NSTS 07700, Volume XIV,

Appendix 1

System Description and Design Data –

Contamination Environment

DESCRIPTION OF CHANGES TO

SYSTEM DESCRIPTION AND DESIGN DATA – CONTAMINATION ENVIRONMENT
NSTS 07700, VOLUME XIV, APPENDIX 1

CHANGE NO.	DESCRIPTION/AUTHORITY	DATE	PAGES AFFECTED
REV J	Complete revision; replaces and supersedes the contamination sections to Revision I of NSTS 07700, Volume XIV (reference CR D07700-014-001-01). The following CR is included: D07700-014-001-02.	1/26/88	ALL
1	The following CR is included: D07700-014-001-03.	6/14/89	Figure 1
REV K	Complete revision (reference CR D07700-014-001-07A). The following CRs are included: D07700-014-001-04, D07700-014-001-05.	1/5/95	ALL
	Reformat Word for Windows.	07/96	ALL
1	The following CR is included: D07700-014-001-0008	11/25/96	3-4, 3-5, 3-6, 3-7, 3-8, 3-9, 3-11, 3-12
REV L	Complete revision; replaces and supercedes Revision K of NSTS 07700-014-001-07A. The following CR is included: D07700-014-001-0009A.	9/29/00	ALL

Preface

This document is designed to be used in conjunction with the series of documents illustrated in Figure 1. Information on the contamination and atomic oxygen environments to which the payload is exposed while in or around the Orbiter payload bay and during ground processing is presented herein.

Agreements for contamination controls must be specified in the individual payload integration plans.

Configuration control of this document will be accomplished through application of procedures contained in NSTS 07700, Volume IV, Configuration Management Requirements.

Questions and recommendations concerning this document should be addressed to:

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Customer and Flight Integration
Space Shuttle Program

NSTS 07700 VOLUME XIV
SPACE SHUTTLE SYSTEM PAYLOAD ACCOMMODATIONS

NSTS 21492 Payload Bay Payload User's Guide

SAFETY
- 45 SPW HB S-100/KHB 1700.7
- NSTS 1700.7B
- NSTS/ISS 13830C
- NSTS 14046
- NSTS 16879
- NSTS/ISS 18798
- NSTS 22648

SHUTTLE/PAYLOAD STANDARD INTEGRATION PLANS (SIP's)

ANNEXES*

NSTS 21000-SIP-ATT
ATTACHED PAYLOADS

NSTS 21000-SIP-DRP
DEPLOYABLE/RETRIEVABLE PAYLOADS

NSTS 21000-SIP-GAS
GET AWAY SPECIAL PAYLOADS

NSTS 21000-SIP-MDK
MIDDECK PAYLOADS

NSTS 21000-SIP-ISS
INTERNATIONAL SPACE STATION

ORBITER/PAYLOAD INTERFACES

ICD 2-19001:
VOL. XIV, ATTACHMENT 1 - SHUTTLE ORBITER/ CARGO STANDARD INTERFACES

NSTS 21000-IDD-SML
SMALL PAYLOADS

NSTS 21000-IDD-ISS
INTERNATIONAL SPACE STATION

NSTS 21000-IDD-MDK
MIDDECK PAYLOADS

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Figure 1.- Space Shuttle Program customer documentation tree.

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This appendix addresses contamination environments during offline and online ground flow operations, flight events, postlanding, and ferry flight. Also included is a review of contamination conditions within and between various launch site facilities. The information provided will aid the Space Shuttle user in planning payload-to-orbiter interfaces and the integration of design considerations for the environments described.

Environmental conditions for payloads installed in the pressurized sections of the orbiter are covered in Shuttle/Payload Interface Definition Document for Middeck Payload Accommodations, NSTS 21000-IDD-MDK.

Payload integration and mission success are dependent on payload customer understanding of contamination conditions to which a payload is exposed from delivery to the launch site to postflight removal of the payload from the orbiter. The Space Shuttle Program (SSP), assists the customer in understanding the Space Shuttle by identifying facility and orbiter design practices and cleanliness and operational controls which determine the payload contamination environment.

Payload Bay System Overview

2

2.1 Payload Bay Description

The payload bay is a cylindrical volume in the upper portion of the orbiter midbody. Its dimensions vary slightly between static and dynamic conditions and the payload does not come in direct contact with the payload bay walls. The maximum payload dimensions by design are 720 inches (18.46 m) long by 180 inches (4.6 m) in diameter, or a volume of 10,600 cubic feet (306.6 m^3).

The payload bay is, with a few exceptions, a smooth surface with filtered vents, lights, and flush-mounted wire trays as shown in Figures 2-1 and 2-2. The standard configuration displays a patchwork of thermal control blankets in the lower half of the payload bay, and a liner of tightly

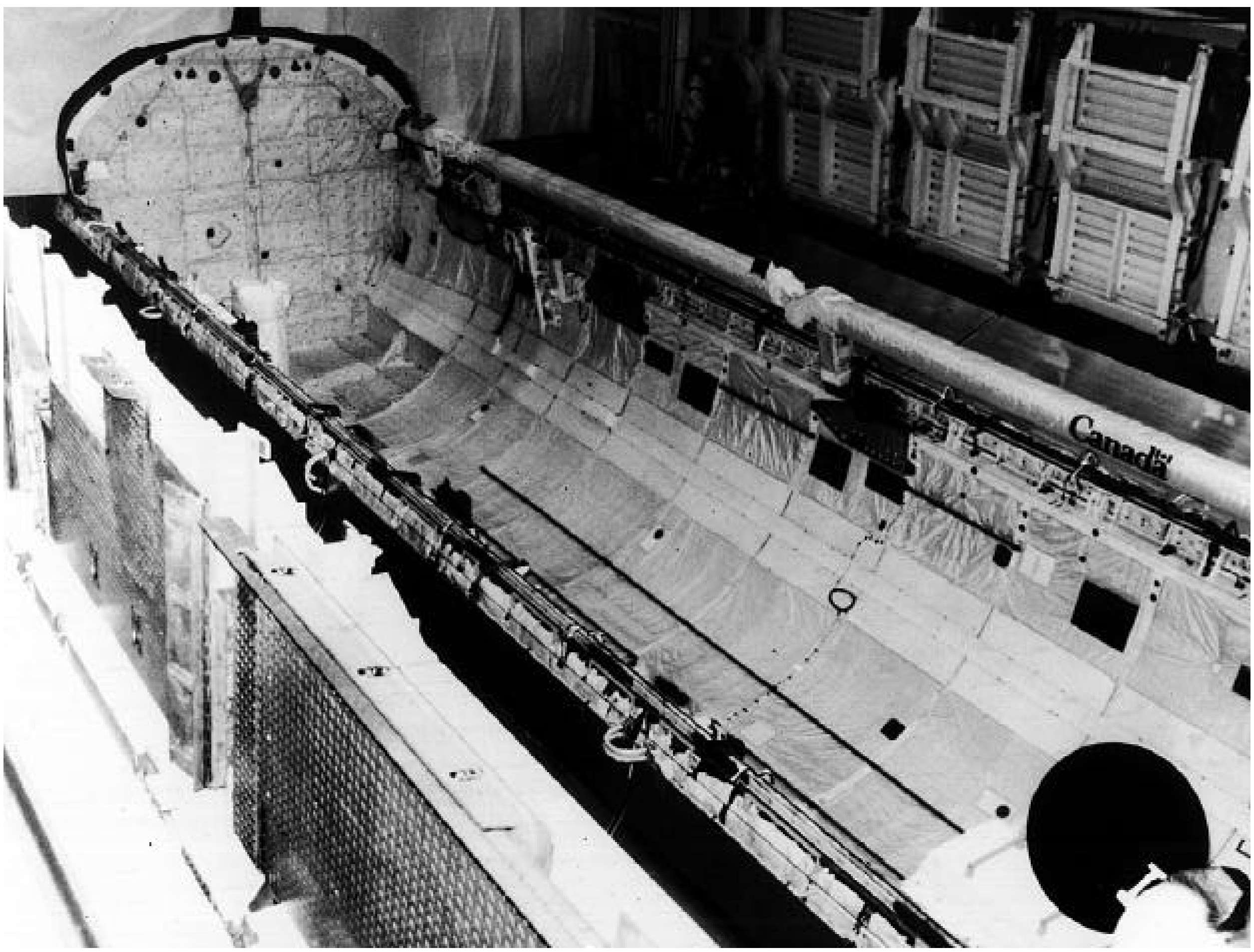

Figure 2-1.- Payload bay looking aft.

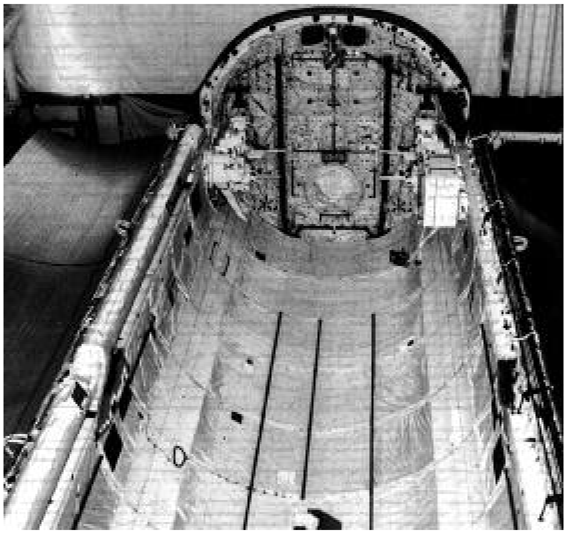

Figure 2-2.- Payload bay looking forward.

woven Teflon-coated Beta Cloth is installed in six-foot widths over the blankets to form a barrier between the payload bay and the equipment bay in the lower part of the mid fuselage. The liner covers almost 1500 square feet of the payload bay's 3300 square feet of surface area.

Without the liner installed (see Figure 2-3), the lower part of the payload bay is covered with a continuous sheath of Beta Cloth and aluminized Kapton (polyimide) insulation blankets, painted metal wire tray covers, metal vent filters and recessed lighting fixtures. The vents that allow the payload bay to breathe with the external environment and the lower midbody contain filters. The filters are a double dutch twilled stainless steel weave with a glass bead rating of 40 micrometers (allowing passage of an 88 micrometer particle).

The payload bay is purged at the forward bulkhead with activated charcoal and High Efficiency Particle Air (HEPA)-filtered air. Filters are installed in the Orbiter Processing Facility (OPF) and Mobile Launch Platform (MLP) Environmental Control System (ECS). No purge is available for orbiter rollover to the VAB; this period can be as long as 72 hours.

2.2 Requirements for Space Shuttle Contamination Environment

This section will delineate the pertinent contamination control requirements, and outline both, the outgassing requirements found in General Specification Vacuum Stability Requirements of Polymeric Material for Spacecraft Applications, SP-R-0022, and the payload bay cleanliness requirements of Contamination Control Requirements for the Space Shuttle Program, SN-C-0005.

The following statements address contamination control during the operational phases of the Space Shuttle with particular emphasis on the gaseous and particulate environment encountered by the orbiter.

- Minimizing cross contamination of payload elements to a level compatible with mission objectives
- Minimizing contamination of payloads and critical payload bay surfaces
- Isolation of orbiter elements not easily cleaned or sources of particulate or volatile condensable material (VCM) from payloads and critical payload bay surfaces
- Selection of nonmetallic materials exposed to the payload which have low outgassing characteristics
- Management of payload effluents and operations so that performance of orbiter systems is not jeopardized
- Cleaning of internal payload bay envelope surfaces to one of three visibly clean levels prior to payload loading
- Prevention of accumulation of visible particulate and film contamination within the payload bay after payload installation by controlled work discipline, cleanliness inspections, and effective cleaning as required

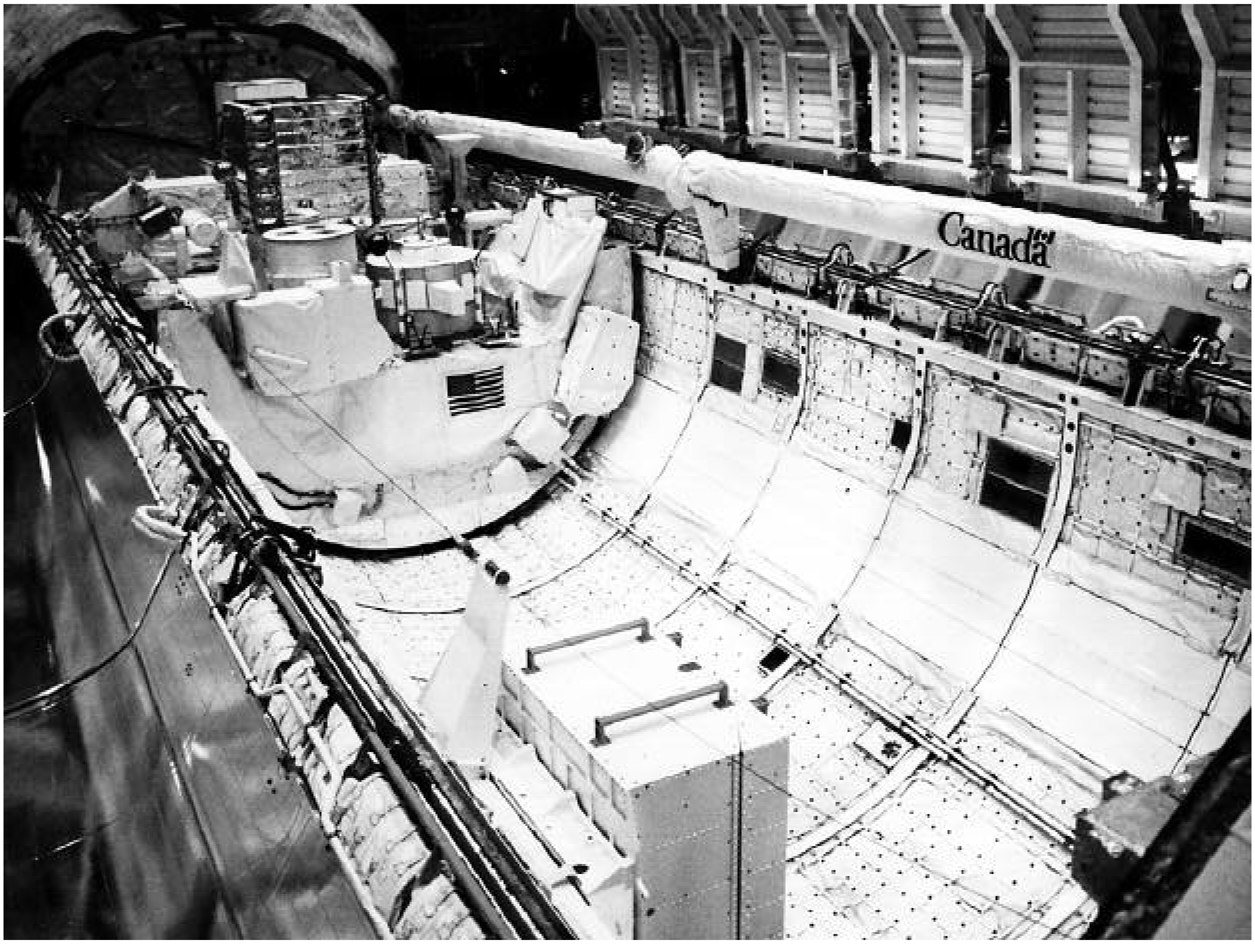

Figure 2-3.- Payload bay without liner installed - view looking aft at KSC.

