mounted in the control room at the health physics console. Activity levels are recorded both on strip chart and magnetic tape recorders. Flashing lights and buzzers at detector locations and at the health physics console are actuated upon the presence of high radiation levels.

14.5.4 (Cont'd)

Gross gamma counting at site locations throughout the test complex (Drawing 6552-9-18) is accomplished by 57 Geiger-Muller chambers. Each detector is equipped with both an audible and visual alarm actuated upon receipt of radiation signal levels above a preset limit. Detector locations are shown on the safety display panel and operational status indication provided for each channel. Remote calibration is accomplished by the insertion of a small radioactive source moved into the range of the Geiger-Muller tube. Recordings of radiation levels are made on strip chart and magnetic tape. Rack mounted meter displays of each channel are available to personnel in the Instrumentation Equipment room.

Neutron monitoring consists of both fast and slow neutron detectors mounted adjacent to the engine, duct, stage and shield (Drawing 6552-9-19). The detectors consist of high sensitivity B₁₀ ionization chambers and U₂₃₅ lined fission chambers. The two neutron detectors mounted in close proximity to the nuclear reactor and the associated period circuits provide a criticality alarm function to denote any excursion of reactor power level. The circuit consists of a thermal neutron counter, log count rate meter, and period amplifier. The signal from the period amplifier can be preset to any exponential rate between -30 seconds, infinity and +3 minutes. Upon detection of a nuclear excursion, audible and visual warnings are broadcast throughout the site to warn personnel. Other neutron detectors determine neutron flux that may activate components of the test stand and verify shielding effectiveness. All neutron detection channels are recorded both on magnetic tape and strip charts with meter readouts on the health physics monitoring rack.

Portable personnel radiation monitoring equipment is stored in accessible locations throughout the test area to enable personnel to monitor their clothing and environment. This equipment consists of portable Geiger-Muller counters for beta, gamma and alpha probes. Portable neutron survey meters are also available. At the decontamination station entrances and exits, portal monitors detect radioactivity of personnel going to the control building. Hand and foot counters are located in each room to monitor the adequacy of decontamination procedures.

14.5.5 Meteorological System

A 30 ft high tower is located above the central control building to provide a base for an anemometer, barometer, psychrometer, wind vane and thermometer (Drawing 6552-9-14). Signals from each detector are transmitted to the safety console for display and recorded on strip chart and tape recorders. A circuit is available to transmit this data to the central meteorological office at NRDS to correlate ground weather conditions with other sites.

14.5.6 Television Subsystem

The television subsystem consists of 12 television cameras mounted as delineated on Drawing 6552-9-110. Junction boxes for placement of additional cameras are provided in other locations around the test stand to zero-in upon specific items of interest during test runs as required. Four cameras are supplied with infra-red Vidicon tubes which will accentuate the hot hydrogen effluent. At the present time the cost of closed-circuit color television systems is approximately \$80,000 per channel. Therefore, color systems are not included in the preliminary cost estimate. If in the future it can be ascertained that a suitable color system can be purchased more economically, it will be included in the final report.

Each monitor location, of which there are 21, has the capability of displaying the picture of any camera within the test complex and can make a video tape recording of any scene. Any one of the twelve camera signals can be displayed on the television monitors located in the control room and Test Director's office and visitor's area. Provision is made for signal transmission of television scenes to the NRDS A & E Building if so desired. Each camera is equipped with fully remote control and is designed to withstand the environmental conditions of radiation, acoustic noise and vibration as applicable to its location. Cameras located in hazardous locations, such as the cryogenic area, are mounted in NEMA IV type enclosures.

