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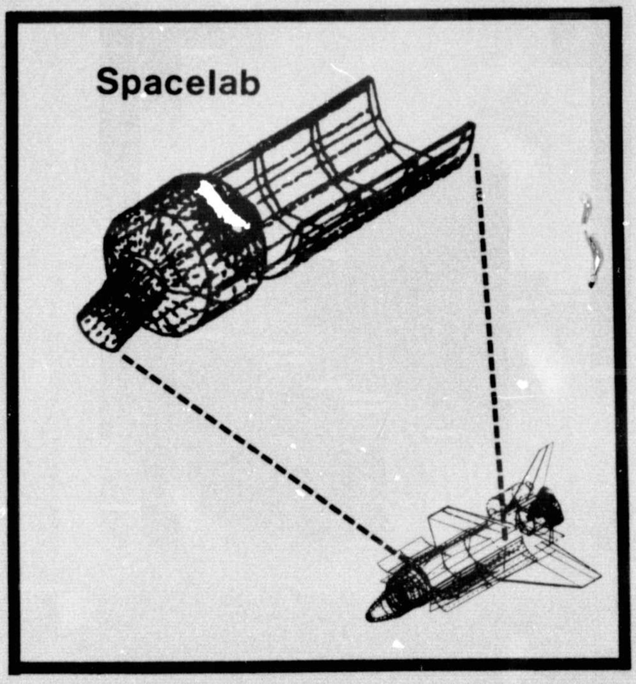
Payload/Orbiter Contamination Control Requirement Study



MARTIN MARIETTA

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TECHNICAL REPORT

PAYLOAD/ORBITER CONTAMINATION CONTROL REQUIREMENT STUDY

INTERIM REPORT

CONTRACT NAS8-31574

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1. INTRODUCTION

The purpose of this study is to continue the assessment of the Spacelab carrier induced contaminant environment and to determine Spacelab's ability to meet established contamination control criteria for the Shuttle Program. The primary areas of on-going activity of this study include updating, refining, and improving the Spacelab Contamination Computer Model and contamination analysis methodology; establishing the resulting adjusted induced environment predictions for comparison with the applicable criteria; determining Spacelab design and operational requirements necessary to meet the criteria; conducting mission feasibility analyses of the combined Spacelab/Orbiter contaminant environment for specific proposed missions and payload mixes; and establishing a preliminary Spacelab mission support plan and model interface requirements between Martin Marietta and Marshall Space Flight Center (MSFC) facilities. These are currently in various phases of completion.

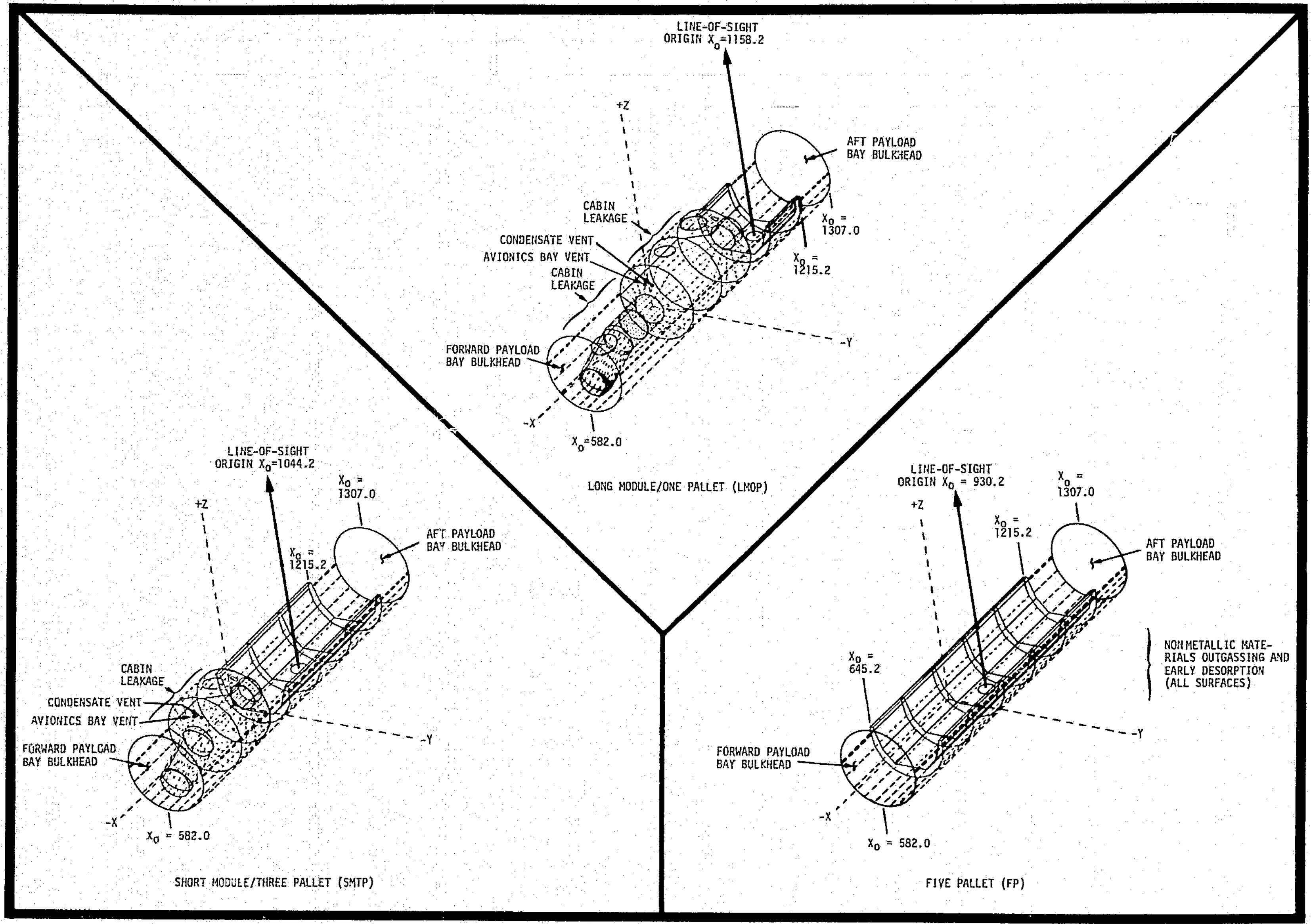
This report presents a summary of these activities conducted to date including any modifications in approach or methodology utilized in the contamination assessment of the Spacelab vehicle. The emphasis in this report has been placed on the Spacelab modeling efforts since several of the other activities will be covered in detail in separate reports. This report covers a period of effort of 6 months and is an extension of previous studies conducted for Spacelab which have spanned an 18 month time period (see References 1, 2 and 3). This is an interim status report which will contain only a summary of activities and results to date, all of which will be updated and expanded in detail in the final report of this contract (September 1976). The brevity of the report has been dictated in part by the limited availability of necessary Spacelab data and on-going configuration and material modifications which will be expanded upon in the text. In this light certain assumptions are currently being used in the analysis in order to bridge the gap between previous known configuration and test data and anticipated data to be supplied when available by the National Aeronautics and Space Administration (NASA), the European Space Agency (ESA), or other European agencies. These are described herein with the thought that modifications will be necessary when the anticipated data is received.