- Maintaining preflight payload and payload bay cleanliness from launch to orbital insertion
- Controlling overboard venting of gases or liquids to avoid contamination of payloads, the payload bay, orbiter windows, optical surfaces, and orbiter thermal protection system (TPS) surfaces
- Venting of gases and liquids from the orbiter to limit particulate release, induced water vapor column density, return flux, scattering, and absorption
- Planning Reaction Control System (RCS) thruster firing operations to avoid contamination; designing and controlling thruster exhausts to minimize direct impingement or reflection upon deployed payloads or the open payload bay
- The payload bay vents contain particulate filters which allow repressurization using filtered atmospheric air (40 micrometers glass bead rating, 88 micrometers longest particle dimension).

2.2.1 General Specification Vacuum Stability Requirements of Polymeric Material for Spacecraft Application, SP-R-0022

The SP-R-0022 specification, referenced through General Specification NASA JSC Requirements for Materials and Processes, SE-R-0006, establishes outgassing requirements and test guidelines for polymeric materials in the payload bay and selected other areas of the orbiter. Its objective is to control outgassing of materials so that contamination is not deposited on sensitive optics or thermal control surfaces. The standard requirement is that a material must not lose more than one percent of its mass nor transfer more than 0.1 percent of its mass to an adjacent cooler surface under the standard space-simulating conditions delineated in SP-R-0022. The weight lost is called the total mass loss (TML). The weight gained by the adjacent cooler plate is condensed VCM. Details of test requirements, specimen size, and preparation methods are included.

Materials that do not meet SP-R-0022 requirements may not necessarily be excluded from use. Rationale can be provided to the SSP as to why the material is not a potential hazard. Examples of reasons why a material might fail and still be acceptable are listed in the specification.

2.2.2 Contamination Control Requirements for the Space Shuttle Program, SN-C-0005

This specification addresses particulate and nonvolatile residue levels for surfaces of the Space Shuttle during assembly and ground operations. It does not specify flight or facility contamination.

The approach utilized is similar to other NASA specifications; it primarily establishes a standard framework that guides requirements. This facilitates commonality of nomenclature among the hundreds of contractor and facility personnel. The precision cleanliness levels offered for selection by the contractors, for instance, are derived from the industry standard Product Cleanliness Levels and Contamination Control Program, MIL-STD-1246.

SN-C-0005 is also the source of the orbiter external surface cleanliness levels: Standard, Sensitive and Highly Sensitive. One of these levels is established in negotiations between SSP and the payload customer, and is then specified in paragraph 6.4 of the applicable Integration Plan (IP). When a request for other than Standard is made, these negotiations must be accompanied by a detailed analysis or data which demonstrate the sensitivity of the payload. Mixed payloads must be compatible with the Standard cleanliness level. The individual payload customer must certify compliance with the specified level of cleanliness during ground processing. Table A-2 of SN-C-0005, which defines these alternate payload bay surface cleanliness levels, is included here as Table 2-I. The Sensitive and Highly Sensitive cleanliness levels require a closer and more painstaking scrutiny and cleaning. Additionally, the Highly Sensitive cleaning incorporates extensive solvent wiping. This cleaning for Sensitive and Highly Sensitive levels necessitates that an extra charge be levied on the payload customer (depending on launch agreement and schedule); however, the vast majority of payloads have flown successfully in a payload bay inspected to just the Standard cleanliness level.

TABLE 2-I.- VISIBLY CLEAN LEVELS AND INSPECTION CRITERIA

TABLE A-2, SN-C-0005 VISIBLY CLEAN (VC) LEVELS AND INSPECTION CRITERIA FOR THE ORBITER PAYLOAD (CARGO) BAY, PAYLOAD CANISTER, AND PAYLOADS*			
Three levels of VC requirements are available for the orbiter payload bay, payload canister and payloads during SSP orbiter/payload integrated operations at launch and landing sites. VC Standard is the baseline referred to in contractual documentation. The VC definition in Table I is applicable to this table with the understanding that incident light levels and inspection distances are specified herein.			
VC LEVEL	INCIDENT LIGHT LEVEL Note-1	OBSERVATION DISTANCE	REMARKS
Standard	≥ 50 footcandles	5 to 10 feet	Notes 2, 3, 5
Sensitive	≥ 50 footcandles	2 to 4 feet	Notes 2, 3, 5
Highly Sensitive	≥ 100 footcandles	6 to 18 inches	Notes 3, 4

*This table has been reprinted from Contamination Control Requirements for the Space Shuttle Program, SN-C-0005; therefore, the reference to Table I is found in SN-C-0005.

Note 1. One footcandle (lumens per square foot) is equivalent to 10.76 lumens per square meter.

Note 2. Cleaning is required if the surface in question does not meet VC under the specified incident light and observation distance conditions.

Note 3. Exposed and accessible surfaces only.

Note 4. Initial cleaning is mandatory; Note 2 applies thereafter.

Note 5. Areas of suspected contamination may be examined at distances closer than specified for final verification.

Payload Bay Environments

3

3.1 Ground Operations and Facilities – General

It is recognized by the launch support organizations that ground operations environments and the control thereof provide a critical link between delivery of a payload and mission operations. A fairly complex and integrated methodology of handling a payload as it moves through various facilities, sometimes miles apart, has been established. This is discussed in Launch Site Accommodations Handbook for Payloads, K-STSM-14.1.

Because of the concern about ground environments, many studies have been conducted on the facilities and transfer containers. Data are presented at Ground Operations Working Group (GOWG) meetings and disseminated to concerned organizations. The data has shown an improvement in the environmental conditions since the early Space Shuttle flows, based on a continuing effort to upgrade the facilities and tighten operational controls.

Representative data for both offline and online facilities at KSC are summarized in this document. More recent data are available from the payload-assigned Launch Site Support Manager (LSSM).

3.2 John F. Kennedy Space Center (KSC)/Cape Canaveral Air Force Station (CCAFS) Facilities

There are two separate facility complexes—Cape Canaveral Air Force Station (CCAFS) and John F. Kennedy Space Center (KSC). Building AE contains a NASA 10,000 class clean work area at CCAFS. The Air Force Shuttle Payload Integration Facility (SPIF) is also located at CCAFS.

Payload facilities at KSC include the Spacecraft Assembly and Encapsulation Facility-2 (SAEF-2), the Payload Hazardous Servicing Facility (PHSF), Multi-Payload Processing Facility (MPPF), Vertical Processing Facility (VPF), Space Station Processing Facility (SSPF) and the Operations and Checkout (O&C) Building. The O&C is also used as an integration facility where horizontally processed payloads are integrated for testing and installation into the payload canister. The VPF is the integration facility for hazardous payloads and other payloads to be installed in the canister for vertical installation at the pad. The OPF at Launch Complex (LC) 39 is the Space Shuttle facility used for horizontal installation of payloads into the orbiter; the Payload Changeout Room (PCR) at the pad is used for vertical installations. Typical horizontal and vertical payload flows are shown in System Description and Design Data - Ground Operations, NSTS 07700, Volume XIV, Appendix 5.

All facilities and the payload canister have been categorized into one of five cleanliness classes based on the facility design, capability, and operational controls. The environmental requirements and operations and maintenance requirements for these five cleanliness classes are described in K-STSM-14.1. A copy of this document is available through the payload-assigned LSSM.

Payload owners are expected to comply with facility rules. Payloads must meet the cleanliness requirements for the mission as defined in the mission-unique Integration Plan (IP) and Operations and Maintenance Requirements and Specifications Document (OMRSD). Joint payload inspections will be made with launch site contamination control engineers to verify compliance. A variety of environmental data as described below are routinely collected in the launch site facilities.

3.2.1 Airborne Particles

A hazard-proofed environmental monitoring data system (EMDS) has been installed in the OPF and

PCR facilities. This system continuously monitors airborne particles as well as the temperature and relative humidity.

Automated laser particle counters are used for particulate monitoring. Data are collected for two categories of particles: those larger than 0.5 micron and those larger than 5.0 microns.

3.2.2 Particle Fallout

Two methods are utilized to determine particle fallout. Particle fallout distributions can be obtained from depositions on 37 mm filters for periods of one to two weeks by methods described in Sizing and Counting Airborne Particulate Contamination in Clean Rooms and Other Dust-Controlled Areas Designed for Electronic and Similar Applications, ASTM-F25-6B. Size ranges are selected in accordance with MIL-STD-1246, and counts are converted to values averaged over 24 hours on a square foot surface. Particle fallout rate can also be determined from depositions on silicon wafers. Percent Area Coverage (PAC) is determined by automated instrumentation. Real time particle fallout data collection is available and can be requested as a non-standard service.

3.2.3 Volatile Hydrocarbons

Measurements have been made periodically, typically every two weeks, by collecting a grab sample in a facility and analyzing the sample using a flame ionization detector sensitive to hydrocarbons and organic solvents. The instrument is calibrated with methane, and data reported in parts per million (ppm) volume/ volume methane equivalent. Data seldom exceed or even approach the quoted limit of 15 ppm. Real time hydrocarbon monitoring is available and can be requested as a non-standard service.

3.2.4 Nonvolatile Residue (NVR)

OPF and PCR NVR plates are analyzed by gravimetric technique. Real time NVR data collection is available and can be requested as a non-standard service.

3.2.5 Temperature and Humidity

Temperature data are monitored continuously in KSC facilities. “Out-of-spec” conditions are usually short-lived and associated with door openings during payload or canister arrivals and departures.

Humidity data are also collected continuously. Again, “out-of-spec” conditions are sometimes associated with door openings in facilities without airlocks. In some facilities during the winter months, values lower than 30 percent relative humidity readings may occur for periods of several days during cold, dry weather.

3.2.6 Optical Witness Sample Reflectivity Loss

A series of tests have been conducted in the VPF, PCR (Pad A), payload canister, and associated ECS/environmental systems using optical witness samples. Exposure times have been representative of time spent in each facility during payload ground processing. Percent change in reflectance, R/Ro x 100, was measured at wavelengths ranging from 121.6 to 200 nanometers. Following a few initial failures and removal of some plastic materials, data typically indicate losses of less than 3 percent. Measurements were also made with samples installed in the payload purge system at both the VPF and Pad A with equally good results.

3.3 NASA/KSC Offline Facilities

NASA Payload Processing Facilities (PPFs) and Hazardous Processing Facilities (HPFs) include facilities for standalone activities and for payload integration as a complete cargo prior to installation into the orbiter. The SSPF, VPF, and the O&C are primarily integration facilities. All other payload facilities are for standalone activities, although standalone activities also take place in integration facilities.

3.3.1 Vertical Processing Facility (VPF)

Integration of vertically processed payloads into a Space Shuttle cargo occurs in the VPF. The VPF has an environmentally controlled high bay and airlock and is operated as a Class 100,000 clean work area. The high bay contains a Vertical Payload Handling Device (VPHD). Two vertical payload stacks can be processed simultaneously.

Hazardous activities including propellant loading, ordnance installation, and solid motor mating occur in the VPF.

3.3.2 Operations and Checkout (O&C) Building

Integration of horizontally processed payloads and ISS elements into a Space Shuttle cargo occurs in the O&C building. Pre-integration assembly occurs in the various test stands of the O&C high bay. The O&C has an environmentally controlled high bay with work stations operated as class 100,000 clean work areas (CWAs). A class 50,000 clean room is located at the west end of the assembly and test area. The clean room provides a work area of 1500 square feet.

3.3.3 Spacecraft Assembly and Encapsulation Facility 2 (SAEF-2) and Payload Hazardous Servicing Facility (PHSF)

SAEF-2 and the PHSF are used for assembly, test, propellant loading, ordnance installation and other activities. They serve as either, or both, PPFs or HPFs. The high bays, adjoining low bays, and airlocks are environmentally controlled and operated as class 100,000 clean work areas.

3.3.4 Multi-Payload Processing Facility (MPPF)

The MPPF serves as a PPF for the assembly, test, and check-out. A high bay and connecting low bay are environmentally controlled and operated as class 100,000 clean work areas. Multiple payloads may be processed simultaneously.