14.5.7 Intercommunication Systems

The interphone and public address system is shown on Drawing 6552-9-111 and -112. The system is designed for 25 trunk lines

of telephone and interphone communication. Trunk lines may be operated individually or in concert to provide flexibility for instrument check-out, test operation, public address and r-f patching. Each station consists of a hand-held transeiver connected to a call and alarm circuit. Intercom patch panels are located at each test stand and the instrumentation room. It is possible to lock the patching system during a test period to prevent noise on the system and interference with vital test communications. A four channel audio magnetic tape recorder can be connected in the system to record conversations that may be of importance for future analysis. The Test Director's phone can be connected directly to the public address system at any time. He can override and interrupt any conversation on any trunk. Each instrument rack has a junction box plug into which an auxiliary hand or head set can be connected to communicate with other areas during calibration and operational check of the instrumentation system.

An emergency battery power system is included to provide two hours of operation after main power failure. A single-side-band Transceiver is also located in the main instrument room for communication with trucks and other mobile equipment. Conversations on radio channels can be patched into the telephone network. An underground telephone cable will be provided from the support area at NRDS to the Control Building and the E/STS 2-3 site.

14.5.8 Photographic System

As illustrated on Drawing 6552-9-15, the photographic system provides complete motion picture and still camera coverage of either test stand from a radiation resistant camera bunker located mid-way between Test Stands 2 and 3. The camera bunker, approximately 45 feet long by 8 feet wide and 8 feet high, is buried beneath 5 feet of earth mounding for radiation and blast protection. Cameras are mounted on fixed pedestals, with an optical path to the test stands via periscopes penetrating room ceiling and the earth overburden. Periscopic rotation of 360° allows the cameras to view either test stand by manual rotation prior to test. Three 24 frames per second cameras loaded with sound color film are operational for approximately an hour and a half. Six black and white cameras, operating at 100 frames per second, are test operational for 48 minutes. A seventh 100 frames per second camera will take infrared

pictures for approximately 6 minutes at the discretion of the operator. Two high speed 1,000 frames per second cameras loaded with black and white film will have an operational time of one minute thirty seconds.

All cameras are capable of remote operation from the control center and can be programmed and sequenced at the discretion of the operator. A photographic control panel mounted on the lead instrument engineer's console, provides status indication of each camera system. The camera bunker is accessible to personnel after test for recovery of film and its processing. A back-up power supply is provided to ensure full photographic coverage in case of power failure.

14.6 Deferral Items

The primary I and C function during the Phase I Budgetary Study period was to establish the concept philosophy in sufficient detail to permit definition and cost estimates of the systems. It should be emphasized that the material included in this report is not complete in detail and many areas require further definition before inclusion in the Phase II report. Some items, such as equipment lists, exist currently only in the form of cost estimate back-up data. Items of work deferred for additional treatment at this time include the following:

- a. Operational procedures
- b. Component outline specifications
- c. Ease of operation and maintenance (human engineering)
- d. Safety (failure mode) philosophy
- e. Individual console and rack arrangement, functions and displays
- f. Forward control areas
- g. Environmental protection

14.6 Cont'd

- h. Control modes
- i. Process and Utility I & C Systems
- j. Annunciation
- k. Equipment sharing (maximum allowable low level transmission distance study)
- l. Computer programs
- m. Use of low level amplifier/multiplexer versus straight low level multiplexers
- n. Pursue use of more 28 v d-c powered data system components and analog controller components
- o. Study signal conditioner stability
- p. Wide band system
- q. Umbilical connections

SECTION 15CONTROL CENTER

The test control center is arranged to satisfy the functional requirements of the Criteria document pages VI-A-3 and VI-A-4. Initially, the test control center design approach evaluated a one story versus a two story scheme. The two story plan was eliminated because of higher costs.

An early layout placed the building below grade with an earth cover. This scheme also had inside parking, unloading and turnaround facilities for trucks and motor cars. Subsequent changes placed all air breathing vehicles outside the building with the unloading and parking facilities near the entrance. The ramp down to the entrance from the unloading area would require an excessive walking distance. Therefore, the finished floor of the control center was raised to grade and protective earth shielding placed over and around the building.

The test control center is located about 1,000 ft from the test stands. It is of single story construction and is specifically designed for the following functions:

1. Operation Test Center
2. Personnel Working Area

Drawing 6552-2-A2 illustrates the general arrangement.

