NASA TECHNICAL MEMORANDUM

May 1974

NASA TM X-64826

MSFC SKYLAB CONTAMINATION CONTROL SYSTEMS MISSION EVALUATION

Skylab Program Office

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

(NASA-TM-X-64826) MSFC SKYLAB CONTAMINATION CONTROL SYSTEMS MISSION EVALUATION (NASA) 244 p HC $15.25 CSCL 22B

N74-26335

Unclas
G3/31 40790

MSFC - Form 3190 (Rev June 1971)

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
NASA TM X-64826		

4. TITLE AND SUBTITLE
MSFC SKYLAB CONTAMINATION CONTROL SYSTEMS MISSION EVALUATION

5. REPORT DATE
May 1974

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)

8. PERFORMING ORGANIZATION REPORT #

9. PERFORMING ORGANIZATION NAME AND ADDRESS
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

10. WORK UNIT NO.

11. CONTRACT OR GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS
National Aeronautics and Space Administration
Washington, D. C. 20546

13. TYPE OF REPORT & PERIOD COVERED
Technical Memorandum

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Cluster external contamination control evaluation was made throughout the Skylab Mission. This evaluation indicated that contamination control measures instigated during the design, development, and operational phases of this program were adequate to reduce the general contamination environment external to the Cluster below the threshold sensitivity levels for experiments and affected subsystems specified by Principal Investigators (PIs) and Technical Discipline Managers (TDMs) except for anomalous conditions.

Launch and orbit contamination control features included eliminating certain vents, rerouting vents for minimum contamination impact, establishing filters, incorporating materials with minimum outgassing characteristics and developing operational constraints and mission rules to minimize contamination effects.

Prior to the launch of Skylab, contamination control math models were developed which were used to predict Cluster surface deposition and background brightness levels throughout the mission.

The report summarizes the Skylab system and experiment contamination control evaluation. The Cluster systems and experiments evaluated include Induced Atmosphere, Corollary and ATM Experiments, Thermal Control Surfaces, Solar Array Systems, Windows, and Star Tracker.

17. KEY WORDS

18. DISTRIBUTION STATEMENT
Unclassified-unlimited

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	244	NTIS

FOREWORD

This document is a portion of the Skylab Systems Reports. This MSFC Skylab Contamination Control System Mission Evaluation Report has been developed in accordance with MSFC Skylab Mission Report Major Report Guidelines.

Because of the differences in systems and systems operations, it is not possible to develop an input format compatible to all disciplines. Necessary deviations to balance the circumstances for each discipline and the MSFC report requirements are worked out with the concerned Mission Support Group Leader/Technical Discipline Manager (MSGL/TDM).

This systems report establishes the post Skylab mission evaluation information which encompasses that information available at this time concerning contamination assessment on this mission. This report also discusses the contamination control approach used for Skylab.

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1.0 SUMMARY

1.0.1 General Discussion - Cluster external contamination control evaluation was made throughout the Skylab Mission. This evaluation indicated that contamination control measures instigated during the design, development, and operational phases of this program were adequate to reduce the general contamination environment external to the Cluster below the threshold sensitivity levels for experiments and affected subsystems specified by Principal Investigators (PIs) and Technical Discipline Managers (TDMs) except for anomalous conditions. Cluster development and operational phases where contamination control was implemented included manufacturing cleanliness requirements, prelaunch transportation and storage for all flight hardware including experiments, OA interior, OWS forward dome and the interior of the payload shroud. In addition, contamination control procedures were executed for ground handling and cleanliness at the launch site.

Launch and orbit contamination control features included eliminating certain vents, rerouting vents for minimum contamination impact, establishing filters, incorporating materials with minimum outgassing characteristics and developing operational constraints and mission rules to minimize contamination effects.

Prior to the launch of Skylab, contamination control math models were developed which were used to predict Cluster surface deposition and background brightness levels throughout the mission.

On orbit external Cluster contamination detection systems including quartz crystal microbalances (QCMs), the T027/S073 experiments and CSM returned data such as photographs and experiment data were used to update the math model on a periodic basis. This was done so that timely meaningful contamination predictions, assessments, and evaluations could be made during periods when specific external experiments were in operation.

The following subsections summarize the Skylab system and experiment contamination control evaluation. The Cluster systems and experiments evaluated include Induced Atmosphere, Corollary and ATM Experiments, Thermal Control Surfaces, Solar Array Systems, Windows, and Star Tracker.

1.0.2 Conclusions - The following conclusions address each of the above listed evaluation areas with respect to contamination.

a. <u>Induced Atmosphere</u> - There were eight QCMs exposed to the external structure of the Cluster to measure contamination deposition. Two QCMs were mounted on the T027A Sample Array Carrousel, four mounted on the ATM truss on the -Z side of the MDA (designated as the EREP QCMs) and two mounted on the ATM Sun Shield (see Figure 1.2.2.2.1). These latter two QCMs faced the +Z direction (toward the Sun in a solar inertial orientation).

The two T027A QCMs were never activated during the Skylab mission due to the lack of a power and telemetry outlet near the anti-solar scientific airlock (SAL). The T027A Experiment was scheduled for deployment from the solar SAL but this SAL could not be used because it was used to deploy and maintain the OWS thermal parasol.

The orientation of the four EREP QCMs was as follows: one was mounted facing the +X direction (toward the CSM); one facing the -X direction (toward the OWS); and two in the -Z direction (toward the earth when the Cluster is in the Z local vertical orientation). One of the Z QCMs was passively temperature compensated and was designated as the Z50 QCM. The other Z QCM was allowed to follow the ambient thermal conditions and was designated as Z AMB.

As a total mass deposition measurement for the Skylab Mission, the CSM (+X) QCM and the OWS (-X) QCM each indicated deposits on the order of 45 $\mu g/cm^2$. On about day 237, the CSM QCM fine voltage (range expander) system electronics failed at an accumulated mass of about 36 $\mu g/cm^2$. The coarse voltage continued to provide a measurement at reduced resolution. On about DOY 281, the CSM QCM essentially reached an unstable deposition reading as a result of the non-rigid nature of the deposition layers at about 42 $\mu g/cm^2$. On about DOY 267, the OWS QCM reached its unstable deposition reading at about 44 $\mu g/cm^2$. Finally, both the CSM and OWS units were essentially saturated (to the available telemetry data range of the QCMs) by DOY 315. From the time period where these QCMs began to show stability problems the deposition math model was used to provide mission support through the remaining portion of the mission. As anticipated, the ATM QCMs saw no deposition since these units have no contaminant source in their field-of-view and since their temperatures were high enough that many contaminants would not deposit. Both the -Z facing QCMs saw deposition on the order of 10 to 20 μ gms/cm^2 accumulated through the mission. As in the case of the ATM QCMs, these QCMs were anticipated to have no deposition since there were no Cluster surfaces in their field-of-view. Some question exists as to the source of deposition on the -Z QCMs. The possibilities include reflection of the induced atmosphere from the ambient atmosphere or the QCM wire bundle inadvertently left in their field of view. These possibilities are still under investigation.

The deposition seen on the X facing QCMs is felt to be the result of Cluster outgassing and CSM RCS firings. Based upon analysis of returned experiment surfaces exposed to the external environment and near the +X and -X QCMs, the deposited material is primarily siliceous in nature and most probably the result of outgassing of the silicon binder used in S13G and Z-93 white thermal control paint. It has also been shown that solar irradiation of these deposits have turned them brown or a yellowish brown as evidenced by photographs taken during EVAs and fly-around (see Figures 1.4.3-1 and 2).

The deposition of a large amount of CSM RCS propellant contamination was recorded on the +X and -X EREP QCMs during multiple docking attempts of the CSM on the SL-1/2 mission. No measurable amounts were recorded on the +Z facing or -Z facing QCMs. On about DOY 150 approximately four days after the SL-1/2 docking, the deposition levels recorded on the +X and -X QCMs had reduced to a steady state condition due to desorption of the majority of the RCS propellant products.

Again, at the start of the SL-3 manned mission on DOY 209, the +X, -X, and -Z EREP QCMs indicated a noticeable increase in the deposition rate reading. By DOY 225, the deposition rate recorded on the QCMs had reduced to a rate comparable to that recorded prior to the SL-3 docking. The sudden increase in deposition rate between DOY 209 and DOY 225 occurred at the same time the CSM RCS Quad B and D oxidizer leaks were occurring.

The deposition math model predictions throughout the mission, with corrections for SL-1/2 and SL-3 docking and adjustments for configuration changes and thermal profile updates, correlated very closely with the flight data provided by the +X and -X EREP QCMs until loss of these data. Subsequent to that time, the deposition rates were extrapolated to the end of the mission.

It is noted that the deposition rate measured by the X QCMs and the lack of deposition rate measurement on the +Z facing QCMs which cannot "see" any other Cluster surfaces, substantiates one of the basic assumptions of the deposition math model. This assumption is that there must be a line-of-sight between a contamination source and a receiving surface for a significant mass to be transferred to the receiving surface.

Analyses of SL-1/2 and SL-3 preliminary flight data from the T027/S073 Photometer indicated that there was an induced atmosphere around the Cluster over and above that calculated prior to the mission. Preflight predicted levels of 1 x 10^{-17} $B/B_{\odot}$ (where $B/B_{\odot}$ is the ratio of background brightness level to the brightness of the sun) were made; however, SL-1/2 measurements indicated a scattering level of 10^{-14} $B/B_{\odot}$. This additional background brightness was not accounted for in the preflight predictions. However, scattering is an extremely dependent function of particle size and until reduced data from T027/S073 Photometer determines the particle size and distribution, this difference will not be resolved. Based upon evaluation of limited data from T027/S073, the Star Tracker, astronaut observation, and S052 video display, it is felt that the particulates around the Cluster primarily range in size from 0.1 to 200 microns in diameter. The sources of these particles include sloughed paint and debris resulting from the SL-1/2 launch meteoroid shield failure and subsequent solar blistering and repair activities. In addition, particulates from the RCS engine propellant leak and exhaust products, EVA generated debris such as particles sloughed off the Cluster by the astronauts, effluents exhausted by the Pressure Control Unit (PCU) and particulate from equipment used during the EVA and debris resulting from normal Cluster vents are also contained in the induced atmosphere.

The +X and -X QCMs measured a higher deposition rate than was anticipated during the SL-3 post-docking period. It was during this time period that the second T027/S073 Photometer measurement was taken. When these data were factored into the background brightness analysis, it was concluded that the brightness level of 1 x 10^{-12} B/B_o recorded on DOY 215 could possibly be accounted for by the addition of the RCS oxidizer to the induced atmosphere about the Cluster, and that a scattering level of 10^{-14} B/B_o is probably the static induced atmosphere with small transients depending upon operational activities.

The video displays from the S052 White Light Coronagraph provided additional evidence of the particulate cloud around the Cluster. Numerous times while the S052 was in use, individual particulates were observed crossing the field-of-view of the experiment. For example, on DOY 162 during a workshop habitation area vent malfunction procedure checkout, the crew commented that as they opened the vent, "it looked like the 4th of July" on the S052 video screen.

On DOY 220, a large shower of particles was observed while the S052 experiment was being conducted. A review of the activities in progress at this time indicated that an overboard dump of liquid from the condensate tank had inadvertently been made through the contingency condensate dump system during a system malfunction test. This liquid dump caused a degradation in the S052 experiment data for the time period of the particle shower.

In general, the induced atmosphere cloud presented little or no effect upon the various sensitive experiments, because its brightness level was below the threshhold sensitivity levels of the experiments. On those occasions where high particle fluxes were noted, the degradation to the data was momentary. The induced atmosphere cloud, in general, is primarily made up of particulates which, fundamentally, no on-orbit operational control can be exercised over and most likely will exist with any spacecraft to some degree.

b. Corollary/ATM Experiments - Preliminary comments from the Corollary and EREP Principal Investigators and Scientists have indicated various degrees of contamination but only moderate affects to most Corollary and EREP experiment data. A preliminary review of available information indicates that the ATM Experiment group was not impacted by external contamination.

In discussions with the D024 and S230 PIs, it was learned that these experiments were heavily coate with contamination during the SL-1/2 and SL-3 missions. The SL-3 crew reported that the S230 cuff removed on the first EVA showed iridescence, like oil on water. The cuff removed on the final SL-3 EVA appeared clean. The D024 PI stated that the samples returned on SL-3 were noticeably more contaminated than those returned from SL-1/2 and had a high level of discoloration due to long time solar radiation.

The SL-4 D024 samples seem to have less deposition than the SL-2 and SL-3 samples with a similar siliceous nature. Secondary Ion Mass Spectroscopy and Auger' analysis is continuing to further substantiate the contaminants elements. The P.I.'s contention is that a coolanol leak interacting with H_2O and ultraviolet radiation is the likely source. Additional tests are being made in an attempt to reproduce the deposits found on the flight samples which the P.I. hopes will further substantiate that coolanol is the strongest candidate.

The SL-4 S230 experiment was also badly discolored with deposits which appear to be similar in nature as those returned from SL-3. Tests made on the SL-3 samples and initial observations on SL-3 indicate a close resemblence to data obtained on D024 samples (a siliceous type material).

The S020 P.I. has expressed concern that almost all of his data below 111Å was absent. His contention is that a contaminant had coated or reacted with the entrance filters.

Experiment S201 (operated during SL-4) had evidence of corona while attached to the A-SAL but not during EVA data takes. It is felt that the interface of the experiment to the A-SAL produced a small leak, allowing increased pressures, which caused corona. Until the data is further analyzed no further contamination effects can be related.

Due to a mechanical camera failure experiments S073, T025 and S063 operated on SL-4 were not focused at infinity during EVA Kohoutek data runs. The T025 PI stated that the focusing at approximately five feet beyond the handrail did show some evidence that particles can be seen in some of the frames. The size and number of particles will not be available until further analysis is made, however, from S052 particle shower data and knowing T025's field-of-view as 24°, it is predicted that four particles per second may be seen.

Mr. Jack Horton at MSFC indicated that analytical chemistry tests on a piece of the thermal sail brought back after SL-4 showed no conclusion evidence of contamination. However, a second series of tests attempting to reproduce the discolored flight samples from the same sail material is in progress, with the hope of obtaining worthwhile contamination information.

Discussions with Dr. Hallgren at Dudley Observatory have indicated that the SL-4 S149 cassettes were not as badly effected by contamination or oxidation as the SL-3 cassettes and should not effect the experiments main objectives.

The S063 P.I.'s have also stated that no contamination impact on their data is evident and that none is expected.

The S191 P.I. feels further analysis on data reduction programming is necessary before further comments are made regarding any contamination effects on the deep space data.

On DOY 232, the AMS was "stuck" in the deployed position for approximately 28 hours. When the AMS was eventually brought back into the OWS, it was retrieved too soon from the SAL for it to have reached ambient temperature. This action caused condensation to form on the mirror, further contaminating it. The mirror had previously been contaminated during SL-1/2 by a smudge or fingerprint on its surface.

A review of the exposure time of the AMS for data gathering indicated that it had been in use for approximately 75 hours as of the end of the SL-3 manned mission.

Although experiment contamination threshold sensitivity levels were not exceeded during Skylab experiment data takes, data from experiments using the Articulating Mirror System (AMS) during the SL-3 mission will have to be analyzed for contamination degradation. Data analyzed so far by the S019 PI indicated that the signal received from a specific star field had degraded approximately 50% when taken during the SL-3 mission as compared to a measurement taken of the same star field at the start of the SL-1/2 mission.

Visual inspection of the AMS by the astronauts and analyses of photographs made by the PI after the SL-3 splashdown indicated that the mirror was noticeably contaminated.

Based on recommendations made by the PI and the Contamination Mission Support Group (CMSG), the AMS was replaced for the SL-4 mission. At the end of the SL-4 mission, no contamination was detectable on the replacement AMS.

Dr. Karl Henize feels that the SL-4 S019 data has not shown any ill effects due to contamination.

An assessment of the internal environment of the OWS based upon T003 and M487 data indicated that the Cluster internal environment was relatively clean. T003 data from SL-1/2 indicated that particle concentration was about 3000 per cubic foot in the 1 to 100 micron size range which is better than a class 10,000 clean room condition. There is no reason at this time to suspect that the Skylab internal environment deteriorated further during the remainder of the mission.

The internal pressure and temperature of the ATM canister were monitored during the mission to obtain data to help assess the degree of outgassing and deposition within the ATM canister.

The ATM canister internal pressure reached a steady state value in the 10^{-5} to 10^{-6} torr range ten days after the SL-1 launch which was a longer time than expected. At that time the ATM Experiments high voltage systems were turned on and no problems were discerned. On DOY 216, the internal pressure increased from the 10^{-6} torr range to the 10^{-5} torr range in approximately 1 hour. This pressure rise was later attributed to an electrical short inside the canister that caused local heating and thus a pressure rise between TV Bus 2 and ATM Bus 2 in the Power Transfer Distributor Assembly (PTDA). The pressure dropped back to the 10^{-6} torr range in 2 days and did not go above the 10^{-5} torr range after that time. A quick-look assessment of the effects of contamination caused from this pressure rise from all ATM Experiment PIs indicates that it did not degrade their data noticeably.

Early in the mission, ATM canister internal temperatures were about 10°C colder than the nominal 20°C due to the thermal control system being off to conserve power. When the thermal control system was activated temperatures returned to nominal and no effects from internal deposition were noted from this thermal cycle.

It was concluded that throughout the mission ATM canister internal pressure and deposition rates from external contamination were within nominal values causing no degradation of ATM experiment hardware or data.

Although four ATM thermal shield aperture doors were fixed open during the mission (S054, S082A, S082B, Hα 2), starting during SL-3, no experiment contamination was reported from this source by the ATM PIs.

Several sightings of particles external to the Cluster were made using the S052 Experiment video display. However, it has been concluded that these particles did not affect the data gathering operations of the ATM experiments.

