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Multimegawatt Space Nuclear Power Supply Phase I Final Report

Supplement

D180-30619-8

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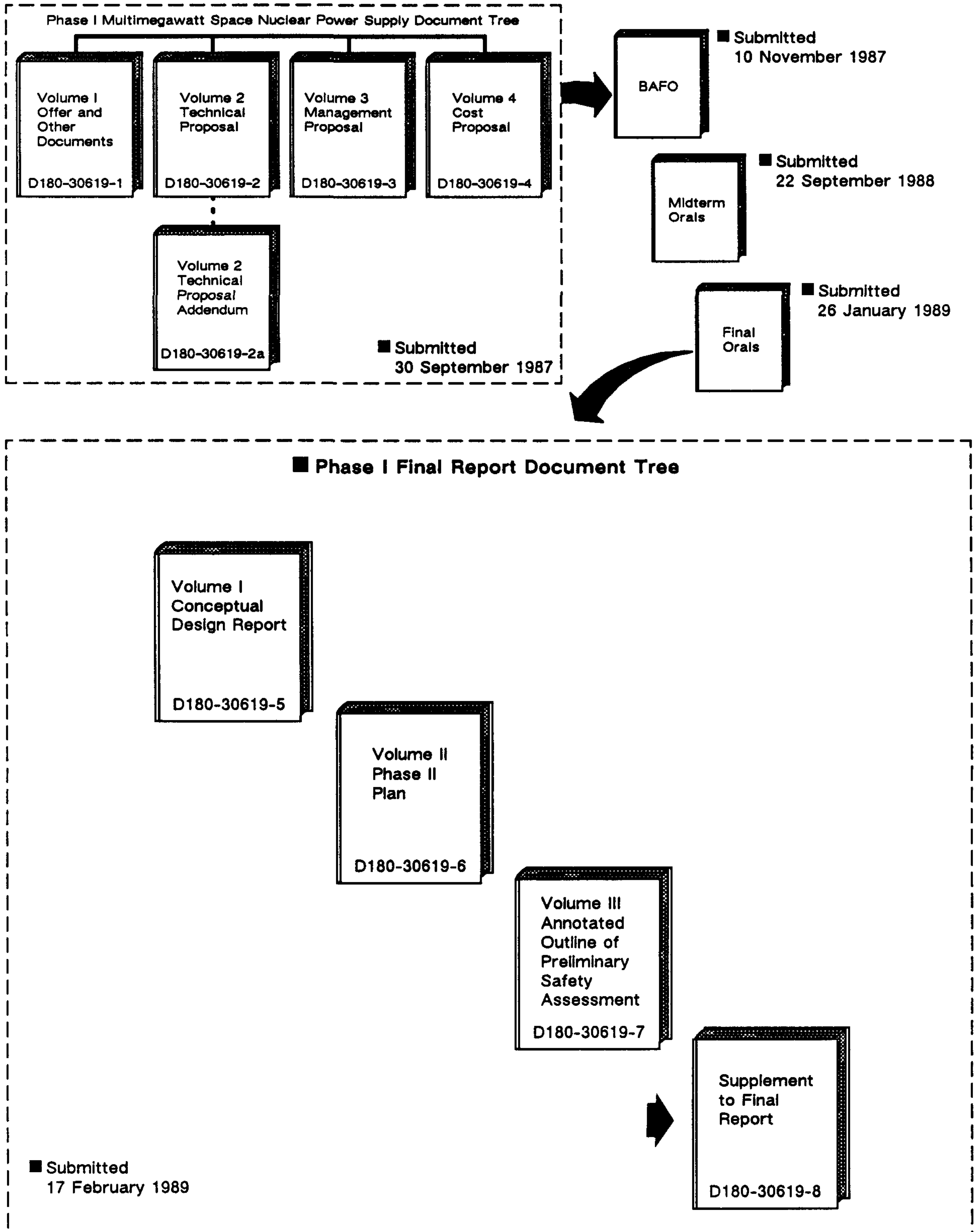
Phase I Multimegawatt Space Nuclear Power Supply Documentation Flow



PREFACE

In an effort to minimize publication and distribution of classified information the phase I-MNSRPS Final Report has been maintained unclassified by referring to C/RD and S/NSI information contained within the Phase II-MNSRP proposal.

The system specification and environmental requirements definition document contained within this supplement were generated during the phase I effort as a preliminary draft and will be modified, updated, and expanded during following phases of the program.

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Functional and Operational Requirements Cross-Reference Matrix

MMW Phase II-U90004-7 R4

1.0 C/RD INFORMATION

1.1 REACTOR - (Phase I - MSNPS Final Report - Volume I, Section 3)

The reactor information referred to in Volume I, Section 3 of this report can be found in the Phase II - MNSRP Proposal, Volume II, Section 2.1.2.

1.2 FLEXIBILITY - (Phase I - MSNPS Final Report - Volume I, Section 14)

The system flexibility information referred to in Volume I, Section 14 of this report can be found in the Phase II - MNSRP Proposal Volume II, Section 2.1.14.

1.3 RESOLVE TECHNICAL FEASIBILITY ISSUES - (Phase I - MSNPS Final Report - Volume II, Section 3)

The feasibility issue information referred to in Volume II, Section 3 of this report can be found in the Phase II - MNSRP Proposal Volume II, Section 2.2.2.

1.4 REACTOR CONCEPT - (Phase I - MSNPS Final Report - Volume II, Section 4.4)

The reactor design concept refinement information referred to in Volume II, Section 4.4 of this report can be found in the Phase II - MNSRP Proposal Volume II, Section 2.2.3.4.

2.0 S/NSI INFORMATION

S/NSI information for this report can be found in the Phase II - MNSRP Proposal Volume III.

3.0 SYSTEM SPECIFICATION

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1 SCOPE

This Specification establishes the performance, design, development, and test requirements for the Boeing Multimegawatt Space Nuclear Power System (MSNPS).

The Boeing Multimegawatt Space Power System is part of the DOE/SDIO Multimegawatt Space Nuclear Power Program. The purpose of this program is to provide a space-based nuclear power system to meet the needs of SDIO missions.

The Boeing MSNPS is a category I concept which is capable of delivering 10's of MW(e) for 100's of seconds with effluent permitted. A design goal is for the system to have growth or downscale capability for other power system concepts. The growth objective is to meet the category III capability of 100's of MW(e) for 100's of seconds, also with effluent permitted.

1.1 PURPOSE

The purpose of this preliminary document is to guide the conceptual design effort throughout the Phase I study effort. This document will be updated through out the study. It will thus result in a record of the development of the design effort.

The requirements stated in sections 3,4, and 5 characterize the Boeing MNSPS reference design capability. Growth requirements and alternative design concept requirements and design definitions will be maintained in section 6. As a result of trade studies and analyses, the reference design will be updated. The basis for these updates will be recorded in section 6. The resulting document at the end of the study will be used as the basis for the system specification for Phase II.

Classified data referenced in the main body of this specification shall be designated by capital letters in parentheses e.g. (A) All classified data , including the specific values designated by the capital letters, will be included in the Appendix. The Appendix will, of course, be documented separately.

Two types of requirements are identified within this document. Requirements which must be complied with, are included using the verb form "shall". Requirements that are desirable and may be included if they can be met within the budgetary constraints are included using the verb form "will".

1.2 MSNPS ROLE AND AVAILABILITY

The roles of the MSNPS are:

-As a lower-weight alternative to chemically driven power system that avoids a possible water retention requirement and;

-As the reference design power system for higher power and energy space applications in view of the substantial weight saving over chemical systems, especially for longer duration requirements.

Category I should be designed for an availability, circa 2000. The Category III growth version will be available some time later. This implies a technical freeze for the Category I system early in the 1990's and a freeze for the Category III system in the mid 1990's. The feasibility of the technology incorporated into the design must be established by the time of the technology freeze.

1.3 SAFETY

The emphasis on safety is paramount in this program. It must be recognized that either space reactors will be safe or they won't be at all.

1.3.1 Safety Regulations

A major objective of the Multimegawatt Project is the development of a flight system design and hardware that provides the desired level of public safety, health protection, environmental protection, and special nuclear material (SNM) protection when used during its designated missions. Present standards referenced in DOE Order 5480.1B will be considered, where appropriate, in the design process.

1.3.2 Safety Policy

It shall be project policy to assure the protection of the environment, the safety and health of the public, and government property against accidental loss and damage. Project activities shall be executed in a manner that will not present undue risk considering the benefits. Taking into account economic and social factors and the level of technology, every effort shall be made to maintain risk as low as reasonably achievable. The effect on safety must be an integral and key consideration in all design and operational decisions. This decision process must include full consideration of normal and off-normal operations and credible accident situations during the life cycle of the system.

2 APPLICABLE DOCUMENTS

The following documents of the exact issue shown, form a part of this specification to the extent specified herein.

2.1 GOVERNMENT DOCUMENTS.

SPECIFICATIONS:

RFP No. DE-RP07-87ID12677	Multimegawatt Space Nuclear Power System Functional and Operational Rqmts. Rev. 1 Dated June, 1988.

STANDARDS:
DOE ORDER 5480.1B

OTHER PUBLICATIONS:
NASA TM 82478
NASA TECH ORDER 2361
NOAA-S/T 76-1962

2.2 NON-GOVERNMENT DOCUMENTS.

OTHER PUBLICATIONS:

2.3 REFERENCE DOCUMENTS.

The following documents are included in this document for reference at this time. As any of these documents become requirements they shall be moved to the above sections.

SPECIFICATIONS:

Federal:

QQ-M-290	Nickle Plating (Electrodeposited)
QQ-C-320	Chromium Plating (Electrodeposited)

Military:

MIL-M-3171	Magnesium Alloy Process for Pretreatment and Prevention of Corrosion on.
MIL-C-5541	Chemical Conversion Coatings on Aluminumand Aluminum Alloys.
MIL-F-7179	Finishes and Coatings, General Specifications for Protection for protection of Aerospace Weapons Systems, Structures and parts.
MIL-A-8625	Anodic Coatings for Aluminum and Aluminum Alloys.

DOD-E-8983	Electronic Equipment, Aerospace, Extended Space Environment, General Specification For.
DOD-W-83575	Wiring Harness, Space Vehicle, Design and Testing, General Specification For.
DOD-A-83577	Assemblies, Moving Mechanical, for Space Vehicles, General Specification For.
DOD-E-83578	Explosive Ordnance for Space Vehicles, General Specification for.

STANDARDS:

Military

MIL-STD-889	Dissimilar Metals
MIL-STD-1246	Product Cleanliness Levels and Contamination Control Program.
MIL-STD-1472	Human Engineering Design Criteria for Military Systems, Equipment and Facilities.
MIL-STD-1522	Standard General Requirements for Safe Design and Operation of Pressurized Missile and Space Systems.
MIL-STD-1539	Electrical Power, Direct Current, Space Vehicle Design Requirements.
MIL-STD-1540	Test Requirements for Space Vehicles.
MIL-STD-1541	Electromagnetic Compatibility Requirements for Space Systems.
MIL-STD-1547	Parts, Materials, and Processes Requirements for Space and Launch Missile Vehicles, Technical
MIL-STD-1574	System Safety Program for Space and Missile Systems.

HANDBOOKS:

MIL-HDBK-5	Metalic, Materials, and Elements for Aerospace Vehicle Structures.

MIL-HDBK-17	Plastics for Aerospace Vehicles - Part I, Reinforced Plastics.
MIL-HDBK-17	Plastics for Aerospace Vehicles - Part II, Transparent Glazing Materials.
DOD-HDBK-263	Electrostatic Discharge Control Handbook for Protection of Electrical and Electronic Parts, Assemblies, and Equipmnet.
MIL-HDBK-340	Application Guidelines for MIL-STD-1540B: Test Requirements for Space Vehicles.

OTHER GOVERNMENT PUBLICATIONS;

JSC-07700	Space Shuttle System Payload Accomodations, Vol. XIV, (NASA JSC)
SP-R-0022	Vacuum Stability Requirements of Polymeric Materials for Spacecraft Applications (NASA JSC).
NHB 1711.7	Safety Policy and Requirements for Payloads Using The Space Transportation System (STS) (NASA).
KHB 1700.7	Space Transportation System Payload Ground Safety Handbook (Joint NASA/Air force document designated by the Air Force a SAMTO HB S-100)
SAMTO HB S-100	See Above
FIPS PUB 1	Code for Information Interchange (Fedral Information Processing Standard: National Bureau of Standards. (This document is the same as ANSI-STD X 3.4-1968).
MSFC-HDBK-527	Materials Selection List for Space Hardware. Rev. E.

NONGOVERNMENT DOCUMENTS:

ANSI-STD X 3.4-1968	See Above.
(DS 89-872)	Environmental Requirements Definition, The Boeing Co. June 1988.

Super Threat Document, Prepared by S-Cubed.

J. Bisentine, L. Leger, et. al., "STS-8, Atomic Oxygen Effects Experiment" AIAA paper No. 85-0415, AIAA 23rd Aerospace Sciences Meeting, January 14-17. 1985

L, Leger, J. Bisentine, B. Santos-Mason, "Selected Material Issues Associated With Space Station", SAMPE Quarterly, Vol. 18, #2, January 1987.

3 REQUIREMENTS.

The system shall be responsive to the development concepts of the U.S. Department of Energy and to the operational concepts of the U.S. Air Force/Strategic Defense Initiative Office. Development of the system will be accomplished by the Boeing Co. and a team of subcontractors responsible for items of hardware and tasks required to develop the following subsystems.

A. Alternator
B. Hydrogen Feed
C. Instrumentation and Control
D. Power Conditioning
E. Reactor
F. Structure
G. Turbine
H. Dummy Load

The system shall be designed to:

A. Generate power using a nuclear reactor.
B. Operate in a burst mode furnishing power for specified payloads.
C. Operate using an open coolant cycle
D. Meet all required safety standards.
E. Meet all design and construction requirements.

Government regulations (e.g. Code of Federal Regulations and DOE Orders) require that all structures, subsystems, and components important to safety shall be designed, built and tested to quality standards commensurate with the safety functions to be performed. Therefore, appropriate codes and standards will be identified and evaluated to determine their applicability, adequacy, and sufficiency, and shall be supplemented or modified as necessary to assure a quality product in keeping with the required safety function.

These requirements are detailed below.

3.1 SYSTEM DEFINITION.

The system shall be analyzed to define (and allocate requirements to) items of equipment and procedures needed to accomplish the requirements of this specification. Functional analyses shall expand upon the diagrams in 3.1.4 utilizing approved procedures and shall be documented in accordance with the study program directives. The requirements derived from these analyses, when approved, shall be incorporated into this specification.

The analysis shall develop a system which, in conjunction with the other systems of the space vehicle, shall be capable of accomplishing its mission despite the identified threat, when operated within the prescribed operational concepts.

3.1.1 General Description

The power system is defined to consist of the following 10 subsystems: alternator, hydrogen feed, instrumentation and control, power conditioning, reactor, structure, turbine, dummy load, and the government furnished (SP100) and attitude control. These subsystems shall include the following.

3.1.1.1 Alternator

The Alternator Subsystem shall consist of (4) round rotor synchronous generators, necessary cooling ducts, electrical cabling, and local control and sensor components.

3.1.1.2 Hydrogen Feed

The hydrogen feed subsystem shall include a liquid hydrogen pump upstream of the NPB accelerator and a second pump downstream of the accelerator which will boost the super critical hydrogen to a pressure slightly higher than the operating pressure of the reactor.

3.1.1.3 Instrumentation and Control

The instrumentation and control subsystem (ICS) shall have a distributed Architecture for interacting with all of the other subsystems. The ICS shall consist of processing, timing, interlock monitoring, and input/output interface components:

3.1.1.4 Power Conditioning

The power conditioning subsystem (PCS) shall consist of (4) modules including a rectifier component and an inverter/transformer component. The PCS shall also include the necessary cooling ducts and interface cabling as well as local instrumentation and control mechanisms needed for the operation of the subsystem.

3.1.1.5 Reactor

The reactor subsystem shall include as components the metal clad fuel rods filled with ceramic fuel pellets, pressure vessel and core structure, internal control rods, internal thermal neutron absorbers, neutron reflectors for secondary reactivity control, an axial neutron reflector, inlet, outlet and internal ducting for coolant flow, and control mechanisms. No shadow shield is required for the NPB platform application. The subsystem shall also include the necessary instrumentation for monitoring and control of the reactor.

3.1.1.6 Structure

The structure subsystem shall include the following components:

1. Structural framework
2. Skin panels/debris shielding
3. Equipment support
4. Thermal control
5. Structural ground support and flight support equipment.

3.1.1.7 Turbine

The turbine subsystem shall consist of (2) multi-stage axial turbines with casings and internal debris shielding. Instrumentation and control mechanisms shall be included in the subsystem as required.

3.1.1.8 Dummy Load

The dummy load subsystem shall consist of a set of slab sections of nickel-chrome alloy for dc power dissipation. For ac power dissipation the material shall be nickel.

3.1.1.9 (SP100).

The (SP100) is government furnished and shall consist of the SP100 plus the extendable truss structure and the required shielding.

3.1.1.10 Attitude Control

The Attitude Control Subsystem (ACS) is government furnished property and shall consist of the ACS equipment which may need to be attached to the MSNFS as a result of the NPB ACS design.

3.1.2 Mission

The primary mission of the MSNFS is to supply power for the SDI Neutral Particle Beam (NPB) SDI payload. The NPB role is to discriminate enemy war-heads from accompanying decoys and to serve as a weapon for destroying the war-heads. The MSNFS shall furnish the power for the discrimination and weapon functions.

3.1.3 Threat

The design shall survive the hostile threats defined in Appendix 2 of the Functional and Operational Requirements (F&OR).

3.1.4 System Diagrams

The top level functional flow is shown in FIGURE 1. The system level layout drawing is shown in FIGURE 2. A functional block diagram of the system is shown in FIGURE 3.

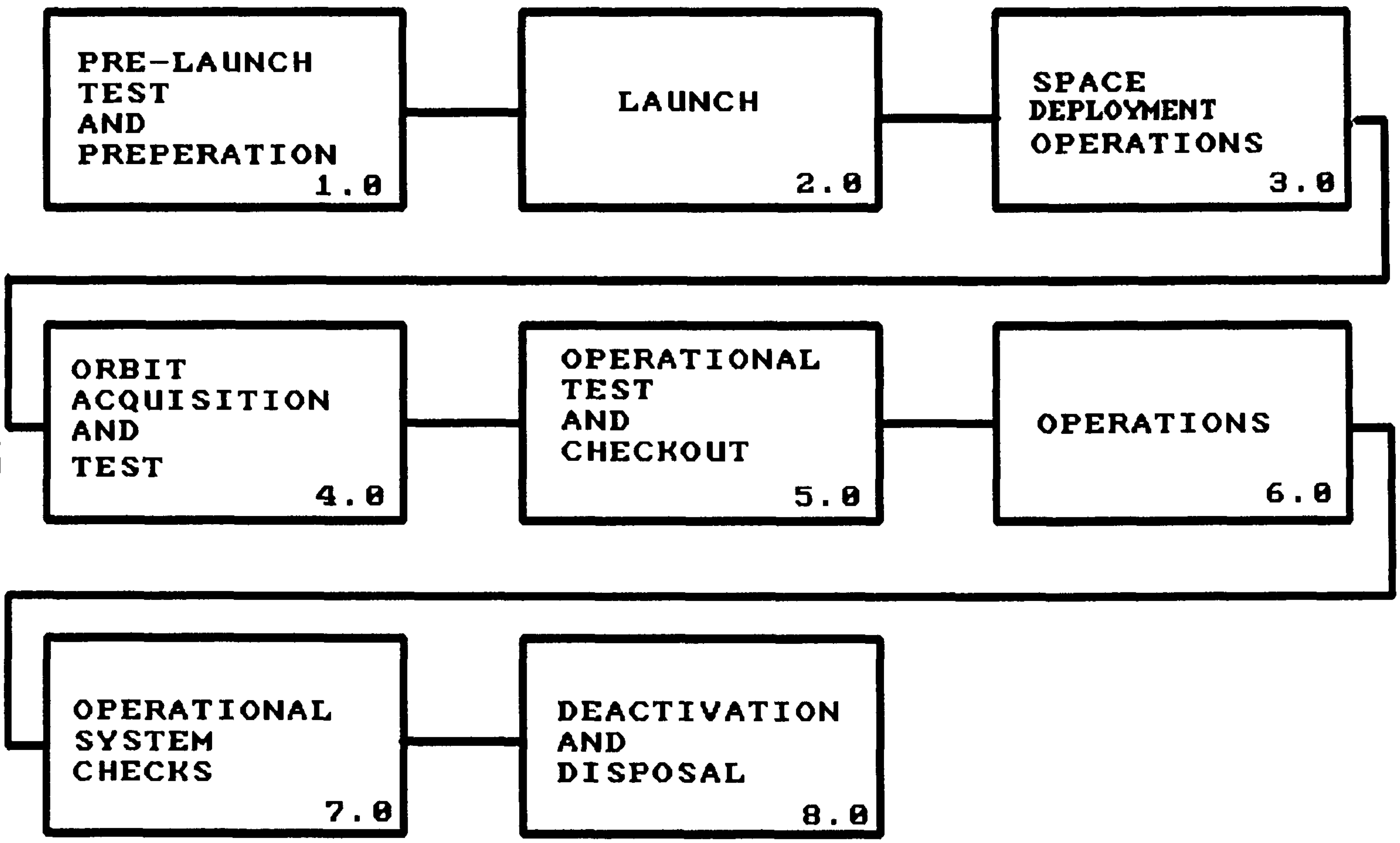

FIGURE 1. Top Level Functional Flow

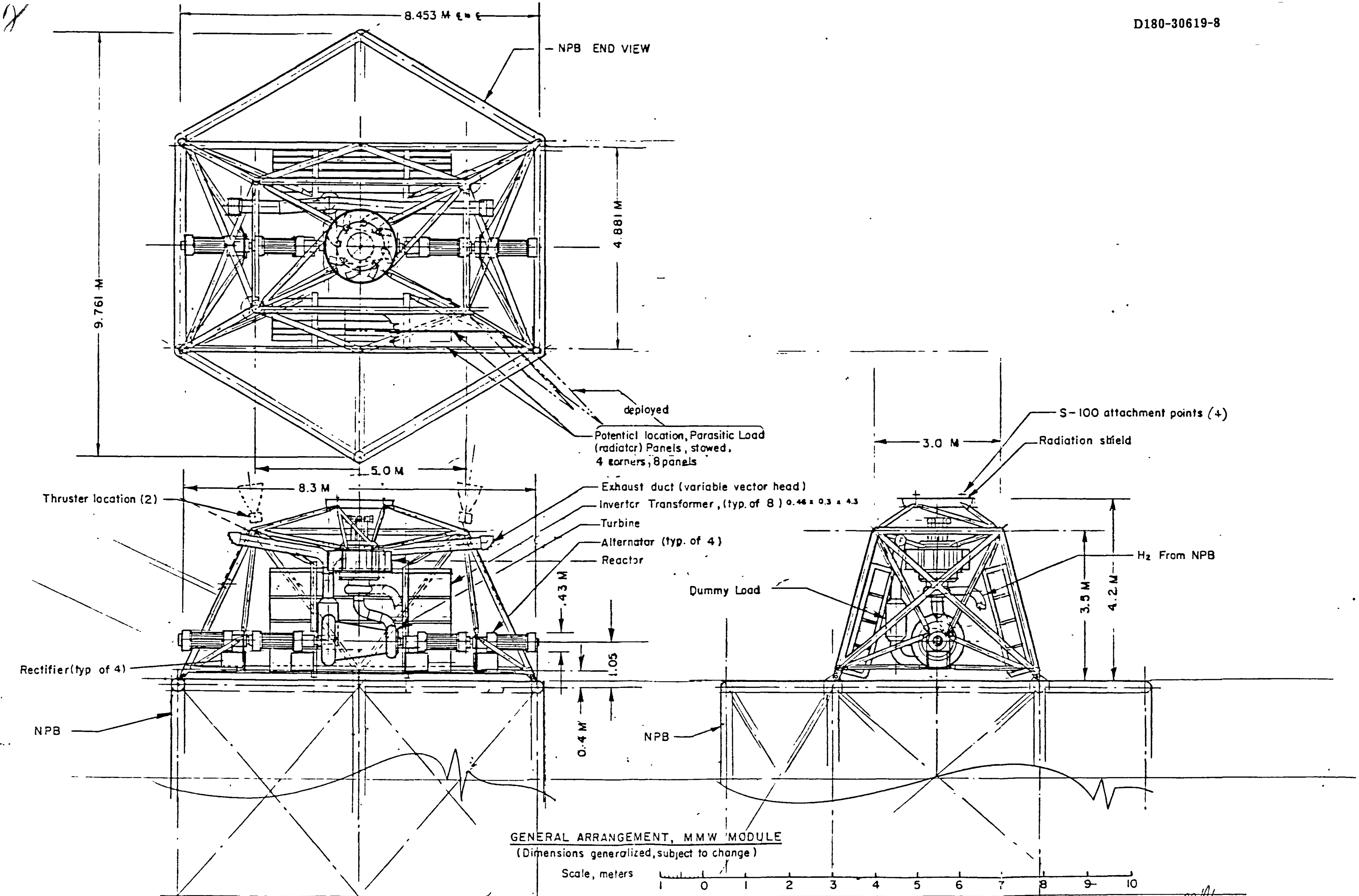

FIGURE 2. MSNPS PRELIMINARY CONFIGURATION 16

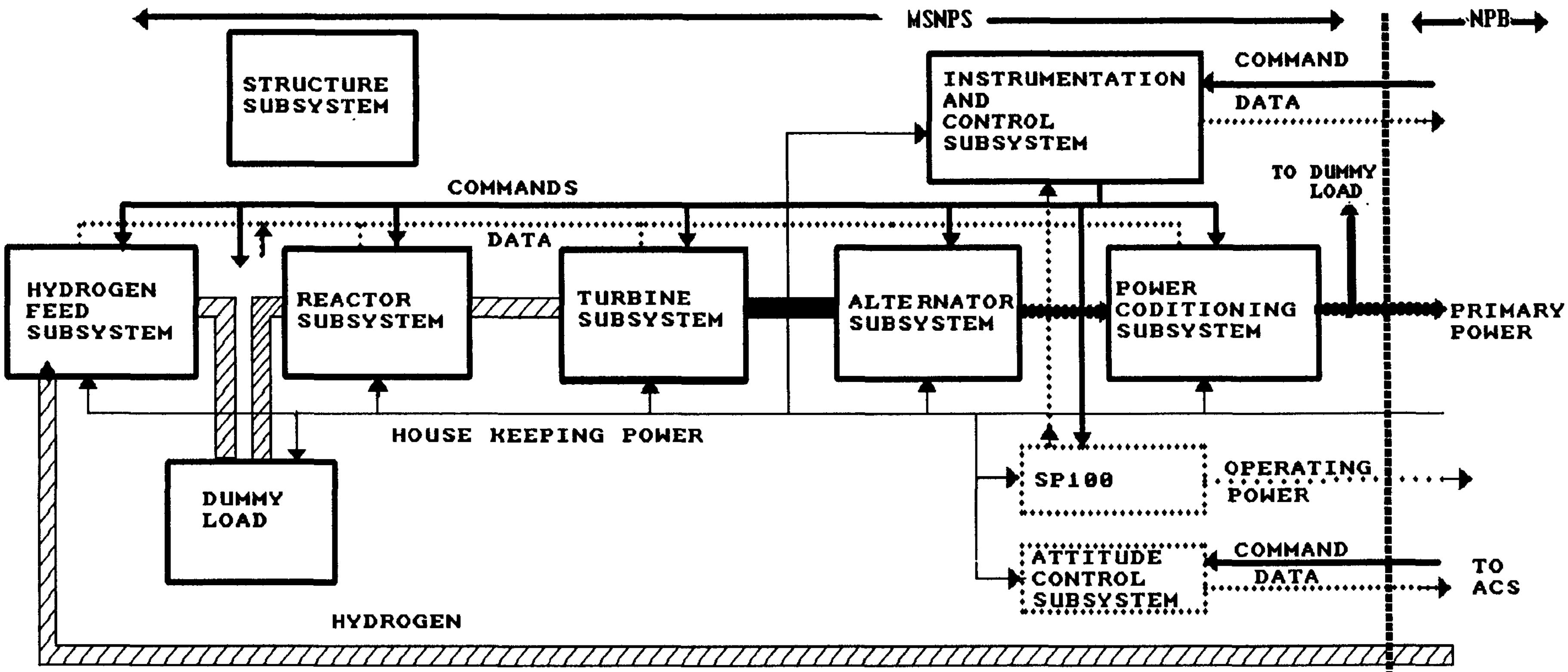

Figure 3 Space Nuclear Power System Functional Block Diagram

3.1.5 Interface Definitions.

The major interfaces are with the NPB and with the Launch Vehicle.

3.1.5.1 NPB.

A generalized view of the structural interface between the NPB and the MSNPS is shown in FIGURE 2. The detailed view of this interface is shown in FIGURE 4. Hydrogen used to cool the NPB shall be used as the coolant for the MSNPS. This interface is also depicted in FIGURE 4. A functional block diagram of the electrical and instrumentation and control interfaces is presented in FIGURE 3. The functional and design requirements are defined in the following:

3.1.5.1.1 Electrical-- Start-up power shall be furnished to the MSNPS by the NPB spacecraft. Once the (SP100) is operational it will furnish all housekeeping and low energy operational power for the spacecraft. The NPB power supply shall then be used as the source for the spacecraft emergency backup power. The electrical characteristics at the interface shall be as follows:

Startup power- TBD

SP100- TBD

MSNPS Operations- Alternating current shall be provided at the interface as follows:

Voltage- (10 to 20 kV)
Voltage Regulation- (+/- 5%) (See note 1)
Frequency-(50 to 100 kHz)
Frequency Regulation- (+/- 2%) (See note 1)

Note 1-- These values apply from the start of the five second hold period (see figure 9). Voltage control during the initial operation and 25% step may be +/-25% of the normal rms value.

3.1.5.1.2 Structure-- The MSNPS shall be capable of sustaining loads resulting from platform orbital transfer maneuvers while in any operational condition and at any power level, including startup and shutdown operations. The platform acceleration and velocity requirements are given in the SUPER Threat Document (See Section 2). The dynamic response of th MSNPS may be calculated in a free-free mode for the Phase I study.

3.1.5.1.3 Instrumentation and Control-- TBD.

3.1.5.1.4 Fluid-- Hydrogen shall be supplied at the interface by the NPB at TBD. (See Section 3.3.2 of the F&OR Rev. 1 June 1988)

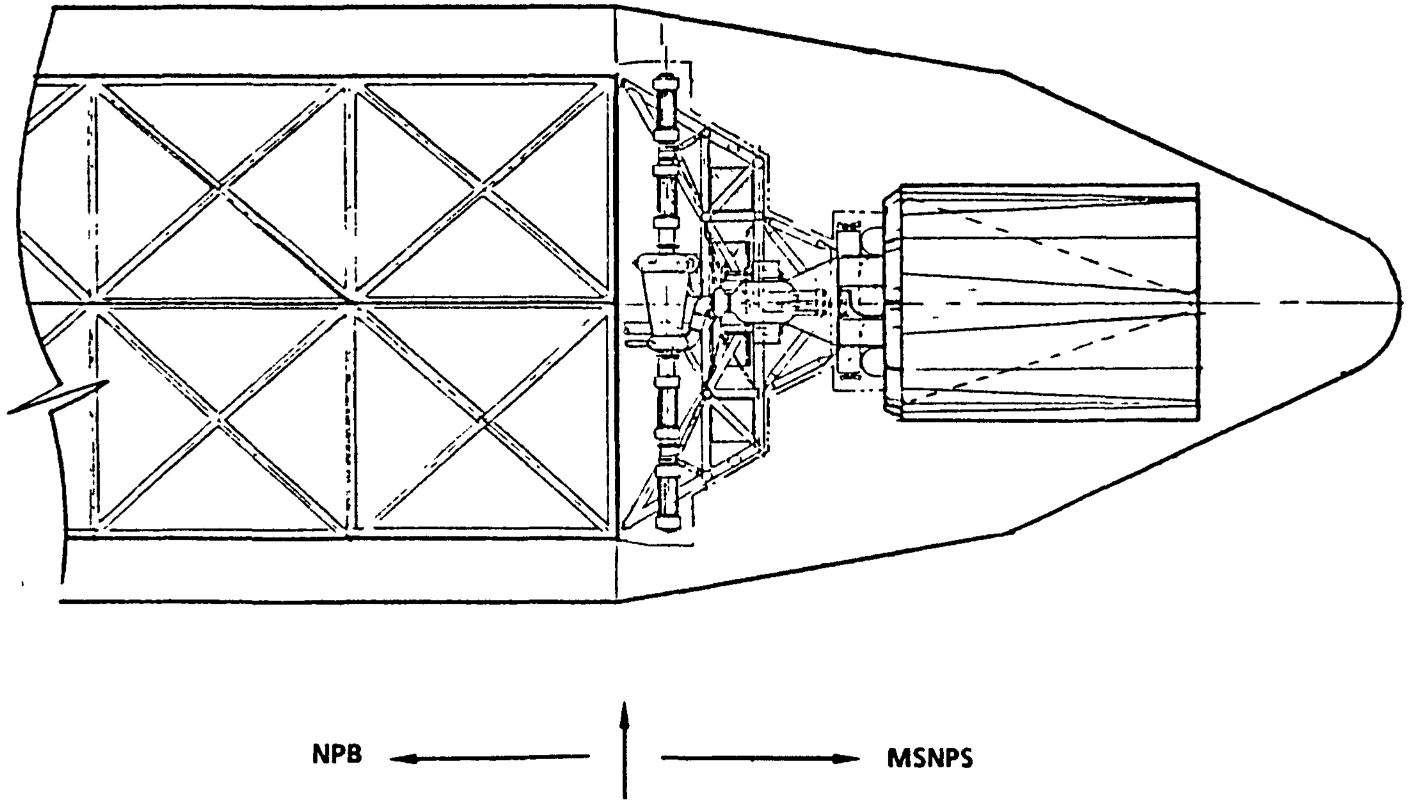

Figure 4. MSNPS to NPB Interface

3.1.5.1.5 Reactor Radiation Limits-- The Radiation shielding design shall include the following:

A. The power source shielding design shall limit the radiation dose to the system components so that the design life and reliability requirements specified in Sections 3.2.1.5 and 3.2.3 are met.

B. The shield design shall assure that the nominal dose 25 m from the reactor does not exceed (E) neutrons/cm2 and an (f) Rad of gamma The area to be shielded is assumed to have a circular cross section with a (15) m diameter.

C. Secondary radiation due to scattering from radiators and other components shall be considered in the shield design.

3.1.5.2 Launch Vehicle.

The baseline launch vehicle shall be the Advanced Launch System (ALS). The launch vehicle interface shall meet the following requirements.

3.1.5.2.1 Payload Capabilities-

Dynamic Envelope-The dynamic envelope for the launch vehicle is shown in FIGURE 5. The allowed cargo space for the MSNPS shall be 13 m. diameter x (TBD) m long).

Mass Properties- The mass of the MSNPS at launch shall not exceed (11,000 kg). The allowed cg location and moments of inertia are TBD.

Launch Dynamics- The MSNPS shall be designed to withstand axial loads of (4.3 g's) over a frequency range of (3 to 20 Hz) and lateral loads of (+2 g's) The payload shall be designed to withstand acoustic and shock environments which occur during launch as shown in FIGURE 6 and FIGURE 7 respectively.

Electrical- The present ALS design does not provide an electrical interface for the payload.

Thermal- The MSNPS shall withstand the aerodynamic heating of the launch vehicle fairing to temperatures of (395-425 K). When the fairing is jettisoned the free molecular heating (630-790 W/m2) shall be sustained.

Fluid- TBD

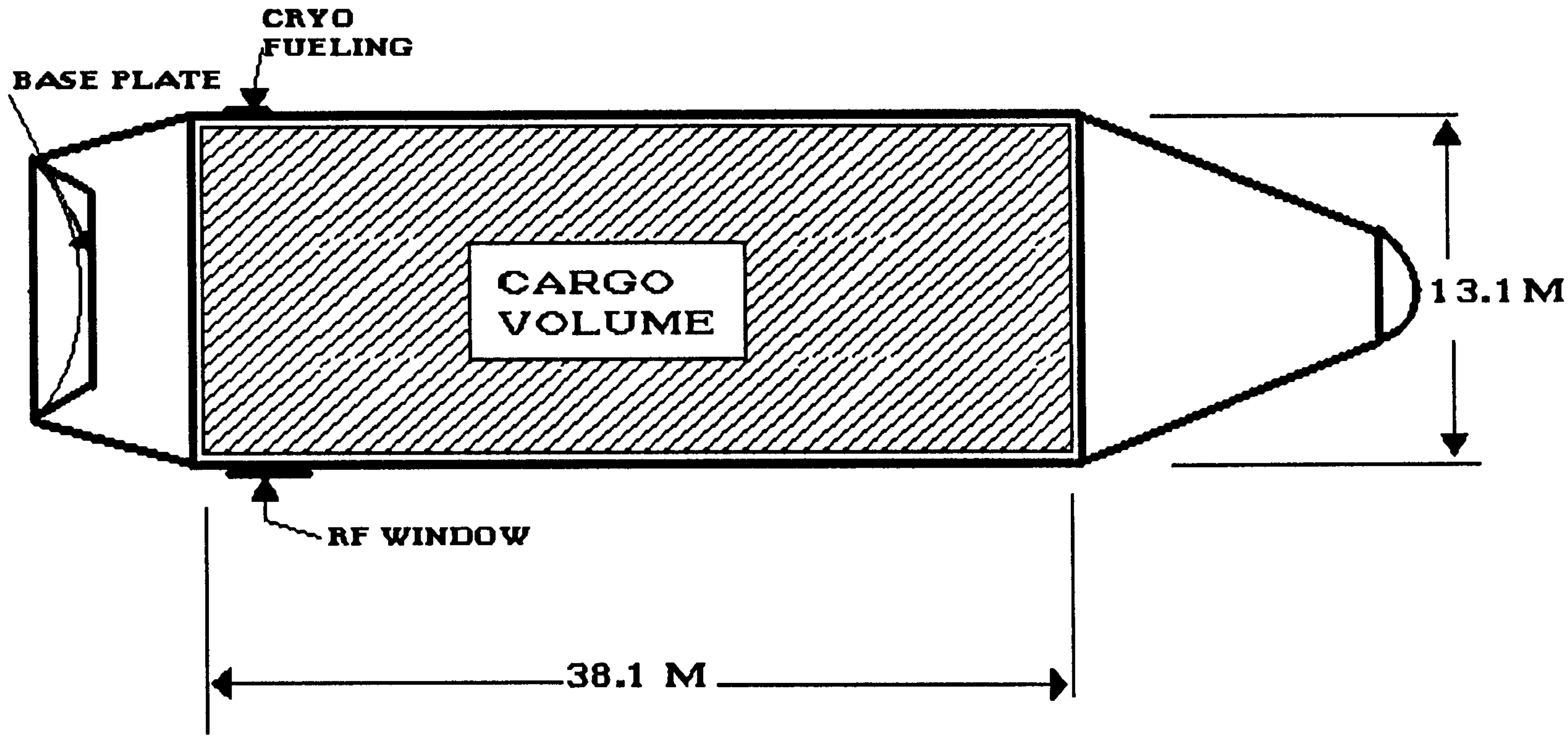

Figure 5. Launch Vehicle Dynamic Envelope

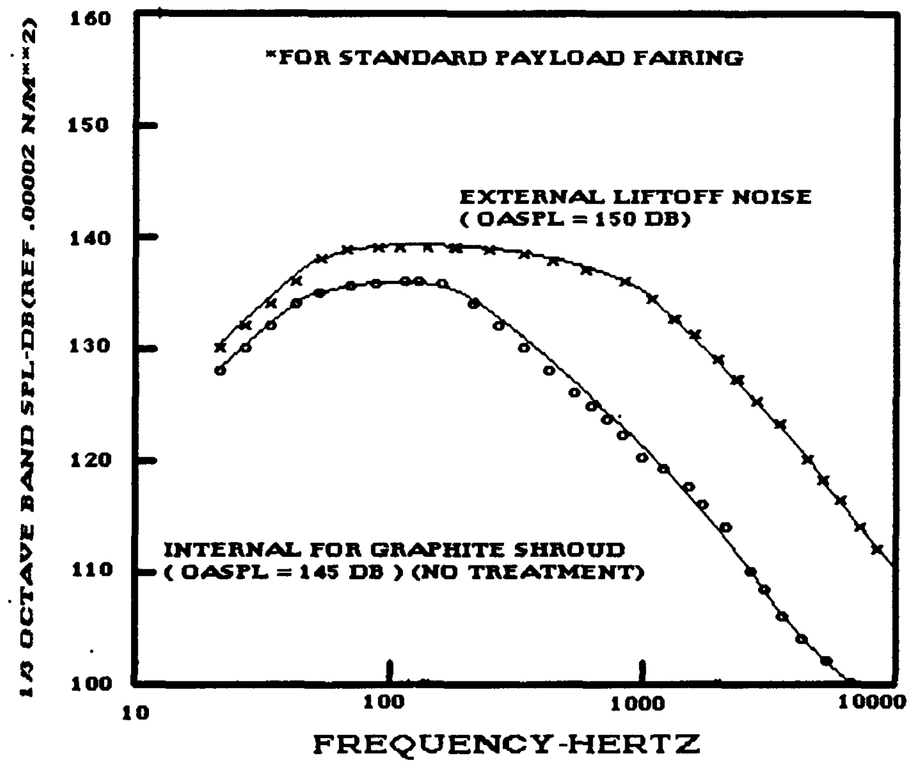

Figure 6. Preliminary ALS Accoustic Environment.