The test control center comprises a total area of approximately 23,400 sq ft and contains the following rooms:

1. Cable Spread and Termination
2. Tape Storage
3. Instrumentation Equipment
4. Control
5. Observation
6. Instrument Workshop and Small Parts Storage
7. Communications
8. Electrical and Mechanical Equipment
9. Offices

The control center arrangement is based primarily on the functional disposition of cabling from the two test stands.

Cables are routed through tunnels from the test stands into the appropriate control center Cable Spread Area, then to the Instrumentation Equipment Room and/or to the Control Room. A raised floor system is used in these areas.

This floor system will consist of an elevated floor of extruded aluminum planks covered with vinyl and designed to carry a uniform live load of 250 lb/sq in., or a concentrated caster load of 1,000 lb at any point. The support structure is a series of individual horizontal beams spaced 2 ft apart and supported by pedestals. The plenum space provides the most flexible cable and equipment arrangement for both initial installation and operational modifications. It also serves as an air conditioning plenum for cooling the control equipment.

Offices, toilet facilities and personnel requirements are arranged near the control areas. A mechanical and electrical support area for the control center completes the building layout.

Main personnel and equipment access is controlled positively at the Personnel Control Room entrance to the center, except for admittance through the tunnels from the test stands. Outside this entrance is an earth shielded parking and truck unloading area for two vehicles. Airlock doors are provided at the tunnel entrances to the control center.

The main emergency safety route for personnel is an exit system of airlock and tunnel out to the access road. One other emergency exit for the building permits direct access to grade after passing through an airlock door. These emergency openings can be used for access during building construction.

For a greater utilization, the observation area was simplified from a stepped floor and seat viewing arrangement to an open space that permits other uses such as office space and conference room.

Beam spans are long to permit optimum flexibility of equipment arrangement. This arrangement keeps major areas such as the control room and observation room free of columns and requires only two columns in the instrumentation equipment room and in the electrical and mechanical room. This long span arrangement is more costly structurally than shorter spans, but is operationally preferred.

A workable scheme was developed during Phase I. Under Phase II, a reappraisal of the two-story arrangement will be undertaken. In addition to a conventional column and beam system, an arch concept will be investigated.

A concept will also be studied incorporating only the minimum test facilities below earth shielding. Other areas shown in the Phase I arrangement will be located in unshielded grade level building which will be evacuated before a test.

SECTION 16

MISCELLANEOUS BUILDINGS

16.1 Gate House

The gate house is a prefabricated metal, insulated building with heating, cooling and toilet facilities.

The operation at the gate house is handled by one man per shift who controls access to and from E/STS 2-3. Functions include checking passes, vehicles and bills of lading and guiding personnel to the proper areas. In addition, a portal monitor is installed in the building. A portable monitor is used for checking vehicles.

16.2 Cryogenic Area Receiving Office

The building is a prefabricated metal, insulated building with heating facilities, and space for files and a desk. The primary function is to check and tally fluid deliveries.

16.3 Cryogenic Substation

The building is of concrete construction to provide a thermal shield from the LH₂ storage area as well as to provide suitable environment for forced ventilation equipment cooling. The function of the building is to enclose transformers, switchgear and motor control equipment. The size is approximately 23 ft x 46 ft x 11 ft clear height.

16.4 Support Shop Building

The function of the support shop is to provide space for light machine shop work or maintenance of the facility and test equipment. The building is a prefabricated metal type with a clear span of approximately 40 ft and length of approximately 100 ft. Heating and toilet facilities are included. Space is arranged for layout of shop equipment and the area is served by a 10-ton bridge crane.

SECTION 17PROCEDURES FOR QUALITY CONTROL AND QUALITY ASSURANCE
FOR THE CONSTRUCTION OF ENGINE/STAGE TEST STAND 2-3
AT THE NEVADA TEST SITE17.1 Introduction17.1.1 General

This procedure is to be applied and followed for the construction, fabrication, installation and assembly of all equipment components and elements for the test complex.

