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THE SELF-INDUCED ENVIRONMENT AND
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A PRELIMINARY ASSESSMENT OF THE SELF-INDUCED ENVIRONMENT AND CONTAMINATION OF THE SPACE TELESCOPE

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April 1982

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Space Administration
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Greenbelt, Maryland 20771

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All measurement values are expressed in the International System of Units (SI) in accordance with NASA Policy Directive 2220.4, paragraph 4.

ABSTRACT

Preliminary estimates for the internal pressures and surface contamination of the Space Telescope have been made. The calculations for the transient pressures in the aft-shroud and telescope compartments considered two large communicating volumes that contain gaseous sources and sinks. The outgassing sources in the aft shroud consist of several scientific instruments, paints, insulations, and graphite-epoxy structure. With the exception of the instruments, these sources also exist in the telescope compartment. The outgassing functions were generated from sample test results at various temperatures and from internal pressure measurements in a vacuum test of one of the instruments. The venting occurs through combinations of series and parallel passages in both compartments. The calculated time constant of the two volumes and their respective passages, with the telescope protective door closed, is a few seconds, which is slightly less than that of the shuttle bay volume with the bay doors closed. With the telescope door closed, the pressures in the two compartments should decay to about 10E-5 torr in about 200 hours.

The contaminant deposits were assessed on the basis of expected partial pressures of the contaminant fraction of the outgassing. These partial pressures are assumed to be on the order of 0.1 to 0.01 percent of the total pressure and to be produced by the high molecular mass fractions of materials released from paints, pottings, encapsulants, and sealant materials. These pressures and the activation energies of those materials were used to calculate the adsorbed and condensed deposits on the surfaces as a function of time. It has been estimated that, after an initial large accumulation of contaminants on 25°C surface, the deposits will reduce to approximately tens of angstroms in about 150 hours if their photolyzation is prevented.

These assessments have implications for the operation and control of the telescope and have provided the basis for several recommendations on material selection, operation, design, and test of the Space Telescope.

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ACRONYMS

BET	Brunauer-Emmett and Teller equation
CCWG	Contamination Control Working Group
CFRP	Composite fiberglass reinforced plastic
FGS	Fine guidance sensor
FOC	Faint-object camera
FOS	Faint-object spectrograph
GE	General Electric Company
GSFC	Goddard Space Flight Center
HRS	High-resolution spectrograph
HSP	High-speed photometer
KSC	Kennedy Space Center
LMSC	Lockheed Missiles and Space Company
MPT	Methyl-phenil-trisiloxane
MLI	Multilayer insulation
MMC	Martin Marietta Corporation
OTA	Optical telescope assembly
RTV	A silicone product
SI	Scientific instrument
SSM	Support systems module
ST	Space Telescope
TWL	Total weight loss
VCM	Volatile condensable material
WFPC	Wide-field and planetary camera

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INTRODUCTION

The Space Telescope (ST) is a large telescope that the National Aeronautics and Space Administration (NASA) will place in orbit during 1985, using the Space Shuttle. The ST is comparable in size to the larger telescopes at observatories on Earth. It will orbit at a 480- to 590-kilometer altitude at an inclination of 28.8 degrees and will weigh about 11,000 kilograms. It will be a cylinder 14.02 meters long with a diameter of 4.27 meters, excluding the solar arrays. The telescope primary mirror is 2.4 meters in diameter. The ST will produce near-diffraction limited images. The size of the image will be 0.1 arc-seconds, which will permit the detection of objects of 28 visual magnitudes corresponding to objects 5 magnitudes fainter (100 times) than those that are observable from the ground. The ST instrumentation will cover the spectral range from 1150 angstroms (Å) to 1 millimeters. The ST vehicle consists of three parts: the optical telescope assembly (OTA), the support systems module (SSM), and the scientific instruments (SI's). The SSM contains the subsystems that are necessary for power, communications, attitude control, fine pointing, data management, and thermal control. The SI consists of four axial mounted instruments and four radially mounted sensor systems. The axial instruments are the faint-object camera (FOC), the faint-object spectrograph (FOS), the high-resolution spectrograph (HRS), and the high-speed photometer (HSP). The radially mounted systems are the wide-field and planetary camera (WFPC) and three fine-guidance sensors (FGS). Figure 1 shows the configuration and locations of the major components of the ST.

This document describes the preliminary assessment of the internal pressures of the OTA and the SI compartments of the telescope and the calculations of the average contaminant deposits to be expected on generic surfaces at 25°C in these compartments.

The need for the estimates of the pressure versus time at these locations arises from several concerns:

- The time when detectors in the instruments can be cooled without being deteriorated by gaseous deposits
- The time when high-voltage apparatus can be energized without danger of voltage breakdown
- The time when internal gaseous densities are low enough to permit optimum data acquisition
- The time when molecular-released desorption from surfaces or diffusion from the materials are so low that they may not deposit on critical surfaces

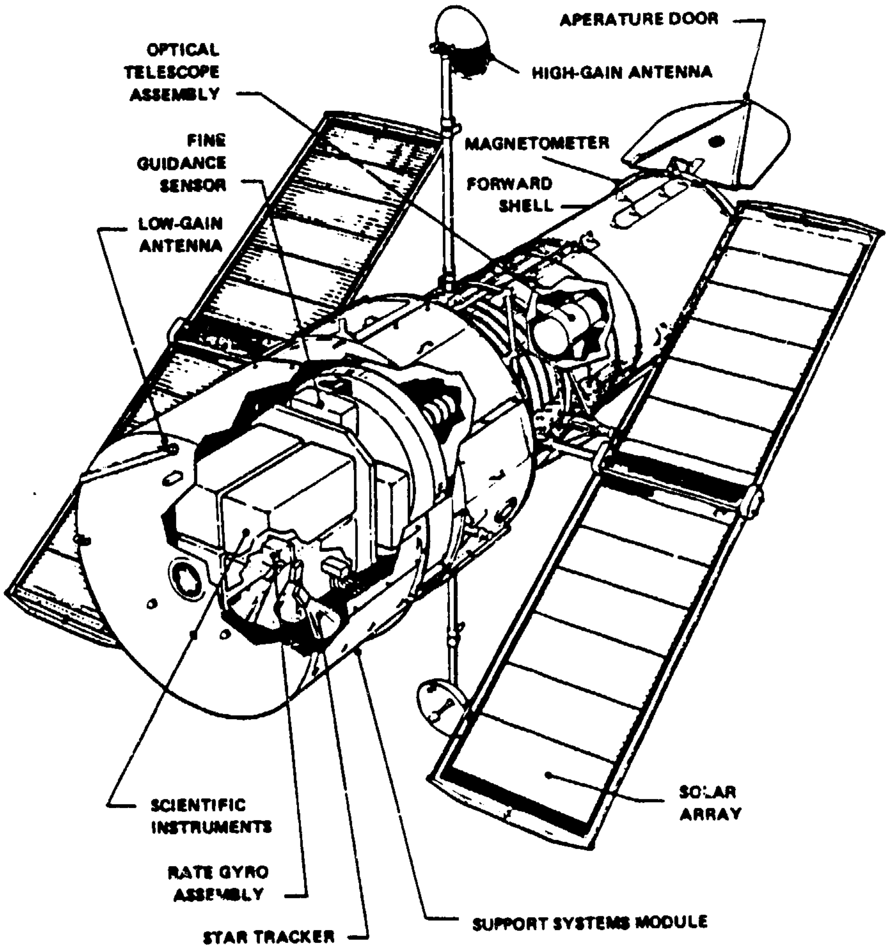


Figure 1. Space Telescope Configuration

- The time when the outgassing from the telescope fails to create an environment around the telescope that scatters, absorbs, or reradiates the incoming radiations from weak distant sources
- The time when the ST should separate from the Shuttle to prevent its internal pressure from being limited by the bay pressure
- The degree of venting required for each instrument so that it will vent as rapidly as the ST plenums

The assessment of the average contaminant deposits to be expected on a surface is needed for:

- Estimating the effect that these deposits will have on the telescope and instrument operation
- Taking appropriate measures to reduce and prevent those deposits
- Estimating how long to allow for some of the contaminants to leave those surfaces

- Estimating when to expose those surfaces to external radiations that may permanently change the nature of the residual deposits

APPROACH

For the purpose of this analysis, the ST has been divided into two large volumes: (1) the telescope volume, which communicates with the exterior through the telescope aperture door and with the aft-shroud volume through the primary mirror passage and secondary mirror reflected beam passage, and (2) the aft-shroud volume, which contains the scientific instruments. The aft-shroud volume can vent locally through passages provided on its cylindrical surface and through the telescope volume via the telescope door. The equivalent conductance for each volume and for the combined volumes was calculated for the molecular flow regime for the two operating conditions of the telescope door either open or closed. The conductances in the continuum flow regime were calculated previously (Reference 1) to establish the venting of the ST during the launch phase of the flight.