TBD

Figure 7. Launch Shock Environment

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3.1.6 Government Furnished Property List.

The following property shall be furnished by the government.

Property	Number	Reference
(SP100)	TBD	TBD
ACS Equipment(TBD)	TBD	TBD

3.1.7 Operational Concepts.

Operational concepts cover ground testing, launch, space assembly, orbit acquisition/testing,initial startup/full power testing, normal operation, deactivation, and disposal. Figure 8 presents a top level operational sequence which the design shall accommodate.

3.1.7.1 Ground Testing.

A. The system shall be designed to permit necessary component and subsystem operational tests to be completed prior to launch to validate the component/subsystem operability.

B. Ground support equipment and special test equipment shall be furnished to support the ground testing.

C. Testing of flight hardware shall not include reactor operation. No material which is radioactive as a result of ground testing shall be included in the launch hardware.

3.1.7.2 Launch.

The design goal is to use one launch vehicle for the entire MSNPS. If more than one launch is needed the MSNPS shall be designed so that all space assembly can be accomplished within (6 months) after the system has been placed in its initial orbit.

A. Launch Sequence- TBD

B.Initial Orbit- The initial orbit in which the MSNPS is placed, and at which any needed space assembly and preliminary check out is conducted, will be at an altitude (TBD km. and at an inclination of 70 degrees). The total period of time in the parking orbit for the initial operations is (TBD).

3.1.7.3 Space assembly.

No assembly in space is anticipated.

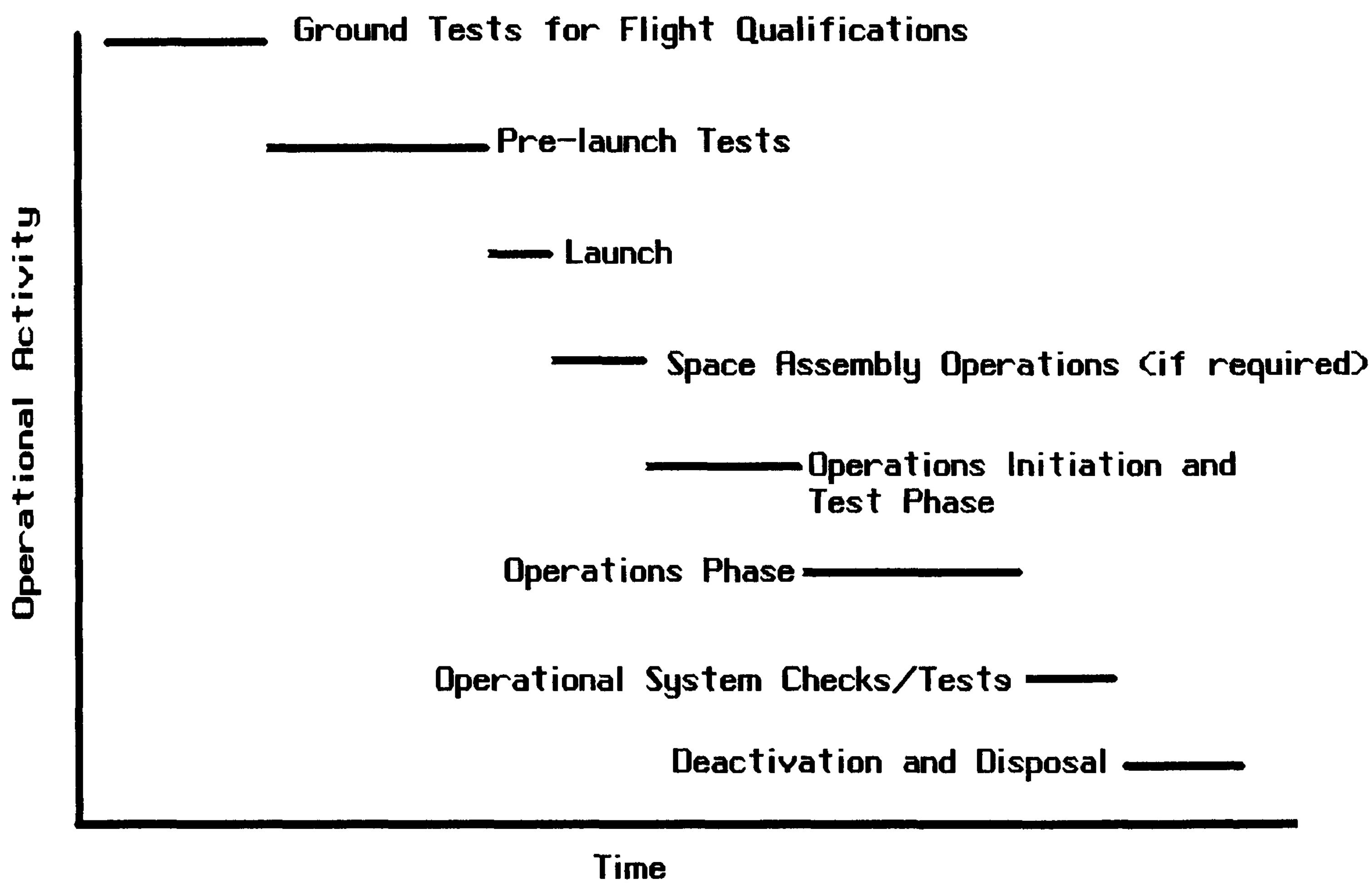

Figure 8 Operational Activity Sequence

3.1.7.4 Orbital Transfer.

Transfer from the initial orbit to the final operational orbit will be accomplished by the NPB spacecraft. The transfer from the low orbit to the maximum altitude and correct inclination orbit shall be accomplished over a (90) day period. The range of operational orbits are from a minimum nominal altitude of (I) km to a maximum nominal altitude of (J) km with any inclination between 60 to 90 dgs.

3.1.7.4 Initial Tests. TBD.

3.1.7.5 Startup.

FIGURE 9 provides a power loading scenario with time. Initially low power is supplied by the (SP100). This period of (70) secs. for the low power operations is used for the cool down of the hydrogen flow path. After the low power operation the MSNPS load demand is increased to 25% of full power as shown. This power will be held for about 5 seconds before ramping to 100% power. During the 5 second period the beam will be turned on. This cycle shall be repeated for at least 2 operational cycles.

3.1.7.6 Routine Integrated Tests.

Platform system tests will be conducted quarterly and will consist of 40 routine tests to include for each test a rapid startup, steady state operation at full power for a minimum of 10 seconds, and shutdown.

3.1.7.7 Final Shutdown. TBD.

3.1.7.8 Disposal. TBD.

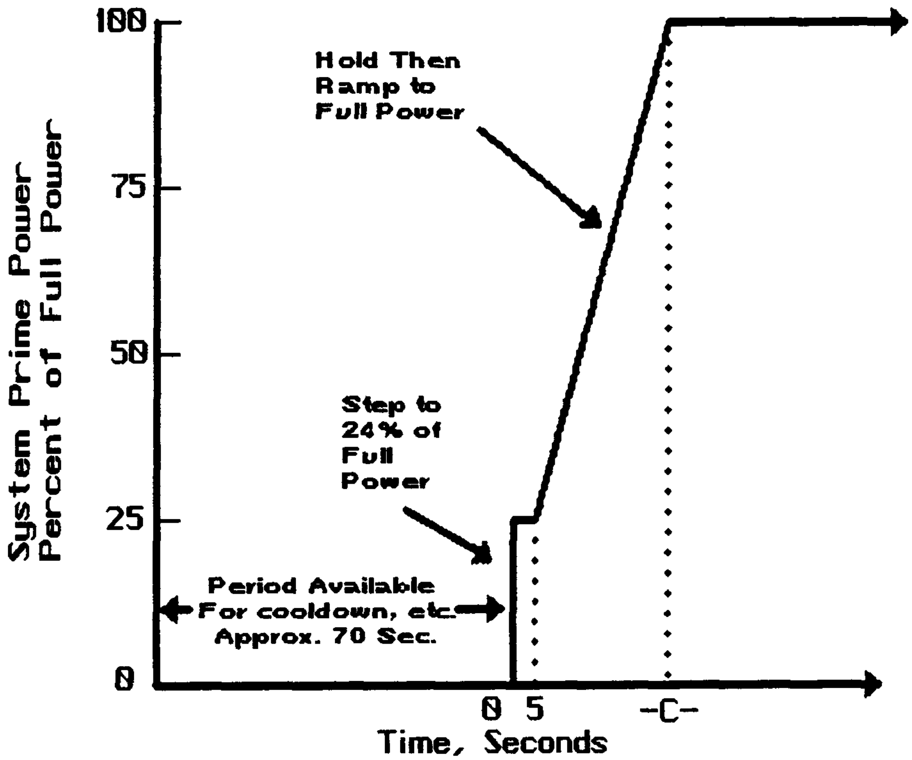

Figure 9. Startup Power Demand

3.2 CHARACTERISTICS

3.2.1 Performance

The Performance requirements are for a Category I MNSPS. Classified data is indicated by capital letters inparenthesis, e.g. (X). Values for these quantities arefound in the classified Appendix TBD.

3.2.1.1 Power System.

The power system shall be capable of producing at least two operational cycles, separated by (one hour). Each cycle shall provide (A1) MW of electrical power for up to (B) continuous seconds of engagement time. It shall be capable of 50 rapid start-ups and shutdowns (See section 3.1.7) to power levels up to full power. A rapid start-up shall produce full electrical power at the output of the Power Conditioning Subsystem within (C) seconds from the time the full-power demand signal is received by the Instrumentation and Control Subsystem.

3.2.1.2 Operating Time.

The power system shall be capable of producing full-power for a minimum total integrated operating time, including power and weapon systems shakedown and operational tests, of (D) seconds. The design will include additional operating time for preliminary system operational tests prior to being turned over as mission ready, or for unique concept specific test requirements.

3.2.1.3 Coolant.

Hydrogen from the NPB shall be available for use by the MSNPS at the conditions specified in Section 3.1.5.1.4. Additional hydrogen, tankage, and associated equipments shall be defined as an interface requirement in section 3.5.1.4.

3.2.1.4 Effluent.

Hydrogen effluent is acceptable. Any effluents other than hydrogen shall be contained. The hydrogen shall leave the MSNPS in a manner that will minimize degradation of the NPB operation.

3.2.1.5 Design Life.

The on station design life shall be (10) years. During this time up to (5) dormant periods of up to (18) months may occur in which no full power testing will be conducted.

3.2.1.6 Electrical Output.

The electrical output of the MSNPS shall meet the interface requirements in Section 3.1.5.1.1

3.2.1.7 Upset Conditions.

The MSNPS shall be designed to withstand faults resulting in partial or full load rejection as follows:

A. Partial Load Rejection: The system shall be capable of remaining on line following a step reduction in power from 100% to 25% of full load. This step load shall be followed by (TBD) seconds of operation at 25% load and then by an additional trip to zero load or by the reestablishing of full load within (10) sec. and operating at full power for up to (B) seconds or a reduced period determined by the remaining hydrogen supply.

B. Full Load Rejection: The system shall be capable of sustaining a load rejection from 100% load to zero load followed by a restart sequence as shown in FIGURE 9 except that the 70-second conditioniong periiod will not exist and a total starting period of about 10 seconds is desirable. After reestablishing full power, operation at full power for up to (B) seconds, or for a reduced period determined by the remaining hydrogen supply

3.2.2 Physical.

3.2.2.1 Configuration.

The reference configuration of the MSNPS shall be as shown in FIGURE 10.

3.2.2.2 Mass Properties. TBD.

3.2.2.3 Thermal. TBD.

3.2.2.4 Structural.

The design shall survive the following loads and vibration conditions.

3.2.2.4.1 Loads. The design shall incorporate features to minimize and mitigate the net effect of the forces, torques and related impulses produced by the MSNPS during normal, abnormal, and upset conditions. The magnitude of these loads are TBD.

3.2.2.4.2 Vibration. The vibration power spectrum during normal, abnormal and upset conditions is TBD. The impact of the MSNPS turbine and alternator induced vibration to the NPB shall be minimized.

Figure 10 TBD

3.2.3 Reliability.

The overall reliability shall be 0.95 for the mission requirements and design life specified in section 3.2.1.5. This 0.95 shall include reliability under natural threats (0.99) and reliability during operation (0.96).

3.2.4 Maintainability.

The MSNPS design shall include the following:

3.2.4.1 Diagnostics.

The system shall be designed with sufficient diagnostic instrumentation so that the status of all critical systems can be monitored routinely.

3.2.4.2 Installed Spares.

Installed spares will be included in the design if proven feasible.

3.2.4.3 Modularization.

The design shall incorporate methods to facilitate change out of key components/ subsystems during test, prelaunch, and in-space remote maintenance operations. The design shall accommodate easy installation and replacement of major components during factory assembly and of explosive ordnance devices, and other site replaceable items at the launch site when mated to the launch vehicle. Access shall be provided to those test plugs, harness break-in points, external umbilical connections, safe and arm devices, explosive ordnance devices, pressurant and fluid fill and drain valves, and other devices as might be required for prelaunch maintenance, alignment, and servicing. Alignment references for critically aligned components shall be visible directly or through windows or access doors.

3.2.5 Availability.

The MSNPS shall be capable of meeting the full power requirements in Section 3.2.1.1 and 3.2.1.2 at any time during the design life time specified in Section 3.2.1.5.

3.2.6 Environment.

The MSNPS design shall consider all environments including the ground and launch conditions. Further the MSNPS system will be subjected to natural radiation, meteoroids, and space debris as well as being exposed to hostile threats as part of the on-orbit environment. It shall be designed to survive these environments, within the overall reliability requirements in Section 3.2.3. Specific design requirements for the expected environments are presented below.

3.2.6.1 Ground Environment

The ground environmental conditions for MSNPS design shall be as defined in Section 5 and in the Environmental Requirements (DS89-832).

3.2.6.2 Launch Environment.

The launch environmental conditions for the MSNPS design shall be as defined section 3.1.5.2 and in (DS89-832).

3.2.6.3 On-orbit Environment.

The on-orbit environment is defined in (DS89-832) and shall include the following.

3.2.6.3.1 Natural Plasma.

The MSNPS shall be capable of operation in a space plasma environment as specified in NASA-TM-82478. The design shall also be in accordance with NASA Technical Paper 2361.

3.2.6.3.2 Natural Radiation.

Tables 1 to 3 specifies the natural radiation design environment.

3.2.6.3.3 Reactor Radiation.

The radiation field from the reactor shall be TBD. These values shall be used for material selection.

3.2.6.3.4 NPB Induced Environment.

The environments induced by the NPB system include magnetic fields, vented hydrogen, and RF generated fields. These are TBD.

Table 1. Proton Fluence-Energy Spectra Natural Radiation Environment

Energy (MeV)	Fluence (particles/ cm2-day)	Energy (MeV)	Fluence (particles/ cm2-day)
1.0-01	2.8+10	3.5+01	2.6+09
2.0-01	2.8+10	4.0+01	2.1+09
5.0-01	2.7+10	4.5+01	1.9+09
1.0+00	2.6+10	5.0+01	1.7+09
2.0+00	2.5+10	5.5+01	1.6+09
3.0+00	2.3+10	6.0+01	1.5+09
4.0+00	2.1+10	7.0+01	1.3+09
5.0+00	1.9+10	8.0+01	1.2+09
6.0+00	1.8+10	9.0+01	1.1+09
8.0+00	1.4+10	1.0+02	9.4+08
1.0+01	1.1+10	1.5+02	5.3+08
1.5+01	6.4+09	2.0+02	3.0+08
2.0+01	3.9+09	3.0+02	1.1+08
2.5+01	3.1+09	4.0+02	4.0+07
3.0+01	2.6+09	5.0+02	1.4+07

Table 2. Electron Fluence-Energy Spectra External Environment-Solar Minimum Period.

Energy (MeV)	Fluence (particles/ cm2-day)	Energy (MeV)	Fluence (particles/ cm2-day)
1.00-01	5.5+12	2.50+00	5.2+09
2.00-01	2.1+12	2.75+00	2.0+09
3.00-01	9.5+11	3.00+00	7.4+08
4.00-01	5.2+11	3.25+00	2.1+08
5.00-01	2.9+11	3.50+00	6.2+07
6.00-01	2.0+11	3.75+00	1.8+07
7.00-01	1.4+11	4.00+00	5.3+06
8.00-01	1.0+11	4.25+00	1.5+06
9.00-01	7.8+10	4.50+00	4.4+05
1.00+00	6.0+10	4.75+00	1.2+05
1.25+00	3.8+10	5.00+00	0.0
1.50+00	2.4+10	5.50+00	0.0
1.75+00	1.6+10	6.00+00	0.0
2.00+00	1.1+10	6.50+00	0.0
2.25+00	7.6+09	7.00+00	0.0

Table 3. Electron Fluence-Energy Spectra External Environment-Solar Maximum Period

Energy (MeV)	Fluence (particles/ cm2-day)	Energy (MeV)	Fluence (particles/ cm2-day)
1.00-01	1.3+13	2.50+00	5.2+09
2.00-01	5.9+12	2.75+00	2.0+09
3.00-01	2.6+12	3.00+00	7.4+08
4.00-01	1.0+12	3.25+00	2.1+08
5.00-01	3.9+11	3.50+00	6.2+07
6.00-01	2.5+11	3.75+00	1.8+07
7.00-01	1.6+11	4.00+00	5.3+06
8.00-01	1.1+11	4.25+00	1.5+06
9.00-01	8.2+10	4.50+00	4.4+05
1.00+00	6.0+10	4.75+00	1.2+05
1.25+00	3.8+10	5.00+00	0.0
1.50+00	2.4+10	5.50+00	0.0
1.75+00	1.6+10	6.00+00	0.0
2.00+00	1.1+10	6.50+00	0.0
2.25+00	7.6+09	7.00+00	0.0

3.2.6.3.5 Hostile Threat.

The MSNPS design shall be evaluated as to its survivability in the hostile threat environment specified in Section 10.

3.2.6.3.6 Meteoroid and Space Debris.

The MSNPS shall be designed to (operate) in a Meteoroid and Space Debris environment as specified in Table 4 and 5 respectively. Meteoroid particles shall be assumed to have a mass density of 0.5 g/cm3 and an impact speed of 20 km/s. Space debris shall be assumed to consist of spherical fragments of aluminum impacting the system at 10 km/s. (Reference NASA-SP-8042 for meteoroid damage assessment and section 4.2.2.2 of the MSNPS Functional and Operational Requirements for space debris damage calculations.)

3.2.6.3.7 Atomic Oxygen.

The system shall be designed to operate in an environment containing atomic oxygen as specified in NOAA-S/T 76-1562.

3.2.6.3.8 Natural Thermal.

The system shall be designed to operate in the natural thermal radiation environment due to direct solar radiation, Earth albedo and Earth long wave radiation. The space heat sink effective temperature is (220K) including the above sources.

Table 4. Space Debris Mass Fluence For Impacts of Debris of Mass (M) or Greater-10 Year Total Fluence.

Mass (M) (grams)	Impacts/m2 (surface area)
10-6	5.0
10-5	1.0
10-4	2.6 x 10-1
10-3	5.0 x 10-2
10-2	1.0 x 10-2
10-1	1.3 x 10-3
10	2.3 x 10-4

Table 5. Meteoroid Mass Fluence For Impacts of Mass (M) or Greater-10 Year Total Fluence.

Mass (M) (grams)	Impacts/m2 (surface area)
10-6	18.0
10-5	1.1
10-4	6.9 x 10-2
10-3	4.2 x 10-3
10-2	2.6 x 10-4
10-1	1.6 x 10-5
10	9.6 x 10-7

3.2.7 Nuclear Control. TBD.

3.2.8 Transportability. TBD

The space equipment shall be designed for ground transportability and for air transportability. The space equipment to be mounted as an assembly in the launch vehicle shall be capable of being transported and handled in both the vertical and horizontal attitude. Attach points for transportation and handling shall be provided on assemblies weighing more than 100 kilograms. The modes of transportation, support, and types of protective covers use shall be chosen to assure that transportation and handling do not impose thermal, vibration, acoustic, or shock environmental conditions which exceed those imposed by operational modes.

3.2.9 Growth.

The system design will include growth or downscale capability. The growth capability will include the Category III power level; however, coverage of this entire range is optional. Consideration of downscaling by a factor of (3 to 5) would be reasonable.

3.3 DESIGN AND CONSTRUCTION.

The design and construction requirements contained below are pertinent to the development and production of all items of equipment and are considered to be a minimum requirement. The design shall facilitate production, installation and removal, and maintenance as well as operation.

In addition to the requirements below, the following general specifications shall be complied with as applicable:

A. TBD
B. TBD
. .
. .
. .
(n) TBD

3.3.1 Materials, Processes and Parts.

Materials, processes and parts (MP&P) shall meet the following requirements:

Selection of MP&P shall be made from an approved Qualified Products List (QPL). Materials and parts included in this list shall be compatible and meet the design life under the design operating conditions. The basis for selection, compatibility with fluids, lubricants, and other materials shall be included in the QPL for each item as applicable.

Unless otherwise specified in the contract, the parts, materials, and processes shall be selected and controlled in accordance with documented procedures to satisfy the specified requirements. The selection and control procedures shall emphasize quality and reliability to meet the mission requirements and to minimize total life cycle cost for the applicable system. An additional objective in the selection of parts, materials, and processes shall be to minimize the variety of parts, related tools, and test equipment required in the fabrication, installation, and maintenance of the space equipment. However, identical electrical connectors, identical fittings, or other identical parts shall not be used on space equipment where inadvertent interchange of items or interconnections could cause possible malfunction. The parts, materials, and processes selected shall be of sufficient, proven quality to allow the space equipment to meet the functional performance, reliability, and strength as required during its life cycle including all environmental degradation effects. Parts shall be in accordance with MIL-STD-1547.

Care shall be exercised in the selection of materials and processes to avoid stress corrosion cracking in highly stressed parts and to preclude failures induced by hydrogen embrittlement (Reference MFSC-SPEC-522A). Parts, materials, and processes shall be selected to ensure that any damage or deterioration from the space environment or the outgassing effects in the space environment would not reduce the performance of the space equipment beyond the specified limits.

Material Selection. Materials shall be selected that have demonstrated their suitability for the intended application (Reference MSFC-HDBK-527 Materials Selection List For Space Hardware Systems and MIL-HDBK-5,and-17). Where practicable, fungus inert materials shall be used. Combustible materials or materials that can generate toxic outgassing or toxic products of combustion shall not be used if cost-effective alternatives exist. Materials shall be corrosion resistant or shall be suitably treated to resist corrosion when subjected to the specified environments. Protection of dissimilar metal combinations shall be in accordance with MIL-STD-889. Structural properties of materials for use in space applications shall be taken from MIL-HDBK-5 for metals and from MIL-HDBK-17 for plastics. Properties not listed shall be based upon appropriate material tests. When such data are not available, they shall be determined by approved test methods. A sufficient number of tests to establish values for mechanical properties on a statistical basis shall be performed.

Materials shall be selected for low outgassing in accordance with SP-R-0022 (NASA JSC). The total mass loss shall be less than 1 percent, and the collected volatile condensable material shall be less than 0.1 percent when heated in vacuum to 125 deg C and collected at 23 deg C. The hygroscopic nature of many materials such as composites, electroformed nickel, and anodic coatings for aluminum should be recognized, if they are used, since they emit water in a vacuum and therefore may be unsuitable for some applications.

Finishes. The finishes used shall be such that completed devices shall be resistant to corrosion. The design goal shall be that there would be no destructive corrosion of the completed devices when exposed to moderately humid or mildly corrosive environments that could inadvertently occur while unprotected during manufacture or handling, such as possible industrial environments or sea coast fog that could be expected prior to launch. Destructive corrosion shall be construed as being any type of corrosion which interferes with meeting the specified performance of the device or its associated parts. Protective methods and materials for cleaning, surface treatment, and applications of finishes and protective coating shall be in accordance with MIL-F-7179. Neither cadmium nor zinc coatings shall be used. Chromium plating shall be in accordance with QQ-C-320. Nickel plating shall be in accordance with QQ-N-290. Corrosion protection of magnesium shall be in accordance with MIL-N-3171. Coatings for aluminum and aluminum alloys shall be in accordance with MIL-C-5541 or MIL-A-8625.

3.3.2 Electromagnetic Radiation.

Space equipment shall be designed for electromagnetic compatibility in accordance with MIL-STD-1541. For Shuttle launched equipment, the requirements of JSC 07700, Vol. XIV also apply. Although Ground Support Equipment (GSE) need not meet the flight electromagnetic compatibility requirements, it is necessary that GSE not be a source of interference to, or be affected by, flight hardware. GSE which is to be used at the launch site, particularly that for Shuttle launched equipment, must also meet the emission requirements imposed by the launch site.

MDNPD specific electromagnetic requirements are defined in DS89-832-6.

3.3.3 Name Plates and Product Marking. TBD.

3.3.4 Workmanship. TBD.

3.3.5 Interchangeability.

To the extent practicable, the design of the space equipment shall make provisions for the factory replacement of components and subassemblies and for the prelaunch installation or replacement of explosive ordnance devices, and other similar equipment.

3.3.6 Safety.

The MSNPS design shall provide for the desired level of public safety, health protection, environmental protection, and special nuclear material (SNM) protection when used during its designated mission. The detailed requirements are presented below.

3.3.6.1 General.

The design for all classes of equipment shall be such that hazards to personnel, to the system, and to the associated equipment are either eliminated or controlled throughout all phases of the system life-cycle. The safety requirements shall be in accordance with MIL-STD-1574.

3.3.6.1.1 Space Transportation System Payloads. For all payloads which are to be launched by the Space Transportation System (STS), the safety requirements shall also be in accordance with Chapter 2 of NHB 1700.7 (NASA). For these payloads, it is required that the payload must tolerate a minimum number of failures and/or operator errors determined by the consequence of any hazardous functions. For catastrophic hazards or hazards that would result in personnel injury, loss of the orbiter or STS facilities and equipment, the hazard needs to be controlled such that no combination of two failures, operator errors, or radio frequency signals would unleash the hazard. For critical hazards or hazards that would result in damage to STS equipment or in the use of contingency or emergency procedures, the hazard needs to be controlled such that no single failure, or operator error, would unleash the hazard. Hazardous functions are thereby controlled with either two or three inhibits, depending on whether the hazard is critical or catastrophic.

In addition, Chapter 2 of NHB 1700.7 (NASA) defines safety requirements for space equipment structural design, stress corrosion, pressure vessels, sealed containers, hazardous materials, pyrotechnics, destruct subsystems, radiation, electrical subsystems, flammable atmospheres, and reflown hardware.

3.3.6.1.2 Ground Equipment. The safety requirements for ground equipment shall be in accordance with SAMTO HB S-100 (designated by NASA as NHB 1700.7).

3.3.6.2 Intact Reentry.

The reactor core shall be designed to remain intact (fuel and associated structure shall remain contiguous) during an inadvertent reentry associated with initial deployment, operation, or subsequent disposal to a storage orbit.

3.3.6.3 Reactor Cooling.

Reliable reactor cooling shall be provided for all normal operations (including decay heat removal) and credible accidents to prevent core disruption and/or structural degradation that could compromise the transfer of this system to a storage orbit or result in release of fission products to the space environment.

3.3.6.4 Reactor Power Control.

The instrumentation and control subsystem in conjunction with the reactor control and protection components shall be designed to reliably control the reactor power during operation (including off normal and credible accidents). These control components shall be capable of preventing core disruption and/or structural degradation that could compromise the ability to transfer this system to a storage orbit or result in the release of fission products to the space environment.

3.3.6.5 Subcriticality.

The reactor shall be design remain subcritical under the following conditions:

A. For credible singular failures or initiating events during normal assembly, transportation, handling, prelaunch, ascent, orbit acquisition, deployment, planned maintenance, planned shut downs, and transfer to storage orbit.

B. Associated with all credible accidents such as launch vehicle explosions of range safety destruct. Accident environments to which the reactor may be exposed include immersion in water, soil, or other fluids; propellant fires; dynamic over pressure; shrapnel fields; impacts; and combinations thereof.

C. An inadvertent reentry and subsequent impact with the Earth during initial deployment, operation, and subsequent transfer to a storage orbit.

3.3.6.6 Toxic Materials Control.

The MSNPS shall be designed to minimize the quantities of toxic materials and to prevent a significant release and dispersal of these materials during all mission phases for both normal operation and environments associated with credible failures and accidents.

3.3.6.7 Benign Fuel.

The reactor shall not be operated (except for zero power testing that yields negligible radioactivity at the time of launch) until a stable orbit or flight path is achieved. The un-irradiated fuel shall pose no significant health of environmental hazard.

3.3.6.8 Transfer To Storage Orbit.

The MSNPS shall be designed such that the entire space platform can be transferred to a storage orbit at the end of its life. The capability to transfer the separated MSNPS to storage orbit will be included. Thus, the reactor shall be designed to prevent such core disruption and structural degradation during and following operation that could compromise the reactor's capability of being transferred to the storage orbit.

3.3.7 Human Engineering.

Throughout the design and development of the equipment, the applicable criteria in MIL-STD-1472 shall be judiciously applied to obtain effective, compatible, and safe man-equipment interactions. Provisions such as tabs, collars, and different thread sizes shall be employed to prevent incorrect assembly which may impair the intended functions.

3.3.8 Corrosion Control and Finishes. TBD.

3.3.9 Structural Criteria.

3.3.9.1 General Structural Design.

The primary support structure for the space equipment shall possess sufficient strength, rigidity, and other characteristics required to survive the critical loading conditions that exist within the envelope of handling and mission requirements. It shall survive those conditions in a manner that assures safety and that does not reduce the mission success probability. The primary support structure of the space equipment shall be electrically conduciveto establish a single point electrical ground. The structure of equipment to be launched shall be designed to meet the applicable safety requirements of NHB 1700.7.

MSNFS specific static and dynamic load requirements are defined in DS89-832-3 and -4.

3.3.9.2 Strength Requirements.

Yield Load. The structure shall be designed to have sufficient strength to withstand simultaneously the yield loads, applied temperature, and other accompanying environmental phenomena for each design condition without experiencing yielding or detrimental deformation.

Ultimate Load. The structure shall be designed to withstand simultaneously the ultimate loads, applied temperature, and other accompanying environmental phenomena without failure.

3.3.9.3 Stiffness Environments.

Dynamic Properties. The structural dynamic properties of the equipment shall be such that its interaction with the space vehicle control subsystem does not result in unacceptable degradation of performance.

Structural Stiffness. Stiffness of the structure and its attachments shall be controlled by the equipment performance requirements and by consideration of the handling, launch, and landing environments. Special storage provisions shall be used, if required, to prevent excessive dynamic amplification during transient flight events such as launch. Component Stiffness. The fundamental resonant frequency of a component weighing (23) kilograms or less shall be 50 Hertz or greater when mounted on its immediate support structure.

3.3.9.4 Factors of Safety.

The factory of safety of the structure is the ratio of the limit load to the allowable load.

Flight Limit Loads. Available options for structural design are listed in Table 6.

Table 6. Structural Design Factors of Safety

Design and Test Options	Design Factor of Safety on Limit Loads		
	Yield	Ultimate	
	(FSy)	(FSu) Unmanned Events	(FSu) Manned Events
Dedicated Test Article	1.00	1.25	1.40
Test One Flight Article	1.25	1.40	1.40
Proof Test Each Flight Article	1.10	1.25	1.40
No Static Test	1.60	2.00	2.25

Pressure Loads. Factors of safety for pressure loads shall be determined individually for each pressure vessel, based on tests to establish material characteristics and an analysis of life requirements and other environmental exposure. Proof and burst pressure factors shall be established at levels that ensure structural integrity, structural life, and safety throughout all phases. The values listed in Table 7 are to be considered as limiting lower bounds.

3.3.9.5 Design Load Conditions.

The equipment shall be capable of withstanding all design load conditions to which it is exposed in all mission phases, as applicable: ground, prelaunch, erection, post-launch, boost, and on-orbit. During the orbit phase, all of the following shall be considered: maneuvering loads, vehicle spin, meteoroid environment, radiation environment, and other environmental factors, such as thermal effects due to internal heating, solar heating, eclipses, and extreme cold due to ambient space environment.

Table 7. Pressurized Components Factors of Safety

Component c/	Design Ultimate	Acceptance (Proof)	Qual
Solid Rocket Motor Cases b/	1.25	1.10 a/	1.25 a/
Pneumatic Vessels b/	2.00	1.50 a/	2.00 a/
Lines, Fittings, and Hoses:			
Less than 3.81 cm dia. d/	4.00	2.00 a/	4.00 a/
3.81 cm dia. and larger d/	1.50	1.10 a/	1.50 a/
Other Pressurized Components	2.50	2.00 a/	2.50 a/

Notes:

a/ No yielding permitted at acceptance (proof) test pressure, and no rupture at qualification pressure.

b/ Factors of safety shown are minimum values applicable to metallic pressure vessels for which ductile fracture mode is predicted via a combination of stress and fracture mechanics analyses. Design of metallic pressure vessels for which brittle fracture mode is predicted by these analyses shall be in accordance with fracture mechanics methodology wherein the proof factor as well as the design ultimate factor of safety shall be established to provide a minimum of four times the specified service life against mission requirements. In addition, a fracture control program shall be established to prevent structural failure due to the initiation of propagation of flaws or crack-like defects during fabrication, testing, and service life.

c/ All pressure vessels, sealed containers, lines, fittings, and other pressurized components of equipment to be launched shall be designed to meet the applicable safety requirement of NHB 1700.7 (NASA) and SAMTO HB S-100 (designated by NASA as KHB 1700.7).

d/ 3.81 cm diameter is equivalent to 1.5 inches diameter.

3.3.10 Fluid Design Criteria

3.3.10.1 Pressurized Components.

Fluid subsystems and pressurized components shall be in accordance with MIL-STD-1522 and NHB 1700.7.

3.3.10.2 Tubing.

Tubing shall be stainless steel, where practicable. Tubing joints shall be thermal welded butt joints, where practicable.

Tubing design shall incorporate provisions for cleaning and to allow proof testing.

3.3.10.3 Separable Fittings.

Separable fittings shall have redundant sealing surfaces, such as double "O" rings, and be of the "parallel loaded" type. "Parallel loaded" means that the fitting contains a compressed element which exerts outward pressure on the other elements of the fitting such that both seals are maintained even if relaxation occurs. Separable fittings shall have provisions for locking. Separable fittings should be accessible for leak tests and for torque checks. Separable fittings should not be designed or assembled with lubricants or fluids that could cause contamination or could mask leakage of a poor assembly.

3.3.11 Mechanical Assemblies Design Criteria.

Deployment mechanisms, sensor mechanisms, pointing mechanisms, drive mechanisms, despin mechanisms, separation mechanisms, and other moving mechanical assemblies shall be in accordance with DOD-A-83577.

3.3.12 Explosive Ordnance Design Criteria.

Explosive ordnance shall be in accordance with DOD-E-83578.

3.3.13 Wiring Design Criteria.

The electrical wiring harnesses between space components shall be in accordance with DOD-W-83576.

3.3.14 Electronic Components Design Criteria.

Electronic components shall be in accordance with DOD-E-8983. Parts shall be in accordance with Mil-std-1547.

3.3.15 Computer Software Criteria. TBD.

3.4 DOCUMENTS

TBD.

3.5 LOGISTICS

TBD.

3.6 PERSONNEL AND TRAINING

3.7 SUBSYSTEM CHARACTERISTICS

The functional description, interface definitions performance parameters, physical characteristics, and special safety considerations for each of the subsystems identified in Section 3.1.1 are presented below.

3.7.1 Alternator

3.7.1.1 Functional Description

General

The alternator subsystem shall convert the rotational energy of the turbine subsystem into electrical energy in a suitable form so that the power conditioning subsystem can optimally condition and distribute the required power to the MSNPS-NPB interface.

Four round-rotor-synchronous alternators shall be driven by two turbines. Two generators per each turbine. The output of each alternator shall be fed into its own dedicated power conditioning subsystem module.

Each alternator shall be instrumented so that proper operation can be monitored for safe operation and for proper control.

Operating temperatures shall be maintained by use of passive thermal control methods as well as through the use of the available hydrogen coolant.

3.7.1.2 Interface Definitions

3.7.1.2.1 Subsystem to Subsystem

Turbine Subsystem-The mechanical interface with the turbine subsystem is TBD.

Hydrogen Feed Subsystem- The mechanical and fluid interfaces with the hydrogen feed subsystem are TBD.

Power Conditioning Subsystem- The electrical interface with the PCS is TBD.

Instrumentation and Control Subsystem- The electrical interface with the ICS is TBD.

3.7.1.2.2 System

Housekeeping power per Section 3.7.1.4.1 shall be obtained from the NPB in accordance with Section 3.1.5.1.

3.7.1.3 Performance Parameters

The following performance parameters shall be met:

1.	Rating per alternator	(A) MVA @ .86 pf (lagging)
2.	Speed	15000 rpm
3.	Efficiency	96.8 %
4.	Cooling	Hydrogen at TBD degK
5.	Voltage	307/532 volts ac
6.	Poles	8

3.7.1.4 Physical Characteristics

3.7.1.4.1 Power- Housekeeping power shall not exceed TBD.

3.7.1.4.2 Mass- The mass of the subsystem shall not exceed (2324) Kg.

3.7.1.4.3 Volume- Each alternator allowed envelope is TBD.

3.7.1.5 Special Safety Considerations

TBD

3.7.2 Hydrogen Feed

3.7.2.1 Functional Description

The hydrogen feed subsystem (HFS) shall condition the liquid hydrogen supplied by the NPB for use by the NPB. It will then condition the hydrogen that has been used to cool the NPB components for use as the working fluid//gas in the power system. The subsystem shall consist of one NPB turbopump, one reactor feed pump, and the hydrogen supply ducting. The later shall consist of the reactor feed line, the reactor to turbine duct and the the turbopump duct.

3.7.2.2 Interface Definitions

3.7.2.2.1 Subsystem to Subsystem

The main subsystem interfaces are the mechanical interface between the hydrogen feed line and the reactor, as well as the turbopump duct. These interfaces are depicted in Figure 11A.

The electrical interface with the ICS is TBD.