3.3.5 Space Station Processing Facility (SSPF)

The SSPF serves as a PPF and integration facility for International Space Station (ISS) elements. A high bay and intermediate bay are environmentally controlled as class 100,000 clean work areas. Multiple ISS elements are processed and tested simultaneously. The SSPF also serves as a PPF for non-ISS payloads.

3.3.6 Environmental Data

NASA/KSC Offline Payload Processing Facilities conform to the environmental requirements defined in K-STSM-14.2.1, KSC Payload Facility Contamination Control Requirements/Plan. Environmental data is available on request.

3.4 NASA/KSC Online Payload Processing Facilities

At KSC, facilities in the LC-39 area in which Space Shuttle payload integration is performed are considered online payload processing facilities. These facilities include all three bays of the OPF for horizontal payload installations and some payload related activities for all Shuttle missions, and PCRs at both launch pads at LC-39.

3.4.1 Orbiter Processing Facility

The OPF main entrance doors are opened and a returning orbiter rolls into a specially designed, environmentally-controlled high bay hangar. With the doors closed, the orbiter is surrounded by a multilevel work platform structure allowing access for refurbishment and reconfiguration operations to begin. Environmental parameters are checked against nominal baseline performance before payload bay door opening. As the payload bay doors begin to cycle open, the payload bay becomes an integrated part of the facility environment. This direct influence makes the environmental management of Space Shuttle PPFs an important factor in contamination control of the payload bay and payload operations.

3.4.2 Physical Description

The OPF is a concrete and steel hangar-type facility with access stands that provide access for maintenance, refurbishment, and reconfiguration of the orbiter and the payload bay. Divided into three high bays of approximately 2.5 million cubic feet each, personnel entry is provided through separate entrance and exit access doors. At one end of the high bays, large access doors open for the orbiter to roll in and roll out. The other end of the bays have two sets of doors, one set for payload canister entry and the other for small equipment entry.

3.4.3 Orbiter Turnaround

When the orbiter is rolled into the OPF from its last mission, orbiter turnaround procedures begin. This reconfiguration process includes waterproofing of the TPS and Orbital Maneuvering System (OMS) deservicing. In the payload bay, beta cloth liners are removed as necessary, the cable tray is rewired and the mechanical payload interfaces are reconfigured for new payload installations. Orbiter facility operations and the cycling of the high bay doors challenge the environmental control in the OPF and the payload bay.

3.4.4 Cleaning Procedures and Operations

The high bays are designated good housekeeping areas with a requirement for generally clean (GC) cleanliness level. GC requires no residue, dirt, debris or other extraneous contamination. Prior to orbiter roll-in, and during orbiter processing, the OPF high bay is periodically vacuumed and wiped down to achieve and maintain this GC level of cleanliness. Either a facility vacuum system with exhaust to the outside or portable HEPA filtered vacuum cleaners are used to clean all accessible areas in the orbiter and the surrounding work platforms.

Following vacuuming, a wipedown is performed in clean work areas using a solution mix of 75 percent isopropyl alcohol and 25 percent water by volume in the orbiter, and 80% isopropyl alcohol and 20% water by volume in the OPF. (100% isopropyl alcohol may be used to clean radiator panel surfaces.) In addition to the general OPF high bay requirements, the work platforms surrounding the payload bay are upgraded to a cleanliness level of visibly clean (VC). The same cleaning techniques and materials are used, but the frequency of cleaning and inspections is increased.

Other steps to maintain the GC level of the OPF include personnel guidelines, equipment maintenance, and operation controls. Technicians are instructed to keep tools and work areas clean. Cranes and hoists are checked to ensure there are no lubricating oil leaks. The OPF doors are opened only when necessary and then closed as soon as possible. Dirt generating work processes are contained and vacuumed. These basic steps help control the environment during orbiter processing in the OPF.

3.4.5 Monitoring

To validate the cleanliness levels in the OPF, especially the workstands surrounding the payload bay, several parameters are monitored and controlled to comply with requirements. These parameters are temperature, relative humidity, airborne particle concentration, particle fallout rates, hydrocarbon concentration, and nonvolatile residue.

3.4.6 Air Quality

Temperature, relative humidity, and air quality are controlled by the facility Heating Ventilating and Air Conditioning (HVAC) system. Two separate air handling units supply conditioned air to each high bay. The air entering each high bay of the OPF passes through a bed of activated charcoal for hydrocarbon removal then through a bank of HEPA filters. The filters are 99.97 percent efficient when tested with 0.3 micron diameter homogeneous particles and supply nominal class 100, guaranteed class 5000 air.

Data indicates that OPF temperature and relative humidity are influenced by ambient weather. High humidity and temperatures outside the facility strain the facility HVAC system.

3.4.7 Particulate Count

Airborne particle count data in the OPF high bays have shown a dramatic decrease in ambient particle concentrations since early Space Shuttle processing flows.

These data represent nominal characteristics during payload bay operations in the OPF. Perturbations to this baseline can be most frequently attributed to orbiter processing requirements such as OPF door openings (transfer aisle or main door), hypergol exhaust fans activation, SCAPE operations, and major activities in close proximity of environmental sensors.

During final payload bay cleaning in preparation for payload bay door closure and OPF rollout, each of the above mentioned potentially particle generating activities will be operationally controlled.

OPF facility data is available upon request.

3.5 Payload Changeout Room

A PCR is located on the rotating service structure (RSS) of pads A and B, extending from the 130-foot level to the 193-foot level, with 157,500 cubic feet in volume. The room is rotated against the orbiter upon arrival of the Space Shuttle vehicle (SSV). Inflatable dock seals provide a cushion for the service structure against the orbiter and also protect the PCR from intrusion of the outside environment. Inside the PCR, the payload ground handling mechanism (PGHM) is used for payload handling. The PGHM is a movable steel structure suspended from the ceiling of the PCR that is used as a strongback to move payloads from the payload canister into the PCR and eventually into the orbiter. The PGHM can be configured to handle payloads and provide access platforms for payload processing. Generally, the payload is transferred from the payload canister into the PCR prior to the orbiter's arrival. Upon SSV arrival at the pad and movement of the RSS to mate with the orbiter payload bay doors, the bifold PCR doors are opened.

Orbiter payload bay and payload operations can now commence. The PCR environment is validated and the payload bay doors are opened. Payload transfer from the PGHM into the payload bay is implemented and payload/orbiter integrated operations begin. Fixed and extendible platforms are positioned as required to provide payload access. Hoists are used to lift ground support equipment (GSE), special access platforms, and handling equipment to the specified fixed platform level. Support equipment entry is via the equipment airlock at the 130-foot level. Personnel entry is at this same level.

3.5.1 Cleaning Procedures and Operations

The PCR is a designated clean work area with a VC surface cleanliness level. This requires the absence of particulate and nonparticulate visible to the unaided eye.

To implement this VC level, total PCR cleaning begins approximately one week prior to the payload's arrival. This cleaning task includes a complete high pressure water spray-down of the PCR exterior doors and interstitial area. Inside the PCR, an air blow-down, vacuuming, and solvent (isopropyl alcohol) wipedown technique is used to achieve a VC level. Also, the telescoping and finger platforms are extended, cleaned and then retracted.

The facility is verified clean through a cleanliness walkdown performed with payload representatives in attendance. The facility is also monitored to ensure it meets KSC facility requirements as referenced in the KSC Payload Facility Contamination Control Requirements Plan , K-STSM-14.2.1, and Shuttle Facility/Orbiter Contamination Control Plan, KVT-PL-0025. PCR facility performance is available upon request.

Payload Bay During Ground Processing

4

4.1 Payload Bay Environment

The orbiter payload bay yields a unique environment for contamination control. The bay is 60 feet long and 15 feet in diameter as described in section 2.1. Its length is divided into 13 sections called bays. Each bay has unique load-carrying hardware to allow payload attach points and numerous payload configurations.

With the payload bay doors open, the payload bay becomes an integral part of the facility to which it is exposed. This factor stresses the importance of facility management and the need for meeting the specified cleanliness criteria designated for the orbiter's mission. There are three levels of cleanliness, as seen in Table 2-I, which may be assigned to a mission.

4.2 Payload Bay Cleaning

In a generic flow, payload bay cleaning occurs in the OPF. Since every day payload bay operations in the OPF involve a high level of activity from both personnel and equipment, daily payload bay surface cleaning operations are performed if required. This operation involves vacuuming and solvent wipedown techniques performed by midbody technicians.

When a specific payload bay area is ready for closeout procedures, a preflight inspection is performed to verify a visibly clean (VC) level. Subsequent to this inspection and prior to payload installation or payload bay door closure for OPF rollout, a final cleanliness verification is performed.

For horizontally installed payload elements, the payload bay area which becomes inaccessible subsequent to payload installation will be cleaned. Prior to payload bay door closure in preparation for rollover, all accessible payload bay surfaces, including radiator panels, are inspected and cleaned to the mission-selected cleanliness level.

Since particle fallout is a function of activity level and surface exposure time, payload bay inspection and cleaning are performed as expediently as possible prior to payload bay door closure for rollout.

The payload bay cleaning procedure is a highly specialized sequence of events to achieve desired cleanliness levels on a variety of payload bay surface types.

Special cleaning techniques involving high grade clean room materials and equipment are used. Self-contained portable vacuum cleaners (Nilfisk GS-80) with HEPA filter exhaust units are used to provide clean air exhaust.

At the beginning of each final payload bay cleaning sequence in preparation for horizontal payload installation and/or payload bay door closure for OPF rollover, several preoperation setups are performed. Among these preoperations are: all applicable payload bay work is verified complete, all environmental parameters are verified to meet specified requirements, and unnecessary personnel are cleared from the payload bay surrounding area.

Each of the payload bay surface cleanliness levels available to the cargo community involves two separate tasks, a cleaning and an inspection verification. The methods and procedures for cleaning are identical; it is the inspection criteria which dictates the amount and extent of cleaning required to meet the Sensitive and Highly Sensitive levels.

Generic to all cleaning levels is the installation of an aft debris cover, with optional witness plates, on the $X_0$1307 bulkhead. This cover will effectively catch any debris during vertical orientation and rollout to the pad. The debris cover is not used for horizontally installed missions with no scheduled payload bay door opening at the pad. It also serves as a barometer of cleaning effectiveness in the OPF. To further evaluate the payload bay environment after cleaning and until payload bay door opening at the pad, an array of contamination monitors can be installed on the cover as a non-standard service.

The installation of a Space Station compatible airlock, in several of the Orbiters, has reduced the access for cleaning and inspection of the Beta Cloth payload bay liner located under the airlock. Customer concerns about the cleanliness of that portion of linear will be addressed on a case-by-case basis.

4.3 Payload Bay Monitoring

For particle fallout rate analysis, 37-mm gridded filter disks or silicon wafers are used. The disks are analyzed according to MIL-STD-1246 distribution and expressed as particles settled/ft^2/24 hours versus particle size. The wafer analysis is expressed in Percent Area Coverage (PAC).

For molecular contaminant measurement and analysis, one-square-foot stainless steel plates are used and analyzed gravimetrically for total nonvolatile residue.

The non Volatile Residue (NVR) is reported in mg/ft2. Surface cleanliness levels for nonvolatile residue (NVR), and the corresponding quantities (mg./0.1 m^2), are defined in Table A.1 of the Space Shuttle Contamination Control Requirements (SN-C-0005).

Ascent Conditions

5

5.1 Ascent Environment

The launch and ascent phase of the flight produces a significant dynamic environment. Particles present in the payload bay at launch can become excited because of energy provided by the vibro acoustic environment. This environment is particularly energetic during solid rocket booster (SRB) firing and ingestion of aeronoise through the payload bay vents (transonic phase). Excited particles can be transported from their original locations to other surfaces due to venting of the payload bay through vents in the lower walls and acceleration of the orbiter. Thus, a redistribution of particles may occur during launch and ascent.

There are three ports on each side of the payload bay as shown in Figure 5-1. Each vent contains a filter to inhibit entry of particulates into the payload bay (40 micrometers glass bead rating, 88 micrometers longest particle dimension). Table 5-I shows vent locations and sizes.

5.2 Data Collection

Particulate data have been collected by the cascade impactor flown as part of the Induced Environment Contamination Monitor (IECM). The IECM is a set of 10 instruments designed to acquire information on the payload bay environment. The results can be found in Update of Induced Environment Contamination Monitor Results, AIAA-83-2582-CP, in Space Shuttle Contamination Measurements from Flight STS-1 through STS-4, J. Spacecraft, Vol. 21, No. 3, May-June 1984, and in SS-2, -3, -4 Induced Environment Contamination Monitor (IECM) Summary Report, NASA TM-82524. The preliminary results from Spacelab-1 can be found in Induced Environment Contamination Monitor-Preliminary Results from the Spacelab 1 Flight, NASA TM-86461.

