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EVALUATION OF THE GROUND CONTAMINATION
ENVIRONMENT FOR STS PAYLOADS

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EVALUATION OF THE GROUND CONTAMINATION ENVIRONMENT FOR STS PAYLOADS

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SHUTTLE ENVIRONMENT WORKSHOP
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OUTLINE

- REQUIREMENTS
- FACILITY VERIFICATION PROGRAM
- RESULTS OF MEASUREMENTS
- CONCLUSIONS

It is worthwhile to review the cleanliness and contamination control requirements for the Shuttle program and to discuss some background material before presenting some results of the measurements.

The objectives of the facility verification program are then discussed.

Although all the data have not yet been analyzed, and Shuttle ground operations are still evolving, it is possible to reach some conclusions.

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Development of Cleanliness Requirements

- NASA WORKING GROUPS
  - PARTICLES AND GASES CONTAMINATION PANEL (PGCP)
    - ESTABLISHED IN 1974
    - ADVISORY GROUP TO STS PROJECT OFFICE
  - CONTAMINATION REQUIREMENTS DEFINITION GROUP (CRDG)
    - ESTABLISHED IN 1974
    - DETERMINE PAYLOAD REQUIREMENTS
- GROUND FACILITIES REQUIREMENTS
  - INPUT DATA
    - PROPOSED STS PAYLOADS
    - PAST EXPERIENCE
    - CLEAN ROOM TECHNOLOGY
  - PHILOSOPHY
    - MEET THE REQUIREMENTS OF THE MAJORITY OF PAYLOADS
    - DO NOT PRECLUDE MEETING MORE STRINGENT REQUIREMENTS

Two NASA working groups on contamination were established in 1974. The PGCP (Particles and Gases Contamination Panel) was, and still is, chaired by Dr. L. Leger of the Johnson Space Center (JSC). The PGCP reviewed Shuttle requirements (1, 2, 3) with respect to cleanliness and contamination control and provided recommendations to the NASA Shuttle Project office.

The CRDG (Contamination Requirements Definition Group) was chaired by Dr. R. Naumann of the Marshall Space Flight Center (MSFC). It is now called the Contamination Working Group (CWG) and is chaired by Ed Miller of MSFC. The CRDG reviewed numerous payload requirements and issued a report containing recommendations[4].

The following charts describe the STS requirements and the CRDG recommendations pertaining to ground facilities and operations.

The NASA philosophy in setting requirements was to meet the requirements of the majority of payloads without precluding the implementation of more stringent requirements when required.

System Requirements

JSC 07700, VOL. X

3.6.12.1 SYSTEM CONTAMINATION CONTROL

CONTAMINATION OF THE SPACE SHUTTLE SYSTEM SHALL BE CONTROLLED TO ASSURE SYSTEM SAFETY, PERFORMANCE, AND RELIABILITY. CONTROL SHALL BE IMPLEMENTED BY A COORDINATED PROGRAM FROM DESIGN CONCEPT THROUGH PROCUREMENT, FABRICATION, ASSEMBLY, TEST, STORAGE, DELIVERY, OPERATIONS, AND MAINTENANCE OF THE SHUTTLE SYSTEM. THIS PROGRAM SHALL COMPLY WITH THE REQUIREMENTS OF SN-C-0005, SPECIFICATION CONTAMINATION CONTROL REQUIREMENTS FOR THE SPACE SHUTTLE PROGRAM. SELECTION OF SYSTEM DESIGN SHALL INCLUDE SELF-CLEANING (filtering) PROTECTION COMPATIBLE WITH COMPONENT SENSITIVITY.

EQUIPMENT DESIGN SPECIFICALLY FOR THE SPACE SHUTTLE PROGRAM SHALL COMPLY WITH THE SPECIFIED REQUIREMENTS. SELECTION OF OFF-THE-SHELF EQUIPMENT FOR APPLICATION TO THE SPACE SHUTTLE PROGRAM SHALL COMPLY WITH THE INTENT OF THESE REQUIREMENTS.

JSC 07700, Volume X, recognized the need for contamination control, internal and external, for the Shuttle system.

System Requirements

JSC 07700, VOL. X

3.6.12.2 OPERATIONAL CONTAMINATION CONTROL

CONTAMINATION CONTROL DURING THE OPERATIONAL PHASES OF THE SPACE SHUTTLE IS NECESSARY TO INSURE OVERALL SATISFACTORY PERFORMANCE OF THE SYSTEM. OF PARTICULAR CONCERN IS THE GASEOUS AND PARTICULATE ENVIRIONMENT OF THE ORBITER DURING ALL OPERATIONAL PHASES. BECAUSE OF THE WIDE RANGE OF PAYLOADS IT IS THE OBJECTIVE OF THE FOLLOWING APPROACH TO PROVIDE REQUIREMENTS TO SATISFY THE NEEDS OF THE LARGE MAJORITY OF PAYLOADS. PAYLOADS THAT HAVE SPECIAL REQUIREMENTS NOT COVERED HEREIN SHALL PROVIDE THE NECESSARY SYSTEM(s) TO SATISFY SUCH REQUIREMENTS.

System Requirements

JSC 07700, VOL. X

3.6.12.2.1 ELEMENT CROSS CONTAMINATION

SPACE SHUTTLE SYSTEM ELEMENT DESIGN AND OPERATION SHALL BE SUCH AS TO MINIMIZE CROSS CONTAMINATION OF THE ELEMENTS TO A LEVEL COMPATIBLE WITH MISSION OBJECTIVES

3.6.12.2.2 PAYLOAD BAY DESIGN

PAYLOAD BAY SHALL BE DESIGNED TO MINIMIZE CONTAMINATION OF PAYLOAD AND CRITICAL PAYLOAD BAY SURFACES TO A LEVEL COMPATIBLE WITH MISSION OBJECTIVES

3.6.12.2.3 PAYLOAD DESIGN

CRITICAL SURFACES SUCH AS ORBITER RADIATORS, WINDOWS, OPTICS, etc., WITHIN THE PAYLOAD BAY AND PART OF THE ORBITER SYSTEM MUST BE PROTECTED IN THE SAME MANNER AS PAYLOADS. THAT IS, PAYLOADS MUST INSURE THAT THEIR EFFLUENTS AND OPERATIONS DO NOT JEOPARDIZE THE PERFORMANCE OF THESE SYSTEMS.

JSC 07700, Volume X, also recognized the need to control contamination for all elements of the Shuttle system. This included the payload bay and ground facilities. It was also necessary to impose requirements on payloads so as to prevent excessive degradation of critical elements of the Orbiter and other payloads.

Requirements for ground operations are contained in paragraphs 3.6.12.2.4.1, 3.6.12.2.4.2, and 3.6.12.2.4.3 of Volume X.

A review of clean room technology confirmed[6, 7, 8] that the cleanliness of the air entering a facility could be controlled to class 100 (per FED-STD-209B)[5] or cleaner by using standard HEPA (high efficiency particulate air) filters (sometimes referred to as 99.97% filters)[9].

It was also recognized that surface cleanliness of payloads was the goal of the contamination control effort and that this included both particulate and molecular contaminants.