In summary, the primary conclusions and recommendations established herein are: 1) outgassing of Spacelab nonmetallic thermal control materials (even if they qualify under materials screening criteria) may dictate that sensitive payloads provide their own protective devices or that the use of these materials be limited or eliminated; 2) a more stable data base is required to assess the Spacelab induced particulate environment; 3) additional design and test data and agreement upon the baseline contamination control requirements is required from ESA in a timely fashion; 4) model improvements and mission feasibility analysis should be continued and the payload and mission description data base should be expanded; and 5) criteria analysis should be conducted in depth for the combined Space Transportation System-Spacelab (STS-SL) contaminant environment.

2. SPACELAB MODELING AND ANALYSIS STATUS

2.1 Background - A primary design goal for the different Spacelab configurations is to insure that Spacelab/Orbiter systems and scientific instrument mission objectives are not compromised by the induced molecular and particulate contaminant environment of the Spacelab carrier. To accomplish this, a rigorous computer modeling and analysis effort has been conducted over the past 24 months to establish the predicted contaminant environment as well as to determine Spacelab contamination related design and operational requirements necessary to meet the maximum allowable induced environment levels set forth by the Contamination Requirements Definition Group (CRDG) at NASA MSFC for the STS-SL.(4,5) A contamination computer model consisting of three unique Spacelab configurations was developed as the primary analytical tool to geometrically synthesize the contaminant sources, susceptible surfaces, and induced environment of the Spacelab carriers modeled. A similar model was developed under separate contract to Johnson Space Center (JSC) for the Shuttle Orbiter which, in conjunction with the Spacelab model, can be used for a total combined Spacelab/Orbiter mission evaluation. The Spacelab configurations modeled were: 1) the long module/one pallet (LMOP); 2) the short module/three pallet (SMTP); and 3) the five pallet (FP) configurations. The major contaminant sources considered were 1) outgassing (i.e., steady-state bulk mass loss of vacuum exposed nonmetallic materials); 2) early on orbit desorption of adsorbed and absorbed gases, liquids and volatiles from external surfaces; 3) cabin atmosphere leakage; 4) the Spacelab condensate vent; and 5) the avionics bay vent which has possibly been deleted from the Spacelab design (see Figure 1). Detailed descriptions of these Spacelab configurations and sources can be found in References 2 and 3, and additional Orbiter source descriptions and predictions are contained in Reference 6. Contained herein will be a brief summary of the thrust of activity and pertinent modifications and updates that have occurred in the interim, and therefore, the above references should be referred to for particular additional detailed baseline information that is desired.

2.2 Updated Modeling Considerations - Throughout the course of this contract period several modifications were made to previously used model input data, and refinements to previous analytical methodology were conducted which illustrate either a change in current



LONG MODULE/ONE PALLET (LMOP)

SHORT MODULE/THREE PALLET (SMTP)

FIVE PALLET (FP)

Figure 1. Modeled Spacelab Configurations and Contaminant Sources

philosophy or actual baseline data. The modifications that have been concluded to date include: 1) adjustments of the Spacelab nonmetallic thermal control material outgassing rates to be equivalent to the maximum allowable implied rate of applicable materials screening criteria; 2) temperature profile updates for the SMTP and FP Spacelab configurations; 3) use of point receivers as opposed to spheres to determine mass column densities; 4) further evaluation of projected Spacelab random particulate emission based upon flight data from Skylab and Agena; and 5) refinement of the Orbiter Orbital Maneuvering System (OMS) engine impact assessment upon Spacelab.

2.2.1 Spacelab Outgassing - Although it is known that some type of nonmetallic materials will probably be used as a thermal control coating for the Spacelab external surfaces, to date this material or materials have not been expressly identified by ESA. At least three candidate materials have been implied at various times but insufficient data has been supplied to perform specific analysis without making gross assumptions for area of coverage, location, vacuum outgassing characteristics, etc. During the previous Spacelab studies a baseline assumption was made that the entire vehicle was to be coated with S13G white thermal control paint; however, existing steady state outgassing rate data obtained during rhe Skylab Program varied between $1x10^{-8}$ g cm^{-2} sec^{-1} and $2.7x10^{-12}$ g cm^{-2} sec^{-1} at 100°C depending strongly upon the materials cure cycle and batch control. Additional test data forthcoming from the MSFC Materials and Processes Laboratory on a current "typical" S13G coating has not yet been generated and even when it is, there is no guarantee that S13G will be the material selected for use by ESA. Recent information indicates that ESA is considering using goldized kapton and/or Z-202 paint in place of all or part of the "S13G". A similar problem of limited information exists here.

Due to the apparent fluid posture of the thermal control coating decision and based upon the extreme variations in existing test data, a decision was made to conduct the on-going modeling activities based upon the assumption that Spacelab would be completely coated with a nonmetallic material that meets the applicable materials screening criteria established for the Space Shuttle Program (50M02442(7) and SP-R-0022A(8)). Using these criteria an implied maximum allowable materials outgassing rate can be determined for qualified materials. The pertinent requirements extracted from these criteria are summarized below:

a) 50M02442 Requirements (Paragraph 3.2)

   1) Weight loss rate during temperature cycling from 25°C to 100°C shall not exceed 0.2%/cm^2/hour when heated at a rate of 2°C/minute.

2) Steady-state weight loss rate at 100°C shall not exceed $0.04\%/\mathrm{cm}^2/\mathrm{hour}$. Steady-state is defined as that point where the rate has been constant for 8 hours.