Review of QCM and T027/S073 Photometer flight data, S052 TV, basic math modeling, astronaut comments with respect to experiment operation and appearance, crew debriefings, and preliminary contacts with PIs and/or their representatives have indicated no specific concern of the impact of external contamination on optical experiments except possibly those noted above.

In summary, no major degradation in performance of experiments other than those noted occurred throughout the Skylab manned mission.

c. Thermal Control Surfaces - During the Skylab mission, the Orbital Assembly (OA) thermal control surfaces apparently experienced some degradation in their properties. Both the S13G paint and the Z-93 coatings have experienced either ultraviolet degradation and/or contamination degradation since all areas exposed to the Sun have turned a tan to brown color. Areas that were noticeably discolored included the ATM rack and canister and the under side of the ATM Solar Array Wings, Airlock Module Radiator, the OWS aft skirt, and the CSM. The crew noticed a tan to brown color pattern on the CSM in solar exposed areas indicating ultraviolet degradation. The SL-3 crew stated that they saw several (5) large potato chip shaped and colored paint flakes attached to the SM between each of the quads that they could see. All "chips" were attached on only one end and the attachment point was the same side for each one. The crew suggested that the SM RCS roll engines caused these chips. The surface around them appeared scorched.

A detailed analysis of the thermal control surfaces was made to discern if the deposited contaminant noted caused a significant change in the thermal characteristics of these surfaces. The results from these analyses indicated that contamination did not cause a major impact on Cluster thermal control even though considerable deposition occurred as also witnessed by the D024 Experiment.

d. Solar Array Systems - Analyses of data generated by the Cluster Solar Array Systems indicated that no discernable degradation of electrical power was indicated due to contamination throughout the Skylab mission. This condition is attributable to the design of the electrical generating systems and relatively high temperatures of the solar panels which tend not to collect but to boil off contaminants that came in contact with them.

e. Windows - Crew comments on the condition of the various Cluster windows have provided the majority of window information. Throughout Skylab Mission, the S190A window showed indications of external contamination. The crew stated that they had to clean two (2) internal smudges off it during the SL-3 mission. A review of photographs of the STS windows indicated that STS window No. two (2) which previously had a "boot" print put on it during SL-1/2 was heavily contaminated. Window No. one (1) had some small spots on it. Windows Nos. three (3) and four (4) appeared clean. In general, the covers were kept on the STS windows at all times except when photography or visual observations were being made. This was done to keep condensation from accumulating on the inside of the windows and light glare off the ATM C&D panel. The Wardroom window was noticeably contaminated throughout the mission. A patch of ice between the panes of the wardroom window was reported by the SL-1/2 crew when the window was first uncovered. The SL-3 crew evacuated the space between the panes on DOY 216. After evacuation, a small spot about one half inch (1.27 centimeters) in diameter was left. At the end of the SL-3 mission, there were several spots and streaks of residue between the panes but the degradation of experiment data taken through this window during SL-3 will have to be analyzed to provide a quantitative value of the effects of contamination. All crews reported they had to clean the inside of this window often as well as STS windows periodically.

The SL-3 crew said the CSM windows remained clean, but the SL-4 crew reported external films on all CSM windows.

f. Star Tracker - Analysis of SL-1/2 and SL-3 Star Tracker data indicated that of the 39 anomalies recorded on the Star Tracker, eleven were identified as contaminant particles because of high gimbal tracking rate and correlation with the aerodynamic drag from the ambient atmosphere. Correlations of these anomalies with events on Skylab indicate that these "false stars" possibly were scattered light from fragments due to deterioration and structural damage to paints and insulation on the solar side of the OWS and possibly were transported by molecular flow fields from various vents and the drag of the ambient atmosphere. The remaining 28 Star Tracker anomalies have not been confirmed due to the lack of Star Tracker tracking data. Far fewer contamination-related Star Tracker anomalies were observed on SL-3 than on SL-1/2 due to the tracking of brighter target stars and a change in Star Tracker management policy. The continuation of these policies completely eliminated the tracking of false stars on the SL-4 mission.

The failure of the Star Tracker on DOY 361 was caused by the failure of the Star Tracker outer gimbal encoder lamp and was not caused by contamination.

1.0.3 Effectiveness of Control Measures - The effectiveness of the many control measures that have been adopted by the Skylab program to reduce the impact of contamination has not been totally assessed but indications are that they were successful. Indications are that the outgassing of the Cluster as measured by the EREP QCMs was within the limits of the steady state outgassing rates that were obtained through material outgassing test specifications (50M02442). These outgassing rates were used for baseline values in the math modeling activity for deposition assessment. With the relatively close agreement between the daily QCM readings and the modeling predictions which were updated with flight data, it is felt that the observed deposition was the result of outgassing rates within the outgassing ranges in 50M02442 and that line-of-sight transportation of the contaminants is valid.

The tracking of false stars by the Star Tracker and the observation of contaminant particles not correlated to specific events indicates that a random source of particulate contamination exists on the Cluster. It is thought that the majority of these particulates were created by sloughing of paint and insulation from the solar side of the OWS. SL-1/2 fly-around photography substantiated this premise by showing large paint blisters and surface damage in this region.

Observations of particle trajectories by the S052 video display and Star Tracker system and fly-around photography of the TACS plume has verified the cloud simulation predictions transport mechanisms affecting contaminant particles and scattering levels from individual particles and plumes. Analysis of T027/S073 photometer data allowed improvement of predicted background scattering levels which had to be revised upward due to the larger particulate cloud around the Cluster than was predicted prior to launch.

The forming of ice and the deposition of particulate matter between the panes of the Wardroom window indicated that more stringent operational environment procedures were needed to keep this window clean. They stated that the contamination condition of the window near its center was so bad that they always took the handheld photography through this window as near as possible to its periphery.

The crews photographed all four of the STS windows to provide data for cleanliness evaluation. STS windows 3 and 4 remained fairly clean throughout the mission. Window 2 was visibly contaminated and window 1 was slightly contaminated. It was evident that window covers and heater usage played an important role in maintaining operational windows (such as S190A) free from contamination.

Contamination Detailed Test Objectives were prepared for observation of the Mole Sieve and Waste Tank non-propulsive vent plumes on each manned mission to insure that ground test activities and hardware modifications had accomplished their objectives. Crew observations were made of these vents. All observations for particulates were negative and it is therefore concluded that the preflight test of the Mole Sieve and Waste Tank non-propulsive vents (NPVs) for particles appeared to have been valid and that long term operations of these systems did not change.

Since there has been no apparent direct on-orbit degradation of experiment data except those noted (with the possible exception of those experiments using the S019 AMS, S020, T025, and the Du24, S149, and S230), the effectiveness and necessity of the operational constraints with respect to operational vents and experiment activities is felt to have been proven. During SL-1/2 and SL-3 there were four instances where these constraints were violated. For example, during SL-3 an overboard dump of condensate occurred through the contingency condensate vent during an ATM pass, and venting of the gas side of the condensate holding tank was performed through the ASAL while the S019 Experiment was in the ASAL. However, it is felt that these violations of the Flight Mission Rules and constraints did not compromise the system or the experiments in question.

1.0.4 Mission Rules and Constraint Changes - As a result of new experiments required for SL-4 Kohoutek observation and the new use of S063 with the AMS, changes were made to the mission rules and operational constraints over those developed at the start of the mission. Table 1.0.4-I contains the mission rules and operational constraints at the end of the Skylab mission and are representative of those operational constraints required to maintain contamination control of the mission.

1.0.5 Contamination Prediction Summary - Based on computer math modeling of the contaminant environment throughout the entire Skylab Mission, contamination prediction summary reports were generated on a daily basis during SL-1/2 and weekly for the remainder of the program. These reports contain contaminant deposition predictions for critical operational surfaces and experiments along with induced environment predictions of mass column densities and radiant scattering as a function of solar brightness ratio (B/B_o) for experiment lines-of-sight. Table 1.0.5-I is the final prediction summary for the Skylab Mission. Where available, susceptible experiment maximum allowable contamination limits are presented to allow comparison with predicted levels and aid in the determination of required operational constraints. All predictions are based on the as-flown exposure timelines of the particular surface or experiment of interest. The day of year that the highest level of contamination occurred is also noted in the table. As indicated, there were no predicted contamination conditions that exceeded experiment or system tolerances.

1.0.6 Skylab Event Timeline - An abbreviated major event timeline of the Skylab mission is presented in Table 1.0.6-I. The purpose of this timeline is to provide reference data allowing correlation of major events referred to in this report.

TABLE 1.0.4-I Operational Vent/Experiment Constraints

VENTS \ EXPERIMENTS		ATM		COROLLARY												EREP
		S052 S054 S055A S056 Hα1, 2 S082A S082B	STAR TRACKER	S020	S063	S149 (IN SAL)	S201	S183	S019	S073	T027/S073	S232	S233	T025	ED 23, 26	S190A, B S191 S192 S193 S194
CABIN ATMOSPHERE VENTS[5]		1←→1	1	1	12	6	2	2	2	12		1	1	1	2	1←→1
EVA		1←→1	1	1	12	4	11	2	2	12		1	1	1	2	1←→1
CSM RCS		1←→1	1	1	12	4	12	2	2	12	1	1	1	1	2	1←→1
WATER DUMP (UNBAGGED) INTO WASTE TANK						4										
AM CONDENSATE SYSTEM VENT (CONTINGENCY)[9]		1←→1	1	1	12	4	2	2	2	12		1	1	1	2	1←→1
CSM VENTS[3]		1←→1	1	1	12	4	2	2	2	12		1	1	1	2	1←→1
MDA EXP (M512) VENT	M479	1←→1	1	1	12	4	1	2	2	12		1	1	1	2	1←→1
	M551, 552, 553					4							1			1←→1
OWS EXP VACUUM VENT	M092				14	4	14	14	14	14					14	
	M171				13	4	11	1	1	1				11	1	
CONDENSATE HOLDING TANK VENT (GAS SIDE)					8	4	8	8	8	8	10				8	8

Table 1.0.4-I (Continued)

NOTES:

1 - Complete Vent 15 Min Prior To Experiment Exposure.

2 - Complete Vent 30 Min Prior To Experiment Exposure.

3 - Includes Steam Duct, Urine Dump, Waste Water Dump, And Fuel Cell Purges.

4 - Deleted. (Prior To SL-4 Note 4 Read: "Cassette Covers Will Be Closed During And For 15 Min After Completion Of Vents").

5 - See Rule No. 6-43 For List Of Vents To Be Used For Atmosphere Mgmt.

6 - Deleted. (Prior To SL-4 Note 6 Read: "Cassette Covers Will Be Closed During And For 15 Min, Or 12 Hours, After Completion Of Cabin Atmosphere Or OWS Final Blowdown, Respectively").

7 - Includes Lock Depress Valve And Suit Overboard Vent. Rule Waived For S149, T025, S020, Or S201 If Deployed EVA.

8 - Complete Vent 15 Min Prior To Installation Of Experiment In Anti-Solar SAL.

9 - Begin Vent After Orbital Midnight And Complete Vent Before Sunrise Crossing Or Double Vent Constraint Times (If Not In SI, Vent In Direction Of Negative Velocity Vector).

10 - Complete Vent 15 Min Prior To Installation Of Experiment In Anti-Solar SAL. If Experiment Is Already Installed, Extend 7 Rods And Place Trunnion To Zero.

11 - (a) Complete Vent 30 Min Prior To Experiment Exposure Using AMS.

(b) No Time Constraint On Vent For EVA Exposure.

12 - (a) Complete Vent 15 Min Prior To Experiment Exposure Without AMS.

(b) Complete Vent 30 Min Prior To Experiment Exposure With AMS.

13 - Complete Vent 15 Min Prior To Experiment Exposure With AMS.

14 - If M092 Vents Overboard, As In SL-2 And Early SL-3, Complete Vent 15 Min Prior To Experiment Exposure Using AMS. No Time Constraint For M092 Vent Into Waste Tank As In Late SL-3 And SL-4.

Table 1.0.5-I Contamination Prediction Summary

EXPERIMENTS		EXPERIMENT SENSITIVITY (1)	PREDICTIONS (2)
ATM:			
	CLOUD ($B/B_\odot$)	Not Available	7.6×10^{-15} (157)
	COLUMN DENSITY	Not Available	1.4×10^{-14} (157) (3)
	DEPOSITION (Å)	Not Available	0.0 (039)
COROLLARY:			
	CLOUD ($B/B_\odot$)		
	S190A	3.7×10^{-9} (4)	5.03×10^{-17} (364)
	S190B	3.7×10^{-9} (4)	1.6×10^{-16} (364)
	S191	4.0×10^{-9} (5)	5.03×10^{-17} (364)
	S192	4.4×10^{-9} (5)	5.03×10^{-17} (364)
	S193	Not Applicable (5)	Not Applicable
	S194	Not Applicable (4)	Not Applicable
	S063	3.3×10^{-10} (6)	2.7×10^{-16} (031)
	S019	Not Applicable (5)	Not Applicable
	S183	Not Applicable (5)	Not Applicable
	S073	1.0×10^{-13} (6)	1.0×10^{-16} (216) (7)
	S201	Not Applicable (5)	2.7×10^{-16} (033)
	T025/S073	1.0×10^{-13} (6)	5.9×10^{-16} (355)
	S063K	3.3×10^{-10} (6)	4.6×10^{-15} (348)
	S019K	Not Available	7.2×10^{-15} (340)
	S183K	Not Available	7.5×10^{-15} (341)
	S201K	Not Applicable (5)	7.0×10^{-15} (339)
	S020K	1.2×10^{-8} (6)	4.6×10^{-15} (363)
	S233	Not Available	7.5×10^{-15} (341)
	T025K	1.0×10^{-9} (6)	4.6×10^{-15} (363)

Table 1.0.5-I (cont.)

EXPERIMENTS	EXPERIMENT SENSITIVITY			PREDICTIONS		
COROLLARY: DEPOSITION	Å	% ⑧	µg/cm^2	Å	% ⑧	µg/cm^2
S190A	50	0.5	0.5 ④	0	0	0 (032)
S190B	50	0.5	0.5 ④	0	0	0 (032)
S191	300	3.0	3.0 ④	0 ⑨	0	0 (032)
S192	560	5.0	5.6 ④	0	0	0 (032)
S193	2.5×10^6	0.5	2.5×10^4 ④	231.6	<1.0	2.316 (032)
S194	2000	20	20 ④	0	0	0 (032)
S063AMS SL3	240	50	2.4 ④	2.6	1.0	0.026 (233)
S063AMS SL4	240	50	2.4 ④	1.5	<1.0	0.015 (029)
S063 ASAL	960	50	9.6 ④	0	0	0 (023)
S063 (STS)	960	50	9.6 ④	94	5.8	0.94 (031)
S063 (WRW)	960	50	9.6 ④	175	10.5	1.75 (031)
S019 SL3	11	10	0.11 ④	2.6	2.7	0.026 (233)
S019 SL4	11	10	0.11 ④	1.6	1.6	0.016 (025)
S183 SL3	18	10	0.18 ④	2.6	1.0	0.026 (233)
S183 SL4	18	10	0.18 ④	1.6	<1.0	0.016 (029)
S073	N/A	N/A	N/A ⑤	0	N/A	0 (216)
S201	N/A	N/A	N/A ⑤	1.6	N/A	0.016 (033)
T025/S073	N/A	N/A	N/A ⑤	0	N/A	0 (023)
T025/S073 w/AMS	N/A	N/A	N/A ⑤	1.6	N/A	0.016 (030)
S063K	240	50	2.4 ④	1.5	<1.0	0.015 (029)
S019K	11	10	0.11 ④	1.5	1.4	0.015 (030)
S183K	18	10	0.18 ④	1.0	<1.0	0.010 (011)
S201K (EVA)	N/A	N/A	N/A ⑤	4.0	N/A	0.040 (363)
S201K (AMS)	N/A	N/A	N/A ⑤	1.6	N/A	0.016 (032)
S020K (EVA)	200	1.0	2.0 ⑥	4.0	0	0.040 (363)
S233 (CSM)	Not Available			5850	10	58.5 (345)
S233 (STS)	Not Available			94.7	<1.0	0.947 (032)
T025K	N/A	N/A	N/A ⑤	5.1	N/A	0.051 (363)

N/A : NOT APPLICABLE

Table 1.0.-·I (cont.)

SYSTEMS	PREDICTIONS DOY 039		
SOLAR ARRAY SYSTEM ACCUMULATIVE POWER LOSS (%)			
OWS SOLAR ARRAY GROUP (1-4)	3.43%		
OWS SOLAR ARRAY GROUP (5-8)	2.92%		
ATM SOLAR ARRAY SYSTEM	0.00%		
THERMAL CONTROL SURFACE ACCUMULATIVE $\Delta\alpha$			
ALL SURFACES:	0.190		
CONTAMINATION DETECTION INSTRUMENTS ACCUMULATIVE (g/cm^2)			
EREP X QCM (CSM FACING)	52.08×10^{-6}		
EREP -X QCM (OWS FACING)	60.77×10^{-6} (9)		
EREP -Z QCM (ANTISOLAR)-2	0.0		
ATM QCM (DAILY RATE)-2	0.0		
T027 X QCM	N/A		
T027 Z QCM	N/A		
WINDOWS - ACCUMULATIVE TRANSMISSION LOSS			
STS:			
DEPOSITION (g/cm^2)	9.549×10^{-7}		
TRANSMISSION LOSS (%)			
@ 6000Å	0.095%		
@ 3000Å	3.15%		
WARDROOM			
DEPOSITION (g/cm^2)	1.78×10^{-6}		
TRANSMISSION LOSS (%)			
@ 6000Å	0.155%		
@ 3000Å	5.8%		
CSM:	SL-2	SL-3	SL-4
DEPOSITION (g/cm^2)	1.38×10^{-4}	2.31×10^{-4}	1.50×10^{-4}
BRIGHTNESS LOSS (%) (10)	21%	31.5%	23%

NOTES ON FOLLOWING PAGE

Table 1.0.5-I (cont.)