3.7.2.2.2 System

The interfaces with the NPB are shown in Figure 11A

3.7.2.3 Performance Parameters

The following performance parameters shall be met:

Pump Requirements

Simplified Hydrogen Cooling System Schematic

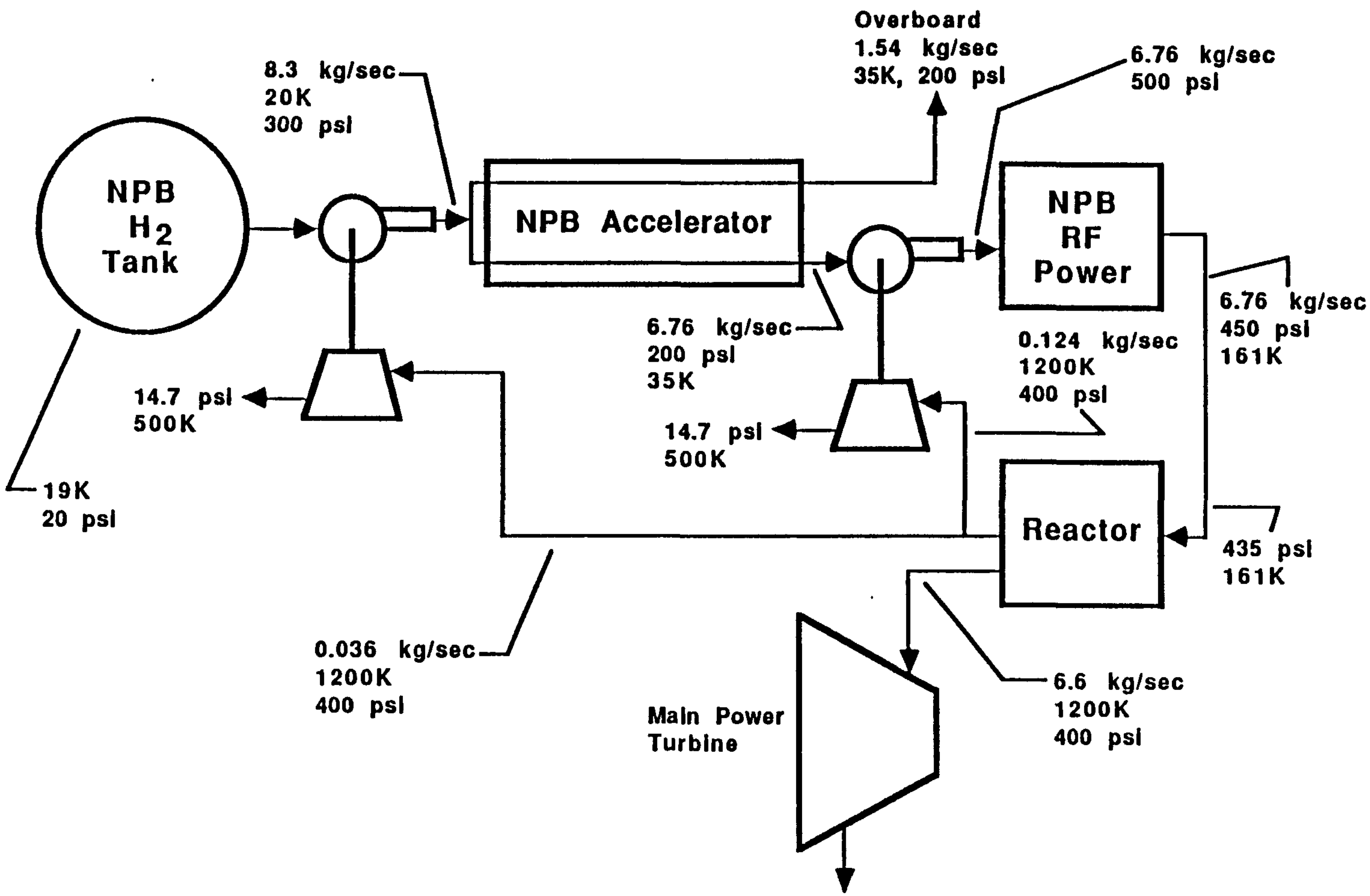

Figure 11A. Hydrogen Feed Interfaces

45a

D180-30619-8

Fluid	Liquid Hydrogen
Inlet temperature	20K
Inlet pressure	Saturation pressure
Flowrate	20 kg/sec(44 lb/sec)
Discharge pressure	XX Mpa (653 PSI)

Turbine Requirements

Fluid	Gaseous hydrogen
Inlet temperature	850K or 1200K
Inlet pressure	XXX MPa (400 PSI)
Flowrate	TBD
Discharge pressure	Vacuum

3.7.2.4 Physical Parameters

3.7.2.4.1 Power- TBD

3.7.2.4.2 Mass- The mass of the Hydrogen feed subsystem shall no exceed (500) KG.

3.7.2.4.3 Volume- TBD.

3.7.2.5 Special Safety Considerations TBD.

3.7.3 Instrumentation and Control

General

The instrumentation and control Subsystem (ICS) shall be a distributed subsystem providing control, monitoring / data acquisition and communication in a standardized way to all subsystems. The ICS shall function at a supervisory level and at a subsystem level, as shown in Figure 11.

Supervisory

At the supervisory level the ICS shall exchange information and receive commands from the NPB. Internal functions associated with housekeeping, task scheduling and data storage shall reside at the supervisory level.

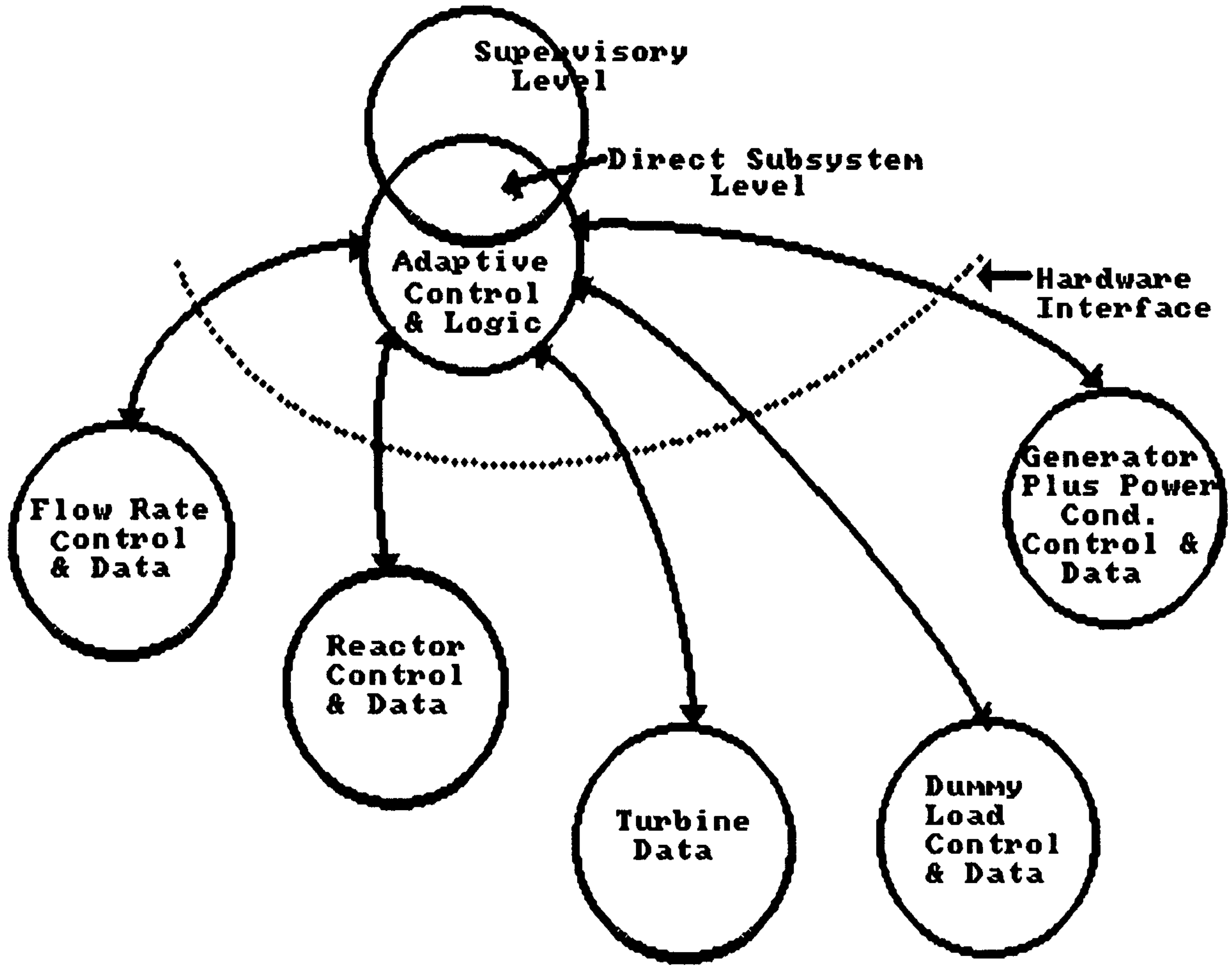

Figure 11. Major Interfaces of the ICS with Other Subsystems

Subsystem

At the subsystem level, adaptive control and associated logic shall be directed via the subsystem interfaces to operate in concert the control functions sited locally at the subsystems. Further, data from the instrumentation for each of the subsystems shall be transmitted via this interface to the ICS. All major local active control units shall receive commands from the ICS, and together with the turbine subsystem ,pass status and measurement data to the subsystem level of the ICS.

No direct, active control over the turbine shall be required. This control shall be furnished through variation of the reactor power and/or variation of the outlet hydrogen temperature. Further loading of the alternators or variation of the hydrogen flow will be used.

The processing component of this subsystem shall include real time applications of computation, routine command (control) and data acquisition. It shall support a high level language.

The timing component shall provide high resolution (1m sec) timing signals to each subsystem. Optical transmission of this digital signal shall be used.

The interlock monitoring component shall include logically programmed interlock controllers for ;shutdown detection and activation.

The input/output components shall interface through a serial digital-data transmission format using optical transmission lines.

3.7.3.2 Interface Definitions

3.7.3.2.1 Subsystem to Subsystem- The subsystem electrical interfaces are shown in Figure 3 in Section 3.1.4. Details of these interfaces as well as the mechanical interface with the structures subsystem are TBD.

3.7.3.2.2 System- The ICS interface with the NPB are shown in Figure 4 of Section 3.1.5.1. The ICS shall output subsystem data to a ground based monitoring station via the NPB telemetry system. Details of this interface are TBD.

3.7.3.3 Performance Parameters

TBD

3.7.3.4 Physical Parameters

3.7.3.4.1Power- TBD

3.7.3.4.2 Mass- *The mass of the subsystem shall not exceed (500)* KG.
3.7.3.4.3 Volume- TBD.

3.7.3.5 Special Safety Considerations

TBD

3.7.4 Power Conditioning

3.7.4.1 Functional Description

General

The function of the power conditioning subsystem (PCS) is to accept the alternator power and provide the required output power in the correct form and with the required control over voltage and frequency. A functional block diagram is shown in Figure 12 which reflects the major components in each of four modules. Each module shall contain the following components:

Rectifier

The first stage in the PCS shall be a rectifier to convert the alternating current from the alternator to direct current for the inverter. This shall be a passive device with no function other than the power conversion. a number of rectifier units shall be operated in parallel to accommodate the the high current output of the alternator.

Inverter

The primary component of the PCS is the inverter which shall provide the 20 KHz frequency required by the NPB. Electronic conversion shall be the method used to generate this frequency.

Transformer

The final stage in the PCS shall be the transformation from the inverter output voltage to the voltage required by the NPB. The transformers shall be closely linked to their respective inverters and their secondary windings shall be connected in parallel to achieve the required output power level.

Enclosures

Enclosures for the PCS shall be furnished to assure that the cooling hydrogen is contained and directed correctly for efficient heat transfer. All PCS high voltage components shall be isolated from the space environment to prevent losses and damage from corona effects.

Each module shall include protective devices (e.g. fusible links or pyrotechnic switches) to isolate all modules in the case one of the modules might have a catastrophic failure. Further each module shall include instrumentation and control functions needed to ensure safe and proper operations.

3.7.4.2 Interface Definitions

The subsystem to subsystem and system electrical interfaces are indicated in Figure 12. Detailed definition of all interfaces is TBD.

3.7.4.3 Performance Parameters

The electrical output of the PCS shall be as specified in Section 3.1.5.1.1. Specific weights for the major components shall be as follows:

Component	Specific Weight	Unit Pwr.	No. of Units
Rectifier	(E) Kg/kw	(C) MW	4
Inverter	(F) Kg/kw		
Transformer	(G) Kg/kw		
Inverter/Transformer	(H) Kg/kw	(D) MW	8

3.7.4.4 Physical Characteristics

3.7.4.4.1 Power– The housekeeping power shall not exceed TBD watts

3.7.4.4.2 Mass– The Mass of the PCS shall not exceed (4200) Kg.

3.7.4.4.3 Volume

Each Inverter/Transformer unit shall be packaged within a rectangular prism .46m x .3m x 4.3m long.

Each Rectifier unit shall be located at the end of its alternator within a volume .4m x .4m x .53m long

3.7.4.5 Special Safety Considerations

TBD

3.7.5 Reactor

3.7.5.1 Functional Description

General

The reactor shall furnish energy, in the form of heated hydrogen, to the turbine. Heat shall be provided by a fast neutron spectrum reactor consisting of metal clad fuel elements filled with ceramic fuel pellets. The coolant flow through the

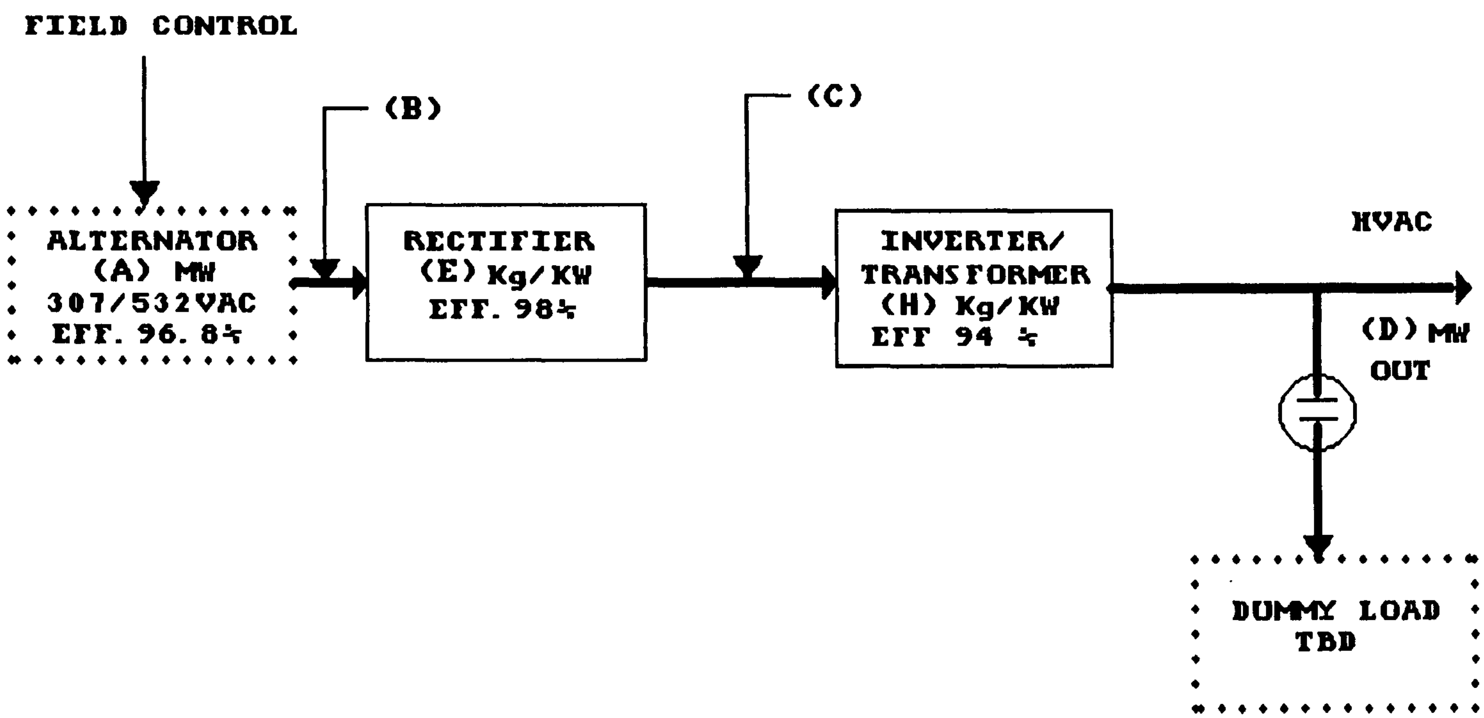

Figure 12. Power Conditioning Subsystem Block Diagram

reactor core shall be a (TBD) pass system.

The reactor shall be contained is a pressure vessel and the core shall be supported at one end to allow for thermal expansion. Internal control rods and thermal neutron absorbers shall be included to compensate for inadvertent water flooding. External neutron reflectors consisting of hinged panels shall be incorporate as a second reactivity control and shutdown device. Within the pressure vessel there shall a provision for an axial reflector. The reactor subsystem includes provision of inlet and outlet ducting and internals to direct the coolant flow within the vessel and to allow for the entry of control rods into the core. A shadow shield will be furnished if need to reduce radiation to acceptable levels. Mechanisms shall be provided to drive the control rods and reflector panels. Instrumentation shall be included to monitor and control the safe operation of the reactor.

The subsystem shall be designed to remain intact during inadvertent reentry into the atmosphere and on impact with the earth. It shall include provisions for protection against reentry heating.

3.7.5.2 Interface Definitions

3.7.5.2.1- Subsystem to subsystem

Hydrogen Feed Subsystem- A hydrogen flow from the reactor shall be provided to power the liquid hydrogen pump after the initial stage of the start up transient.

Turbine subsystem- The turbine shall accept the full flow from the reactor apart from subsidiary flows to the turbine which drives cooling in the other subsystems.

Instrumentation and Control Subsystem- The reactor subsystem shall provide performance data to the ICS which in turn shall furnish input to the control rod and reflector panel drive systems.

3.7.5.3 Performance Parameters

The reactor subsystem shall have meet the following performance parameters:

Fissile fuel inventory (U235) kg.	270
Enrichment %	40
Average power density W/cm^3	2010
Thermal Power	(XX)
Coolant outlet temperature K	1200

Maximum fuel temperature K	1800
Maximum clad temperature K	1450
Average fuel temperature K	1350

3.7.5.4 Physical Characteristics

The reactor shall consist of UC fuel pellets clad in stainless steel (first Pass) and Mo/Re (second pass) metal. The fuel pins shall be grouped in hexagonal sub-assemblies (127 pins per sub-assembly) of which 24 constitute the first pass and 30 the second pass. Seven sub-assemblies containing boron carbide control and shutdown rods shall also be included in the second pass. Eight rotable shutdown reflector wings made of Beryllium shall form an annular region around the reactor pressure vessel. (See Figures 13 and 14)

3.7.5.5 Special Safety Considerations

The reactor shall be designed to minimise the probability of release of any radioactive material during any phase of construction, operation and ultimate disposal. The doses to operational staff and to the public shall be kept well below the accepted limits for exposure under the as low as reasonably achievable (ALARA) principle. The reactor shall be kept sub-critical at all times except when it is in operational orbit. It shall remain sub-critical during launch mishaps, including immersion, or following accidental compaction of the core.

3.7.6 Structure.

TBD

3.7.7 Turbine

3.7.7.1 Functional Description.

The turbine shall provide sufficient shaft power to the alternators to enable overall power output targets to be achieved when due count is taken of generator and power conditioning efficiencies.

The turbine shall accept full temperature, flow and pressure hydrogen from the reactor, with inlet ducting interfacing with the reactor exit duct.

Exhaust ducting and nozzles shall direct hydrogen flow fromthe turbine exit safely to space and shall result in minimal reaction thrust being imparted to the space vehicle.

The turbine subsystem shall be comprised of two multi-stage axial turbines in series. Each turbine shall furnish half of the total power requirement and arranged to rotate in opposite

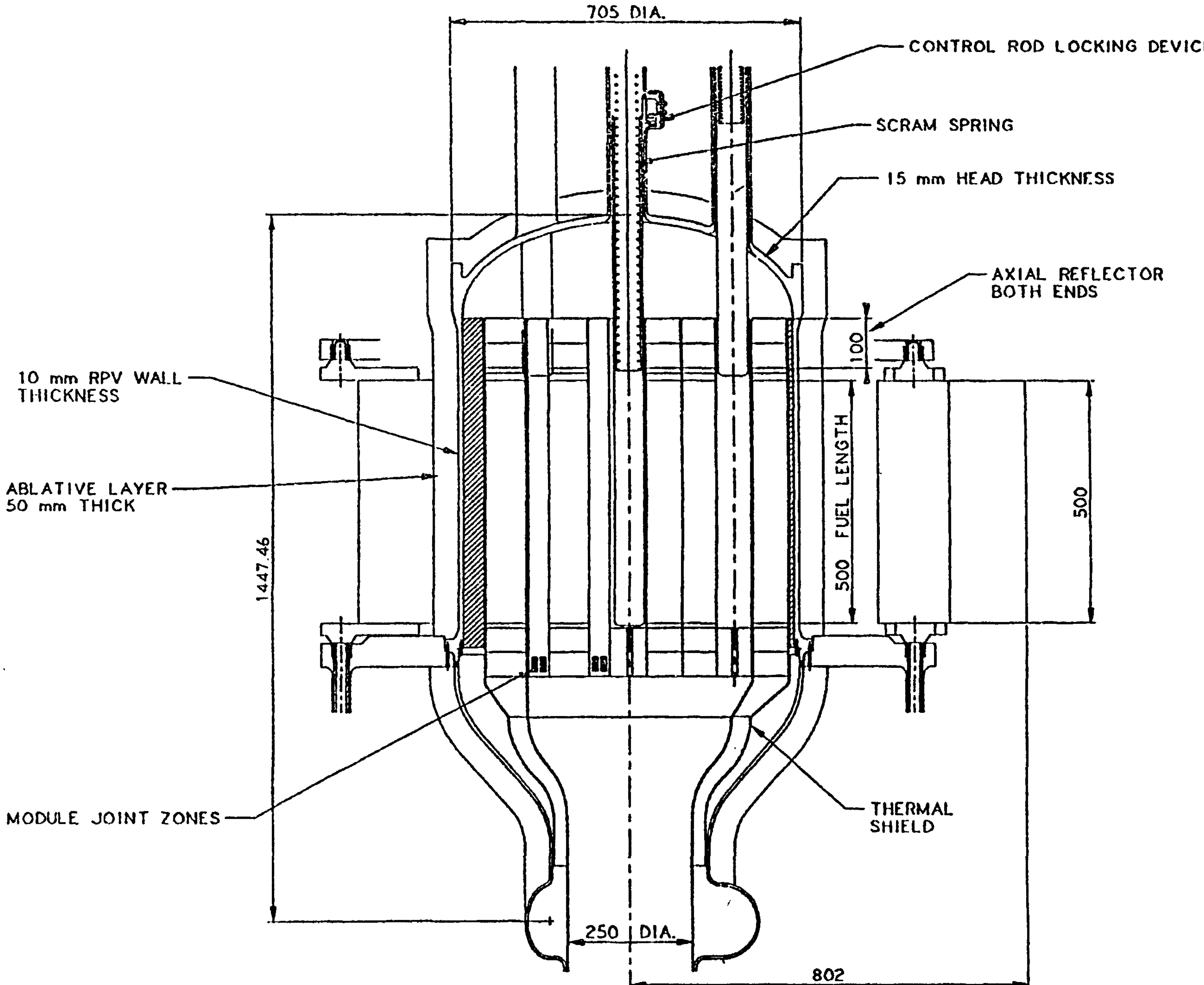

Figure 13. Reactor Pressure Vessel

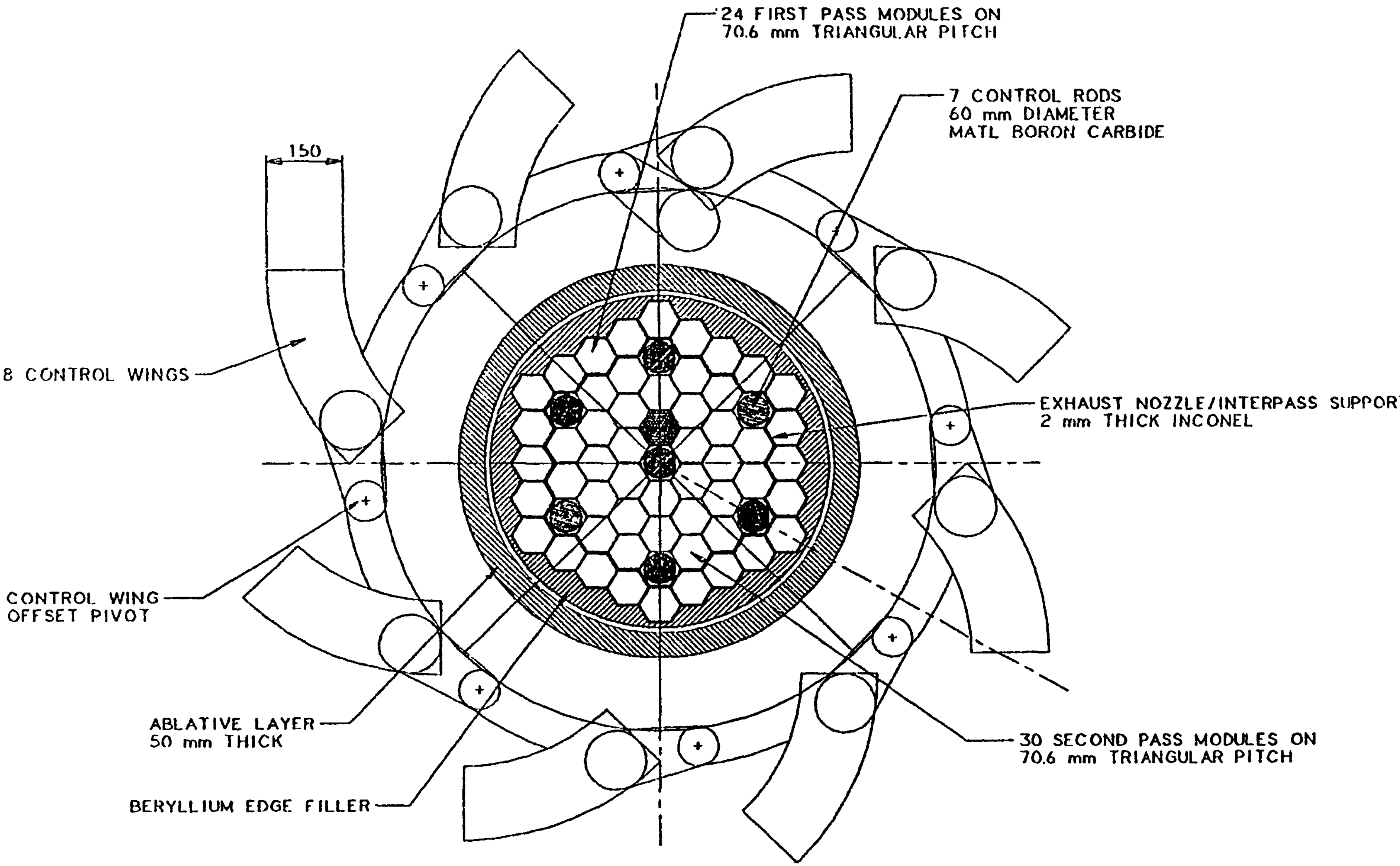

Figure 14. Reactor Pressure Vessel Cross-Section

directions. The rotating inertias of each shaft shall be matched to avoid any torque reaction moments being experienced during operations that will interfere with the Attitude control of the vehicle.

Shaft sealing and disc and bearing cooling shall be included.

Casings and/or additional containment shall be designed to contain debris resulting from and turbine blade failures.

3.7.7.2 Interface Definition

Dummy Load Subsystem- The coolant flow shall pass through the dummy load prior to exhausting it overboard by the turbine subsystem.

3.7.7.3 Performance Parameters (nominal)

The turbine shall meet the following performance parameters:

	INLET	OUTLET
Temperature K	1200	802
Pressure bar.	28	3.8
Va/U	0.5	0.5
Hub/tip ratio	0.91	0.70
N^2A (x 10^9)	17	74
Shaft speed (rpm)		15000
Flow kg/ sec		6

3.7.7.4 Physical Characteristics

3.7.7.4.1 Power- TBD

3.7.7.4.2 Mass- The mass of the subsystem shall not exceed (1125) kg.

3.7.7.4.3 Volume- The turbine general arrangement is shown in Figure 15. It shall have the following dimensions:

Length cm.	35.3
Hub diameter cm.	53.8 (inlet) 51.1 (exit)
Tip diameter cm	58.9 (inlet) 72.9 (exit)
Number of stages	8

3.7.7.5 Special Safety Considerations

The turbine casings shall be designed to contain blade failures. The turbines may be oriented such that the plane in which a disc failure would occur will not intersect the reactor.

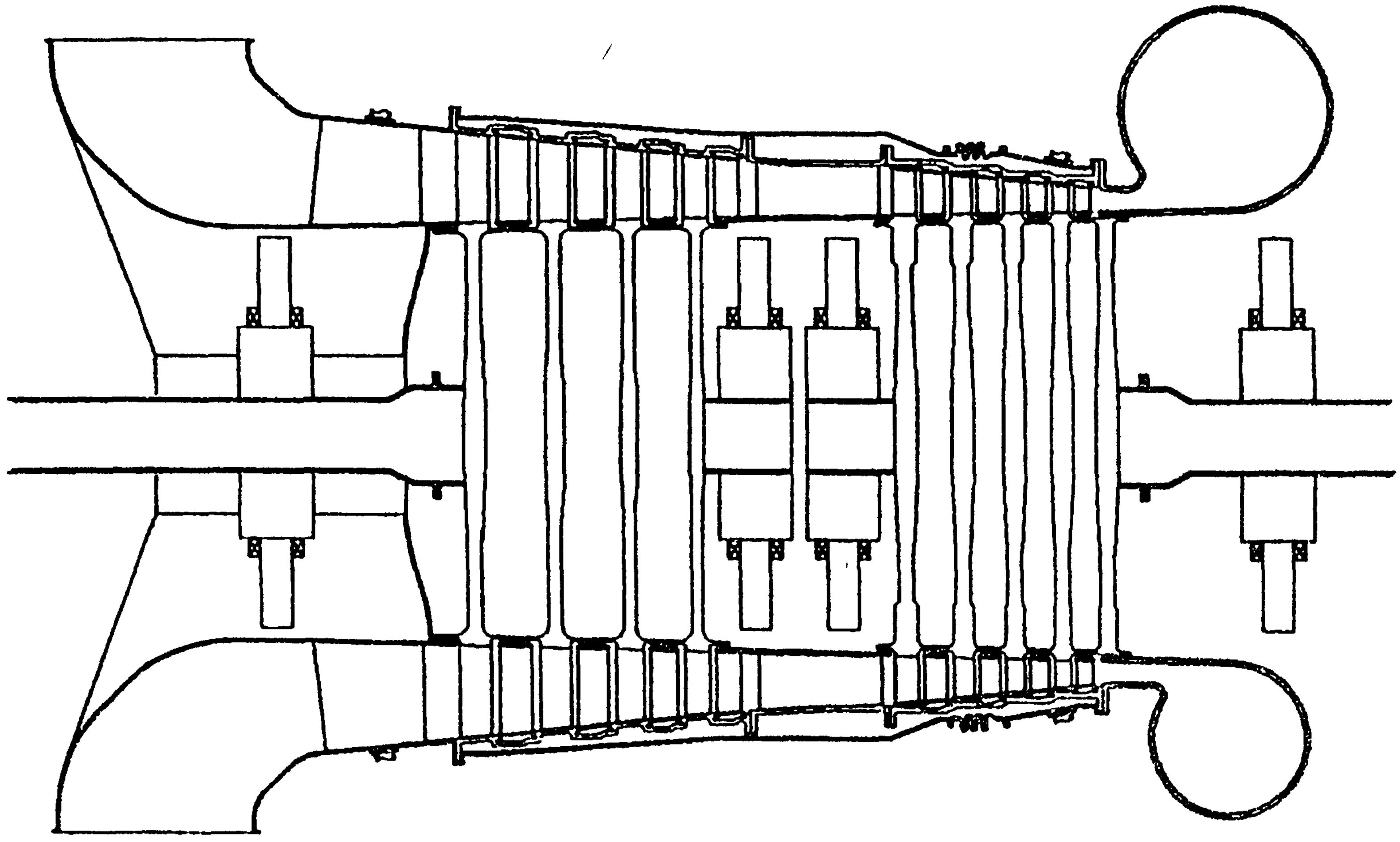

Figure 15. Turbine General Arrangement

3.7.8 Dummy Load

3.7.8.1 Functional Description

The dummy load shall dissipate power generated by the MSNPS which can not be passed to the NPB. This shall include power generated during the 70 seconds prior to time zero of the start up phase and power generated during a partial or full load rejection from the NPB. Further this parasitic load shall be required to dissipate system output power at the output conditions to verify operational capability of the entire power system

The resistive load bank shall be isolated from the PCS output busses with vacuum contactors. Resistive elements isolated from their surrounding enclosure by ceramic stand off insulators and cooled by the hydrogen gas shall be required to dissipate the power.

(Cold hydrogen flow shall cool the dummy load prior to entering the reactor.)

3.7.8.2 Interface Definitions

Turbine Subsystem- The interface with the turbine subsystem shall be as defined in Section 3.7.7.2.

Electrical- The dummy load shall interface either with the d.c. or the a.c. sections of the power conditioning subsystem. this interface shall include high conductivity electrodes and cables.

Thermal- Thermodynamically the dummy load shall interface either with the cryogenic hydrogen af the reactor inlet or with the hot hydrogen at the turbine exhaust.

3.7.8.3 Performance Parameters

The performance of the dummy load shall allow full power dissipation, partial power dissipation. The surface ares a shall be matched to the maximum power dissipation. The maximum operating temperature shall not exceed 1400 K for d.c or a.c. Electromagnetic stresses shall be self cancelling.

3.7.8.4 Physical Characteristics

The mass of the dummy load subsystem shall not exceed 256 kg (d.c.) and 287 kg (a.c.)

3.7.8.5 Special Safety Considerations

TBD

3.7.9 SP100 TBD.

3.7.10 Attitude Control.

TBD

3.8 PRECEDENCE.

TBD.

4 QUALITY ASSURANCE PROVISIONS

TBD.

5 PREPARATION FOR DELIVERY

5.1 STORAGE AND HANDLING PROVISIONS

5.1.1 In-plant Prior to Acceptance.

Environmental conditions during processing, and during storage prior to shipment, shall be within the following limits:

a. Temperature: 21 deg C + 20 deg C

b. Humidity: 50 percent + 40 percent

Cleanliness shall be maintained during processing using appropriate protective containers or covers.

MSNPS specific handling environments are defined in DS89-832-5.

5.1.2 Subsequent to Acceptance.

Electrostatic sensitive items, such as most electronic assemblies and components containing explosives, shall be stored and transported in sealed packages using intestates wrapping material. The antistatic wrapping material used should not produce nonvolatile residues. The antistatic wrapping material shall be grounded through a resistor prior to removal. The grounding resistor shall have a value between 100,000 ohms and 1 megohm.

Storage, handling, and transportation conditions to which items are to be subjected prior to flight shall be controlled to acceptable limits. Cleanliness shall be maintained during storage and transportation using appropriate protective containers or covers. Temperature and humidity conditions and transportation shock exposure shall be monitored subsequent to manufacture, and the measured levels shall be evaluated against the acceptance test limits.

6 NOTES

6.1 DEFINITIONS.

6.1.1 Class Definitions.

Class A High Priority, Minimum Risk.

Class A is defined as a high-priority, minimum-risk effort. The characteristics for Class A usually also involve some combination of the following features: high national prestige, long life, high complexity, high use of redundancy, soft failure modes, independent qualification items, complete flight spares, highest cost, and a critical launch time. Vehicle and experiment retrievability or in-orbit maintenance is usually not possible.

6.1.2 System Definitions

The following definitions are presented for your convenience. These definitions as well as others can be found in MIL-STD-1540B.

System

A system is the composite of equipment, skills, and techniques capable of performing or supporting an operational role. A system includes all operational equipment, related facilities, material, documentation, services, and personnel required for its operation and maintenance.

Equipment

Equipment is a general term that refers to an assembly or set of hardware, including the associated software, that is intended to serve some purpose. Equipment does not include the related facilities, material, documentation, services, or personnel required for operation or maintenance of the items.

Space Equipment

Space equipment is a general term that refers to any equipment in a space system that is intended for use in space. The various levels of assembly of space equipment as defined in this document are: space vehicle, space experiment, subsystem, component, subassembly, and part.

6.1.3 Levels of Assembly of Space Equipment

The following are definitions for space equipment items at various levels of assembly. They are listed in decreasing levels of complexity, from the most complex to the least complex.

Space Vehicle.

A space vehicle is a complete, integrated set of subsystems and components capable of supporting an operational role in space. A space vehicle may be an orbiting vehicle, a major portion of an orbiting vehicle, or a payload which performs its mission while attached to recoverable launch vehicle. The airborne support equipment which is peculiar to programs utilizing a recoverable launch vehicle is considered to be a part of the space vehicle being carried by the launch vehicle.

Subsystem.

A subsystem is an assembly of two or more components, including the supporting structure to which they are mounted, and any interconnecting cables or tubing. A subsystem is composed of functionally related components that perform one or more prescribed functions. Typical space vehicle subsystems are electrical power, attitude control, telemetry, instrumentation, command, structure, thermal control, and propulsion.

Component.

A component is a functional unit that is viewed as an entity for purposes of analysis, manufacturing, maintenance, or record keeping. Examples are hydraulic actuators, valves, batteries, electrical harnesses, and individual electronic boxes such as transmitters, receivers, or multiplexers.

Subassembly.

The term subassembly denotes two or more parts joined together to form a stockable unit which is capable of disassembly or part replacement. Examples are a printed circuit board with parts mounted, or a gear train.

Part.

A part is a single piece, or two or more pieces joined together, which are not normally subject to disassembly without destruction or impairment of the design use. Some examples are resistors, transistors, integrated circuits, relays, capacitors, gears, screws, and mounting brackets.

6.1.3 Design.

Design Environments, Space Vehicle-

The design environments for a space vehicle are the composite of the various environmental stresses to which the space vehicle must be designed. Each of the design environments for a space vehicle is based upon:

a. The maximum and minimum predicted environments during the operational life of the space vehicle, plus

b. An environmental design margin that increases the environmental range to provide an acceptable level of confidence that a failure will not occur during the service life of the space vehicle.

Limit Load-

The limit is the maximum anticipated load or combination of loads which a structure may be expected to experience during the performance of specified missions in a specified environment. Since the actual loads that are experienced is service are in part random in nature, statistical methods for predicting limit loads are employed whereverappropriate.

Ultimate Load-

The ultimate load is the maximum static load to which a structure is designed. It is obtained by multiplying the limit load by the ultimate factor of safety.

6.2 ABBREVIATIONS AND ACRONYMS.

TBD

6.3 SAFETY REGULATIONS AND POLICY.

6.3.1 Regulations.

A major objective of the Multimegawatt Project is the development of a reference flight system design that provides the desired levels of public safety, health protection, environmental protection, and special nuclear material protection when used during the designated missions. To measure how well these objectives are met, standards are generally invoked and applied. It is therefore appropriate to review those standards referenced in DOE Order 5480.1B and provide feedback to the Project Integration Office as to which are "space applicable" and which should be ignored and why.

6.3.2 Policy.

The Multimegawatt Project will stress the importance of safety as its highest priority in the overall project in order to ensure the protection of the health and safety of the public and the environment.

It is the policy of the Multimegawatt Project to assure the protection of the environment, the safety and health of the public, and government property against accidental loss and damage (reference DOE Order 5480.1B). Project activities shall be executed in conformance with this order in a manner that will not present undue risk considering the benefits. Taking into account economic and social factors and the level of technology, every effort shall be made to maintain risks as low as reasonably achievable. The effect on safety must be an integral and key consideration in all design and operational decisions. This decision process must include full consideration of normal and off-normal operations, and credible accident situations, during the life cycle of the system.

6.3.3.1 Space Transportation System Payloads.

For all payloads which are to be launched by the Space Transportation System (STS), the safety requirements shall also be in accordance with Chapter 2 of NHB 1700.7 (NASA). For these payloads, it is required that the payload must tolerate a minimum number of failures and/or operator errors determined by the consequence of any hazardous functions. For catastrophic hazards or hazards that would result in personnel injury, loss of the orbiter or STS facilities and equipment, the hazard needs to be controlled such that no combination of two failures, operator errors, or radio frequency signals would unleash the hazard. For critical hazards or hazards that would result in damage to STS equipment or in the use of contingency or emergency procedures, the hazard needs to be controlled such that no single failure, or operator error, would unleash the hazard. Hazardous functions are thereby controlled with either two or three inhibits, depending on whether the hazard is critical or catastrophic.

In addition, Chapter 2 of NHB 1700.7 (NASA) defines safety requirements for space equipment structural design, stress corrosion, pressure vessels, sealed containers, hazardous materials, pyrotechnics, destruct subsystems, radiation, electrical subsystems, flammable atmospheres, and reflown hardware.

6.3.3.2 Ground Equipment.

The safety requirements for ground equipment shall be in accordance with SAMTO HB S-100 (designated by NASA as KHB 1700.7).

The safety concerns shall be precluded or their risk shall be minimized to acceptable levels in the following priority.

- Potential for exposure of humans to ionizing radiation, including the potential for inadvertent criticality.

- Potential for exposure of humans to toxic materials.

- Potential for the contamination of the environment through the release of toxic and/or radioactive materials.

- Potential for failure to physically control or to protect the system or its SPM

- Potential for failures in the MSNPS.

- System to perform as intended, which could affect safety at any time during the life cycle.

6.4 CATEGORY III REQUIREMENTS.

The requirements in this section include the requirements that differ from the Category I requirements.

6.4.1 Performance

The Performance requirements are for a Category III MSNPS. Classified data is indicated by capital letters in parenthesis, e.g.(X). Values for these quantities are found in the classified Appendix TBD.

6.4.1.1 Power System.

The power system shall be capable of producing at least two operational cycles, separated by (one hour). Each cycleshall provide (A3) MW of electrical power for up to (B) continuous seconds of engagement time. It shall be capable of 50 rapid start-ups and shutdowns to power levels up to full power. A rapid start-up shall produce full electrical power at the output of the Power Conditioning Subsystem within (C) seconds from the time the full-power demand signal is received by the Instrumentation and Control Subsystem.

6.4.1.2 Operating Time.

The power system shall be capable of producing full-power for a minimum total integrated operating time, including power and weapon systems shakedown and operational tests, of (D) seconds. The design will include additional operating time for preliminary system operational tests prior to being turned over as mission ready, or for unique concept specific test requirements.

6.4.1.3 Coolant.

Hydrogen from the NPB shall be available for use by the MSNPS at the conditions specified in Section 3.1.5.1.4. Additional hydrogen, tankage, and associated equipments will be included in the MSNPS design as required by an inadequate supply from the NPB.

6.4.1.4 Effluent.

Hydrogen effluent is acceptable. Any effluents other than hydrogen shall be contained. The hydrogen shall leave the MSNPS in a manner that will not cause unacceptable degradation of the NPB operation.