3) Desorption of surface adsorbed atmospheric gases or other contaminants shall be included in the rates.

b) SP-R-0022A Requirements (Paragraph 7.4)

1) The materials shall have a VCM (Volatile Condensible Material) content of $< 0.1\%$ by weight. The total weight loss of material shall not exceed 1.0% by weight.

2) This is for a 24 hour test period for samples at 125°C.

To determine the implied allowable outgassing rate (OGR) from these criteria requires that the basic parameter of surface density be established for the material as applied to a space vehicle. This parameter is, of course, a variable with each material and application; therefore, a nonmetallic material assumed to be "typical" of aerospace thermal control coatings was chosen for the analysis. The selected material was S13G white thermal control paint which, based upon data supplied by McDonnell Douglas-West in supplemental information to the Skylab Design Certification Review, demonstrated an average surface density of 0.052 $\mathrm{g\ cm^{-2}}$ for a 6 mil thick application. Based upon this assumption, the maximum allowable outgassing rate at 100°C per 50M02442 criteria 2) would be:

$$\begin{aligned} \mathrm{OGR_{MAX}} &= (0.052\ \mathrm{g\ cm^{-2}})(1\ \mathrm{cm^2})(0.04\%\ \mathrm{cm^{-2}\ hr^{-1}})(\mathrm{hr}/3600\ \mathrm{sec}) \\ &= 5.77 \times 10^{-9}\ \mathrm{g\ cm^{-2}\ sec^{-1}} \end{aligned}$$

An equivalent OGR determined by utilizing a similar approach based upon the SP-R-0022A criteria normalized to 100°C would be:

$$\begin{aligned} \mathrm{OGR_{MAX}} &= (0.052\ \mathrm{g\ cm^{-2}})(1\%/24\ \mathrm{hr})\ (\mathrm{hr}/3600\ \mathrm{sec})\left[e^{(100-T)/29}\right] \\ &= 2.54 \times 10^{-9}\ \mathrm{g\ cm^{-2}\ sec^{-1}} \text{ for } T = 125^\circ\mathrm{C} \end{aligned}$$

The rates are normalized to 100°C to be compatible with model input format requirements. The model internally adjusts individual surface rates consistent with their specific temperatures and thermal profiles.

The implied early desorption rate (EDR) can also be determined using criteria 1) of 50M02442 assuming the same S13G surface density and that the maximum allowable EDR extrapolated to 100°C will occur when the material is at 25°C. The maximum allowable EDR normalized to 100°C would, therefore, be:

$$\begin{aligned} \mathrm{EDR}_{\mathrm{MAX}} &= (0.052 \text{ g cm}^{-2})(1 \text{ cm}^{2})(0.2\% \text{ cm}^{-2} \text{ hr}^{-1})(\text{hr}/3600 \text{ sec}) \\ &\quad \left[e^{(100-T)/29} \right] \\ &= 4 \times 10^{-7} \text{ g cm}^{-2} \text{ sec}^{-1} \text{ for } T = 25^{\circ}\mathrm{C} \end{aligned}$$

Assuming that the EDR decay curve as a function of vacuum exposure time is similar in shape to that of S13G test data, the EDR at 10 hours (which is that point in a mission when on orbit operations might be expected to commence) would be approximately 1.5×10^{-7} g cm^{-2} $\sec^{-1}$ at 100°C. The ratio of the EDR at 10 hours to the steady-state OGR calculated from the materials screening criteria of 26:1 compares favorably to the ratio of outgassing and early desorption data (25:1) modeled during previous studies (3,4). Therefore, based upon the analyses presented, an implied materials steady-state outgassing rate of 6×10^{-9} g cm^{-2} $\sec^{-1}$ at 100°C and an early desorption rate at 10 hours of 1.5×10^{-7} g cm^{-2} $\sec^{-1}$ at 100°C are used in the current contamination modeling for surfaces such as thermal control paints where actual test data is not available. The need to pursue such an empirical approach to determine necessary modeling parameters tends to further amplify the requirement for specific test data and materials identification and mapping for those nonmetallic materials displaying large surface areas (greater than 0.1 m^{2}) and those whose locations indicate potential contamination threats to sensitive instruments and systems.

2.2.2 Spacelab Temperature Profiles - The mass loss rates of Spacelab vacuum exposed nonmetallic materials are strongly dependent upon the surface temperatures and thermal profile histories of the materials in question. It follows then that the more accurate the model input thermal profile data, the higher will be the fidelity of the resulting induced environment predictions. Therefore, the thermal profile input data has been updated to be consistent with the most recent Spacelab thermal modeling being conducted by Teledyne Brown Engineering in conjunction with MSFC (9). Current data includes Spacelab LMOP and FP surface temperatures for the maximum hot case orbital attitude (+Z solar inertial, Y local vertical, 100% solar exposure) and the minimum cold case attitude (+X or aft end solar inertial, -Z local vertical). These attitudes encompass the Spacelab temperature extremes and correspondingly encompass the maximum and minimum outgassing and early desorption periods. This data indicates that Spacelab LMOP surface temperatures vary between the extremes of -193°C to +88°C and the FP surfaces vary between -150°C and +67°C for these attitudes. It is important to note that the combined use of pallet insulation, thermal shields, coatings, and heaters has not been fully investigated.(9) A preliminary analysis of an insulated pallet showed significant changes in the predicted temperatures. This will in turn modify the contamination predictions, therefore future required updates to the input temperature data are anticipated.

The Teledyne Brown thermal model currently does not include the SMTP configuration, however, due to its similarity to the LMOP Spacelab, the assumption was made that the LMOP thermal profiles would be applicable for similar surfaces and more accurate than the previously used data supplied by ESRO(10). The SMTP module configuration was reconfigured to be compatible with the nodal structure of the LMOP thermal model which expanded the SMTP model to 55 nodes as compared to the previous 38 node configuration. New view factors were calculated for the SMTP lines-of-sight and corresponding outgassing and early desorption predictions were determined based upon the adjusted thermal data. The results of these model update activities will be reflected in a later section of this report.

2.2.3 Line-of-sight View Factor Calculation Refinement - The Spacelab contamination modeling approach to predict molecular column densities along a given line-of-sight in the past involved the input of a series of pseudo-surfaces as spheres divided into quadrants along the line-of-sight of interest allowing them to act as individual contaminant receivers. This process is quite costly in terms of computer run time, and the accuracy of calculated sphere view factors is questionable under certain circumstances. To overcome this, a modeling approach was developed with the capability of treating points as contaminant receivers along a line-of-sight (requiring only one input node/point) which more closely approximates a geometric line in space. The result has been that view factor computer run times for the point lines-of-sight have been reduced significantly over those required for the quad sphere approach and the model fidelity has been increased. This refinement, which is reflected in the predictions presented later in this report, should represent considerable computer cost savings in the future.