NOTES:

1 Sensitivities are based upon the most susceptible wavelength of a particular experiment.

2 Predicted deposition levels are based upon accumulative deposition over operational time frames of systems or experiments. $B/B_{\odot}$ predictions presented are for the highest levels witnessed during the Skylab mission. DOY that these levels were reached are indicated in parenthesis beside each prediction.

3 Column density predictions are based on total molecular column density in g/cm^2.

4 Sensitivity based on tolerable percent degradation quoted from experiment P.I. and ensuing calculation of tolerable B/B_o and deposition levels.

5 Sensitivity quoted directly from experiment P.I.

6 Sensitivity calculated from known experiment characteristics and objectives.

7 Preliminary flight data indicates B/B_o readings in the 10^{-14} range.

8 Signal loss percent.

9 Flight data from the -Z facing QCMs indicates a deposition rate of approximately 12Å/day. The only source appears to be localized outgassing from the X facing QCM connectors which are in the field-of-view of the -Z QCMs. This is believed to be a localized condition and not representative of Skylab outgassing although the effect of ambient reflection has not been totally assessed at this time. Therefore, math modeling continues to use zero deposition on the -Z QCMs and the -Z facing EREP experiments including S191 which had its outer door left open for 40 days during SL-3.

10 CSM window brightness loss is the visible transmission loss based on the spectral response of the human eye.

Table 1.0.6-I Abbreviated Skylab Event Timeline

Mission	Date	DOY	Hr. (GMT)	MD	Event
SL-1	5/14/73	134	18	1	SL-1 Launch
SL-2	5/25/73	145	20	1	SL-2 Launch
	5/25/73	145	21	1	Fly-around-Inspect Cluster Damage
	5/25/73	145	23	1	SEVA-Inspect OWS SAS Wing
	5/26/73	146	04	2	Dock
	5/26/73	146	22	2	Parasol Deployment
	6/7/73	158	15	14	OWS SAS Wing Deployment
	6/22/73	173	09	29	Undock
SL-3	7/28/73	209	11	1	SL-3 Launch
	7/28/73	209	19	1	Dock
	7/30/73	211	18	3	Thermal Sail Deployment
	9/25/73	268	19	60	Undock
SL-4	11/16/73	320	14	1	SL-4 Launch
	11/16/73	320	22	1	Dock
	2/8/74	039	10	85	Undock

1.1 DESCRIPTION

1.1.1 Introduction - This final Skylab Contamination Evaluation Report presents a contamination Summary which covers the entire Skylab Mission. It addresses briefly the rationale for developing a contamination control system for Skylab, describes the techniques, controls and computer models, data evaluations, and the contamination control results obtained throughout the Skylab orbital operations. The report discusses results versus predictions, where applicable, "lessons learned" during this program, and makes recommendations for contamination control for future spacecraft programs.

Since contamination does not fall into a specific category as a spacecraft system such as Electrical Power Systems or Thermal Control and Environmental Control Systems, an explicit system's definition of contamination must be established for the spacecraft and each concerned spacecraft system. The contamination control systems definition for Skylab is a description of spacecraft optical contamination, definition of the sources and their characteristics, identification of critical surfaces and elements and their susceptibility, and the measures and controls (such as ground protection, design changes, time lines, and constraints) that have been established so that contamination would not compromise the Skylab mission objectives.

Skylab is the first manned space vehicle that has operated in a space environment in excess of a two week period. As a result of a manned spacecraft's outgassing from exposed non-metallic surfaces, leakage characteristics, controlled engine firings, vented waste materials, and other necessary but unavoidable vents, an induced atmosphere around the spacecraft exists which is dependent upon the ambient orbital conditions and the nature of the contaminant. This induced atmosphere is capable of generating an optical interference background which affects experiments and instrumentation in the spectral range from the X-ray through the microwave region (Figure 1.1.1-1) from particulate scattering, broadband and selective band absorption, and emission in the infrared. The induced atmosphere also provides a source of contaminants which may deposit upon critical experimental or operational surfaces in the form of thin films or particulate matter.

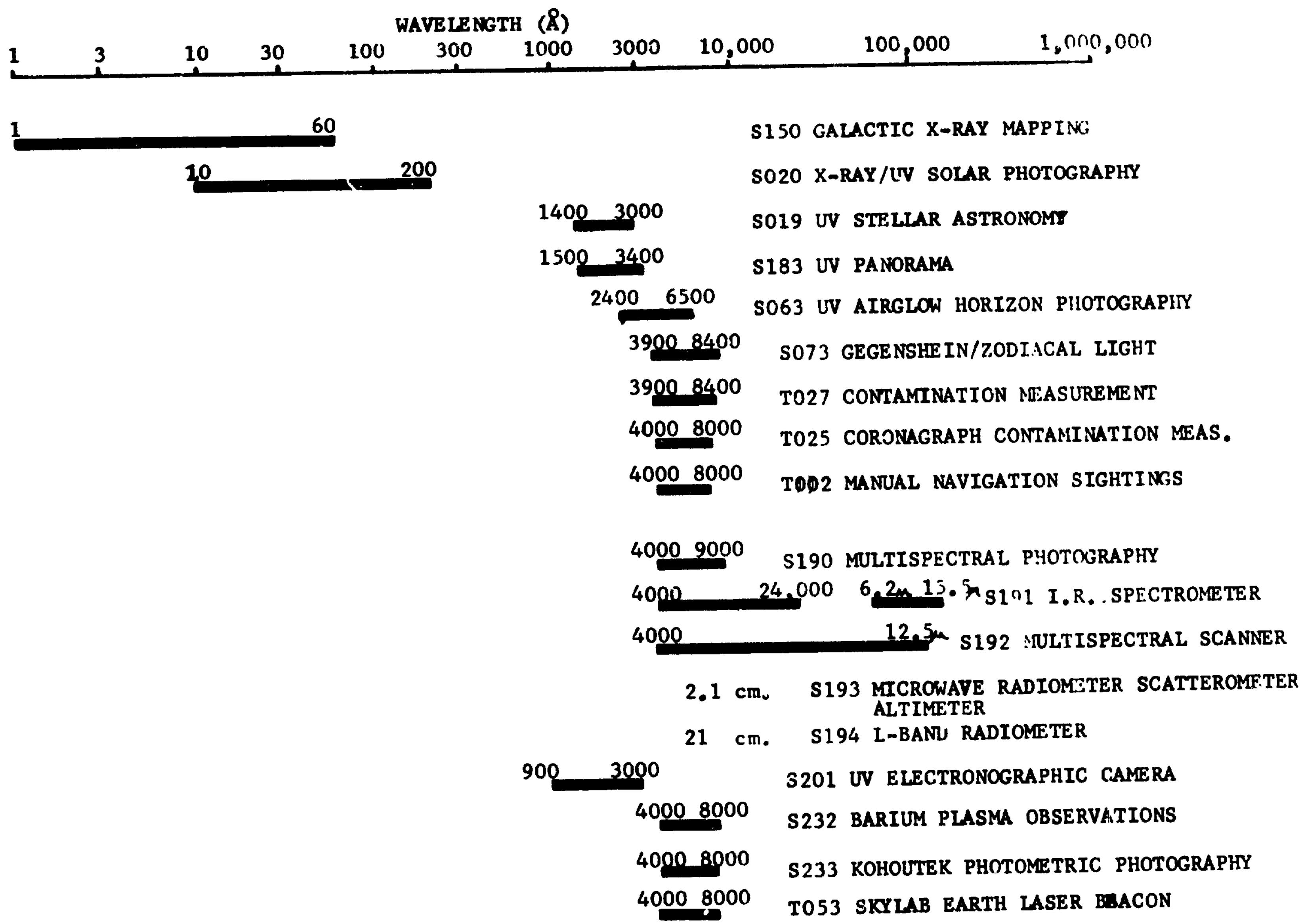

Figure 1.1.1-1 Spectral Range of Skylab Experiments

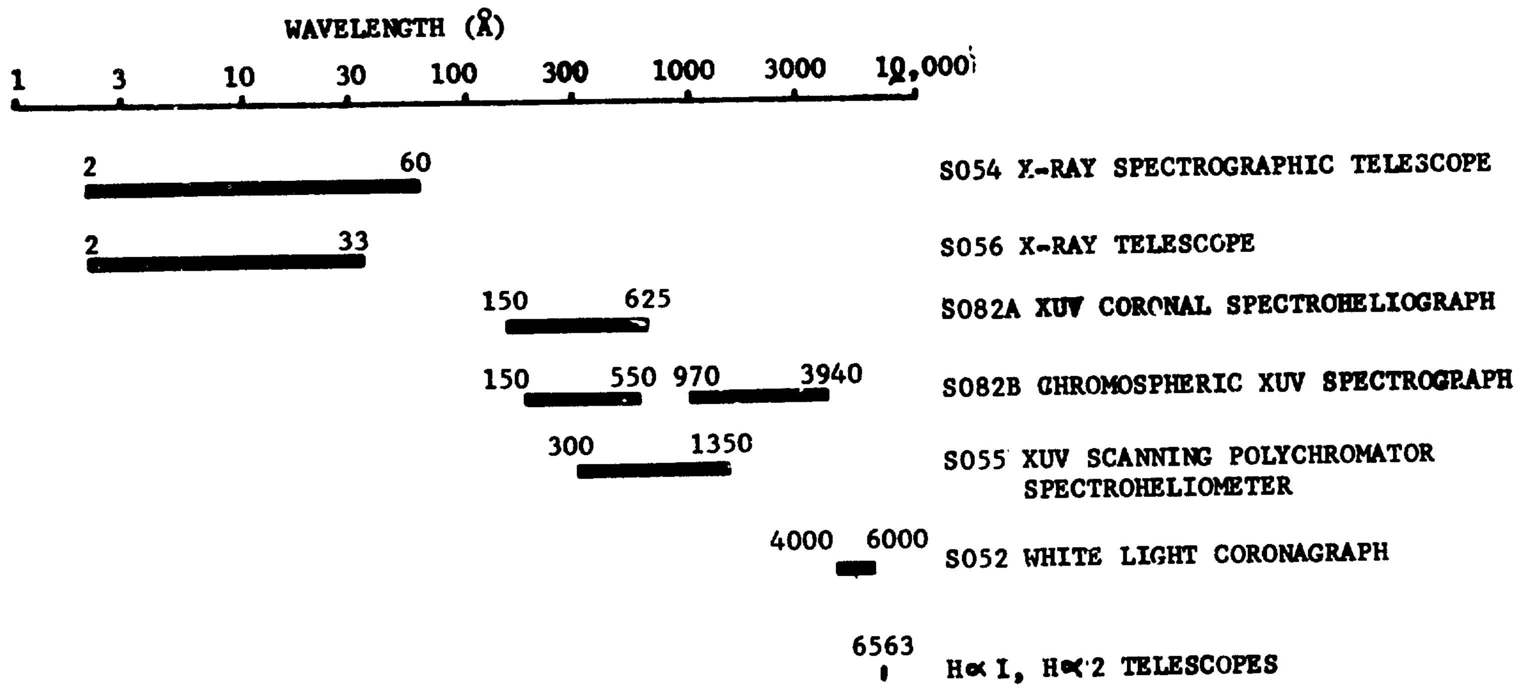

Figure 1.1.1-1 Spectral Range of Skylab Experiments (continued)

The Contamination control for Skylab came as a result of the direction of a special chartered group at the Marshall Space Flight Center designated to manage this inter-discipline work throughout the Skylab Program. This group was named the Contamination Control Working Group (CCWC). It was composed of Marshall Space Flight Center Laboratories and Program Office personnel, other NASA Centers, Principal Scientists, and contractor personnel. The actual contamination control mission operations including assessment, anomalies and evaluation were conducted by the Contamination Mission Support Group (CMSG). This group was composed of representatives from the following MSFC disciplines: Thermal, Solar Array Systems and Star Tracker, Induced Atmosphere, ATM Experiments, Coroliary Experiments, and Windows. For further information concerning the approach to contamination control for Skylab, see Appendix D.

Skylab contamination control included identifying contaminant sources and sensitive elements, eliminating these sources where possible through hardware modifications, and resolving problems that arose regarding design and testing. In addition, mission operational scheduling was performed to control release of contaminants, exposure of sensitive experiments and instrumentation and data acquisition by them. The basic documentation used for specifying contamination control for the Skylab Program was the Cluster Requirement Specification (CRS), RS003M0003.

The CRS established the prelaunch cleanliness requirements for manufacturing, transportation and storage for all flight hardware including experiments, OA interior, OWS forward dome and interior payload shroud, and contamination control plans for ground handling and cleanliness at KSC. It set forth the launch and/or orbit control requirements which specified the allowable degradations due to contamination on thermal control surfaces, Cluster windows, optical experiments and instruments, and solar cell panels. For these requirements, consideration was given to Cluster assembly, geometry (or line-of-sight), locations of sensitive elements, protective shields and covers, material selection, and material outgassing control. In addition, the CRS established design requirements for contamination tolerances, orbital venting and dumping, leakage, operational controls, and timelining of orbital operations.

The CCWG was established to formulate and coordinate the technical efforts of MSFC for the implementation of CRS requirements stated above. In particular, this group was responsible for the following tasks and/or activities:

a. Assuring the identification, coordination and implementation of optical contamination orbital control requirements and constraints;

b. Assuring the necessary overall coordination to properly develop requirements for control of orbital optical environment through the definition and resolution of problems associated with;

   1) Elimination of contamination sources

   2) Selection of materials of construction

   3) Orbital vent locations

   4) Scheduling of certain mission events such as docking activities and venting

   5) Attitude control thruster selection, location, and firing

   6) Ordnance and pyrotechnic devices

   7) EVA activities

   8) Ground Assembly, test, and handling

   9) Manufacturing operations.

c. Resolving problems and initiating actions regarding design, analysis, study, test, and operations by employing the line organizations of MSFC or of various contractors.

The CCWG accordingly supported both the development of analytical models and a series of extensive ground test programs to verify the models being developed and to provide the leadership of many control measures implemented with respect to flight hardware.

As a result of these activities, analytical capability presently exists such that direct mission support of Skylab was performed by predicting and verifying through flight data the Skylab environment, establishing constraints or controls, assessing anomalies, and preparing a contamination section for the Skylab Mission Evaluation Report. In addition, the CCWG was effective in eliminating vents, rerouting vents for minimum impact, establishing filters, and recommending many changes to minimize the effects of contamination to Skylab. Many materials were subjected to tighter controls by virtue of the CCWG actions. In the Summary, the effectiveness of these control measures observed throughout the Skylab Mission are discussed in this report.

Subsequent sections in this report address the areas where specific evaluation of contamination of Skylab was performed. These are Induced Atmosphere, Optical Experiments and Windows, Thermal Control Surfaces, Solar Array Systems and Star Tracker, and anomalies.

1.1.2 <u>Contamination Operation Constraints and Mission Rules</u> - Coupled with establishing the necessary prelaunch contamination control, assessment, and evaluation, operational constraints and Mission Rules were established to provide for the day to day mission support to the Huntsville Operations Support Center. To do this, it was necessary to impose numerous constraints on operational vent activities. These constraints were effective between experiment and vehicle systems and were modified from mission to mission to reflect unique requirements for each mission. Previous mission evaluation reports provided the constraints and Mission Rules as applicable for those missions. The constraints for each experiment and system for the SL-4 mission defined in Section 1.0.4 indicate the nature of the requirements set forth in establishing proper mission control of contamination.

1.2 INDUCED ATMOSPHERE

1.2.1 General Discussion - The following sections address two aspects of the evaluation of the induced contaminant atmosphere during the Skylab mission. One aspect deals with Quartz Crystal Microbalance (QCM) instrumentation, detection and evaluation of the contaminant deposition, and the scattering or cloud effects as the result of the induced atmosphere. The second aspect is the validation of three mathematical models which were developed primarily for premission contamination assessment and evaluation controls, daily mission support, and post mission evaluation activities. The validation of these models is important in being able to establish contamination conditions at various Cluster positions as a result of obtaining specific flight data from various experiments such as D024, S230, and T027/S073 photometer and instrumentation such as the QCMs.

1.2.2 Induced Atmosphere Evaluation

1.2.2.1 Introduction - This section of the report is the evaluation of the induced atmosphere around Skylab for the complete mission.

A major concern for Skylab was the presence of particulates being generated that produced a higher scattering background than was predicted before the start of the mission. Such particulates consisted of ice crystals resulting from liquid dumps or from nucleation of water vapor or other vented gases, dust and lint leaving the spacecraft surface, paint chips, and loose material such as insulation flakes and other debris working their way out of the spacecraft interior. Elaborate precautions were taken to reduce the particulate background by eliminating liquid dumps and by keeping the spacecraft as clean as possible. However, the generation of particulates is very difficult to predict and there have been very few measurements of the scattering background around manned spacecraft to accurately assess this problem.

The QCMs continued to record contaminant deposition throughout the mission. It is noted however that the +X and -X QCMs coarse voltage readings became unstable during the latter part of the SL-3 mission with loss of reliable data from these instruments occurring on DOY 281 for the +X QCM and DOY 267 for the -X QCM. Higher than predicted readings were recorded on the +X and -X QCM early in the mission. This condition was attributed to the SL-1/2 docking and the SL-3 CSM RCS oxidizer leaks.

Measurements for the induced atmosphere have been made by the T027/S073 Photometer on both SL-1/2 and SL-3. Preliminary results of these measurements are discussed in Section 1.2.3.1. The T027A Sample Array was exposed to the Skylab external atmosphere on DOY 169 through 171. The results of a preliminary analysis of these data are discussed in Section 1.3.3.4.

1.2.2.2 Quartz Crystal Microbalance Description - The Quartz Crystal Microbalance (QCM) is a mass deposition transducer. The active elements consist of two quartz crystal oscillators; a sensing crystal oscillator and a reference crystal oscillator. The frequency of oscillation depends on the mass of the quartz crystal. The sensing crystal is exposed to the ambient environment where mass deposition causes a decrease in oscillator resonant frequency. The reference crystal is shielded from deposition and the oscillator is biased 1 KHz above the sensing crystal oscillator. The two oscillator frequencies are mixed and the output beat frequency is an indicator of mass deposition. Thermal effects are minimized by careful crystal selection and packaging.