6.5 RELIABILITY, AVAILABILITY, AND MAINTAINABILITY.

The approach and definitions pertaining to the subject design considerations are included in this section.

6.5.1 Reliability.

The systems/subsystems specified herein require a unique approach to reliability because of significant differences compared to more traditional ground based nuclear systems. They incorporate more the spacecraft type of requirements for short operational life,(long start-up times compared to steady state operation), no operators, essentially no maintenance, long periods of time between operations, and very little data base. Therefore,while traditional reliability methods such as failure mode and effects analysis and probabilistic risk assessment is an essential part of the reliability approach, more extensive "ground up" treatment is needed. This will include a large amount of engineering assessment to ensure that the complete environment to which the materials, components, and systems will be subjected is considered.

The probabilistic approach will require establishing the uncertainty in component requirements using power system codes and comprehensive failure mode analysis to provide a basis for selecting alternative redundancy schemes, test planning, at the component and the subsystem level, and at the system level. This will ensure that the test program considers the total environmental envelop to which a component or subsystem may be subjected. The test program will require extensive instrumentation to assure that the uncertainty in loads and environmental factors obtained from the system sensitivity studies are fully investigated, and that all critical failure modes are prevented. Extension of the spacecraft reliability approach to the nuclear portions of this system may require unique and innovative procedures. An evaluation which establishes the extremes in the expected environment, must be initiated in Phase I and progress in detail as the design is developed to show that material and component selection is appropriate and/or to identify supporting technology development. Materials and technology selection used in the MSNPS designs shall be evaluated considering the multidimensional environmental envelope to which they will be subjected, and test programs identified for later phases must be designed to"proof" the components or subsystems at the extremes of the expected operating conditions, not just at the nominal conditions. See also Section 6.8.1 for the reliability approach to particulate threats in space (e.g. debris and micrometeoroids).

6.5.2 Maintainability.

The maintenance philosophy and capability planning for SDI space based systems are currently being formulated. In lieu of specific requirements the following general requirements are presented which reflect the present SDIO philosophy. In general this philosophy recognizes the increased consideration of space based maintenance by the Air Force and NASA

Power system designs shall not, a priori, exclude the possibility of space based maintenance. The design shall consider a reliability-centered maintenance approach to the extent feasible. While a design which incurs no additional cost (or very little) for a maintenance-free system is an ideal to be sought, actual systems must consider the cost of maintenance to achieve the required reliability and life against the cost to achieve a high reliability maintenance free system. Therefore, trade studies shall be performed that consider the degree of capability needed, the frequency, and the impact of these considerations on life cycle costs.

The power system design shall address a proposed approach to maintainability, clearly define the space based requirements, and estimate the logistical support necessary.

In addition to the requirements specified in Section 3.2.4 The following guidelines should be considered in the design study:

A. Arrangement. The physical arrangement of the power system modules and components shall provide for maintenance based upon those most likely to need replacement during ground operations and space operations.

B. Robotics. Space based maintenance shall consider only the use of robotics automation. (Consideration of manned maintenance is considered unlikely due to the natural radiation and the probable excess weight required for a man rated reactor shield.) The design study shall identify the robotic functions and capabilities required.

C. Maintenance Cycle. The conceptual design study shall identify the space based maintenance cycle required by the power system. This maintenance cycle would include resupply of consumables and replacement or maintenance of designated components required to ensure the reliability of the power system and would be limited to very simple preprogramable operations(7).

D. Resources. The time and resources necessary to repair, or replace failed components or subsystems is space should be minimized. The conceptual design study should clearly outline key maintenance features and provide estimates of the time and resources necessary to carry out maintenance procedures.

6.6 ALTERNATIVE APPLICATIONS AND DESIGNS.

This section records the alternative application studies and the trade studies on alternative system and subsystem designs. As these studies are completed and the reference design is up dated, traceability of these decisions and resulting requirements will be recorded in section 6.7. Table 8 Identifies the present studies scheduled to be conducted. Details of these studies will be added is this section at a later revision. The propulsion application study defined in th F&OR follows:

6.6.1 Propulsion Application.

As an enhancement, Category I and III designs may include consideration of using the basic nuclear system as the heat source for propulsion system capable of producing a thrust in the range of 65 kN for a total period of 30 minutes. The general application would be for an OMV/OTV or some other space application where a nuclear-driven propulsion system would be an advantage The intent of this requirement is to obtain a preliminary assessment of the potential of the proposed design for this application. This will include the technical feasibility of this application without excessive modification or change in the technology program. It is not the intent or desire of this requirement to reorient the program away from the basic intent of producing electrical power; rather, it recognizes that significant synergism may exist between open cycle power systems and propulsion systems. Consideration of this possibility is not a mandatory requirement and is at the discretion of the contractor. The level of detail should be sufficient to show comparisons with a nuclear system specifically designed for the thrust application (estimates of thrust-to-weight ratio, specific impulse, etc.) and indicates the extent of the changes to conceptual design, where new technology would be needed, etc. It is expected that the response to this section would not be provided unless the reactor in the prime power system design was quite similar to that envisioned for the direct propulsion use. This is expected to be only a "top level" evaluation of the design and technologyapplication and would only be a few pages in length. (In light of the requirement for major plane changes in this application as well as the "recent"

Table 8. Analyses/Trade Study Matrix

Study Title/Type	Options	Selection Criteria	Comments/References	Study Selection/Results Rationale and Approach Basis: F&OD (Rev.1)	Study Selection/Results Rationale and Approach Basis: Study Plan
Future Missions Analysis	Nuclear Orbital Transfer Vehicle	N/A	D180-30619-2 Sec. 2.1.1.3	Sect. 1.2 & 1.3	Task 1.0
	Spacecraft and Aircraft Propulsion	N/A	Same +D180-30619 Sec. 6.6	Sect. 3.1.9	
	Lunar and Planetary Missions	N/A	Same		
	Space Based Radar	N/A	Same		
Attitude Control/Analysis Spacecraft Simulation Studies		N/A	D180-30619-2 Sec. 2.1.2.2	Sect. 2.0 p. 14 Sect. 3.2.1 Sect. 3.3	Task 1.0
Spacecraft Configuration Trade Study	Single inline structure	TBD	D180-30619-2 Sec. 2.1.2.3	Sect. 2.0 & 3.0	Task 1.0
	Same with deployable truss			Sect. 3.1.9	Task 1.2.1.2
	Articulated fork-gimbal			Sect. 3.3,4,5,6	
	Articulated side-mounted One side				
	Same - Two sided				
Hydrogen Feed/Trade and Analysis	Open vs Closed cycle	TBD	D180-30619-2 Sec. 2.2	Sect. 2.0	Task 1.0
	Amount hydrogen required	N/A	Same	Sect. 3.0 & 3.1.9	
	Hydrogen conditioning		Same Section 2.3.6		
Performance Trade Studies				Sect. 3.1 & 3.1.4 Sect. 3.3 & 3.4.5	
1) Alternator/Trade	Three salient pole vs. single pole		D180-30619-2 Sec. 2.2		Task 1.2.6
	Rotor material Structure & permability		Same Section 2.4.9		Task 1.2.7
	Rotor configuration containment & bearings		Same		Task 2.1.3
	Cooling configuration & pressure drop		Same		Task 3.6
	Stator		Same		Task 3.7
	Bore Seal		Same		
2) Reactor/Trade and Analysis	Nonconventional Gas conditioning	TBD	D180-30619-2 Sec. 2.3/4.2	Sect. 3.1.6 & 3.1.8	Task 1.2.2
	Reactor selection review			Sect. 3.1.9	Task 1.2.3
	Physics & Fast/in???			Sect. 3.2.2	Task 2.1.1
	Design (Kinetics/Thermal Hydraulics)				Task 2.3.1
	Fuel Alternatives & Arrangement/Forms/Clodding				Task 3.5
	Material Selection (Pin Dia. Spacing; Clad/Wrapper, Asorbers)				
	Shielding/Control Rods (Reflectors)				
	Reactivity Control (Starting/Shutdown)				
3) Turbine/Trade and Analysis	Parallel vs series	TBD	D180-30619-2 Sect. 2.4.7		Task 1.2.3.2
	Optimal inlet gas conditions/Pressur Control				Task 1.2.3.3
	Turbine geometry (Inlets, disk, drum, blades, casing)				Task 1.2.3.4
	Radial turbine?				
	Number of turbine stanges				
	Bearing type		Same Sect. 4.2.3		
	Shaft Speed				
	Combustion Turbogenerator considerations				
4) Power Concitioning Trades/Analysis	Poser cond./alternator mass	TBD	D180-30619-2 Sect. 2.4.11	Sect. 3.1.5	Task 1.2.4
	DC/AC Impact				Task 2.1.2
	Supercooled				
Concept Design/Configuration				All Sections	Task 1.2
Concept Scalability				All Sections	Task 5.0
System Reliability/Redundancy				Sect. 3.1.7 Sect. 3.6	Task 1.2.4.4
rational Modes (Contracts/Diagnostics/Divisions)	- Prelaunch - Launch - Commission (Low/Ops/High/Decommission /Disposal)			Sect. 3.2	Task 2.2
Safety				Sect. 5, 3.1.6, 3.1.8	Task 7.0
Risk Assessment/Feasibility Issues					Task 4.0

concepts for manned Mars exploration, this study could be of major importance. The British input to this concept is a breath of fresh air compared to what has been done in the past. Both electric propulsion as well as high thrust application should be investigated.

6.7 TRACEABILITY

An analyses and trade study matrix is presented in Table 9. As these studies are completed and design decisions are made, this matrix shall be updated. The design selection or results should be summarized and the analysis referenced.

A similar matrix can be prepared for each study task so that design change decisions can be traced. The Work Breakdown Structure (WBS) (Reference the Boeing Integrated Management System) to be developed for cost estimates can also be used for this purpose when combined with the WBS dictionary. The dictionary defines each WBS task in a similar depth to that presented in the Phase I task descriptions.

6.8 DESIGN AND EVALUATION PHILOSOPHY

6.8.1 Space Debris/Natural Threats.

The design and protection of the MMW power plant shall account for the probability of loss due to the natural environment expected over the system design life. This probability of loss shall be calculated as the summation of all failure probabilities leading to a loss of the platform availability. The relationship to be used for calculation of the probability of loss should be of the general type

P= {(f*k*Ac*L) }**R

where:

P= probability that a component will be rendered inoperative

f= impact frequency of particles capable of destroying a component or rendering a subsystem inoperable (particle/square meter/year)

k=direction factor

Ac= maximum projected area of component (square meters)

L= operational life of platform (years)

R= redundancy of component capable of maintaining full operational status

The above relationship is the so-called "rare event approximation" and is accurate to within about 10 percent of the true probability when the individual component failure probability is < 0.1. Any error made is on the conservative side, in that the true probability is slightly lower.

For further discussion of this approach see the F&OR identified in Section 2.

6.8.2 Analysis Philosophy

6.8.3 Resource Allocation

4.0 ENVIRONMENTAL REQUIREMENTS DEFINITION

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ACRONYMS

ALS	Advanced Launch System
ASE	Auxilliary Support Equipment
BTU	British Thermal Unit
cm	centimeter
dB	decibel
DEMP	Dispersed Electromagnetic Pulse
EMP	Electromagnetic Pulse
ETR	Eastern Test Range
ft	feet
g	gram
g's	gravitational acceleration
GBR	Glass Bead Rating
HDBK	Handbook
HEPA	High Efficiency Particulate Absorber
Hz	hertz
ICD	Interface Control Document
IUS	Inertial Upper Stage
JSC	Johnson Space Center (NASA)
kHz	Kilo hertz
Klbm	Thousands pounds mass
km	kilometer
m	meter
MMH	Mono-methal Hydrazine
MSNPS	Multimegawatt Space Nuclear Power Supply
NASA	National Aeronautics and Space Administration
nmi	nautical miles
NORAD	North American Aerospace Defense Command
NPB	Neutral Particle Beam
N_2O_4	Nitrogen-Texroxide
OMS	Orbital Maneuvering System
OTV	Orbital Transfer Vehicle
P/L	Payload
PLF	Payload Fairing
PPM	Parts per million

ACRONYMS
(Continued)

PSF	Pounds per square foot
psi	pounds per square inch
PSIA	Pounds per square inch absolute
R.H.	Relative Humidity
rad	Radiation Absorbed Dose [100 ergs (10^{-5} jules) per gram of absorbing material]
RCS	Reaction Control System
rms	Root Mean Square
SBR	Space-Based Radar
SDI	Strategic Defense Initiative
SDIO	Strategic Defense Initiative Office
SEU	Single-event upset
SGEMP	Self-Generated Electromagnetic Pulse
STD	Standard
STS	Space Transportation System
TBD	To Be Determined
TBS	To Be Supplied
T34D	Titan 34D
UV	Ultraviolent
V/M	Volts per meter
VRCS	Vernier Reaction Control System
VS	Vehicle Station
WTR	Western Test Range
yr	year

SECTION 1

SCOPE

1.1 PURPOSE

This document provides the environmental requirements definitions for the Multimegawatt Space Nuclear Power Supply (MSNPS) Program. The information presented is intended to aid in the formulation of more detailed requirements for the design of the MSNPS.

1.2 APPLICATION

These environmental requirements are applicable to the MSNPS program and are defined for ground, launch, and on-orbit conditions. These environments are those under which the MSNPS will be required to survive and/or operate.

The MSNPS will also be required to meet other design criteria imposed by the launch vehicle or attached payloads to prevent the MSNPS induced environment from impacting other pieces of the system. These criteria will become available as the system design matures and the final launch vehicle is selected.

1.3 DOCUMENT OVERVIEW

Section 2 lists the references from which the environmental requirements were obtained. Section 3 describes the intended use of the MSNPS and summarizes the threat environment. Details of ground, launch, and on-orbit environmental conditions are provided in sections 4, 5, and 6 respectively.

SECTION 2

REFERENCE DOCUMENTS

2.1 GOVERNMENT DOCUMENTS

SPECIFICATIONS:

Military

MIL-F-7179	Finishes and Coatings, General Specification for Protection of Aerospace Weapons Systems, Structures and Parts
DOD-E-8983	Electronic Equipment, Aerospace, Extended Space Environment, General Specification for
SS-STS-100, Rev A, 12 Sep 1980	System Specification, Performance and Design Requirements for the DoD STS, Vol 3, Basic Requirements for Inertial Upper Stage System Segment

STANDARDS:

Department of Energy

DOE ORDER 5480.3	Safety Requirements for the Packaging and Transportation of Hazardous Materials, Hazardous Substances, and Hazardous Wastes

Military

MIL-STD-1522	Standard General Requirements for Safe Design and Operation of Pressurized Missile and Space Systems
MIL-STD-1540	Test Requirements for Space Vehicles
MIL-STD-1541	Electromagnetic Compatibility Requirements for Space Systems
MIL-STD-1547	Parts, Materials, and Processes Requirements for Space and Launch Vehicles, Technical
MIL-STD-1574	System Safety Program for Space and Missile Systems

HANDBOOKS:

MIL-HDBK-5	Metallic, Materials and Elements for Aerospace Vehicle Structures
DOD-HDBK-263	Electrostatic Discharge Control Handbook for Protection of Electrical and Electronic Parts, Assemblies and Equipment
MIL-HDBK-340	Application Guidelines for MIL-STD-1540B: Test Requirements for Space Vehicles
DOD-HDBK-343	Design, Construction, and Testing Requirements for One of a Kind Space Equipment
KHB 1700.7	Space Transportation System Payload Ground Safety Handbook (Joint NASA/Air Force document designated by the Air Force as SAMTO HB S-100)
SAMTO HB S-100	Space Transportation System Payload Ground Safety Handbook (Joint NASA/Air Force document designated by NASA as KHB 1700.7)

OTHER PUBLICATIONS:

JSC 07700	Space Shuttle System Payload Accommodations, Vol XIV, (NASA JSC)
SP-R-0022	Vacuum Stability Requirements of Polymeric Materials for Spacecraft Applications (NASA JSC)
NHB 1700.7	Safety Policy and Requirements for Payloads Using the Space Transportation System (STS) (NASA)
NASA-TM-82478	Space and Planetary Environment Criteria Guidelines for Use in Space Vehicle Development, Vol 1, Jan 83
NASA-TP-2361	Design Guidelines for Assessing and Controlling Spacecraft Charging Effects, Sep 84
JSC 30425 15 Jan 1987	Space Station Program Natural Environment Definition for Design

NSTS 07700, Vol XIV, Atch 1 (ICD2-19001) Rev 1, 16 Sep 1986	Shuttle Orbiter/Cargo Standard Interfaces
SD-ALS-R-SRD-v1.1 4 Apr 1988	Advanced Launch System Requirements Document

2.2 NONGOVERNMENT DOCUMENTS

ICD-T34D-10001 6 Dec 1979	T34D/IUS Avionics and Electrical Parameter ICD (Boeing)
ICD-T34D-10002 17 Apr 1979	T34D/IUS Structural, Mechanical and Environmental Parametric ICD (Boeing)
Performance Review DR-2 10 Feb 1988	Definition of a Space Transportation System Cargo Element (Shuttle-C) (Rockwell International)
CDR Presentation 3-4 Feb 1988	Titan IV Centaur Systems (McDonnell Douglas)

SECTION 3

BACKGROUND

3.1 MSNPS MISSION

The purpose of the Multimegawatt Space Nuclear Power Supply (MSNPS) Program is to provide for the development of a space-based nuclear power system to meet the needs of the Strategic Defense Initiative Office (SDIO) missions. In cooperation with the SDIO, the Department of Energy (DoE) is seeking conceptual designs for a space-based, nuclear power system capable of providing the SDIO with a safe, reliable, cost effective, and timely power source for certain space applications. Missions specifically mentioned are the Neutral Particle Beam (NPB) discriminator and/or weapon, the Space-Based Radar (SBR), and the Orbital Transfer Vehicle (OTV).

3.2 MSNPS THREAT ENVIRONMENT SUMMARY

The space power system is exposed to natural, self-induced, and hostile environments, as summarized in Table 3-1. The most significant threats from the natural environment are micrometeoroids, space debris, cosmic rays, and the total radiation dose from trapped and solar charged particles.

Thermal radiation effects may result from a laser beam attack or from X-rays from a nuclear detonation. In addition, the self induced thermal environment may necessitate a careful look at the upper temperature limits at which the electronic components can safely operate for long periods of time.

Nuclear radiation effects include the effects of neutron fluence, ionizing radiation (gamma) dose, and gamma dose rate. The total dose primarily affects electronics and can damage semiconductor components. The dose rate is an effect of prompt radiation and produces several effects discussed later. Large dose rates can produce large currents in semiconductor components.

Electromagnetic pulse (EMP) effects are due to dispersed EMP, which is small, as well as self-generated EMP (SGEMP). SGEMP is a result of X-rays, but is addressed as an EMP effect because the damage mechanisms and protection techniques are the same as those resulting from normal EMP.

The system must also be protected against NPB and kinetic energy pellet attack, as well as kinetic energy weapons such as small missiles.

In addition to the above threats, the effect of effluent from the power system on the performance of the payload needs to be addressed. Effluents can cause sensor interference and beam attenuation, can lead to high-voltage breakdown, and can cause ionization in a natural or hostile environment.

Table 3-1 Threat Environments Affecting the MSNPS.

Natural environment	Self-induced environments	Hostile environments
o Solar flux o Trapped and solar charged particles o Space plasma o Micrometeoroid and debris o Atomic oxygen	o System outgassing o Electric and magnetic fields o Thermal o Neutron and gamma radiation o Effluent	o Nuclear - X-ray - Neutron and gamma - Enhanced trapped electrons o Laser - Ground - Space o Kinetic energy pellets

SECTION 4

GROUND ENVIRONMENTAL CONDITIONS

The environments specified herein are those associated with all ground operations except testing, and include storage, handling, and transportation. The space equipment shall be designed to function within performance specifications following and/or during exposure in the ground configuration to these environments. The design shall be capable of sustaining exposures up to 12 hours in humid and mildly corrosive environments that could inadvertently occur while the equipment is unprotected during manufacture or handling. These environments include possible industrial environments or sea coast fog that could be expected prior to launch. Relative humidities up to 100 percent may be encountered.

4.1 STORAGE

4.1.1 Handling and Storage Prior to Acceptance. Environmental conditions during processing, and during storage prior to shipment, shall be within the following limits:

a. Temperature: 21 deg C $\pm$ 20 deg C

b. Humidity: 50 percent $\pm$ 50 percent

Cleanliness shall be maintained during processing to minimize and control contamination. Appropriate protective containers or covers should be used to control contamination from materials outgassing, propellant leakage, mechanical systems operation, and consumable venting.

4.1.2 Storage and Transportation Subsequent to Acceptance. Items sensitive to electrostatic discharge, such as most electronic assemblies and components containing explosives, shall be stored and transported in sealed packages using antistatic wrapping material. The antistatic wrapping material used should not produce nonvolatile residues. The antistatic wrapping material shall be grounded through a resistor prior to removal. The grounding resistor shall have a value between 100,000 ohms and 1 megohm.

Storage, handling, and transportation conditions to which items are to be subjected prior to flight shall be controlled to acceptable limits. Cleanliness shall be maintained during storage and transportation using appropriate protective containers or covers. Temperature and humidity conditions and transportation shock exposure shall be monitored subsequent to manufacture, and the measured levels shall be evaluated against the acceptance test limits.

4.2 TRANSPORTATION

The space equipment shall be designed for ground transportability and for air transportability. The space equipment to be mounted as an assembly in the launch vehicle shall be capable of being transported and handled in both the vertical and horizontal attitude. Attach points for transportation and handling shall be provided on assemblies weighing more than 100 kilograms. The modes of transportation, support, and types of protective covers used shall be chosen to assure that transportation and handling do not impose thermal, vibration, acoustic, or shock environmental conditions which exceed those imposed by operational modes.

Hazardous materials shall be packaged per DoE Order 5480.3, and applicable DoD and DoT regulations.

4.3 AGE BUILDING ENVIRONMENT

The following are the facility environments:

a. Ambient Light Levels - Lighting which meets industrial standards for operation of switches and reading of meters/gauges.

b. Ambient Air Conditioning - Temperature 62° to 82° F; relative Humidity 55% maximum.

c. Acoustic Sound Levels - Less than 140 db, random frequency from 2 to 10,000 Hz.

d. Radiographic Inspection - The T34D shall have the option to use x-ray type machines and/or radioactive sources to obtain radiographs of T34D equipment. The cumulative dose at the T34D/payload interface (Vehicle Station 195.0) shall be determined using standard radiation detectors and shall not exceed 100 millirads.

4.4 PRELAUNCH

The prelaunch environment consists of that time immediately following mating of the space vehicle to the selected launch vehicle and preceding the actual launch. Specific environmental conditions may vary as a function of the selected launch vehicle.

4.4.1 Orbiter/Cargo Bay

4.4.1.1 Particulate and Gases Environment- Ground Operations with Closed Cargo Bay. Conditioned purge gas (air or GN2) which has been HEPA filtered, Class 5000, and containing 15 PPM or less hydrocarbons based on methane equivalent, shall be used to purge the cargo bay as specified in Table 4-1. The cargo shall have been installed in the cargo bay, the doors closed, and the Shuttle Vehicle fully mated before purge is started.

4.4.1.2 Particulate and Gases Environment - Re-entry and Descent. Atmospheric air filtered through 35-micron glass-bead-rating filters shall be used to repressurize the cargo bay. Figure 4-1 defines the Orbiter cargo bay internal pressure history to be used by payloads for design and venting analyses. Orbiter cargo bay vent door opening shall occur at altitudes between 70,000 ft (21,336 m) and 94,000 ft (28,651 m). The repressurization rate (i.e., dP/dt) of the cargo bay shall not exceed 0.3 psi/sec during descent.

4.4.1.3 Thermal Environment. Prelaunch and post-landing thermal environments are detailed in paragraphs 5.1.5.3 and 5.1.5.4.

4.4.2 Titan Payload Fairing Environment. Following installation of the payload fairing (PLF), conditioned air shall be introduced aft of the nose of the PLF, flow downward past the spacecraft and be discharged through the T34D. The payload fairing conditioned air system shall be independent of any environmental shelter conditioned air system. Conditioned air delivered to the payload fairing shall meet the following requirements:

a. Flow rate - 50 to 250 lb/min
b. Temperature Range - 49° to 80° F (±10° F)
c. Humidity - 28 to 50 % R.H.
d. Filtration - Class 10,000 (per Fed Std 209b)

The payload fairing conditioned air shall be provided from the time of PLF installation to the time of umbilical disconnect at vehicle liftoff.

Table 4-1 Mid-Section (Cargo Bay) Purge Fluid Flow Rates

PARAMETER	PAD LOW PRESSURE	PAD HIGH PRESSURE	POST-LANDING RUNWAY TO OFF	OFF/VAB VAB TO PAD
Gas Type	Air/GN_2 (1)	GN_2	Air (2)	Air (3)
Temperature: deg. C (deg. F) Selectable throughout range with accuracy of ± 1C (±2F)	7-37.8(45-100)	7-37.8(45-100)	7-37.8(45-100)	18-29(65-85)
Humidity: grams H_2O/kg (grains H_2O/lbs) ground controlled. Not Selectable Air GN_2	 ≤4.14 (≤29) ≤0.14 (≤1)	 ---- ≤0.14 (≤1)	 ≤4.86 (≤34) ----	 ≤4.86 (≤34) ----
Flow Rate: Spigots Closed kg/Min (lbs/min)	57.4 (126) (minimum)	165.1 (364) (minimum)	54.9 (121) (minimum)	54.9 (112) (minimum)
Flow Rate: Spigots Open kg/min (lbs/min) (4) Manifold	54.9 (121) (minimum) 68.0 (150) (maximum)	97.5 (215) (minimum) 68.0 (150) (maximum)	50.8 (112) (minimum) 61.8 (136) (maximum)	50.8 (112) (minimum) 61.8 (136) (maximum)

Note:

(1) Initiation of GN_2 purge prior to cryp tanking for inerting Cargo Bay is defined in ICD-2-0A002 "Shuttle System Launch Pad and MLP".

(2) Purge flow to be initiated at Touchdown + 15 minutes. Purge available at primary and secondary landing sites, not available at contingency landing sites.

(3) Continuous purging during closed Cargo Bay operations except during switch-over between mobile and facility GSE at OPF, VAB, Pad and during towingfrom CPF until mating operations are complete in VAB.

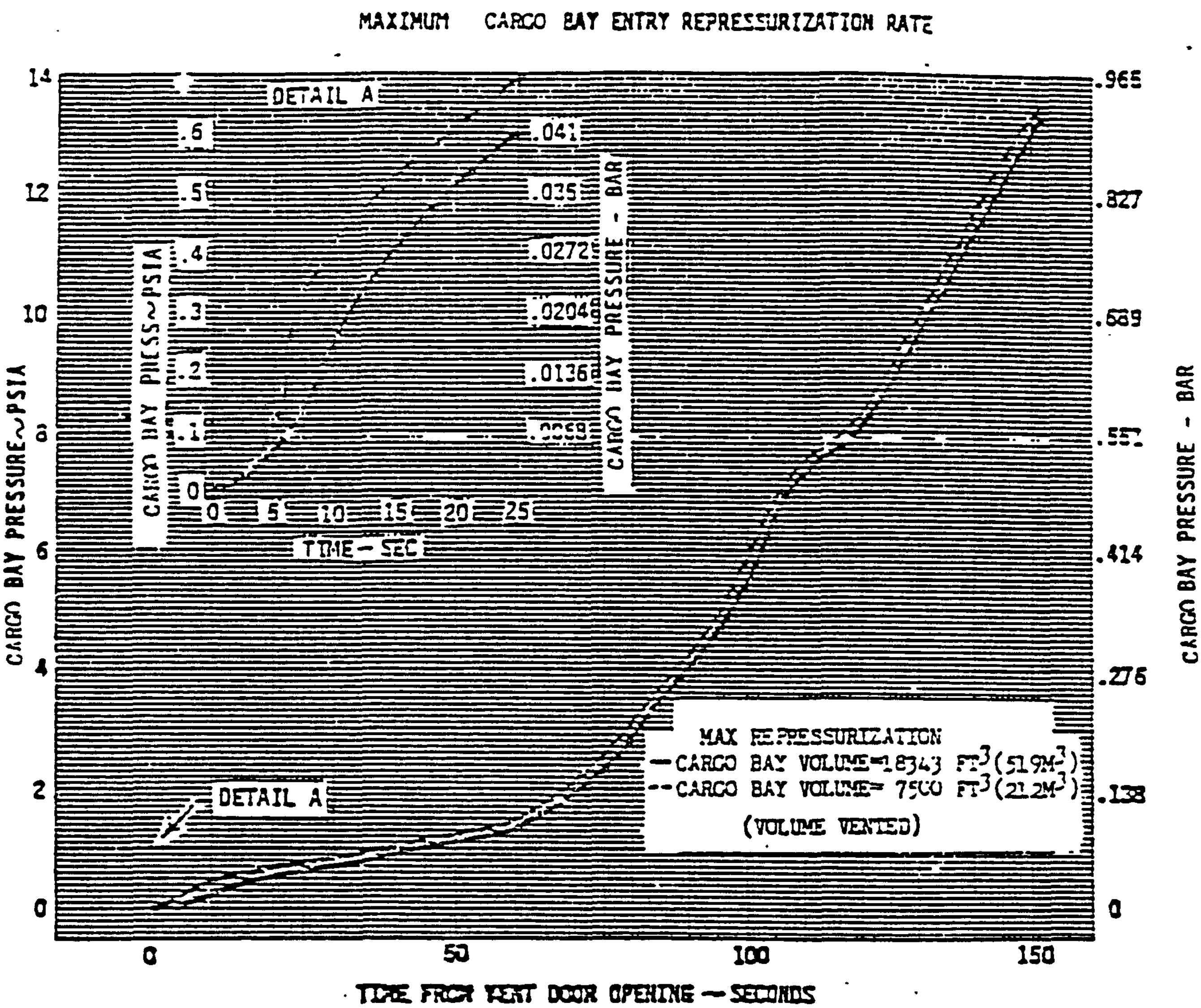
(4) Measurement and accuracy of flowrate is specified and controllable to be within ± 5%. For combined manifold and spigot flow rate greater than 140 lb/min (63.5 kg/min) the purge flow rate to the cargo bay shall be reduced, starting no

Table 4-1 Mid-Section (Cargo Bay) Purge Fluid Flow Rates (Continued)

earlier than T-11 minutes, to a range of 110 to 140 lb/min (49.9 to 63.5 kg/min) total.

Vents No. 6 (Port and Starboard) open to accommodate flow rates greater than 81.8 Kg/min (180 lbs/min) (Total Midfuselage Flow). This corresponds to a flow rate greater than 65.5 Kg/min (144 lbs/min) to Cargo Bay only.

(5) The maximum pressure drop at allocated flow shall not exceed 0.45 psi from the Orbiter spigot/duct interface through the duct system including duct exit and spacecraft.



(NASA/JSC PSEUDO TRAJECTORY, MAXIMUM DYNAMIC PRESSURE (375/450)~ PSF)

Figure 4-1 Entry Phase Cargo Bay Internal Pressure Valves, To Be Used For Payload Design

SECTION 5
LAUNCH ENVIRONMENTAL CONDITIONS

The space equipment shall be designed to function within performance specifications after or, if appropriate, during, exposure in the launch configuration to their design environmental levels. These design environmental levels for launch exceed the maximum predicted launch environments for each item by the environmental design margin.

Both reusable and expendable launch vehicles may be used for insertion of the power supply into orbit. Primary candidates include the Space Transportation System (STS) and its derivatives (Shuttle-C), the Titan IV system (represented by the Titan 34D), and the Advanced Launch System (ALS). Each vehicle will provide different payload/cargo envelopes, mass limitations, and mounting/attach point requirements. Payload envelopes and mass limits are shown in Table 5-1 for each candidate vehicle. Mounting/attach point requirements are provided in the following paragraphs, as applicable.

Table 5-1 Candidate Launch Vehicle Payload Envelopes

Launch Vehicle	Dynamic Envelope(ft)	Payload (Klbm)	Orbit Altidude (nmi)
Shuttle	15 dia x 60	55	110 circ.
Shuttle (uprated)	15 dia x 60	65	150 circ.
Shuttle-C	15 dia x 60	100-150	220 circ.
Titan 34D	TBS	TBS	TBS
Titan 4	16.7 dia x 56-86	TBS	TBS
Advanced Launch System (ALS)	15 dia x 80	100-150	80x150

5.1 REUSABLE LAUNCH VEHICLE

The candidate reusable launch vehicles are the current STS Space Shuttle and the uprated/advanced Shuttle-C. Except where noted, the requirements defined in the following paragraphs are applicable to the current STS. Additional detail may be obtained from NSTS 07700, Volume XIV, Attachment 1 (ICD 2-19001). These requirements form a reference that must be updated as Shuttle-C information becomes available.

5.1.1 Loads and Accelerations. The MSNPS shall be designed to account for all Shuttle and transfer vehicle induced static, thermal, and dynamic loadings.

5.1.1.1 In Orbiter Cargo Bay. The load factors for the conceptual design of the MSNPS vehicle and ASE structure are provided in Tables 5-2, 5-3, and 5-4. These factors are applicable to the complete spacecraft configuration. The signs of the applied spacecraft load factors shall be consistent with the Shuttle system. Loads estimated with the specified factors will be superseded with the results of dynamic loads analyses (with the use of specified uncertainty factors) when the loads predicted by the dynamic analysis are higher than the loads estimated with the factors. These requirements apply for all spacecraft defined by the Government and for Shuttle characteristics and forcing functions supplied by the Government. The total load shall include thermal induced loads.

5.1.1.2 Free Flight. The accelerations due to SRM burn and thrust vector control shall be limited to -5 g's longitudinal and ±2 g's in the pitch and yaw directions. Free flight loads for structural design shall be based on coupled spacecraft dynamic analysis using forcing functions derived from solid rocket motor test firings and simultaneous operation of the thrust vector control system.

5.1.2 Random Vibration. The random vibration environments for Trunnion and Longeron/Adaptor supported payloads are shown in Tables 5-5, 5-6, and 5-7.

5.1.3 Acoustic Noise. The acoustic noise environment internal to the Orbiter cargo bay is shown in Table 5-8.

5.1.4 Shock. Equipment located in the Orbiter cargo bay or aft flight deck shall not experience any pyroshock environments while attached to the Shuttle. Shock environments induced by MSNPS pyrotechnic devices and/or the transfer vehicle are TBD.

5.1.5 Thermal Environment.

5.1.5.1 Cargo Bay Wall Temperature. Typical temperature ranges at the cargo bay walls are defined in Table 5-9.. Actual temperatures are dependent upon flight parameters and upon cargo element configuration. The maximum temperature for the radiator panels when the doors are closed shall not exceed 210°F.

5.1.5.2 Reflected Solar Energy. Cargo Elements and Orbiter components which extend above the cargo bay door hinge line (Zo 400.0 ref.), or which are deployed transversely over the radiators, may be subjected to locally concentrated solar radiation. The magnitude of the local fluxes will be a function of cargo element or component location and Orbiter orientation relative to the sun. Objects located over the radiators may be irradiated with a flux substantially higher

Table 5-2 Cargo Limit-Load Factors/Angular Accelerations for Preliminary Design (quasi-Static Flight Events)

FLIGHT EVENT	LOAD FACTOR g			ANGULAR ACCELERATION RAD/SEC^2			CARGO WEIGHT
	Nx	Ny	Nz				
ASCENT							
HIGH-Q BOOST ENVELOPE	-1.9	±0.40	0.25 -0.50	±0.10	±0.15	±0.15	Up to 65 Klb
INTEGRATED VEHICLE BOOST MAX Nx	-2.9 -2.6	±0.06 ±0.02	-0.15 -0.20	±0.20 ±0.20	±0.25 ±0.25	±0.25 ±0.25	
ORBITER BOOST MAX Nx	-3.17 -3.05	0 0	-0.60 -0.80	±0.20 ±0.20	±0.25 ±0.25	±0.25 ±0.25	
POST SRB STAGING	-1.10	±0.12	-0.59				
DESCENT							
TAEM: PITCH MANEUVER	1.01 -0.15	0	2.50	0	0	0	Up to 32 Klb
	0.25	0	2.50	0	-0.11	0	
	0.97 0	0	-1.00	0	0	0	
TAEM: ROLL MANEUVER	0.65	±0.12	1.98	±1.28	0.02	±0.13	
TAEM: YAW MANEUVER	0.60 0.56 0.61	±0.85 ±0.49 ±0.002	1.0 1.44 0.92	0 0 0	0 0 0	0 ±0.044 ±0.056	

Table 5-3 Cargo Limit-Load Factors/Angular Accelerations for Preliminary Design (Transient Flight Events)

FLIGHT EVENT	LOAD FACTOR g			ACCELERATION RAD/SEC^2			CARGO WEIGHT
	Nx	Ny	Nz	ϕ	θ	ψ	
<u>ASCENT</u>							
LIFT-OFF	-0.2 -3.2	±1.4	2.5 -2.5	±3.7	±7.7	±3.1	Up to 65 Klb (29484 kg)
<u>DESCENT</u>							
LANDING	1.8 -2.0	±1.5	+4.2 -1.0	±4.0	±11.3	±4.9	Up to 32 Klb (14515 kg)

Table 5-4 Emergency Landing Design Load Factors

	Load Factor 65 Klb (29484 kg) Up 32 Klb (14515 kg) Down			Load Factor 65 Klb (29484 kg) Down		
CONDITION	X	Y	Z	X	Y	Z
Emergency Landing (Outside Crew Compartment)	+4.5 -1.5	+1.50 -1.50	+4.5 -2.0	+4.50 -0.738	+0.738 -0.738	+2.215 -0.985
Emergency Landing (Inside Crew Compartment)	+20.0 -3.3	+3.3 -3.3	+10.0 -4.4			

Sign convention follows that of the Orbiter coordinate system.

Emergency landing load factors are ultimate. The longitudinal load factors are directed in all aftward azimuths within a cone of 20 degrees half-angle. The specified load factors shall operate separately.

For cargo weight between 32 Klb and 65 Klb, use a linear interpolation between the load factors given.

Table 5-5 Orbiter Cargo Bay Random Vibration Trunnion Supported Payloads - On P/L Trunnion

Payload Weight *Less Than 10,000 Lbs.		
o X Axis	20 to 50 Hz 50 to 125 Hz 125 to 300 Hz 300 to 2000 Hz Overall = 3.0 g(rms)	.0015 G^2/Hz +9 dB/oct .025 G^2/Hz -9 dB/oct
o Y Axis (fwd of Sta. Xo = 919)	20 to 68 Hz 68 to 100 Hz 100 to 380 Hz 380 to 2000 Hz Overall = 2.5 g(rms)	.004 G^2/Hz +9 dB/oct .013 G^2/Hz -9 dB/oct
o Y Axis (Aft to Sta. Xo = 919) And o Z Axis	20 to 68 Hz 68 to 125 Hz 125 to 300 Hz 300 to 2000 Hz Overall = 3.0 g(rms)	.004 G^2/Hz +9 dB/oct .025 G^2/Hz -9 dB/oct
Payload Weight *Greater Than 10,000 Lbs.		
o X Axis	20 to 50 Hz 50 to 80 Hz 80 to 480 Hz 480 to 2000 Hz Overall = 2.0 g(rms)	.0015 G^2/Hz +9 dB/oct .0063 G^2/Hz -9 dB/oct
o Y and Z Axes	20 to 68 Hz 68 to 80 Hz 80 to 480 Hz 480 to 2000 Hz Overall = 2.4 g(rms)	.004 G^2/Hz +9 dB/oct .0063 G^2/Hz -9 dB/oct

The associated time duration is 20 seconds per axis per flight which includes a fatigue scatter factor of 4.

*Total payload weight is irrespective of the number of mounting points.

Table 5-6 Orbiter Cargo Bay Random Vibration Trunnion Supported Payloads - On P/L Keel Pin

Payload Weight *Less Than 10,000 Lbs.		
o All Axes	20 to 60 Hz 60 to 100 Hz 100 to 300 Hz 300 to 2000 Hz Overall = 1.9 g(rms)	.0023 G^2/Hz +9 dB/oct 0.01 G^2/Hz -9 dB/oct
Payload Weight *Greater Than 10,000 Lbs.		
o All Axes	20 to 480 Hz 480 to 2000 Hz Overall = 1.2 g(rms)	.0023 G^2/Hz -9 dB/oct

The associated time duration is 20 seconds per axis per flight which includes a fatigue scatter factor of 4.

*Total payload weight is irrespective of the number of mounting points.