2.2.4 Random Particulate Environment Reassessment - In determining the induced particulate environment of a manned spacecraft such as the Spacelab carrier, known defined particulate sources like the Spacelab condensate vent can be parametrically analyzed in a closed mathematical form by knowing the primary vent system characteristics (based upon existing system test data or detailed stream tube vent plume and freezing analysis) and integrating these into the particle trajectory analysis program. In contrast, intermittent particulate sources (i.e., random particle emission) present a more difficult analytical problem with actual flight observations of past orbiting systems being used in most instances as the primary data base. The applicability of such flight data to a different space vehicle such as Spacelab is questionable. Previous analysis of this phenomena has been based primarily upon particle tracks observed on the Skylab ATM S052 White Light Coronograph film frames which were analyzed by J. McGuire, MSFC.(11) His data presented the number of detectible random events (particles) per time period ($\approx 4.8\ sr^{-1}\ sec^{-1}$), and information about their velocity and size ranges for the field-of-view and sensitivity of the S052. This excluded such known particulate producing events as overboard liquid vents. Early information from McGuire indicated the sizes to be greater than 10 to 25 μ in diameter which is near the size level of 10 μ quoted in existing contamination control criteria.* (4,5) Later analysis by F. Witteborn, Ames Research Center (12) for the Sensitive Infrared Telescope Facility (SIRTF) indicated that only much larger particles could be detected by the S052. The fact that such variations existed in the data interpretation prompted a further investigation into the sensitivity of the S052 instrument and its detectivity of particulate matter within its field-of-view.

Data supplied by R. M. MacQueen,(13) PI for S052, stated that the Coronograph had an 8 arc second resolution (3.88×10^{-5} radians) and that the faintest particle track on the S052 film had a brightness, $B = 7 \times 10^{-10}\ B_{\odot}$ ergs $cm^{-2}\ sec^{-1}\ sr^{-1}$ where $B_{\odot}$ = radiance of mean solar disc. The power radiated into the 3.2 cm aperture of the S052 camera from a particle of this angular size and brightness is found by:

$$P = B \cdot \Omega \cdot A$$

where P = power radiated from source, erg sec^{-1}

B = brightness of source = $7 \times 10^{-10}\ B_{\odot}$ erg $cm^{-2}\ sec^{-1}\ sr^{-1}$

$B_{\odot}$ = radiance of mean solar disk = 1.989×10^{10} erg $cm^{-2}\ sec^{-1}\ sr^{-1}$

$$\Omega = \pi \sin^2 \left(\frac{2.2 \times 10^{-3}}{2}\right) = 1.2 \times 10^{-9}\ \text{sr}$$

A = area of aperture = 8 cm^2

$$\therefore\ P = (13.9)(1.2 \times 10^{-9})(8) = 1.33 \times 10^{-7}\ \text{erg sec}^{-1}$$

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* The baseline criteria for particles (contained in reference 4) limits events to less than 1 particle larger than 10 microns in a 4 arc minute half angle field-of-view per orbit within 1 Km.

The best contrasted data frames were exposed for 9 seconds, therefore, the minimum amount of energy required to expose the film was $1.2\text{x}10^{-6}$ ergs which is the smallest amount of energy detectable on a $3.88\text{x}10^{-5}$ radian square piece of film. The intensity of light scattered from a particle in the S052 field-of-view would be:$^{(14)}$

$$I = I_o \left(\frac{(\pi a^2)^2}{\lambda^2 r^2}\right)\left(\frac{2 J_1 (X \sin \theta)}{X \sin \theta}\right)^2$$

where a = particle radius, cm

r = distance from particle, cm

λ = wavelength of incident radiation, cm

I_o = incident intensity, erg cm^{-2} sec^{-1}

θ = scattering angle

J_1 = Bessel function of order 1

Consider the case where $\lambda = 5\text{x}10^{-5}$ cm, $r = 6\text{x}10^{4}$ cm (distance where particle image size equals S052 resolution element), $4R_\odot \leq \theta \leq 6R_\odot$, and $I = 1.36\text{x}10^{6}$ erg cm^{-2} sec^{-1} ($R_\odot$ = one solar radii). The power at $5R_\odot$ (1.25° from the center of the S052 photographs) is approximated by $1/4 \left[I_{max} (1.0^\circ) + I_{max} (1.5^\circ)\right] \cdot A$, where $I_{max} (1.0^\circ)$ and $I_{max} (1.5^\circ)$ are the nearest maximum of I, and A is the area of the camera lens. The energy deposited per unit length of particle track is dependent on the velocity parallel to the plane of the film. McGuire found that the most probable velocity for focused particles was $4.6\text{x}10^{-4}$ radians/second so that a particle track resolution element ($3.88\text{x}10^{-5}$ radians) was exposed for 0.084 seconds. Using the above parameters for 400 and 510 micron diameter particles yields:

Diameter Microns	Arc Power ergs sec^{-1}	Energy Deposited in .084 seconds, ergs
400	$1.2\text{x}10^{-5}$	$1\text{x}10^{-6}$
510	$2.3\text{x}10^{-5}$	$1.9\text{x}10^{-6}$

From this calculation it is seen that to deposit the minimum energy ($1.2\text{x}10^{-6}$ ergs) to leave a particle track on the film, the particle must have been approximately 450 microns in diameter at 600 meters away. This is, therefore, the minimum detectable particle size for the S052 instrument.

It is difficult to compare the S052 particle observation data for detected particles $\geq 450\,\mu$ to the ECR contamination control criteria$^{(4)}$, for example, since this criteria is for 10 micron diameter particles which is 45 times smaller than what the S052 Coronograph could detect. A possible comparison that can be made by assuming a log-normal particle size distribution (representative of a given clean room environment) as identified in MIL-STD 1246A would give a factor of 5×10^5 more particles $\geq$ 10 microns in diameter for every particle 450 microns in diameter. This would equate to approximately 5.5×10^4 particles greater than 10 microns per orbit in a 4 arc minute half angle field-of-view at 600 meters based on McGuire's data which far surpasses the criteria. Using such a method has some logical basis, but is questionable at best. Qualitative assessments utilizing the S052 data can still be made, but when quoting or referencing the data, all assumptions and limitations should be clearly stated to insure proper interpretation of the results. One important implication that might be drawn from the S052 analysis is that the current contamination control criteria for particles may be very difficult for the Spacelab carrier to meet.