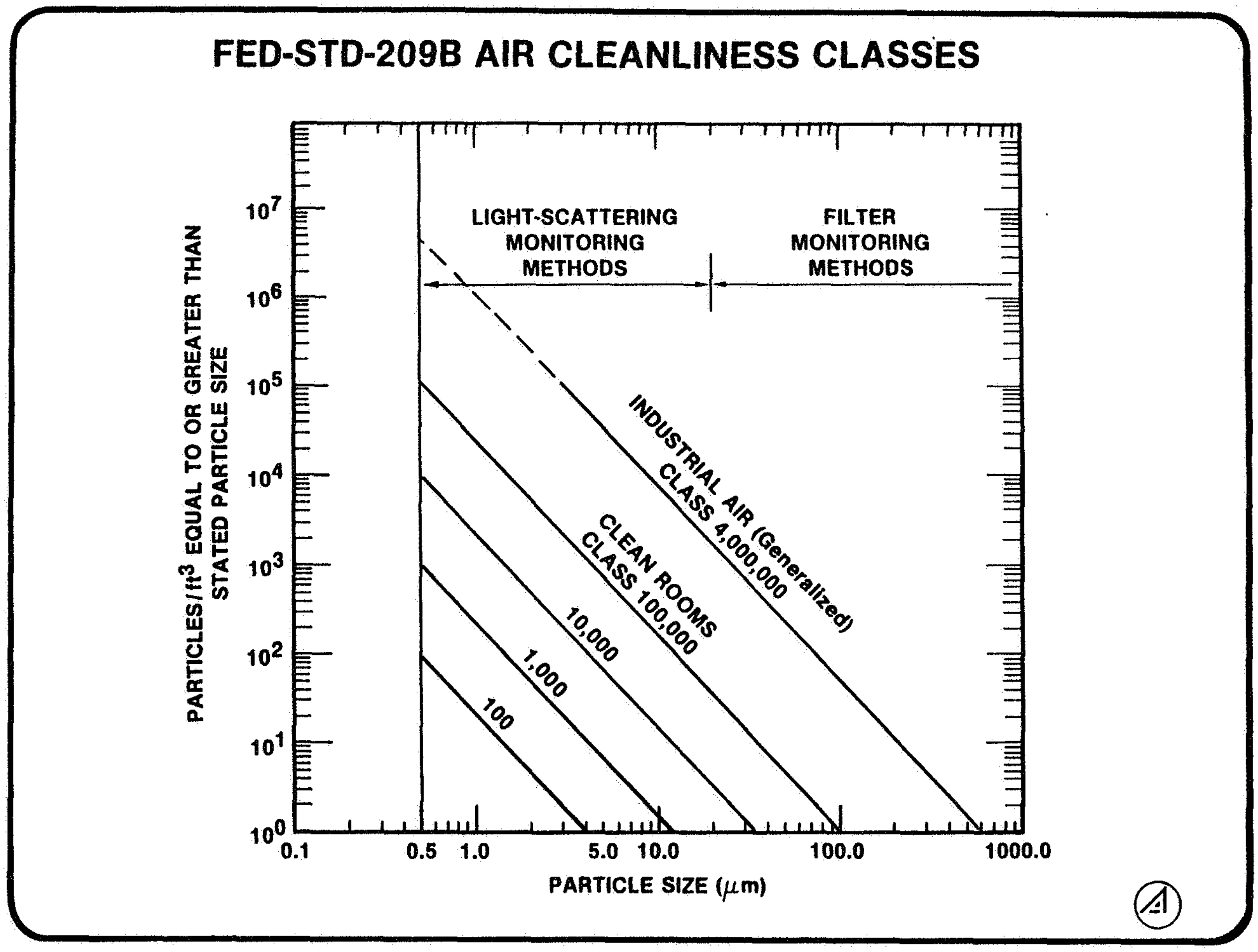
System Requirements

- PAYLOAD BAY AND CANISTER SURFACES
  - VISIBLY CLEAN PER SN-C-0005
- CLEANLINESS FOR AIR ENTERING PAYLOAD ENCLOSURES AND PAYLOAD BAY
  - NOMINAL CLASS 100, GUARANTEED CLASS 5000 PER FED-STD-209B
  - LESS THAN 15 PPM OF HYDROCARBONS, METHANE EQUIVALENT
  - TEMPERATURE: 70 $\pm$ 5°F (21 $\pm$ 3°C)
  - RELATIVE HUMIDITY: 50% OR LESS
- CLEANLINESS FOR GN_2 PURGE OF PAYLOAD BAY
  - SAME AS FOR AIR EXCEPT FOR LOW R.H.
- PAYLOAD BAY PURGE IS OFF
  - DURING SWITCHOVER BETWEEN MOBILE AND FACILITY SYSTEMS
  - DURING STACKING OPERATIONS IN THE VAB
  - CLOSING OF PAYLOAD BAY DOORS
  - IGNITION OF SHUTTLE MAIN ENGINES

3.6.12.2.4.1 Payload Loading and Checkout. Prior to payload loading the internal surfaces of the payload bay envelope shall be cleaned to a visibly clean level, as defined in SN-C-0005. This cleaning shall be accomplished within a protective enclosure in order to isolate sources of contamination from critical regions. This enclosure shall be continuously purged with nominally class 100, guaranteed class 5000 (HEPA filtered) air per FED-STD-209 and shall contain less than 15 parts per million hydrocarbons, based on methane equivalent. The air within the enclosure shall be maintained at 70 $\pm$ 5°F and 50% or less relative humidity. The payload loading operation shall be accomplished so as to avoid contaminating the payload and payload bay by temperature, humidity, and particulates consistent with requirements specified herein. More stringent particulate and relative humidity requirements may be implemented on particular payloads pending technical justification of the requirement.

3.6.12.2.4.2 Contamination Control Subsequent to Payload Loading. Subsequent to payload loading, accumulation of visisble particulate and film contamination on all surfaces within the payload bay shall be prevented by controlled work discipline, cleanliness inspections and effective cleaning as required. The air purge, temperature, and humidity requirements of the above paragraph 3.6.12.2.4.1 shall be maintained.

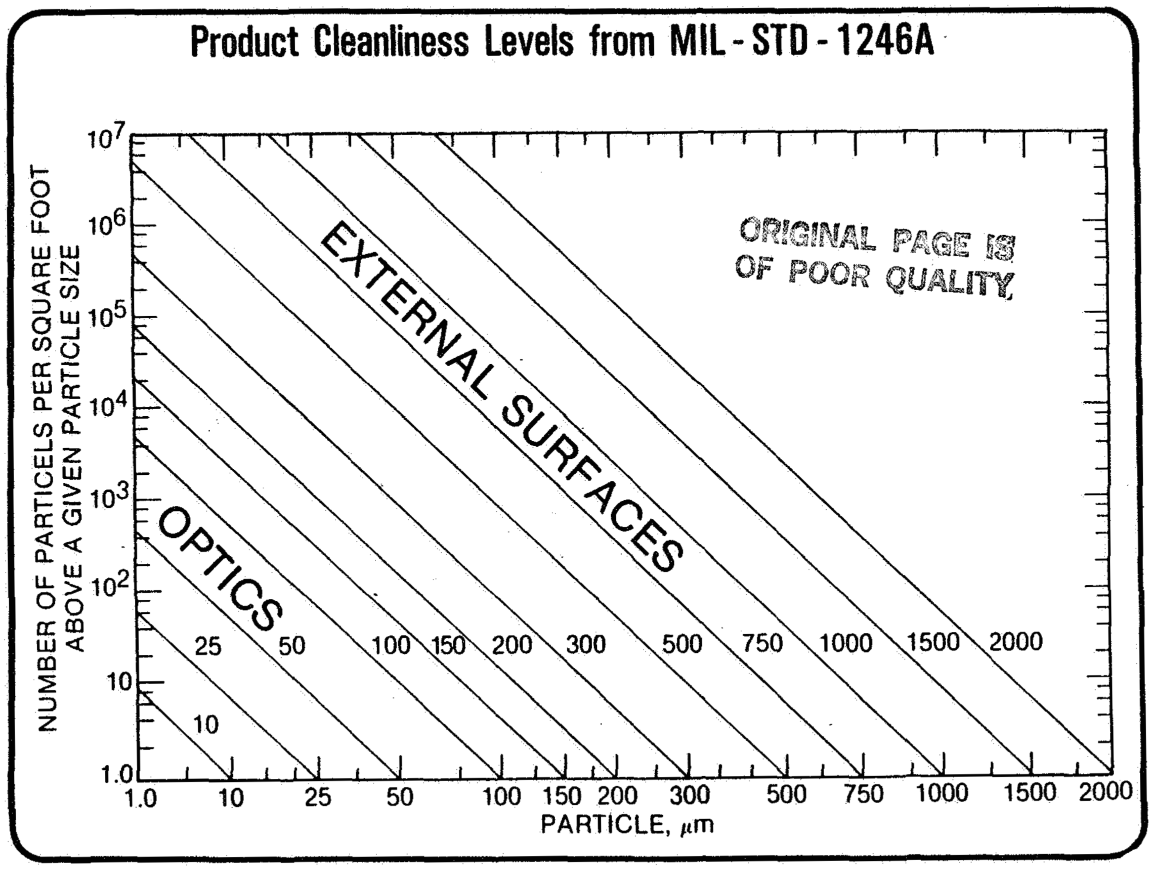
3.6.12.2.4.3 Preparation for Closeup of Payload Bay. Prior to final closure of the payload bay in preparation for vehicle mating, inspection and cleaning, as required, shall be conducted to verify that all accessible surfaces within the payload bay, including external surfaces of payloads, meet the visibly clean level stipulated in the above paragraph 3.6.12.2.4.1. When payload changeout in the vertical configuration is required, the purge gas class, temperature, and humidity requirements of the above paragraph 3.6.12.2.4.1 shall apply.



FED-STD-209B defines cleanliness on the basis of the number of particles per cubic foot of air. The "class of air" is defined as the total number of particles per cubic foot of air of all sizes of 0.5 μm and larger. Table II from FED-STD-209B defines a standard particle size distribution. For any particle size, the number per cubic foot is for all particles of that size and larger. Air cleanliness classes other than those plotted can be defined by parallel lines through the appropriate number on the ordinate.

The term "class" may be used in two ways. One is to describe the actual particulate environment as measured by an airborne particle monitor. The other is to designate a particular class of clean room.

The latter usage implies a facility that meets a number of operating and design requirements such as those described in T.O. 00-25-203[6] and AFM 88-4, Chapter 5[7]. In this case the "class of clean room" designates the maximum airborne particle counts, and for normal operations the particle counts should be an order of magnitude or more below the maximum. For periods of no activity in a clean room the airborne particle counts will approach the cleanliness of the air leaving the HEPA filter, class 100 or less.



MIL-STD-1246A[10] defines the product cleanliness levels on the basis of the number of particles on the components. A square foot area is generally used as a baseline for comparing surface cleanliness; however, MIL-STD-1246A specifies the use of the total number of particles for surface areas of less than one square foot.

The NASA Shuttle cleanliness specification, SN-C-0005A[1], is based on the same particle size distribution but does not contain the graph from MIL-STD-1246A that is on the chart on the facing page.

The number of particles per square foot of surface for all particles of the specified size and larger plot as a straight line on the log vs. $\log^2$ scales. The particulate cleanliness level is defined by the line crossing the abscissa. For example, the Level 500 line crosses the abscissa at one 500μm particle per sqare foot.

Typical external spacecraft surface cleanliness levels are in the range of 500 to 1000 but could be greater. For critical internal surfaces, such as optics, the levels could be at 100 or less.

MIL-STD-1246A and SN-C-0005A also define the NVR (non-volatile residue) levels on the basis of mg/ft^2. For example, NVR Level A designates a quantity of 1 mg/ft^2 or less and Level B as 2 mg/ft^2 or less.

CRDG Recommendations

- CLEANING OF PAYLOAD SURFACES
  - PARTICLES: VISIBLY CLEAN PER SN-C-0005
  - NVR: $<1 \mu g\ cm^{-2}$
  - ASSUMED TO BE LEVEL 300A PER MIL-STD-1246A OR SN-C-0005
- ENCLOSURE
  - ENTERING AIR
    - PARTICLES: NOMINAL CLASS 100, GUARANTTED CLASS 5,000 PER FED-STD-209B
    - MOLECULAR DEPOSITION: NO MORE THAN 1 $\mu g \cdot cm^{-2}$ ON AMBIENT TEMPERATURE SURFACE
    - TEMPERATURE: 70 $\pm$ 50°F (21 $\pm$ 3°C)
    - RELATIVE HUMIDITY: 30% TO 50%, SELECTABLE TO $\pm$ 5%
  - ENVIRONMENT AROUND PAYLOAD
    - CLASS 100,000 OR LESS PER FED-STD-209B
- PAYLOAD BAY
  - USE PAYLOAD BAY LINER
  - VISIBLY CLEAN PER SN-C-0005
  - NVR: $< 1 \mu g \cdot cm^{-2}$

The members of the working groups agreed that surface cleanliness is the critical aspect, and the CRDG recommended the use of NVR Level A (1 mg/ft^2) which is equivalent to 1 $\mu g/cm^2$ and 10 mg/m^2 for both payload and cargo bay surfaces(4). If the NVR is assumed to have a density of 1 g/cm^3 and is uniformly distributed over the surface, the thickness would be 100 Å for 1 $\mu g/cm^2$.