Table 5-7 Orbiter Cargo Bay Random Vibration Longeron/Adapter Supported Payloads - At Orbiter Interface

o X Axis	20 to 100 Hz 100 to 500 Hz 500 to 2000 Hz Overall = 5.4 g(rms)	+6 db/oct .03 G^2/Hz -4 dB/oct
o Y Axis (Fwd of Sta. Xo = 919)	20 to 40 Hz 40 to 100 Hz 100 to 170 Hz 170 to 600 Hz 600 to 2000 Hz Overall = 4.5 g(rms)	+12 dB/oct .06 G^2/Hz -6 dB/oct .02 G^2/Hz -9 dB/oct
o Y Axis (Aft to Sta. Xo = 919)	20 to 40 Hz 40 to 500 Hz 500 to 2000 Hz Overall = 7.8 g(rms)	.12 dB/oct .06 G^2/Hz -4 dB/oct
o Z Axis	20 to 100 Hz 100 to 1000 Hz Overall = 7.6 g(rms)	+6 dB/oct .03 G^2/Hz

The associated time duration is 20 seconds per axis per flight which includes a scatter factor of 4.

Table 5-8 Orbiter Cargo Bay Internal Acoustic Environment

1/3 Octave Band Center Frequency (Hz)	Sound Pressure Level (dB) ref. 2X10^{-5} N/m^{2}	
	Lift-off 5 Seconds/Flight*	Aeronoise 10 Seconds/Flight*
31.5	122.0	112.0
40.0	124.0	114.0
50.0	125.5	116.0
63.0	127.0	118.0
80.0	128.0	120.0
100.0	128.5	121.0
125.0	129.0	122.5
160.0	129.0	123.5
200.0	128.5	124.5
250.0	127.0	125.0**
315.0	126.0	125.0**
400.0	125.0	124.0**
500.0	123.0	121.5
630.0	121.5	119.5
800.0	120.0	117.5
1000.0	117.5	116.0
1250.0	114.0	112.5
2000.0	112.0	110.5
2500.0	110.0	108.0
Overall	138.0	133.5

*Time per flight does not include a scatter factor.

**NOTE: Narrow band discrete noise is radiated from the cargo bay vent doors during transonic/low supersonic flight. The noise radiated from any one vent is described below:

This environment is not intended for the full payload exposure but only to those areas of the payload adjacent to a cargo bay vent opening.

One-third Octave Band Center Frequencies, Hz	Sound Power Level dB re 10^{-12} watts
	8 Seconds/Flight
250	128
315	136
400	130

Table 5-9 Cargo Bay Wall Temperature

Condition	Temperature	
	Minimum	Maximum
1. Preluanch	+40°F	+120°F
2. Launch	+40°F	+150°F
3. On-Orbit (doors open)	-250°F	+200°F
4. Entry and Post-landing	-50°F	+220°F

Note:

a. Conditions 1 and 2 are for an assumed adiabatic cargo element.

b. Condition 3 is for an assumed empty cargo bay. The effect on wall temperature which results with a cargo element installed is dependent upon cargo element configuration, cargo element location in the bay, and on-orbit attitude. Under hot case conditions, cargo element effects can cause local insulation surface wall temperatures to exceed 200°F substantially.

c. Condition 4, minimum, is for an assumed adiabatic cargo element with an initial -250°F cargo bay wall temperature. Condition 4, maximum, is for an assumed empty cargo bay.

d. Conditions 3 and 4 should be analyzed using detailed integrated Orbiter/cargo element math models to define cargo element and Orbiter cargo bay temperatures for specific cargo element configurations.

than the solar constant due to focusing by the specularly reflective radiators.

5.1.5.3 Entry Air Inlet Conditions. The air temperature, mass flow rate and pressure entering the cargo bay during entry to be utilized for cargo design thermal analysis is as defined in Figures 5-1 and 5-2.

5.1.5.4 Prelaunch and Post-landing Environments. Worst case hot and cold prelaunch and post-landing environments, as well as nominal environments are defined, which shall be used in verifying Orbiter/cargo elements thermal compatibility. Constant values for environmental extremes are provided which may be used for calculating conservative thermal predictions. Diurnal data is also provided which may be used for performing more rigorous predictions.

5.2.5.4.1 Solar Flux. The solar constant, which is defined as the heating flux to a surface normal to the incident solar radiation, has a mean value of 429 BTU/hr-ft^2 outside the earth's atmosphere. Because of attenuation due to atmospheric interference, the solar constant at the earth's surface varies as a function of time of day. Figure 5-3 shows the diurnal variation of the solar constant to be used for normal hot and cold environment cases of prelaunch and post-landing analyses. For prelaunch conditions, it shall be assumed that the Orbiter is in the vertical position on the launch pad with its tail facing south at the Eastern Test Range (ETR) or facing west at the Western Test Range (WTR). For landings at the ETR the Orbiter is assumed to be generally oriented with the X-axis in a north-south direction; for the WTR, the orientation is also assumed to be generally in the north-south direction

For hot case analysis, the flux represents the direct flux for a surface normal to the flux. The direct fluxes for the various surfaces of the Orbiter must be corrected for the angle of incidence which varies for each surface and with the time of day. For cold analysis, the flux is assumed to represent the diffuse flux for a cloudy day and does not need to be corrected for the angle of incidence.

Figure 5-4 shows the curve to be used for the maximum solar flux at contingency landing sites. The curve was generated assuming March "noontime" equatorial flux of 396 BTU/hr-ft^2 and the timewise distribution equation shown on the figure. Minimum flux at a contingency landing site is assumed to be equal to zero.

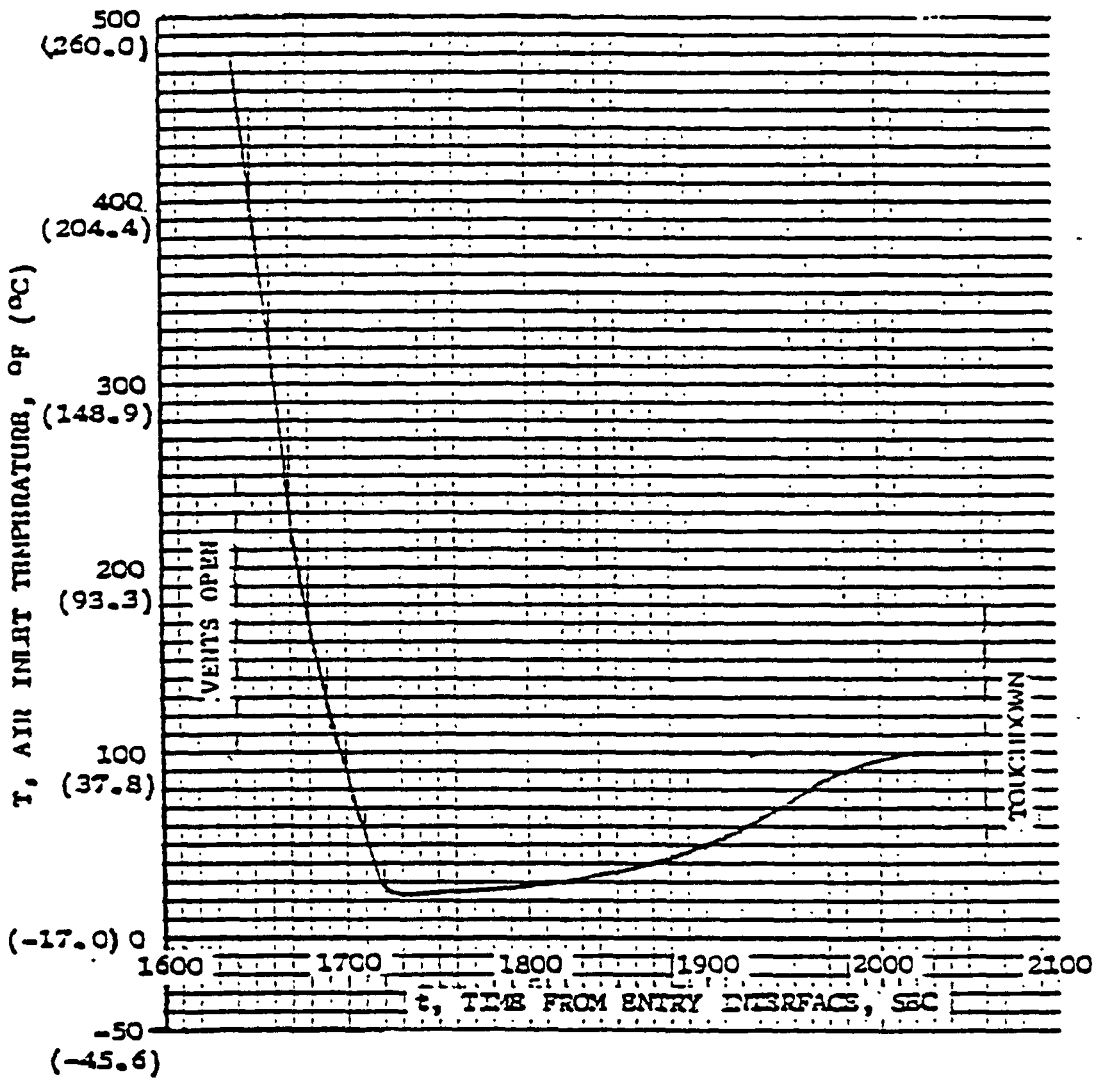


Figure 5-1 Air Temperature Entering The Cargo Bay During Entry - Max Air Temperature Case

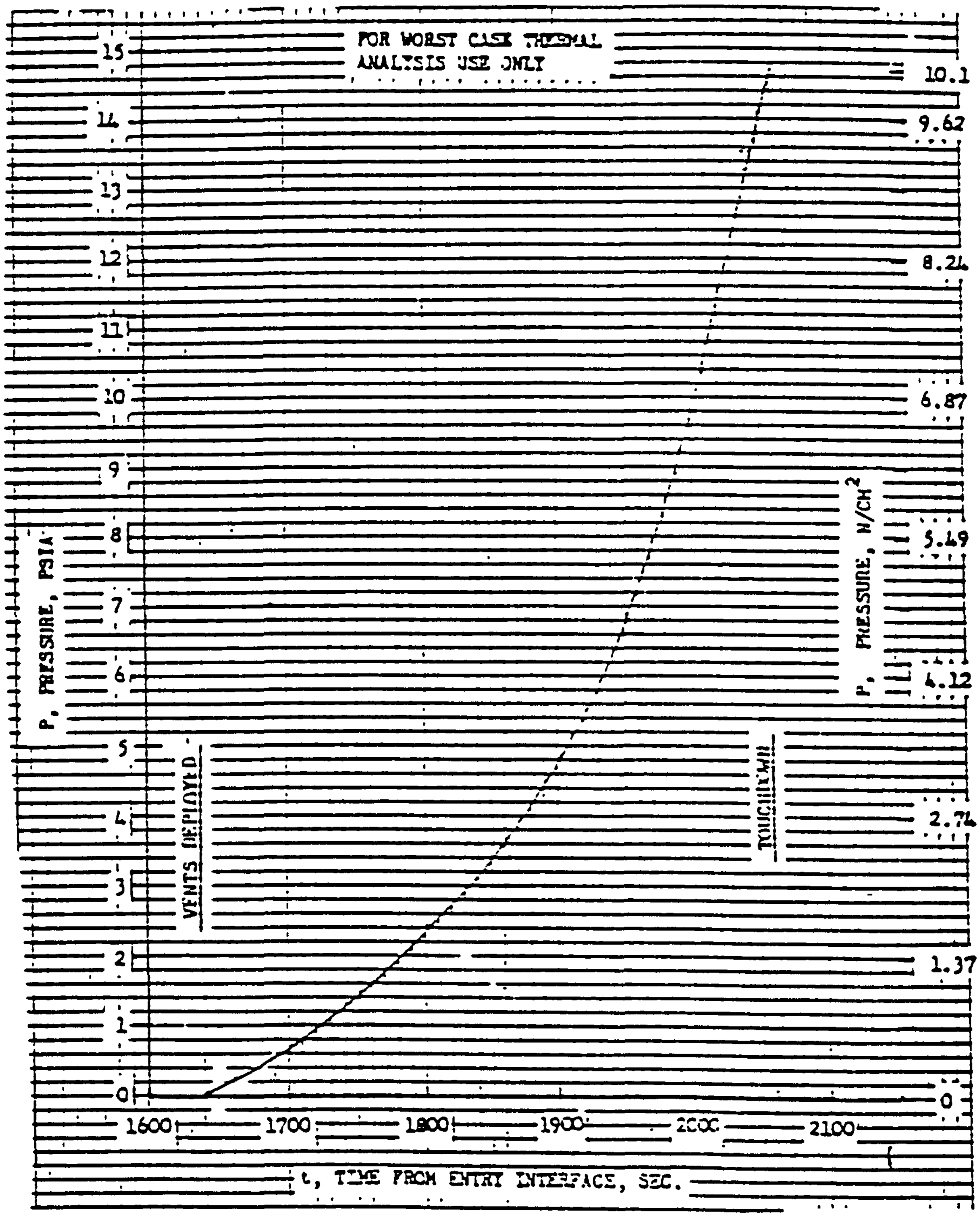


Figure 5-2 Air Pressure During Entry For Estimated Thermal Worst Case

TIME OF DAY	DESIGN HIGH SOLAR RADIATION		DESIGN LOW SOLAR RADIATION	
HOUR	BTU/FT^2/HR	GM-CAL/CM^2/MIN	BTU/FT^2/HR	GM-CAL/CM^2/MIN
0500	0	0.00	0	0.00
1100	363	1.64	70	0.32
1300			80	0.36
1400	363	1.64		
2000	0	0.00	0	0.00

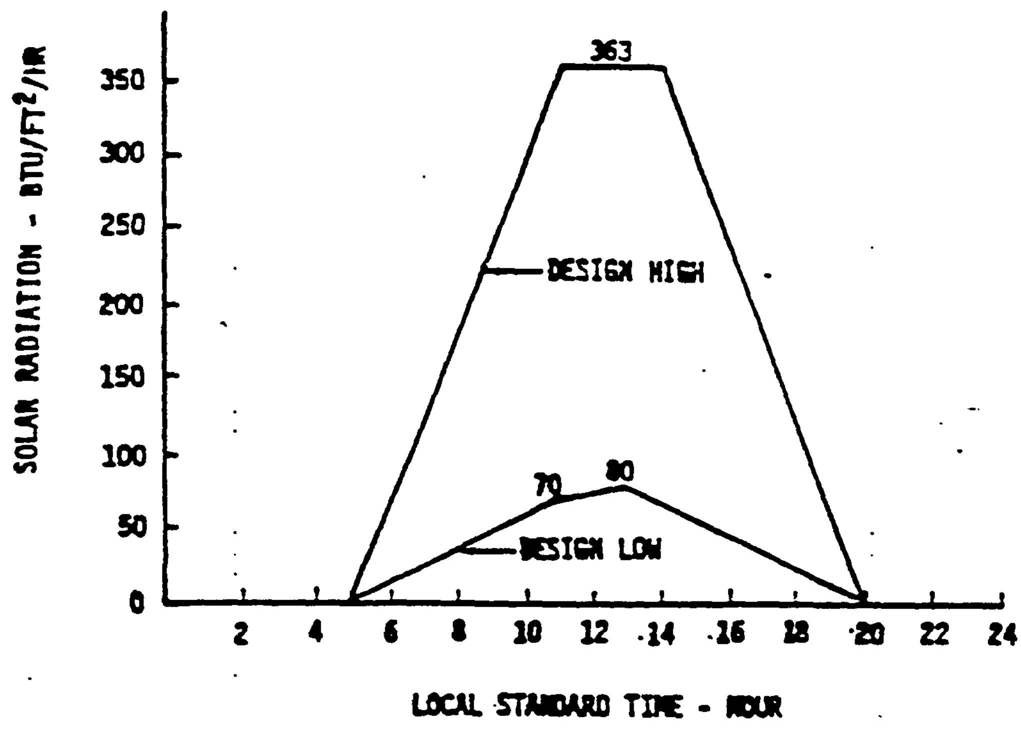


Figure 5-3 Diurnal Variation Of Solar Constant

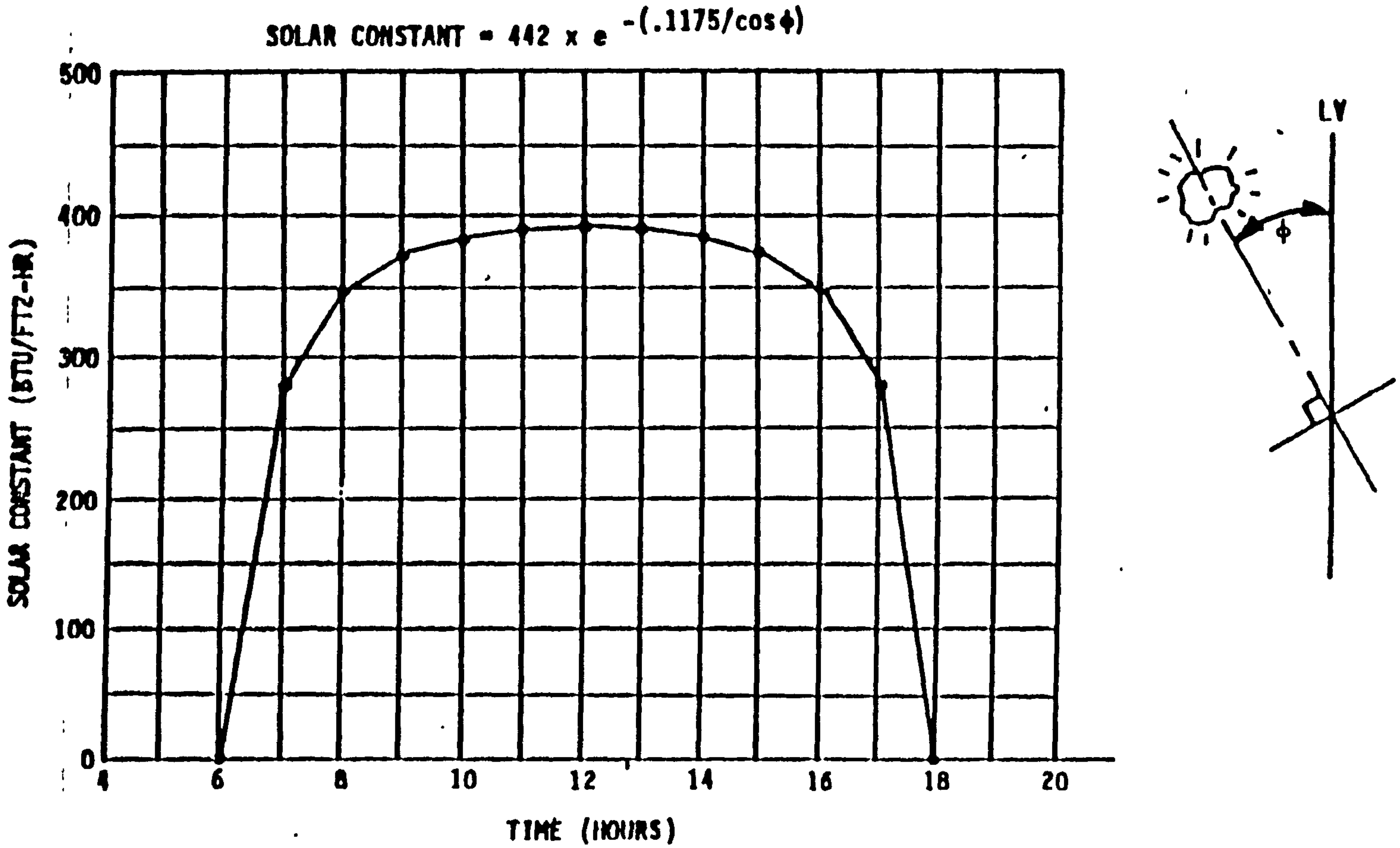


Figure 5-4 Equatorial Solar Constant Variation

For cases where it is desirable to use constant (conservative) values for the solar flux, the following values may be used:

Hot Environment*

Prelaunch and normal post-landing	363 $BTU/hr\text{-}ft^2$
Contingency landing	396 $BTU/hr\text{-}ft^2$

Cold Environment**

Prelaunch and normal post-landing	70 $BTU/hr\text{-}ft^2$
Contingency landing	0 $BTU/hr\text{-}ft^2$

* For prelaunch hot conditions with the Orbiter in a vertical position on the pad, assume the sun is in the Orbiter X-Z plane at an angle 38° up from the local horizontal at the ETR, and in the Orbiter X-Y plane at an angle 31° up from the local horizontal at the WTR. For hot analyses for normal post-landing and contingency landings, assume the sun is directly overhead.

** For cold conditions, assume the flux is diffuse.

5.1.5.4.2 Ambient Air Temperature. The ambient air temperature varies with time of day, season and local weather conditions. Figures 5-5 and 5-6 show diurnal air temperatures for ETR and WTR locations for cold, hot and "nominal" days for representative months. The temperatures for hot and cold days represent the maximum and minimum values, respectively, for 95 percent of all measurements while the temperature for a "nominal" day represents the median (50 percentile) of all measurements.

Figure 5-7 shows diurnal air temperatures for hot and cold days at contingency landing sites. The curve for a hot day was synthesized assuming a maximum temperature of 110°F at noon and the minimum temperature at ETR in July for a 95 percent hot day. The curve for a cold day was synthesized assuming a minimum temperature of 0°F and a 50°F temperature rise and fall in the morning and afternoon, respectively.

Where it is desired to use constant (conservative) values of ambient temperature, the following values are recommended:

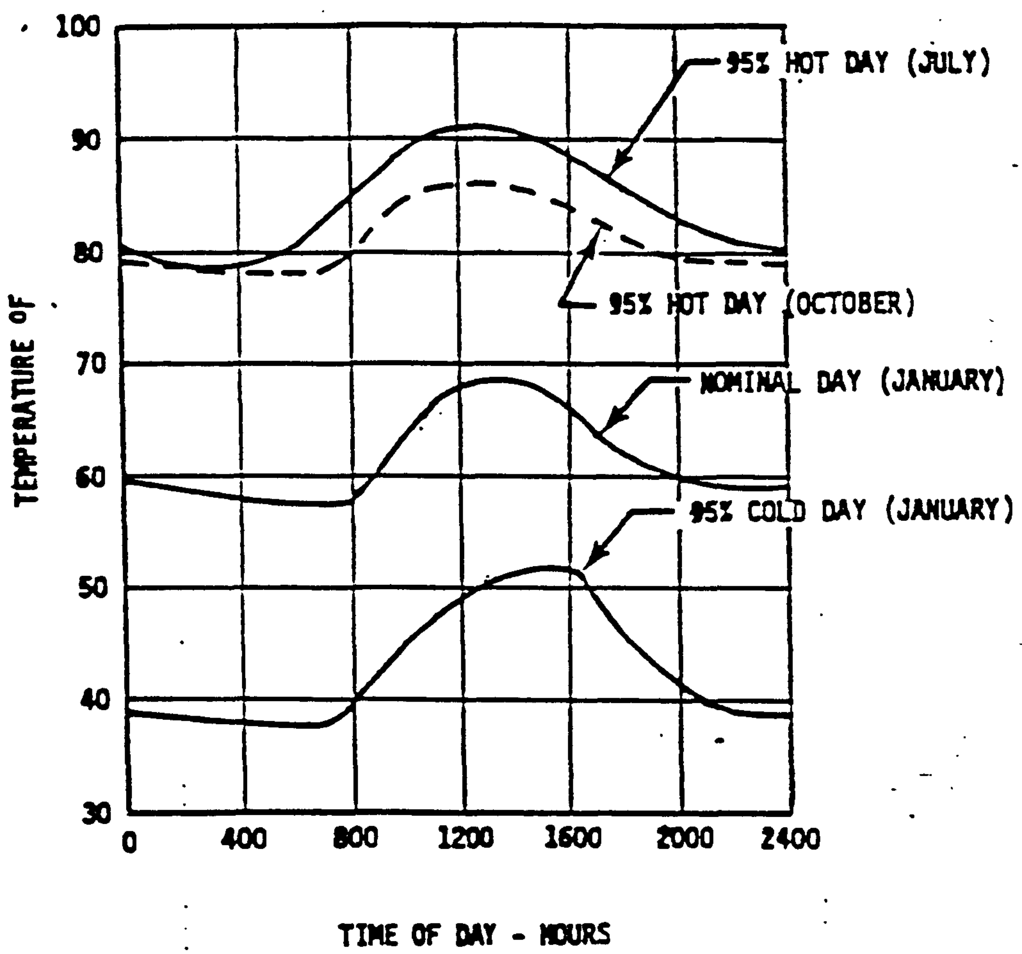


Figure 5-5 Eastern Test Range (ETR) Diurnal Air Temperature Experience

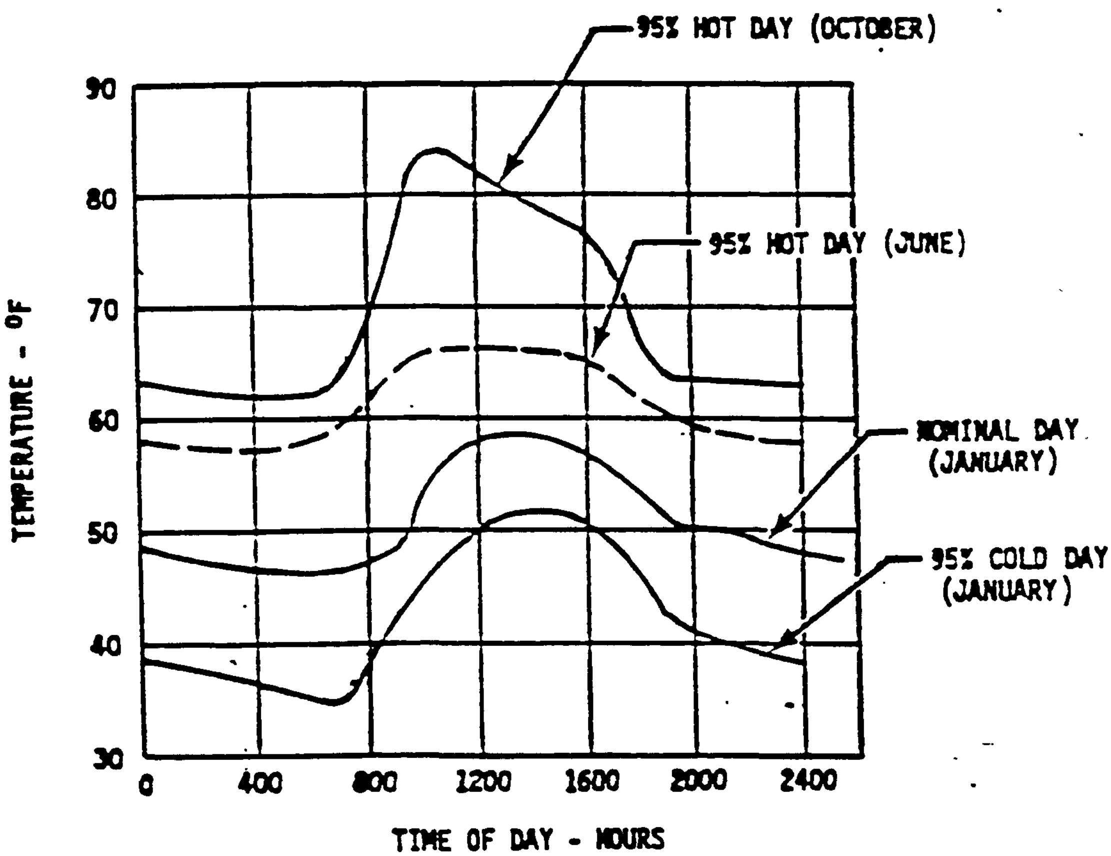


Figure 5-6 Western Test Range (WTR) Diurnal Air Temperature Experience

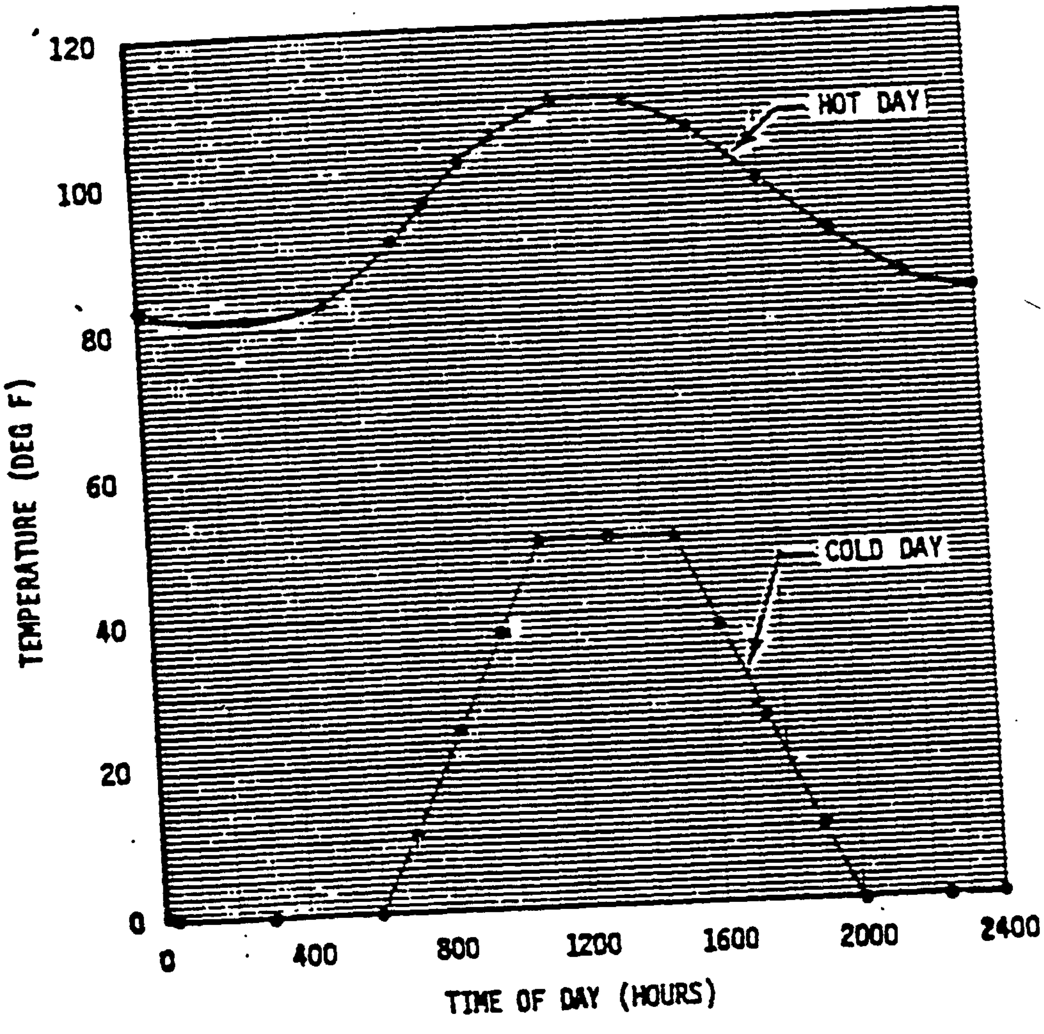


Figure 5-7 Worst Case Diurnal Air Temperature

Hot Environment

Prelaunch and normal post-landing	99°F
Contingency landing	110°F

Cold Environment

Prelaunch and normal post-landing	25°F
Contingency landing	0°F

5.1.5.4.3 Ground Surface Temperature. The ground surface temperature is influenced by incident daytime solar radiation, sky/ground radiation interchange, air temperature and velocity, and surface properties. Generally, it is assumed that the ground surface temperature is the same as the air temperature. If desired, the ground temperature may be assumed to be equal to the diurnal air temperature. When constant (conservative) values are appropriate, the following values may be used:

Hot Environment

Prelaunch	99°F (60°F*)
Normal post-landing	99°F
Contingency landing	110°F

Cold Environment

Prelaunch	25°F
Normal post-landing	25°F
Contingency landing	0°F

* When in a vertical position on the launch pad, the bottom of the Orbiter views the external tank which has a temperature of approximately 60°F.

5.1.5.4.4 Sky Temperature. The sky temperature is influenced by climatic conditions such as ambient temperature and cloud cover and time of day. While on the runway the upperbody surfaces of the Orbiter radiate heat primarily to the sky. While on the launch pad in a vertical position, these surfaces radiate approximately one-half to the ground and one-half to the sky. The following constant values are recommended for design purposes:

Hot Environment

Prelaunch	50°F*
Normal post-landing	50°F
Contingency landing	50°F

Cold Environment

Prelaunch	5°F
Normal post-landing	-22°F
Contingency landing	-22°F

* Average radiation temperature viewed by Orbiter top surfaces is 76°F assuming sky temperature of 50°F and ground temperature of 99°F.

5.1.6 Orbiter/Cargo Bay Particulates and Gases Environment. (Lift-Off Through Orbit Insertion) The cargo bay gas shall be the residue remaining from the Orbiter ground purge conducted prior to lift-off. The nominal cargo bay pressure during ascent shall be within the curves shown in Figure 5-8. The maximum cargo bay ascent pressure decay rate (i.e., dP/dt) is shown in Figure 5-9 with a maximum value of 0.76 psi/second. Table 5-10 presents values for the data plotted in Figures 5-8 and 5-9.

5.1.7 Contamination.

5.1.7.1 Accessibility for Cleaning. Interior surfaces of the cargo bay and exterior surfaces of the cargo shall be designed to provide accessibility for cleaning purposes.

5.1.7.2 Cargo Bay Liner. The Orbiter shall provide a cargo bay liner, as required, to isolate cargo element surfaces which are sensitive to particulate contamination effects from the Orbiter lower mid-fuselage. The liner shall prevent the transfer of particulates greater than 35 microns GBR (nominal max. Particle size 87 microns in length) from the lower mid-fuselage to the cargo bay. All cargo bay surfaces, including the cargo bay liner shall be cleaned to a visibly clean level as defined in NSTS Specification SN-C-0005.

5.1.7.3 Orbiter Sources of Contamination. Number column density and return flux predictions for outgassing, flash evaporation, leakage, and vernier RCS effluents for various lines-of-sight and altitudes are shown in Table 5-11. Direct flux predictions for outgassing and leakage are also shown in Table 5-11. These numbers will be refined further as improvements of input data to the predictive program are made. Time lining analyses will be performed for optimum selection of Orbiter effluent release including water dumps, where possible.

5.1.7.4 Thruster Bipropellant Combustion Products. Table 5-12 lists the Reaction Control System (RCS) and Vernier Reaction Control System (VRCS) exhaust products due to the combustion of MMH/N_2O_4 bipropellant. Distribution of these products within

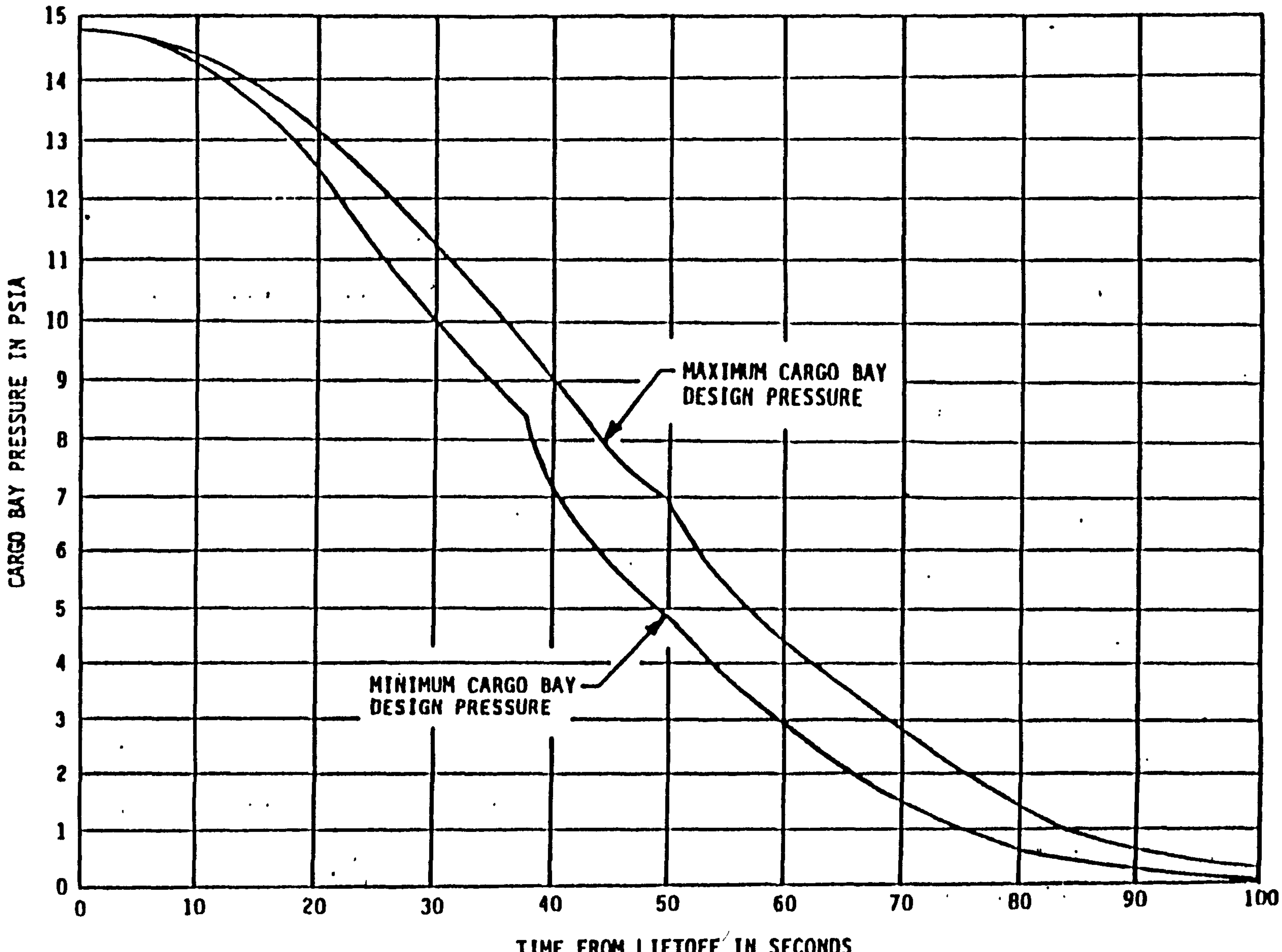


Figure 5-8 Orbiter Cargo Bay Internal Pressure History During Ascent

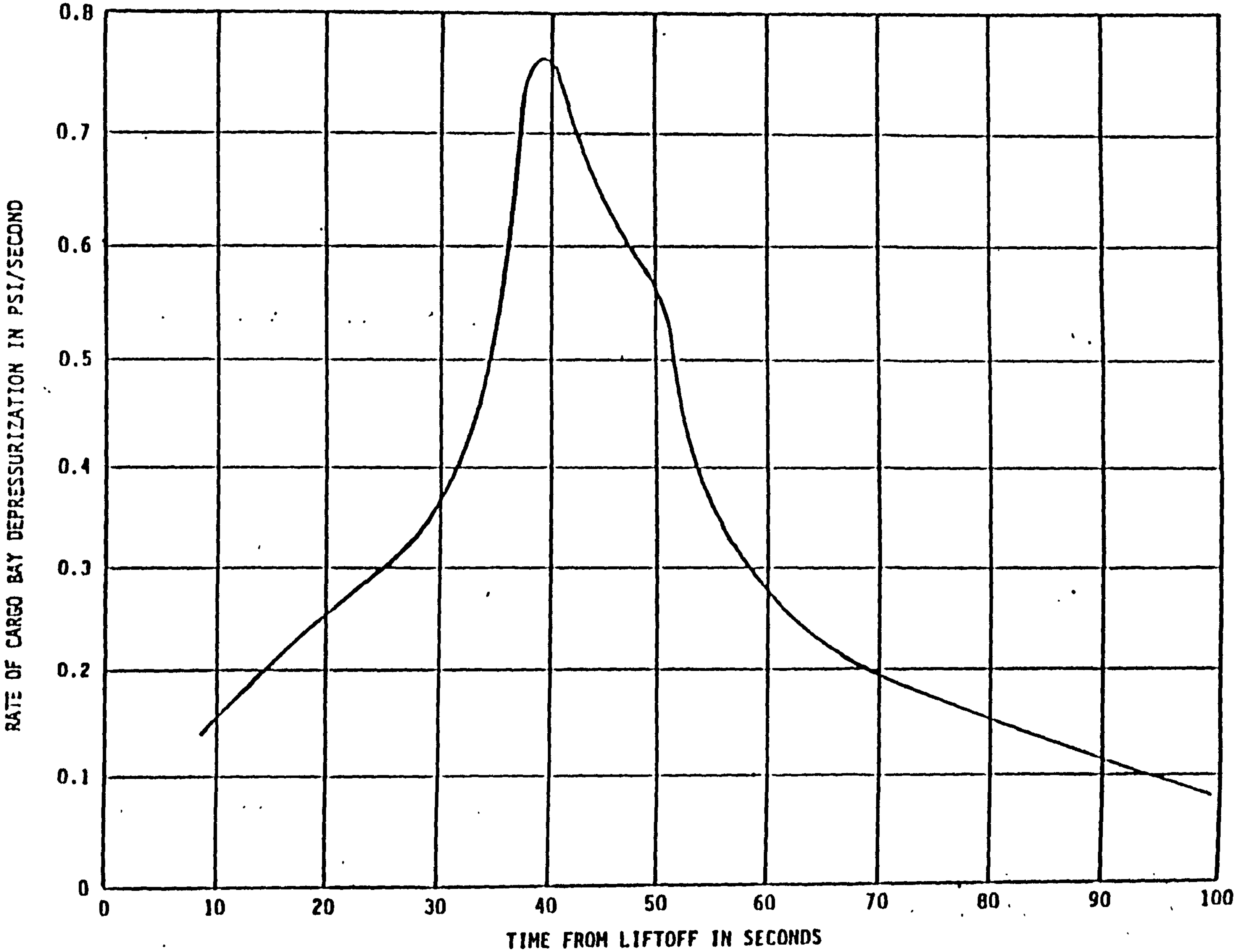


Figure 5-9 Maximum Cargo Bay Pressure Decay Rate During Ascent

Table 5-10 Ascent Cargo Bay Pressure and Decay Rate

Time	Maximum Cargo Bay Pressure	Minimum Cargo Bay Pressure	Maximum Rate of Depressurization
10	14.45	14.20	0.155
20	13.20	12.50	0.255
30	11.25	10.00	0.360
35	10.05	8.90	0.510
38	9.40	8.20	0.735
39	9.15	7.60	0.760
40	8.95	7.20	0.760
41	8.70	6.80	0.760
45	7.75	5.70	0.640
48	7.20	5.10	0.570
49	7.05	4.90	0.575
50	6.90	4.70	0.550
51	6.60	4.50	0.520
52	6.10	4.30	0.455
55	5.35	3.65	0.355
60	4.30	2.70	0.273
65	3.50	2.00	0.225
70	2.70	1.40	0.195
80	1.30	0.60	0.150
90	0.60	0.20	0.115
100	0.25	0.10	0.075

Note:

(1) Pressure in psia

(2) Rate of depressurization in psi/second

(3) Time in seconds from lift-off

Table 5-11 Predicted Number Column Density and Return Flux Contributions From Shuttle Orbiter Sources of Contamination

PARAMETER / SOURCE	NUMBER COLUMN DENSITY (MOLECULES/Cm^2)	RETURN FLUX (BF) (1) (MOLECULES/Cm^2/sec)			DIRECT FLUX FOR OUTGASSING AND LEAKAGE
		300km	400km	700km	
Outgassing (2)					TBD
LOS 1 (3)	2.75×10^{10}	5.2×10^{10}	1.1×10^{10}	2.5×10^{8}	
LOS 3 (3)	3.1×10^{10}	2.9×10^{10}	6.2×10^{9}	1.4×10^{8}	
LOS 7 (3)	2.7×10^{10}	2.5×10^{10}	5.3×10^{9}	1.2×10^{8}	
Flash Evaporator (4)					TBD
LOS 1	6.6×10^{13}	4.2×10^{13}	8.9×10^{12}	2.1×10^{11}	
LOS 3	1.4×10^{14}	4.5×10^{13}	9.6×10^{12}	2.2×10^{11}	
LOS 7	3.4×10^{14}	1.1×10^{14}	2.3×10^{13}	5.3×10^{11}	
LOS 11 (3)	4.4×10^{13}	1.3×10^{13}	2.8×10^{12}	6.5×10^{10}	
Leakage					TBD
LOS 1	2.0×10^{12}	1.6×10^{12}	3.4×10^{11}	7.8×10^{9}	
LOS 3	2.3×10^{12}	9.4×10^{11}	2.0×10^{11}	4.6×10^{9}	
LOS 7	1.9×10^{12}	8.0×10^{11}	1.7×10^{11}	3.9×10^{9}	
LOS 11	2.9×10^{12}	1.1×10^{12}	2.4×10^{11}	5.5×10^{9}	
Vernier RCS AFT-Z					TBD
LOS 1	2.1×10^{14}	1.6×10^{14}	3.4×10^{13}	7.8×10^{11}	
LOS 3	2.6×10^{14}	9.9×10^{13}	2.1×10^{13}	4.8×10^{11}	
LOS 7	3.4×10^{14}	1.3×10^{14}	2.8×10^{13}	6.5×10^{11}	
LOS 11	9.3×10^{13}	3.5×10^{13}	7.4×10^{12}	1.7×10^{11}	
Venrnier RCS AFT+Y					TBD
LOS 1	1.8×10^{14}	1.2×10^{14}	2.5×10^{13}	5.8×10^{11}	
LOS 3	2.4×10^{14}	8.5×10^{13}	1.8×10^{13}	4.1×10^{11}	
LOS 7	6.3×10^{14}	2.3×10^{14}	4.9×10^{13}	1.1×10^{12}	
LOS 11	6.7×10^{13}	2.5×10^{13}	5.3×10^{12}	1.2×10^{11}	
Main RCS AFT-Z					TBD
LOS 1	9.8×10^{15}	7.4×10^{15}	1.6×10^{15}	3.6×10^{13}	
LOS 3	1.5×10^{16}	5.3×10^{15}	1.1×10^{15}	2.6×10^{13}	
LOS 7	2.0×10^{16}	7.7×10^{15}	1.6×10^{15}	3.8×10^{13}	
LOS 11	5.3×10^{15}	2.0×10^{15}	4.2×10^{14}	9.8×10^{12}	
Main RCS AFT+Y					TBD
LOS 1	8.9×10^{15}	6.7×10^{15}	1.4×10^{15}	3.3×10^{13}	
LOS 3	1.2×10^{16}	4.4×10^{15}	9.2×10^{14}	2.2×10^{13}	
LOS 7	3.4×10^{16}	1.3×10^{16}	2.6×10^{15}	6.1×10^{13}	
LOS 11	3.7×10^{15}	1.4×10^{15}	3.0×10^{14}	7.0×10^{12}	

Table 5-11 Predicted Number Column Density and Return Flux Contributions From Shuttle Orbiter Sources Of Contamination - Concluded

Note:

(1) Ambient velocity direction: -Z, Field of View: 10°, medium density atmosphere.