The particle sighting study conducted by Hughes Aircraft on the Infrared Sensor Celestial Mapping Program$^{(15)}$ orbited on the USAF Space Test Program 71-2 Agena vehicle attempted to correlate (with limited quick-look IR sensor flight data) the particles detected on orbit with the prelaunch ground handling procedures utilized. These varied from class 10K clean room and level 200-300 surface cleanliness for the sensor system to lesser control for the Agena. Although the report states that the quick-look data indicated minimal particle sightings for the spacecraft, the quantity of presented data does not appear adequate to draw any final conclusions. Three to five particles were detected in 6220 seconds of observation or 2.9 to 4.8 particles/orbit for the sensor's 1.2° field-of-view. This equates to 0.036 to 0.059 particles in a 4 arc minute half angle field-of-view per orbit for a vehicle that has approximately 1/30 the surface area of the Shuttle Orbiter. Since the sensitivity of the sensor is classified, correlation with contamination control criteria cannot be firmly established. It is, therefore, felt that this data is far too inconclusive as presented to use as a data base for random particulate emission assessment of Spacelab.

2.2.5 Orbital Maneuvering System (OMS) Engine Evaluation - Although the OMS engines are not explicitly a Spacelab contaminant source, their use is dictated by the particular Spacelab mission requirements levied upon them. At any time during a mission that the OMS engines are operated while the Orbiter payload bay doors are open, the potential of significant contamination of Spacelab and payload surfaces exists and requires evaluation. The modeling of this source has been refined during this period and the resulting posigrade predictions have diminished considerably from those previously reported while the retro thrust predictions have remained essentially unchanged.(3) This change evolved from the integration of an expanded approach to molecular mean free path influence upon return flux as a function of orbital altitude at OMS burn initiation. Figure 2 presents the updated deposition rate predictions for a 2π steradian surface oriented in the X-Y plane (representative of a +Z facing Spacelab thermal control surface for example) for posigrade and retro thrust maneuvers as a function of engine burn initiation altitude. Given any OMS engine burn time or fuel usage and the altitude of burn initiation, the resulting deposition can be determined. Sticking coefficient data used in the modeling was derived from MMH-N_2O_4 engine test data resulting from Lewis Research Center small engine testing. This analysis would tend to indicate that closing of the payload bay doors during OMS posigrade maneuvers may no longer be necessary. However, until engine design and performance data becomes more firmly established, the potential of contamination during posigrade maneuvers should not be ignored. The analysis still substantiates the need to close the payload bay doors during retro thrust maneuvers.

2.3 Spacelab Molecular Induced Environment Predictions - The Spacelab contamination computer model prediction format has been modified to be compatible with the existing contamination control requirements for comparative purposes in addition to being used for analysis of specific surfaces and lines-of-sight of interest when conducting contamination evaluations for particular mission profiles and payload mixes. There are currently two unique sets of contamination control criteria applicable to the Spacelab carrier which can be used for contamination evaluation. The requirements specified in ECR #EL52-0032(4) have been used as the baseline for the on-going analysis, however, a second set of criteria being proposed by the CRDG at MSFC(5) (still awaiting official approval) is far more comprehensive and will replace the ECR requirements as the baseline upon final approval for program documentation. The ECR requirements with which the molecular contamination modeling can be directly compared are quoted below.

a) Column density less than 10^{12} molecules cm^{-2} for polar molecules.

b) Return flux of less than 10^{12} molecules cm^{-2} sec^{-1}.

c) No more than 1 percent absorption from IR through UV by condensibles on optical surfaces.