This procedure is applicable to the general contractor, subcontractors, lower tier contractors, suppliers and vendors of components or elements to be installed or fabricated for the test complex.

17.1.2 Items Not Covered By This Procedure

This procedure does not apply to items furnished by the Government or its appointed agent for installation by the general contractors for the test facility. However, the installing contractor will be required to follow this procedure for the installation of Government furnished equipment.

17.1.3 Purpose

The purpose of this document is to establish policies and procedures for the control of quality of products constructed, fabricated and installed at the test complex to ensure reliability and safety of the test facilities.

The emphasis throughout this section is on the planning of a comprehensive inspection system which will assure the production, fabrication and installation of a reliable, safe facility.

In the event of conflict between this inspection plan and the suppliers quality control procedures, this procedure shall control unless written approval is obtained from the Government's administrators or his assigned agent.

17.1.4 Requirements

The contractor will be required to submit for contracting officer approval, a quality control plan using MILQ-9858A as reference guide. The plan, upon approval, will automatically become a part of the contract.

17.2 Quality Control Requirements

17.2.1 General

The supplier and/or contractor shall maintain effective quality control procedures to assure that all equipment components, elements to be used on this facility and installation procedures meet the requirements and intent of the specifications.

The general contractor will be responsible to the Government or its agencies for the quality and reliability of all equipment furnished by subcontractors, lower tier subcontractors, and vendors of equipment furnished for this facility. The general contractor will appoint one or more qualified employee reporting to top management and who will be responsible for all quality control of materials utilized in the test facility.

The general contractor will be responsible for accumulating all reports, data and drawings called for in the specifications. These reports must be transmitted to the appropriate Government contracting officer or its assigned representative in a timely manner.

17.2.2 Suppliers and Contractors Inspection Plan

The general contractor and major subcontractors shall submit a written Quality Control Plan to the Government contracting administrator or its assigned agent. This Plan must be applicable to the type of material contracted for and be in such detail that compliance therewith demonstrates concurrence with requirements of the specifications for the facilities. This Plan shall include flow charts showing inspection and test intervals for subassemblies and finished articles.

This inspection plan must be approved prior to commencing fabrication. The general contractors will receive similar plans for their approval from fabricators and lower tier contractors.

17.2.3 Noncritical Items

Suppliers or fabricators of noncritical items required for this project will not be required to furnish inspections plans prior to proceeding with fabrication. Definition of noncritical items will be the responsibility of the A-E or contract administrator.

17.2.4 Contractors Obligation

The general contractor will be responsible to the Government to see that all inspections, tests and documentation required by the specifications are submitted by the subcontractors or suppliers in a timely manner, and in accordance with the approved quality control plan.

17.2.5 Engineering and Change Control

The general contractor will be responsible for transmitting and keeping records of all engineering drawings required, including those for the lower tier contractors and suppliers.

Shop drawings and vendor fabrication drawings must be submitted for approval prior to any authorization to proceed with fabrication. Drawings submitted to the Government or its agent must be complete in detail to the extent that an engineering review can ascertain the technical integrity of each part. Drawings submitted for approval must show overall dimensions and tolerances, clearances required for removal of subassemblies including dimensions of the outside envelope of the subassembly.

Drawings submitted for approval shall indicate proper weld symbols along with type of quality control inspections, such as radiograph, magnaflux, etc. All drawings must be signed by the design engineer, stress engineer, quality engineer, material engineer and manufacturing engineer and checker before submission for approval. These drawings should also show complete parts list, necessary descriptions, drawing number and cross references as required to make the drawings easily interpreted.

17.2.6 Off the Shelf Equipment Drawing Submittals

Drawings for off the shelf noncritical facility items can be submitted as catalog cuts. However, these drawings must show in detail overall dimensions and all pertinent information required for anchoring supports as well as the location and size of necessary connections.