Visibly clean per SN-C-0005 was selected for particulate surface cleanliness. This was optimistically assumed to be equivalent to a Level 300. Later studies showed that Level 500 or higher would be more representative of "visibly clean". The ability to see particles depends upon the surface roughness, color contrasts, and illumination.

The CRDG recommendations agreed with JSC 07700, Volume X, on the particulate cleanliness of the air entering the facilities (nominal Class 100, guaranteed Class 5,000). However, the CRDG recommended the measurement of molecular deposition rather than hydrocarbons based on methane equivalent.

The environment around the payload was recommended to be Class 100,000 or less. Based on experience, it would appear that typical payload environments have been well below Class 100,000 during ground operations.

For the payload bay, there was a consensus that the liner would be required and that visibly clean per SN-C-0005 would be satisfactory for particulate contamination. However, NVR Level A was recommended because visible inspection would not detect molecular deposits to an acceptable sensitivity.

Visibly Clean Levels and Inspection Criteria for the Orbiter Payload Bay, Payload Canister, and Payloads

VC LEVEL	ILLUMINATION	OBSERVATION DISTANCE	REMARKS
1	≥50 FOOT CANDLES	5 TO 10 ft	KSC STANDARD SERVICE
2	100 TO 200 FOOT CANDLES	6 TO 18 in.	OPTIONAL SERVICE
3	100 TO 200 FOOT CANDLES	6 TO 18 in.	OPTIONAL SERVICE: 2X TO 7X POWER OPTICAL AID PERMITTED FOR INSPECTION
VC + SPECIAL	100 TO 200 FOOT CANDLES	6 TO 18 in.	OPTIONAL SERVICE: SAME INSPECTION AS LEVELS 2 OR 3 PLUS SPECIAL METROLOGY REQUIREMENTS

From NASA SN-C-0005A

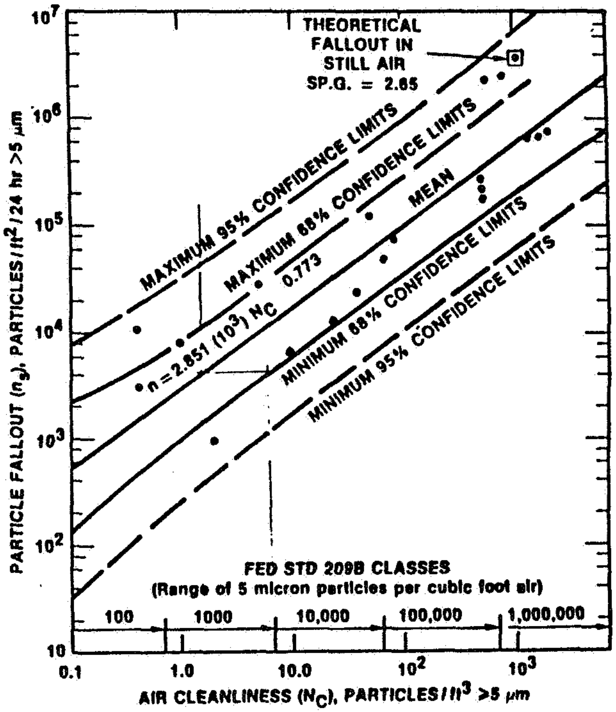
The Shuttle contamination control specification, SN-C-0005[11], was revised in March 1982 in order to better define visibly clean. The facing chart shows the visibly clean levels now defined in SN-C-0005A for the payload bay, payload canister and payload surfaces.

An OMI (Operational Maintenance Instruction)[12] has been written to cover the cleaning and inspection of payload bay surfaces to the VC Level 1 criteria. Future changes will incorporate VC Level 2 and other criteria.

Special requirements, such as an NVR level, would be included under VC + Special.

PARTICLE FALLOUT RATE ANALYSIS

- LOGARITHMIC REGRESSION ANALYSIS
  - PREDICT FALLOUT RATE KNOWING AIR CLEANLINESS
  - PROVIDE CONFIDENCE LIMITS OF PREDICTIONS



The relationship between surface cleanliness and air cleanliness for particles is not well defined. Hamberg[13] calculated the particulate fallout rate for particles of 5 µm and larger. He assumed a constant concentration of 5 µm and larger sizes in the air in accordance with the distribution defined by FED-STD-209B[5]. The 5 to 200 µm size range and a specific gravity of 2.65 were used to calculate the particulate fallout rate.

The chart on the facing page shows the results of Hamberg's calculations and includes some experimental data points.

The relationship between airborne particle concentrations and fallout will be used to evaluate the data gathered during operations in the various KSC facilities.

KSC Facility Contamination Verification Test Plan

- VERIFY BASIC REQUIREMENTS FROM JSC-007700, VOL. X
  - AIRBORNE PARTICLES
  - HYDROCARBONS (methane equivalent)
- VERIFY FACILITY CAPABILITIES
  - AIRBORNE PARTICLES
  - PARTICLE FALLOUT
  - MOLECULAR DEPOSITION
  - MICRO-BIOLOGICAL
- FACILITIES
  - VERTICAL PROCESSING FACILITY (VPF)
  - OPERATIONS AND CHECKOUT BUILDING (O&C)
  - PAYLOAD CANISTER AND TRANSPORTER
  - ORBITER PROCESSING FACILITY (OPF)
  - VEHICLE ASSEMBLY BUILDING (VAB)
  - ROTATING SERVICE STRUCTURE (RSS)/PAYLOAD CHANGEOUT ROOM (PCR)

The KSC Facility Contamination Verification Plan[14] was drafted by KSC and reviewed by members of the working groups and participants in the measurement activities.

Experience gained during the facility measurement program has resulted in some changes from the originally published plan, and there is an effort in progress to revise the test plan.

The facility verification program has two general objectives. One is to verify the basic Level II requirements on air cleanliness:

1. Nominal class 100, guaranteed class 5000 for airborne particles.
2. Less than 15 ppm of hydrocarbons, methane equivalent.

The second objective is to define the environment within the facilities under various real and simulated operations. The measurements included the fallout and deposition of particles and molecular species. The surface contamination as a result of fallout and deposition is the major concern of people designing and building spacecraft and experiments.

The biological measurements were not performed.

ELS Shuttle Facilities

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FACILITY	AIR FILTERS	AIR CHANGE RATE/FLOW RATE	RELATIVE HUMIDITY CONTROL
O&C BUILDING	80-85% NBS	3.9 CHANGES/hr	50% MAX
VPF	HEPA (99.97%)	8 CHANGES/hr	45 ± 5%
SPIF	HEPA + CARBON	15 CHANGES/HR	30%-50%
CANISTER	HEPA	150 LBM/MIN	30%-50%
OPF	80-85% NBS	4 CHANGES/HR	50% MAX
VAB	NONE	NONE	NONE
ORBITER BAY	HEPA + CARBON HEPA	112 TO 265 LBM/MIN (Mobile) 140 TO 290 LBM/MIN (PAD)	50% MAX 50% MAX
RSS/PCR	HEPA	15 CHANGES/HR	50% MAX

The operating characteristics of the air conditioning systems in various on-line Shuttle facilities are summarized in the facing chart.

The chart on page 28 shows typical airborne particle counts for a class 100,000 clean room. This is based on requirements in Air Force T.O. 00-25-203[6].

Comparing the information on page 27 with that on page 28, it is possible to evaluate the facilities on the basis of clean room performance. However, it is important to consider the differences in operations within the Shuttle facilities as compared with typical clean rooms when the environments are analyzed.

The Assembly and Test Area (A&TA) in the O & C (Operations and Checkout) building is equivalent to a controlled area (Class 300,000) facility.

The VPF (Vertical Processing Facility) is equivalent to a class 100,000 clean room although the number of air changes per hour may be less than required for a clean room.

The payload canister has HEPA filtered air and can be considered to be equivalent to a class 100,000 facility.

The OPF (Orbiter Processing Facility) with only 4 air changes an hour might be considered as not meeting the requirements of a controlled area facility.

The VAB (Vehicle Assembly Building) has no environmental control, but the cargo bay doors are closed during Orbiter operations within the VAB.

The cargo bay purge air is HEPA filtered, and the portable purge units include a carbon filter that will remove molecular contaminants, such as hydrocarbons from the exhausts of internal combustion engines.

The PCR (Payload Changeout Room) on the RSS (Rotating Service Structure) at launch complex 39 is equivalent to a class 100,000 clean room.