Two QCMs (designated HCO and NRL-B) are mounted on the ATM Sun Shield looking along the +Z axis (see Figure 1.2.2.2-1). The crystals are slightly recessed and have field-of-view of 4.14 steradians (70° half-cone angle). There is no part of the spacecraft in the direct field-of-view of these units, therefore, their primary function is to monitor the return flux of contamination molecules that could enter the ATM aperture doors. These can monitor the effects of docking and other orbital operations such as EVA on the ATM experiments.

Four QCMs are mounted on a truss below the MDA in the vicinity of the EREP experiments. These units have a 1.59 steradian field-of-view (42.5° half-cone angle). Two of these units look in the -Z direction. One unit is designated Z AMB and operates at the ambient temperature of the truss assembly (0 to -23°C). The other unit, designated Z50, is insulated to retain some of its internal heat in an attempt to elevate its temperature to the S-190 window which is controlled at 10°C (50°F). These units have no part of the spacecraft in their field-of-view, although the Z AMB unit does have the wire and connector from the CSM module in its field and the Z50 unit can see the face of the OWS module. The unit designated CSM looks along the +X axis toward the CSM, and the unit designated OWS looks along the -X axis toward the OWS forward dome which is covered by the meteoroid curtain. Figure 1.2.2.2-1 shows the location of these units on the Skylab Cluster. The primary purpose of these units is to monitor the environment in the vicinity of the EREP experiments and to assess the contamination associated with docking, Mol Sieve operation, and other Cluster functions.

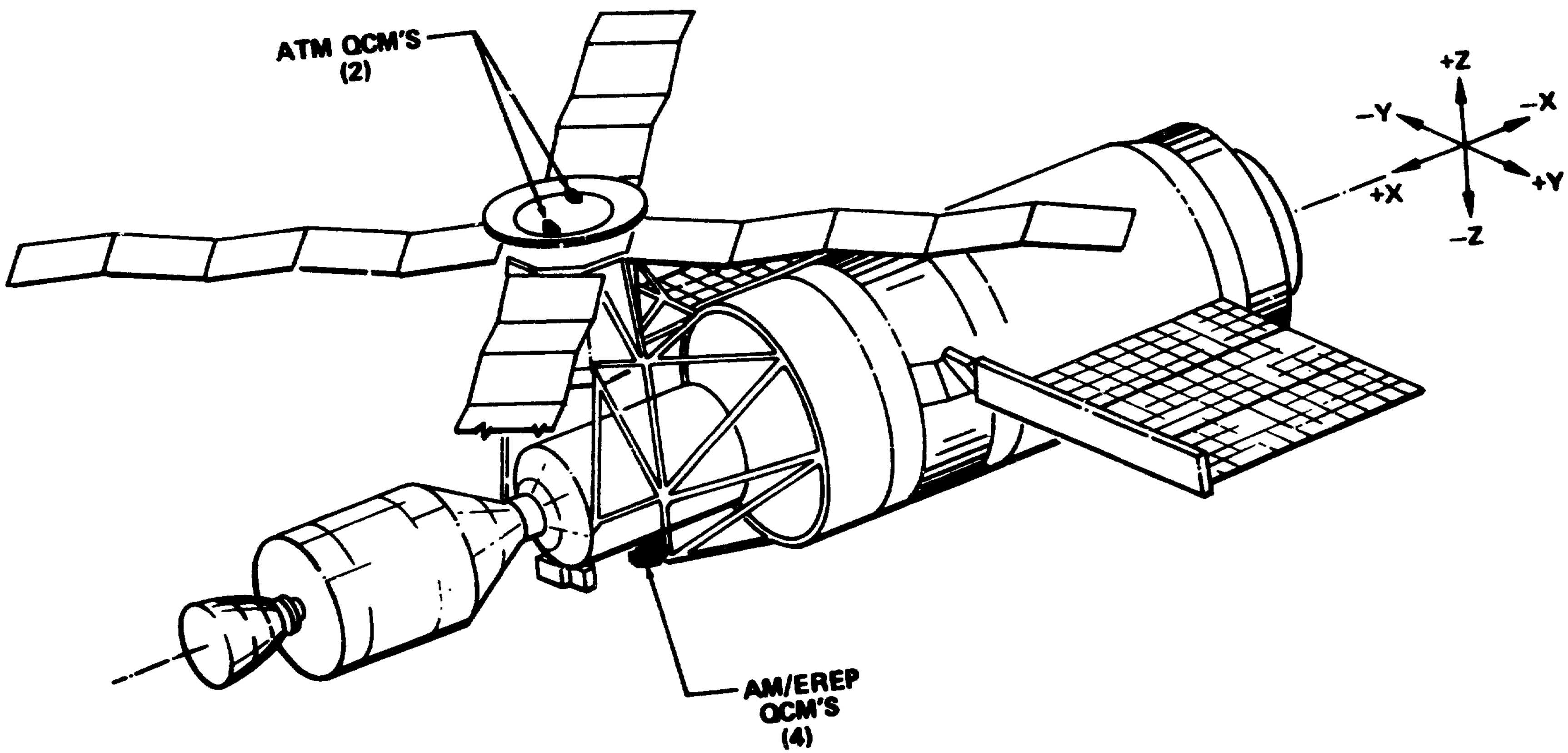

Figure 1.2.2.2-1 QCM Locations

1.2.2.3 Deposition Timeline Description - The following results have been obtained from quick look analysis using raw data. Processed data which allows much better analysis of rates, attitude effect, orbital effects, and temperature effects, is not yet available. Therefore, all results stated herein must be regarded as preliminary and subject to change when a more refined analysis is complete.

The QCMs provided data until SL-4 when the X facing QCMs reached electronic saturation. Flight measurements appear to correlate well with premission math modeling. Major contaminants are considered to be the result of outgassants and the line-of-sight assumption appears to be the primary mode of transportation for deposition. The ATM QCMs have shown no deposition as anticipated, and external contamination effects on ATM Experiments are negligible.

a. SL-1 Unmanned Phase - The long term behavior can be seen in Figure 1.2.2.3-1. The CSM unit began picking up deposition as soon as the Cluster was placed at a 50° Sun angle. The rate was observed to be .21 $\mu g/cm^2$ day. The OWS unit collected at almost steady rate of .34 $\mu g/cm^2$ day. The Z AMB unit was collecting at the rate of .03 $\mu g/cm^2$/day prior to docking, and the Z50 unit slowly cleaned up, leveling out at .4 $\mu g/cm^2$ below the reference level.

The ATM QCMs (Figure 1.2.2.3-2) were first turned on at 32 minutes after SL-1 launch. Therefore, the initial outgassing could not be seen. Consequently, the last readings before lift-off were taken as the reference. When the units first received power, they both indicated .24 $\mu g/cm^2$ above the reference value. Again, this could be due to thermal shifts or to the reference crystals cleaning up, or some contamination may have resulted during launch.

b. SL-1/2 Rendezvous and Docking - The contamination associated with the rendezvous and fly-around ranged from .14 $\mu g/cm^2$ on the OWS QCM which was partially shadowed by the OWS to .556 $\mu g/cm^2$ for the CSM QCM which has a much greater exposure to the CSM.

The soft dock maneuver resulted in a mass increase of 2.3 $\mu g/cm^2$ on the CSM unit. A decay rate of .162 $\mu g/cm^2$/hr was observed. The OWS QCM showed an increase of .108 $\mu g/cm^2$ from the docking, presumably from RCS

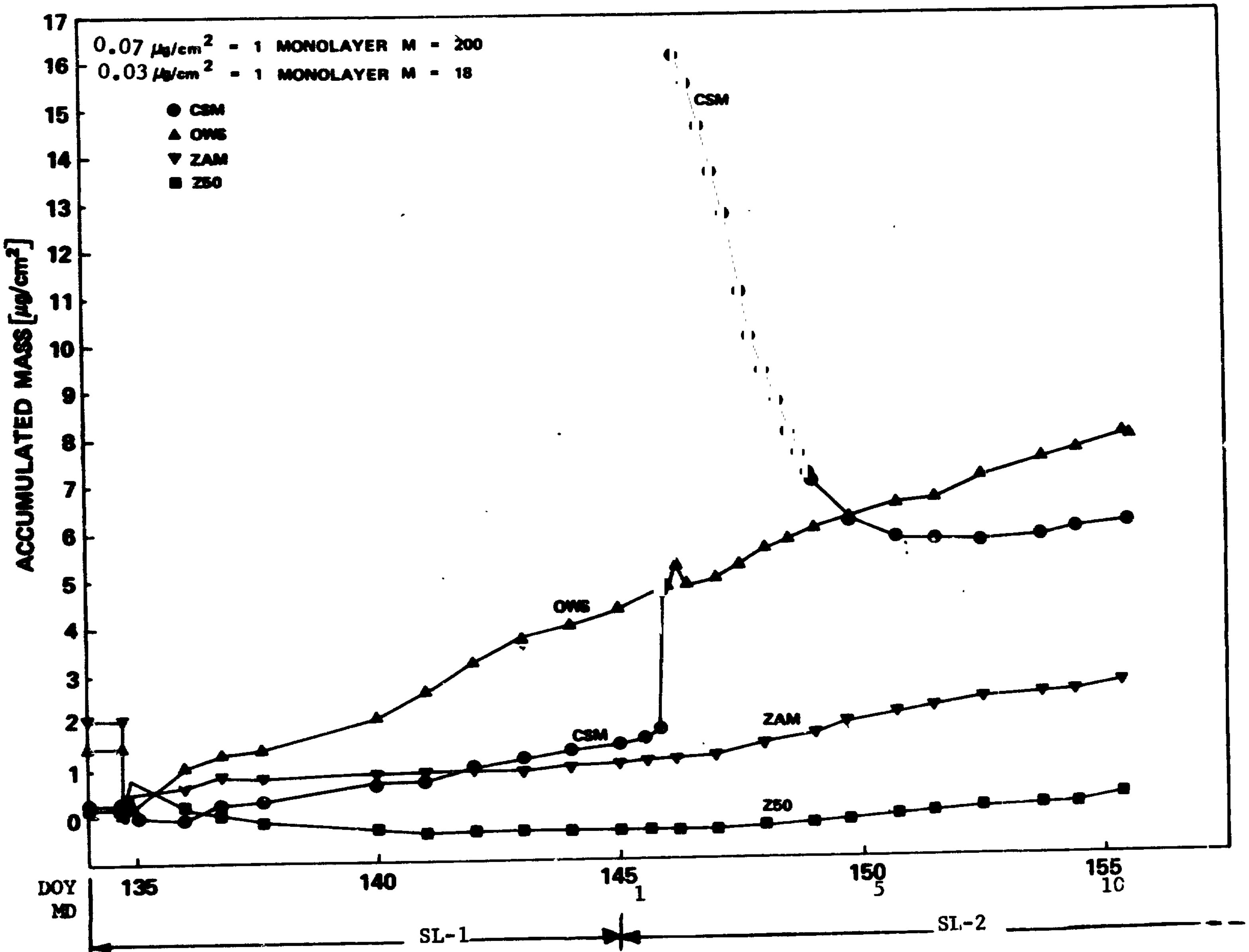

Figure 1.2.2.3-1 SL-1/2 EREP QCM Timeline - Long Term Deposition

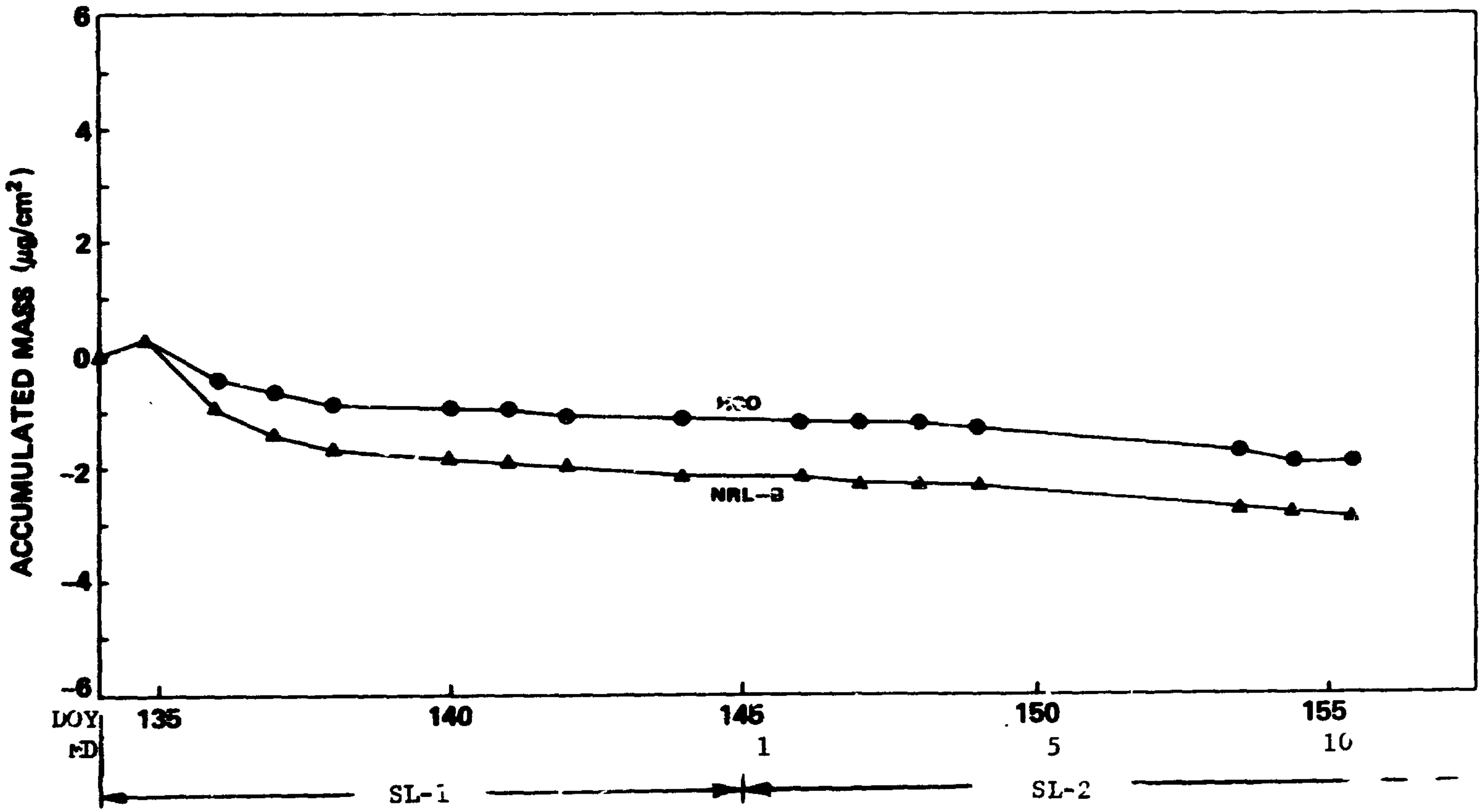

Figure 1.2.2.?-2 SL-1/2 ATM QCM Timeline - Long Term Deposition

plume reflection from the OWS forward dome. The other QCMs collected only .09 $\mu g/cm^2$.

During hard docking a large amount of RCS propellant ($\sim$310 lbs) was consumed. The CSM QCM had accumulated a total of at least 16.7 $\mu g/cm^2$, 12.93 $\mu g/cm^2$ during SEVA and the various attempts at docking. A gain (.323 $\mu g/cm^2$) was seen on the OWS QCM before and after the SEVA and docking sequence. Note the slight increase and subsequent decay of the -Z axis QCMs during each docking attempt. This may be material scattered from the plume, or may be material from the plume undergoing multiple reflections. In any event, it appears to leave rapidly.

The material deposited on the OWS QCM has a maximum decay rate of 6.15 $\mu g/cm^2/hr$. For a material with a molecular weight of 100, and $\rho = 1\ g/cm^3$, a monolayer has a mass of 5.5×10^{-8} g. An evaporation rate of 6.15 $\mu g/cm^2/hr$ or $1.708 \times 10^{-9}\ g/cm^2$ sec would require a surface stay time of 32 sec. For a surface temperature of 273°K (the QCM had a temperature ranging from -15°C to +8°C during this time) the heat of absorption must be approximately 18 - 23 Kcal/mol and the vapor pressure is 4.8×10^{-8} Torr.

Although considerable deposition was noted by the QCMs during rendezvous and docking, there was no optical surface exposed; and the effect of this activity was minimal upon exposed operational surfaces.

c. <u>SL-1/2 Manned Phase</u> - After docking, the CSM QCM continued to decline, reaching a dynamic equilibrium about DOY 152. The OWS QCM continued to collect at nearly the same rate it had throughout the mission. The peculiar thing is that the Z AMB had increased its rate from .097 $\mu g/cm^2/day$ to .216 $\mu g/cm^2/day$, and Z50 which was collecting nothing before the docking, was collecting at the rate of .097 $\mu g/cm^2/day$. This is not well understood since there was no part of the CSM in the field-of-view of these QCMs.

By DOY 152, the more volatile RCS products had evaporated from the CSM QCM to the point where the evaporation rate had fallen below the arrival rate. The rate increased to .54 $\mu g/cm^2/day$ by DOY 159 and then declined to .12 $\mu g/cm^2$/day on DOY 170. Both -Z QCMs also tend to level out at this time for reasons that are not understood.

d. Undock and Flyaround - Undocking was accomplished during DOY 173. The CSM moved along the +X axis and began moving upward in the +Z direction, flying directly above the ATM. Spacecraft Commander Conrad reported firing RCS toward the ATM and seeing the ATM Sun Shield rattle and the dipole antenna vibrate. However, absolutely no indication of any deposit was seen on the ATM or any of the EREP QCMs unless it occurred during one of the two signal loss periods during this time.