The two volumes include the sources of outgassing. The sources in the aft-shroud that have been considered are:

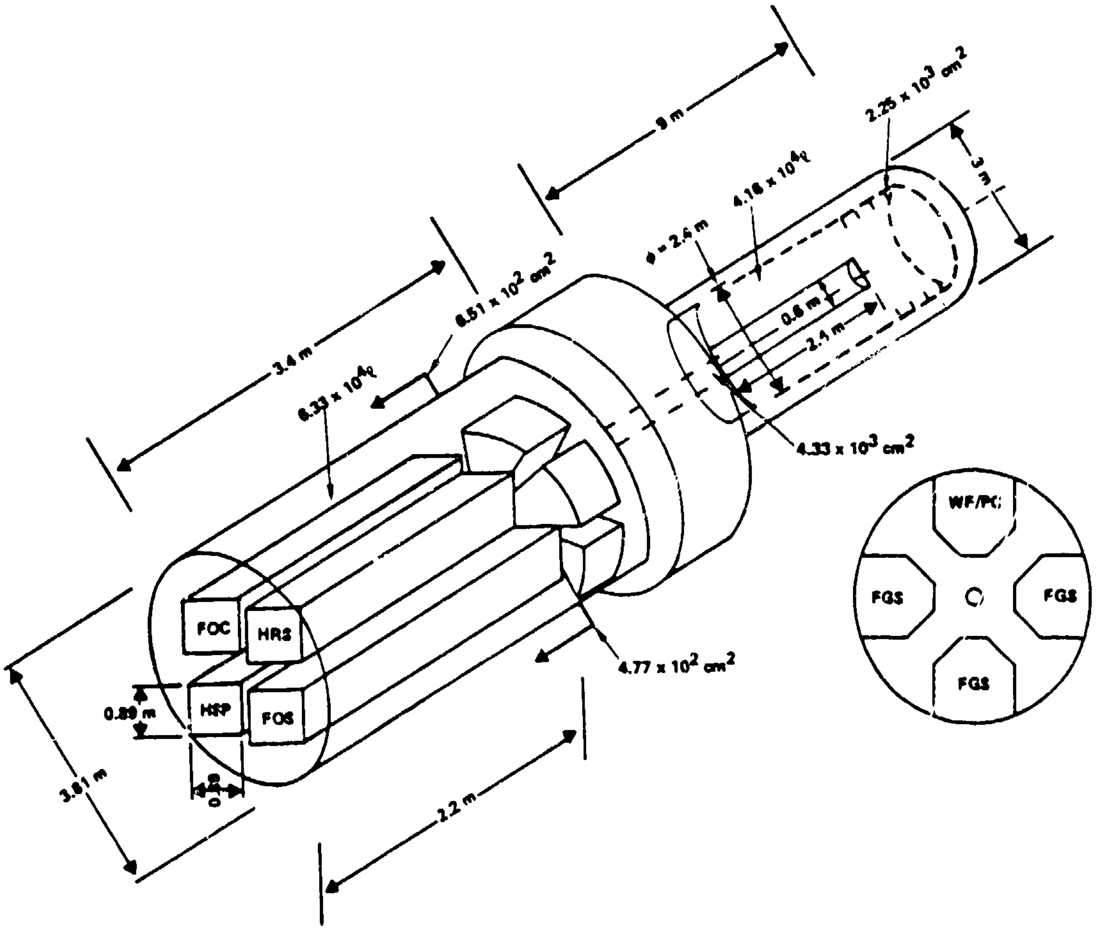
- The four scientific instruments and the four sensor systems, each with a total source of outgassing issuing from their venting passages
- The epoxy paint (Z-306 w/9922) that is assumed to cover the external surfaces of the instruments and the interior surface of the volume
- The multilayer insulation (MLI) that covers the instruments and the interior surface of the volume.
- The outgassing from the epoxy-graphite structure of the telescope (CFRP-GE)

The outgassing sources in the telescope-tube volume are the paint and the structure. Figures 2 and 3 show the two volumes and the respective sources and sinks. The sources are described as a function of time and temperatures, using data from the literature and from sample test results. The pressure versus time for each volume was calculated from the conditions of open and closed telescope door, using the calculated conductances and the functions of the outgassing sources.

The contaminant deposit versus time on a surface was calculated on the basis of the partial pressures of the contaminant fraction that makes up the total pressures in the two volumes, the chemical characteristics of the contaminants such as the saturated vapor pressures, and their activation energies for condensation/evaporation and adsorption/desorption. The adsorption/condensation and desorption/evaporation were calculated as a function of time for a surface at 25°C. These calculated results for the expected pressures and contaminant deposits are shown graphically. Finally, the conclusions and recommendations resulting from the analysis are discussed.

ST GEOMETRIC DATA, CONDUCTANCES, AND VOLUME RESPONSES

Figures 1 and 2 show the basic configuration and the geometrical dimensions that were used in the analysis. It is assumed that the instruments and sensor systems are basically the same in weight, external dimensions, and outgassing properties. The sensors are considered to be the same as the instruments and are referred to as such in this document. Their volumetric and venting dimensions and the resulting flow parameters are listed in Table 1.



AXIAL SI (4)
FOC-ESA, 317.1 kg (700 LB)
HRS-GSFC/BASD, 317.1 kg (700 LB)
HSP-U. WISC., 271 kg (600 LB)
FOS-UCSD/MMC, 317 kg (700 LB)

RADIAL SI (4)
WF/PC-CIT/JPL 271.8 kg (600 LB)
FGS/PE
FGS/PE
FGS/PE

Figure 2. ST approximate dimensions and configuration for gas flow and contamination assessment.

The venting for the aft shroud is accomplished through:

- A passage (A_i) with an entrance area of 6.51 X 10^2 cm^2 and a tortuous slot passage that has a calculated equivalent length of 36.32 cm
- A second passage (A_2) of area 4.77 X 10^2 cm^2 and equivalent length of 35.05 cm
- An equivalent orifice (A_3) of area 4.33 X 10^3 cm^2 leading into the telescope volume

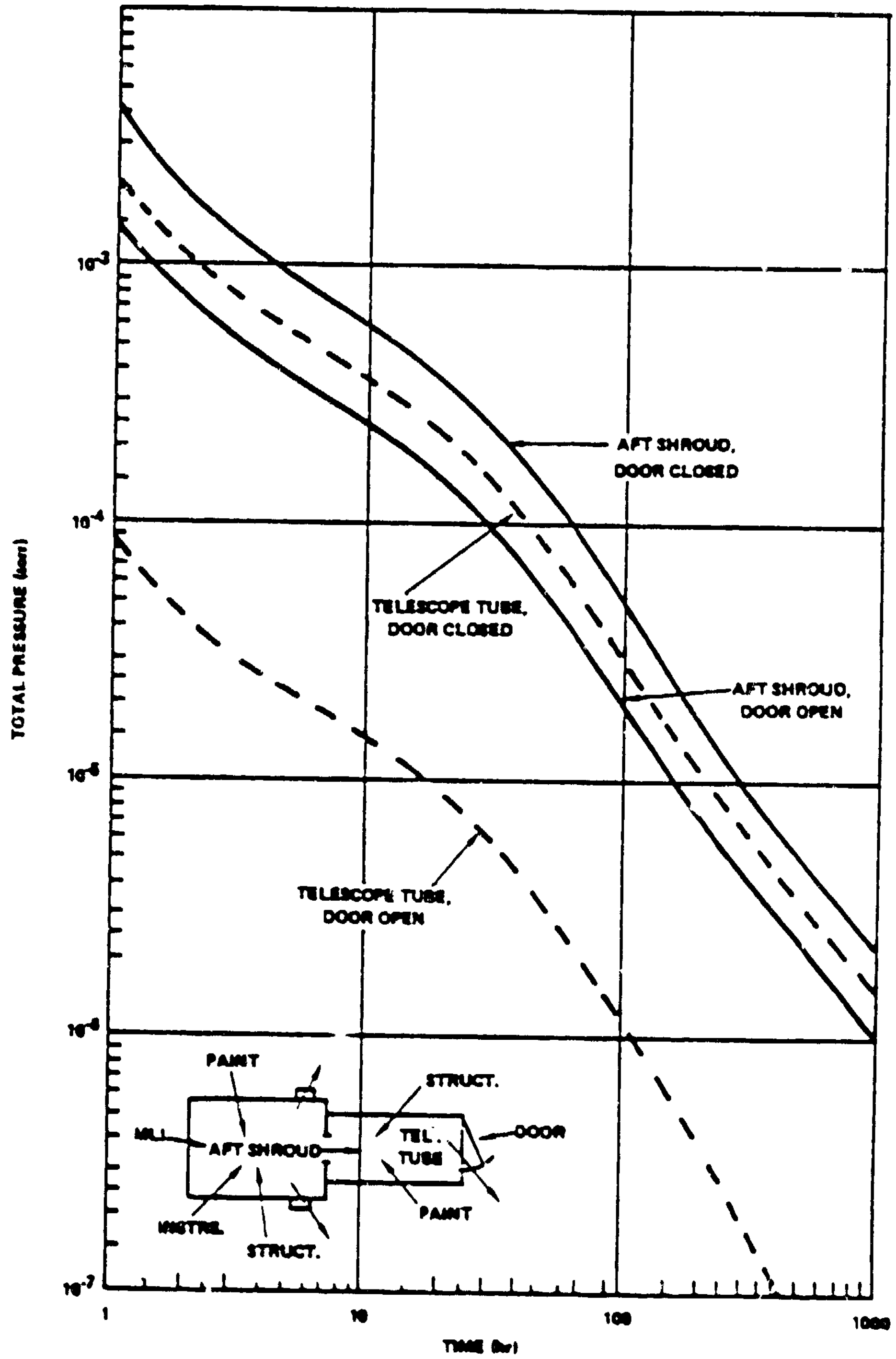


Figure 3. Total pressures in the aft shroud and the telescope tube.