TABLE 5-I.- VENT LOCATIONS AND SIZES

	Payload bay outside ambient vents approximate point location				Payload bay lower midbody vents when liner is installed approximate point location			
Vent set (four vents/set)	X_0	Y_0	Z_0	Approx. area in.^{2}	X_0	Y_0	Z_0	Approx. area in.^{2}
3	765	± 105	385	140	704	± 93	382	380
5	996	± 105	385	140	1029	± 93	382	410
6	1128	± 105	385	140	1152	± 93	382	300

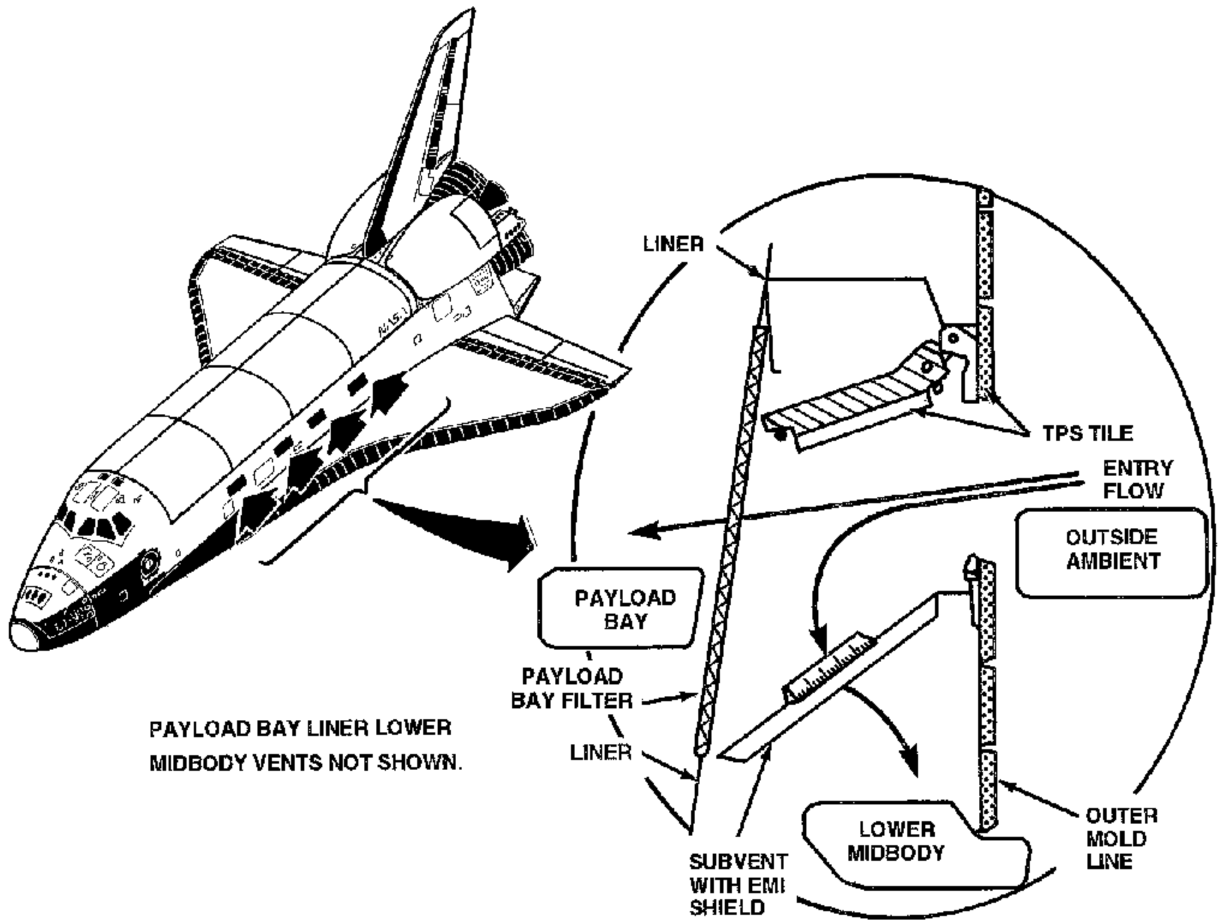

Figure 5-1.- Side wall vents.

5.3 Data Results

A summary of the data collected by this instrument is shown in Table 5-II. The data indicate that maximum particle counts usually occur within one minute after launch and decay thereafter. Results of the measurements taken on the Spacelab-1 mission indicate that there was insufficient particle deposition for detection.

Gases were collected by the IECM air sampler during ascent for postflight analysis. Table 5-III summarizes the results of these analyses. The quantity of volatile hydrocarbons present was very low and no hydrogen chloride (HCl), which would be present because of solid rocket plumes, was found.

The humidity monitor measured less than 1 percent relative humidity, reflecting the environment provided by the dry nitrogen gas purge prior to launch. Dewpoint was below the hygrometer's lower measurement limit of -6.7 degrees C.

Temperature-controlled quartz crystal microbalances (TQCMs) were used to measure mass deposition during ascent. Levels near 100 ng/cm^2(10A) were detected within the first minute after liftoff. These depositions rapidly dissipated, often below prelaunch levels.

Additional mass deposition measurements were made with the Interim Operational Contamination Monitor (IOCM) during STS-32 and as part of the Plume Impingement Contamination measurements (DTO 829) during STS-74.

Optical (253.7 nm) transmittance losses of 1 to 2 percent were detected This loss occurred during the time period from last ground measurement to first on-orbit measurement.

Overall, the ascent contamination environment does not appear to be too severe. Typically, contaminants will build up for the first minute after launch when the dynamic environment is most severe, and decay to low levels thereafter.

TABLE 5-II.- ASCENT PARTICLE MEASUREMENT SUMMARY

Particle size µm	Flight results from three missions (µg/m^3)
> 5	30 10 Nonfunctional
1 to 5	500 10 400
0.3 to 1	250 10 150

Table 5-III.- ASCENT AIR SAMPLE SUMMARY

Species	Detection method	Flight results
Volatile hydrocarbons*	Concentration on absorbent; postflight GC/MS analysis	50 ppm by weight 10 ppm by volume
Reaction HCL	Reaction with silver oxide/hydroxide surfaces	None detected to ppm sensitivity

* Covers C_9 to C_{24} range and uses $\underset{\sim}{}$ C_{12} as average molecular weight to obtain ppm by volume

On-orbit Conditions

6

6.1 Pressure

The pressure in the payload bay drops rapidly after the bay doors are opened on orbit. After an initial rapid drop, the pressure decays to near space ambient levels. The pressure decay occurs slowly because of gas densities resulting from outgassing, leakage, and other contaminant sources. Figure 6-1 shows payload bay pressure decay versus mission elapsed time.

Certain events, such as thruster firings and payload bay door closing can increase the payload bay pressure by several orders of magnitude as shown in Figure 6-1. Pressure effects because of thruster firings depend on thrusters used, length of time fired, and orbiter attitude, and are typically not as great as the special L2U-RCS test case shown where three engines fired for as long as 100 seconds. Pressures returned to near pretest levels within five minutes of termination. Rotating the payload bay from the wake to the ram orientation can also increase the pressure significantly, as shown in Figure 6-1. When the payload bay is in the direction of the velocity vector, the ramming ambient pressure in the payload bay is about two orders of magnitude higher than if no ramming occurred for altitudes in the range of 54 nautical miles.

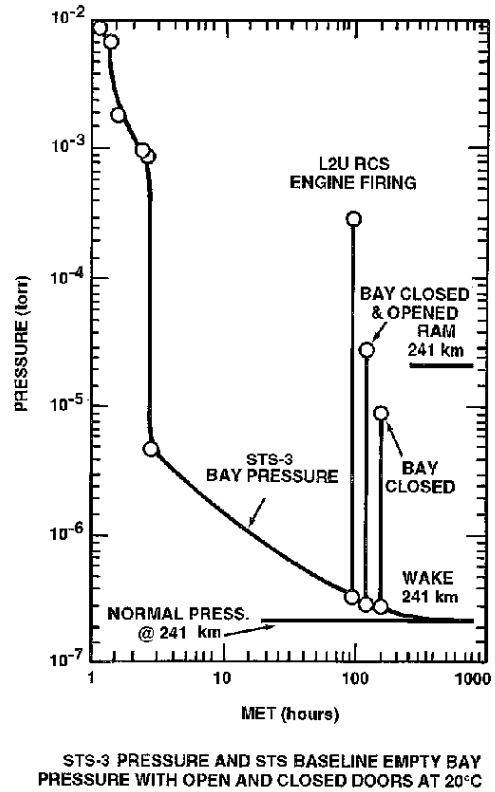

Figure 6-1.- Baseline payload bay pressure.

6.2 Particles and Gases Data Collection and Analysis

The Space Shuttle provides a unique environment for study and measurement without the restrictions imposed by the Earth's atmosphere; however, the orbiter has its own environment which can affect on-orbit measurements. It is important to understand this environment so that potential effects on payloads may be determined and appropriate actions taken.

Table 6-I lists contamination requirements and goals developed for the orbiter from the Contamination Requirements Definition Group (CRDG) report, and the Particles and Gases Contamination Panel (PGCP).

TABLE 6-I.- SUMMARY OF CONTAMINATION SPECIFICATION AND MEASUREMENT REQUIREMENTS ON-ORBIT

Contamination specification

Molecular column density less than:
10^{12} molecules/cm^2 for H_2O
10^{11} molecules/cm^2 for $H_2O + CO_2$
10^{13} molecules/cm^2 for $N_2 + O_2$
10^{10} molecules/cm^2 for all other species

Scattered/emission light background less than:

m_v = 20th magnitude star per square arc second in the ultraviolet region

$3.5X10^{-11}$W/m^2/sr/nm,λ = 155 nm	
$1.9X10^{-11}$W/m^2/sr/nm,λ = 191 nm	
$1.3X10^{-11}$W/m^2/sr/nm,λ = 246 nm	In
$5.9X10^{-11}$W/m^2/sr/nm,λ = 298 nm	ultraviolet
$1.0X10^{-10}$W/m^2/sr/nm,λ = 332 nm	and visible
$2.5X10^{-10}$W/m^2/sr/nm,λ = 425 nm	at 90°
$2.0X10^{-10}$W/m^2/sr/nm,λ = 550 nm	Sun angle
$1.0X10^{-10}$W/m^2/sr/nm,λ = 1000 nm	
10^{-11}W/m^2/m^2/nm, $\lambda \geq 30$ µm	
10^{-10}W/m^2/sr/nm, $\lambda < 30$ µm	

Fewer than one particle larger than -5 µm per orbit in 1.5 X 10^{-5} sr field of view within 5 km
Molecular return flux (RF) such that:

- RF <10^{12} molecules/cm^2/s for H_2O
- Deposition < 10^{-7} g/cm^2/s for H_2O
  0.1 sr on 300 K surface at 400 km altitude
- Deposition < 10^{-5} g/cm^2/30 days
  2π sr on 300 K surface
- Deposition < 10^{-5} g/cm^2/30 days
  0.1 sr on 20 K surface at 400 km altitude
- Degradation of optics < 1%

The primary contamination measurements taken aboard the orbiter to date were acquired by the IECM, which provided most of the data presented. Missions flown with a virtually empty payload bay generally represent the environment of the orbiter. Missions flown with a full payload bay may produce a more severe environment due to payload contributions.

NASA has developed the Shuttle/Payload Contamination Evaluation (SPACE-II) model to predict on-orbit induced molecular contamination levels. SPACE-II can predict direct flux and deposition, return flux (from ambient and self-scattering) and deposition, and molecular column density. Contamination sources considered by the model include early desorption, nonmetallic materials outgassing, thrusters, water dumps and vents, and crew cabin leakage.

SPACE-II utilizes geometric math models and surface viewfactors developed from the Thermal Radiation Analysis System (TRASYS) program. TRASYS uses simple shapes (e.g., rectangles and cylinders) to define complex configurations, then calculates mass transport factors (the percentage of mass emitted by a Lambertian source that will impinge upon another surface) and geometrical relationships for all the surfaces. Mass transport factors are used by SPACE-II to calculate contaminant transport for Lambertian sources, such as early desorption and nonmetallic materials outgassing, and to determine the effects of surface shadowing and reflection. SPACE-II uses the geometrical relationships in the mathematical expressions utilized for such sources as thrusters and vents.

Mass transport data files for the orbiter configurations have been precalculated and are available as permanent data files. Modifications or other configurations can be developed using TRASYS. Thermal data (used to determine material mass loss rates and deposition rates) for a hot and a cold thermal profile and mass loss rates normalized to 100 degrees C are also available for the orbiter configuration. Data for other configurations can be easily developed.

Contamination analyses using SPACE-II can be performed by NASA as a non-standard service. Once SPACE-II predicts molecular contamination levels, the levels must be checked against payload sensitivities to determine any effects. Design or operational changes may then be made to minimize the effects.

On-orbit Contamination Sources and Effects

7

7.1 General

In this section, the Space Shuttle sources of contamination are described. Data are provided on the location and characteristics of each source, including the constituents, mass rate, typical operation, and molecular velocity. Information is also included on decay rates for the contaminants and their deposition potential for the payload bay. Figure 7-1 and Table 7-I show the major orbiter contamination source characteristics.

7.2 Leakage

Atmospheric gases may leak through seals in pressurized spacecraft volumes. Orbiter leakage locations are considered to be concentrated at the forward payload bay bulkhead as shown in Figure 7-1. Orbiter leakage characteristics and constituents are listed in Tables 7-I and 7-II, respectively. Pressurized payloads may also leak into the payload bay. The quantity and species of the contaminants depends on the specific payload configuration.

Orbiter leakage results in a continuous contamination source emanating from the forward bulkhead. Pressurized payload leakage will also result in a continuous source concentrated around the pressurized volume. Transport of the gases is Lambertian or diffuse in nature, indicating that the gases will disperse with a cosine distribution. Contaminants will travel in a direct line-of-sight to other parts of the payload bay to be deposited or reflected to other payload bay surfaces. Contaminants may also travel out of the payload bay envelope and be diffused into the environment or returned into the payload bay because of scattering with the ambient environment.

7.3 Water Dumps/Vents

During orbital operations, dumping of potable water occurs on a thermal demand basis. Normally, all excess fuel cell water is automatically used by the flash evaporator system (FES) to reject heat. Location of water vents and FES are shown in Figure 7-1. The characteristics of this source are listed in Table 7-I. The FES operates in 200 millisecond pulses and an on-off pulsing frequency variable between 0 and 4 Hertz. The specific frequency is determined by the heat rejection requirements. The water vent operates as required and is normally scheduled to be compatible with payload requirements.

The water vents and the flash evaporator do not eject waste water directly into the payload bay; however, water dumps can produce numerous ice particles. Typically, the ice particle population decays quickly (15 to 20 minutes) and the effluent can be directed so that recontact with the orbiter is precluded.