No deposition was observed during the shaping burn at DOY 173 10:07, which is not surprising since the Skylab was some distance away and in front of the CSM.

e. SL-3 Rendezvous and Docking - The second manned Skylab mission, SL-3, was initiated with launch occurring on DOY 209. The subsequent high activity period included approach and rendezvous, flyaround, station keeping and docking. Between DOY 209 18:00 and DOY 209 19:00 as the CSM approached, all EREP QCMs followed their normal behavior cycle. No comparable depositions to those of the SL-1/2 approach were recorded. This is due primarily to the smaller usage of the RCS engines for initial braking during the SL-3 approach.

There was no mention of visible effects of the thruster plumes on the ATM Sun Shields nor was there any detection of mass on the ATM QCMs, but films and real time TV did show significant impingement upon the solar parasol. It is still most probable that the ATM QCM sensing surfaces are several tens of degrees or so too high in operating temperature to be expected to experience much exhaust condensation. The CSM, Z AMB, and Z50 QCM units detected respectively 0.6, 0.9, and 0.9 $\mu gm/cm^2$ of mass accumulation from the thruster firings of flyaround and station keeping.

The hard dock was achieved with relative ease using a minimum of RCS thruster activity. It should be noted also that the CSM Quad B thruster group has an optimum line-of-sight geometry to the EREP QCMs in the docked or near docked mode. Due to an oxidizer leak, the Quad B Cluster was isolated thus further indicating a low probability of deposition was to be expected.

f. SL-3 Manned Phase - Figure 1.2.2.3-3 summarizes the overall EREP QCM measurements of deposition for the SL-3 mission period. To assist in evaluating the data, Table 1.2.2.3-I presents a computed five-day average rate of deposition. For the initial period of DOY 209 to 219, the +X and -X EREP QCMs show as expected increased deposition rate as a result of the influence of the materials outgassing of the "new" CSM spacecraft and the earth radiation heating affect on overall outgassing occurring at lower beta angles. The +X (CSM) unit rate is seen to increase by a factor of three whereas the -X and -Z units rates increase by about a factor of two.

The Quad B oxidizer leak was occurring prior to CSM docking with Cluster. A trouble shooting procedure was performed at DOY 209 16:00 which determined a leak rate of 0.075 pounds per second. The RCS engine was isolated; however, Mission Problem Report 209-J-43 states the engine was not completely stable. The SL-3 crew had commented on a large, nozzle-shaped Cluster of frozen oxidizer leaving the CSM. It is not known if sufficient solidified oxidizer existed in the B-3 RCS engine at dock for sublimation to be considered as a short term deposition source.

The Quad D oxidizer leak was occurring during the first data period being considered. A total leakage of 29 pounds was reported with the leak located beneath the SM outer cover. The SL-3 crew reported "snow" about the vehicle at about DOY 214 10:00. The location of this RCS quad and the venting being internal mean the only path to the EREP QCMs would have been by seepage through forward seams of the CM/SM interfaces. There is no way to definitely evaluate if a sufficient quantity of sublimating oxidizer existed with favorable geometry to warrant serious consideration of this possible source but oxidizer leak residue must be considered as a possible but not certain source.

The sources for the increased deposition occurring during this initial period of SL-3 in order of importance are concluded to be:

1) Outgassing of the docked CSM;

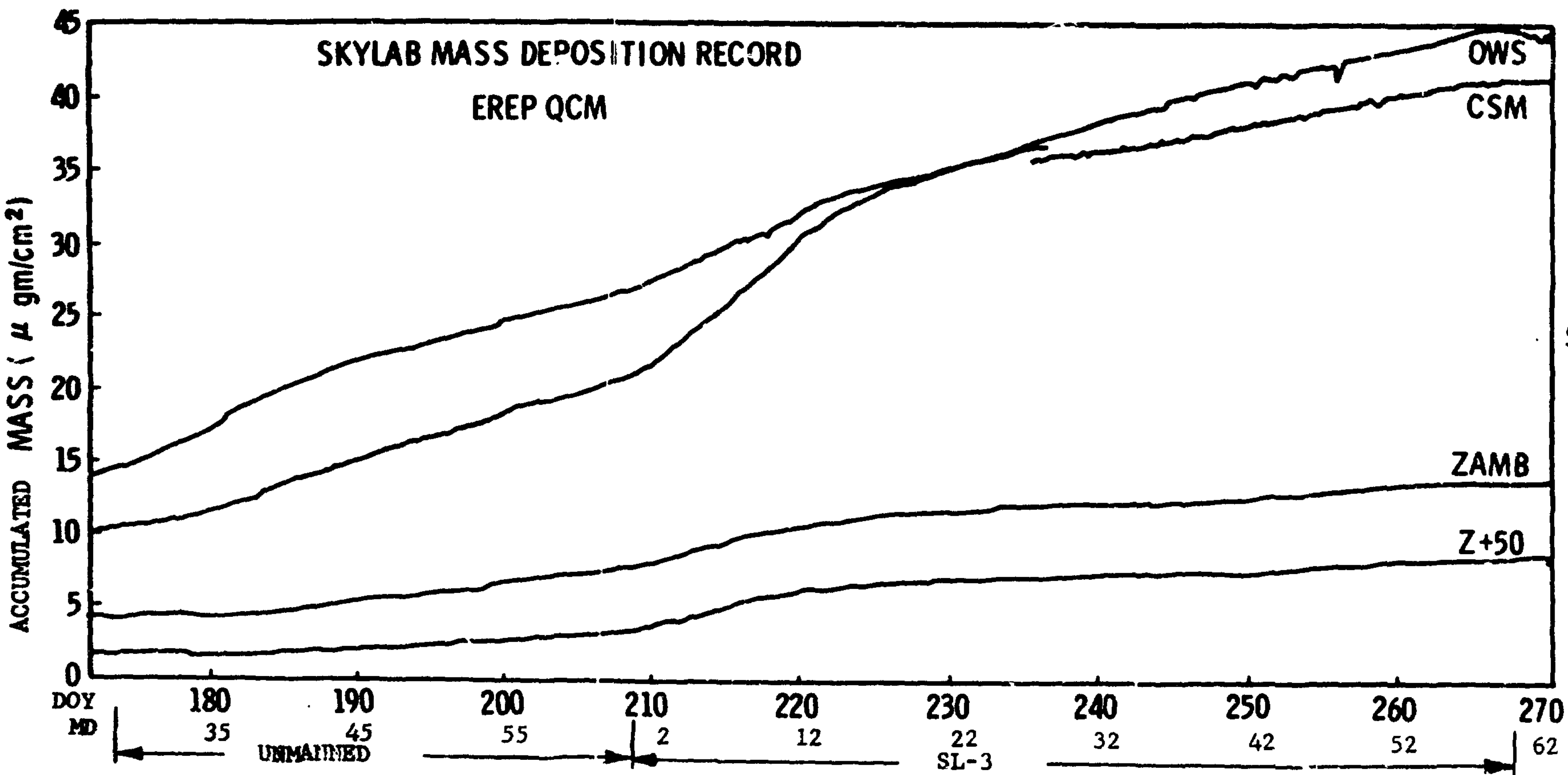

Figure 1.2.2.3-3 SL-3 Mission Period Summary of EREP QCM Data

Table 1.2.2.3-I Table of Five-Day Average Rates for EREP QCMs

SKYLAB - 3

DEPOSITION RATES FOR EREP QCM'S

	MICROGRAMS/CM^2/DAY			
TIME	CSM RATE	OWS RATE	ZAMB RATE	Z+50 RATE
197:12:00	0.277	0.222	0.096	0.070
202:12:00	0.231	0.194	0.096	0.079
207:12:00	0.235	0.315	0.141	0.087
212:12:00	0.767	0.414	0.240	0.203
217:12:00	0.916	0.394	0.203	0.222
222:12:00	0.625	0.104	0.114	0.105
227:12:00	0.364	0.277	0.061	0.061
232:12:00	0.268	0.277	0.052	0.017
237:12:00	0.140	0.315	0.017	0.009
242:12:00	0.105	0.268	0.017	0.009
247:12:00	0.105	0.240	0.035	0.009
252:12:00	0.176	0.225	0.048	0.025
257:12:00	0.185	0.176	0.087	0.052
262:12:00	0.158	0.249	0.035	0.017
267:12:00	0.070	-0.141	0.000	0.000

2) Re-evaporation of deposits from the near field surfaces at lower beta angles due to earth albedo followed by subsequent redeposition; and

3) The contribution from nitrogen tetroxide (oxidizer) plus impurity metal oxides and/or nitrates due to the RCS engines leaks.

During the sustained orbit portion of the SL-3 mission about DOY 230 to 267 the EREP QCM systems measured essentially the normal orbital variations in deposition data plus nominal steady state flux of spacecraft outgassing and return flux caused by molecular physical interactions. This is perhaps best described by examination of Figures 1.2.2.3-3 and Table 1.2.2.3-I. The discontinuity in the CSM QCM curve (Figure 1.2.2.3-3) at about DOY 236 is the change from a higher resolution data to a lower resolution data due to a range expander failure of the QCM signal conditioner which is described in the next section. The difference in indicated deposition is due to coarser raw data and to uncertainties built into the expander data by the range change steps necessary to keep the telemetry signal in a 0 to 5 volt range.

The ATM QCM systems continued throughout the SL-3 mission to indicate their sensing surfaces had been cleaned by exposure to the orbital vacuum and solar irradiation environments during the SL-1/2 missions. The SL-3 ATM QCM data is summarized by using only the orbital dark side measurement envelope for clarity (Figure 1.2.2.3-4). The conclusion is; these measurements, within the uncertainty of the given data value, have decreased in value indicating surface cleaning and related effects relative to the conditions following orbit insertion.

g. Undock and Flyaround - On DOY 268, the SL-3 end of mission high activity period began. During this time several functional events were monitored closely in real time at JSC Mission Control. These events included:

1) CSM engine hot burn - DOY 268 15:29;

2) CSM/Skylab undock - DOY 268 19:49;

3) CSM initial movements following undock - Doy 268 19:50; and

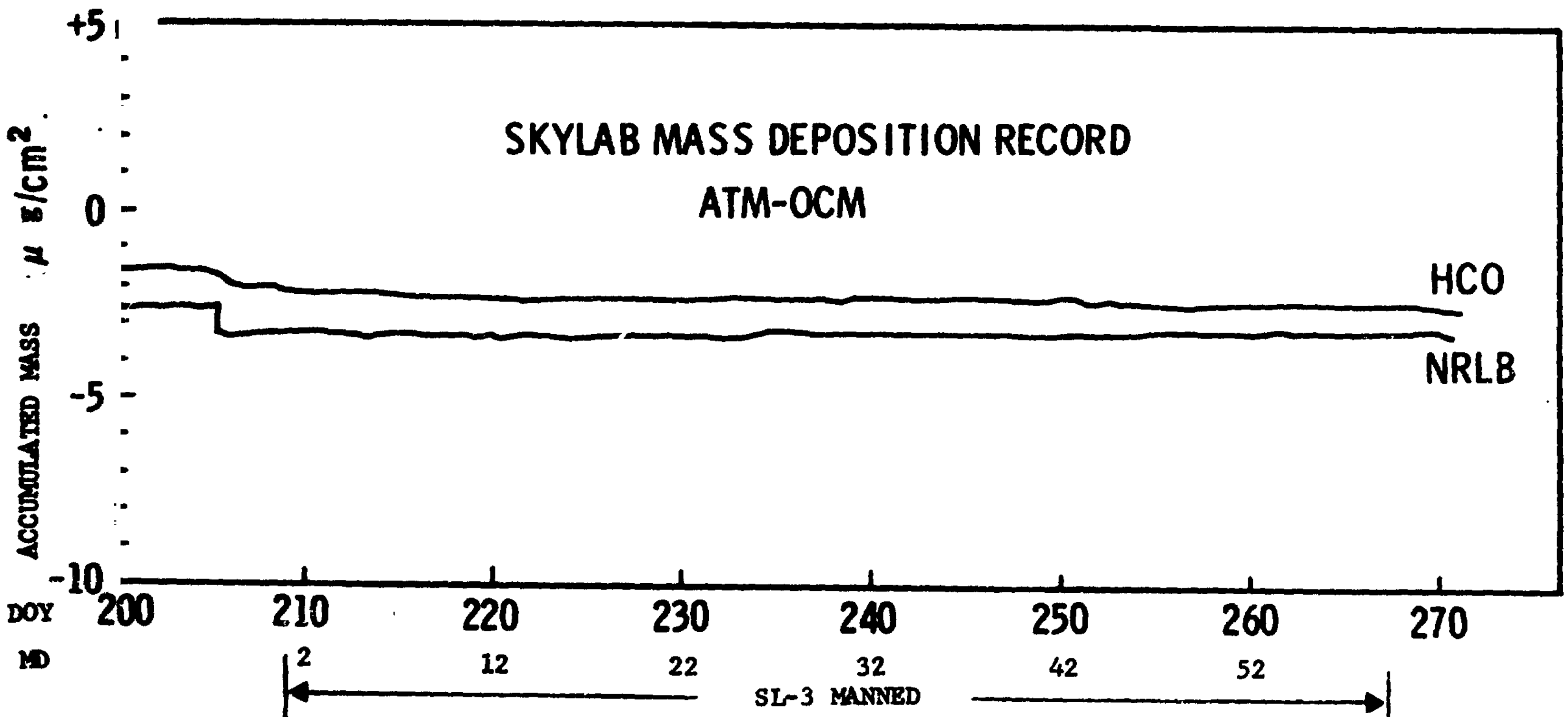

Figure 1.2.2.3-4 SL-3 Mission Period Summary of ATM QCM Data

4) OWS atmosphere blow down initiation - DOY 269 04:25

In addition data checks were made on the QCM measurements during the final EVA period on DOY 265. This investigation indicated that the ATM QCMs recorded zero deposition, and the deposition on the EREP QCMs was insignificant.

h) SL-4 Activities - Of the six QCM monitors on Skylab only four were considered to be giving valid data by the end of SL-4. These are the two ATM QCMs and Z AMB and Z50 EREP QCMs. The Z AMB and Z50 data are shown in Figure 1.2.2.3-5. There is no known evidence of anomalies or unusual measurements for these QCMs. They view away from the spacecraft thus contaminants moving toward the vehicle are the only ones that would accumulate.

The ATM QCM data is shown in Figure 1.2.2.3-6. A direct interpretation of the data indicates a continuing loss of mass. It is difficult to believe that this is entirely correct. It is more reasonable to believe that the units are also indicating an effect of near continuous exposure to solar radiation. Whether this is a change in the crystal physical properties due to a temperature effect or some other phenomena, e.g., sputtering of the gold electrode, is not known. It was requested that an ATM unit be returned for examination during one of the SL-4 EVAs but was not approved.

The QCM data for nine SL-4 events was analyzed for any deviation from normally expected rates. The events and times are shown below.

	EVENT	DOY
1)	SL-4 Docking	320
2)	EVA 1	326
3)	Trim Burn	329
4)	Trim Burn	346
5)	EVA 2	359
6)	EVA 3	363