Table 1
Space Telescope Calculated Parameters

	Volume (ℓ)	Venting Area (cm^2)		Conductance (ℓ/s)		Time Constant (s)	
		Closed Door	Open Door	Closed Door	Open Door	Closed Door	Open Door
Aft shroud	6.3×10^4	6.51×10^2 (36.3 cm) 4.77×10^2 (35 cm) 4.33×10^3		2.8×10^4	6.37×10^4	2.25	1.0
Telescope tube	4.16×10^4	2.25×10^3	7.2×10^4	3.42×10^4	9.91×10^5	1.21	0.04
Aft shroud plus telescope tube	1.05×10^5	–	–	3.86×10^4	9.94×10^5	2.71	0.105
Instrument (each)	$\sim 1.78 \times 10^3$	$\sim 2 \times 10^2$		$\sim 2 \times 10^3$		0.8	
Shuttle bay	3.5×10^5	5.0×10^3	>>	7.3×10^4	>>	4.78	>>

The telescope volume can vent through A_{4o}, which has an area of 7.2×10^4 cm^2 when the telescope door is fully open or a vent passage (A_{4c}) equal to 2.25×10^3 cm^2 when the door is closed. The molecular flow conductance (C) for an orifice of equivalent area (A_e (cm^2)) as obtained from kinetic theory (reference 2) is:

$$C = \frac{\nu}{4} A_e = \frac{1}{4} \sqrt{\frac{8RT}{\pi M}} A_e \qquad (1)$$

$$= 3.64 \sqrt{\frac{T}{M}} \; A_e \quad (\ell/s)$$

where ν is the average velocity of the molecules of a gas having a mass (M (gram/mole)) and temperature (T (K)), and R is the universal gas constant, which is 8.314×10^7 erg/g mole/K. The equivalent areas (A_e (cm^2)) were estimated using the Dushman approximation (Reference 2) for a conductance that has an entrance aperture (A) with an equivalent diameter ($D = \sqrt{4/\pi A}$) and a pipe length of L(cm); that is,

$$A_e = A \left(1 + \frac{4}{3} \frac{D}{L}\right)^{-1} \quad (cm^2) \qquad (2)$$

The equivalent conductance for a volume that has several conductances (C_i) in parallel connections is:

$$C_e = \sum_i C_i \qquad (3)$$

If the conductances are in series connection, the equivalent conductance is:

$$\frac{1}{C_e} = \sum_i \frac{1}{C_i} \qquad (4)$$

The calculated conductances for each vent passage for M = 18 g/mole and T = 293 K are as follows:

Equivalent Area of Entrance (cm²)	Conductance (ℓ/s)
$A_1 = 3.16 \times 10^2$	$C_1 = 4.33 \times 10^3$
$A_2 = 2.47 \times 10^2$	$C_2 = 3.38 \times 10^3$
$A_3 = 4.33 \times 10^3$	$C_3 = 5.93 \times 10^4$
$A_{4c} = 2.25 \times 10^3$ (closed)	$C_{4c} = 3.09 \times 10^4$
$A_{4o} = 7.2 \times 10^4$ (open)	$C_{4o} = 9.87 \times 10^5$

The equivalent conductance of the aft-shroud volume is a parallel combination of conductances C_1, C_2, and C_{34}, where C_{34} is the series connection of conductances C_3 and C_{4o} or C_{4c}. Therefore, the equivalent conductance of the aft-shroud volume with the telescope door closed is:

$$C_{ac} = C_1 + C_2 + \frac{C_3 \quad C_{4c}}{C_3 + C_{4c}} \qquad (5)$$

$$= 2.802 \times 10^4 \quad (\ell/s)$$

The conductance with the door open is:

$$C_{ao} = C_1 + C_2 + \frac{C_3 \quad C_{4o}}{C_3 + C_{4c}} \qquad (6)$$

$$= 6.37 \times 10^4 \quad (\ell/s)$$

The telescope volume has an equivalent conductance that is a parallel combination of C_4 and the series combination of $(C_1 + C_2)$ and C_3. The closed-door conductance is then:

$$C_{Tc} = C_{4c} + \frac{(C_1 + C_2) \times C_3}{(C_1 + C_2) + C_3}$$

$$= 3.42 \times 10^4 \quad (\ell/s) \qquad (7)$$

and the open-door conductance is:

$$C_{To} = C_{4o} + \frac{(C_1 + C_2) \times C_3}{(C_1 + C_2) + C_3} \qquad (8)$$

$$= 9.91 \times 10^5 \quad (\ell/s)$$

The equivalent conductance of the ST, taken to consist of a single volume made up of the aft-shroud and telescope volumes, for the closed-door condition is:

$$C_c = C_1 + C_2 + C_{4c} = 3.86 \times 10^4 \quad (\ell/s) \quad (9)$$

and that for the open-door condition is:

$$C_o = C_1 + C_2 + C_{4o} = 99.4 \times 10^4 \quad (\ell/s) \quad (10)$$

The venting conductances of the various instruments and sensors are not known except for that of the FOC, which is reported in Reference 3 to have a conductance of 2×10^3 ℓ/s. This implies a venting area of about 2×10^2 cm². It is assumed that all the other instruments and sensors that have approximately the same volumes and weights as the FOC will have about the same conductance.

The volumes of the aft-shroud, of the telescope, and of each instrument were estimated using the dimensions shown Figure 2. They are 6.3×10^4 ℓ for the aft shroud, 4.16×10^4 ℓ for the telescope, and 1.78×10^3 ℓ for each instrument.

The response of the various volumes is characterized by their time constants, defined as the time for the 1/e pressure drop and is given by the expression $\tau = V/C$ (sec). It was calculated to be 2.25 and ~1 seconds for the aft-shroud volume with the telescope door closed and open, respectively; 1.21 and 0.04 seconds for the telescope volume with door closed and open, respectively; and 2.71 and 0.105 seconds for the total ST with door closed and open, respectively. The time constant for the instruments has been estimated at 0.8 second. These calculated parameters are listed in Table 1 for convenience. Table 1 also shows the estimated equivalent parameters of the shuttle bay. With its doors closed and with venting through about 0.5 m^2 filtered ports, the bay has a time constant of about 4.78 seconds.

OUTGASSING SOURCES

The major sources of outgassing in the two volumes are the eight instruments, the paint, the structure, and the multilayer insulation (Table 2). A functional description of each of these sources follows.

Instrument Outgassing

Experiment data on the outgassing of the FOC instrument is reported by R. Thomas (Reference 3), who shows that the pressure inside the instrument at 17°C decreased inversely with the first power of time (hours) and that it measured about 3×10^{-3} torr after 1 hour of test time. These data and the given pumping speed for the FOC, $S = 2 \times 10^3$ ℓ/s, indicate that the outgassing throughput, in pv units, was:

$$Q = \frac{P}{t} \times S = \frac{6}{t} \quad (\text{torr } \ell/\text{s}) \qquad (11)$$

where t = hours. Because no other data were available and because all eight instruments weigh on the average approximately 295 kg, it was assumed that the total outgassing from the instruments is 8 times that of the FOC and that the pressure will decay in the same manner. Therefore, the cumulative outgassing rate of the instruments was taken as:

$$Q_{PI} = 48/t \quad (\text{torr } \ell/\text{s}) \qquad (12)$$

where t = hours. Note that, when many materials are outgassing simultaneously, the linearly decaying function of time for the outgassing is often measured experimentally.

Outgassing Rate of Paint (Z-306 w/9922)

The outgassing rate of this paint was obtained from an interpretation of the test results obtained by C. Vest, Goddard Space Flight Center (GSFC), on sample mass losses versus times and temperatures; by J. Muscari, Martin Marietta Corporation (MMC), from thermogravimetric tests on the same material; and by Lockheed Missiles and Space Company (LMSC) from results on the percent of mass-loss of the material. These data are reported in Reference 3 on pages 49, 62, and 56, respectively. According to GSFC tests, this material lost 0.121 mg/cm^2 after 912 hours of vacuum exposure at temperatures varying from 22° to 50°C. The temperature was varied in steps of about 10°C, remaining at each step about 20 hours, except for the 50°C temperature step, which was held for about 832 hours. The LMSC data indicate that the test percentage mass loss of a sample 5.03 by 5.03 cm at 125°C for 24 hours was 0.94 percent, which, when using a density of 1 g/cm^3 and a thickness of about 0.068 cm, corresponds to a mass loss of about 0.32 mg/cm^2. The MMC test on emission measurements of the deposited material indicated activation energies of 14,700 and 18,700 cal/mole with frequency factors of 2.7×10^{11} min^{-1} and 3.5 and 10^{12} min^{-1}, respectively, for two emitted materials. Reference 4 shows that, for

Table 2
Major Outgassing Sources

	Quantity	Surface (cm^2)	Weight (kg)	Outgassing Rate (torr ℓ/s); t(hr)	Notes
Instruments	8	–	~318 ea	48/t	Data from FOC T/V test Ref. CCWG 12/80
Aft-shroud paint (Z-306 + 9992)	–	1.43×10^6	–	$2.8 \times 10^2 e^{-t/0.27}$	From test sample data of MMC & GSFC Ref. CCWG 12/80
Telescope tube paint (Z-306 + 9992)	–	2.06×10^6	–	$4.01 \times 10^2 e^{-t/0.27}$	Same as above
Structure [CFRP. (GE)]	–	–	516	$12.6 e^{-t/34.4}$	From test on 20 lb by MMC Ref. as above
Multilayer insulation (double aluminized Mylar 6.35 μm thick)	5000	1.42×10^{10}	-	24/t	From LMSC tests Ref. J. Vac ST Vol. 17(3) 6/80

a first-order reaction, the total mass loss is given by $M = m_o (1 - e^{-t/\tau})$ and the mass rate $\dot{m}$ is given by $\dot{m} = \frac{m_o}{\tau} e^{-t/\tau}$, where m_o is the mass per unit area available for outgassing and $\tau = \tau_o e^{E/RT}$ is the residence time at a temperature (T) for an outgassing activation energy (E). The pre-exponential factor (τ_o) is the inverse of the frequency factor. The following values, $m_o = 0.32$ mg/cm², $\tau_o = 1/3.5 \times 10^{12}$ minutes, E = 18.7 kcal/mole, T = 298 K, R = 1.978 cal/mole K, were used to calculate $\tau = 0.27$ hours and the rate at 298 K to be $\dot{m} = 3.21 \times 10^{-7} e^{-t/0.27}$ g/cm²/s, which, when expressed in pv units (i.e., multiplied by $P_o V_o/M_o$ (torr ℓ/g)), becomes:

$$Q = 1.95 \times 10^{-4} e^{-t/0.27} \text{ (torr ℓ/cm}^2\text{/s)} \quad (13)$$

The surface area covered by this paint was estimated to be about 1.43×10^6 cm², including the internal surface of the aft-shroud volume and the external surface areas of the eight instruments. The dimensions used are those shown in Figure 2. As a result, the outgassing of the paint in the aft shroud was estimated to be:

$$Q_{P_a} = 2.8 \times 10^2 \quad e^{-t/0.27} \quad (\text{torr } \ell/\text{s}) \qquad (14)$$

where t = hours.