Typical Guidelines for Clean Room Classes from Air Force T.O. 00-25-203

DECRIPTION	MAXIMUM PARTICLE COUNT PER cu ft AIR >0.5μm (>5μm)	AIR CONDITIONING		AIR FILTRATION	PRESSURE DIFFERENTIAL	AIR FLOW	MONITORING	CLOTHING
		TEMPERATURE °F (°C)	RH %					
CONTROLLED AREA (Class 300,000)	300,000 (700)	80 MAX (27)	50 MAX	ROUGH (50 to 60%) MEDIUM (80 to 85%)	POSITIVE	10 AIR CHANGES PER hr, min	ONCE PER MONTH	DETERMINE LOCALLY
CONVENTIONAL CLEAN ROOM (Class 100,000)	100,000 (700)	72 ± 5 (22 ± 3)	30 TO 50	ROUGH (50 to 60%) MEDIUM (80 to 85%) HEPA (99.7%)	0.05 in WATER	15 TO 20 AIR CHANGES per hr	ONCE PER MONTH	COVERALLS CAP/HOOD/SNOOD CLEAN ROOM SHOES OR SHOE COVERS
LAMINAR CROSS FLOW (Class 10,000)	10,000 (65)	72 ± 5 (22 ± 3)	30 TO 50	ROUGH MEDIUM HEPA	0.05 in WATER	100 ft/min AT HEPA FILTER FACE	ONCE PER MONTH	SMOCK/FROCK CAP/HOOD/SNOOD "BUNNY SUIT" AS REQUIRED
LAMINAR DOWN FLOW (Class 1,000)	1,000	72 ± 5 (22 ± 3)	30 TO 50	ROUGH MEDIUM HEPA	0.05 in WATER	50 ft/min OVER ENTIRE FACILITY	ONCE PER MONTH	SMOCK/FROCK CAP/HOOD/SNOOD "BUNNY SUIT" AS REQUIRED
LAMINAR FLOW CLEAN WORK STATION (Class 100)	100	CONTROLLED BY ROOM	CONTROLLED BY ROOM	MEDIUM HEPA	NOT APPLICABLE	90 ft/min AVERAGE OVER AIR EXIT AREA BUT NOT LESS THAN 75 ft/min AT ANY POINT	ONCE EVERY 6 mo	AS REQUIRED

Typical Conventional Clean Room (Class 100,000)

AIRBORNE PARTICLES (FROM T0.00-25-203)

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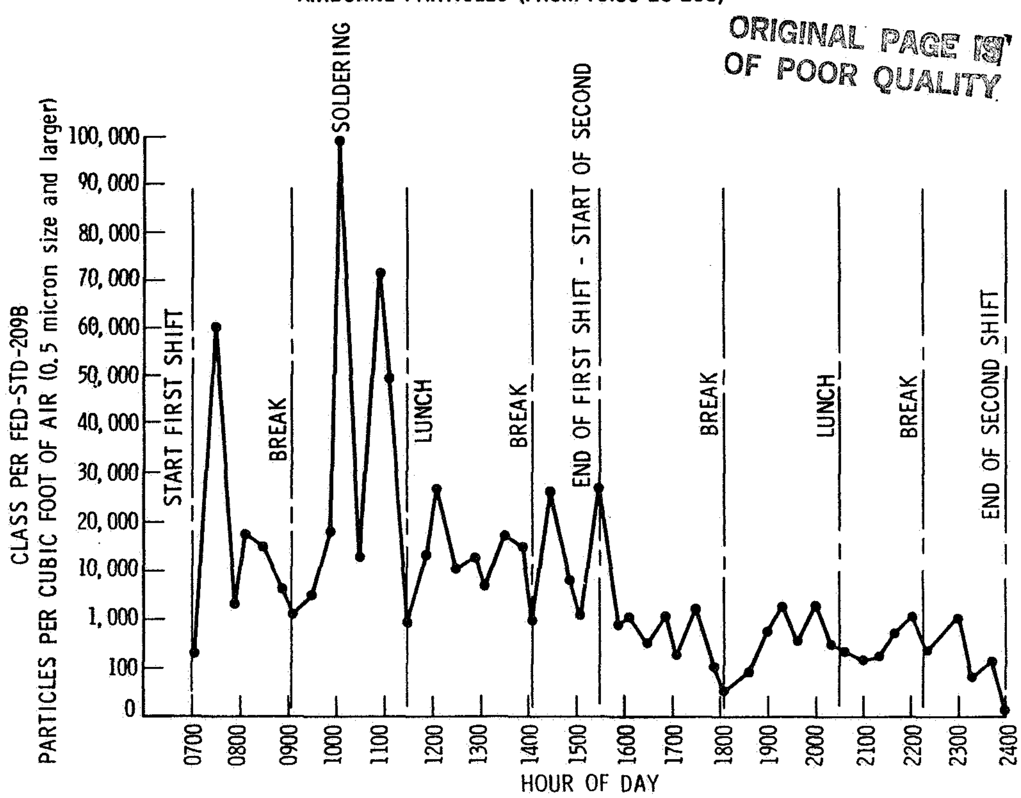

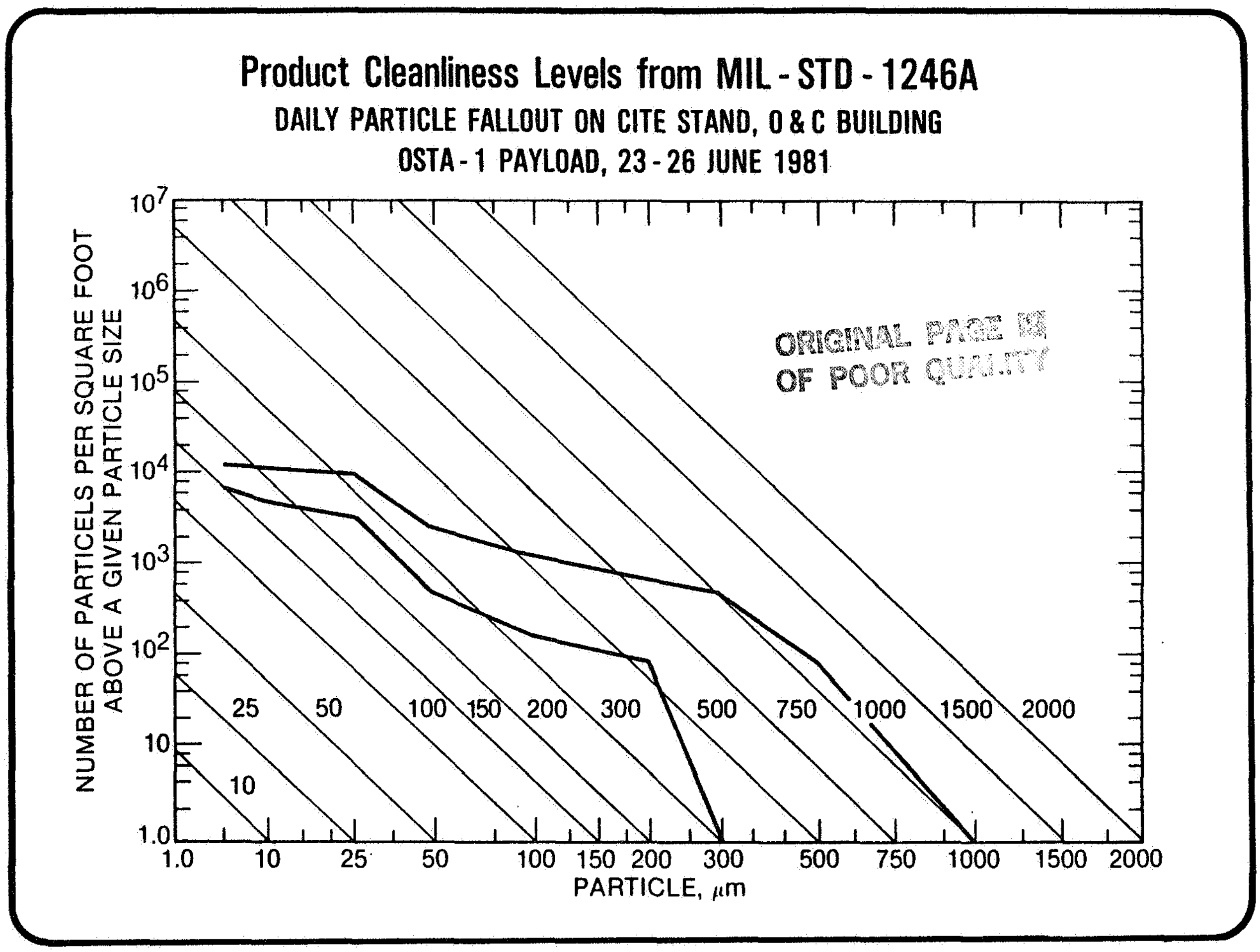

Particle fallout was measured by KSC contractor and Aerospace Corporation personnel during the integration activities of the OSTA-1 payload in the O & C building. The facing graph shows the maximum and minimum particle counts taken from data provided by Virginia Whitehead at KSC[19].

The lower curve shows a period of no activity on the CITE stand where the fallout plates were located. The upper curve includes a period when the large doors were open and the canister was moved into the building. Particle fallout during transfer of the OSTA-1 pallet to the canister was slightly below the maximum.

O & C Building Assessment

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- AIRBORNE PARTICLES
  - LESS THAN CLASS 100,000 EXCEPT WHEN LARGE DOORS ARE OPEN
  - PARTICLES LARGER THAN 5 μm APPEAR TO BE GENERATED WITHIN THE FACILITY
- PARTICLE FALLOUT ON CITE STAND
  - 20 μm AND LARGER PARTICLES RESULT FROM ACTIVITIES ON THE CITE STAND
- COVERS CAN BE USED TO PROTECT SENSITIVE COMPONENTS
  - LOCAL COVERS
  - LARGE COVER OVER THE PAYLOAD
  - COVER WITH A HEPA FILTERED AIR PURGE OVER THE STAND
- NVR LEVELS ARE LOW
  - LESS THAN 0.004 mg/0.1 m^2 (0.004 $\mu g/cm^2$)

The airborne particle counts are generally less than class 100,000 except when the large doors are opened to admit the truck carrying the strongback (for lifting the pallet) and the canister transporter. At these times the airborne particle counts exceeded the class 100,000 requirements in the 5 μm and larger size range.

The airborne particle counts at other times were well below class 100,000.

The particle fallout data show large numbers of particles greater than 25 μm. This can be attributed to a number of factors. Large particles have high settling velocities and will tend to fallout near the locations where they are being generated. The sources of these particles probably are the personnel on the CITE stand and their activities. Except when the doors to the outside are open, the air entering the facility will have negligible large particles.

Airborne particle counters that use optical light scatter techniques may not be effective in measuring particles larger than 20 μm and were not located close to the fallout plates on the CITE stand.