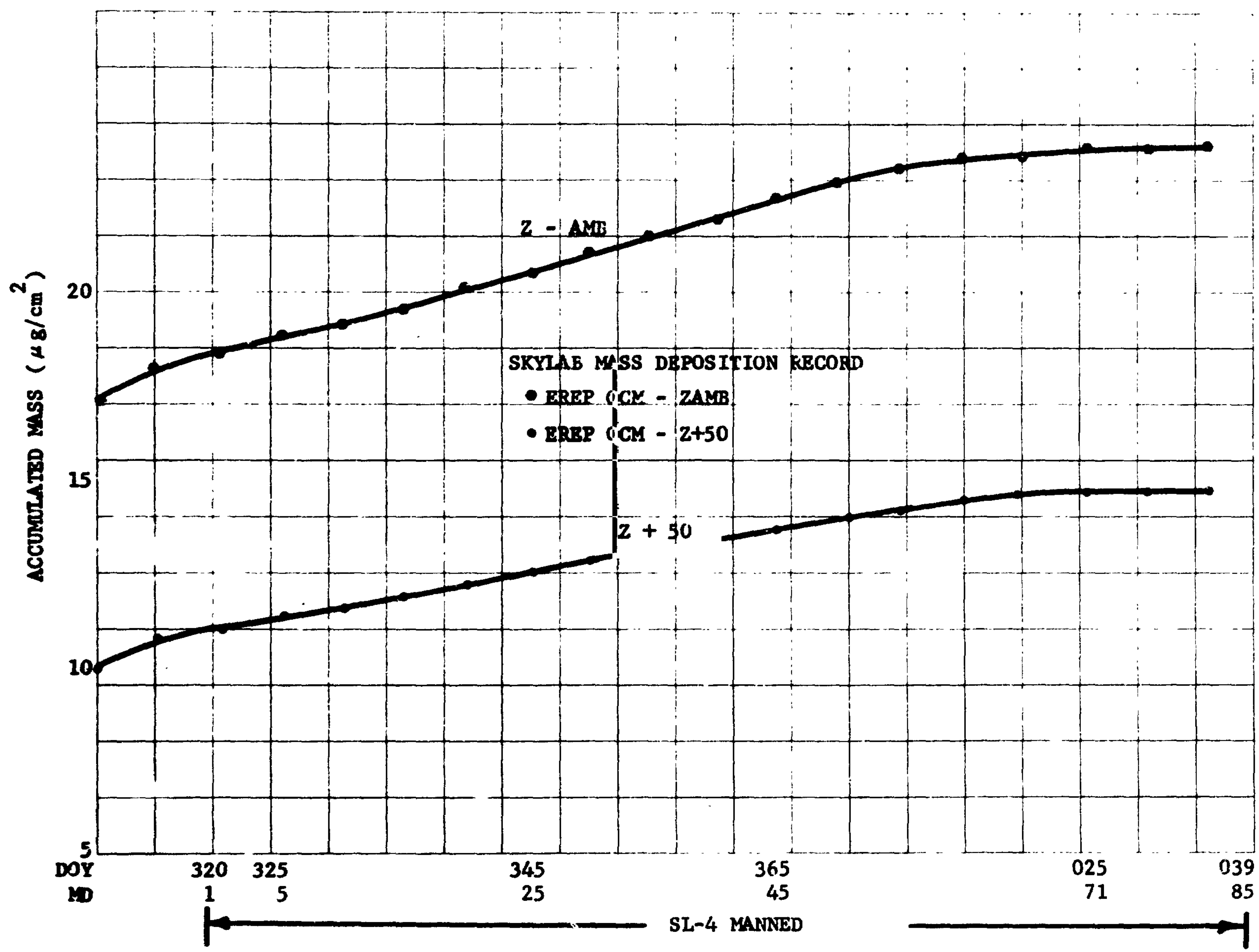

Figure 1.2.2.3-5 SL-4 Mission Period Summary of EREP QCM Data

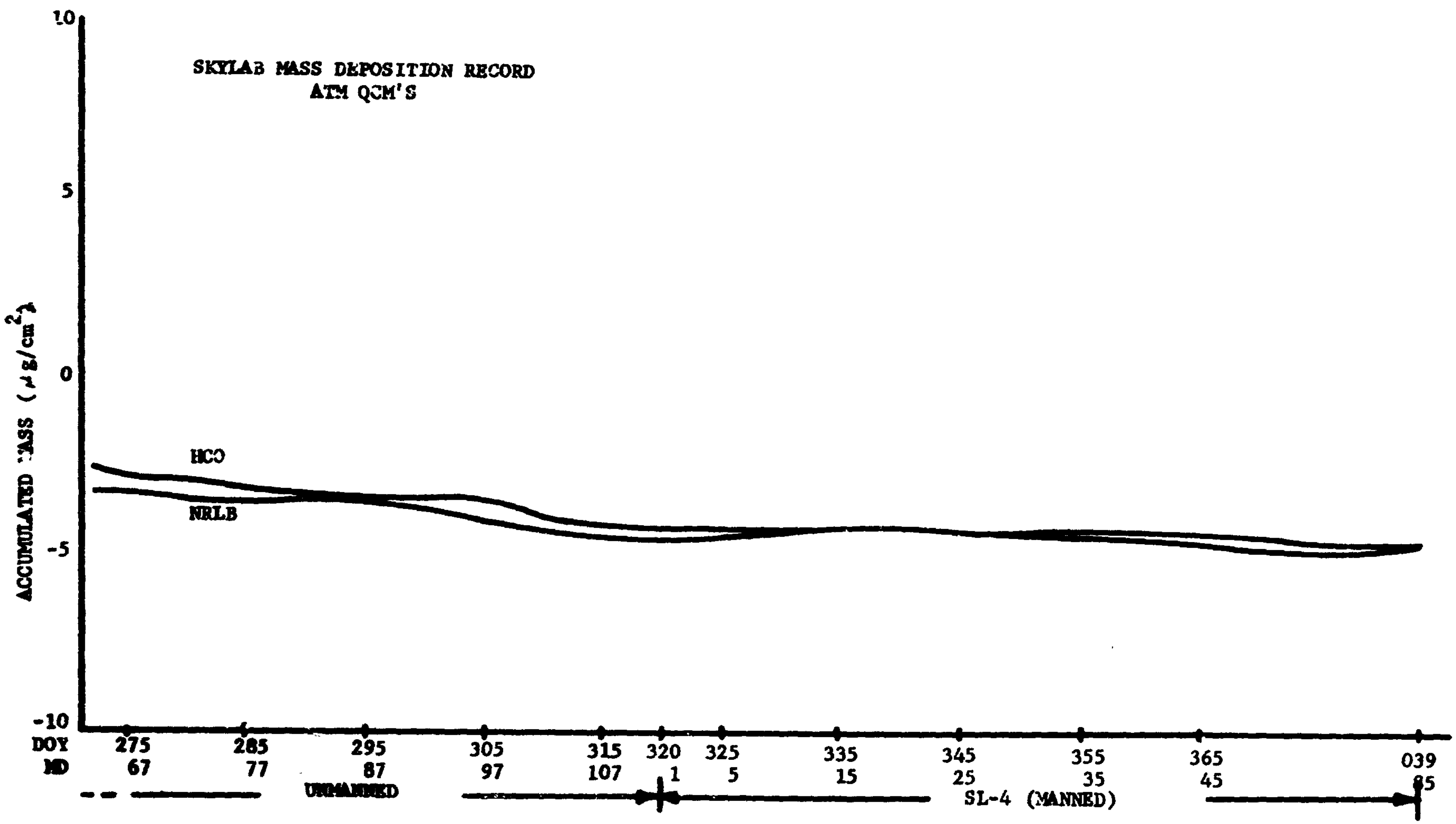

Figure 1.2.2.3-6 SL-4 Mission Period Summary of ATM QCM Data DOY 272 thru DOY 019

7)	EVA 4	034
8)	M479 Venting	035
9)	Trim Burn	037

There was no indication that any of these events provided a definite increase in the contamination rate being monitored by the Z AMB or Z50 QCMs. A scaling or cycling change occurred near events 8) and 9).

Table 1.2.2.3-II gives the rate of accumulating mass during 5 day periods. It begins with DOY 310, which is 10 days before SL-4 docking and ends with DOY 035 which is 5 days prior to Cluster deactivation. These rates appear to be typical of the increasing and leveling cycle that has been observed for each of the Skylab missions.

1.2.2.4 Instrument Anomalies - At DOY 230 22:30 (SL-3), the +X (CSM) EREP QCM began to exhibit an erratic pattern of off-scale low range dropout with subsequent gradual build-up voltage through the appropriate ranges. This randomly occurring behavior continued with increasing event frequency until about DOY 243 at which point this measurement (M016-544) was lost. It is noted that actual loss of meaningful numerical values occurred on DOY 237. The cause of this problem has been determined, by SSL, to be electronic component failures in the circuit board controlling the QCM fine voltage range changes. Possible specific areas include the high/low comparator circuit and the clock/counter system circuit. There are several resistors in these areas whose failure would result in the measurement behavior noted. It should be pointed out there is no problem with the QCM instrument itself. This problem is located in the supplementary Skylab electronics in the MDA used to provide range expanding, i.e., resolution increasing, capabilities to measurements of need. The +X contamination flux continued to be monitored by measurement M015-544 which is the coarse voltage measurement and there was no instrument impact due to the use of isolation resistors in the range expander design. The +X (CSM) QCM saturated about DOY 315.

Beginning about DOY 251, the -X (OWS) EREP QCM indicated random short voltage drops with return to nominal operating and measuring behavior. In this problem, the two OWS measurements (Fine Voltage/M018-544; Coarse Voltage/M019-544) both tracked the behavior pattern described. Additionally, the OWS signal

Table 1.2.2.3-II SL-4 Deposition Rates for 5-Day Periods for Z AMB and Z50 EREP QCMs

DOY	Z AMB RATE ($\mu g/cm^2$-hr)	Z50 RATE ($\mu g/cm^2$-hr)
315	0.00750 (range change)	0.00667
320	0.00375	0.00292
325	0.00500	0.00292
330	0.00167	0.00125
335	0.00375	0.00167
340	0.00417	0.00333
345	0.00417	0.00250
350	0.00417	0.00208
355	0.00417	0.00250
360	0.00333	0.00250
365	0.00470	0.00250
005	0.00375	0.00250
010	0.00292	0.00250
015	0.00250	0.00250
020	0.00125	0.00083
025	0.00083	0.00083
030	0.00083	0
035	0.00083	0.000417
039	----- (range change)	0.000417

output on DOY 275 was on the order of 4.90 volts of a 5.00 volt dynamic range. Because of the tendency of "thick" deposits to be non-rigid or "lossy", the QCM system tends to dampen out or fall-off to saturation under these high deposition conditions. It is therefore concluded that this instrument problem was really a characteristic system pattern as the deposited matter becomes too thick to maintain a tight bond to the crystal surface.

1.2.2.5 Induced Atmosphere Evaluation Conclusions - The QCMs operated very much as expected and provided information on the behavior of contamination in the vicinity of a large manned spacecraft. Figure 1.2.2.3-7 shows the accumulative deposition for all active QCMs over the duration of the Skylab mission. From preliminary data the following tentative conclusions can be drawn on the contamination environment:

a. Surfaces that have portions of the spacecraft in their field-of-view collect considerable contamination. The amount depends on the sources viewed and their temperatures, plus the temperature of the collector. Also an optical surface continuously exposed at the position of the Z AMB QCM could have collected 1400 Å of contamination by DOY 275 for example. This would produce significant degradation of an optical surface operating in the ultraviolet, and measurable degradation in the visible region. The amount of contamination is surprising considering the temperatures of the Skylab materials and the absence of line-of-sight geometry. Section 1.2.3.2 has further discussion on this QCM.

b. It appears that surfaces can be effectively protected by shadow shielding or by locating them in such a manner that no contamination source is in their field-of-view. The -Z QCMs are accumulating 12 Å per day and this is believed to be due in part to re-evaporation from near field surfaces such as a wire bundle which redeposits on these QCMs. However, the accumulation is also apparently of the right order in rate and accumulation [illegible] possibly be caused by scatter back to the spacecraft from molecular collisions.

c. The use of RCS thrusters will produce considerable contamination on surfaces exposed to their plume. However, there appears to be little or no material scattered from the plume so that shielding from direct exposure to the plume appears to be an effective protective method.

d. Outgassing appeared to be a near steady state source of contamination as indicated in Figure 1.2.2.3-7.

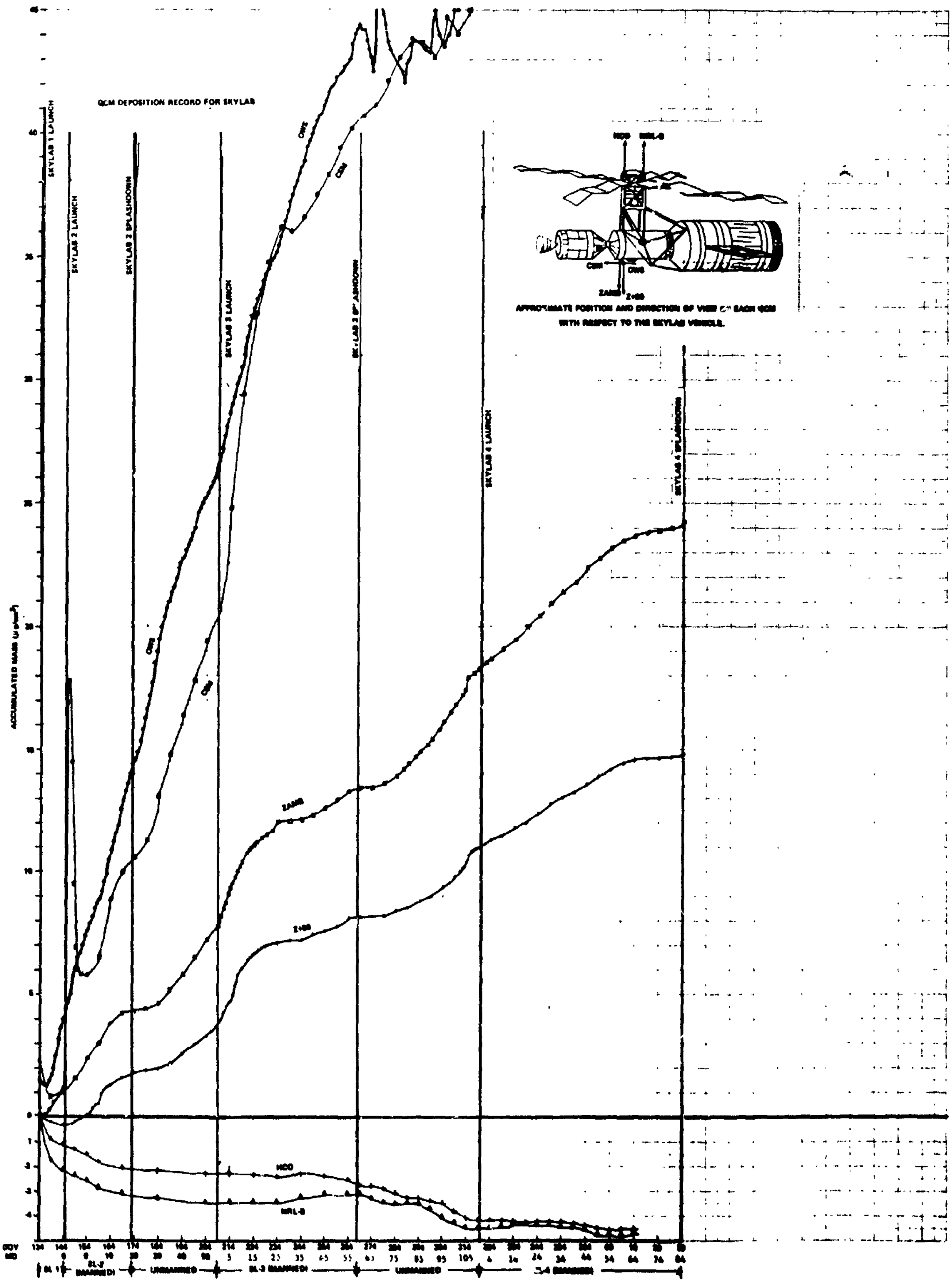

FIGURE 1.2.2.3-7 QUARTZ CRYSTAL MICROBALANCE (QCM) MASS ACCUMULATION RECORD FOR SKYLAB MISSIONS

1.2.3 Model Validation - As a result of Skylab premission contamination assessment and control activities, three computer programs were developed to provide contamination models for Skylab. The three programs are: 1) the Cloud Math Model (CLOUD), 2) the Deposition Math Model (ODRAP), and 3) the OWS Waste Tank Model. These models were developed for premission contamination evaluation and controls, daily mission support, and post mission evaluation. These programs represent a present state-of-the-art understanding of the phenomena of contamination encompassing the physics of the contamination aspect as related to Skylab, summary of all the available related ground testing (including specific performance data concerning Skylab vent hardware simulated in large scale ground test programs), and the various relationships between contamination and the predicted and P.I. reported effects on the contaminant sensitive instruments. These models have the following capabilities:

Cloud Math Model - Three dimensional simulation of Skylab geometry;

- Vent characteristics (particle sizes, velocities, plume extent, etc.) and critical lines-of-sights are contained in the model. (Particle sizes, velocities, plume extent, as derived from ground test programs and were adjusted where flight data became available).

- Treats particulate trajectories from various vents;

- Considers residual Earth's atmosphere influence (drag) on the particles and the velocity vector of Skylab with respect to the trajectory of particles;

- Considers the effect of sublimation on particles that result from liquid vents;

- Establishes either the electromagnetic scattering, absorption, or emittance properties of the particles as a function of time.

Deposition Math Model - Three dimensional simulation of Skylab geometry;

- Considers mass source rate as a function of time and temperature for all major outgassing materials and vents;

- Considers the fraction of this mass capable of impinging on any surface (i.e., considers configuration factors and plume mass distribution);

- Considers temperature of the source of contamination and surfaces impinged upon;

- Considers the fraction of mass capable of condensing on a surface as a function of temperature (i.e., sticking coefficients) and influence of angular considerations to the sticking coefficients;

- Considers resublimation (desorption rate) of the deposited material as a function of temperature;

- Establishes local "pressure" regimes for evaluation of corona susceptible experiments;

- Established degradation in functional properties of specific surfaces as a result of contaminant thickness.

OWS Waste Tank Math Model - Treats quasi steady state and transient conditions in Waste Tank as a function of vented liquid materials;

- Establishes sublimation rates of liquid materials dumped into the Waste Tank;

- Establishes mass accumulation as a function of time;

- Establishes tank internal pressure as a function of time;

- Establishes gaseous flow rates/mass flow rates through the Waste Tank nonpropulsive vents.

These models provided for a unique and timely support of the Skylab mission in conjunction with the QCMs through establishing a continuous real time assessment of contamination surrounding the Orbital Assembly. The purpose of this assessment was four-fold. It was to assure optimum contamination control performance of the Orbital Assembly through assisting in scheduling dumps and/or experiments in order to minimize the contaminant effects on susceptible experiments. Long-term trends or effects were established on important operational surfaces such as solar cells and thermal usage requirements. The basic format for the immediate and long-term mission evaluation requirements for the contamination subsystem were established. Finally, these programs have provided a working log of contamination information governing the Skylab mission that is available to all P.I.s and responsible system disciplines for final analysis of their respective data and performance of their experiment or system. For a summary of these results see Table 1.0.5-I.

The utility and value of these models were dependent upon their subsequent validation through flight data. The following sections address the status of these models based upon flight data throughout the Skylab mission.

1.2.3.1 Cloud Model Update - Premission predictions were made for the anticipated Skylab induced environment brightness. These anticipated background brightness values, calculated from known and tested sources of contamination, were consistently between 10^{-17} and 10^{-15} B/B_o. This was due to assessing the scattering of sunlight from the molecular and known particulate contaminant environment produced by outgassing, leakage, the molecular sieve vent and the OWS Waste Tank vents as determined from premission vent testing and timelines. Particles from random sources were not considered during this time since fluxes were unknown and expected to be small. However, frequent observations and indications of random particulate contamination on the Skylab missions, like the S052 video display, crew reports, Star tracking data, and 10^{-13} B/B_o

by the T027/S073 Photometer at 90° sun angle, have indicated that random particles do form a significant portion of the induced atmosphere.