17.2.7 Stock Control

The general contractor will be responsible to the Government or its subcontractors and suppliers of assuring that only acceptable material is used in the manufacturing or fabrication of any component required for this project. This control is to be maintained on all raw materials completely through the assembly and construction processes. Certification of materials must be submitted when equipment or components are delivered for all critical items required for this facility. Each supplier will be responsible for maintaining proper stock controls to ensure compliance of materials. All parts, wherever possible, must have part numbers and inspection stamps identifying the part.

17.2.8 Process Control

The procedures used to control personnel qualifications and for the quality of critical processes used for manufacturing or fabrication of components or elements required for this facility must be submitted for approval. The following is a list of processes requiring certification; however, additional certification of processes may be required by the specifications or other contract documents.

1. Welding	9. Castings
2. Dye Penetrant Test	10. Platings
3. Magnetic Particle Test	11. Test Procedures
4. Hardness Test	12. Brazing
5. Cleaning	13. Forgings
6. Radiographic Inspection	14. Ultrasonic Testing
7. Heat Treating	15. Certification of Personnel
8. Soldering	16. Leak Testing

17.2.9 Source Surveillance

The general contractor will be responsible to the Government or its appointed agent to ensure that all lower tier subcontractors and suppliers have the necessary surveillance of procured materials to ensure that the quality of the end product conforms to the requirements of the specifications and meets the needs of the intended service required for the facility.

17.2.10 Tool and Gauge Control

Each of the contractors and suppliers shall be responsible for maintaining all production tooling required in manufacture of any article used for this facility. All inspection tools, jigs, fixtures and gauges must show up-to-date calibration to ensure proper fabrication of all components. Similar requirements for calibration of instrumentation used for acceptance testing will apply. In addition, primary standards will be traceable to the National Bureau of Standards.

17.2.11 Shipping and Packaging

This procedure is applicable to all items delivered to the construction site for use in the test complex. After acceptance and inspection, the supplier must prepare the equipment in such a manner that it is easily identifiable when received at the test facility.

The supplies or parts shall be packaged in accordance with the purchase order or contract requirements. Where specifications call for Mill spec packaging or for special supporting for impact loads, it is the suppliers responsibility to ensure that the contract requirements have been fulfilled. Each individual item shall be packed separately and the individual containers marked showing manufacturer's address, model and part number, customer part number, serial number, purchase order or contract number and date of manufacture.

17.2.12 Shipping Documents

Shipping documents shall be prepared to show routing model, and/or part number, serial number, purchase order or contract number and shipping date.

The supplier must include or have attached to the shipping container, the following information:

1. Shipper
2. Applicable drawings showing detail assembly and interface dimensions
3. Maintenance manual and assembly instructions
4. Spare parts list
5. Inspection and Quality Control Documents
6. Test Reports

Under separate cover, the required number of quality control documents as called for in the specifications must be transmitted to the contracting officer within one week of the shipping date.

17.3 Inspection and Testing

17.3.1 Procedures

The contractor and/or suppliers will be required to supply procedures for all stages of functional and final testing of components as called for in the specifications. A copy of these procedures will be returned to the supplier with comments showing acceptance of the procedures or indicating changes required to ensure proper compliance with the specification or intended use.

17.3.2 Government Source Inspection

The Government or its appointed agents must be notified as to the date of any functional or final test. The amount of advance notice will be indicated in the contract documents. Final acceptance of any article will be at the discretion of the Government contracting officer or its appointed agent.

17.3.3 Discrepancies

Discrepancies observed during functional test or during inspections or during final acceptance test shall be recorded on a Discrepancy Report Form showing corrective action, cause of discrepancy and the affect on the final performance of the item.

17.3.4 Test Reports

Test results shall be original data recorded on the Test Report Form. This form shall show all pertinent test information. Where calculations are required to arrive at final figures, copies of the calculations must be attached to the Test Report Form. Each required test must be signed by the person in charge of performing the test and by the cognizant quality control inspector.

17.3.5 Waiver of Government Inspection

The Government or its appointed representative may waiver the witnessing of tests. It will be the supplier's responsibility to

perform all tests and inspections according to the approved procedures and in accordance with all contract documents. All quality control report forms must be submitted for approval before shipment of the article unless notification is given to the contrary.