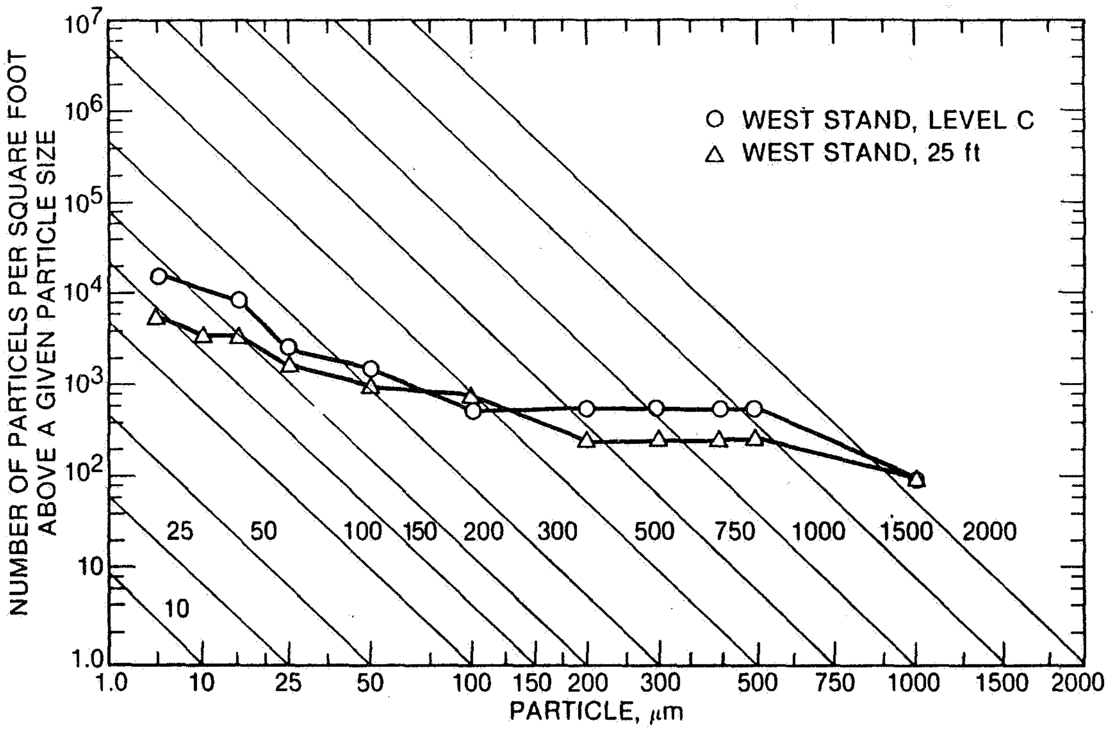
NVR fallout levels were low as measured by the KSC wash plates and the Aerospace Corp. KRS-5 infrared plates. Level A of SN-C-0005A and MIL-STD-1246A is equal to or less than 1 mg/ft^2 (1 $\mu g/cm^2$ or 1 mg/0.1 m^2). Measured levels were less than 0.004 mg/0.1 m^2 (N-hexadecane equivalent). Real time measurements using a QCM (quartz crystal microbalance) showed negligible change at a sensitivity of approximately 7 ng/cm^2 (0.007 $\mu g/cm^2$).

Protective covers over small components up to a cover over the CITE stand (with HEPA filtered air) are possible approaches to protecting sensitive components and payloads.

Product Cleanliness Levels from MIL-STD-1246A

24-hr PARTICLE FALLOUT ON VPF WORKSTAND

IUS PATHFINDER FLOW, 23-24 MARCH 1982



Particle fallout during the IUS pathfinder operations was measured by KSC contractor and Aerospace Corp. personnel. The plots on the facing graph are taken from data plotted by V. Whitehead[19].

As observed in the O & C building, there are numerous large particles.

VPF Assessment

- AIRBORNE PARTICLES
  - CLASS 10,000 DURING OPERATIONS
    - TYPICAL OF CLASS 100,000 CLEAN ROOM
    - COULD BE HIGHER WITH INCREASED ACTIVITY
  - GREATER THAN CLASS 100,000 IN AIRLOCK WITH DOOR OPEN
- PARTICLE FALLOUT ON STAND
  - 20 μm AND LARGE PARTICLES RESULT OF LOCAL ACTIVITIES
- NVR
  - RANGED FROM $<$0.003 TO 0.70 mg/0.1 m^2 IN 24 hr
    - HIGH LEVELS PROBABLY CAUSED BY FACILITY ACTIVITIES
- COMMENTS
  - CONTROL OF PROCEDURES CRITICAL TO MAINTAINING CLEANLINESS
    - FACILITY
    - PAYLOADS

The performance of the VPF is comparable to that of a class 100,000 clean room. The differences between the VPF and a typical clean room include equipment such as cranes and movable platforms, large numbers of people for some operations, and the movement of vehicles and equipment from outside into the facility.

The high airborne particle counts in the airlock when the door is open and equipment is moved in should be considered when planning operations.

The particle fallout onto surfaces is the result of activities in the vicinity of the surfaces. The airborne particle monitor will not necessarily measure the particles larger than 20 μm especially away from the location of the activity.

The occasionally high NVR levels probably are the result of activities with facility equipment such as cranes and platforms.

Although the facility environment is generally good, it is essential to plan and control procedures so as to avoid contamination during typical "dirty" operations. This applies to both facility and payload operations.

Payload Canister Assessment

- AIRBORNE PARTICLES
  - LESS THAN CLASS 10,000 FOR MAJORITY OF TIME
  - PEAK COUNTS EXCEEDED CLASS 10,000 FOR SHORT TIMES
- PARTICLE FALLOUT
  - AN ANALYSIS SHOWS WALNUT SHELL PARTICLES
    - WALNUT SHELL BLASTING USED TO REMOVE INTERIOR PAINT
- NVR
  - APPEARS TO BE LOW
- COMMENTS
  - RESIDUAL WALNUT SHELL PARTICLES TO BE ELIMINATED BY FURTHER CLEANING
  - PAYLOADS COULD BE SOURCE OF PARTICLES
    - CROSS-CONTAMINATION BETWEEN CARGO ELEMENTS
    - MAY REQUIRE CLEANING TO REQUIREMENTS OF MOST SENSITIVE PAYLOAD

The transporter for the canister contains instrumentation to continuously monitor the airborne particles. The monitor only counts particles greater than 0.5 μm so it is not possible to determine the numbers of large particles within the count.

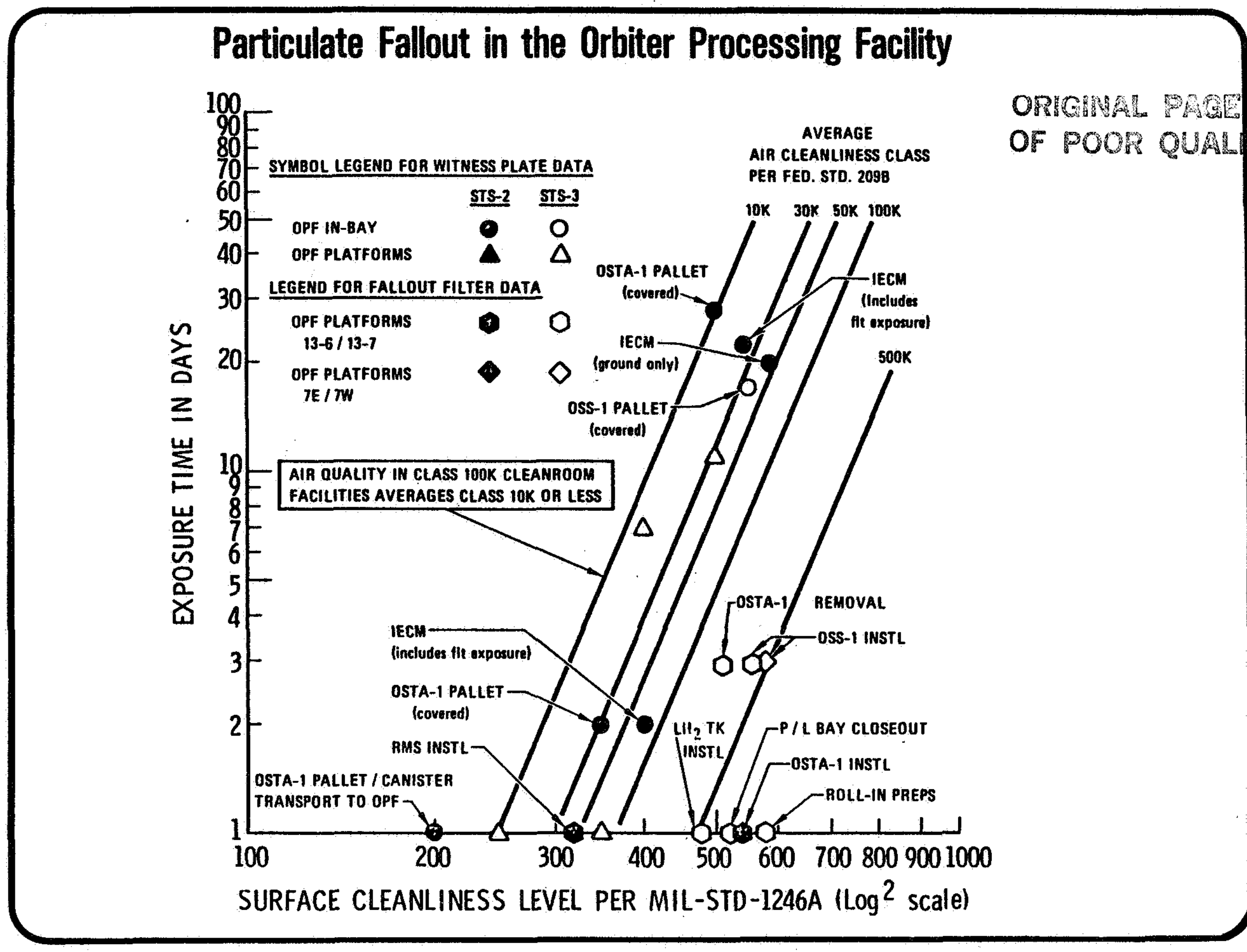
During transport, peak particle counts exceeded 10,246 per ft^3, the maximum number for the instrument scale being used. Therefore, the actual maximum count is not known.

The peak counts may occur during transport as a result of road bumps. The source could be the canister or the cargo within the canister.