7.4 Thrusters

The thrusters used by the orbiter to control on-orbit maneuvers are the 870-pound Reaction Control System (RCS) thrusters and the 25-pound Vernier Reaction Control System (VRCS) thrusters. The RCS thrusters are used for major vehicle pitch, yaw, roll, and translation maneuvers. The VRCS thrusters are utilized for fine corrections. Both systems use hypergolics with monomethyl hydrazine (MMH) as the fuel and nitrogen tetroxide (N_2O_4) as the oxidizer. One forward thruster module is in the nose and two aft thruster subsystems are in the pods, as shown in Figure 7-1. There are no upward firing VRCS thrusters.

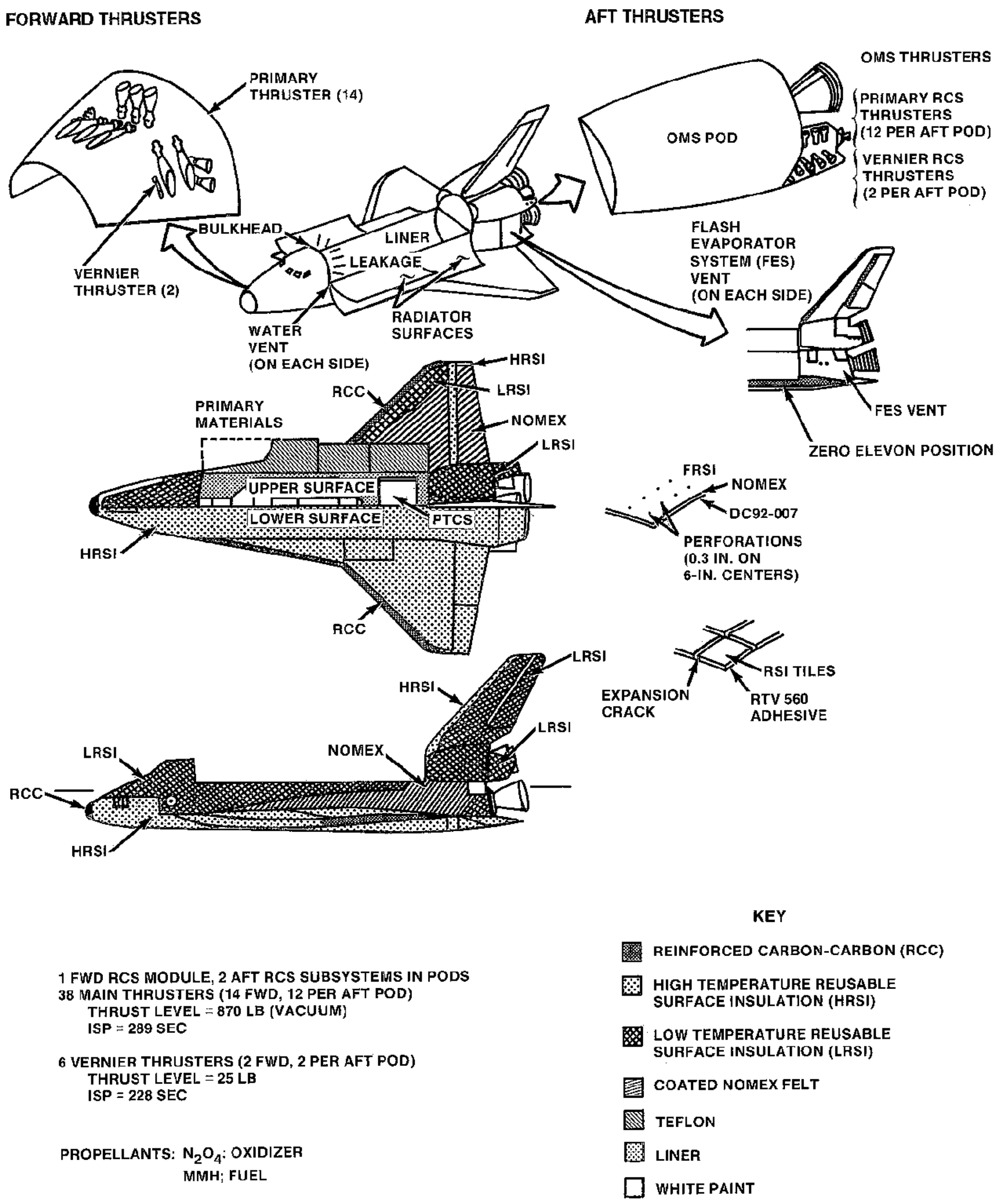

Figure 7-1.- Space Shuttle contamination sources.

TABLE 7-I.- MAJOR ON-ORBIT CONTAMINANT SOURCE SUMMARY

Source	Duration/ frequency	Flowrate	Constituents	Velocity	Size parameter
Cabin atmosphere leakage and venting	Continuous	3.18 kg/day; design limit may be considerably lower	See Table 7-II	$129 \sqrt{\frac{T}{M}}$ m / sec M = Molecular wt T = Ambient temp, °K	Average molecular wt = 29
Supply nozzle dumps and waste water dumps	As required	100-150 lbm/hr	50 to 95 percent water mixed with inorganic salts	100 to 200 m/s	Predominately Molecular wt = 18
Fuel Cell Purges	As required	0.9 lbm/hr hydrogen 3.3 lbm/hr oxygen	Hydrogen Oxygen	TBD	Molecular
Evaporator(2) water dump	As required	13.6 kg/hr total 1.8 lb/min	Water	1012 m/sec	Molecular wt = 18
RCS engines	As required	1419.8g/ sec/engine	See Table 7-III	3505 m/sec	Molecular
Vernier RCS engines	As required	40.8g/ sec/engine	See Table 7-III	3505 m/sec	Molecular
Early desorption/ offgassing	Estimated decay e = t/τ t = time/(hr) τ = 18 hr		Water light gases volatiles (see Table 7-IV)	$129 \sqrt{\frac{T}{M}}$ m / sec T = Surface temp °K M = Molecular wt	Average molecular wt = 18
Outgassing	Continuous	Dependent on materials, temperature, and time on orbit	Hydrocarbon chain fragments, RTV's, etc.	$129 \sqrt{\frac{T}{M}}$ m / sec T = Surface temp °K M = Molecular wt	Average molecular wt = 100

Characteristics of the thrusters are listed in Table 7-I. Contaminant characteristics change as the effluents expand through the nozzle and disperse through space. Average plume constituents after the plume has expanded from the thrusters are listed in Table 7-II. The RCS thrusters operate as required for orbiter maneuvers with pulsing or steady-state burns lasting nominally from 80 milliseconds to 150 seconds. The VRCS thrusters also operate on an as-required basis with 80 millisecond pulses at 12.5 Hertz maximum frequency.

TABLE 7-II.- AVERAGE CONTAMINANT SPECIES AND MOLE FRACTIONS FOR RCS AND VRCS THRUSTERS

Contaminant species	Mole fraction
H_2O	0.328
N_2	0.306
CO_2	0.036
O_2	0.0004
CO	0.134
H_2	0.17
H	0.015
$MMH\text{-}NO_3$*	0.002

* Represents a group of unreacted and partially reacted thruster fuel products

The thrusters have been oriented to eliminate firing or reflection directly into the payload bay. Thruster contaminants can only be transported into the payload bay because of ambient interactions and backscatter of the plume. Instruments in the payload bay may have lines-of-sight through transient contaminant above the payload bay envelope caused by upward firing thrusters. Because of their velocity, thruster effluents will typically dissipate within a second after thruster firing. Satellites launched from or captured by the Space Shuttle may be unavoidably impinged upon by thruster effluents. Figure 7-2 shows plume contours for the forward/aft and upward-firing RCS engines.

7.5 Early Desorption of Low Molecular Weight Materials

On Earth, nonmetallic materials on the orbiter and payloads will adsorb gases present in the atmosphere. The gases will consequently desorb from the surfaces upon exposure to space vacuum after launch. This is a short term process known as early desorption. The characteristics of this contamination source are listed in Tables 7-I and 7-III. Contaminant characteristics depend upon prelaunch conditions. For instance, rain showers while the orbiter is on the pad will increase the amount of water absorbed.

Early desorption occurs from all materials so that contaminants are either produced from or have a direct path to almost all surfaces in the payload bay. Fortunately, early desorption is a short-term contaminant source having an exponential decay rate with a time constant of about 18 hours. After approximately one day on orbit, contaminant levels will have dropped to minimal amounts.

7.6 Outgassing

Gases are released when materials are exposed to the vacuum environment of space. This process, known as outgassing, is caused by the bulk mass loss of the material resulting in the release of fairly large chain fragments (with an average molecular weight of 100 atomic mass units [amu]) .

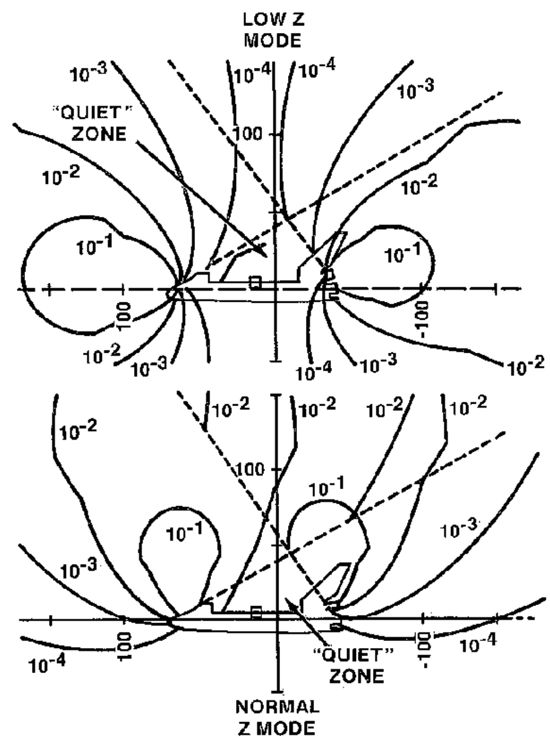

Figure 7-2.- Forward/aft and upward firing thruster plumes.

TABLE 7-III.- AVERAGE CONTAMINANT SPECIES AND MOLE FRACTIONS FOR EARLY DESORPTION/OFFGASSING PRODUCTS

Contaminant species	Mole fraction
H_2O	0.57
N_2	0.23
CO_2	0.12
O_2	0.08

Outgassing source characteristics are listed in Table 7-I. The rate at which a material outgasses and the molecules outgassed depend on the characteristics of the particular material. Outgassing allowables for materials used in the midbody and selected other areas of the orbiter are controlled as discussed in Section 2.

Outgassing allowables for a payload are controlled by the payload-unique interface control document

(ICD) with the payload provider. The locations of the major exterior orbiter materials are shown in Figure 7-1.

The best way to minimize outgassing is selection of materials with the lowest possible outgassing rates. Vacuum chamber exposure, particularly thermovacuum exposure, can decrease the outgassing rate of unacceptable materials to render them acceptable. However, because of the time involved, proper material selection is the best alternative and should always be used in the design of new hardware. Materials on an orbiter that has flown a number of missions will have a lower outgassing rate than similar materials with less vacuum exposure, thereby reducing the overall rate of contaminant production.

7.7 Particle Production

Materials used in the payload bay are selected with minimum particle sloughing as a consideration. The passive optical sample array (POSA) on STS-1 and the passive sample arrays (PSAs) on subsequent flights indicated that surface fallout was in the range of 10^3 particles per square centimeter. About 30 percent of these were in the 2 to 4 micrometers range, with the overwhelming majority below 10 micrometers. About 3 percent were above 24 micrometers.

Optical tests were performed on passive sample array optical materials as well as payloads that contain sensors and optics sensitive to film and particle contamination. These tests have not demonstrated significant degradation of performance attributable to induced contamination from the orbiter. The degradation of performance is in the range of 1 to 2 percent.

7.8 Macrodebris

There is photographic evidence of loose objects in the payload bay at payload bay door opening. These are most likely lost residuals of vehicle manufacture, rework, or repair. These could be a washer, a screw, a snip of spot tie material, a flake of cut insulation material, etc. These objects generally exit the payload bay and are rarely seen after 15 hours of mission-elapsed time. There has not been an incident as a result of macrodebris and few objects have been noted in recent flights.

7.9 Flux Deposition and Effects

Flux of contaminant molecules to a surface can occur in two ways: either directly from another surface, or due to contaminant molecules from a surface interacting with ambient or other molecules and being scattered to a surface. These processes are commonly known as direct flux and return flux, respectively. Deposition of contaminants on a surface is a complex phenomenon and depends on surface temperature, sublimation rates, contaminant type, surface type, etc. However, only high molecular weight gases, such as outgassing products and unburned thruster fuel, will deposit on typical surfaces. All gases can deposit on cryogenically-cooled surfaces, if the temperature is low enough.

Analysis of results from the PSA and the Optical Effects Module flown as part of the IECM show no significant evidence of molecular film deposition. TQCM measurements from the IECM on three flights are listed in Table 7-IV. As shown in this table, mass accumulation depends greatly upon the orientation of the sensor. The differences in mass accumulation rates detected during the missions are probably due to several factors including payload complements and vehicle attitude.

Results from the Spacelab-1 mission indicate significantly greater mass accumulation, probably due to the large payload, location of sensors, and unacceptable materials.

Large rapid increases in mass accumulation can result from particular mission events. Figure 7-3 shows the mass accumulation recorded during an abnormally extensive planned RCS test firing. This effect is caused primarily by the return flux, since no thrusters fire into the bay, and will depend on vehicle attitude relative to the velocity vector.

Cryogenically-cooled quartz crystal microbalance (CQCM) measurements from three missions are listed in Table 7-V. The CQCM has a nearly 2π sr view to space. The temperature of the CQCM is not controlled but determined by the spacecraft attitude and varied from -101 to 35 degrees C. During the initial hours of each mission, the CQCM indicated mass losses, then a gradual increase throughout the on-orbit period.