17.4 General Construction and Fabrication Requirements

The requirements imposed by this document are intended to supplement the specifications and drawings which will be used during the construction of the facility. The following describes elements of effort required to construct the facility, lists categories and defines the minimum requirements for inspection and testing.

17.4.1 General Construction

17.4.1.1 Group A - Construction Materials

This category of construction materials is intended to cover the brick and mortar type of processes and materials required for the facility.

1. Excavation and Backfill

The contractor responsible for excavation and backfill shall have at his disposal a complete, approved testing laboratory and will be responsible for meeting the requirements for the specifications, drawings and making tests on compaction during the entire phase of this work.

2. Concrete

Concrete will be poured in accordance with the requirements outlined by the American Concrete Institute and shall be tested in accordance with the procedures outlined by the American Society for Testing and Materials. The specifications and drawings will indicate the required quality of concrete and reinforcing steel for each section of the facility. The testing laboratory will be employed to prove and document that the quality of concrete used meets the specifications. Equipment used for batching and placing the concrete must meet the conditions imposed by the American Concrete Institute.

3. Structural and Miscellaneous Steel

Structural steel will be fabricated and erected in accordance with the American Institute of Steel Construction and all welding of structural steel will be in accordance with the provisions set forth by the American Welding Institute.

4. Miscellaneous Contract Materials

Other materials such as lumber, sheet metal, roofing materials, etc., will be required to meet the specifications and be in compliance with the Uniform Building Code, Nevada State Industrial Code and other applicable standards as set forth by the industry.

17.4.1.2 Group B - Industrial Machinery Items

Equipment falling into this group will require submission of shop drawings as outlined in Section 17.2. Any prototype equipment furnished by fabricators shall be tested in accordance with specifications and test reports will be submitted prior to shipment. Standard equipment furnished by fabricators shall submit performance curves and other pertinent data necessary to ascertain that the equipment will meet the requirements of the facility.

The following items fall in Group B, and will be required to meet the standards of the industry as well as the conditions imposed by the American Society of Testing Materials, Uniform Building Code, Nevada State Industrial Safety Code, Pressure Vessel Code and the latest issue of the Electrical Code.

Compressors	Pumps
Blowers	Motors (Engine Type)
Diesel Engines	

17.4.1.3 Group C - Electrical Equipment

All equipment falling into this group shall be manufactured according to the following codes and shall be in compliance with the construction specifications and drawings.

Equipment

American Standards Association (ASA)

National Electrical Manufacturers Association (NEMA)
Standards

Underwriters Laboratories, Inc., Standards For Safety

Transmission Lines

National Electrical Safety Code (NESC)

Electrical Work in General

National Electrical Code

NASA NPC 325-1 Design Criteria & Construction Standards

Equipment falling within the category of Group C is listed below.

Motors	Motor-controllers
Starters	Circuit Breakers
Exciters	Pressure, temperature, vibration
Regulators	switches
Transmission Lines	Manually-operated switchgear
	and similar equipment

17.4.1.4 Group D - Instrumentation Equipment and Transmission Systems

The following standards are selected to provide a measure of uniformity for assuring specified system and component performance within the framework of relevant applicability.

The latest revised versions of the following standards and codes apply:

Military

MIL-E-4158C General Requirements for Electronic Equipment, Grounds

MIL-C-17C Cables, Radio Frequency, Coaxial

MIL-W-16878 Cable Shielding

MIL-W-76B Wire and Cable, Hookup, Electrical,
Insulated

Society and Codes

AEC	U. S. Atomic Energy Commission - Minimum Safety
ASTM	Applicable Documents of the American Society for Testing Materials
IPCEA	Insulated Power Cable Engineering Association S-19-81
ISA-RP	Recommended Practices of the Instrument Society of America
NEMA	Standards of National Electrical Manufacturer's Association
SAMA	Recorder-Controller Section Standards of the Scientific Apparatus Makers of America
UL	Underwriters Laboratories, Inc.
NEC	National Electrical Code
	Federal Standard 595 Colors
IRIG	Inter-Range Instrumentation Group Standards