Analyses of particles picked up on the Aerospace Corp. witness plates proved to be from walnut shells. Walnut shell blasting was used to remove white paint from the interior surfaces during refurbishment of the canister. The interior surfaces are unpainted aluminum and are easy to clean. However, residual walnut shell particles still appear to be in the nooks and crannies as of the STS-4 operations. Further cleaning is expected to eliminate these particles.

NVR levels appear to be low based on analyses of the Aerospace Corp. witness plates.

Since payloads could also be a major source of particles, cleanliness requirements and procedures should consider cross contamination between cargo elements. During vertical transport of the canister, the payload on the bottom of the stack could experience the most fallout.



The chart on the facing page is based on the particle fallout rate presented earlier. The vertical axis is the exposure time in days. The horizontal axis is the particulate cleanliness level from MIL-STD-1246A. The solid lines show the theoretical fallout as developed by Hamberg[(13)].

The theoretical fallout rates are calculated assuming an average air cleanliness class for the total exposure.

Data from various activities during STS-2 and STS-3 operations are plotted.[(18)] The IECM data are from Aerospace Corp. plates on the passive sample array.

It appears that significant fallout occurs during specific operations that may take place in less than one full day. These activities in addition to long exposures contribute to payload contamination.

OPF Assessment

- AIRBORNE PARTICLES
  - CLASS 200,000 TO 300,000 ARE NOT UNUSUAL
    - DEPENDS UPON ACTIVITIES
  - CLASS 10,000 TO GREATER THAN 100,000 IS OPERATING RANGE
- PARTICLE FALLOUT
  - GREATER THAN LEVEL 1000 FOR 24 hr PERIOD
  - FALLOUT ON PASSIVE SAMPLES FROM IECM APPEARS TO CORRELATE WITH EXPOSURE TO THE OPF
- NVR
  - 0.057 mg/0.1 m^2 PER 24 hr AVERAGE
  - 0.134 mg/0.1 m^2 PER 24 hr PEAK
  - INFRARED ANALYSES OF IECM SAMPLES SHOWS NEGLIGIBLE DEPOSITION
- COMMENTS
  - MODIFICATIONS TO OPF NECESSARY TO ISOLATE THE PAYLOAD BAY FROM OTHER OPF ACTIVITIES
  - CONTROL OF PROCEDURES CRITICAL TO MAINTAINING CLEANLINESS
    - FACILITY
    - PAYLOADS

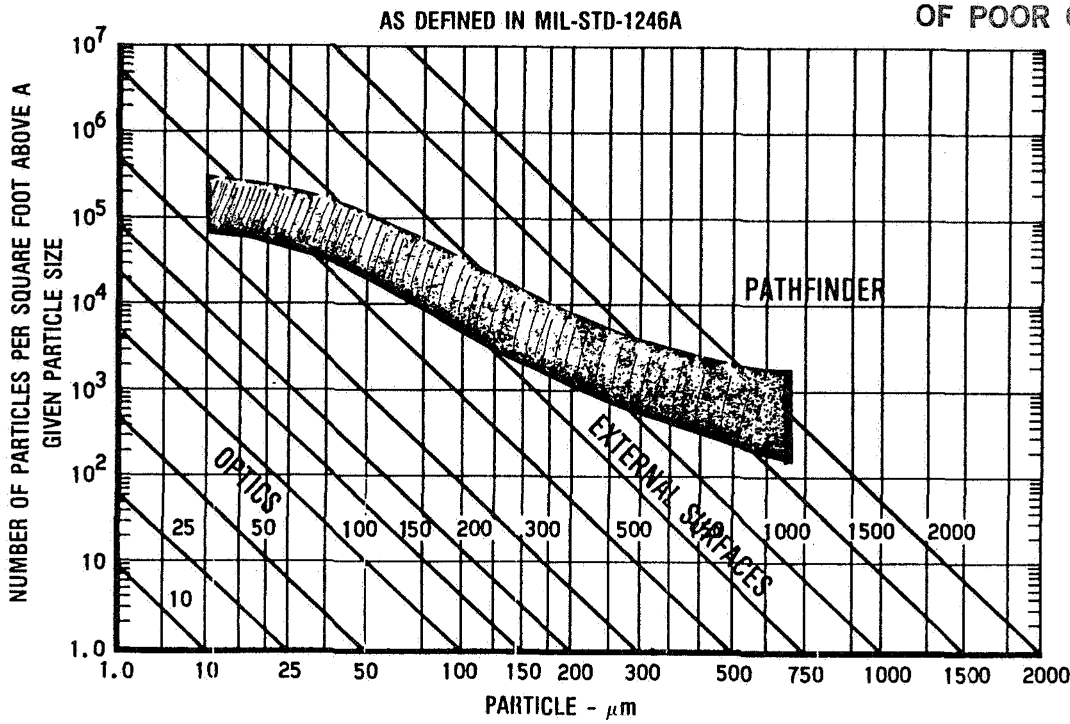
The major difficulties in the OPF are the wide range of activities that must be performed during Orbiter maintenance and cargo installation.

Based on analyses of data gathered the two high bay areas that will isolate the cargo bay from the generally "dirty" operations that are done in the OPF.

Even when these modifications are completed, it will be necessary to plan ground operations so as to protect sensitive components from the "dirty" operations.

Particle Fallout Measurements During Pathfinder Operations

PTV-D

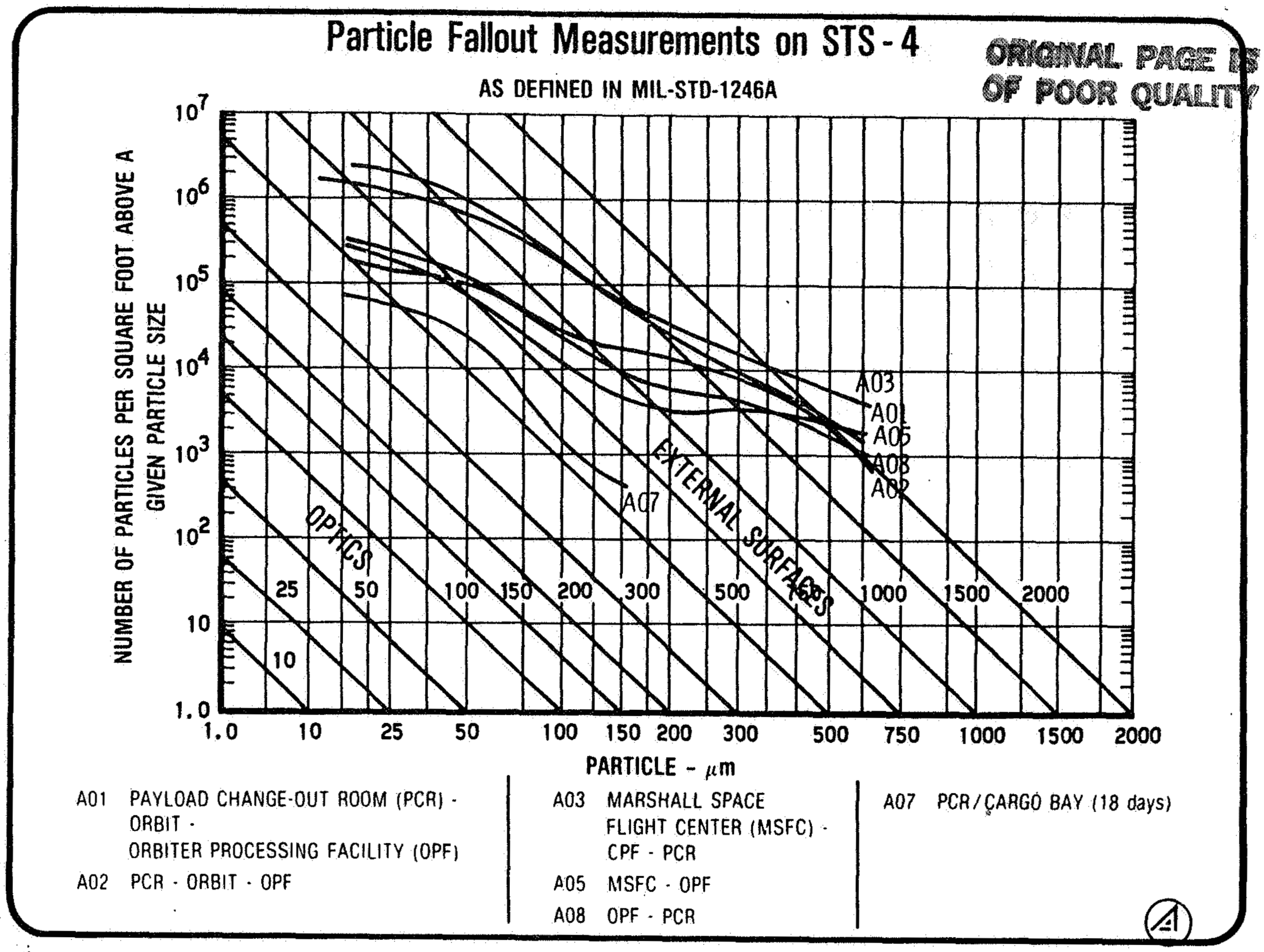


The PTV-D consisted of an IUS (Imertial Upper Stage) and a mechanical model simulating a spacecraft.

Contaminant fallout and airborne particle counts were measured at various times during the flow. The flow started in the Air Force Satellite Assembly building with the simulated spacecraft which was transported to the Vertical Processing Facility (VPF). The simulated spacecraft was integrated with the IUS in the VPF. The cargo was then placed into the canister and transported to Launch Complex 39A. The canister was mated to the Payload Changeout Room (PCR) on the Rotating Service Structure (RSS). The cargo was transferred to the Payload Ground Handling Mechanism (PGHM) in the PCR. The flow was reversed to complete the path finder program.

The band of particle fallout data on the opposite page represents exposures of 11 through 14 days on the simulated spacecraft during mating to the IUS and subsequent cargo operations.

The purpose of the PTV-D was primarily to evaluate the mechanical interfaces; therefore, there were no special contamination control procedures employed. However, the fallout data are typical of what can be expected during payload operations, but it may be possible to reduce the fallout levels during future operations.