(2) Maximum temperature, after 100 hours.

(3) LOS 1, zero degree line-of-sight (in the +Zo direction) originating at Xo = 1107, Yo = 0, Zo = 507.
LOS 3, 60° off of +Z towards -Xo (backward) originating at Xo = 1107, Yo = 0, Zo = 507.
LOS 7, 60° off of +Z towards +Yo (right) originating at Xo = 1107, Yo = 0, Zo = 507.
LOS 11, 60° off of +Z towards -Xo (forward) originating at Xo = 1107, Yo = 0, Zo = 507.

(4) Elevon is in nominal position, maximum flow.

Table 5-12 N_2C_4/MMH Exhaust Products (Mole Fractions) And Trace Partially Reacted Contaminants

Steady State Operations	RCS	VRCS	CMS ENGINE
Completely Reacted Products			
H_2O	0.339	0.333	
N_2	0.309	0.312	
H_2	0.163	0.181	
CO	0.129	0.129	TBD
CO_2	0.042	0.042	
O_2	0.002	Traces	
NO	0.001	--	
Free Radicals			
H	0.012	0.003	
OH	0.006	Traces	
O	Traces	Traces	
Pulse Mode Trace Products (solid or liquid)			TBD
MMH	N_2H_3 CH_3		
MMH-nitrate	N_2H_2 CH_3 NO_3; N_2H CH_3 $(NO_3)_2$		
Nitric Acid	HNO_3		
Ammonium nitrate	NH_4 NO_3		

the engine plumes is further defined in ICD-2-19001. Plume constant-density contours for the OMS, RCS, and VRCS thrusters are shown in Figures 5-10, 5-11, and 5-12.

5.1.8 Electromagnetic Compatibility (EMC).

5.1.8.1 Shuttle-Produced Interference Environment.

5.1.8.1.1 Conducted Interference. TBS

5.1.8.1.2 Radiated Interference. The Shuttle produced radiated fields environment shall be limited as follows:

a. AC Magnetic fields shall be limited to less than 140 dB above 1 picotesla (30 Hz to 2 kHz), falling 40 dB per decade to 50 kHz. The DC field shall be less than 170 dB above 1 picotesla. These are worst case values for locations near the Orbiter power busses at Yo = ± 79, Zo = 349, Xo = any value in the cargo bay.

   The above values of magnetic flux density are reduced in accordance with the following equation for separation from the power busses in the Y-Z plane.

   $$\text{dB (reduction)} = 20 \log_{10} (57R^2)$$

   where R (meters) = radial separation in the Y-Z plane from the nearest port or starboard power bus described by the above location coordinates.

   For locations within 2.5 meters of the 576 or 1307 Xo locations, the value of R in the equation should be the separation from the Xo = 576 or Xo = 1307 locations in meters.

b. Electric fields along the cargo bay center line under normal operating modes are defined in Figures 5-13 and 5-14 for unintentional emissions. These levels should be considered when evaluating the possibility of operating radio frequency receiving equipment or electrical field sensing instruments in the cargo bay. The worst case electric field intensities produced by Orbiter-installed transmitters, with the exception of the Ku-band system, are defined for the cargo bay and for the volume above the cargo bay/cabin. The values defined in Figure 5-15 are the maximum field intensities on the upper (+Z, +Y), (+Z, -Y) quadrants of the payload bay envelope with the

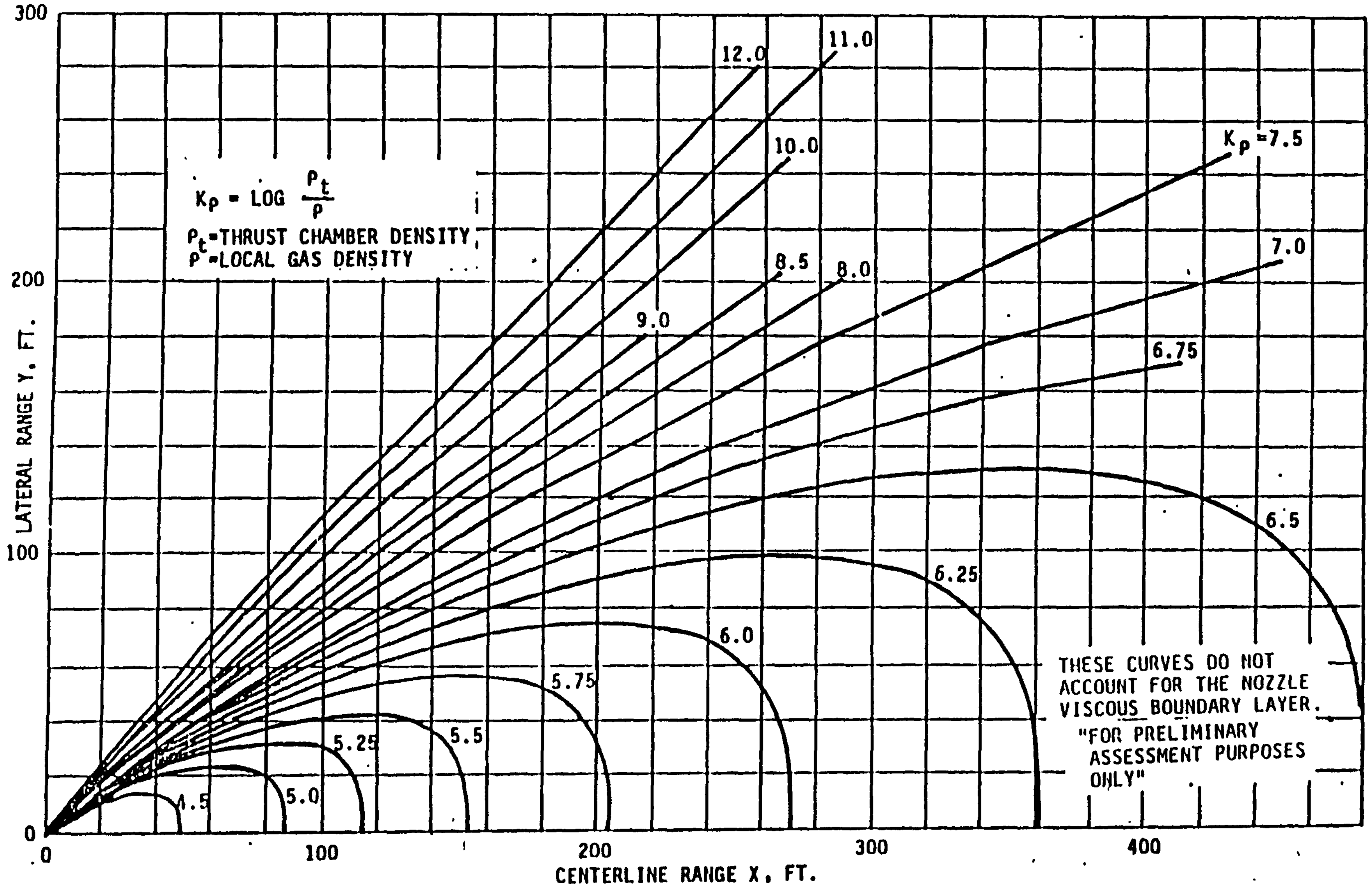


Figure 5-10 OMS Plume Constant-Density Contours, K_p

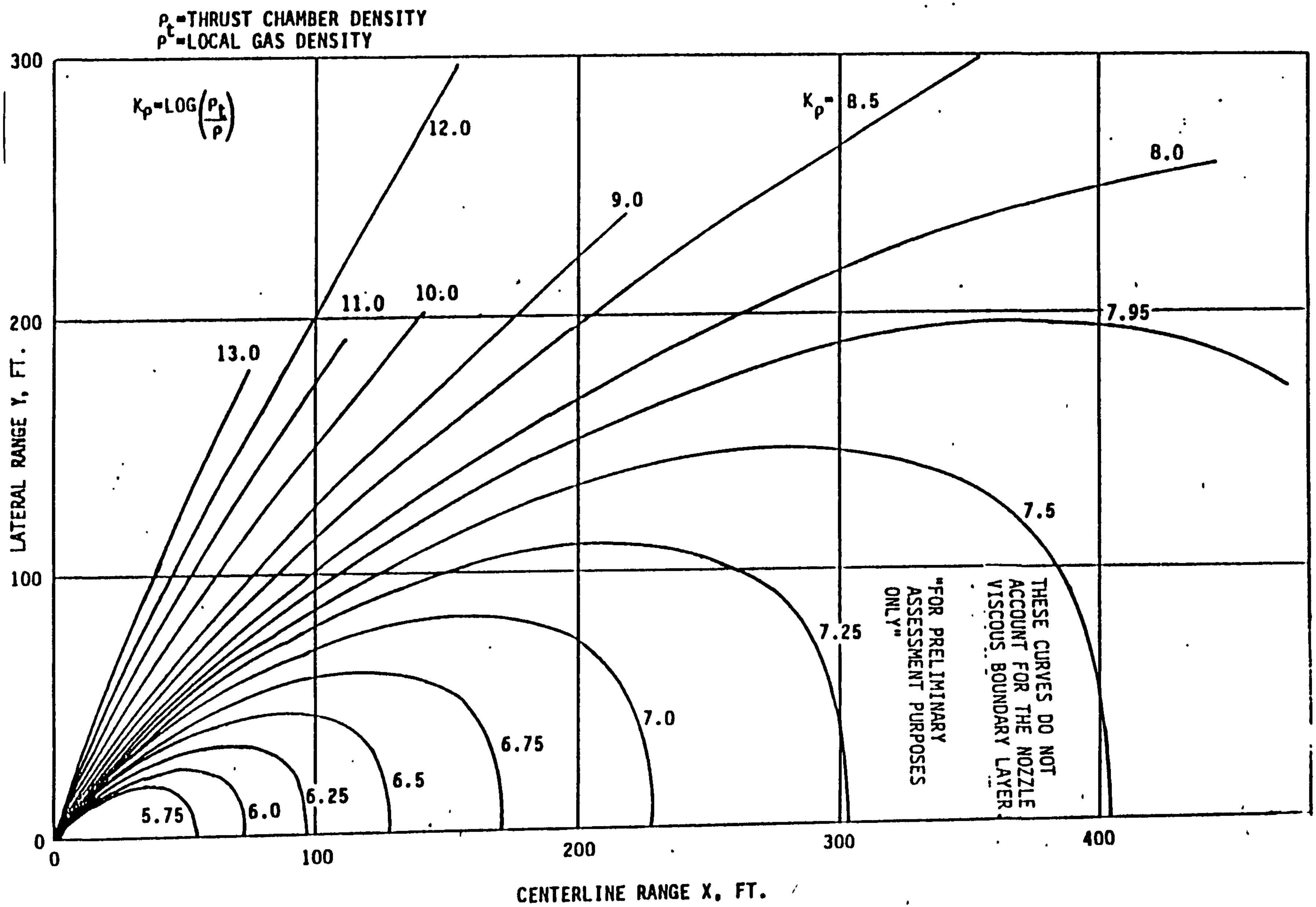


Figure 5-11 RCS Plume Constant Density Contours - K_p

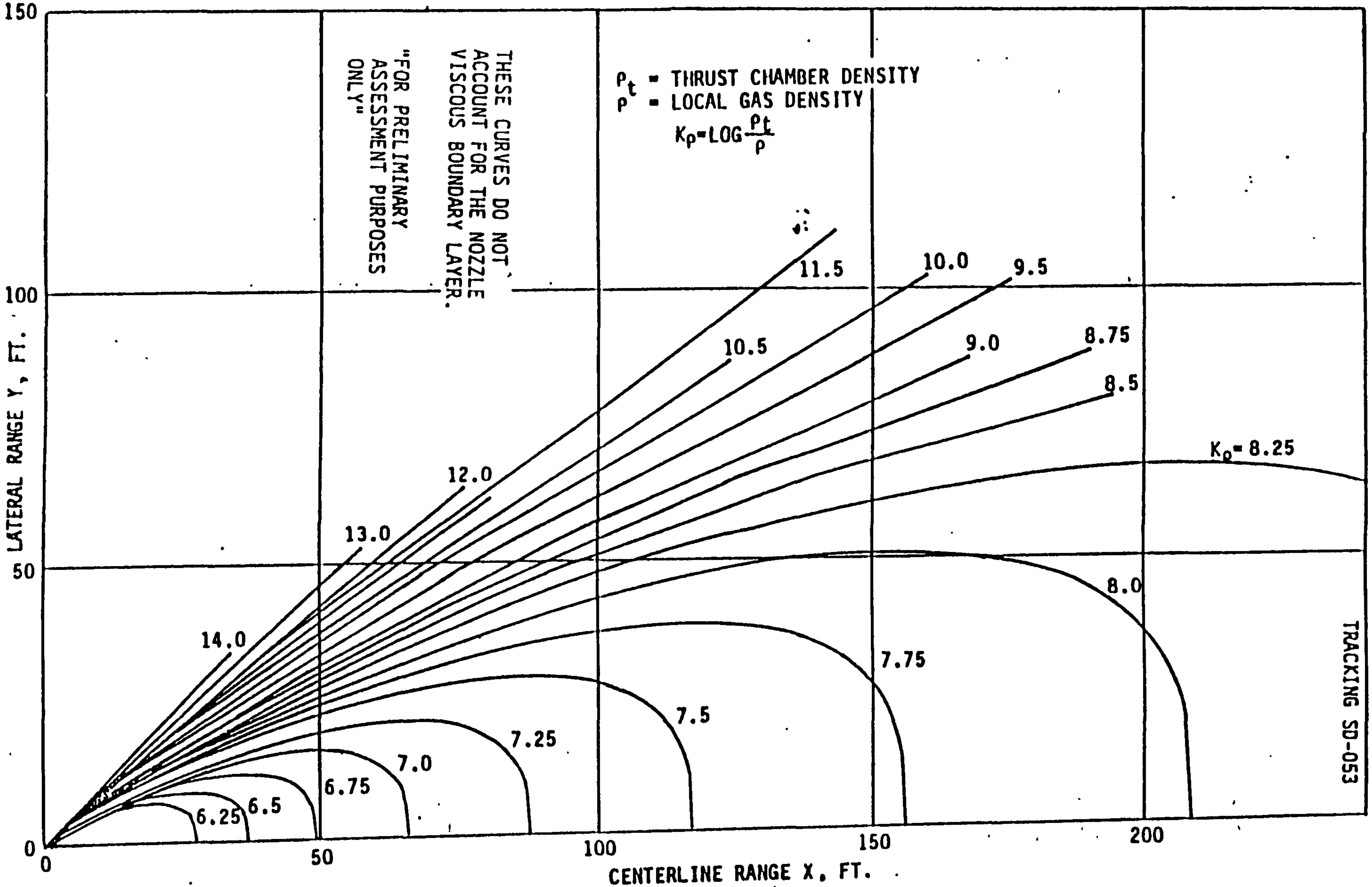


Figure 5-12 VRCS Constant Density Contours, K_p

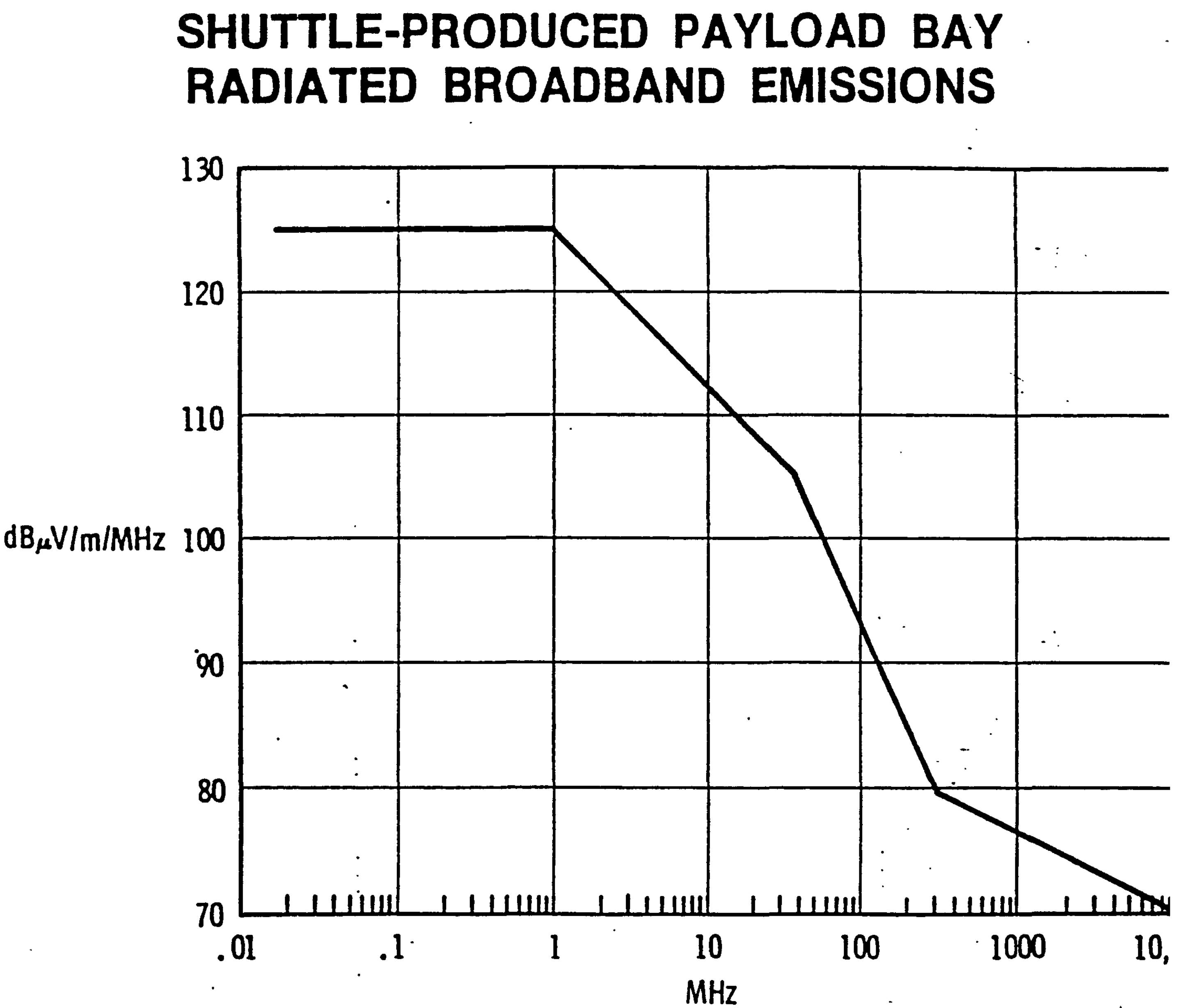


Figure 5-13 Shuttle-Produced Cargo Bay Radiated Broadband Emissions

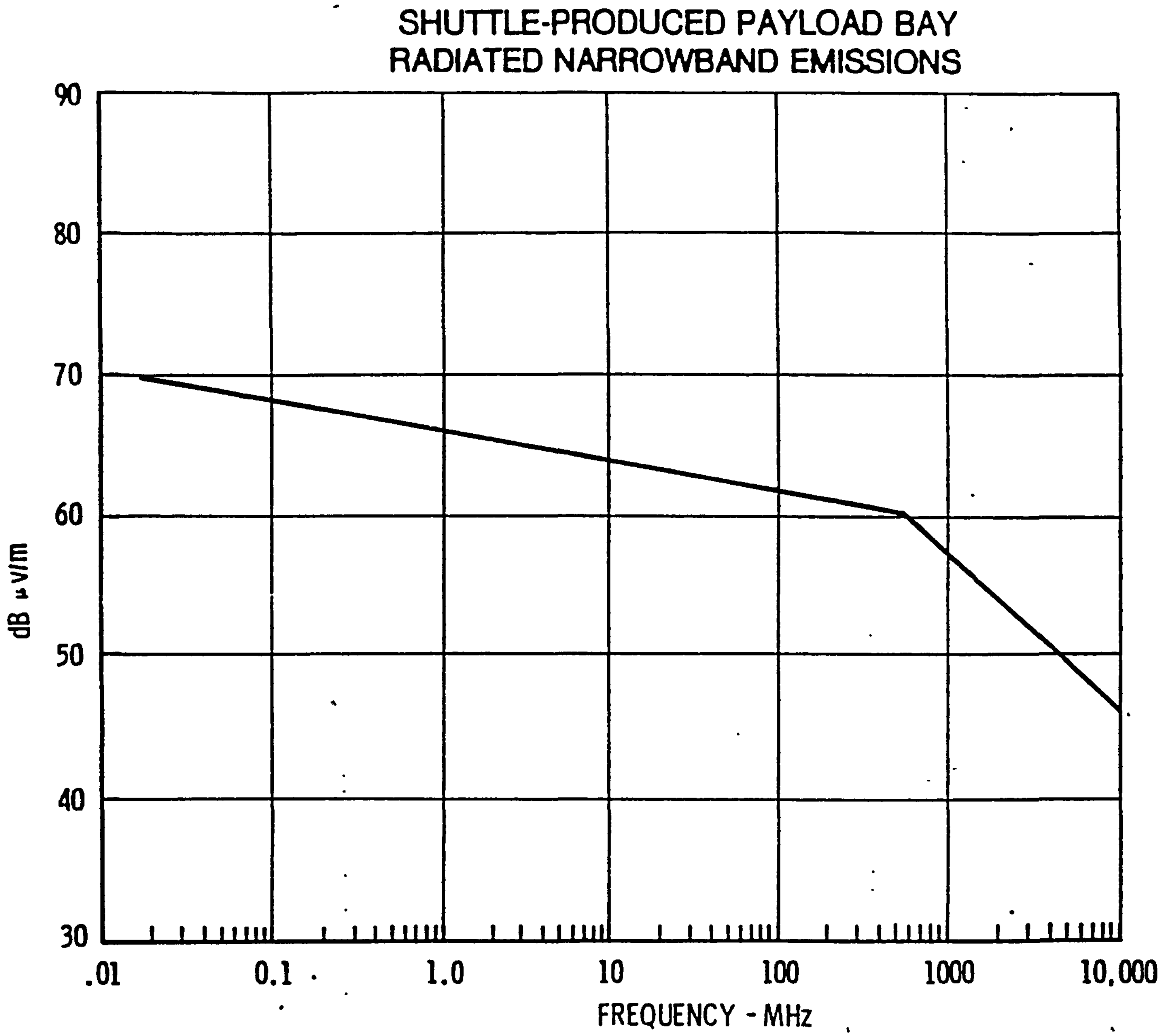


Figure 5-14 Shuttle-Produced Cargo Bay Radiated Narrowband Emissions

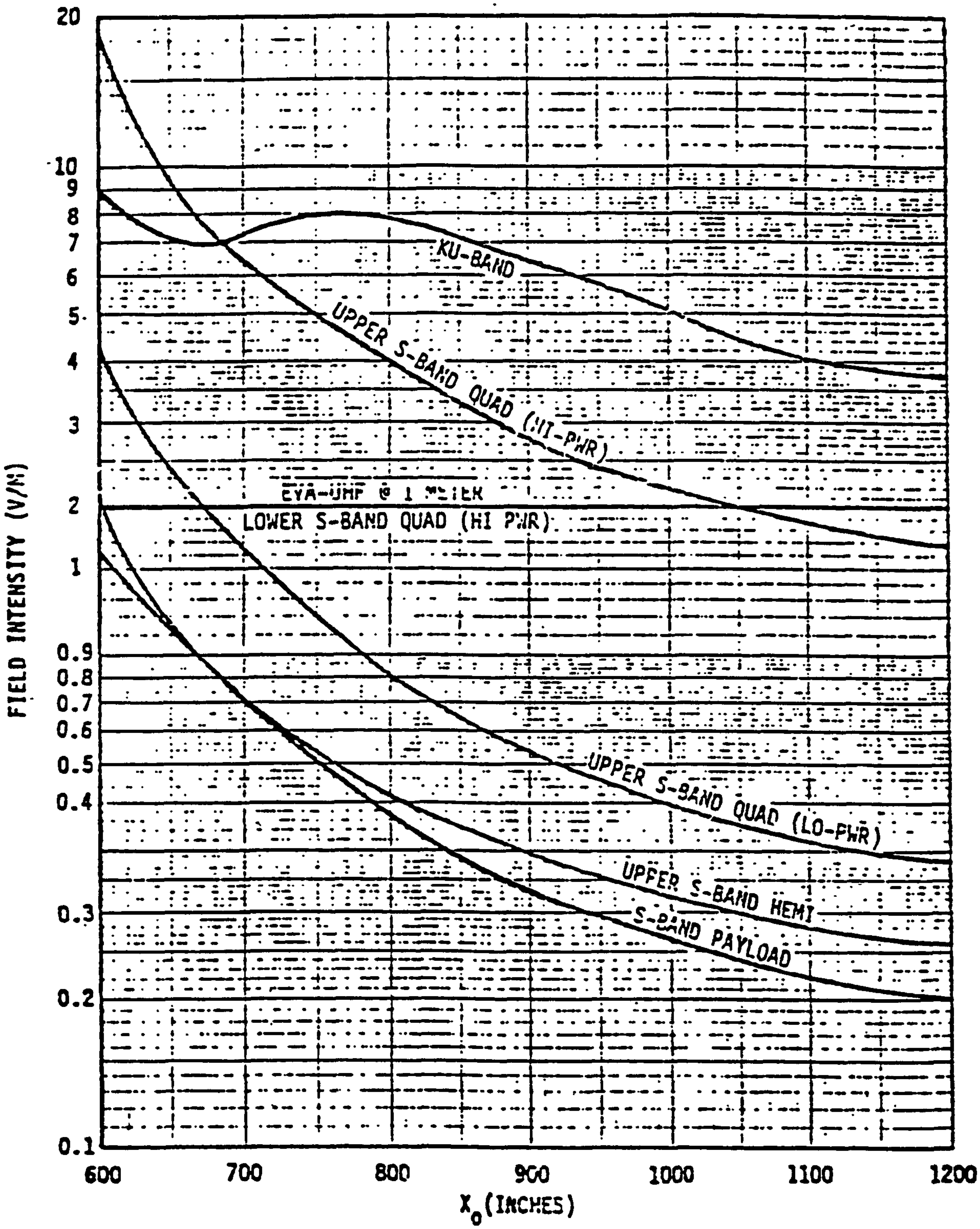


Figure 5-15 Maximum Field Intensities On Payload Envelope

doors open. The values defined in Figures 5-16, 5-17, 5-18, and 5-19 are the maximum field intensities that may impinge on payloads in the -Z hemisphere above the Orbiter during deployment and retrieval operations. The electric field strengths produced by the Orbiter installed transmitters are defined in Figure 5-15. these values, with the exception of the Ku-band system, are worst case values in the upper (+Z) quadrant of the cargo bay envelope with doors open. The Ku-band levels are greater along a line defined by the +Yo = 90 and +Zo = 444. Reduced levels can be expected in the lower Y and Z areas of the cargo bay; however, the levels are payload geometry dependent.

For equipment that can be in the main beam of the Ku-band Antenna, the field level can be approximated by E = 2500/R (R = METERS) for distances greater than 20 meters from the dish. The field level between 20 meters and the dish can be linearly extrapolated from 125 V/M at 20 meters to 300 V/M at the dish. When operating the Ku-band system in the radar mode the field may be attenuated in accordance with ICD-2-19001.

Table 5-13 gives the frequency range and modulation type associated with the transmitter field strength in Figure 5-15.

c. Lightning-produced magnetic fields shall be limited to a peak level of 75 amperes/meter with a rise to peak value in 2 microseconds and fall to zero in 100 microseconds. The payload shall be designed so that a failure due to a lightning strike shall not propagate to the Space Shuttle.

d. The design of the cargo bay and cargo bay doors shall preclude any electrostatic discharges.

5.2 EXPENDABLE LAUNCH VEHICLE

The candidate expendable launch vehicles include the Titan IV and the ALS. The requirements for each vehicle are discussed separately in the following paragraphs.

5.2.1 Titan IV. Except as noted, the following environmental requirements are for the Titan 34D. They form a reference requirement that must be updated as Titan IV data become available.

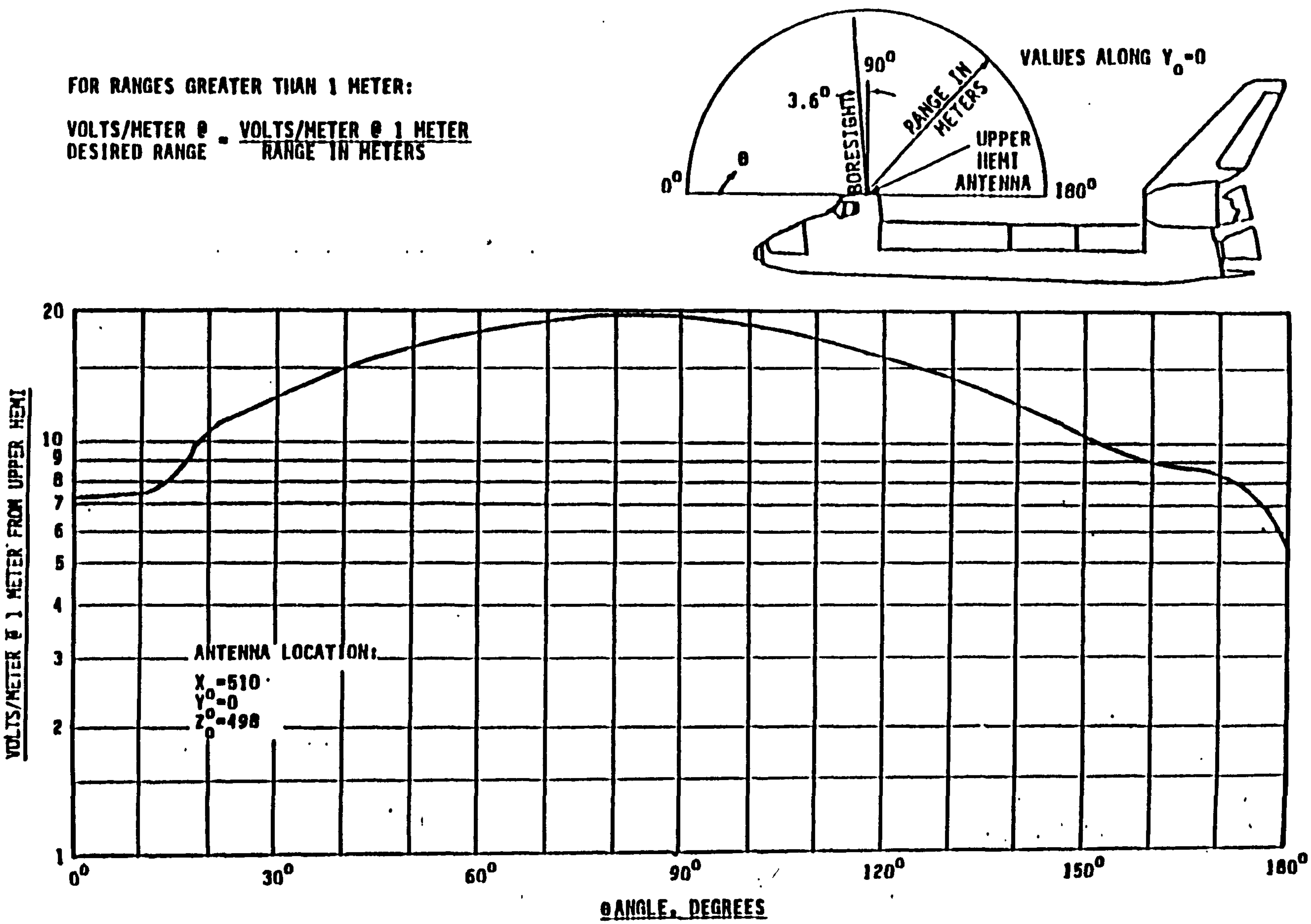


Figure 5-16 S-Band FM Transmitter, Upper HEMI Antenna, Maximum Field Intensities

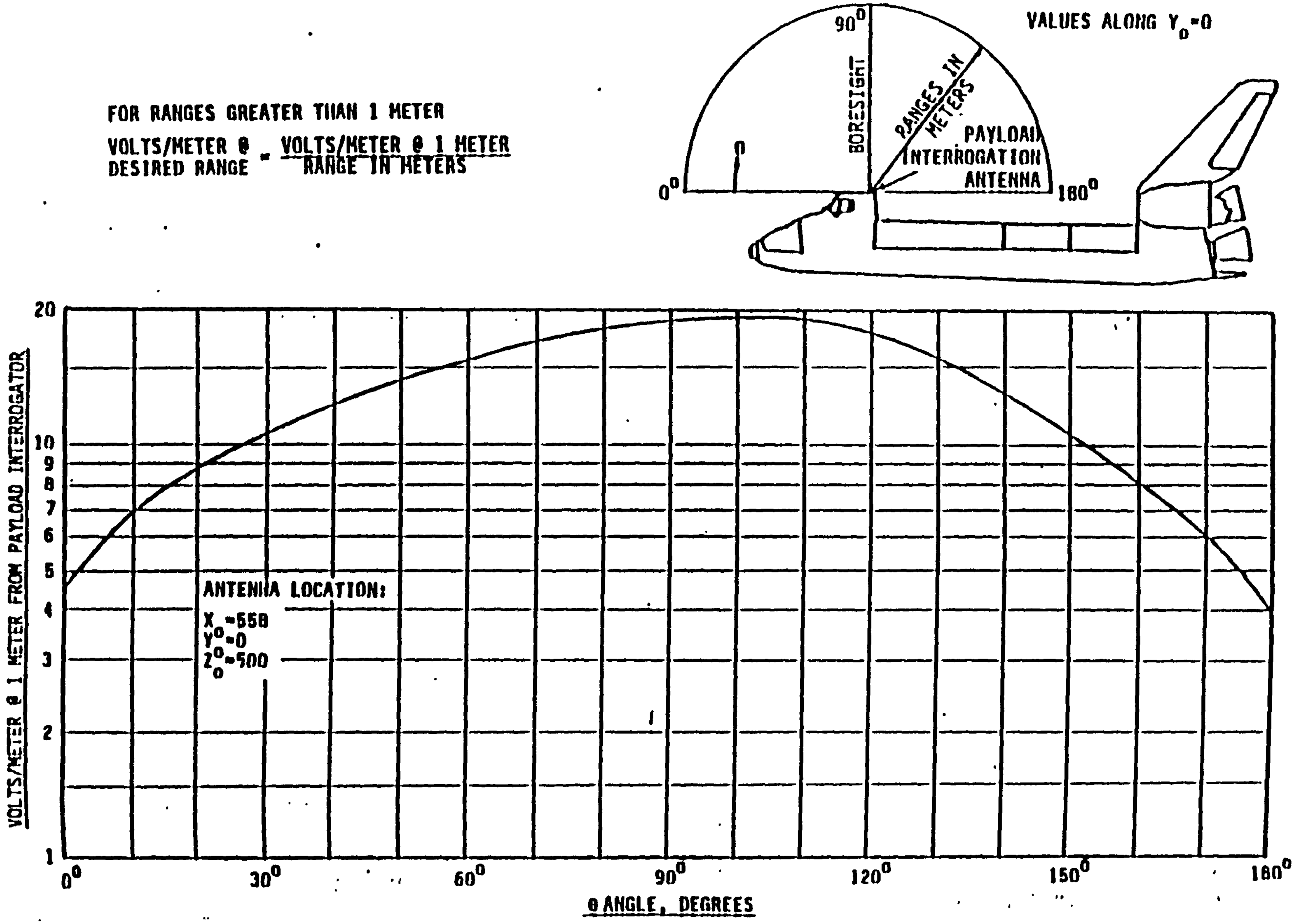


Figure 5-17 S-Band Payload Interrogator, Maximum Field Intensities

FOR RANGES GREATER THAN 1 METER:

VOLTS/METER @ DESIRED RANGE = VOLTS/METER @ METER / RANGE IN METERS

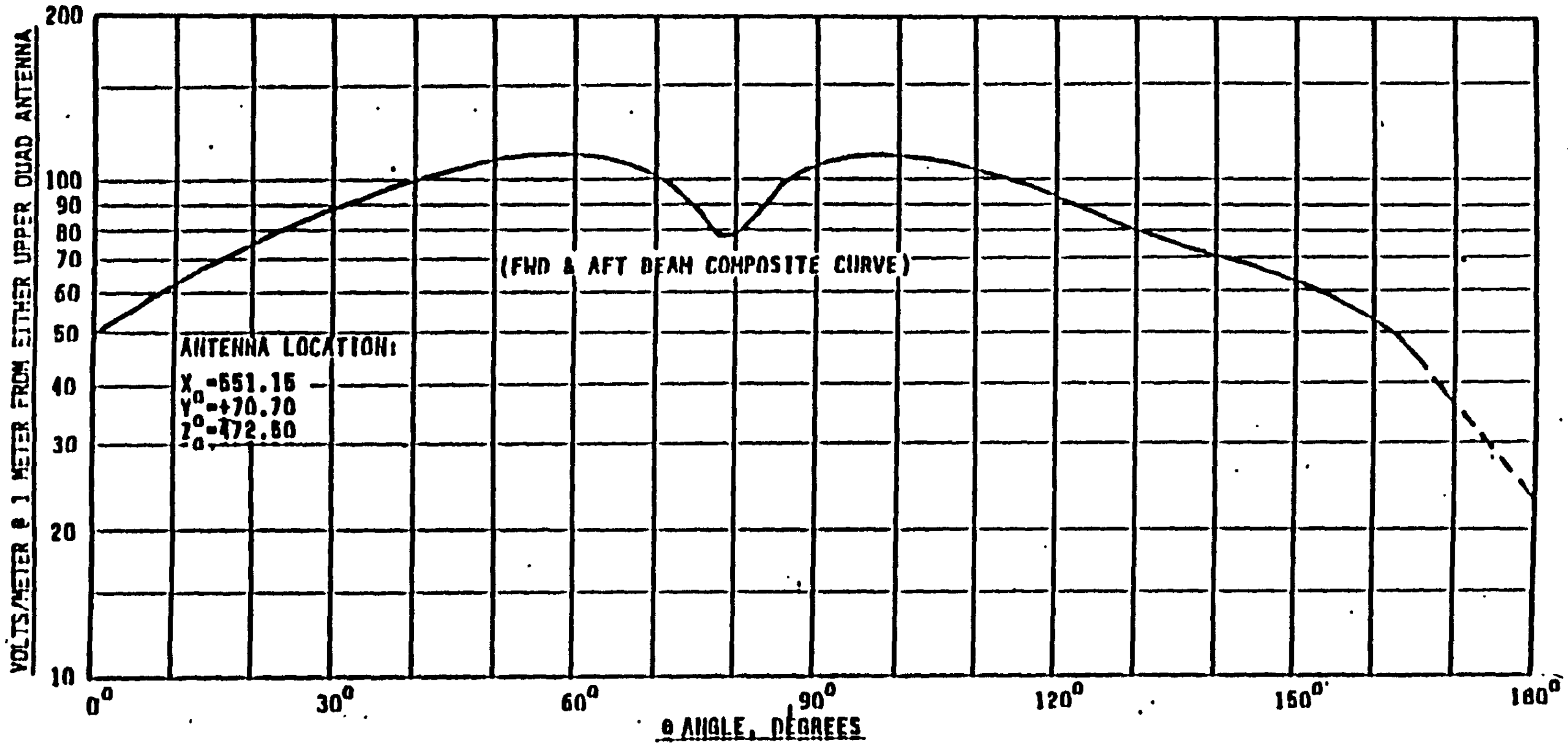


Figure 5-18 S-Band Network Transponder, Upper Quad Antennas, Maximum Field Intensities

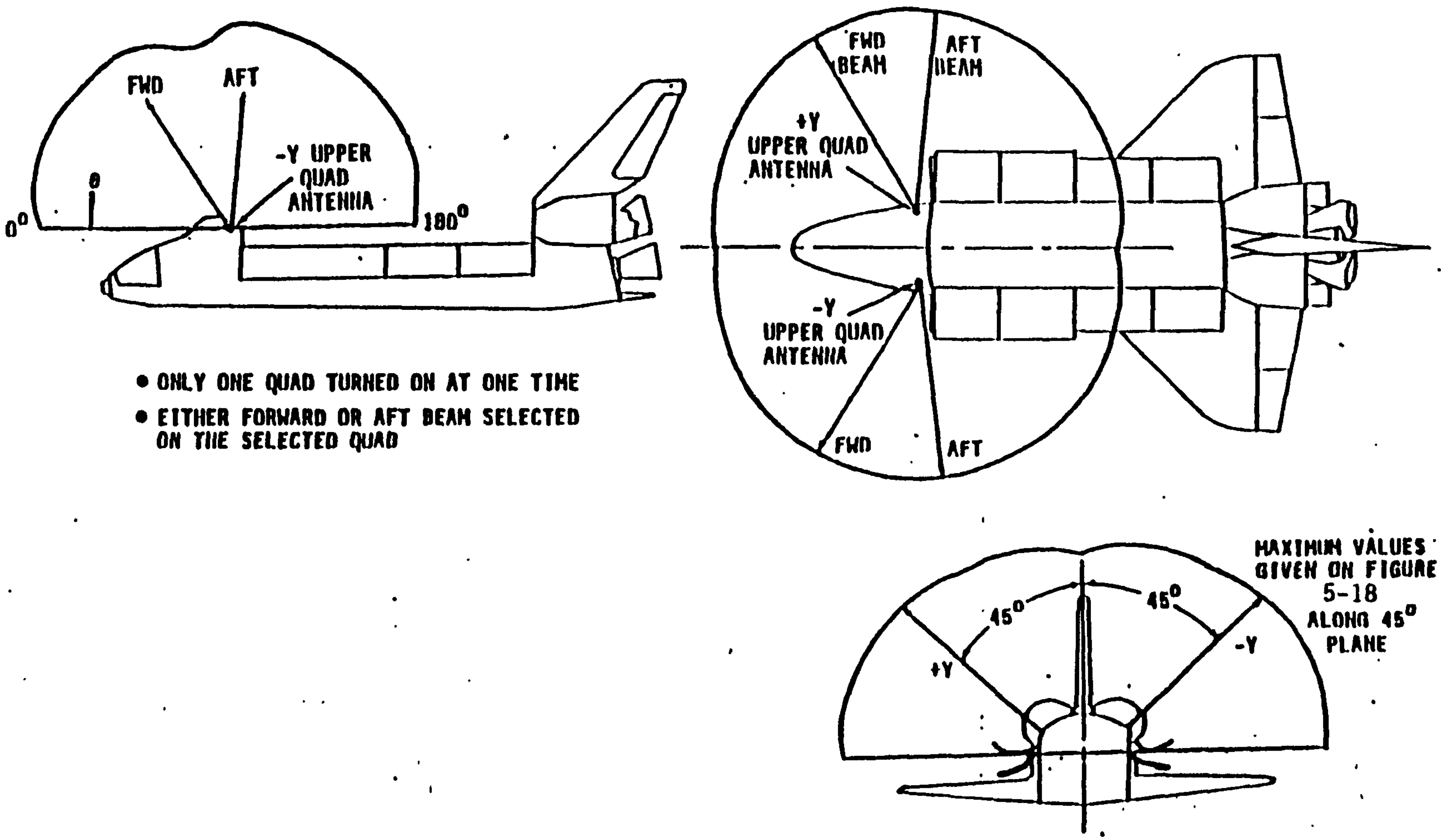


Figure 5-19 S-Band Network Transponder, Upper Quad Antennas, Beam Configuration

Table 5-13 Transmitter Characteristics

	ANTENNA (1)	CARRIER FREQ (fc)	MODULATION
S-BAND FM	S-BAND HEMI	2250.0 MHz	FM
S-BAND PM (NETWORK TRANSPONDER)	S-BAND QUAD	2717.5 OR 2287.5 MHz	PSK, PM
PAYLOAD INTERROGATOR			
STDN (NASA) (2)	S-BAND PAYLOAD	2025.8334 TO 2117.9166 MHz	PM
DSN (NASA) (3)	S-BAND PAYLOAD	2110.2431 TO 2119.7924 MHz	PM
SGLS (DOD) (4)	S-BAND PAYLOAD	1763.721 TO 1839.795 MHz	PM
KU-BAND	KU-BAND		
	REUTRN LINK	15.0034 GHz	QPSK, FM
	RADAR RANGING	13.883 GHz (5)	PULSED CARRIER PULSE RATES: 268, 3000, 7000 PPS PULSE WIDTH - 66.4 μs max. 122.0 ns min.
EVA/ATC	UHF	243.0, 259.7 OR 296.8 MHz (SELECTABLE)	AM (90%) (VOICE AND DATA)

Note:

(1) Cargo bay radiation levels defined in Figure 10.7.2.2-3.

(2) 801 Selectable channels over indicated frequency range. (See Table 8.3.1.1.1-1)

(3) 29 Selectable channels over indicated frequency range. (See Table 8.3.1.1.2-1)

(4) 20 Selectable channels over indicated frequency range. (See Table 8.3.1.1.3-1)

(5) Passive tracking uses frequency diversity technique employing center frequencies of 13.779, 13.831, 13.883, 13.935 and 13.987 GHz. Active tracking uses 13.883 GHz only.

5.2.1.1 Loads and Accelerations. The vehicle shall be designed to account for the Titan static, thermal, and dynamic loads and the angular rates and accelerations specified below.

a. Maximum T34D vehicle angular rates with a vector sum not to exceed 27 degrees/second in the boost vehicle control mode frequency range of 0.2 to 2.0 Hz for transient recovery from maximum g. The boost vehicle control mode damping ratio shall be greater than 0.2 during transient recovery.

b. Maximum vector sum angular accelerations of 110 degrees/second^2 in the boost vehicle control mode frequency range of 0.1 to 2.0 Hz for transient recovery from maximum g. The control mode damping frequency shall be greater than 0.2.

c. Limit design interface loads and load factors are provided in Table 5-14 for the T34D/IUS combination. Dynamic analysis of the Titan IV/MSNPS vehicle is required.

d. Maximum sustained longitudinal acceleration is 5.0 g's during T34D stage 1 flight. Titan IV axial loads are estimated to be 6.0 g's over a frequency range of 3 to 20 Hz with lateral loads of $\pm$ 2 g's.

5.2.1.2 Random Vibration. The random vibration spectrum at the T34D/payload interface is shown in Figure 5-20. The maximum power spectral density vs frequency within the payload fairing is shown in Figure 5-21.

5.2.1.3 Acoustic Noise. The acoustic noise environment internal to the payload fairing is shown in Table 5-15.

5.2.1.4 Shock. The MSNPS shall be compatible with the induced shock due to the separation of the payload fairing as shown in Figure 5-22. The shock resulting from staging the MSNPS from the T34D shall not exceed the level shown in Figure 5-23.

5.2.1.5 Thermal. The prelaunch and flight temperature range at the T34D side of the payload adapter ring shall be in the range of +55° F to +85° F when the ring is considered adiabatic. The temperature-time profile internal to the payload fairing during flight is shown in Figures 5-24, 5-25, and 5-26. Aerodynamic heating of the launch vehicle fairing to temperatures of 395-425K will occur during flight. When the fairing is jettisoned, free molecular heating of 630-790 W/m^2 shall be sustained.

Table 5-14 Limit Design Interface Loads and IUS Load Factors - T34D/IUS

EVENT	LOAD TYPE	LOADS @ IUS (3) STA. 379.0	IUS LOAD FACTORS AXIS	IUS LOAD FACTORS FROM STA. 379.0 TO STA. 279.0	IUS LOAD FACTORS FROM STA. 279.0 TO STA. 231.6
LIFT-OFF	AXIAL SHEAR MOMENT TORSION	-6, +19 k ± 13 k ±2500 in-k ±380 in-k	AXIAL LATERAL TOROSIONAL	+.5, +2.2g + 1.8 g ±25 rad/sec^2	+1.0g +1.0 g -----
MAXIMUM AIRLOADS	AXIAL SHEAR MOMENT	±18k ±15k ±2400 in-k	AXIAL LATERAL	±2.3g ±1.0g	+2.0g ±1.0g
STG I S/D	AXIAL SHEAR MOMENT	-19, + 37k ±8.6k ±1400 in-k	AXIAL LATERAL	-2.0, +5.3g ±1.1g	-.4, +3.7g ±1.0g
STG II S/D	AXIAL SHEAR MOMENT	-35, + 46k ±6.5 k ±1050 in-k	AXIAL LATERAL	-4.0, +5.5g ±1.0g	-2.6, +5.0g ±.75g

NOTES: (1) SPACECRAFT AND IUS LOADS ARE IN PHASE AND APPLIED SIMULTANEOUSLY IN WORST CASE COMBINATION.

(2) AXIAL LOAD SIGN CONENTION:
(-) TENSION

(3) k = kilopounds

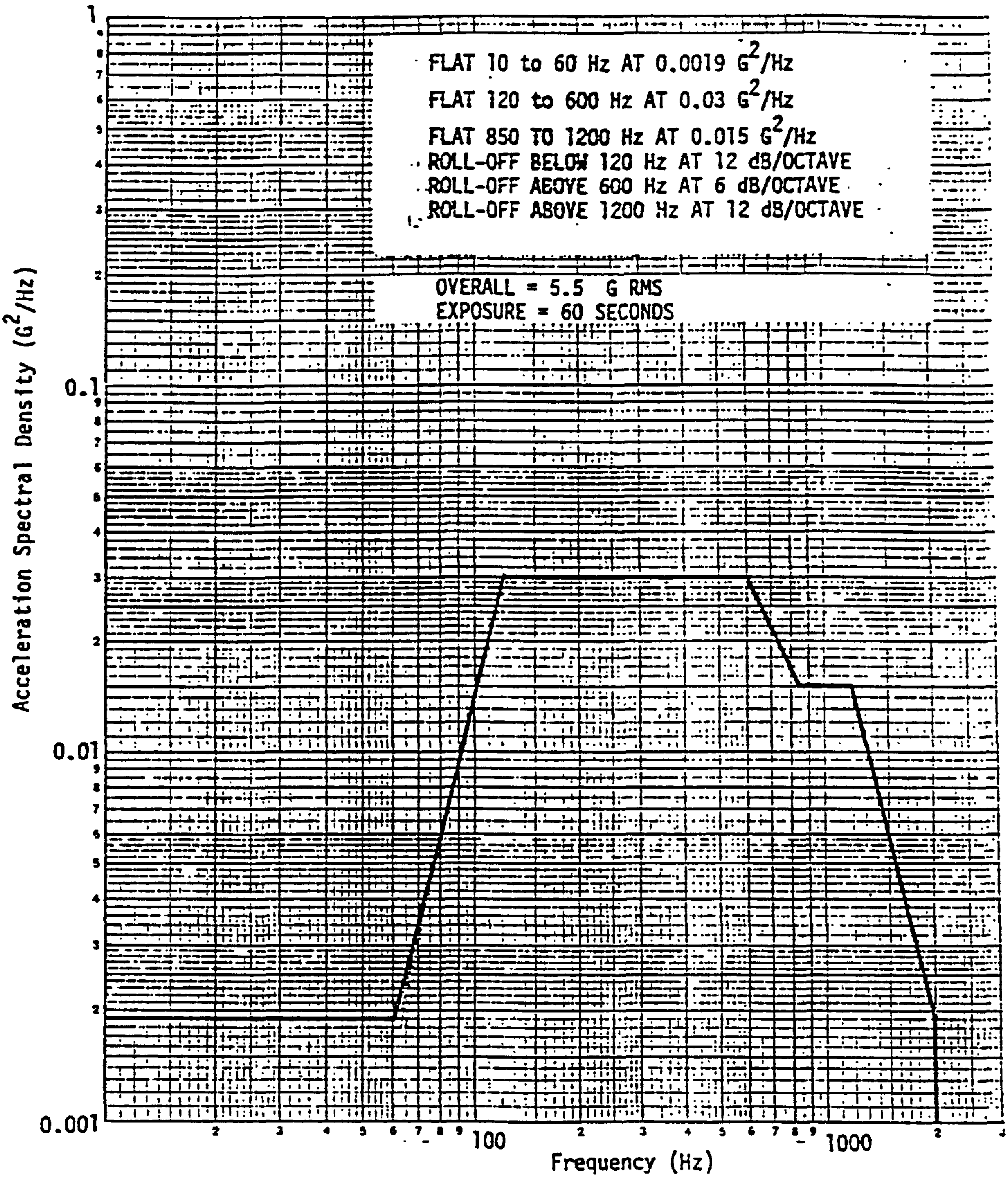


Figure 5-20 Random Vibration Environment For New Design, T34D/IUS Interface, Launch And Flight

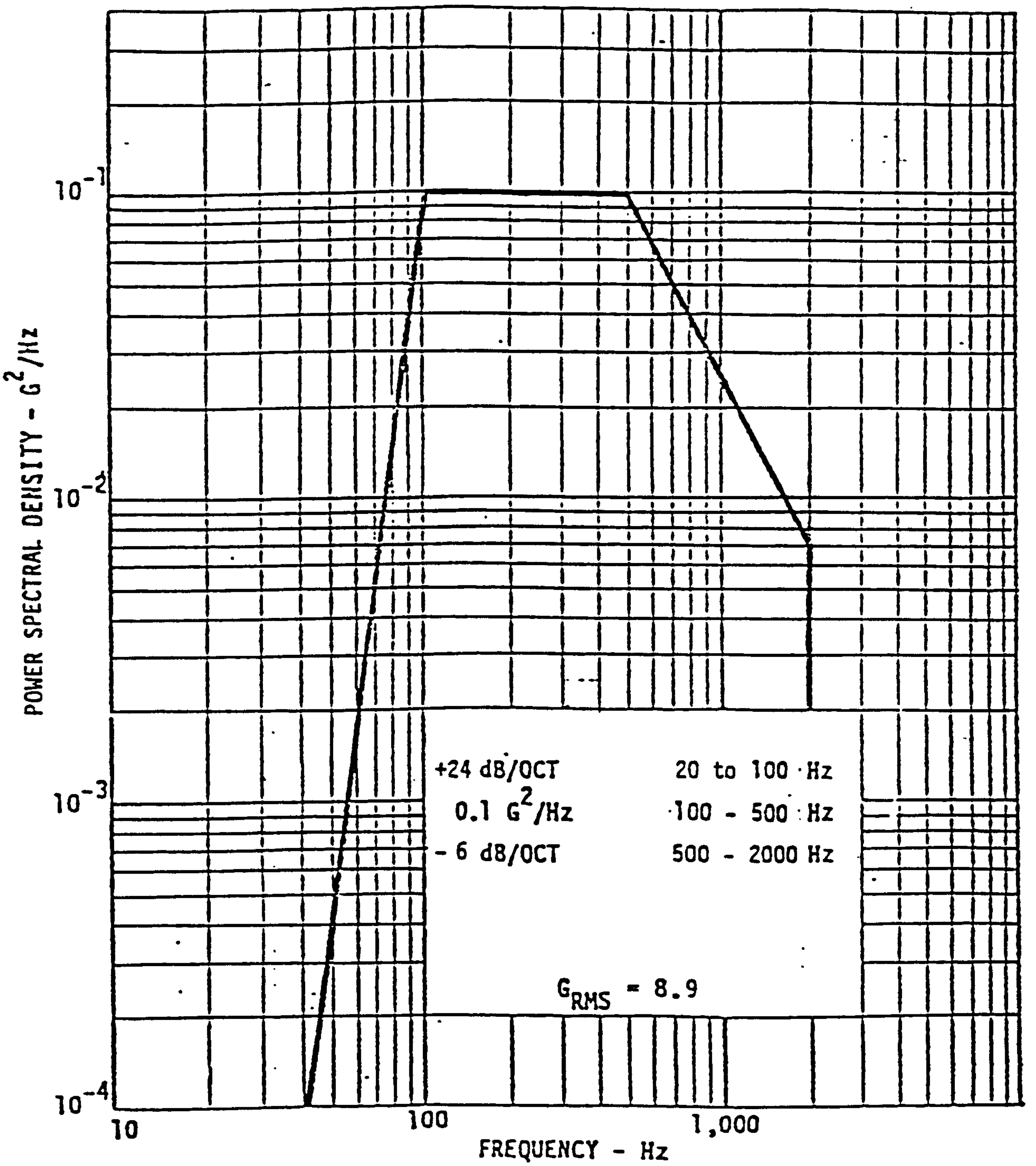


Figure 5-21 Spacecraft Interface Maximum Vibration Environment

Table 5-15 Maximum Estimated Noise Levels Internal to Payload Fairing - Launch and Flight

1/3 OCTAVE BAND CENTER FREQUENCY, Hz	1/3 OCTAVE BAND SOUND PRESSURE LEVEL, dB*
OVERALL	145
25	121
31.5	122.5
40	124
50	125.5
63	127
80	129
100	130.5
125	131.5
160	132.5
200	133.5
250	134
315	134.5
400	134.5
500	134
630	133.5
800	133
1000	132
1250	131
1600	129.5
2000	128.5
2500	126.5
3150	125
4000	123
5000	121.5
6300	120
8000	118
10000	116

DURATION: TOTAL OF 60 SECONDS FROM LIFTOFF THROUGH MAXIMUM DYNAMIC PRESSURE (MAX Q)

*dB (IN REFERENCE TO 0.0002 dynes/cm^2)

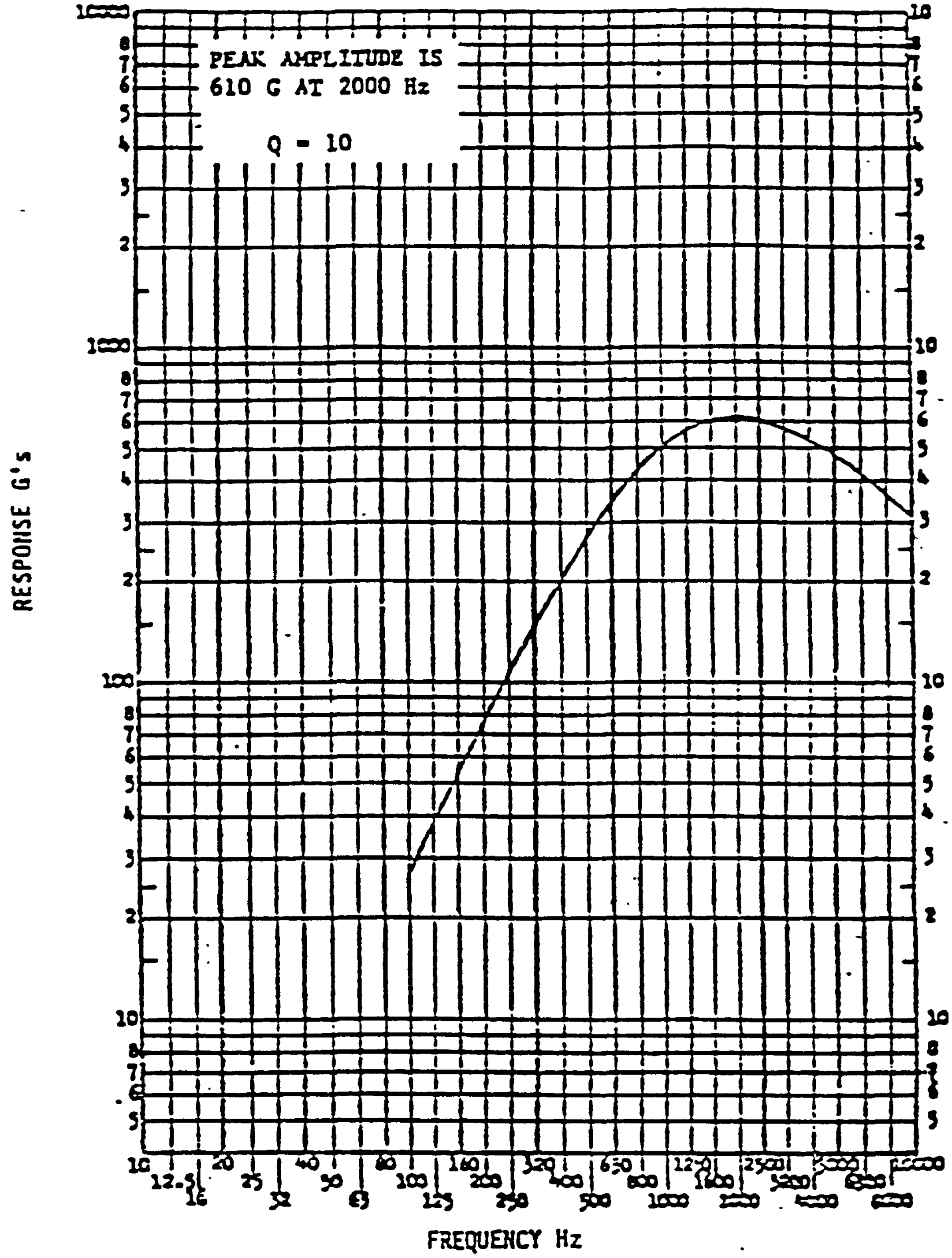


Figure 5-22 Pyrotechnic Shock Environment Spectra at T34D/IUS Interface, Payload Fairing Separation

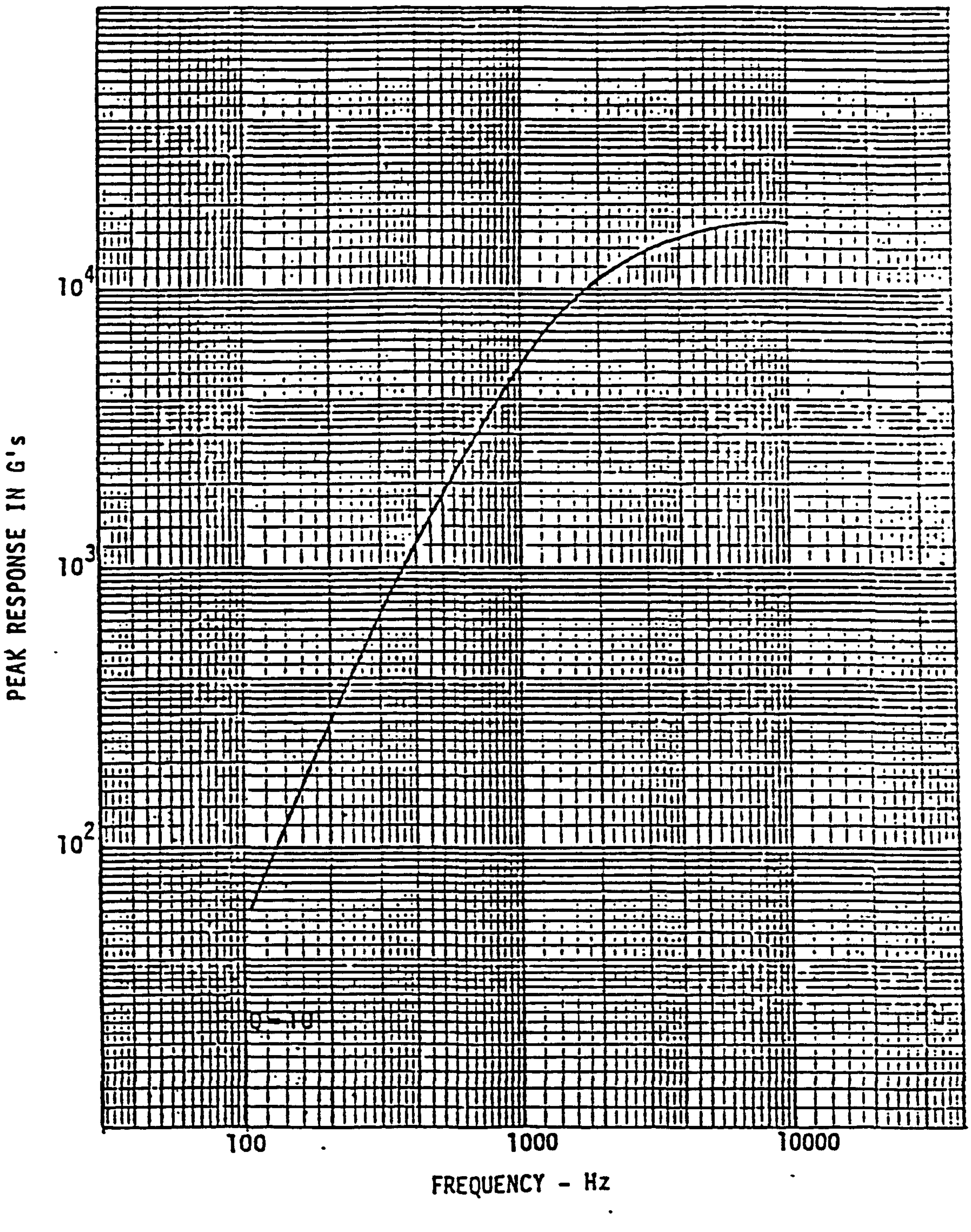


Figure 5-23 Pyrotechnic Shock Environment Spectra at Interface - T34D/IUS Separation

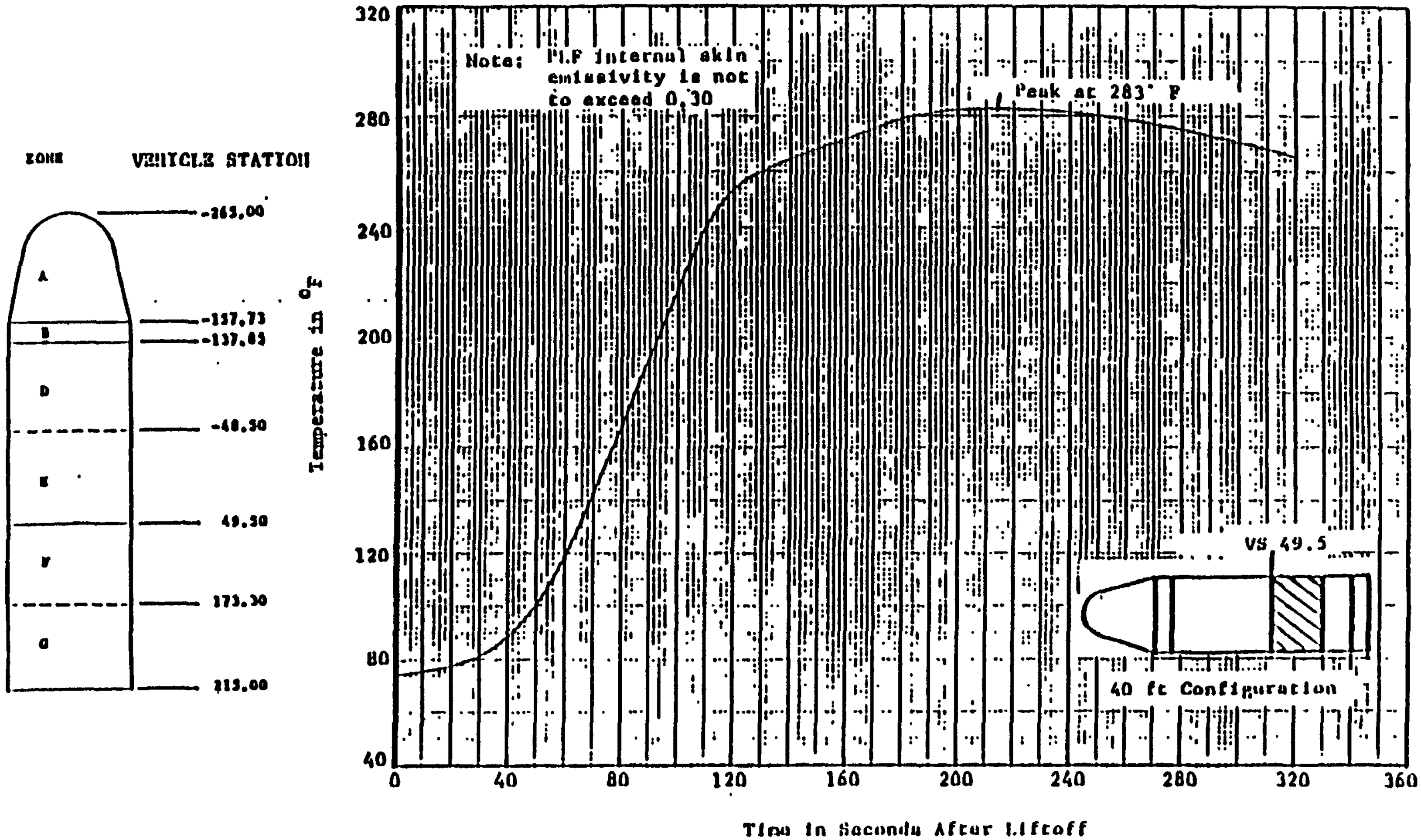


Figure 5-24 PLF Forward Zone F Internal Temperature Profile (Preliminary)

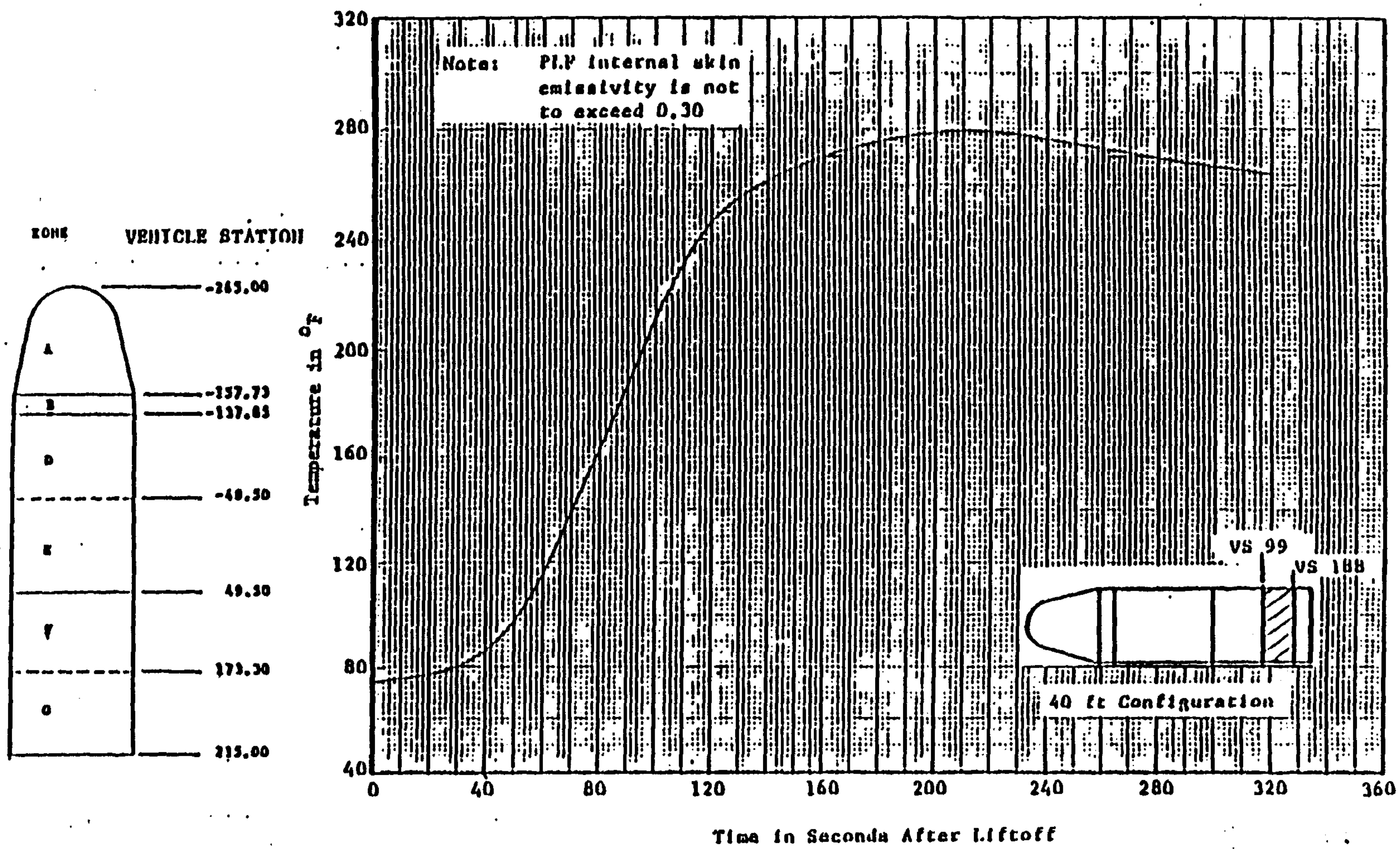


Figure 5-25 PLF AFT Zone F Internal Temperature Profile (Preliminary)

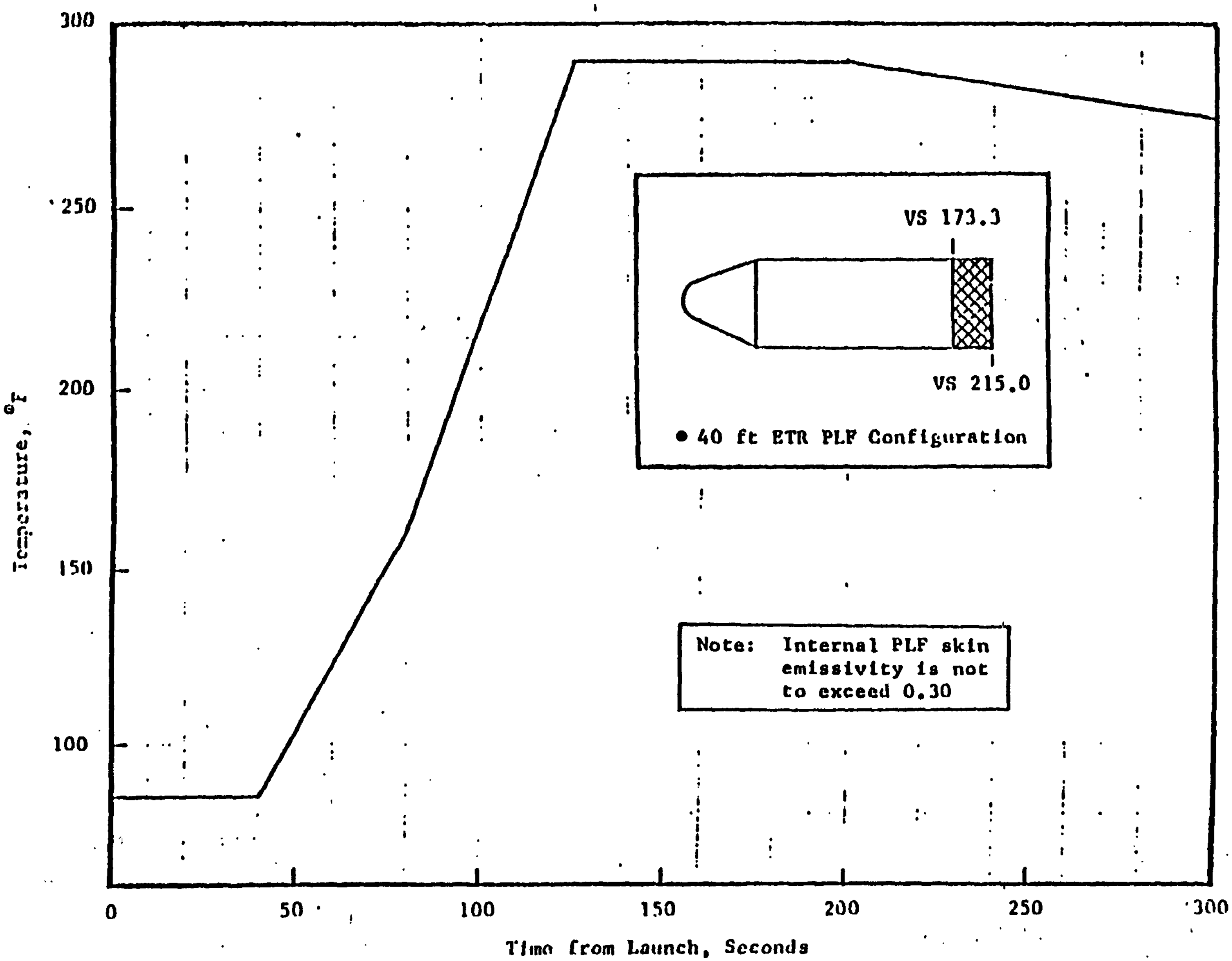


Figure 5-26 Time-Temperature Profile Internal to the Payload Fairing, vs 173.3 to 215 (Preliminary)

5.2.1.6 Propellant Compatibility. Normal operations shall be such as to preclude any contamination by the T34D propellant nitrogen tetroxide (N_2O_4). Specification MIL-P-26539 provides the propellant assay. The vehicle materials below T34D station 182.6 shall be capable of withstanding N2O4 vapors for a period of one (1) hour at 70°F and 80% relative humidity and not produce a flammable hazard. The materials above T34D station 182.6 are not required to be compatible with N_2O_4 vapors.