17. 4. 1. 5 Group E - Process Piping Fabrication and Installation

All process piping will be fabricated and installed in accordance with the specifications and the pressure piping code. Welding will be in accordance with the Standards of the American Welding Society and the ASME Boiler and Pressure Vessel Code. Qualifications of welders will be in accordance with Appendix A, Section 6 of the ASA Code B31. 1. Radiograph acceptance will be judged according to the ASME Boiler and Pressure Vessel Code, Section VIII. The following piping will be required to have 100 percent radiographing:

Liquid Hydrogen
Piping (any pressure)
Liquid oxygen and liquid nitrogen piping above 2 in. in
diameter
All piping with a design pressure in excess of 600 psi,
2 in. diameter and larger

All other piping systems will have radiographic inspection per code.

The fabricators shall submit procedures to the contract administrator for approval prior to fabrication or installation of any piping system. This procedure shall show conformance to the

ASA and AWS codes where applicable and shall indicate the method for stress relieving, joint preparation and the welding processes to be used on the various systems.

Shop and field cleaning of piping systems shall be in accordance with the specifications and shall be generally in conformance with the National Aeronautics and Space Administration Requirements.

Testing requirements prior to acceptance of all piping systems will be in accordance with the specifications with the above mentioned codes.

17.4.1.6 Group F - Valves and Piping Equipment

This group of equipment is classified into two categories: critical and noncritical. The specifications will indicate the required testing and inspection for all valves and equipment. In general, all valves or equipment in cryogenic service or gas supply will be considered critical items. Valves and equipment required in water service and miscellaneous services will be classified as noncritical. All process valves and equipment will be manufactured in accordance with the ASME, ASTM and other applicable codes.

Radiographic inspection will be required on all critical valves and components which will be in contact with cryogenic fluids or which will have pressure applied above 600 psi. Magnaflux or dye-penetrant inspections of welds will be allowed for instrumentation bosses where radiographing is impractical.

Vacuum Jacket Valves	Filters
Relief Valves	Flow Straighteners
Hand Operated Valves	Gimbals
Control Valves	Fill Connectors
Flow Meters	Pressure Gauges and Similar
Expansion Joints	Components

17.4.1.7 Group G - Pressure Vessels and Cryogenic Storage Facilities

This category of facility items includes all pressure and storage facilities required for the test facility. All vessels falling within this group will be designed and fabricated according to

the ASME Unfired Pressure Vessel Code and will conform to the requirements of AWS for welding and shall meet the requirements of the ASTM for materials as called out in the specifications and drawings for the individual units. Items included in this group are listed below:

Cryogenic Storage Vessels
High Pressure Gas Storage Receivers
Pneumatic and Hydraulic Accumulators
Water Storage Tanks and Air Receivers

SECTION 18RESEARCH AND DEVELOPMENT18.1 General

In general, the test complex has been conceived within the state-of-the-art and little or no research costs are expected in the development of the design for the complex.

Attempts have been made to select materials and equipment that are available from industry. However, development costs may be incurred due to the size or environment in which the equipment will be required to operate. Costs for development of items to meet special conditions have been included where specific requirements have been identified; for example, development costs for the steam generator system have been included as part of the equipment.

Substantiation of heat transfer calculations and diffuser/ejector performance requirements should be obtained through model tests after a design concept has been made and before final design is complete. The cost associated with this test program has not been included in the cost of the complex.