The vertical installation of the cargo on STS-4 provided an opportunity to monitor various phases of the ground operations from the OPF to the PCR. This was accomplished by changing out Passive Sample Array trays on the IECM at times through the ground flow.

The changeout schedule was as follows:

A03 - Installed at MSFC, removed in OPF

A05 - Installed at MSFC, removed in OPF

A08 - Installed in OPF prior to bay door closing

A07 - Installed in PCR, removed prior to flight (bay door closing)

A01 - Installed in PCR, removed after flight and return to OPF

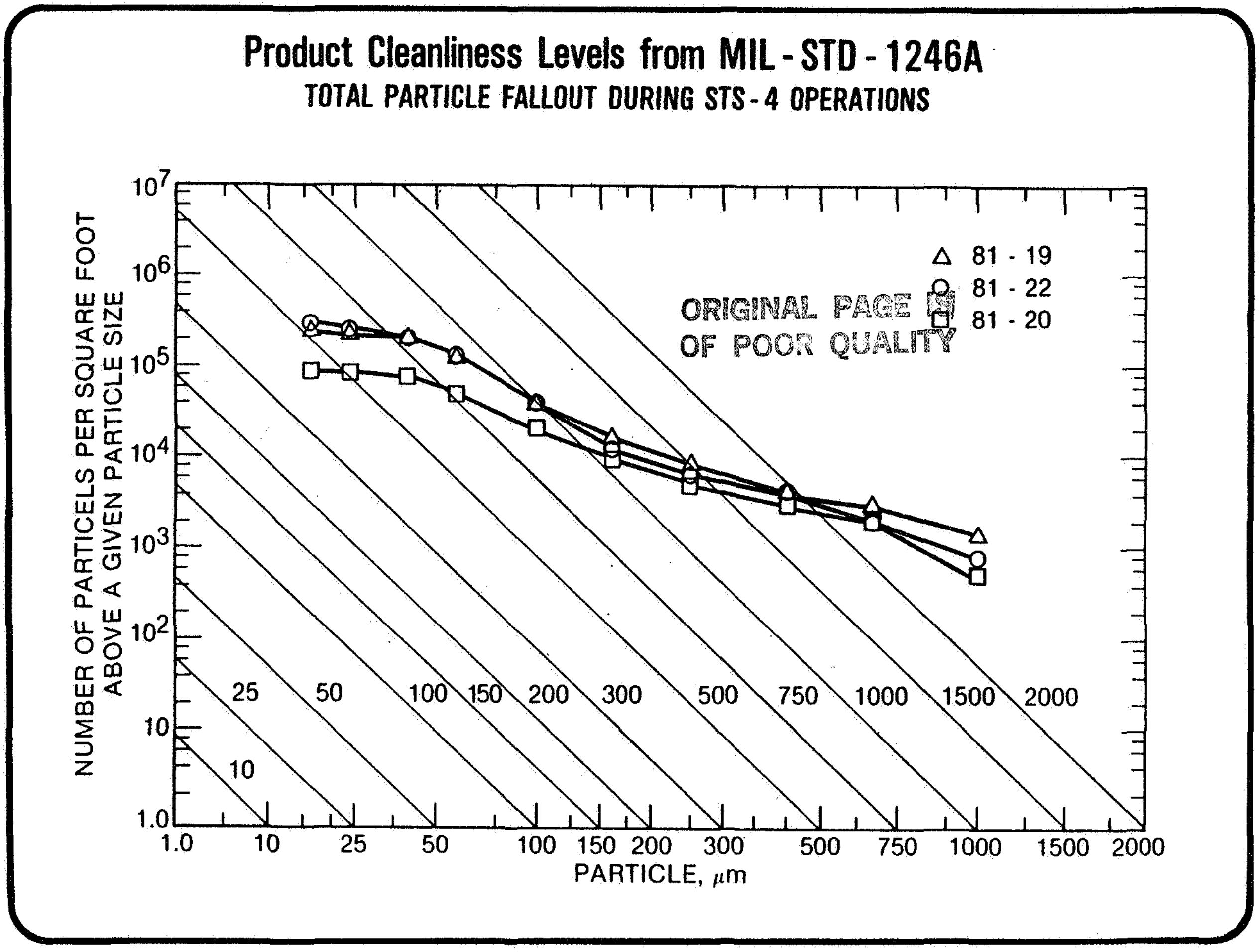
A02 - Installed in PCR prior to bay door closing (replaced A07)

The only samples that were not exposed to the OPF were on tray A07. These samples were exposed only to PCR (for 18 days). At this time the A07 samples were vertical which would reduce the fallout as compared with horizontal samples.

The flight samples (A01 and A02) stayed on the IECM during the landing at Edwards Air Force Base and the ferry flight back to KSC, and were removed from the IECM while in the OPF.

There appears to be a correlation between the particle fallout and exposure to the OPF.

Fallout was also measured during ground operations using plates on the front end of the PGHM (Payload Ground Handling Mechanism). The results are shown on page 43a. The higher levels on these samples as compared with tray A07 may result from the two factors. Tray A07 was in the Cargo Bay and the surfaces were vertical. The plates on the PGHM were horizontal.



Aerospace Corp. witness plates provided data on the fallout of particles during operations with the 82-1 payload.

Plate 81-20 was exposed for 10-2/3 days during operations in the Satellite Assembly Building (SAB).

Plate 81-19 was exposed in the payload transporter during operations from the SAB to the Verticle Processing Facility (VPF). The exposure time was 3-1/3 days.

Plate 81-22 was exposed for 21-1/4 days on the front of the PGHM (Payload Ground Handling Mechanism) during payload operations in the PCR.

The particle size distributions and numbers are similar although the locations and exposure times are quite different.

Airborne particle counts do not necessarily correlate with the fallout. In the PCR, the airborne counts were generally low, and the counters were well away from the witness plates.

It is reasonable to assume that activities in the vicinity of the witness plates were the sources for the particles.

PCR Assessment

- AIRBORNE PARTICLES
  - LESS THAN CLASS 10,000 DURING MANY OPERATIONS
  - LESS THAN CLASS 400 DURING LOW ACTIVITY LEVELS
  - CLASS 60,000 DURING PURGE FOR HYPERGOL SPILL
- PARTICLE FALLOUT
  - LEVELS DEPEND ON ACTIVITIES
  - LARGE PARTICLES TYPICAL OF LOCAL ACTIVITIES
- NVR
  - NEGLIGIBLE ON IECM PASSIVE SAMPLES
  - MAXIMUM: 0.05 mg/0.1 m^2 PER 24 hr
  - MINIMUM: LESS THAN 0.001 mg/0.1 m^2 PER 24 hr
- COMMENTS
  - CONTROL OF PROCEDURES CRITICAL TO MAINTAINING CLEANLINESS
    - FACILITY
    - PAYLOADS

As was concluded with respect to other facilities, it appears that surface contamination is the result of payload and facility activities.

The facility appears to be comparable to a class 100,000 clean room in that it operates in the class 10,000 range and drops to below class 400 when there is no or minimal activity.

Again, control of procedures and local protection are important in maintaining payload cleanliness.

NVR ON OV-102 CARGO BAY SURFACES			
LOCATION	STS-1 MG/FT^2	STS-2 MG/FT^2	STS-3 MG/FT^2
FWD, RT RADIATOR	1.14	0.33	0.15
MID, RT RADIATOR	0.80	-	-
AFT, RT RADIATOR	0.34	0.46	
AFT, LFT RADIATOR	0.26	0.15	-
FWD, LFT RADIATOR	-	0.61	-
FWD BULKHEAD	-	0.48 0.80	1.45
RT LONGERON		14.9 5.0	1.60 0.05
AFT BULKHEAD	-	0	-

ORIGINAL PAGE IS
OF POOR QUALITY

The visual cleanliness definitions from NASA SN-C-0005A (See Page 21) do not provide quantitative cleanliness levels of surfaces and possible transfer of contaminants to payloads during launch through deployment operations.

NVR (non-volatile residue) measurements were performed on various cargo bay surfaces during operations of STS-1, 2, and 3.