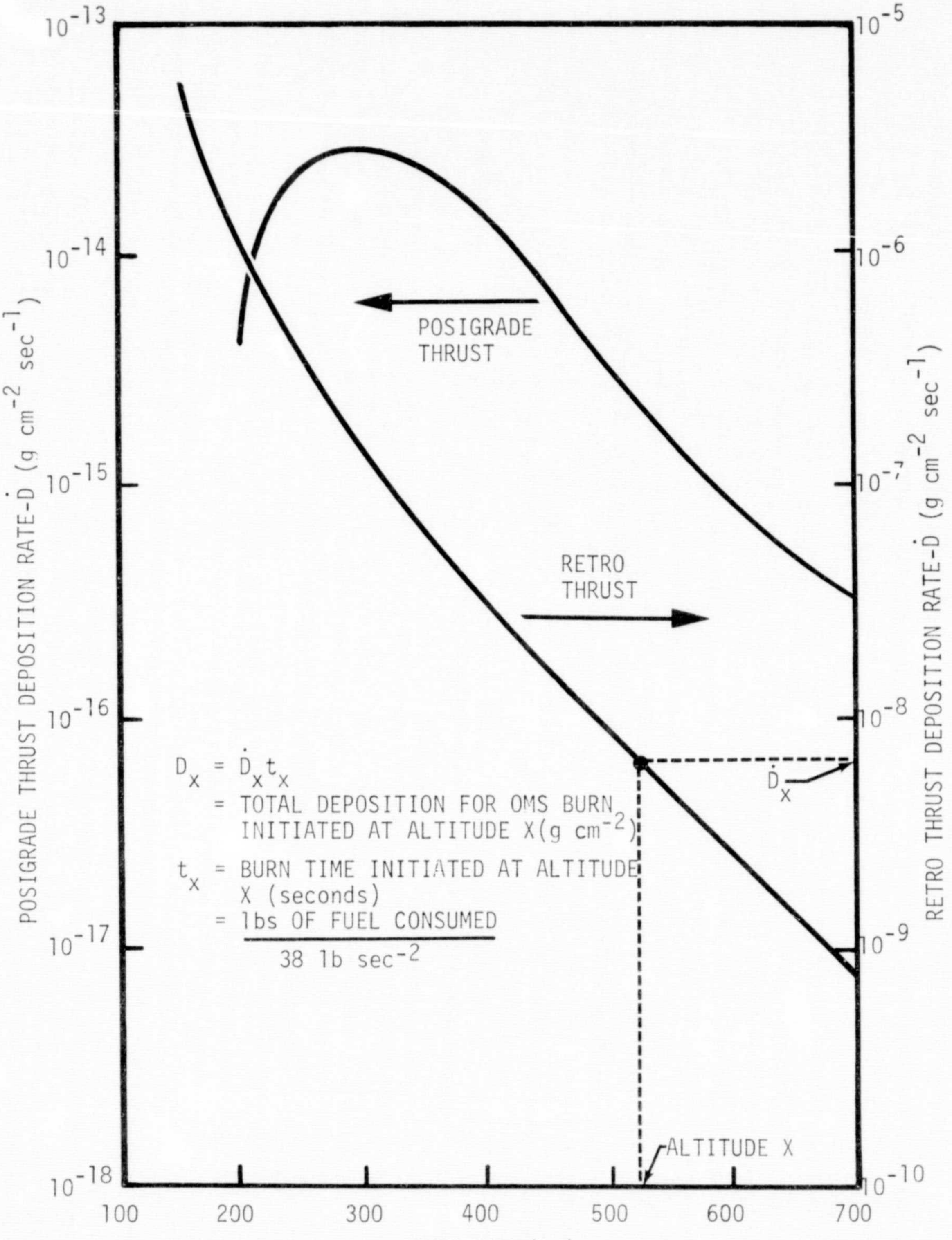

Figure 2. OMS Effluent Deposition Rate on a +Z Facing 2π Steradian Field-of-View Spacelab Surface as a Function of Orbital Altitude

The current contamination computer model predictions as related to the above criteria are presented in Table I for the three modeled Spacelab configurations for the lines-of-sight parallel to the +Z axis as illustrated in Figure 1. These predictions reflect the model updates and improvements previously discussed in Section 2.2 for outgassing, early desorption at 10 hours, and cabin atmosphere leakage. Eight additional lines-of-sight have been modeled for these configurations encompassing a 100° conical viewing volume above Spacelab, but these results have been excluded for brevity. Maximum variations for these lines-of-sight over the values presented in Table I are approximately a factor of 2. Since predictions for the condensate and avionics vents have not been modified from previous reports,(2,3) they are not repeated herein. Included in Table I are molecular column densities, maximum return flux rates resulting from contaminant collisions with the ambient atmosphere to a 0.1 steradian surface parallel to the X-Y plane at the line-of-sight origin for three orbital altitudes, and maximum deposition and signal degradation (assuming total accommodation of outgassants) on a reflective optic with a 0.1 steradian geometric acceptance angle detecting at $\lambda = 1500\text{Å}$ for continuous 7 day exposure to the maximum return flux. Outgassing and early desorption predictions are for both the maximum hot and minimum cold Spacelab thermal profiles discussed in section 2.2.2.

By comparison of the predictions presented in Table I with applicable ECR contamination control criteria, it can be seen that for a material qualified under 50M02442(7) the column density and signal loss criteria are exceeded under certain temperature and altitude conditions as based upon 100% Spacelab coverage. The intent of the column density criteria can be met for all sources and conditions presented in Table I if the activation of susceptible instruments is delayed up to 24 hours until the early desorption rate has decayed to an acceptable level. However, to meet the signal loss criteria for outgassing either radical on orbit attitude constraints will be required to minimize return flux impingement or the sensitive payloads will be required to supply their own protective devices such as covers and surface heaters. The latter choice is probably the most appropriate. In addition, the signal loss criteria could be met if Spacelab demonstrated an effective outgassing rate in the 10^{-12} g cm^{-2} sec^{-1} range at 100°C. This could be accomplished by using stricter materials screening criteria or by limiting or eliminating the use of nonmetallic external coatings.

This evaluation will definitely require modification when and if the new CRDG criteria(5) are approved. During this period, the new CRDG criteria was evaluated in detail to establish Spacelab's ability to comply and similar results were obtained (i.e. outgassing

Table I. Spacelab Molecular Induced Environment Predictions for Line-of-Sight Parallel to +Z Axis

PREDICTED PARAMETER / CONFIGURATION/ SOURCE	COLUMN DENSITY (molecules cm^{-2})		MAX RETURN FLUX* (molecules cm^{-2} sec^{-1})			MAX DEPOSITION-7 DAYS (Å)/ MAX SIGNAL LOSS (%)**		
	TOTAL	POLAR	@ 200 km[+]	@ 435 km	@ 700 km	@ 200 km[+]	@ 435 km	@ 700 km
LONG MODULE/ ONE PALLET (LMOP)								
OUTGASSING[†]								
MAX TEMP	1.1(10)[††]	1.1(10)	5.2(10)[+]	2.8(9)	1.0(8)	522.1/ 87.6 [+]	28.1/ 10.6	1.0/ 0.4
MIN TEMP	6.2(8)	6.2(8)	3.0(9)[+]	1.6(8)	5.8(6)	30.1/ 11.3 [+]	1.6/ 0.6	0.058/ 0.02
EARLY DESORPTION[†]								
MAX TEMP	6.3(11)	6.3(11)	3.0(11)	5.6(9)	2.0(8)	NEGLIGIBLE DEPOSITION AND SIGNAL LOSS FOR ALL SURFACES NOT AT CRYOGENIC TEMPERATURES		
MIN TEMP	3.7(10)	3.7(10)	1.7(10)	3.3(8)	1.2(7)			
ATMOS LEAKAGE	4.2(11)	8.9(9)	2.0(11)	3.8(9)	1.3(8)			
SHORT MODULE/ THREE PALLET (SMTP)								
OUTGASSING[†]								
MAX TEMP	2.1(10)	2.1(10)	9.8(10)[+]	5.3(9)	2.0(8)	983.9/ 98.0 [+]	53.2/ 19.2	2.0/ 0.8
MIN TEMP	7.6(8)	7.6(8)	3.5(9)[+]	1.9(8)	7.1(6)	35.1/ 13.1 [+]	1.9/ 0.8	0.071/ 0.03
EARLY DESORPTION[†]								
MAX TEMP	1.2(12)	1.2(12)	5.7(11)	1.1(10)	3.8(8)	NEGLIGIBLE DEPOSITION AND SIGNAL LOSS FOR ALL SURFACES NOT AT CRYOGENIC TEMPERATURES		
MIN TEMP	4.5(10)	4.5(10)	2.1(10)	4.0(8)	1.4(7)			
ATMOS LEAKAGE	3.5(11)	7.4(9)	1.7(11)	3.1(9)	1.1(8)			
FIVE PALLET (FP)								
OUTGASSING[†]								
MAX TEMP	2.3(10)	2.3(10)	1.1(11)[+]	5.8(9)	2.2(8)	1104.4/ 98.8 [+]	58.2/ 20.8	2.2/ 0.9
MIN TEMP	3.9(7)	3.9(7)	1.8(8)[+]	9.9(6)	3.7(5)	1.8/ 0.7 [+]	0.099/ 0.04	0.0037/ 0.001
EARLY DESORPTION[†]								
MAX TEMP	1.4(12)	1.4(12)	6.6(11)	1.3(10)	4.4(8)	NEGLIGIBLE DEPOSITION AND SIGNAL LOSS FOR ALL SURFACES NOT AT CRYOGENIC TEMPERATURES		
MIN TEMP	2.3(9)	2.3(9)	1.1(9)	2.1(7)	7.3(5)			
ATMOS LEAKAGE	0	0	0	0	0			

* Maximum return flux to a 0.1 sr surface occurs when ambient drag vector is parallel to optical axis.