APPENDIX AABBREVIATIONS

AEC-NVOO	- Atomic Energy Commission - Nevada Operations Office
DOD	- Department of Defense
EIV	- Engine Installation Vehicle
ETS-1	- Engine Test Stand No. 1 at NRDS
GFE	- Government Furnished Equipment
GH	- Gaseous Hydrogen
GH _e	- Gaseous Helium
GN	- Gaseous Nitrogen
IU	- Instrumentation Unit
LASL	- Los Alamos Scientific Laboratories
LH ₂	- Liquid Hydrogen
LN ₂	- Liquid Nitrogen
LOX	- Liquid Oxygen (LO ₂)
LTC	- Load Tap Changer
MAM	- Module Assembly and Maintenance
MCC	- Manned Control Car
MSFC	- Marshall Space Flight Center
NRDS	- Nuclear Rocket Development Station
PAM-FM	- Pulse Amplitude Modulation - Frequency Modulation
r-f	- Radio Frequency
RIFT	- Reactor In-Flight Test
SNPO	- Space Nuclear Propulsion Office

APPENDIX BDRAWINGS

Drawings in this appendix are presented in the following order:

<u>Drawing No.</u>	<u>Title</u>
6552-2-A1	- Test Complex Site Perspective
6552-2-A2	- Control Center Arrangement
6552-2-A3	- Control Center Sections
6552-2-C1	- Plot Plan
6552-4-M1	- Test Stands - General Arrangement - Elevations
6552-4-M2	- Test Stands - General Arrangement - Plans and Sections
6552-4-ML-26	- Test Stand - Concept Study - Scheme 17 - Engine Shield Arrangement - Retractable Shield Tank - Sheet 2
6552-4-ML-30	- Test Stand - Concept Study - Engine Handling
6552-5-ML-27	- Diffuser - Ejector Exhaust System - 5,000 MW Engine - Inside Dimensions - Test Stand Area
6552-5-ML-28	- Diffuser - Ejector Exhaust System - 5,000 MW Engine
6552-5-ML-29	- Diffuser - Ejector Exhaust System - 10,000 MW Engine
6552-5-ML-33	- Diffuser - Ejector Exhaust System - 5,000 MW Engine Base Configuration - Test Stand Area
6552-5-P1	- Water System - Diffuser Ejector - Flow Schematic - Test Stand Area
6552-6-ML-21	- Diffuser and Ejector Handling
6552-6-ML-25	- Stage Handling
6552-7-P1	- Liquid and Gaseous Hydrogen Systems - Flow Schematic - Storage Complex Area
6552-7-P2	- Liquid and Gaseous Hydrogen Systems - Flow Schematic - Storage Complex Area
6552-7-P3	- Cryogenic & Gaseous Systems - Flow Schematic - Test Stand Area
6552-7-P4	- Gaseous Helium System - Flow Schematic - Storage Complex Area

APPENDIX B
(Cont'd)

<u>Drawing No.</u>	<u>Title</u>
6552-7-P5	- Oxygen, Propane & Hot Gas Generation - Flow Schematic - Storage Complex Area
6552-7-P6	- Cryogenic & Gaseous Systems - Flow Schematic - Test Stand Area
6552-7-P7	- Cryogenic & Gaseous Systems - General Arrangement - Storage Complex Area
6552-8-E1	- Normal and Emergency Power - One Line Diagram
6552-9-I1	- Instrumentation & Control Systems - Test Stand - Block Diagram
6552-9-I2	- Instrumentation & Control Systems - Control Center - Block Diagram
6552-9-I3	- Instrumentation & Control Systems - Combustible Gas Detection - Block Diagram
6552-9-I4	- Instrumentation & Control System - Meteor- ological Monitoring - Block Diagram
6552-9-I5	- Instrumentation & Control System - Photo- graphic Monitoring - Block Diagram
6552-9-I6	- Instrumentation & Control System - Oxygen Detection - Block Diagram
6552-9-I7	- Instrumentation & Control System - Atmospheric Radiation Detection Block Diagram
6552-9-I8	- Instrumentation & Control System - Gamma Monitoring Block Diagram
6552-9-I9	- Instrumentation & Control System - Neutron Monitoring Block Diagram
6552-9-I10	- Instrumentation & Control System - Television Monitoring Block Diagram
6552-9-I11	- Instrumentation & Control System - Intercom System Block Diagram - Sheet 1
6552-9-I12	- Instrumentation & Control System - Intercom System Block Diagram - Sheet 2