Molecular return flux was determined from on-orbit measurements using a 2 to 150 amu quadrupole mass spectrometer. The gases observed by the mass spectrometer have been generally those with molecular weight below 50 amu. The mass spectrometer was configured to spend half its time on mass 18 since water is a significant contaminant. Table 7-VI lists the return flux determined for water.

Measurements taken to date indicate deposition is typically within the range of the requirements and goals listed in Table 7-I for quiescent periods. Contamination levels from certain events, such as thruster firings, exceed the limits in Table 7-VI momentarily.

Direct and return flux and deposition resulting from orbiter and payload contaminant sources can be calculated using SPACE-II. Predictions to date have agreed well with flight measurements. Once the contamination levels have been predicted, the levels must be compared with the sensitivity of the instrument to determine any potential problems which may require design or operational changes.

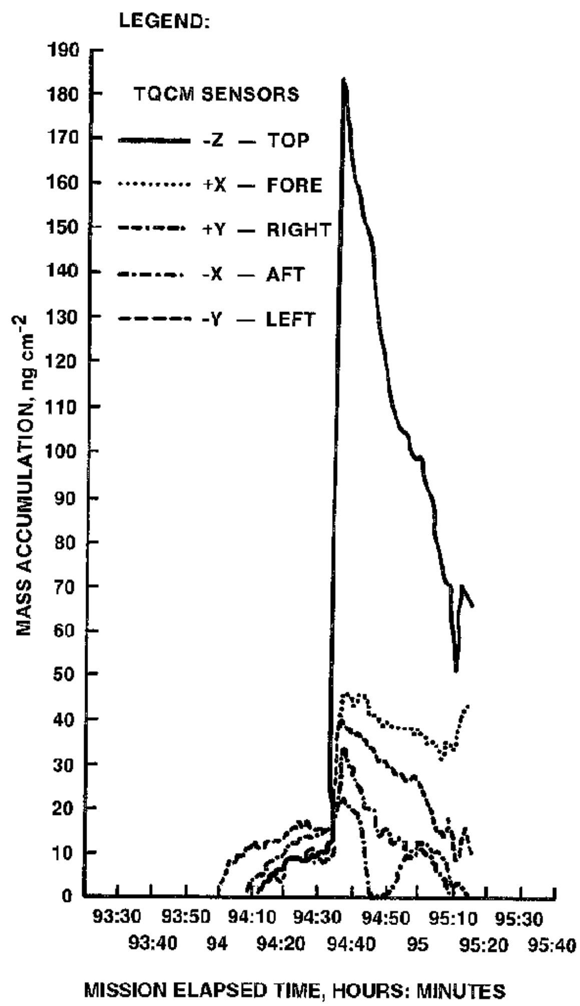

Figure 7-3.- Mass accumulation during an L2U engine firing.

TABLE 7-IV.- TQCM AVERAGE MASS ACCUMULATION RATES (ng/cm^2/hr)
WITH MINIMUM AND MAXIMUM RATES DETECTED DURING THREE MISSIONS

Mission	Temp (°C) \ Sensor*	-X			+X			-Y			+Y			-Z		
		Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max
STS-2	30**	5	11	70	25	33	45	-15	-2	10	9	21	44		Inoperative	
	0	2	9	15	24	35	52	-8	-2	8	10	15	21			
	-30	-4	13	25	44	57	74	3	22	35	18	27	34			
	-60	-3	20	30	31	78	191	-41	40	155	70	130	218			
STS-3	30	5	12	17	10	32	70	-20	0	2	-10	16		-15	5	20
	0	5	38	125	20	60	105	0	19	50	-10	28	80	5	22	35
	-30	0	14	60	5	44	65	-5	9	20	5	16	25	0	11	25
	-60	5	38	175	50	75	105	10	21	35	10	32	75	0	14	25
STS-4	30	5	6	10	-25	-2	5	-5	3	20	-5	1	15	0	5	10
	0	-5	9	50	0	12	50	0	9	20	-5	4	20	0	6	20
	-30	-15	22	90	-20	11	115	0	19	50	-15	3	25	-10	4	10
	-60	0	19	40	-25	9	55	-20	3	30	-15	17	95	-20	14	45

* -X Aft (toward Shuttle tail)
+X Forward
-Y Left
+Y Right
-Z Out of payload bay

** Large first 30°C collection period excursions on STS-2 omitted (-347 to +126 ng/cm^2/hr)

TABLE 7-V.- CQCM ON-ORBIT MASS ACCUMULATION SUMMARY FOR THREE MISSIONS

	Mass accumulation rate ($ng/cm^2/hr$)	Total accumulation (ng/cm^2)	Accumulation period (hr)
STS-2	5	246	49.3
STS-3	2	376	188
STS-4	-1	-162	162

TABLE 7-VI.- RETURN FLUX FOR WATER FOR THREE MISSIONS

	Return flux (molecules/cm^2/sr/sec) Initial *	Final
STS-2	1.3×10^{14}	1.8×10^{13}
STS-3	9.8×10^{11}	2.6×10^{11}
STS-4	2.1×10^{14}	6.6×10^{12}

*Except for RCS firings and payload bay door closing.

7.10 Column Density

Column density is the density of gaseous molecules integrated over a line-of-sight and can be expressed as either mass or number of molecules per square centimeter. This quantity has never been directly measured on orbit, but has been calculated using SPACE-II, based upon return flux measurements. Column densities calculated for water are listed in Table 7-VII.

The requirement for water column density is less than 1×10^{12} molecules/cm^2. This requirement was met on one of the flights but was exceeded on the other two. The high water column density subsequently decayed and was found generally acceptable after 48 hours. The high concentrations are thought to be due to water vapor from the tiles of the thermal protection system which were exposed to rain prior to launch. It is expected that these excessive initial desorption rates will not recur on later flights because of improved waterproofing techniques for the orbiter thermal protection system.

Column densities for other gases will have to be measured more directly using optical instruments. Densities for such sources as outgassing and early desorption have been predicted using SPACE-II and fall within the requirements and goals listed in Table 7-I for quiescent periods.

If an instrument is sensitive to these levels of contamination a more complete analysis can be performed as a non-standard service using SPACE-II. SPACE-II can predict column densities from all orbiter or payload contamination sources. These levels must then be compared with the sensitivity of the instrument. The payload designer is advised that potential problems arising from this analysis may require solutions involving design or operational timeline changes.

Table 7-VII.- CALCULATED COLUMN DENSITIES FOR WATER FOR THREE MISSIONS

	Column density (molecules/cm^2) Initial *	Final
STS-2	2.0×10^{13}	2.7×10^{12}
STS-3	1.5×10^{11}	4.0×10^{10}
STS-4	3.2×10^{13}	1.0×10^{12}

*Except for RCS firings and payload bay door closing.

7.11 Particle Density Effects

The particulate environment of the orbiter is of concern because particles, which were present prior to launch or generated by orbiter activities, may deposit on sensitive surfaces or obscure the field-of-view of an instrument. Currently, flight data have been limited to photographic images of particles in the vicinity of the payload bay.

Particle images and counts have been made by the camera photometer flown as part of the IECM. Useful images can only be made from this instrument when the orbiter is sunlit and the camera and the payload bay face a dark stellar or terrestrial background. This instrument can detect particles as small as 25 µm within 20 meters of the orbiter. Larger particles can be detected at greater distances.

The camera photometer has been used on various flights to gain flight particulate data. Figure 7-4 shows the average time history, as a function of the percentage of the total number of frames that could show contamination for particle detection. Figure 7-5 is a similar plot for the Spacelab-1 mission. In all cases, high levels of particulates were observed early in the flight. The origin of these particles is unknown, but it is felt that they are caused by the release and redistribution of particles that were present on the surfaces prior to launch. These particles generally are swept away from the orbiter because of atmospheric drag effects. Particle levels drop to low levels within the first 15 to 20 hours on orbit with a general decay for the first 48 hours. Figure 7-5 shows a high particulate level after 48 hours perhaps because of the complexity of the Spacelab-1 payload as compared to the earlier flights.

Water dumps have produced large quantities of particles exceeding 100 counts per frame. Protection of sensitive surfaces may be required for the first 15 minutes after water dumps with normal operation resumed within 25 minutes. Particle releases have not been detected from operation of the flash evaporator system.

In general, particulate levels early in the mission could affect equipment (such as star tracker) performance if particles occur in the field-of-view. However, after 15 to 17 hours on-orbit background brightness levels in the visible spectrum are not detectable except during water dumps. A telescope with a one degree field-of-view would detect particles at an average of one particle (equivalent diameter greater than 25 µm) every two orbits. Degradation of optical samples on the IECM has generally been too small to provide useful particle effects data.

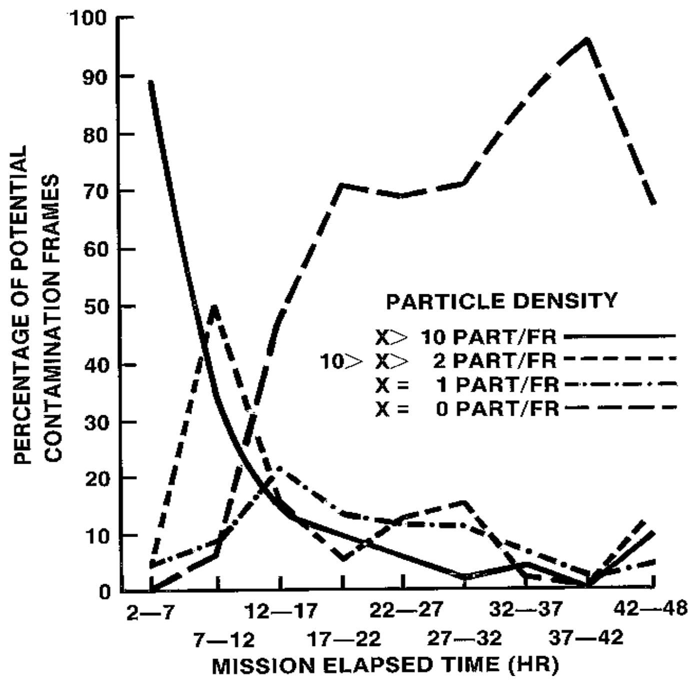

Figure 7-4.- Particle densities.

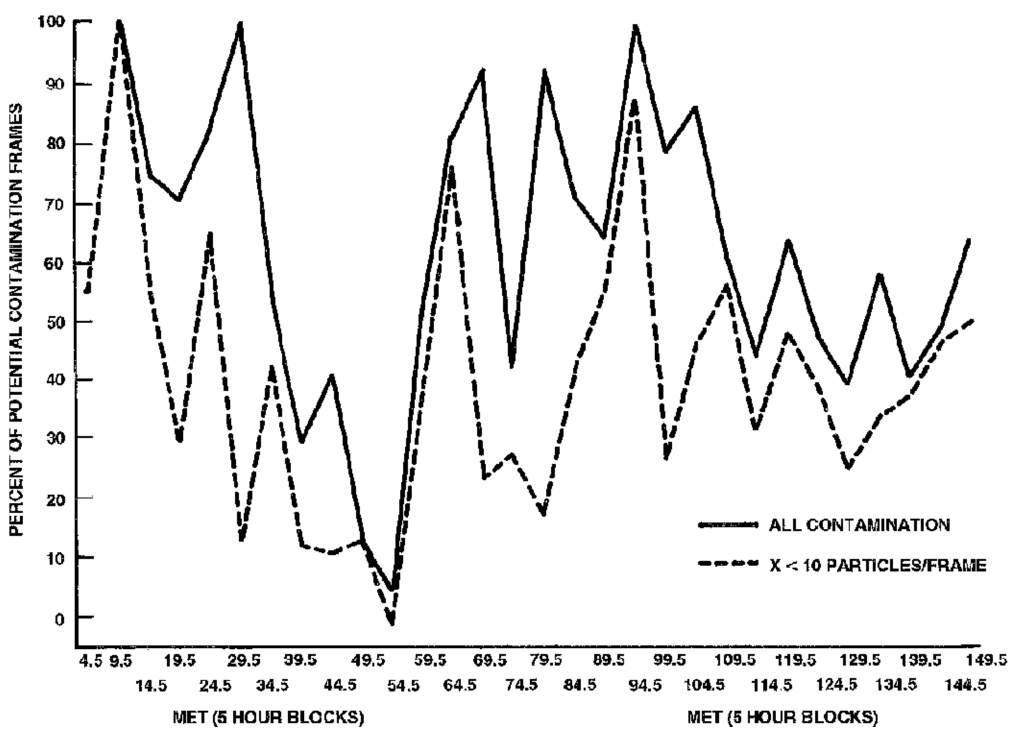

Figure 7-5.- Particle densities for the Spacelab-1 mission.

7.12 Particle Protection Techniques

If it is determined that an experiment may be sensitive to the particle levels expected, protection techniques may be appropriate. Some useful techniques include:

1. Shrouds (removed shortly before launch)
2. Special cleaning and inspection procedures for the payload and payload bay (Sensitive and Highly Sensitive classifications per, SN-C-0005)
3. Active covers (openable, or openable and closable on orbit)
4. Experiments scheduled to avoid contamination events; *e.g.*, scheduled late in mission, during unilluminated times, or during engine/vent suppression.
5. Experiments designed to tolerate a certain amount of degradation

The first two protection techniques for flight particle protection are actually ground activities. The techniques are included here because ground activities establish part of the particle reservoir for flight, and the effects of ground particles are usually most critical during orbital phases. Covering the critical surface itself can minimize the background level at the time of launch. The second technique serves to decrease the total payload bay particle population, and is more effective at controlling launch particles.