The estimated surface area of the paint in the telescope volume is 2.06×10^6 cm^2. This estimate includes the cylindrical area (doubled in length to account for the ribs), the central 2.4 m long baffle (shield) and nine 15 cm wide baffles.

The paint outgassing source in the telescope was therefore taken as:

$$Q_{P_t} = 4.01 \times 10^2 \quad e^{-t/0.27} \quad (\text{torr } \ell/\text{s}) \qquad (15)$$

where t = hours.

Structure (CFRP) Outgassing

As reported by Thomas (Reference 3), a test performed by MMC on 9.1 kg of this material, presumably as it will be used on the ST, at a temperature of 20°C indicated a mass loss that can be expressed as:

$$M = 29.29 \left(1 - e^{-4.84 \times 10^{-4} t}\right) \quad (\text{g}) \qquad (16)$$

where t = minutes. Because this expression indicates a first-order reaction, the expressions previously indicated for paint are applicable. The mass loss per unit mass is:

$$m_s = 3.21 \times 10^{-3} \left(1 - e^{-t/34.4}\right) \quad (\text{g/g}) \qquad (17)$$

where t = hours and $\tau = 1/4.84 \times 10^{-4}$ minutes = 34.4 hours. The rate will be:

$$\dot{m} = \frac{m_s}{\tau} e^{-t/\tau} = 2.58 \times 10^{-8} \, e^{-t/34.4} \quad (\text{g/g/s}) \qquad (18)$$

or in pv units:

$$q = 2.44 \times 10^{-5} \, e^{-t/34.4} \quad (\text{torr } \ell/\text{g/s}) \qquad (19)$$

It has been estimated that the total weight of the structure will be 5.164×10^5 g (1140 lb); therefore, the total outgassing rate of the structure will be:

$$Q_s = 12.6 \, e^{-t/34.4} \quad (\text{torr } \ell/\text{s}) \qquad (20)$$

Thomas (Reference 3) stated that the outgassing from that material had been reported to be almost entirely water.

Multilayer Insulation

At the time of this assessment, the number of layers, their locations, and their attachments have not been established. It has been conservatively assumed for reasons that will be clear later that approximately 5000 layers of insulation will cover the internal surface of the ST and all the instruments. It is expected that part of the ST insulation will be vented internally. In Reference 5, an embossed, double-aluminized, 6.35-μm thick Mylar exhibited a linear outgassing rate of $3.6 \times 10^{-12}/t$ g/cm^2-s, or:

$$q = \frac{3.4 \times 10^{-9}}{t} \quad (\text{torr } \ell/\text{s/cm}^2) \qquad (21)$$

where t = hours.

As with the paint, the surface area was taken as 1.42×10^6 cm^2, and for the chosen very conservative number of layers, the total outgassing will be:

$$Q_M = \frac{2.4 \times 10^1}{t} \quad (\text{torr } \ell/\text{s}) \qquad (22)$$

PRESSURE TIME HISTORY

The rate of pressure change in a volume (V_i) that includes Q_i sources of outgassing has a gaseous inflow, C_{ij} (P_j - P_i), and an outflow, L_{ij} (P_i - P_j), with adjacent volumes can be expressed (Reference 6) as:

$$\dot{P}_i = \frac{1}{V_i} \left[\sum_n Q_i + \sum_{j=0}^{N} (C_{ij} + L_{ij}) (P_j - P_i) \right] \qquad (23)$$

$$(\text{torr/s})$$

The solution of this equation for $P_j << P_i$, $(C_{ij} + L_{ij}) = C_e$ and an initial pressure ($P_i = P_o$) is:

$$P_i = P_o \; e^{-t/\tau} + \frac{\Sigma Q_i}{C_e} \; (\text{torr}) \qquad (24)$$

where $\tau = V_i/C_e$ seconds is the volume time constant. The transient pressure contribution decays very rapidly for a small time constant. Because the ST time constant, as previously calculated, is on the order of 3 to 4 seconds for either open- or closed-door conditions, the pressure will approach the steady-state pressure as dictated by the outgassing sources in about 30 seconds. The quasi-steady pressure in the volume is then:

$$P_i = \frac{\sum^{n} Q_i(t)}{C_e} \quad (\text{torr}) \qquad (25)$$

where P_i is the total pressure in the volume produced by the sum of pressures contributed by each outgassing source.

AFT-SHROUD PRESSURE

The ST will be launched with the telescope door closed, and the door will remain closed for a number of hours. The length of time the door will remain closed is predicated on factors such as protection of critical surfaces against external contaminants and exposure to sun radiations, temperature stabilizations, and time required for the systems to outgas sufficiently. The pressure in the aft-shroud and telescope volumes must be calculated for the telescope door both open and closed.

Telescope Door Closed

The conductance of the aft-shroud volume with the telescope door closed was calculated to be C_{ac} = 2.802 X 10^4 ℓ/s. The sources of outgassing in this volume are Q_{PI} for the instruments, Q_{Pa} for the paint, Q_s for the structure, and Q_M for the insulation. In addition, there will be a contribution of the paint outgassing in the telescope volume when the door is closed. This contribution can be expressed in terms of conductances as:

$$Q_{Pt} \; \frac{C_3}{C_3 + C_{10}} \sim 0.65 \; Q_{Pt} \qquad (26)$$

where Q_{Pt} is the outgassing of the paint in the telescope section and going into the aft shroud. Using equation 25, the aft-shroud total pressure with the door closed is given by:

$$P_{ASC} = \frac{1}{C_{ac}} \left[Q_{PI} + Q_{Pa} + Q_s + Q_M \right]$$

$$= P_{PI} + P_{Pa} + P_s + P_M$$

or

$$P_{ASC} = \frac{1}{2.802 \times 10^4} \Big[48 \, t^{-1} + 5.43 \times 10^2 \qquad (27)$$

$$e^{-t/0.27} + 12.6 \, e^{-t/34.4} + 24 \, t^{-1} \Big] \quad (\text{torr})$$

where the first term on the right is the instrument outgassing, the second is the paint, including the contribution from telescope volume, the third is the structure, and the last is the insulation outgassing. Figure 3 shows the calculated values of P_{ASC} versus time, and Figure 4 shows the pressures produced by the individual outgassing that contributed to this total pressure.

Telescope Door Open

When the door is open, the conductance of the aft shroud is $C_{ao} = 6.37 \times 10^4$ ℓ/s. The outgassing sources are the same as those with the door closed except that the contribution of the telescope paint will be:

$$Q_{Pt}\left(\frac{C_3}{C_3 + C_{4o}}\right) = 5.6 \times 10^{-2}\, Q_{Pt} \qquad (28)$$

The aft-shroud pressure with door open is therefore:

$$P_{ASO} = \frac{1}{6.37 \times 10^4}\left[48\, t^{-1} + 3.02 \times 10^2\, e^{-t/0.27} + 12.5\, e^{-t/34.4} + 24\, t^{-1}\right] \text{(torr)} \qquad (29)$$

The significance of each member on the right is the same as that of equation 27. The total pressure is shown in Figure 3.

TELESCOPE-VOLUME PRESSURE

The pressure in the telescope volume is maintained by its paint outgassing and the fraction of the outgassing contributed by the aft-shroud volume, which can be expressed as:

$$(Q_{PI} + Q_{Pa} + Q_S + Q_M)_{AS}\left(\frac{C_3}{C_1 + C_2 + C_3}\right) \qquad (30)$$

$$= 0.87\,(Q_{AS})$$

Therefore, the pressures in the telescope for the door both closed and open are as follows.

Telescope Door Closed

The conductance of the telescope volume with the door closed is calculated as $C_{Tc} = 3.42 \times 10^4$ ℓ/s. The pressure is therefore:

$$P_{TC} = \frac{1}{C_{Tc}}\left[0.87\, Q_{AS} + Q_{PaT}\right]$$

$$= P_{PI} + P_{Pa} + P_S + P_M$$

or explicitly,

$$P_{TC} = \frac{1}{3.42 \times 10^4}\left[41.76\, t^{-1} + 6.44 \times 10^2\, e^{-t/0.27} + 10.4\, e^{-t/34.4} + 20.8\, t^{-1}\right] \text{(torr)} \qquad (31)$$

This total pressure in the telescope is shown in Figure 3.

Telescope Door Open

The outgassing contribution from the aft shroud is the same as that of equation 30 (i.e., 87-percent Q_{AS}). However, the conductance of the telescope with the door open is $C_{To} = 9.91 \times 10^5$ ℓ/s, and the total pressure is:

$$P_{TO} = \frac{1}{C_{To}}\left[0.87\, Q_{AS} + Q_{PaT}\right]$$

$$= \frac{1}{9.91 \times 10^5}\left[41.76\, t^{-1} + 6.44 \times 10^2\, e^{-t/0.27} + 10.4\, e^{-t/34.4} + 20.8\, t^{-1}\right] \qquad (32)$$

$$\text{(torr)}$$

which has been plotted and is shown in Figure 3.