A mass column density of only 10 particles (radiu ≈ 100 microns) per square meter could produce a brightness ratio on the order of 10^{-13}B/B at a 90° scattering angle as seen by T027/S073 during SL-1/2. This could be generated by an average of 40 particles per second sloughing from the Cluster, or less than 0.4 grams per day, in the form of small (100 microns) flakes. Vehicle vibration, mechanical activity or flow from the TACS or a vent could loosen and/or transport particles which are tenuously adhered to the vehicle surface. Once freed, these particles will move under the influence of the molecular flow fields and the aerodynamic drag from the ambient atmosphere. However, it is unknown how much of a direct contribution to the measured scattered light levels as seen by the T027/S073 experiment that these particles contribute. Since scattering is highly dependent upon particle size (e.g., scattering is proportional to the cube of the radius of the particle) and distribution, an accurate assessment of the difference between premission predictions of scattering levels, and those measured by T027/S073 on SL-1/2 and SL-3 cannot be made. These data are not available from the T027 P.I. Further supportive data on SL-4 was not available for assessing levels of scattering since the T027 Photometer was jettisoned on DOY 216 due to an instrumentation anomaly.

When particle size and particle distribution data becomes available from data taken during SL-1/2 and SL-3 by the T027/S073 Photometer it will be incorporated to update the modeling and establish the rationale for the difference between preflight and actual mission values. Final update and rationale for the differences observed was not available in time for inclusion in this report. Cloud model predicted values were lower than those actually measured by T027/S073, however, even these levels of scattered light were relatively low in comparison to sensitivity levels of experiments in the ATM and Corollary Experiment Groups, EREP Group, and that for the Kohoutek observations made on SL-4.

A tabulation of SL-1/2 and SL-3 particulate observations as seen by the Star Tracker with time correlated events has been compiled (see Table 1.5.4-I). This was to help establish the sources and amounts of contamination responsible for these observed particulates so that an assessment of the Skylab contaminant environment could be made when the reduced T027/S073 data become available. Particle sightings, related anomalies, and possible sources and clues to contaminant behavior are discussed below.

a. TACS Observation - The TACS cold nitrogen gas thrusters were observed by all Skylab crews. An early evaluation calculated a maximum particle size of 0.16 micron with a maximum condensation of 40% of the flow, a plume half angle of 35 degrees and a scattering level of about $10^{-7} B/B_{\odot}$ (easily visible to the eye against a deep space background). A clearing time of 3 seconds due to sublimation was predicted. The SL-2 fly-around photography reveals a 23^{o} half angle, a brightness close to that predicted, and verification of the very short lifetime of the plume.

b. S052 Observation - The S052 experiment observed particles on numerous occasions. However, most of these occasions showed 1 to 10 particles and had no deleterious affect on the data. One one occasion (DOY 159 @ 02:14 GMT), the particulate cloud caused a momentary loss of data near the end of an ATM pass. This loss of data was due to a CSM oxygen fuel cell purge which was being vented at this time. The activity occurred near orbital sunset, when the drag of the ambient atmosphere would transport particles near the CSM into the S052 line-of-sight. Another example of correlating particle sightings to specific events occurred on DOY 162 @ 13:36 GMT when a "particle storm" was created by particles condensed from cabin atmosphere vented from the habitation area vent. On DOY 166 @ 19:02 simultaneous with the Star Tracker locking onto a contaminant particle, a storm of particles was seen by S052. This was attributed to continuous venting of hydrogen from the CSM fuel cells during fuel cell shutdown. The aerodynamic drag vector was oriented towards the ATM from the CSM, which would accelerate any particles from the CSM vents towards the ATM and S052. During SL-3 DOY 220 @ 17:40 GMT, a particle storm was observed which was produced by water dumped overboard through the primary contingency condensate vent during a condensate malfunction procedure checkout.

Many particle sightings (other than particle storms) from the S052 have not been correlated with specific events. This indicates that a random source of particulate contamination also exists on the Cluster. It is thought that the majority of the particulates were created by sloughing of paint and insulation from the solar side of the Cluster. SL-1/2 rendezvous and fly-around photography substantiates this premise by showing large paint blisters, surface deterioration and skin damage near the solar Scientific Airlock (see Figure 1.2.3.1-1). The crew has also mentioned paint flaking on ATM surfaces and especially paint blistering on the CSM near the RCS engine quads. This blistering was probably due to the high thermal transients from RCS firings.

Particles could be loosened and or transported by TACS firing, large overboard vents or more smaller vents which create local pressure fields near the vehicle. Pressure increases in the OWS Waste Tank increase the local pressure field near the Waste Tank vent. This affect has been calculated to greatly exceed the atmosphere drag effect when Waste Tank pressures exceed 1 Torr. This can occur during condensate holding tank dumps (about 4 to 5 Torr), squeezer bag dumps (about 1.5 Torr), TAL events (about 1 Torr) and certain other dumps or vents into the Waste Tank. SL-2 undocking photograph (see Figure 1.2.3.1-2), with the parasol deployed, illustrates a pronounced filling of the sail from the increased pressure resulting from sublimation as a result of the deactivation water line flush and drain emanating from the solar facing Waste Tank vent. This pressure is sufficient to transport particles from near this vent into the line-of-sight of the ATM, Star Tracker, and in certain orientations, where aided by the drag of the ambient atmosphere, into the lines-of-sight of the Wardroom window and EREP experiments.

Calculated particle fluxes from S052 video displays and photographs indicated that the random particle fluxes were on the order of 1.3 particles per second per steradian.

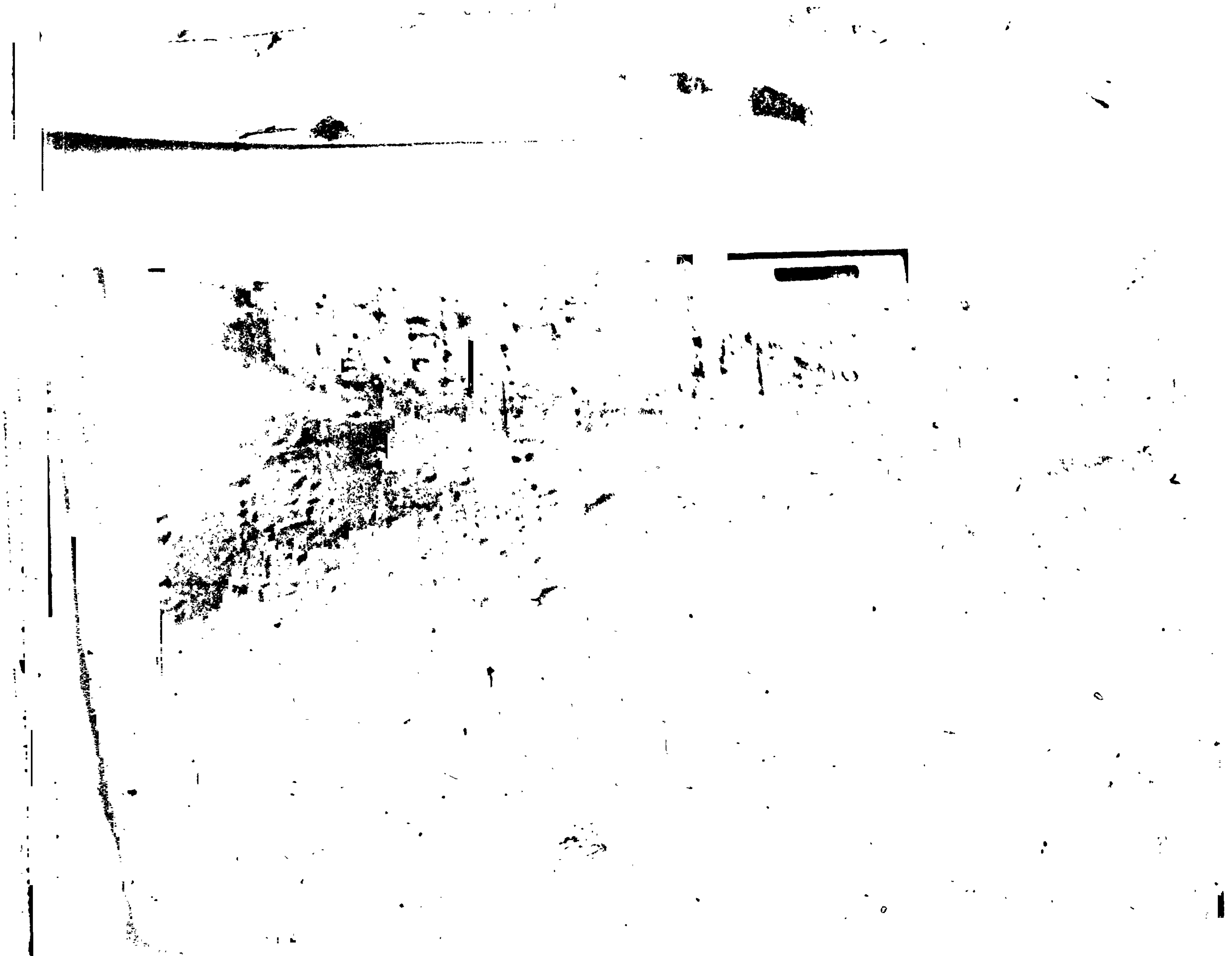

Figure 1.2.3.1-1 The Solar Facing Surface of the OWS

Figure 1.2.3.1-2 View Showing Deployed Parasol

c. <u>Star Tracker Anomalies</u> - Star Tracker gimbal rate histories and aerodynamic drag influence have been analyzed (see Section 1.5.4). It has been indicated that at least eleven of these anomalies are the result of contaminant particles. This analysis also gives an indication of particle size and correlation with vehicle events. In addition, it adds to the evidence indicating numerous sources of particulate contamination are possibly present.

An analysis of the tracking of false stars by the Star Tracker during SL-1/2 provided an indication of the number of large particles in the induced Skylab atmosphere. Using the following Star Tracker data from SL-1/2:

- apparent magnitude of false stars (+0.5 to -0.5) between Achernar and Canopus,
- tracking rates (0.9 to 0.74 degree/sec),
- field-of-view (15 X 15 arc minutes while tracking approximately 12 hours/day),
- particle ejection velocity (0.1 meter/sec), and observed anomaly rate (1.6/day),

it was calculated that the false stars could be particles in the 25 to 100μ size range within 25 meters of the vehicle. This establishes a rate of between 2.5 and 25 particles/sec ($r > 25\mu$) leaving the vehicle which results in a brightness of from 2.5 X 10^{-15} and 2.5 X 10^{-14} B/B_0 corresponding to ≈ 2 particles/square meter or a column density of 8 X 10^{-9} kg/square meter. Since T027/S073 data indicates a minimum brightness of 6.0 X 10^{-14} B/B_0, a substantial number of particles smaller than 25μ, undetectible as false stars, but nonetheless contributing to the background, could be expected along with large particles.

There were fewer Star Tracker anomalies on SL-3 than on SL-1/2. This was due to the tracking of brighter target stars and at the same time changing Star Tracker sensitivity to a higher threshold so that it did not respond to dimmer sources. In addition, the vehicle attitude (NU Z) updating was inhibited except when needed and the Star Tracker shutter was kept closed except for 10 seconds intervals needed for NU Z updating.

d. T027/S073 Photometer - Particulates have been observed on S052 video display, S052 photography, the Star Tracker and visually by the astronauts through Skylab windows. In addition, T027/S073 photometric readings have been made of the Skylab environment. During SL-1/2 on DOY 163, the T027/S073 Photometer measured scattered light levels on the order of $10^{-13} B/B_{\odot}$ at a 90^{o} sun angle. Preliminary values from SL-3 show values near $2 \times 10^{-12} B/B_{\odot}$ at 90^{o} on DOY 215. However, it is thought at this time that this high reading was influenced by an oxidizer leak in the CSM D Quadrant RCS engine which lost 29 pounds of N_2O_4 between DOY 211 and 215.

The T027/S073 Photometer data on DOY 163 gives what is felt to be a good indication of the nominal Skylab environment since there were no anomalous contamination sources at that time. The nominal brightness is from 6×10^{-14} to $3.6 \times 10^{-13} B/B_{\odot}$ between 4765 Å and 8225 Å. The possibility exists that on some occasions the brightness may have been slightly higher due to an active source not counted upon in preflight evaluation. Since preflight evaluations depend strongly upon ascertaining particle size and distribution, the variation between predicted and measured brightness is currently not resolved except that scattering was not considered a problem from preflight evaluations and has essentially been born out by the T027/S073 Photometer measurements.

e. <u>Theoretical Particulate Input Parameter to Math Model</u> - The premission contamination sources input parameter to the Cloud Math Model included known and predictable input factors. However, it did not include a factor for random/unpredictable sources of particulate. Based on observations by the crews and TV observation by S052, it is known that considerable amounts of particulate up to 200 microns in size existed around the Cluster throughout the mission.

This section presents the theory for proposing an input factor for such particulates so as to bring agreement between the Cloud Model predictions and the background brightness observed by the T027/S073 Photometer.

The cloud math model predictions assume small particle sizes (radii of ≈ 10 Å for molecular scattering and radii of $\approx 1.0\mu$ for particles, based upon various vent test and evaluation programs) in its predictions. As the T027 flight data is reduced in detail, an indication of the measured particle sizes or size distribution may help account for the present difference between flight measured and preflight predicted values of scattering. However, it is presently felt that particle sizes may be as large as 200μ (which has not been predicted from known sources prior to mission activities) and would likely be due to flakes of paint, deterioration of the thermal solar shades, or other random sources.

Table 1.2.3.1-I presents reduced T027/S073 strip chart data for DOY 163.

The Photometer measured 6×10^{-14} to 3.6×10^{-13} $B/B_{\odot}$ between 6440 Å and 8225 Å. A series of calculations were made for different particle radii at $\lambda = 4750$ Å using the same scattering angle assuming spherical dirty ice particles ($m = 1.33 + .02\,i$) where m is the index of refraction. These calculations were compared to the measured flight data at 4765 Å for a brightness ratio of 8.6×10^{-14} in an attempt to establish a particle size

Table 1.2.3.1-I T027 Strip Chart Data for DOY 163

Measured Wavelength (Å)	Measured Brightness Ratio* ($B/B_{\odot}$)	Measured Polarization (P)
4765	.86 E-13	.33
5081	1.48 E-13	.27
5299	.87 E-13	.14
6440	.56 E-13	.33
7117	.68 E-13	.33
8225	3.55 E-13	.14

* Scattering angle of 95°.

distribution which could account for the measured scattering levels. These calculations are presented in Table 1.2.3.1-II.

Table 1.2.3.1-II Calculated Polarization and Mass Column Density Values for a Scattering Ratio of $B/B_{\odot} = 8.6 \times 10^{-14}$ at Discrete Particle Sizes

Particle Radii (r in microns)	Size Parameter ($\alpha = \frac{2\pi r}{\lambda^*}$)	Scattering Coefficient ($K = \frac{B}{D_c B_{\odot}}$)	Polarization Constant ($P = \frac{I_1 - I_2}{I_1 + I_2}$)	Mass Column Density ($D_c = Kg/M^2$)
0.01	0.13	8.8 E-6	0.98	9.8 E-9
0.1	1.3	4.5 E-2	0.99	1.9 E-11
0.15	2.0	2.3 E-3	0.79	2.8 E-11
1.0	13.0	2.9 E-4	-0.89	3.0 E-10
1.5	20.0	1.4 E-4	0.48	5.8 E-10
10.0	130.0	8.8 E-6	0.82	9.8 E-9
100.0	1300.0	8.9 E-7	0.83	9.8 E-8
150.0	2000.0	4.4 E-7	0.84	2.0 E-7
200.0	2645.0	4.4 E-7	0.83	2.0 E-7

* Where λ is equal to 4750 Å (Peak emission of Sun).

If the particles present were Rayleigh scatterers ($.01 < r < .15$), scattering would be proportional to $1/\lambda^4$ and the polarization would be ≈ 1.0. If the particles are large and scattering is due to diffraction ($r > 200\mu$), then scattering would not be proportional to λ and would not increase with increasing wavelength. If the particles scatter as white Lambertian reflectors, then the scattering would be independent of wavelength. In either of these cases, the polarization would be very low. Since neither of these patterns are apparent as seen in Tables 1.2.3.1-II and III, it is concluded that the scattering is due primarily to a particle distribution centered below 200μ radius but above 0.1.

Data from the Skylab Contamination Ground Test Program indicated that the Molecular Sieve and the Waste Tank both emitted particulates in the micron and submicron range but the mass flow rates were so small that scattering would be $\approx 10^{-17} B/B_{\odot}$ from these sources. It is therefore thought that the scattering levels observed are not from a predicted and known test source, but rather from sloughing of particulates from the exposed OWS solar surfaces, paints, and thermal sail, and other general vehicle surface degradation.

Table 1.2.3.1-III Polarization Particle Size Distribution

Particle Distribution Radii (r in microns)	Polarization Constant ($P = \frac{I_1 - I_2}{I_1 + I_2}$)
0.01 - 0.15	0.8
0.15 - 10.0	-0.4 thru +0.4
10.0 - 200.00	0.4

Many 16mm photographs, having an exposure time of 2.375 seconds each, were taken during all the photometer sequences. Various arrays of bright specks and sweeping horizontal and verticle lines are indicated on the film. These arrays of specks and lines are cyclic relative to the mode of operation (some occur every 8th or 10th frame while others are in several continuous frames). The bright dots which create "streaks" seem to indicate the direction of the Photometer head movement which varies in shaft and/or trunnion (depending on what mode of operation is occurring). To determine which "specks or streaks" are caused by stars or particles it will be necessary to know the Photometer head orientation and what star Clusters are in its field-of-view. Then, knowing the star brightness vs camera film sensitivity, the number of particles, directional movement, brightness level, and the relative size could be determined. This analysis is continuing and will be made available when it is completed.

During SL-3, strip chart contamination data were obtained only for DOY 215 and 216. The evaluated $B/B_\odot$ level from DOY 215 data indicated a scattering level of 10^{-12} throughout the various wavelength regions. This scattering level is orders of magnitude higher than that seen during SL-1/2.