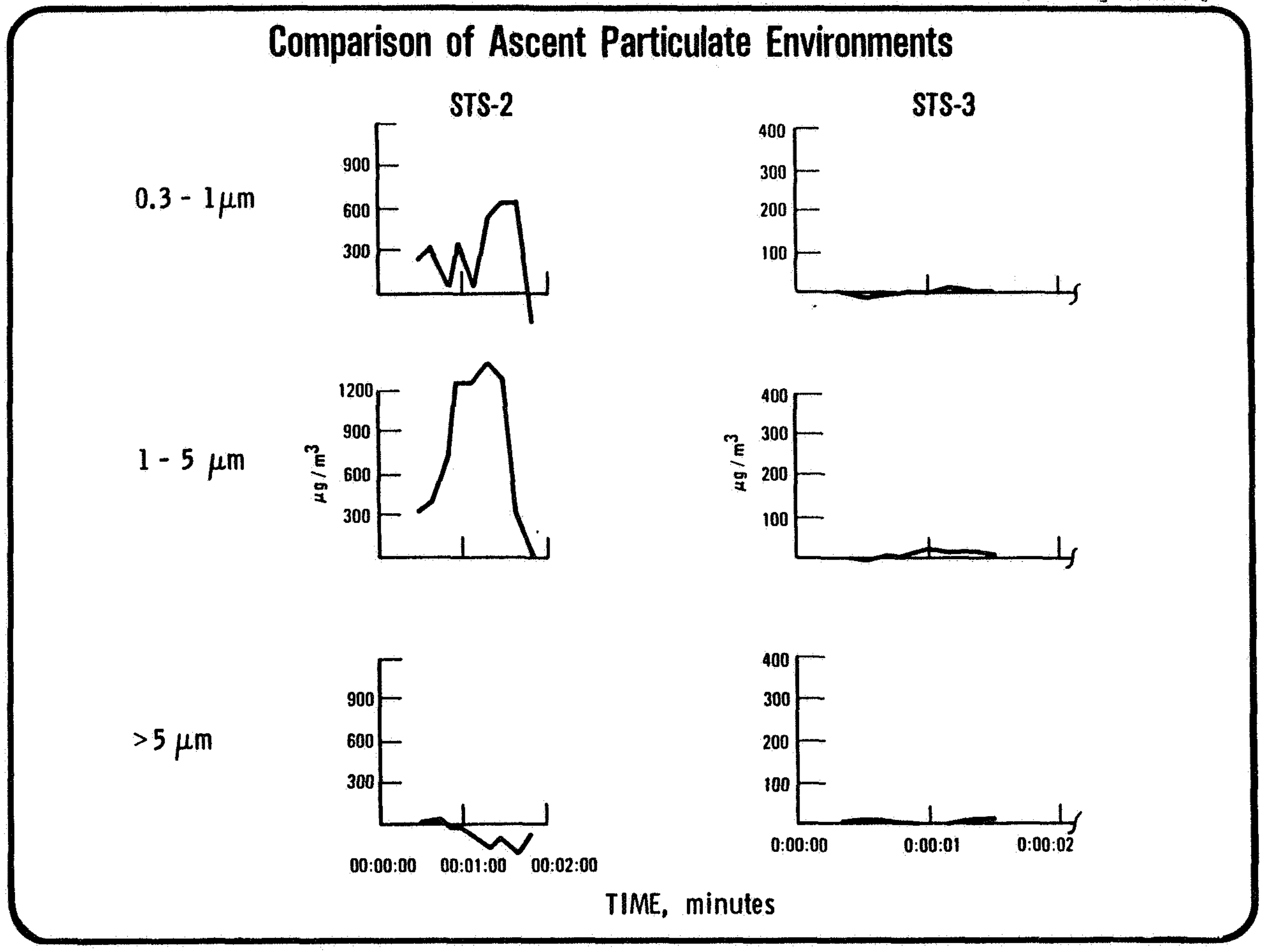
Surfaces were sampled using cotton wipes that had been soxhlet extracted to remove residual molecular contaminants. Each surface (usually 1/4 to 1 square foot) was wiped with a cloth dampened with a mixture of 1, 1, 1 trichloroethane (75%) and ethanol which had been distilled so that the solvent NVR was less than one ppm. Each surface was wiped a second time with a fresh wipe in the same manner. The cloths were extracted, using the same solvent; the extract was filtered to remove particles and evaporated; and the residue was weighed. The NVR levels are reported in mg/ft^2 which is nearly equivalent to mg/0.1m^2 and μg/cm^2. 1 mg/ft^2 is NVR level A per SN-C-0005A and MIL-STD-1246A.

The results show NVR levels that are generally acceptable for most payloads. This is good considering that no formal cleaning and inspection procedures were implemented until STS-4.

The radiators show the lowest NVR levels, probably because of generally greater care in handling.

The high NVR levels on bay surfaces during STS-2 operations may be local spots that had not been cleaned or had recently been contaminated from Orbiter activities.

The NVR measurements for STS-3 were performed after the return of Columbia to the OPF at KSC.



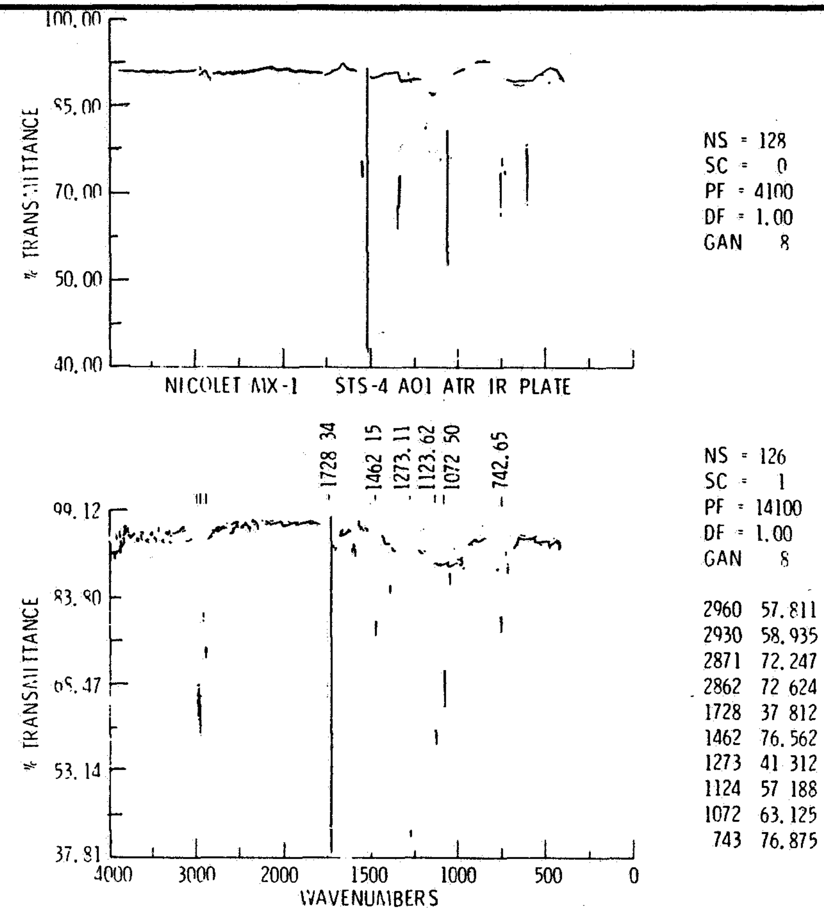
The particle data from the Cascade Impactor on the IECM are inconclusive. Also, it is not possible to deduce contamination of payloads in bay from this data.

The Cascade Impactor has three QCM (quartz crystal microbalance) stages designed to separate the particles into different size ranges. The three size ranges are 0.3 to 1 μm, 1 to 5 μm, and greater than 5 μm[15]. A single pump draws air from the cargo bay through the instrument. The data are reported in μg/m^3 of air.

The peak particle concentrations for STS-2 appear to occur during the high vibration and acoustic levels during launch[20]. Because the instrument depends upon a flow of air for operation, by approximately two minutes after Orbiter main engine ignition, the air density in the bay is too low for particles and air to be pumped. Therefore, the dropoff in particle concentrations may not indicate a reduction in particle fallout.

A comparison between STS-2[20] and STS-3[21] data tends to indicate that the cargo bay and/or payload surfaces were cleaner than those on STS-2. Results from STS-4 show concentrations greater than those from STS-3 but less than those from STS-2.

At this time it is not possible to determine the effects of particle fallout on payloads during launch because of the difficulty in interpreting the cascade impactor results and no passive samples were on the +X side (forward looking side) of the IECM. Samples on the -Z side of the IECM (looking towards the bay doors) were vertical during launch so that the air flow and particle trajectories were parallel to the surfaces. Consequently, deposition onto the surfaces could be small relative to horizontal surfaces that would be normal to the flow.



NICOLET MX-1 OCTOIL ON ATR IR PLATE EQUIVALENT TO 1 mg sq ft

KRS-5 internal reflectance elements (IRE's) (also called ATR [attenuated total reflectance] plates) were included on the Passive Sample Array of the IECM. This provided opportunities to evaluate the deposition of contaminants during ground and flight operations.

The top IR spectra on the opposite page was exposed to the Orbiter bay environment during launch and on orbit as well as the out-of-bay survey of the RCS thruster plumes and Orbiter outgassing. It was also exposed in the Orbiter bay during entry, landing at Edwards Air Force Base, the return to KSC, and to the OPF.

The lower IR spectra is from a laboratory sample coated with 1 mg/ft^2 of Octoil diffusion dump fluid. The objective was to calibrate the hydrocarbon absorption loads at 2800 to 3000 cm^{-1} and the carbonyl band at 1728 cm^{-1}.

A comparison of the two spectra showed significant quantities of silica-silicate type materials that could be from dust in the OPF.

The other absorption peaks in the above spectra could be from nitrates as a result of RCS thruster plumes or earth based air pollution.

SUMMARY/CONCLUSIONS/RECOMMENDATIONS

- O & C, VPF, CANISTER, AND PCR WILL GENERALLY PROVIDE ACCEPTABLE ENVIRONMENTS
- OPF MAY BE ACCEPTABLE WHEN MODIFICATIONS ARE COMPLETED
- FACILITY AND PAYLOAD ACTIVITIES ARE MAJOR SOURCES OF CONTAMINANTS
    - PARTICLES AND NVR
    - PLANNING AND CONTROL OF PROCEDURES IS ESSENTIAL
        - COVER SENSITIVE COMPONENTS DURING "DIRTY" OPERATIONS
        - USE LOCAL CLEAN AIR OR GAS PURGES
- DEFINE PAYLOAD CLEANLINESS REQUIREMENTS
    - NVR AND PARTICLES ON SURFACES
    - ANY SPECIAL SENSITIVITIES
- MONITORING CONTAMINATION MAY BE NECESSARY TO VERIFY CLEANLINESS
    - AIRBORNE PARTICLE COUNTS DO NOT NECESSARILY INDICATE SURFACE CLEANLINESS LEVELS

The OPF appears to be the only facility that has significant problems in meeting payload requirements. The modifications to the OPF should resolve these problems.

Although the O & C building is not a class 100,000 clean room, based on typical design criteria, it does appear to be acceptable.

It is evident, however, that even in the best clean room facilities that significant contamination results from personnel and operations within the facility.

Although particles are the major problem, there is always a possibility of molecular contaminants (NVR) as well.

Therefore, it is essential to plan facility and payload operations so as to protect payloads, especially during "dirty" activities.

The use of protective covers, HEPA filtered air purges or enclosures, and gaseous nitrogen purges may be used as appropriate to protect full spacecraft or sensitive components.

In order to plan ground operations it is necessary to define the surface cleanliness requirements for payloads and to indicate any special sensitivities that could affect the planning.

Payloads should consider the cleanliness/contamination monitoring that is necessary to verify performance. It is evident that airborne particle counts are not sufficient to verify surface cleanliness levels.

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