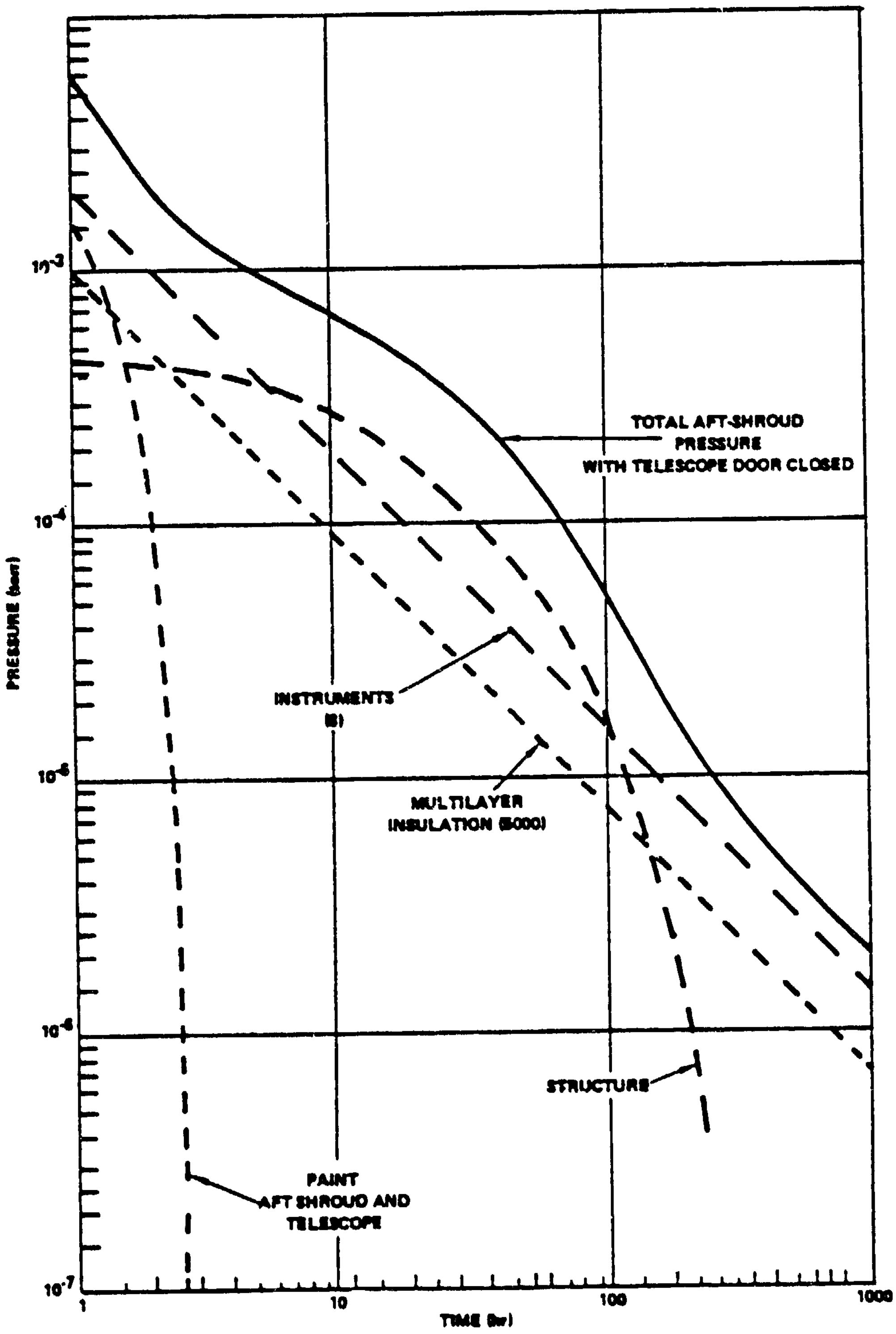


Figure 4. Partial pressures in aft shroud contributed by instruments, structure, paint, and multilayer insulations.

COMMENTS ON THE PRESSURE HISTORY

For these calculations, it was assumed that the shuttle-bay pressure does not control the exhaust flow from the ST. The pressure in the aft shroud with the door closed (Figure 3) should be about 10^{-4} torr after 60 hours and 10^{-5} torr after 300 to 400 hours in orbit. With the door open, these pressures should be reached in about half the foregoing times. The internal pressures of the instruments will be tracking the aft-shroud pressures. If the ST remains in the shuttle bay longer than about 5 hours, its internal pressures, which have been calculated to become less than 10^{-3} torr at that time, will subsequently be controlled by the bay pressure. The predicted bay pressure will be 10^{-3} to 10^{-4} torr after about 1 hour in orbit, and it should remain in that range while slowly decaying for some time (Reference 5).

Figure 4 shows the partial pressures within the aft shroud that are produced by the various sources of outgassing, which combine to produce the total pressure for the closed-door conditions shown in Figure 3. The total pressure for the other conditions were obtained in the same manner. As shown in Figure 4, the total pressure in the aft shroud is dictated initially by the outgassing of the instruments and paint. The paint contribution becomes negligible after about 2 hours. The outgassing of the instruments and structure predominate for about 150 hours, after which the instruments and multilayer insulation are the controlling sources. Note that the contribution of the multilayer insulation is slightly below that of the instruments, although a large quantity was intentionally assumed. With much less insulation and some of the ST venting occurring externally, the pressure contributions from the insulation will be less than those calculated. However, the total pressure will not change appreciably. This can be verified by adding the various contributions (Figure 4).

CONTAMINATION

Theory

Deposits of contaminants on a surface will occur when a partial pressure of the contaminant is present in the environment. The accumulation may proceed until a balance is established between the molecules arriving and leaving the surface. If the conditions are such that the partial pressure of the contaminant in the environment (P) is less than the saturated vapor pressure (P_s) of the same contaminant at the temperature of the surface, an accumulation will occur by an adsorption process. The Langmuir adsorption isotherm predicts that the accumulation (References 7 and 8) will be:

$$\sigma = \gamma \phi_i \tau \qquad (\text{g/cm}^2) \qquad (33)$$

where γ is a coefficient close to one, ϕ_i (g/cm²/s) is the gaseous impinging flux, and τ is the residence time. The residence time is $\tau = \tau_0 e^{E/RT}$, where $\tau_0 \sim 10^{-13}$ seconds is an oscillation period of the molecule on the surface, E (cal/mole) is the activation or binding energy of the molecule on the surface at temperature T (K), and R (cal/mole/K) is the gas constant. A desorption of the contaminant occurs when the flux (ϕ_i) is removed. In this case, the deposited material leaves the surface according to:

$$\sigma = \sigma_0 \, e^{-t/\gamma\tau} \qquad (\text{g/cm}^2/\text{s}) \qquad (34)$$

which is obtained by integrating equation 33 and where σ_0 is the initial equilibrium deposit.

A more accurate evaluation of the deposit coverage can be obtained by using the BET relation (Reference 9):

$$\sigma = \sigma_m \frac{C\phi_i/\phi_L}{(1 - \phi_i/\phi_L)\,[1 + (C - 1)\,\phi_i/\phi_L]} \qquad (35)$$

$$= \left(\frac{1}{1 - P_i / P_L}\right)_{C \to \infty} \qquad (\mathrm{cm}^{-2})$$

where $\sigma_m = (\rho N/M)^{2/3}$ is the monolayer density (cm^{-2}) for full surface coverage, which is characterized by ρ, the contaminant density; N, the Avogadro's number; and M, the mass of the mole. The other parameters in the foregoing equation are $C = \exp(E - E_v/RT)$, where E_v is the heat of evaporation of the contaminant, E is the binding energy of the first layer of molecules to the surface, $\phi_i \approx P_i$ is the impinging flux of molecules at a partial pressure (P_i), and $\phi_L \approx P_s$ is the flux leaving the surface, which is at a saturated vapor pressure (P_s).

For the cases of condensation ($P_i > P_s$) and evaporation ($P_i < P_s$), the material on the surface at a time (t) is:

$$\omega = \gamma \int_{t_o}^{t} \phi_i dt - \int_{t_o}^{t} \phi_L dt \quad (\mathrm{g/cm^2}) \tag{36}$$

where t_o is the initial exposure of the surface to the impinging flux (ϕ_i ($\mathrm{g/cm^2/s}$)) and γ is a sticking (accommodation) coefficient. These fluxes are expressible in terms of pressure, temperature, and molecular mass, using the Langmuir expression:

$$\phi = \frac{1}{4} n v = \left(5.83 \times 10^{-2} \sqrt{\frac{M}{T}}\right) P = kP \tag{37}$$

$$(\mathrm{g/cm^2/s})$$

where P = torr, and k is the expression in parentheses.

With these substitutions, the deposit on the surface will be:

$$\omega = k_i \cdot \gamma \int_{t_o}^{t} P_i\,(t)\,dt - K_L \int_{t_o}^{t} P_L\,(t)\,dt \tag{38}$$

$$(\mathrm{g/cm^2})$$

where P(t) indicates that those pressures may be a known function of time. Equations 33 and 38 will be used to calculate the deposits of each contaminant on ST surfaces at 25°C as a function of time.

Prelaunch Deposits

Before launch and while the shuttle is on the launch pad, the bay will be purged with N_2 to prevent deposits on the surfaces. During nonpurging periods, however, particulates or vapors that exist in the atmosphere, whether natural or those produced by surface abrasion, people walking, or lubricant evaporation, may deposit on the surfaces. These contaminants should be removed with efficient cleaning before launch. In addition, it is expected that critical surfaces will be carefully protected from most of these contaminants.

The following paragraphs describe the contamination that is produced during flight by various sources and evaluate the adsorption of water vapor on the surfaces while the ST is on the ground, under the assumption that purging may not have been done or that it may have been stopped for a period of 3 to 4 days before launch.

H_2O and Organic Vapor Adsorption

The shuttle bay may be exposed to ambient conditions if the purging was not done or if it was stopped for a period of 3 to 4 days before launch. The indicated period is based on calculations that predict the amount of time required for ambient water vapor to diffuse into the shuttle bay (~350 $\mathrm{m^3}$) through the venting ports (~0.5 $\mathrm{m^2}$) for expected atmospheric conditions (Reference 10). When this occurs, the water-vapor pressure in the bay will be the same as the ambient surrounding the shuttle.