** Deposition and signal loss based on 7 day continuous exposure to maximum return flux to a 0.1 sr reflective optic detecting a 1500 Å with total accommodation for outgassed species.

[†] Outgassing rate = 6×10^{-9} g cm^{-2} sec^{-1} and early desorption rate @ 10 hours = 1.5×10^{-7} g cm^{-2} sec^{-1} at 100°C (50M02442 limits)

[††] 1.1(10) = 1.1×10^{10}

[+] At 250 km altitude for outgassing only. At 200 km outgassing molecular mean free paths are small and return flux and deposition are attenuated to approximately zero.

deposition is still the most restrictive parameter). However, ESA, the Spacelab controlling agency, has not indicated recognition of any requirements for providing an acceptable optical environment. It is, therefore, very important that early agreement be established between NASA and ESA as to which set of criteria (or possibly a new set) will be followed for final Spacelab design and development.

2.4 Additional Studies - Several additional study activities have been undertaken during this contract period which are currently in various phases of completion. These activities are briefly summarized in the following subsections and will be covered in detail when applicable in the contract final reports.

2.4.1 Model Improvement Studies - The Spacelab contamination model has proven to be an effective tool in contamination analysis and assessment although it is still in the development phase for certain contaminant phenomena. Refinements and improvements in the modeling technology and methodology are currently being evaluated to determine what increases in the fidelity of the model predictions are required. These studies are still in progress with final impact analyses forthcoming. Those modifications deemed of adequate value will be integrated into the model for Spacelab design and development and mission feasibility analysis. The major improvements currently under investigation include:

a) Refinement of return flux predictions to large field-of-view surfaces - Published analyses on the subject by Robertson(16) have been investigated and a modified modeling approach involving a series of concentric dome surfaces as opposed to individual lines-of-sight is being analyzed for applicability and advantages over the Robertson approach.

b) Return flux contribution from contaminant self-scattering - A special study conducted by Robertson(17) applicable to the Shuttle/Spacelab Programs is being assessed for the degree of impact of this phenomena. Previous indications were that this would yield only second order contaminant impacts, however, interactions between different contaminant species may prove to be more significant. A costly Monte Carlo modeling approach might be required to simulate this "near the payload bay" phenomena and the trade off option of a less rigorous, more generalized analytical technique may be sufficient in this case.

c) Second surface source characteristics for outgassing and early desorption - This involves the integration of the surface to surface, column density, and return flux program subroutines as well as the JSC Orbiter model to simulate desorption or reflection of impinging contaminants from a receiving surface to another surface or into a payload line-of-sight. Second order effects are expected here as well.

d) Mean free path influence upon molecular column density - The concentric dome model approach mentioned previously is being considered here also in conjunction with standard mean free path variations with ambient drag vector orientation. The phenomena of line-of-sight contaminant flux attenuation and scattering of molecules into a line-of-sight are both under investigation.

e) Orbital variations resulting from frequent altitude changes during a mission - This is being investigated to determine the logic of incorporating an ambient density data profile selection routine into the model compatible with any potential mission orbital parameter profile input.

It is necessary that such improvement studies be continued not only to refine the contamination analysis capabilities but also to establish a model of the necessary fidelity to do timely and effective Spacelab design, development, and mission analysis.

2.4.2 Spacelab Model Computer Interface Study - This activity involves investigating the requirements to format the Spacelab configuration contamination computer program for use on MSFC computers. Time allotted to this study to date has been spent in determining the present computer complement at MSFC, the projected future changes, the suitability and availability of specific computers at MSFC for processing the contamination program, and in starting a comparison of characteristics of the suitable and available MSFC computers and the CDC 6000 series computer for which the program is presently formatted.

The present computer complement at MSFC and future plans for it have been determined. Considering projected usage plans and available computer characteristics, only the UNIVAC 1108 models will be both available and suitable for processing the contamination program. Accordingly, users manuals for the UNIVAC and CDC computers have been obtained and a comparison of characteristics has been started to determine the program changes necessary for processing on the UNIVAC. These considerations will be enlarged upon in the interim report (to be published under separate cover in February 1976) and at least a partial list of comparable characteristics will be presented in a format suitable for rapid comparison and determination of requisite changes to the program.

2.4.3 Mission Profile Data Bank (MPDB) - As a result of the continuing Spacelab/Orbiter mission feasibility analyses conducted during this period, the MPDB has been updated and expanded wherever possible to establish a strong, yet flexible data base system of contamination oriented Spacelab/Orbiter mission and payload information formatted for direct input into the contamination computer model. Included in the data bank is such data as mission duration, orbital attitudes and altitudes, pointing requirements, payload definitions, thermal profiles, and usage requirements. The limitations of the primary source of information (i.e. the Payload Description Documents or SSPD)(17) still exist and have been discussed in reference 3 and will not be reiterated here. Consequently, the MPDB is far from a complete or finished product, although information obtained in conducting the mission feasibility task tends to fill many of the information voids for a given mission being evaluated. Such analyses should therefore be continued to the point where the data base is adequate for model utilization and complete integration is possible.