Active covers give experimenters the greatest control over experiment surface cleanliness. However, the use of such a device may greatly complicate hardware and operation design, particularly if crew or ground activation is required. The mechanism also provides another possible failure point if the cover does not deploy.

Experiment scheduling is probably the most effective technique for dealing with orbital particles crossing fields-of-view. Some experiments, however, may not have the flexibility to select operation times. Also, the camera-photometer data of the Spacelab-1 mission does not show a steady decrease in particles with mission time. It is possible that this will also be the case in other habitable module missions, with a large number of experiments located in the payload bay. The length of time that engines and vents may be inhibited is limited, which also interferes with a scheduling approach to particle protection.

The final approach listed for protection from orbital particles is to include greater tolerances in the design of hardware elements. For example, if degradation of a thermal control surface caused by particles is anticipated, the surface could be sized to allow it to meet its requirements even in a degraded state.

7.13 Space Glow

A diffuse near-field glow phenomenon has been observed above spacecraft surfaces subjected to the impact of atmospheric species as the spacecraft travels through the low-Earth orbital atmosphere (Figure 7-6). This phenomenon results from interactions between the ambient atmosphere and the spacecraft surfaces, or in some instances between the ambient environment and the induced environment generated by the spacecraft. Although sufficient data do not exist to fully understand the phenomenon, a number of theories have been proposed which could account for the glow. These include: (1) gas phase collisions (during quiescent periods, thruster firings and water dumps), (2) surface-aided chemiluminescence reactions with adsorbates on orbiter surfaces, and (3) surface bulk reactions with the atomic oxygen environment leading to material loss or compositional changes. The following data are the best available to describe the effects of this phenomenon.

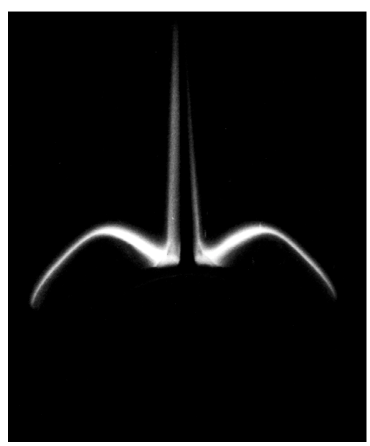

Figure 7-6.- Vehicle glow on OMS pods.

1. The glow has been spectrally measured in the ultraviolet, visible, and infrared. Emissions due to electronically excited molecular nitrogen have been observed in the ultraviolet. A broad continuum is present in the visible region due to nitrogen dioxide. In the infrared, emissions are observed from 0.7 - 5.3 μm and are attributable primarily to nitric oxide, ionized nitric oxide, and hydroxyl.

2. The glow intensity is dependent upon the surface orientation to the velocity vector; however, the relationship is not directly cosine and in the infrared exhibits a cosine squared dependency.

3. The glow intensity viewed normal to the surface on STS-9 was calculated as 3. 88 R/A. (R = Rayleigh (1R = 10^6 photons/cm^2-sec)). The glow intensity normalized for normal incidence of the velocity vector gives an equivalent intensity of 4.3 R/A.

4. The glow intensity of STS-41D at 6300A normalized to the NASA data resulted in an intensity of 9.7 R/A. Infrared measurements from STS-39 and STS-62 show quiescent glow emission intensities on the order of 10^{-9} W/cm^2 sr μm (Noise Equivalent Spectral Radiance) and that during thruster firings the intensities are enhanced by a factor of ten with resultant changes in the spectral distributions.

5. The exponential folding distance of the glow above spacecraft surfaces appears to be 20 centimeters.

6. Within the altitude regimes of the orbiter, the glow intensity varies as a function of the atomic oxygen density.

7. Glow intensity has been observed to depend on the type of material and, therefore, on some material property. The spatial extent, however, appears to be the same for all materials. Glow intensities relative to different materials are shown in Table 7-VIII.

TABLE 7-VIII.- MATERIAL GLOW VALUES

Material	Glow Value (1=least, 9=most)
M_gF_2 (Magnesium fluoride)	8
Z306 (Polyurethane coating)	6
Z302 Overcoated with silicon	9
Z302 (Polyurethane coating)	7
Polyethylene	1
401-C10 (Black polyester)	2
Carbon cloth	4
Chemical conversion film	5
Anodized aluminum	3

8. The difference in glow intensity above various materials is not proportional to material erosion. For example, some organic materials, such as black Chemglaze paint, glowed the brightest, yet suffered no detectable mass loss on orbit.

   By contrast, polyethylene, which is one of the most reactive materials, glowed the least.

9. Emissivity characteristics of the material samples along with the thermal capacitance may produce variations in the glow intensity. Cooler surfaces appear to produce a more intense glow, as shown in Figure 7-7.

10. During STS-39, nitric oxide gas was released into the payload bay while the orbiter was in a bay-to-ram attitude. At the start of the release the visible glow was significantly enhanced. At the end of the gas release the glow intensity decreased with two different decay times. A fast decay was attributable to gas phase interactions while a slower decay time was due to surface mediated reactions. During STS-62, molecular nitrogen was released into the payload bay while the orbiter was in a bay-to-ram attitude. The nitrogen release extinguished the existing quiescent glow on all nearby surfaces. When the gas was turned off the glow came back. This was observed in the visible and infrared.

Numerous experiments are planned so that the glow process may be understood and approaches developed to minimize its effects.

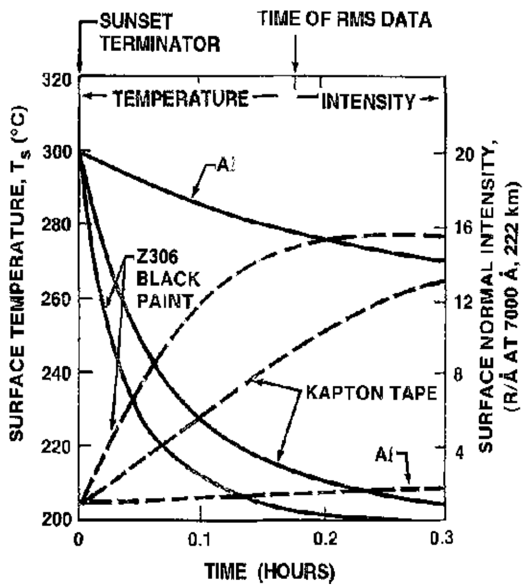

Figure 7-7.- Vehicle glow as a function of material temperature.

A short-term effect is also produced by operation of the orbiter's attitude control thrusters. The effluent clouds produced during thruster operations contain abundant amounts of H_2O, N_2, CO, and H_2 and minor amounts of CO_2, O_2, H, and MMH-NO_3. It is suspected that visible glow emissions arise as atomic oxygen within the atmosphere atom exchanges with N_2 molecules to form vibrationally excited NO and N within the thruster cloud. This glow is widespread and can fill most of the sky. It is strongest in the red region of the emission spectrum. Although they are very bright, these thruster glow effects last only for a few seconds.

7.14 Atomic Oxygen Surface Interactions

As the orbiter travels in low Earth orbit, it undergoes energetic collisions with the ambient atmosphere. These collisions have resulted in rapid oxidation and surface recession of a number of materials exposed to the ambient environment. Observations have shown a loss of surface gloss, an apparent aging of painted surfaces, and film thickness degradation. Atomic oxygen, produced by photo-disassociation of molecular oxygen in the upper atmosphere, is the predominant species in low Earth orbit and has been proposed as the cause of the material recession process. In addition to being highly chemically reactive, the atomic oxygen atoms have a high kinetic energy (> 5 eV) relative to the spacecraft as a result of its orbital velocity and can have a flux as high as 10^{15} atoms/cm^2-sec. This can result in thickness losses for organic compounds as high as 6 μm/day during periods of high solar activity at moderate altitudes.

The quantity of erosion depends upon the atomic oxygen fluence and the reaction efficiency of the particular material. Atomic oxygen fluence is the flux of atomic oxygen atoms intercepting the surface integrated over the time in which the surface is exposed to the ambient velocity vector. The flux depends upon the atomic oxygen density which, in turn, depends on such things as vehicle altitude, orbital inclination, attitude, and solar/ geomagnetic activity. Reaction efficiency, a quantitative factor for reaction characterization, is derived by normalizing the material thickness loss to the atomic oxygen fluence and is given in units of cm^3/atom. The reaction efficiency of a material depends on its particular chemical structure and consequently must be determined individually for each material.

A number of material samples have been flown aboard the orbiter in an attempt to understand the erosion process and to quantify its effects on various materials. The general conclusions drawn from these experiments are:

1. Unfilled organic materials containing only C, H, O, N, and S react with approximately the same reaction efficiency ($2\text{-}4 \times 10^{-24}$ cm^3/atom).

2. Prefluorinated carbon-based polymers and silicones have lower reaction efficiencies by a factor of 10 or more than organics.

3. Filled or composite materials have reaction efficiencies that are strongly dependent upon the characteristics of the fillers.

4. Metals, except for silver, carbon, and osmium, do not show macroscopic changes. Microscopic changes, however, have been observed and should be investigated for systems very sensitive to surface properties. Silver and osmium react rapidly and are

generally considered unacceptable for use in uncoated applications.

5. Magnesium fluoride and oxides in various forms show good stability.

Table 7-IX lists reaction efficiencies derived for a number of typical spacecraft materials.

TABLE 7-IX.- REACTION EFFICIENCIES OF SELECTED MATERIALS WITH ATOMIC OXYGEN IN LOW EARTH ORBIT

Material	Reaction efficiency (cm^3/atom)
Kapton	3×10^{-24}
Mylar	3.4
Tedlar	3.2
Polyethylene	3.7
Polysulfone	2.4
Graphite/epoxy	
1034C	2.1
5208/T300	2.6
Epoxy	1.7
Polystyrene	1.7
Polybenzimidazole	1.5
25% Polysiloxane/45% polyimide	0.3
Polyester 7% polysilane/ 93% polyimide	0.6
Polyester	Heavily attacked
Polyester with antioxidant	Heavily attacked
Silicones	
RTV-560	0.2*
DC6-1104	0.2*
T-650	0.2*
DC1-2577	0.2*
Black paint Z306	0.3-0.4*
White paint A276	0.3-0.4*
Black paint Z302	2.03*
Perfluorinated polymers	
Teflon, TFE	EO .05
Teflon, FEP	EO .05
Carbon (various forms)	0.9-1.7
Silver (various forms)	Heavily attacked
Osmium	0.026

*Units of mg/cm^2. Loss is assumed to occur in early part of exposure; therefore, no assessment of efficiency can be made.

Descent Conditions

8

Deceleration and repressurization of the payload bay during descent can disperse particles concentrated on the vent filters and located on surfaces throughout the bay. As during ascent, particulate measurement during descent has been limited to the measurements made by the cascade impactor on the IECM and has been inconclusive. Table 8-I lists the particle measurements for three missions. The data indicate that the particulate environment during descent should have minimal impact on payloads.

Gas samples were collected by the IECM air sampler for postflight analysis. Table 8-II summarizes the results of these analyses. The quantity of volatile hydrocarbons detected was very low.

TABLE 8-I.- DESCENT PARTICLE MEASUREMENT SUMMARY

Particle size µm	Flight results (µg/m^3)
>5	10 10 20
1 to 5	250 10 10
0.3 to 1	125 10 NF*

*NF - Nonfunctional

Nitrogen compounds, caused by RCS and auxiliary propulsion unit (APU) exhaust product ingestion into the payload bay, were not detected.

Relative humidity during descent ranged from 15 to 25 percent. Air temperature in the payload bay was 10 to 20 degrees C.

TQCMs were used to measure deposition during descent. Levels on most of the sensors rose steadily to a worst case of approximately 370 ng/cm^2 for a +X sensor. Deposition depended upon sensor location and axis. The -Y sensors decreased in weight during descent.

Optical (253 nm) transmittance losses of one percent were detected. Unfortunately, this loss covered not only descent but also landing, ferry flight, and deintegration, a period of about four weeks.

TABLE 8-II.- DESCENT AIR SAMPLE SUMMARY

Species	Detection method	Flight results
Reactives NO, NO_2, NH_3	Reaction with rutheniumtrichloride surfaces	None detected to ppm sensitivity
Volatile hydrocarbons*	Concentration on absorbent; postflight GC/MS analysis	20 ppm by weight 4 ppm by volume

* Covers C_9 to C_{24} range and uses $\simeq C_{12}$ as average molecular weight to obtain ppm by volume

Postlanding Conditions

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Limited contamination and environmental data are available for orbiter landing and postlanding phases, and all data are for landings at Edwards Air Force Base (EAFB). Between landing and the 45 minutes it takes to initiate an air-conditioned purge, payload bay temperatures have ranged between 10 and 20 degrees C. Relative humidity remains fairly constant between 15 and 25 percent. This is predictable since a proportion of the air in the bay is from higher altitudes where the absolute humidity is lower.

There are no data for particle and residue deposition during this time phase other than from witness plates that also were exposed during the flight.

At KSC, the orbiter, with the air-conditioning truck attached by an umbilical, can be taken to the OPF where environmental controls can be established within a few hours if necessary. At EAFB and White Sands Test Facility (WSTF) landing sites, no accommodations exist for environmental controls other than the closed payload bay conditioned purge from the truck when specified.

At landing sites other than those above, the primary consideration is safety and an orbiter forced to land at one of these sites might not have conditioned air or environmental protection for extended periods.

Ferry Flight

10

When the orbiter uses any landing site other than KSC, the payload generally remains in the payload bay and returns to the launch site via ferry flight. This is accomplished by hoisting the orbiter up in an open-air mate/demate device outside the hangar and attaching it to a Boeing 747 Shuttle carrier aircraft (SCA) that is rolled in beneath the orbiter. The SCA provides electrical power to the orbiter during the ferry flight. However, environmental conditions in the payload bay are not controlled. If a payload is still in the bay, it experiences the ambient environment in multiple cycles depending upon the ferry route.