The partial vapor pressure would be $P = \psi P_s$, where ψ is the relative humidity and P_s is the saturated water-vapor pressure at the ambient temperature. For an assumed 20°C, 70-percent relative humidity, the pressure is $P = 0.7 \times 18 = 12.6$ torr and the impinging flux of water molecule on a surface will be:

$$\phi = \frac{\nu n}{4} = \frac{1}{4} \sqrt{\frac{8RT}{\pi M}} \cdot \frac{PM}{RT} = 1.81 \times 10^{-1} \quad (g/cm^2/s) \tag{39}$$

The activation energy for adsorption of water on a surface is $E \sim$ 10 kcal/mole, as for the heat of evaporation. The residence time (τ) of the molecule on a surface that is assumed to be quite warm at 100°F (37°C) will be about 7.2×10^{-7} seconds. The equilibrium adsorbate layer on this fairly hot surface would then be:

$$\sigma = \gamma\phi\tau \sim 1.17 \times 10^{-7} \text{ g/cm}^2 \sim 11.7\ \text{Å} \tag{40}$$

where γ was taken to be 0.9. This deposit will either remain unchanged on the surface or change according to the variations of vapor pressure in the environment. When the pressure is removed, the deposit will leave the surface quite rapidly, according to equation 34, unless the water is chemisorbed. If the water is chemisorbed, the energy required for desorption will be much higher than the 10 kcal/mole required for evaporation. The required energy results in a τ that is much longer than 7.2×10^{-7} seconds (Reference 11). The magnitude of this initial H_2O adsorption and its desorption from the ST surfaces are shown in Figures 5 and 6, which will be discussed later.

The same calculations could be used for determining the adsorption of organic substances that are in the environment (requirements for KSC environment is specified at which 10-ppm concentration of equivalent methane, which corresponds to about 7×10^{-5} partial pressure). Although the flux of these organic vapors may be orders of magnitude lower that those of the water vapor, their residence times at normal surface temperature are much higher because they have a high energy of activation (20 to 25 kcal/mole for oils) (Reference 10). Their deposits may be comparable to those of the water, but they will leave the surface more slowly, particularly if their chemical natures were changed by radiation exposure during orbit.

In-Orbit Contamination

The sources that must be considered for contamination hazard in orbit are the outgassing from the paint (Z-306 w/9922), the graphite-epoxy structure (CFRP), and the instruments.

Paint

As reported in Reference 3, the emission of condensed materials from the paint indicate two main components. The more volatile component had a frequency factor of 2.7×10^{11}/min and an activation energy of 14.7 kcal/mole. The less volatile indicated a 3.5×10^{12}/min frequency factor and 18.7 kcal/mole energy. The residence times of these two components on a surface at 25°C can be estimated, using the previous relation, $\tau = \tau_0 e^{E/RT}$, to be about 15 and 995 seconds. The impinging flux, as shown previously, is:

$$\phi = 5.83 \times 10^{-2} \sqrt{\frac{M}{T}}\, P = 6.75 \times 10^{-2}\, P \quad (g/cm^2/s) \tag{41}$$

for M = 400 g/mole. The adsorbate deposit as a function of time of the less-volatile material on a 25°C surface can then be expressed as:

$$\sigma = \gamma\phi\tau = 0.9 \times 9.95 \times 10^{2} \times 6.75 \times 10^{-2}\, P(t) \simeq 60.4\, P_{Pa}(t) \quad (g/cm^2) \tag{42}$$

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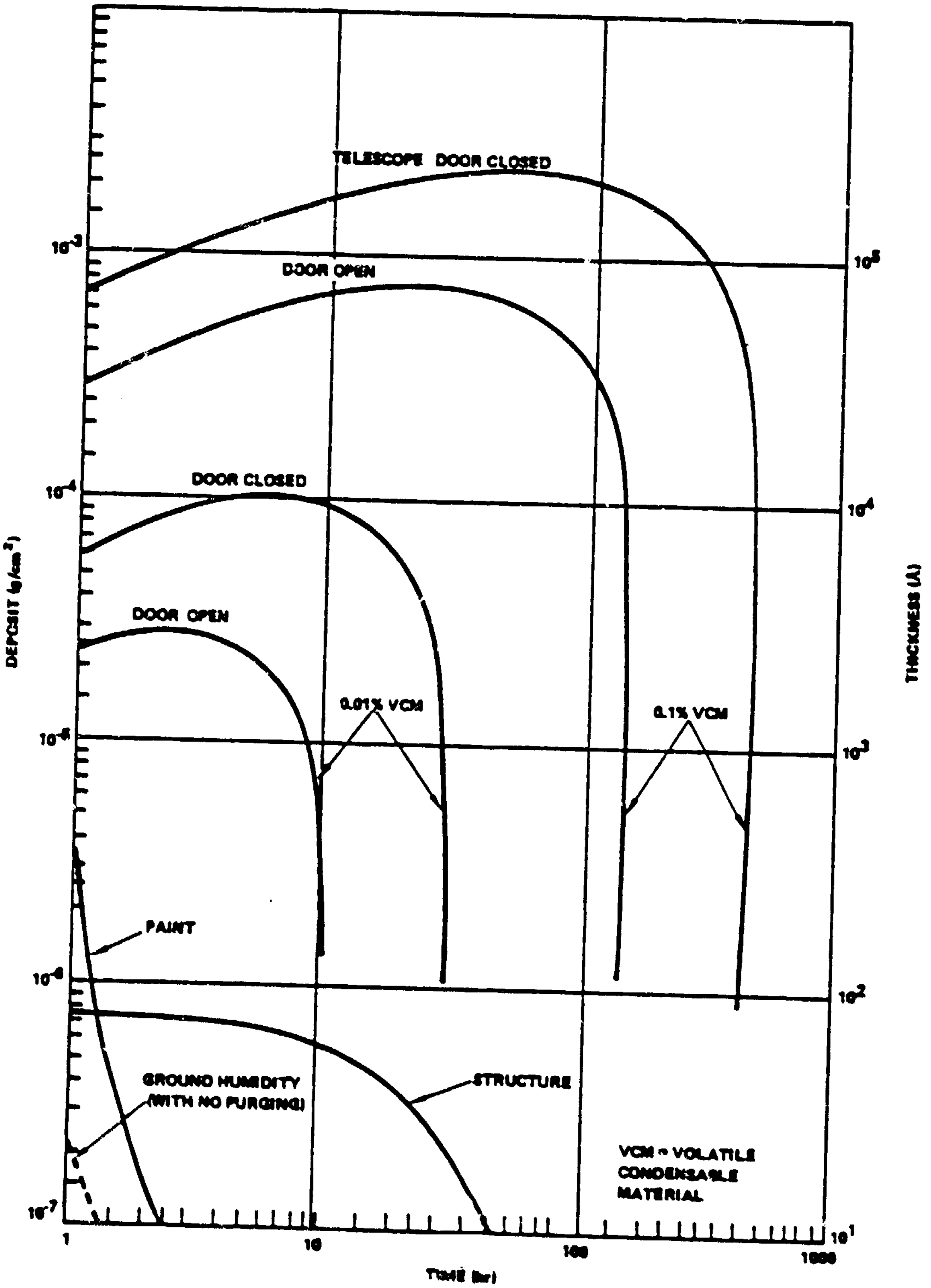

Figure 5. Contaminant deposits on 25°C surfaces in the aft shroud. The contaminant materials (RTV-506/602, S-13G) are outgassed from sealants, encapsulants, pottings, paint, and structures.