5.2.1.7 Electromagnetic Compatibility. The EMC requirements of MIL-STD-1541 and MIL-STD-1542 shall be applied to the airborne equipment segment and the support equipment segment of the MSNPS, respectively.

5.2.1.7.1 T34D Produced Radiated Fields. The limitations on electromagnetic field radiation at the interface from the Spacecraft components will be those specified by MIL-STD-1541. Installed T34D transmitters have the characteristics and produce the field intensities at the interface specified in Table 5-16.

5.2.1.7.2 Electrostatic Charging Protection. Materials on either side of the T34D interface which are exposed to electrostatic charging environments shall comply with the electrostatic charging protection requirements specified for the T34D.

5.3 ADVANCED LAUNCH SYSTEM

The launch environments of the ALS are TBD.

Table 5-16 Installed T34D Transmitter Produced Electric Fields

TRANSMITTER	FREQUENCY	PEAK POWER	MODULATION	DUTY CYCLE
S-Band	2.2875 GHz	20 watts (Max)	FM	CW
C-Band	5.765 GHz	1000 watts (Max) 440 watts (Min)	Pulse Transponder	.002

PULSE WIDTH	ANTENNA/ POLARIZATION	LOCATION	INTERFACE FIELD STRENGTH
N/A	Linear Polarization E Vector Parallel to Roll Axis	V.S. 228.99 on target	10.89 volts/M*
0.5 ± .1 sec	Linear Polarization E Vector Parallel to Roll Axis	V.S. 262.25 on target	9.78 V/M (Peak) 0.210 V/M (Ave)

*Preliminary value, final value provided as soon as test data is available.

SECTION 6
ON-ORBIT ENVIRONMENTAL CONDITIONS

6.1 NATURAL ENVIRONMENT

The space equipment shall be designed to function within performance specification following or, if appropriate, during exposure in the on-orbit configuration to their design environmental levels. These design environmental levels for on orbit exceed the maximum predicted on-orbit environments for each item by the environmental design margin.

6.1.1 Micrometeoroids and Debris. Spacecraft operating in low Earth orbit are exposed to natural and man-made particles traveling at very high velocities relative to the spacecraft. The man-made portion of this environment, referred to as debris, occurs in greater concentration at the more common altitudes and is projected to increase with time as the use of orbiting spacecraft increases. Figure 6-1 shows how the concentration of these particles is expected to increase with time, and how it increases inversely with particle size.

The source of this debris is often exploding bolts and other devices used to separate spacecraft and boosters and the explosion of propellant tanks from spacecraft and boosters left in orbit after their usefulness has ended. As of June 15, 1988, there were 7145 objects of 10 cm diameter or greater being tracked by NORAD. Approximately 60% of these objects are fragments resulting from explosions; 20% are mission related such as shrouds, rocket stages, etc.; and 20% are payloads (both operating or non-operating).

Debris shielding per mass is comparable to micrometeoroid shielding. Figure 6-2 shows the effective bumper density required to protect a projected area over a specified time of operation as a function of the probability of impact.

The MSNPS shall be designed to (operate) in a Meteoroid and Space Debris environment as specified in Table 6-1 and 6-2 respectively. Figures 6-3 and 6-4 indicate space debris fluence versus mass and projected debris design basis for the year 2010. Meteoroid particles shall be assumed to have a mass density of 0.5 g/cm^3 and an impact speed of 20 km/s. Space debris shall be assumed to consist of spherical fragments of aluminum impacting the system at 10 km/s.

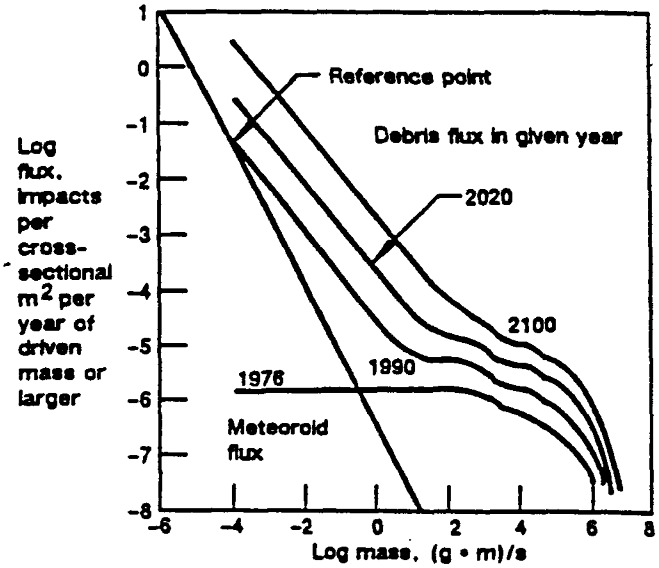


Figure 6-1 Debris Model

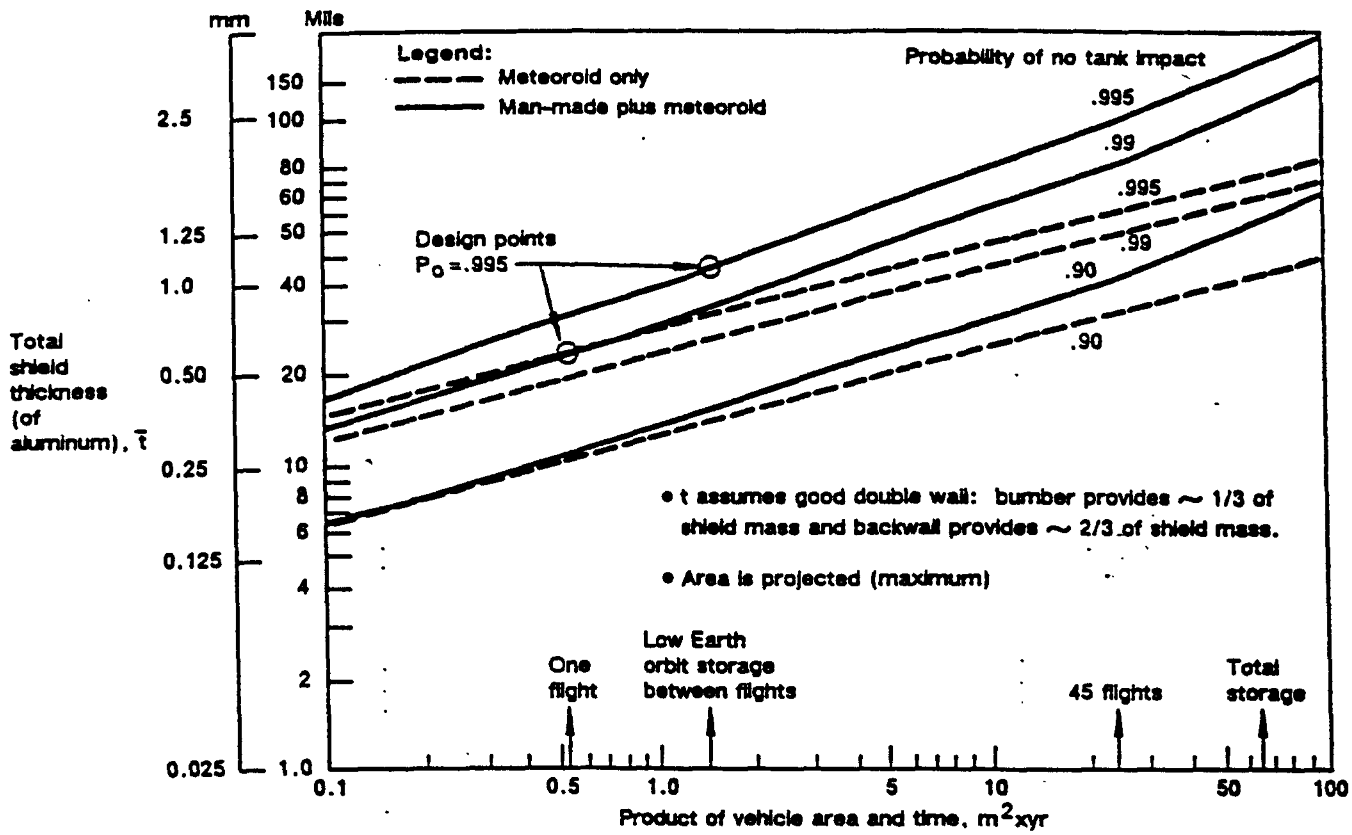


Figure 6-2 Debris Shield Requirement

Table 6-1 Space Debris Mass Fluence For Impacts of Debris of Mass (M) or Greater-10 Year Total Fluence

Mass (M) (grams)	Impacts/m^2 (surface area)
10^{-6}	5.0
10^{-5}	1.0
10^{-4}	2.6×10^{-1}
10^{-3}	5.0×10^{-2}
10^{-2}	1.0×10^{-2}
10^{-1}	1.3×10^{-3}
10^{0}	2.3×10^{-4}

Table 6-2 Meteoroid Mass Fluence of Impacts of Mass (M) or Greater-10 Year Total Fluence

Mass (M) (grams)	Impacts/m^2 (surface area)
10^{-6}	18.0
10^{-5}	1.1
10^{-4}	6.9×10^{-2}
10^{-3}	4.2×10^{-3}
10^{-2}	2.6×10^{-4}
10^{-1}	1.6×10^{-5}
10^{0}	9.6×10^{-7}

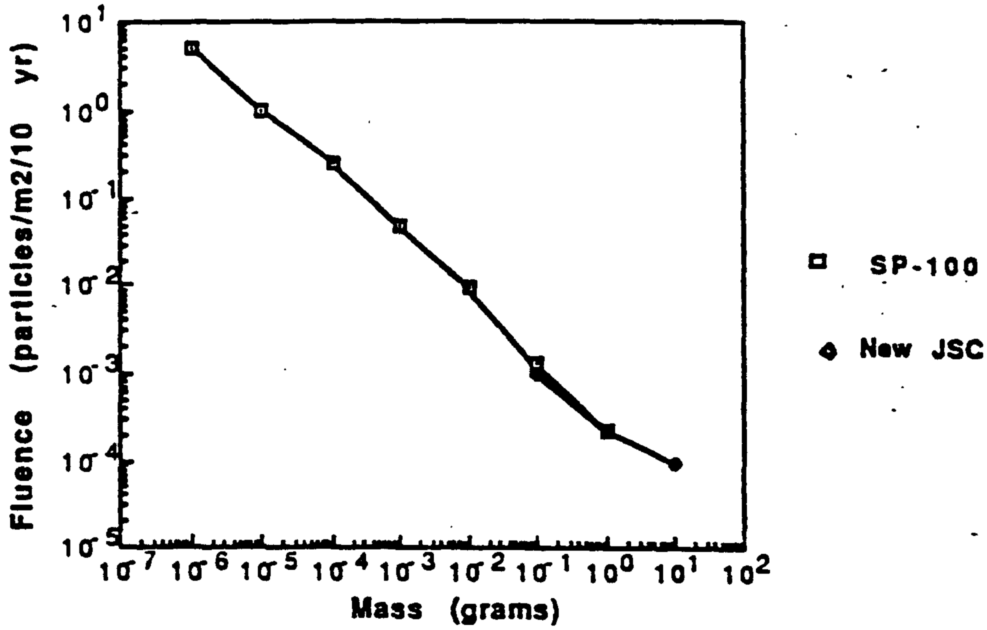


Figure 6-3 Space Debris Fluence vs Mass

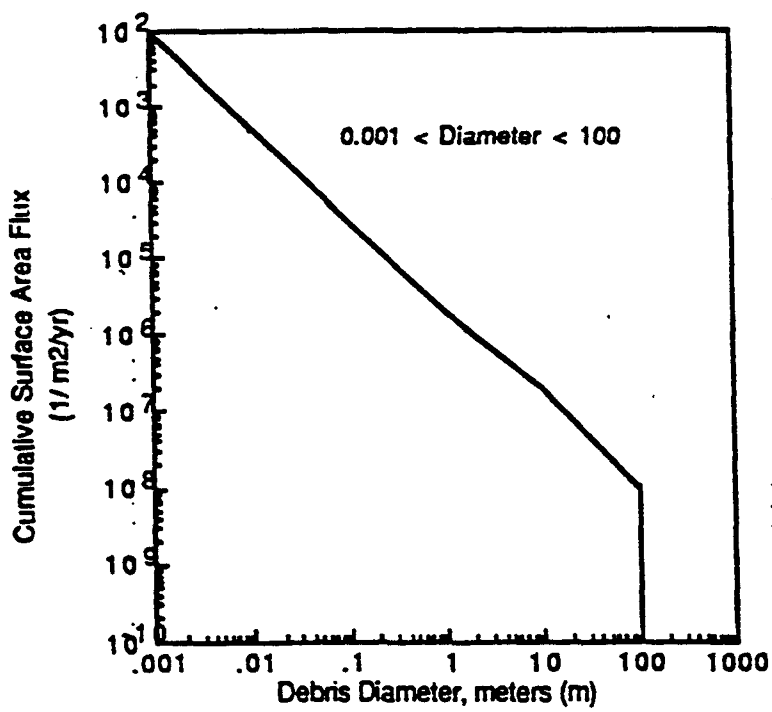


Figure 6-4 Year 2010 Space Debris Design Basis

The relationship to be used for calculation of the probability of loss should be of the general type:

$$p = \text{SUM} \; (f * k * A_c * L) \; R$$

where:

- p = probability that a component will be rendered inoperative
- f = impact frequency of particles capable of destroying a component or rendering a subsystem inoperable (particles/square meter/year)
- k = direction factor
- A_c = maximum projected area of components (square meters)
- L = operational life of platform (years)
- R = redundancy of component capable of maintaining full operational status

The above relationship is the so-called "rare event approximation" and is accurate to within about 10 percent of the true probability when the individual component failure probability is < 0.1. Any error made is on the conservative side, in that the true probability is slightly lower.

6.1.2 Space Plasma. The high power production of the MSNPS will result in a susceptibility to voltage breakdown due to naturally existing plasma. Breakdown voltage is defined as the minimum voltage that can generate a discharge in a select, well-defined environment. The breakdown voltage can be correlated to altitude by Figure 6-5, which shows the plasma density versus altitude for an equatorial orbit. The plasma density will vary with the 11-year sun-spot cycle. This figure provides maximum and minimum densities, both of which peak near 150 nmi, reach a plateau near 1100 nmi, and fall off rapidly above 6600 nmi. Figure 6-6 provides the initiation breakdown voltage versus altitude for maximum and minimum densities. It is important to recognize that the data of Figure 6-6 are for non-insulated electrical elements in the natural environment of an equatorial orbit. Induced environments in other orbits must be considered as applicable.

Breakdown levels, as shown in Figure 6-6, are the minimum breakdowns recorded in experiments and space flights. Designing for safe operation can be accomplished by solid shielding. Screen shielding is unacceptable because no protection against solar ultraviolet (UV) is provided.

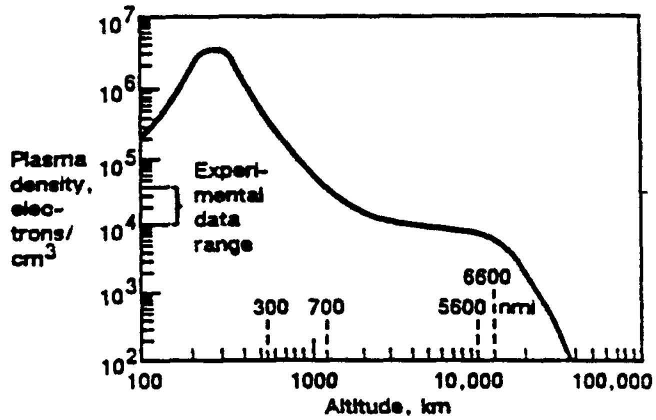


Figure 6-5 Plasma Density Versus Altitude

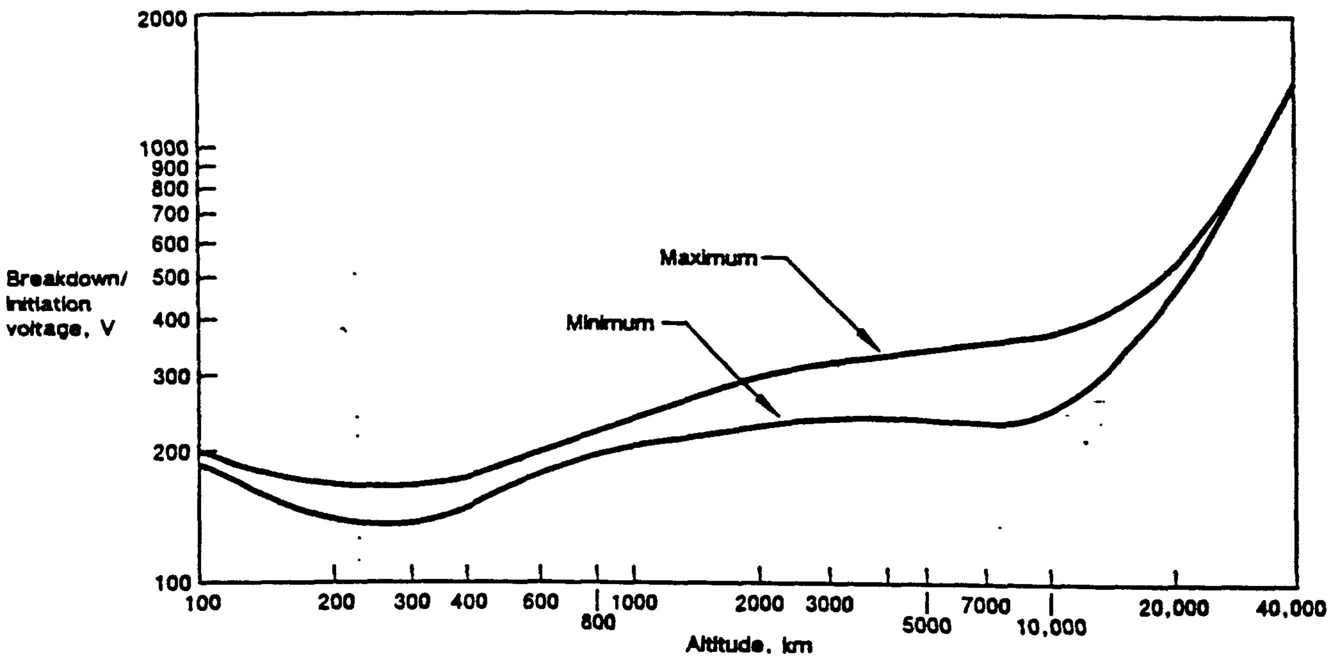


Figure 6-6 Effects of Plasma on Exposed Bare Conductors

Additional detail on the space plasma environment may be found in NASA-TM-82478, Space and Planetary Environment Criteria Guidelines for use in Space Vehicle Development, Volume 1. Additional design criteria is contained within NASA-TP-2361, Design Guidelines for Assessing and Controlling Spacecraft Charging Effects.

6.1.3 <u>Ionizing Radiation</u>. In the orbit specified for the MSNPS, the spacecraft will be exposed to the three main sources of space radiation: (1) trapped radiation (the Van Allen belts), (2) galactic cosmic rays, and (3) solar cosmic rays. These sources are in addition to the radiation emitted by the MSNPS during its operation (discussed in section 6.2.2).

Due to the interaction of the solar wind and the Earth's magnetic field, high-energy atomic particles flow above the sensible atmosphere along the magnetic flux lines are toward the magnetic poles. Within these belts, which extend from approximately 600 to 10,000 km (Fig. 6-7), ionizing radiation increases by several orders of magnitude above that found at altitudes below 600 km. As seen in Figure 6-7, the electronic flux is greater than the proton flux. However, the protons are the dominating factor in damage to electronics since they have the greater displacement damage cross-section in silicon. The effects on design requirements for unmanned spacecraft operating within these belts involve increased shielding to protect electronic components.

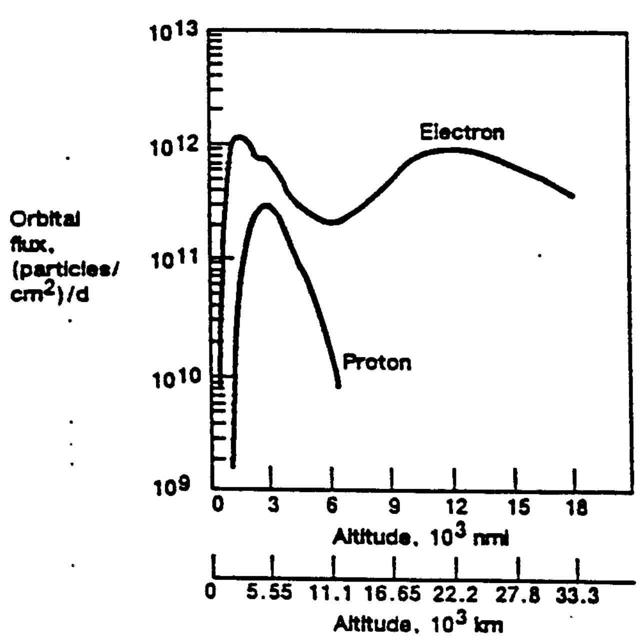


Figure 6-7 Radiation Flux Versus Altitude

The free-space radiation levels to which the MSNPS spacecraft will be exposed in its intended orbit is approximately 6000 rad/yr from protons and 2E6 rad/yr from electrons. With shielding by outer casings, covers, or other spacecraft structure, these levels decrease sharply. Shielding of 1 g/cm^2 (about 150 mil of aluminum) reduces the yearly doses to approximately 1000 rad from protons and 200 rad from electrons. Thus, with minimum shielding, the doses from space radiation to the most sensitive components (i.e., electronics) are low enough that they are not a problem. Available off-the-shelf electronics can withstand doses of 10E4 rad (Fig. 6-8), and hardened electronics are available that can withstand considerably higher levels.

Galactic cosmic rays are not a major threat in terms of total dose, but may cause single-event upsets (SEUs) to electronic devices, particularly memory devices. SEUs induced by cosmic rays can result in loss of bits in memories, microprocessors, and computers. Hardening may be accomplished by selecting hardened electronic components, hardened circuit design, and selective shielding that makes the electrical and electronic components tolerant of the total radiation dose and the SEUs. Since the solar cosmic rays consist of at least 95% protons, the sporadic eruption of these proton showers can be handled in a manner similar to the trapped-belt protons (i.e., by direct shielding).

Tables 6-3 to 6-5 specify the natural radiation design environment.

6.1.4 Atomic Oxygen. Atomic oxygen is present in the upper atmosphere as a result of the interaction of solar radiation with molecular oxygen causing breakdown through photodissociation to the atomic state. The large mean free path of the rarified atmosphere slows the rate of recombination to the extent that there is a constant presence of atomic oxygen at the lower orbit altitudes. At higher orbital altitudes, the concentration of atomic oxygen diminishes along with the other gases (Fig. 6-9). Atomic oxygen is a vigorous, highly reactive oxidizer that erodes organic materials when these materials are impacted with atomic oxygen at high velocities. This erosion is most severe on windward-facing surfaces that are not shielded by intervening structure. The types of spacecraft materials most affected by atomic oxygen are graphite/epoxy, mylar, kapton, etc. Surfaces can be protected with inorganic materials that form a hard oxide coating, such as aluminum. Atomic oxygen and its reactants are believed to be responsible for the infrared and airglow effects that can adversely affect the use of sensitive optical instruments.

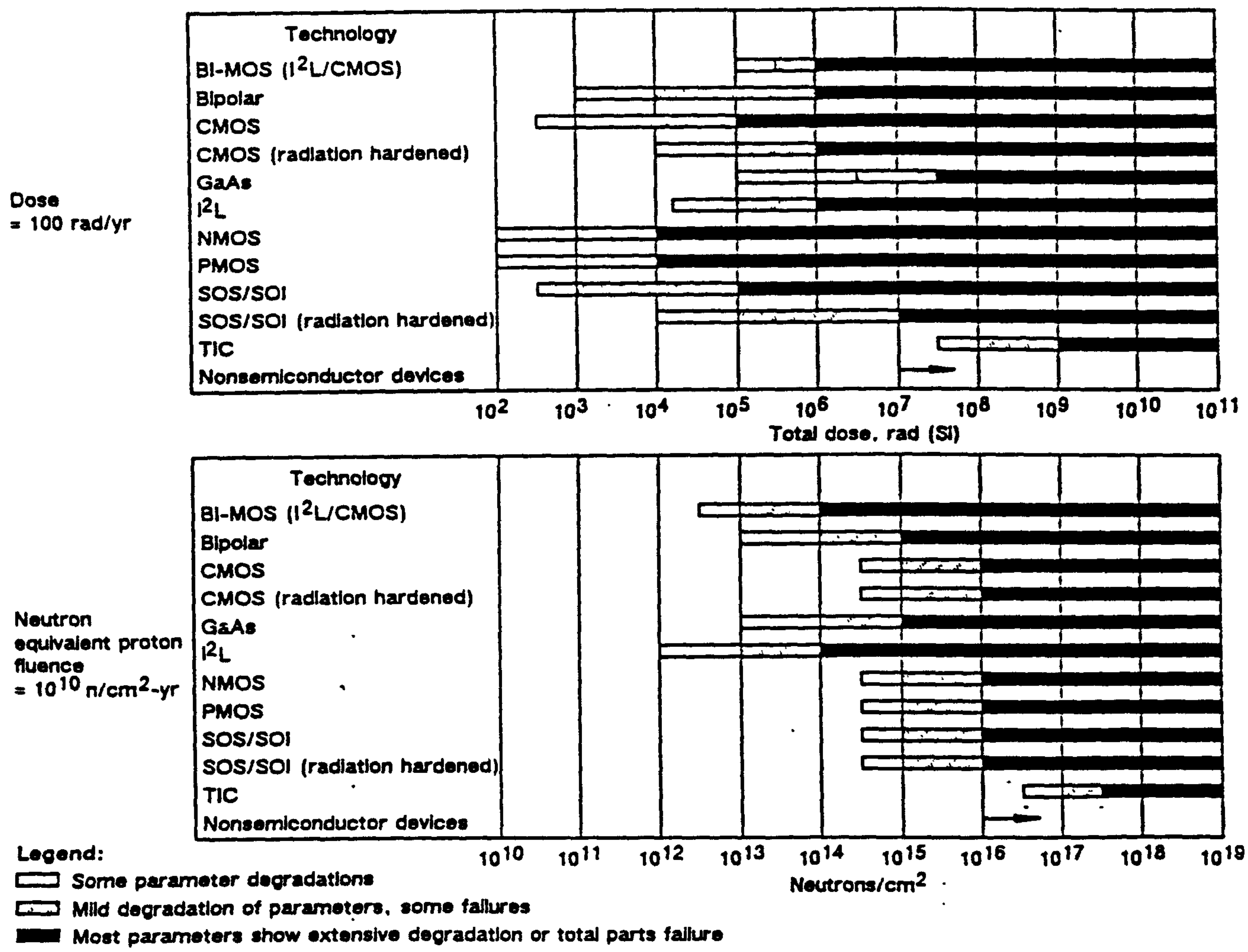


Figure 6-8 Radiation Susceptibility Of Semiconductor Techniques

Table 6-3 Proton Fluence-Energy Spectra Natural Radiation Environment

Energy (MeV)	Fluence (particles/cm^2-day)
1.0 - 01	2.8 + 10
2.0 - 01	2.8 + 10
5.0 - 01	2.7 + 10
1.0 + 00	2.6 + 10
2.0 + 00	2.5 + 10
3.0 + 00	2.3 + 10
4.0 + 00	2.1 + 10
5.0 + 00	1.9 + 10
6.0 + 00	1.8 + 10
8.0 + 00	1.4 + 10
1.0 + 01	1.1 + 10
1.5 + 01	6.4 + 09
2.0 + 01	3.9 + 09
2.5 + 01	3.1 + 09
3.0 + 01	2.6 + 09
3.5 + 01	2.3 + 09
4.0 + 01	2.1 + 09
4.5 + 01	1.9 + 09
5.0 + 01	1.7 + 09
5.5 + 01	1.6 + 09
6.0 + 01	1.5 + 09
7.0 + 01	1.3 + 09
8.0 + 01	1.2 + 09
9.0 + 01	1.1 + 09
1.0 + 02	9.4 + 08
1.5 + 02	5.3 + 08
2.0 + 02	3.0 + 08
3.0 + 02	1.1 + 08
4.0 + 02	4.0 + 07
5.0 + 02	1.4 + 07

Table 6-4 Electron Fluence-Energy Spectra External Environment-Solar Minimum Period

Energy (MeV)	Fluence (particles/cm^2-day)
1.00 - 01	5.5 + 12
2.00 - 01	2.1 + 12
3.00 - 01	9.5 + 11
4.00 - 01	5.2 + 11
5.00 - 01	2.9 + 11
6.00 - 01	2.0 + 11
7.00 - 01	1.4 + 11
8.00 - 01	1.0 + 11
9.00 - 01	7.8 + 10
1.00 + 00	6.0 + 10
1.25 + 00	3.8 + 10
1.50 + 00	2.4 + 10
1.75 + 00	1.6 + 10
2.00 + 00	1.1 + 10
2.25 + 00	7.6 + 09
2.50 + 00	5.2 + 09
2.75 + 00	2.0 + 09
3.00 + 00	7.4 + 08
3.25 + 00	2.1 + 08
3.50 + 00	6.2 + 07
3.75 + 00	1.8 + 07
4.00 + 00	5.3 + 06
4.25 + 00	1.5 + 06
4.50 + 00	4.4 + 05
4.75 + 00	1.2 + 05
5.00 + 00	0.0
5.50 + 00	0.0
6.00 + 00	0.0
6.50 + 00	0.0
7.00 + 00	0.0

Table 6-5 Electron Fluence Energy Spectra Natural Radiation Environment-Solar Maximum Period

Energy (MeV)	Fluence (particles/cm^2-day)
1.00 - 01	1.2 + 13
2.00 - 01	5.9 + 12
3.00 - 01	2.6 + 12
4.00 - 01	1.0 + 12
5.00 - 01	3.9 + 11
6.00 - 01	2.5 + 11
7.00 - 01	1.6 + 11
8.00 - 01	1.1 + 11
9.00 - 01	8.2 + 10
1.00 + 00	6.0 + 10
1.25 + 00	3.8 + 10
1.50 + 00	2.4 + 10
1.75 + 00	1.6 + 10
2.00 + 00	1.1 + 10
2.25 + 00	7.6 + 09
2.50 + 00	5.2 + 09
2.75 + 00	2.0 + 09
3.00 + 00	7.4 + 08
3.25 + 00	2.1 + 08
3.50 + 00	6.2 + 07
3.75 + 00	1.8 + 07
4.00 + 00	5.3 + 06
4.25 + 00	1.5 + 06
4.50 + 00	4.4 + 05
4.75 + 00	1.2 + 05
5.00 + 00	0.0
5.50 + 00	0.0
6.00 + 00	0.0
6.50 + 00	0.0
7.00 + 00	0.0

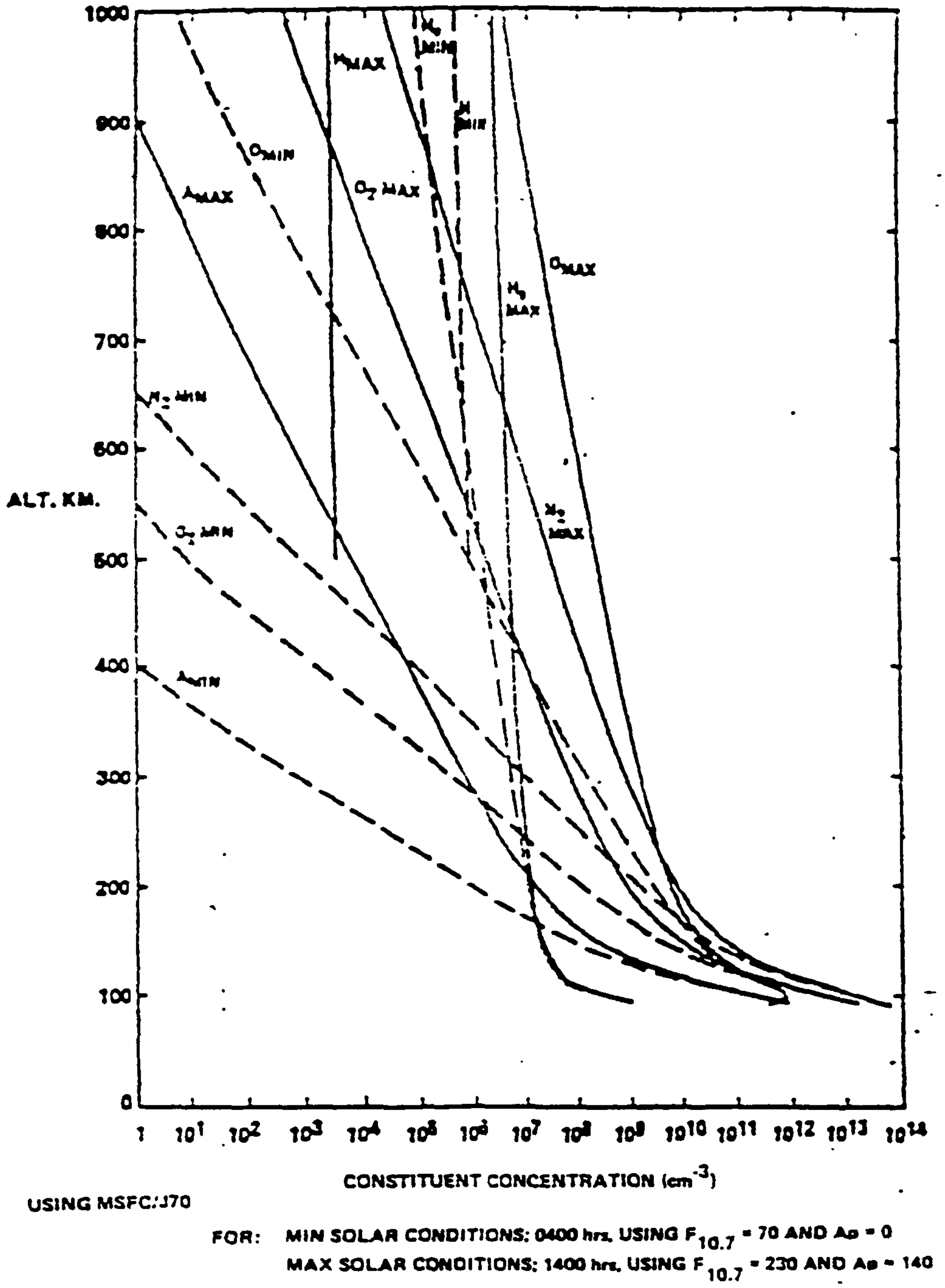


Figure 6-9 Number Density Of Atmospheric Constituents Versus Height

At Shuttle altitudes, the atomic oxygen density is on the order of $10^9/cm^3$, which corresponds to a flux of approximately $10^{15}/cm^2$-sec. Atomic oxygen density decreases as atmospheric density decreases; as a result, the deleterious effects are reduced by an order of magnitude from about 400 km to about 500 km. Therefore, for the intended orbit of the MSNPS, atomic oxygen should not be a problem in general, although at higher altitudes atomic oxygen may still be a problem for certain materials.

6.1.5 Thermal. The system shall be designed to operate in the natural thermal radiation environment due to direct solar radiation, Earth albedo, and Earth long wave radiation. The space heat sink effective temperature is (220K) including the above sources.

Where practicable, each component shall be designed to operate continuously within an ambient temperature range of at least -34 deg C to +71 deg C. To prevent generating a possible ignition source, the temperature of any part exposed to the atmosphere shall not exceed 178 deg C.

6.2 SELF-INDUCED ENVIRONMENT

6.2.1 Effluent. The quantities of effluents are expected to be much larger than the quantities of contamination (e.g., outgassing) from other sources. Effluents can adversely influence the performance of the spacecraft by interfering with the sensor functions, by causing an attenuation of the NPB beam, by reducing the threshold for high-voltage breakdown, and by producing an ionized plasma that potentially can adversely affect communications and cause spacecraft charging.

The key issue to be investigated in Phases I and II of the program is the effluent ionization potential resulting from the interaction of the effluent with the environment. It is expected that the effluent will ionize under the influence of the solar flux as well as other natural and hostile threat conditions.

6.2.2 Radiation. A preliminary assessment of the radiation from the core, assuming 125 mm of beryllium neutron reflector around the core, showed a neutron fluence of approximately 4×10^{13} neutron/cm^2 and a total integrated gamma dose of approximately 5×10^5 rad. Depending on the power level required, the standby power level could result in a doubling of these doses over the mission lifetime.

For the short run times of the MSNPS, the total dose of gamma rays and neutrons received by the electronic components are several orders of magnitude below the levels the electronic components of the 1990s are expected to tolerate.

6.2.3 Thermal. TBD

6.3 NPB INDUCED ENVIRONMENT

The environments induced by the NPB system include magnetic fields, vented hydrogen, and RF generated fields. They are TBD.

6.4 STRUCTURAL

Static and dynamic loads are primarily driven by launch conditions. On-orbit structural loads will be a function of the MSNPS design, the Orbital Transfer Vehicle, and the payload or other system to which the MSNPS is attached. Orbital transfer thrust levels and payload skew rates and momentum reactions will be defined as the system design matures.

6.5 HOSTILE ENVIRONMENT

Specific hostile environments are unknown or cannot be included in this document for security reasons. The following paragraphs provide a general discussion of some probable environments and their effects.

6.5.1 Kinetic Energy Weapon Pellets. Pellet sizes are in the same range as the larger space debris, but their flux is much higher. Consequently, the bumper thickness is dictated by the need to protect against kinetic energy weapon pellets. Conventional aluminum armor of a 150-mil thickness has been found to adequately protect piping and other vulnerable components against these threats.

6.5.2 Radiation. Nuclear radiation resulting from nuclear weapon detonations include neutrons, gamma rays, and fission electrons similar to the radiation emitted from the MSNPS reactor. This radiation can affect electronic components producing circuit upset and device damage. Prompt X-ray dose rates also adversely affect electronic components. Total integrated dose from gamma rays and neutrons may cause permanent charge displacement in semiconductors and reduce their performance. At the survivability level being considered for the space power system, gamma-ray and neutron doses caused by detonations appear to be small when compared to the total dose received from the reactor.

Prompt X-ray dose rates may be protected against by shielding electronic boxes with 20- to 40-mil tantalum shielding. Component hardening can be coupled with circuitry circumvention to prevent upset or inadvertent sending of signals or data to CMOS/SOS microchip devices due to gamma-ray or X-ray dose rates up to 10E10 rad (Si)/s.

Control electronics, as contrasted with power electronics, operate with small electrical currents at low voltages. Consequently, these are much more vulnerable to SEUs and high gamma-ray and X-ray dose rates. Radiation-hardened microprocessors can be used to handle digital controls.

6.5.3 Thermal. High-energy X-rays and laser beams are the primary source of the hostile thermal environment effecting the elements of the system that carry fluids. Continuous wave (CW) laser energy is absorbed on the vehicle surface in contrast to pulsed lasers and X-ray heating, which cause depth effects from bulk absorption. The X-ray heating is less severe than laser heat, but couples into the system in a different way. X-rays are absorbed in the bulk material, producing an almost instantaneous heating. In addition to the melt and vaporization of the laser threat, x-rays also induce failure by thermal shock and spallation. Heat-sensitive elements undergo pyrolysis, melting, or even vaporization. The amount of heat present depends on surface optical properties that can change with temperature. Heat can then be conducted to adjacent structures to raise temperatures above allowable levels. A high-temperature design incorporates surface protection and insulation from conducted heat for buried components.

Hardening approaches have used both passive and active measures. Passive measures to reject heat absorption use coatings ranging from IR reflective to high emissivity black coatings to low absorptivity white coatings. Multiple layer insulation (MLI) works well as long as the MLI survives. Metal foils or carbon mats can also protect against this threat.

Carbon fiber mats provide excellent X-ray and laser protection. These blankets have a density ranging from 50 to 100 kg/m^2 and thus add to the weight of the space craft.

6.5.4 Electromagnetic Pulse (EMP). Dispersed EMP (DEMP) is the EMP signal from high-altitude nuclear bursts that is dispersed by the ionosphere and propagated to the power system. Self generated EMP (SGEMP) results from the interaction of X-rays with the system to induce large charges, voltages, and currents on conductors. These currents or charges can penetrate into the system and cause upset or burnout.

For bursts under consideration, fields of the order of magnitude of 100 to 200 v/m can be expected as a result of the EMP effects. The current and voltage loads associated with the SDI payload are much higher than the transient perturbation caused by EMP effects; consequently, the power circuit is not as adversely affected as the control circuits which are most vulnerable.

The most severe effect of SGEMP is the cable SGEMP. It is caused by the electrons interacting directly with the conductor. This necessitates use of surge arrestors and filters to reduce the large electrical transients. To protect the electronics a full topology protection is employed. For example, a complete conducting surface encloses the electronic boxes to be protected. DEMP is overcontrolled by the topology and terminal protective devices required by SGEMP. Low-Z coatings also reduce internal and external SGEMP. It will also be necessary to pay careful attention to grounding to mitigate the effects of SGEMP.