During a ferry flight to KSC from EAFB, the POSA flown during the mission remained exposed. To allow differentiation of contaminants collected subsequently on the ferry flight, two samples were added at Dryden Flight Research Center at EAFB. Contamination collected on these two samples could be subtracted from the contamination on the corresponding positioned samples that had been exposed during the whole flight (from KSC and return to KSC) to yield a particle distribution that could be attributed just to the ascent/on-orbit/descent part of the flight. The specimens were electrets of tetrafluoroethylene (TFE) Teflon, one facing up (-Z) and one facing down (+Z) into the bay. In each case, the positively charged side of these organic "magnets" faced out. The particle distributions of each is graphed in Figure 10-1.

Chemical elements in the contaminants were predominantly aluminum; the upfacing specimen had some silver and the downfacing specimen had some calcium. The trace amount of contamination is not considered significant.

Similar tests using the Passive Sample Array were conducted on three separate missions. Ferry flight samples were optical-grade wafers inserted through a small access door in the forward part of the payload bay at the landing site. A summary of these results compared to KSC (OPF) and flight samples is shown in Figure 10-2. Note that the values shown for the flight are a net value after the ferry flight distributions were subtracted from the gross amounts; *i.e.*, the flight samples were exposed continuously until they were removed at KSC.

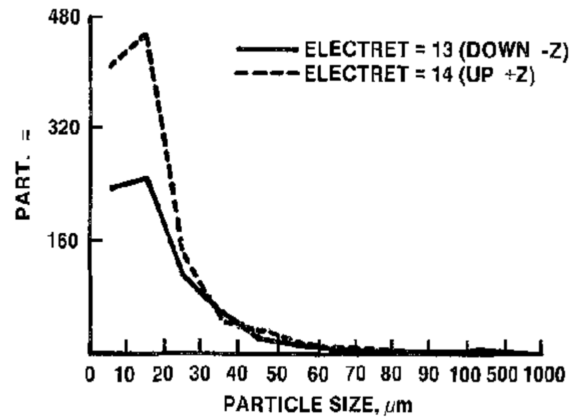

Figure 10-1.- Particle distribution on electrets of Passive Optical Sample Array ferry flight.

The measured optical change in the ferry flight samples was so low as to be in the realm of measurement uncertainty, and could be attributed to the deposited particulate. This indicates that film formation or nonvolatile residue was very low, much like what has been found at KSC in the OPF and PCR facilities.

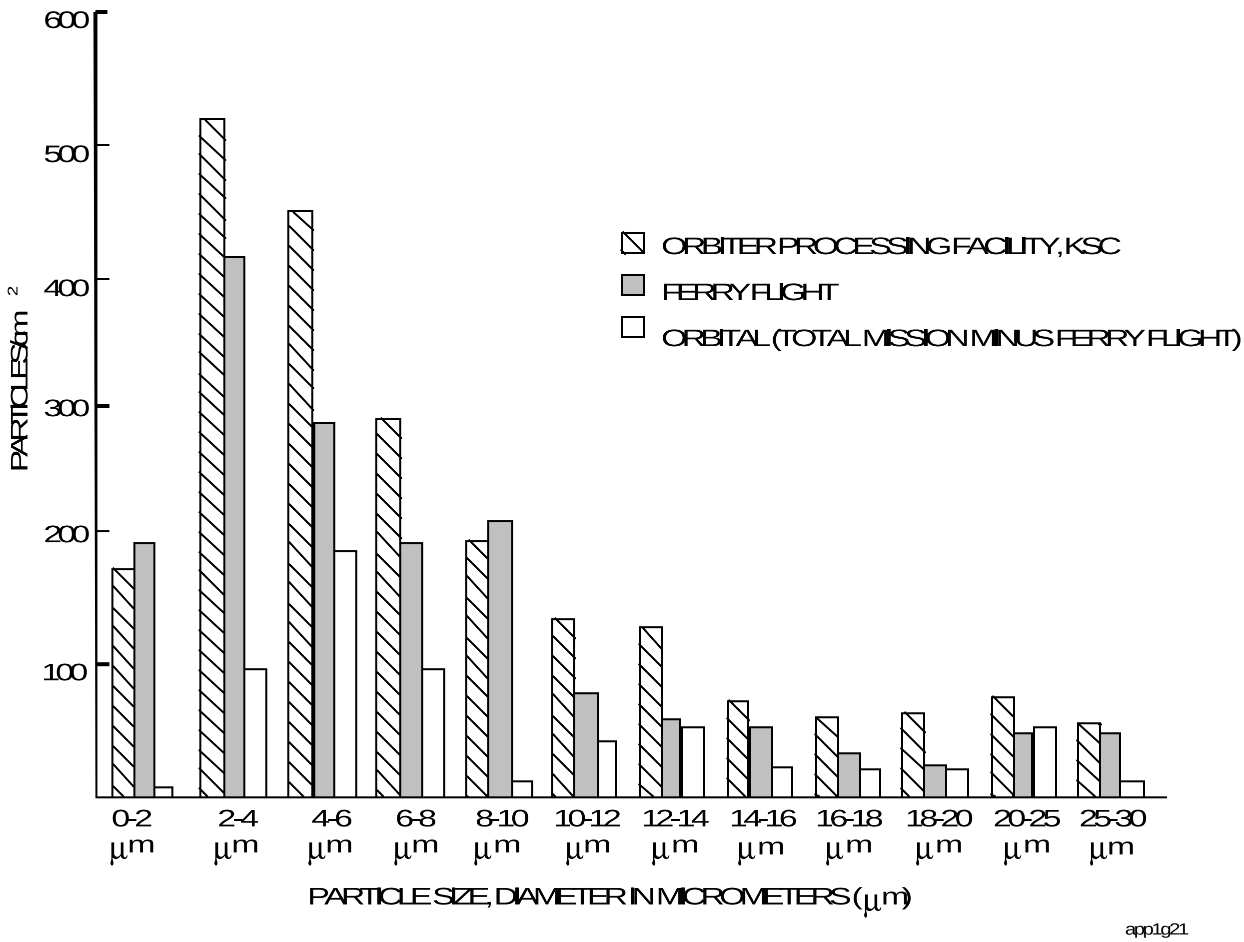

Figure 10-2.- Passive sample array particle distributions.

Acronyms and Abbreviations

11

AIAA	American Institute of Aeronautics and Astronautics
amu	atomic mass unit
APU	auxiliary propulsion unit
ASTM	American Society for Testing and Materials
C	Celsius, or Carbon
CCAFS	Cape Canaveral Air Force Station
cm	centimeter(s)
CO_2	carbon dioxide
CQCM	cryogenically-cooled quartz crystal microbalance
CRDG	Contamination Requirements Definition Group
CWA	Clean Work Area
DEG	degree(s)
EAFB	Edwards Air Force Base
ECS	environmental control system
EMDS	Environmental Monitoring Data System
eV	electron volt(s)
F	Fahrenheit
FES	flash evaporator system
ft	foot, or feet
g	gram(s)
GC	generally clean
GOWG	Ground Operations Working Groups
GSE	Ground Support Equipment
H	hydrogen
HC	hydrocarbons
HCl	hydrogen chloride
HEPA	high efficiency particle air
HPF	hazardous processing facility
hr	hour(s)
HVAC	heating, ventilating and air conditioning
ICD	interface control document
IECM	induced environment contamination monitor
IOCM	Interim Operational Contamination Monitor
IP	Integration Plan
ISS	International Space Station
JSC	Lyndon B. Johnson Space Center
K	Kelvin
km	kilometer(s)
KSC	John F. Kennedy Space Center
LB	pound(s)
LSSM	Launch Site Support Manager
m	meter(s)
MAX	maximum
mg	milligram(s)
MIN	minimum
MLP	Mobile Launch Platform
mm	millimeter(s)
MMH	monomethyl hydrazine
MMPF	Multi-payload Processing Facility
N_2	nitrogen
N_2O_4	nitrogen tetroxide
NASA	National Aeronautics and Space Administration
ng	nanogram(s)
nm	nanometer(s)
NO	nitrous oxide
NO_2	nitrogen dioxide
NVR	nonvolatile residue
O_2	oxygen
O & C	Operations and Checkout
OMRSD	Operations and Maintenance Requirements and Specifications Document
OMS	orbital maneuvering system
OPF	Orbiter Processing Facility
PAC	Percent Area Coverage
PCR	Payload Changeout Room
PGCP	Particles and Gases Contamination Panel

PGHM	payload ground handling mechanism
PHSF	Payload Handling Servicing Facility
PIP	payload integration plan
POSA	passive optical sample array
PPF	payload processing facility
ppm	parts per million
PSA	passive sample array
psi	pounds per square inch
RCS	reaction control system
RSS	rotating service structure
RTV	room temperature vulcanized
S	sulfur
SAEF	Spacecraft Assembly and Encapsulation Facility
sec	second(s)
SL	Spacelab
SPACE	Shuttle/Payload Contamination Evaluation
SPIF	Shuttle Payload Integration Facility
sq	square
sr	storadian
SRB	solid rocket booster
SSP	Space Shuttle Program
SSPF	Space Station Processing Facility
SSV	Space Shuttle vehicle
TFE	tetrafluoroethylene
TML	total mass loss
TPS	thermal protection system
TQCM	temperature-controlled quartz crystal microbalance
TRASYS	thermal radiation analysis system
VAB	Vertical Assembly Building
VC	visibly clean
VCM	volatile condensable material
VRCS	vernier reaction control system
VPF	Vertical Processing Facility
VPHD	Vertical Payload Handling Device
w	watt(s)
WSTF	White Sands Test Facility
wt	weight

Glossary

12

Beta Angle:
The minimum angle between the Earth-sun line and the plane of the orbit

Cargo:
The total complement of cargo elements (one or more), including support equipment, carried on any one flight. In other words, everything contained in the orbiter payload bay plus other equipment, hardware and consumables located elsewhere in the orbiter which is user-unique and is not carried as part of the basic orbiter.

Cargo Element:
The total complement of specific instruments, space equipment, support hardware and consumables carried in the orbiter (but not included as part of the basic orbiter cargo element support) to accomplish a discrete activity in space. A cargo element is functionally independent of other cargo elements within a cargo. A cargo element is also known as a payload.

Column Density:
The number or mass of gas molecules along a line-of-sight which is one centimeter on each side and infinitely (calculated by SPACE-II to 100 meters) long

Direct Flux:
See Flux

Electret:
A dielectric that is processed so as to produce a permanent surface charge that gives it properties analogous to a magnet with a positive and negative pole (surface). Electrically active particles are retained on their surfaces. The two most popular electret materials are Teflon and polypropylene.

Early Desorption:
The desorption of gases on orbit which were adsorbed from the Earth's atmosphere. This effect is known as offgassing.

Fluence:
Flux integrated over time

Flux:
The rate of mass transfer across a surface. Direct flux is mass transfer directly from one surface to another. Return flux is due to mass transfer from a surface being acted upon by the ambient or other molecules and returning to the same or other surfaces.

Glass Bead Rating (GBR):
The value in micrometers that represents the maximum diameter of a hard spherical particle that characteristically can get through a given rigid mesh of an absolute filter such as a woven wire filter. Glass bead ratings do not apply to depth filters or those made of organic material. The filters in the payload bay vents are double dutch twill woven stainless steel of 40 micrometers GBR.

High Efficiency Particulate Air (HEPA):
The designation given to a grade of atmospheric filters procured to MIL-F-51068. It is 99.97 percent efficient for particles 0.3 micrometers in diameter. This filter is typically used in the PCR at KSC and the air shower into the payload bay during payload preparation operations. HEPA filters typically deliver air well within the requirement of less than 100 particles of 0.5 micrometers in size and larger per cubic foot of air.

Lambertian:
The flux emitted in a given direction from a small area of a perfectly diffusing surface which varies as the cosine of the angle of emission.

Nonvolatile Residue (NVR):
Classically, NVR is the remaining weight of residue in milligrams after controlled evaporation at about 220 degrees F of rinse liquid that has first been filtered through a membrane filter rated at 0.8 micrometers. At launch site this term is also used for the total weight in milligrams collected on one square foot of surface in one month.

Offgassing:
See Early Desorption

Outgassing:
Gases, mostly silicones and organics, given off due to the bulk mass loss of nonmetallic materials when exposed to the vacuum environment

Payload:
See cargo element

Payload bay:
The cylindrical space in the upper section of the midbody of the orbiter. It is 65 feet long and 15 feet in diameter.

Payload bay liner:
Sections of Teflon coated glass fabric with very low permeability that, when installed, forms a continuous sheet of material between the lower midbody and the payload bay. It is 1531 square feet and weighs 400 pounds completely installed. It does not cover the bulkheads nor the "floor" sections of the rear two bays, bays 12 and 13.

Payload Integration Plan (PIP):
The PIP is the contractual document between the payload contractor and NASA-JSC where detailed special agreements and provisions are documented for the specific payload.

Return Flux:
See Flux

Total Mass Loss (TML):
The weight lost by a payload or payload bay material in 24 hours when maintained at 125 degrees C and 10^{-6} torr pressure per SP-R-0022. The maximum allowable is one percent of the initial material's weight.

Volatile Condensable Material (VCM):
The weight picked up by a 25 degree C collector plate one foot away from a material under test per SP-R-0022 at 125 degrees C and 10^{-6} torr pressure. The maximum VCM is 0.1 percent of the tested specimen initial weight.

Witness plate:
Any one of several plate materials placed in and around areas where particle fallout or deposition of films is of interest. These might be membrane filters in petri dishes, germanium crystal plates or polished aluminum. Witness plates used during the first orbital flights were made of gold, fused silica, magnesium fluoride or calcium fluoride.

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13

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