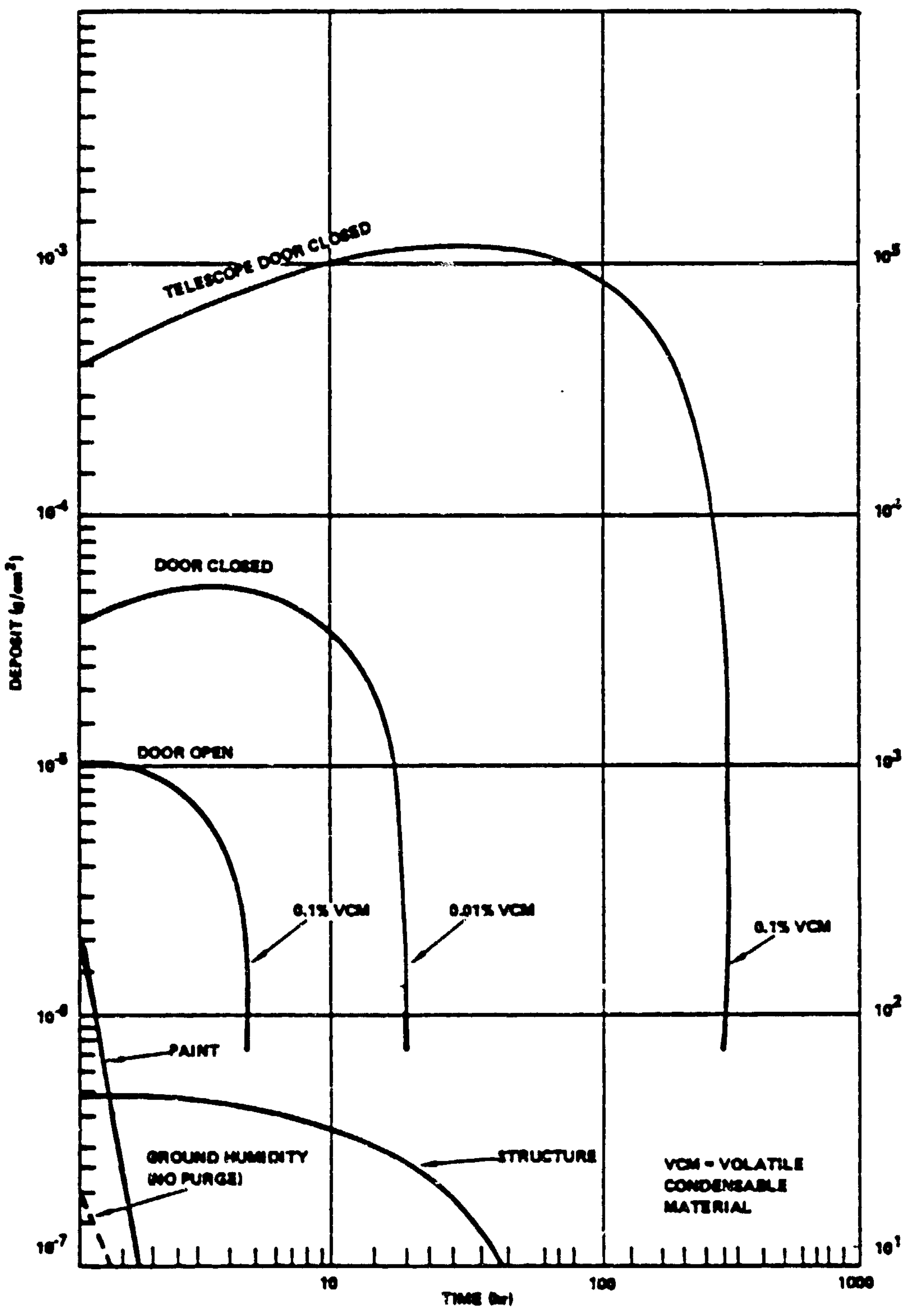

Figure 6. Contamination deposits on 25°C surfaces in the telescope. The contaminant materials (RTV-506/602, S-13G) are outgassed from sealants, encapsulants, pottings, paints, and structures.

The calculations were performed under the assumption that the partial pressure ($P_{p_s}(t)$) of the contaminant material in the paint outgassing is 0.1 or 0.01 percent of the calculated total pressure of the paint as shown in Figure 4 for the aft shroud. The results indicated in Figures 5 and 6 show that the deposit with the telescope door closed could be between 8×10^{-5} and 8×10^{-6} on a surface in the aft shroud and between 2×10^{-5} and 2×10^{-6} g/cm^2 on a surface in the telescope after 1 hour in orbit. These figures reduce to less than 10^{-7} g/cm^2 (~10 Å) within 2 to 3 hours in orbit.

Deposits from the Structure (CFRP)

A 20-pound block of this material was tested at Martin Marietta Company (Reference 3). The mass loss at 20°C appeared to be expressible by:

$$M_s = 29.29\,(1 - \exp - 4.84 \times 10^{-4}\ t) \quad (\mathrm{g}) \quad (43)$$

where t = minutes. This indicates that at 20°C the residence time, the inverse of reaction time (Reference 4), was:

$$\tau = 1/4.84 \times 10^{-4}\ \mathrm{min} = 1.23 \times 10^{5}\ (\mathrm{s}) \qquad (44)$$

Additional data on similar material, also indicated by MMC, showed that Fiberite GY-70 had a frequency factor of 3.6×10^3 min^{-1} and an activation energy of 5.78 kcal/mole. The residence time calculated from these data at 25°C is about 298 seconds, which is compatible with the other value at 25°C. With regard to the condensable fraction of the outgassing to be expected from these materials, Reference 12 indicates that laminate AS-4/1908 graphite-epoxy produces a volatile condensable material (VCM) of 0.01 percent and a total weight loss (TWL) of 0.11 percent and that laminate T-300/394 graphite-epoxy produces a VCM of 0.00 percent and a TWL of 0.58 percent.

The adsorbate from the CFRP on a surface at 25°C, with a sticking coefficient of 0.9, a contaminant having M = 400 g/mole, and with the foregoing calculated residence time of 298 seconds, can be expressed as:

$$\sigma = \gamma \phi \tau = 18.1\ P_s(t) \quad (\mathrm{g/cm^2}) \qquad (45)$$

where $P_s(t)$ in torr is the partial pressure of the contaminant produced by the structure. The partial pressure of the contaminant was assumed to be 0.01 percent of the structure total pressure, which is shown in Figure 4 for the aft shroud. This choice was based on the results of the laminate outgassing criteria and on the Fiberite indication that the material has a low activation energy. The calculated deposits from the material are shown in Figures 5 and 6. These figures show that, after 1 hour in orbit, the deposit for the closed-door condition is about 7.8×10^{-7} g/cm^2 for a surface in the aft shroud and 4×10^{-7} for a surface in the telescope section. These deposits will be less than 10^{-8} g/cm^2 after about 50 hours.

Deposits from Instruments' Outgassing

The condensable fraction of the outgassing from the instruments may be estimated to be on the order of 0.1 to 0.01 percent of the total outgassed material. This fraction is based on the material selection criteria, which require that materials used for the ST produce less than 0.1-percent condensable emission on a surface at 25°C when that material is maintained at 125°C for 24 hours in a vacuum of 10^{-6} torr. For this project, many materials were selected according to a more stringent criteria (i.e., to produce a VCM of 0.01 percent). In any case, the calculations were made for partial pressures of both 0.1 and 0.01 percent of the total pressure.

The following considerations were made to characterize the contaminants from the instruments. A variety of materials in the instruments will be outgassing. Most of the outgassing, however, will originate from pottings, sealants, encapsulants, and coatings. These may be represented by RTV-566, a silicone sealant; RTV-602, also a silicone sealant; S-13G, a thermal-control paint that includes RTV-602 sealant; and DC-704 silicone oils. These materials are representative of methyl-phenil-trisiloxane (MPT), which, according to Reference 13, have equivalent vapor pressures:

$$\log p = 11.025 - \frac{5570}{T} \qquad (46)$$

where p (torr) and T (K). The slope of the equation provides data on the energy; that is:

$$E = \frac{5570\,R}{0.434} = 25.065 \text{ kcal/mole} \qquad (47)$$

where R = 1.978 cal/mole K is the gas constant, and 0.434 = 1/ln10 accounts for the logarithmic representation of the equation. The equivalent molecular mass is given as 484 g/mole. According to equation 46, the saturated vapor pressure of these materials at 25°C is 3×10^{-8} torr. When the activation energy is known, the residence time at 25°C can be estimated by using $\tau = \tau_o \exp E/RT$. It is calculated to be 2.8×10^{5} seconds. Other materials normally found as contaminants are dibutyl phtalate, which has a vapor pressure of about 10^{-4} at 25°C, and ethylhexyl phtalate (EP), which has a pressure of 2×10^{-7} at the same temperature. Both are relatively high-pressure materials, and their deposits would leave the surfaces before those of the RTV.

Figure 7 shows the partial pressures of the contaminants in the aft shroud with the telescope door both open and closed. Figure 7 shows the two alternatives for the partial pressures being either 0.1 or 0.01 percent of the total pressure. The corresponding total pressure induced by the instruments with the door closed is shown in Figure 4. The equations for the total pressure in the aft shroud with the door closed was:

$$P_{PI} = 1.71 \times 10^{-3}/t = \frac{Q_{PI}}{C_{ac}}/t \quad \text{(torr)} \qquad (48)$$

and with the door open:

$$P_{PI} = \frac{Q_{PI}}{C_{ac}}/t = 7.35 \times 10^{-4}/t \quad \text{(torr)} \qquad (49)$$

where t = hours. The values of the saturated pressures of the EP and that of the MPT were superposed on the partial pressures as shown in Figure 7. In this figure, the times at which the saturated pressures become higher than the ambient pressures (i.e., $P < P_s$) are at the intersection of the aft-shroud pressures and the material saturated pressures. At those times, the contaminants leaving the surface become larger than those that arrive. Also, maximum deposits exist at those times. The deposits as a function of time were calculated by using the expression derived previously (equation 38) and using the equations for the pressures versus times; that is,

$$\begin{aligned}
\omega &= \gamma \int_{t_o}^{t} \phi_i \, dt - \int_{t_o}^{t} \phi_L \, dt \\
&= \gamma \left(5.83 \times 10^{-2} \sqrt{\frac{M}{T}}\right) P_{PI} \int_{t_o}^{t} \frac{dt}{t} \\
&\quad - 5.83 \times 10^{-2} \sqrt{\frac{M}{T}}\, P_s \int_{t_o}^{t} dt \\
&= 266 \left[\gamma(\%)\, P_{PI} \int_{t_o}^{t} \frac{dt}{t} - P_s (t - t_o)\right] \\
&= 266 \left[\gamma(\%)\, P_{PI}\, \ln \frac{t}{t_o} - P_s \, (t - t_o)\right]
\end{aligned}$$

(gr/cm²)