3. CONCLUSIONS AND RECOMMENDATIONS

3.1 Conclusions - The following conclusions are presented as a result of activities conducted during this reporting period of the on-going contract effort. These should be considered in addition to or as amendments of those stated in previous reports.(3)

a) The applicability of the existing random particulate emission data base to Spacelab evaluation is questionable, although implications are that the contamination criteria for particles may be difficult for Spacelab to meet. This may not be determined until data is received from OFT and early Spacelab missions.

b) Nonmetallic material outgassing and early desorption for the anticipated thermal control material on Spacelab and qualified under current materials screening criteria exceed column density and signal loss criteria in certain situations assuming 100% Spacelab coverage. Materials test data as specified in reference 3 is required for more exact analysis.

c) Updated NASA Spacelab thermal profile data which is generally much more cold-biased than the previously used ESA data has decreased outgassing and early desorption predictions by up to a factor of 20 for some configurations. It is indicated that anticipated updates of pallet temperature profiles (with insulation, thermal shields, coatings, and heaters considered) will result in an increase in the contamination predictions (based on preliminary insulated configuration analysis). In addition, SMTP profile data which is currently based on LMOP profiles is required for more accurate SMTP predictions.

d) The modeling approach of using point receivers to calculate line-of-sight view factors appears to offer a substantial computer cost savings as well as increasing model resolution. This method will be used in all future analyses.

e) Updated OMS engine effluent deposition predictions would tend to negate the need to close the payload bay doors during posigrade maneuvers, although the doors should be closed during retro thrust periods. Until OMS engine design and test parameters are more firmly established, consideration should be given to closing the doors during all OMS firings due to the enormous amount of material that is expelled by these engines on orbit.

3.2 Recommendations - The following recommendations are presented as a result of the activities conducted during this reporting period which are felt necessary to insure Spacelab compliance with the current criteria or required to continue the modeling and analysis activities.

a) Early agreement (preferably in the first quarter of 1976) should be established between NASA and ESA as to what explicit contamination control requirements the Spacelab design and development effort should be working to.

b) ESA should supply the following design configuration data during the first half of 1976 with periodic updates on at least a yearly basis to be consistent with program milestones: 1) nonmetallic materials map of surfaces in excess of 0.1 m^2; 2) corresponding materials mass loss/contamination data; 3) current baseline configuration drawings; 4) allowable systems degradation (passive thermal surfaces, windows, etc.); 5) overboard vent system designs, flowrates, constituents, locations, vent directions, etc. for condensate, airlock and experiment vents; and 6) Igloo purge gas leakage flowrates, constituents and locations. The lack of such data up to this point in the contract has significantly limited the scope of activities performed.

c) Required nonmetallic materials test data not furnished by ESA should be supplied by NASA through inhouse testing.

d) To meet the intent of the 1% signal loss criteria consideration should be given to either eliminating or restricting the use of nonmetallic external materials, selecting materials demonstrating effective outgassing rates at 100°C less than the mid 10^{-12} g cm^{-2} sec^{-1} range, or requiring sensitive payloads to provide their own protective devices and procedures.

e) To meet the intent of the column density criteria activation of sensitive instruments should be delayed up to 24 hours until the early desorption rate has decayed sufficiently.

f) To avoid being overly restrictive or overly optimistic of Spacelab contamination control a detailed criteria evaluation of the entire STS (i.e., Orbiter, external tanks, and solid rocket boosters) in conjunction with Spacelab should be conducted to establish necessary contaminant environment "budgeting" between the STS-SL components.

g) Activities which should be continued or expanded include: 1) Spacelab model improvement and update studies; 2) MPDB formatting and expansion; 3) combined Orbiter/Spacelab mission feasibility analysis supplying MPDB input parameters, and 4) analysis of the Spacelab model interface requirements with MSFC in the event that model transfer might be necessary.

4. REFERENCES

The following references are presented to support the technical and programmatic material referenced in the text of this report.

1) "Payload/Orbiter Contamination Control Requirement Study," MSFC NAS8-30452, MCR-74-93, May 1974, Martin Marietta Aerospace, Denver Division.

2) "Payload/Orbiter Contamination Control Requirement Study," MSFC NAS8-30755 Exhibit A, MCR 74-474, December 1974, Martin Marietta Aerospace, Denver Division.

3) "Payload/Orbiter Contamination Control Requirement Study," MSFC NAS8-30755 Exhibit B, MCR-75-202, June 1975, Martin Marietta Aerospace, Denver Division.

4) ECR #EL52-0032, Paragraph 1.10.4, "Contamination Control Requirements."

5) "Payload Contamination Control Requirements for STS Induced Environment," July 22, 1975, (Preliminary), George C. Marshall Space Flight Center.

6) "Payload/Orbiter Contamination Control Assessment Support," JSC NAS9-14212, MCR 75-13, June 1975, Martin Marietta Aerospace, Denver Division.

7) "ATM Material Control for Contamination Due to Outgassing," 50M02442 Revision W, March 1, 1972, George C. Marshall Space Flight Center.

8) "Specification - Vacuum Stability Requirements of Polymeric Material for Spacecraft Application," SP-R-0022A, September 9, 1974, Lyndon B. Johnson Space Center.

9) Memo: EP45 (75-78) from EP41/Mr. Hopson to NA01/Mr. Lee, Subject: Spacelab/Orbiter Payload Bay Thermal Analysis, June 1975.

10) Presentation to NASA on the "European Spacelab Design and Development Effort," Part F: ECS, ESRO/ESTEC, July 1974.

11) Informal Report/Private Communication with J. McGuire, NASA MSFC, Subject: Particle Sightings by the Skylab ATM White Light Coronograph - S052.

12) Witteborn, F.: "The Effect of the Shuttle Contaminant Environment on a Sensitive Infrared Telescope," (Preliminary), Ames Research Center, 1975.

13) Private Communication, Dr. R. M. MacQueen, Principal Investigator for S052, High Altitude Observatory, Boulder, Colorado, October 1975.

14) Van De Hulst: Light Scattering by Small Particles, New York: John Wiley & Sons, Inc. 1957.

15) "Shuttle Infrared Telescope Facility Particle Sighting Study," ARC NAS2-8494, Item ID-4.2., September 1975, Hughes Aircraft Company.

16) Robertson, S. J.: "Backflow of Outgas Contamination onto Orbiting Spacecraft as a Result of Intermolecular Collisions," HREC-6554-2, LMSC-HREC D306000, MSFC NAS8-26554, June 1972, Lockheed Missiles and Space Company, Inc.

17) Robertson, S. J.: "Spacecraft Self-Contamination Due to Back-Scattering of Surface Outgassing," November 1975, Lockheed Missiles and Space Company, Inc.

18) "Summarized NASA Payload Descriptions-Sortie Payloads," Level A & B Data, July 1975, George C. Marshall Space Flight Center.