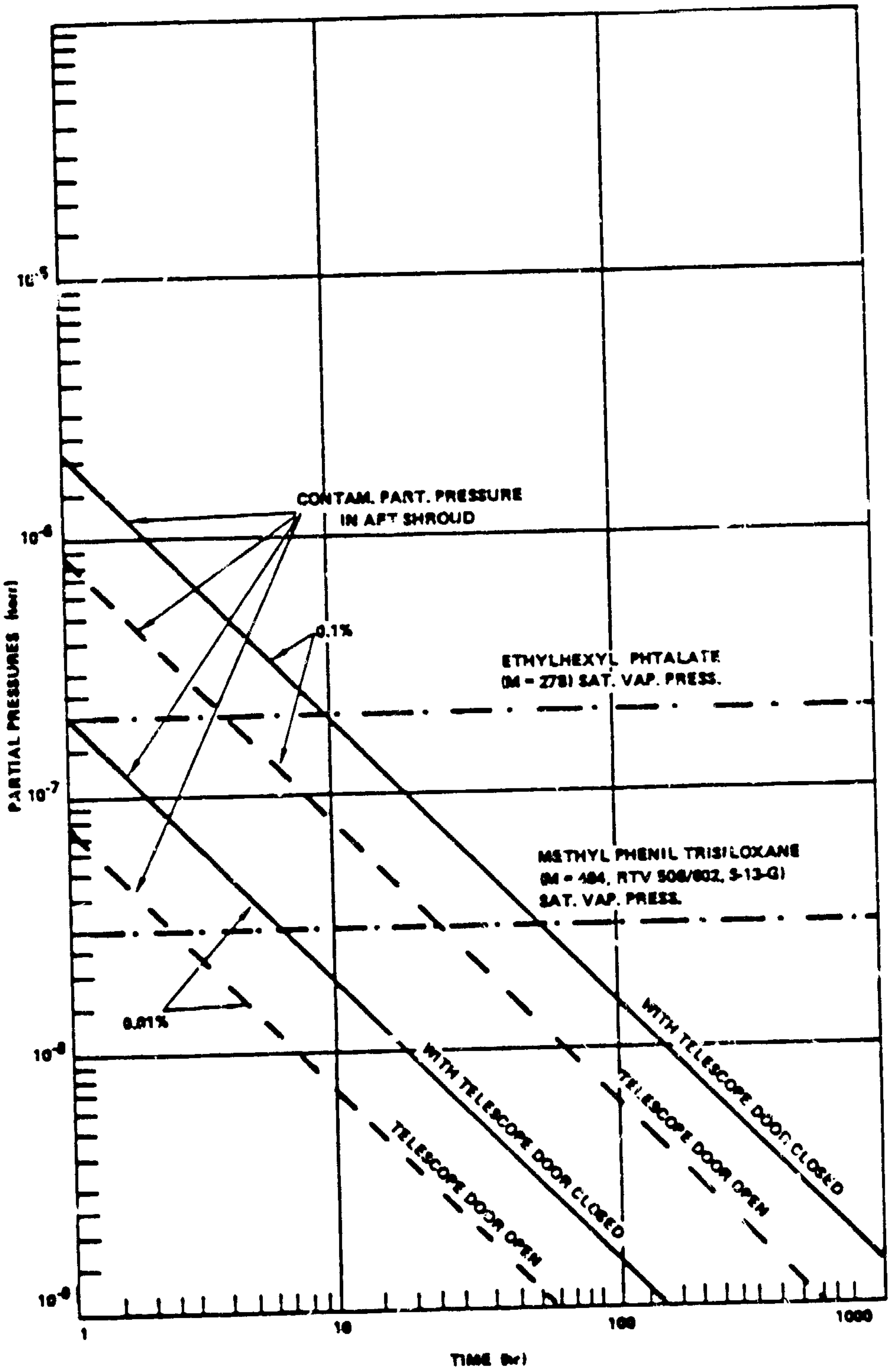

Figure 7. Contaminant partial pressures in the aft-shroud compared to saturated vapor pressures of RTV-50P/602 and phtalate at 25°C. The partial pressures are 0.1 and 0.01 percent of the instruments' total induced pressure in the aft shroud.

where for MPT, M = 484 g/mole, T = 298 K, t = hours. The calculations were performed for P_{PIC} = 1.71 × 10^{-3} torr for the door closed, P_{PIO} = 7.35 × 10^{-4} torr for the door open, $\gamma \sim 0.9$, $P_S = 3 \times 10^{-3}$ torr and for the percentage of 0.1 and 0.01 percent. Note that the dimensions of 266 = 5.83 × 10^{-2} $\sqrt{M/T}$ × 3600 are g/cm²/hr/torr. The initial time was taken as t_0 = 0.2 hour. At that time, the total pressure should be about 10^{-2} torr, which is low enough to permit the outgassing to occur unimpeded.

Figure 5 shows the results of these calculations plotted for the aft shroud. The deposits for 0.1 percent VCM material should reach a maximum at about 80 to 90 hours and then reduce to a few monolayers after 150 to 500 hours in orbit, depending on the telescope door being open or closed. On the other hand, the deposits will reach a maximum is about 5 hours and drop to acceptable values in about 30 hours if the outgassing contains about 0.01 percent condensables.

The deposits of the outgassing from the instruments in the telescope section were calculated in a similar manner. The results shown in Figure 6 indicate that the maximum deposit occurs at about 40 hours, and the cleanup is completed in about 300 hours in orbit for the 0.1-percent VCM with the door closed. With better materials, the maximum deposit is obtained in about 3 hours with cleanup in about 20 hours. With the door opened, the accumulations and subsequent cleanup are accomplished in about 4 hours into the flight.

These calculations show that, in all cases, there will be an initial accumulation of contaminants on 25°C surfaces, followed by a cleanup process. However, the removal of contaminants may not occur or may occur partially if the chemical/physical properties of the deposits change while on the contaminated surface. The changes may result from chemical reactions of the contaminants with the substrates on which they deposit or by molecular structural changes of the contaminants caused by external sources of energies such as irradiation. Furthermore, although the calculations show that the surface should eventually clean itself, it is expected that a few monolayers of contaminants will remain on a surface by virtue of the short-range dispersion forces. The number of layers will depend on the molecular configuration of the contaminant and the substrate. The foregoing calculations are for average thicknesses. In general, molecules accumulate in clusters if the quantity of deposit is small as in the case of physical/chemical adsorption.

COMMENTS ON CONTAMINANT DEPOSITS

The accumulation of contaminants on surfaces at 25°C will be maximum after about 70 hours in orbit and will be less than 10^2 Å in about 450 hours if the telescope door remains closed and the outgassing material contains 0.1-percent VCM. With the door open and for the same VCM, maximum accumulation occurs in about 30 hours and cleanup should occur in about 140 hours. If the materials contain less VCM (0.01 percent) or they are sufficiently outgassed before launch, the maximum accumulations will occur within 10 hours in orbit and the cleanup will be accomplished within 10 to 30 hours with the telescope door either open or closed. The outgassing from paint and from the graphite-epoxy structure, which appear to have condensables with low energies of activation and to a produce small amount of outgassing when tested for the material selection criteria, will deposit on the surfaces at 25°C, but they will leave in less than 50 hours.

In the telescope section, maximum accumulations are 50 to 70 percent of those in the aft shroud if the door is closed, but 2 orders of magnitude smaller if the door is open. The times for maximum accumulation are less than 100 hours. With the door open, they occur within 1 to 2 hours in orbit. The contaminants are assumed to originate from the outgassing of the instrument's sealants, encapsulants, pottings, and coating materials. They have been characterized by using the properties of the MPT, which are the constituents of various RTV and thermal-control paints. The calculations have also assumed that the deposits from these materials will not be exposed to irradiations and will not accumulate on surfaces that may react to them and change their desorption/evaporation characteristics.

The calculations indicate that the contaminants should leave the surfaces and have a thickness of less than 10^2 Å after a number of hours in orbit. It is expected that the cleanup will not be complete, and a few monolayers will remain on some surfaces. These monolayers are retained on the surfaces by short-range electrostatic forces.

CONCLUSIONS AND RECOMMENDATIONS

The preliminary assessment of the pressure and contaminant deposits internal to the ST indicate that:

- The pressure in the aft shroud will be 10^{-5} torr after about 300 hours in orbit and in the lower 10^{-6} torr after about 1000 hours when the ST is a free-flyer with the telescope door closed.
- The outgassing of the instruments and structure will control the ST internal pressure for about 150 hours, and the outgassing of the instruments and multilayer insulation will control the pressure thereafter.
- The contaminat deposits on surfaces at 25°C with the telescope door closed will reach a maximum in about 100 hours and will reduce to a few monolayers after about 1 week in orbit.
- The maximum deposits will be considerably less and will drop to minimum levels in about 100 hours if the telescope door is open.

The following recommendations are derived from the analysis:

- The ST should be separated from the shuttle within 5 to 6 hours of orbital flight to prevent the shuttle bay pressure from controlling the internal pressure of the ST. The bay pressure is expected to be 10^{-3} to 10^{-4} torr after about 1 hour in orbit and remain in that range for a considerable period of time, thus slowing down the venting of the ST.
- The telescope door should be opened as soon as possible to allow the pressure in the aft shroud to drop to a lower value at an earlier time.
- The telescope critical surfaces should not be exposed to direct solar radiation and high-energy particles. These may polymerize and prevent the contaminant deposits from leaving the surface.
- The temperature of critical surfaces should be held at about 20 to 25°C until the total pressures drop to 10^{-5} to 10^{-6} torr.
- The venting areas of the instruments and sensor systems should be about 200 cm^2 or more so that their internal pressures

will decay at approximately the same rate as those of the aft-shroud and telescope sections.

- Materials used in the ST should be selected or cured to produce only a small amount of VCM, preferably less than 0.1 percent. Systems and instruments should be exposed to vacuum, baked-out, and purged to reduce their outgassing.
- The internal pressures of each instrument and system should be monitored during their thermal-vacuum tests to provide a better description of their outgassing.
- The pressure inside the aft shroud should be monitored for a sufficient time during its thermal-vacuum test to provide data on the total outgassing and as a bake-out of the total system.
- Detailed analysis of the ST instruments and sensor systems should be conducted to investigate local sources of outgassing that may have a direct view of critical surfaces. Each instrument and system should be analyzed for internal pressure decay and contamination hazard.
- An estimate of the number of layers, surface areas, venting locations, and methods of venting the multilayer insulation should be provided. When possible, venting should be made to occur outside the ST.
- The particulate contaminants should be evaluated to provide an estimate of the quantity and size distribution of particulates residing inside the ST and those induced by sources external to the ST.
- The ST and the surfaces should be protected at all times against external contaminants, particularly when they are exposed to an environment that includes more particulates and volatile residue.

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