Mode 1a, DOY 215 from 15:59:01 to 16:05:32 GMT was a dark side data take at approximately an 85° scattering angle (95° trunnion angle). Since the induced atmosphere was not sunlit, the values measured are expected to be from the starfields in the field-of-view. From the earth, the average brightness of the sky is about 10^{-14} $B/B_\odot$ but can get as high as 10^{-12} to $10^{-13} B/B_\odot$ in the ecliptic plane (zodiacal light and gegenschein). T027/S073 data shows values on the order of $10^{-13} B/B_\odot$ between 4765 and 8225 Å. Returned telemetered data indicated that on DOY 214 the Photometer stuck in a shaft position of 356°. Even though the design only allows for a maximum shaft of 354° it is possible that the photometer banged into the stop indicating the higher reading. It is also doubtful that it was viewing toward the ecliptic. Assuming that the field-of-view does not include the ecliptic, the measured values are an order of magnitude higher than that expected from sky background.

Mode 1a, DOY 215 from 17:28 to 17:42 GMT was operated in the sunlight at approximately 85^{o} scattering angle. T027/S073 data shows differences of $1.5 \times 10^{-12} B/B_{o}$ to $2.5 \times 10^{-12} B/B_{o}$, between dark and sunlit data takes, which presumably is from light scattered from the induced contaminant environment.

Mode 2b, DOY 216 experienced automatic shutter closures on consecutive orbital sunrises. This can result from viewing too near the Sun, Earth or a vehicle surface or from an average cloud brightness of 1×10^{-11} at 5299 Å to 4×10^{-11} at 8225Å.

These brightness values are not considered to be steady-state values for the contaminant environment, but rather due to an oxidizer leak from the CSM RCS "D" quad. 11.4 kg of N_2O_4 leaked into a substructure near this quad on DOY 214. Exactly how much sublimated, the resultant particle sizes, or the net Cluster leak rate is unknown; however, a general correlation can be made with QCM data. The QCM data indicates abnormally high deposition levels on DOY 210, a larger peak on DOY 215, and a slow tapering off until, on DOY 225, anticipated normal levels were again reached. Figure A-5 of Appendix A shows the hourly deposition rate on the +X QCM. The CSM is in the QCM field-of-view. Assuming an isotropic leak over a hemisphere and that 10% of the impinging oxidizer deposits, the 10 to 50×10^{-9} g/cm^{-2} hour $^{-1}$ deposition rates correspond to a 1 to 2.5 g/day leak from the CSM which is reasonable and could be expected with respect to the total amount leaked. The QCM data indicates that the oxidizer, starting on DOY 214, was continually leaking from the Cluster from DOY 214 to DOY 225, peaking at DOY 215. Any photometry data from T027/S073 or other sensitive experiments used in this time period, would be obtained through an abnormally high contaminant environment due to the oxidizer leak. A 10 g/day leak of 100 μ

particles (or a 1 g/day leak of 10 μ particles) would produce a brightness of 2×10^{-12} B/B_o. These particles do not remain in the vicinity of the spacecraft, as aerodynamic acceleration would cause 100μ particles to be 31 km from the OA in 1 hour and sublimation would have dissipated them much sooner. A continuous leak source is needed to explain this condition. At sunrise, the aerodynamic drag would increase the column density on the anti-solar side of the vehicle which would account for the higher values seen by the Photometer in the 2b (180° scattering) mode.

The slight polarization values indicated in Table 1.2.3.1-I give rise to a wide particle distribution in the "Mie" region, as does the apparent lack of a definite pattern in the wavelength brightness dependence. It is hoped that further data analysis from flight data tapes will reveal a pattern but presently it is felt that there is a wide distribution of "Mie" scatterers between 0.1 and 200μ particle sizes. The high scattering efficiencies of particles in the 0.1-5μ particle sizes would allow a minimum mass column density to produce the observed scattering. It is therefore assumed that the baseline contaminant environment for these wavelengths is composed of particle sizes in the 0.1 to 200μ range probably peaking about 5.0μ having a typical column density from 1×10^{-11} kg/m^2 to 1×10^{-10} kg/m^2. The most probable cause of scattering is that small and large particulates from the external surface of the Cluster including the solar shades as opposed specifically to any known active vent.

The T027/S073 Photometer measurements near star background levels are reasonable and would be expected if scattering is not a problem. The ATM experiment S052 has a threshold sensitivity of approximately 2×10^{-10} B/B_o at 1.5 R_o and from all indications this was not exceeded (except one instance when a constraint against an OWS vent was violated and should not be considered as representative of the nominal Skylab environment).

Since these brightness values are below (except for Gegenschein) indicated thresholds for Skylab experiments (10^{-13} to $10^{-9} B/B_{\odot}$), it indicates that no loss of data due to scattering should result from the observed background brightness of the nominal Skylab contaminant environment.

1.2.3.2 Deposition Model Validation - The outgassing deposition rate assessment program (ODRAP) was updated a total of 6 times during the SL-1/2 mission. These changes incorporated temperature profile changes and configuration changes due to the malfunction of the meteoroid shield. During SL-3, major parameters in the model were adjusted after a long term trend analysis of the mass accumulation rate readings from the quartz crystal microbalances. This final model adjustment incorporated changes in the non-metallic materials outgassing decay time of the source rates and the temperature dependence of the source rates. This final model update was then applied to all surfaces from SL-1 through SL-4 to determine deposition parameters.

The justification for applying the final model update established during SL-3 was based on the close correlation achieved with the +X (CSM) and -X (OWS) EREP QCMs as illustrated in Figures A-1 and 2 of Appendix A. The flight data from the X facing EREP QCMs became erratic near DOY 250. From this point in time, the model predictions were used to indicate the deposition levels for the X facing EREP QCM locations during SL-4. Further confirmation of the updated deposition model was achieved from measurements made on returned experiment samples. See Section 1.3.3.4 where this is discussed with respect to the applicable experiment.

The model baseline adjustments shown in Figures A-1 and A-2 were incorporated after an anomalous high deposition rate period had ceased on DOY 225. This high rate began shortly after DOY 209 and stopped near DOY 225. Figures A-3, 4 and 5 of Appendix A show these anomalous high rate periods for the -X (OWS) and +X (CSM) QCMs. The correlation of the model predicted-rates to actual flight data prior to and after this anomalous period are close enough that the anomalous period is evident. The rate begins to fall on DOY 215 and again correlates with model predictions on DOY 225. The increase in rates for the -X (OWS) QCMs was about 100% during this period and near 300% for the +X (CSM) QCM. Presently, it is felt this anomalous source was CSM oriented and occurred during the time of large N_2O_4 oxidizer leaks from the B and D RCS engine quads. The B quad RCS engine leak was terminated before docking, but some frozen residual from this leak could have remained and influenced early QCM readings from DOY 209 to 211. The shutdown of the large

D quad leak (total 29 pounds) occurred midday on DOY 214 and corresponds to the decrease in rates near DOY 215. The leak rate for the D quad RCS engine increased with time from the start on DOY 211 such that 90% of the loss occurred 1.75 hours prior to shutdown on DOY 214.

The ZAMB and Z50 EREP QCMs continued to read increasing deposition levels that were not predicted by the deposition model.

The contrasting behavior in deposition rates between the X facing EREP QCMs and the Z facing EREP QCMs indicates different sources or mechanisms may be responsible. For example, Figures A-6 and 7 of Appendix A show the different behavior between the -X (OWS) and ZAMB QCM. When the -X (OWS) QCM exhibits its highest hourly deposition rate, the ZAMB QCM exhibits its lowest hourly deposition rate. These times in orbit occur when the EREP QCMs are at their coldest temperature while the Cluster itself has the longest period of sunlight exposure.

The -X (OWS) QCM behavior can be explained by a source that is solar oriented such as the ATM Solar Arrays which are in their field-of-view.

The ZAMB QCM behavior can be explained by a source in the QCM field-of-view that is warmer than the QCM during high temperature periods, thus allowing deposition to occur, and cooler than the QCM during cold periods, resulting in less deposition occurring on the QCM. This would be the case for a source such as local wiring or connectors that are not connected to as large a heat sink as the QCMs.

Another possible contribution to the EREP QCM readings could be reflected outgassed material from interaction with the ambient atmosphere. The largest contribution periods observed for the Z facing EREP QCMs occurred at sunset for a solar inertial attitude and a zero beta angle. However, at a zero beta angle, the Cluster has minimum sun exposure per orbit which results in a condition at sunset where a minimum amount of contaminant is available for reflection.

It is presently felt that local line of sight sources are major contributors to the Z EREP QCMs in the first 16 days of SL-1; however, reflected outgassants also could contribute to some of the observed mass accumulation rates. This is yet to be resolved. The reflected contribution to the X facing EREP QCMs will be less than that for the Z facing because of the blocking effect of the CSM and OWS on the ambient atmosphere.

At the time the X facing EREP QCMs exceeded their preset electronic ranging capability, they exhibited an accumulative deposition reading within 20% to 30% of premission predictions. This deposition accumulation included contaminant from the SL-1/2 RCS firing and the anomalous high deposition occurring during DOY 209 to 225.

The ATM QCMs have recorded zero deposition during the total Skylab mission as predicted. This results from no line-of-sight surfaces in their field-of-view and the fact that the mass column densities of material in their field-of-view were very low at the times the velocity vector orientation had maximum capability to return reflected material.

The updated model was applied to the important experimental or operational surfaces of the vehicle. Figures A-8 through A-17 of Appendix A are presented for "as flown" exposure conditions for these surfaces and where flight data was available it is noted on these figures for correlation. These are presented to aid in experiment and system evaluation, and are subject to some modification as additional P.I. reduced data becomes available. In particular, the anomalous source period from DOY 209 to DOY 225 is being assessed since preliminary analysis indicates the T027/S073 Photometer observed a cloud brightness near two orders of magnitude above previous observations for this period for a given measurement mode.

Premission modeling assumed a value of 1000 hours for outgassing sources to reach a fraction of 1/e (36.7%) of their original value. This premission value was based on data obtained from observations of previous unmanned satellites. Long term analysis of the X facing QCM rates indicated that it took the outgassing sources of Skylab 4100 hours to reach the same fraction of 1/e of their original value. This latter value was then used in the final updating of the model and reflects the long term nature of outgassing of materials.

It should be noted that since the QCM crystals are gold coated and since the model was updated using the QCM deposition data, the model predictions necessarily apply to gold coated surfaces. Consequently, some errors in mass deposition may exist for other surfaces. The variation in deposition levels among different surface materials was to be determined from T027 Sample Array data. However, the T027 Sample Array was not able to perform as planned and therefore did not yield this data since it was deployed out the ASAL instead of the SAL and for only a short time duration.

The following example substantiates the validity of the contamination prediction model after updates were made using SL-1/2 and SL-3 flight data. A sample of deposited film was removed from a CSM rendezvous window for analysis after SL-4 splashdown. The film had a measured thickness of about 1.7 microns compared to a math model predicted deposition thickness of 1.5 microns.

1.2.3.3 <u>OWS Waste Tank Model Validation</u> - The Orbital Workshop Waste Tank pressure was monitored in an effort to determine the operational characteristics of the Waste Tank with respect to liquid dumps. The Waste Tank is a source of molecular and submicron particulate contaminants for the Cluster and is considered an important data source for both the Cloud and Deposition models.

The Skylab Contamination Ground Test Program (SCGTP) was performed at MMA Denver, in part, to simulate the Waste Tank characteristics during normal and contingency mission sequences. The results of this test were used as basic inputs to the Waste Tank Model. Flight data has been analyzed and compared to SCGTP test results in an effort to validate the model and follow the performance of the Waste Tank during the mission.

Waste Tank pressure data were obtained for various vents during the mission by two flight measurement transducers. These are D7106-406 Pressure-PCS Waste Tank, Low Range, and D7103-438 Waste Processor Exhaust Line Pressure. The measurement range of these pressure transducers is 0 to 0.2 psia (0 to 10.0 Torr).

Although a pressure survey history of the Waste Tank is available, insufficient data on the quantity of liquid dumped and the dumping procedure were available to conduct a detailed quantitative Waste Tank model validation.

However, some qualitative statements concerning Waste Tank performance can be made using the available data.

a. Observation of the OWS Waste Tank non-propulsive vents (NPVs) by the astronauts during a squeeze bag dump on DOY 266 resulted in no particles being observed. We therefore concluded that the filter screens in the Waste Tank performed nominally.

b. The shapes of the normalized Waste Tank pressure decay profiles after a liquid dump corresponded, within measurement uncertainty, to those observed during the SCGTP. We therefore conclude that no significant deterioration in vent performance had occurred.

c. The steady state Waste Tank pressure corresponded, within measurement uncertainty, to that observed during the SCGTP. The preflight mass flow rate derived from SCGTP data and input to the cloud and deposition models is considered valid.

Three anomalous events occurred during the mission which could have degraded the filter screens. On DOY 147 the Wardroom Water Chiller purge was extended beyond the planned duration causing the Waste Tank pressure to rise to approximately 5 Torr. The pressure exceeded the established redline value of 4.1 Torr for approximately 12 minutes. (The redline value was established to minimize the existence of liquid in the Waste Tank which could potentially degrade the filter screens.)

On DOY 167, the ECS Condensate System was vented into the Waste Tank. The Waste Tank pressure rose to 5.4 Torr exceeding the redline value for approximately 15 minutes. Also, on DOY 242, a hot water, high pressure dump, was made into the Waste Tank through the condensate dump line for the purpose of unblocking the line. The Waste Tank pressure rose to 5.2 Torr exceeding the redline value for approximately 6 minutes.

The extent of the physical damage incurred by the filter screens due to these three dumps is unknown. However, since no particles were observed by the astronauts while viewing the Waste Tank NPVs during a liquid dump on DOY 266, it is felt that no significant damage occurred.

1.3 OPTICAL EXPERIMENT AND WINDOWS

1.3.1 General Discussion - This section discusses the contamination evaluation of the optical experiments and windows on the overall Skylab mission. The ATM Experiments and the Corollary Experiments (which are broken up into the Astrophysical, Earth Resources, and Engineering Technology Experiments) are discussed with respect to current indications from preliminary P.I. comments, flight data, and math modeling. The operational windows; S190A window, STS windows, Wardroom window, and the CSM windows are evaluated for contamination degradation during the mission.

1.3.2 ATM Experiments - Available flight data and preliminary evalutation by all Principal Investigators of the ATM Experiments indicate there have been no contamination problems during the Skylab mission. With one exception (use of the contingency condensate dump during an ECS malfunction test) there is no evidence to date that any external contamination, such as outgassing or discharged particles, have degraded ATM experiment data. In general, the contamination control measures employed for the mission appeared to be adequate.

Quartz Crystal Microbalances (QCMs) were mounted on the ATM Sun Shield to determine if potential contaminant deposition occurred during the mission. These instruments have a larger view angle than the ATM Experiments. Hence, the presence of any contaminants from external sources should be registered by the QCMs before the ATM Experiments would be affected. No deposition was recorded by these instruments. This resulted from no line-of-sight surfaces in their field-of-view and the fact that the mass column densities of the material in their field-of-view was very low at the times the velocity vector orientation had maximum capability to return reflected material.

A final assessment of contamination effects cannot be made until the ATM P.I.s have reviewed their respective data in detail. At this time there is no reason to expect any performance degradation.

Some of the Skylab contamination environment that could affect the ATM Experiments were correlated with other spacecraft events. These are noted below:

a. Based on preliminary data, it appeared that no observable scattering light detrimental to the ATM Experiments was observed by T027/S073 Photometer prior to jettison of T027/S073 Photometer on DOY 216. This correlated with S052 data which also showed no degradation due to scattering.

b. Throughout the mission the ATM QCMs indicated no measurable deposition. Preliminary evaluation of ATM Experiment data by P.I.s showed no data degradation from deposition. This correlated with the fact that ATM QCMs have seen no deposition.

c. Thirty-nine Star Tracker anomalies were observed during the mission. After instigation of specific Star Tracker management procedures early in the SL-3 part of the mission, no Star Tracker anomalies occurred. Analysis indicated that eleven of these anomalies were caused by the Star Tracker following particles (based on aerodynamic drag correlation). Instances of particulates near the spacecraft were observed by S052 throughout the mission. However, these sightings presented no problems for the ATM Experiments.

1.3.2.1 Experiment Preliminary P.I. Comments - Preliminary comments from ATM Experiments Principal Investigators indicate no degradation or loss of data due to external contamination although many discrete particles including toroidal or "washer shaped" images were observed at various times throughout the mission by the S052 White Light Coronagraph video display. Analyses of these video displays indicated that the toroidal and washer shaped images were particulates that were not in focus to the camera. The S052 Principal Investigator has stated that these few particle sightings would not affect his data. Particles were removed from the S052 external occulting disc by the astronauts during EVAs on DOY 170 and 265.

Quick look assessment of the effects of contamination upon ATM experiments is generally optimistic. The ATM project scientist's evaluation is that the contamination levels experienced during all phases of the mission were low. In addition, the total amount of ATM Experiment data collected was in excess of what was expected. Specific early assessments by ATM Experiments are as follows:

a. S052 - The P.I.s representative has estimated that the data are 95% particle free, and there is no concern whatsoever about any degradation from contamination.

b. S054 - No significant contamination problems were encountered during the mission.

c. S055 - No significant contamination problems were encountered during the mission.

d. S056 - No significant contamination problems were encountered throughout the mission.

e. S082A & B - All data have not been reviewed but no significant contamination problems are anticipated.

f. H-ALPHA 1 & 2 - No significant contamination problems were encountered during the mission.

1.3.2.2 Internal Pressure and Deposition Rates - Internal pressure of the ATM canister was monitored during the mission to provide an assessment of the degree of outgassing within the ATM canister.

The ATM Quartz Crystal Microbalances (QCMs) provided an assessment of contamination external to the ATM canister. A set of internal temperature measurements was monitored in conjunction with pressure and QCM deposition measurements to determine abnormally cold areas susceptible to deposition of contaminants and to determine abnormally hot areas that could be outgassing sources.

Although it took ten days longer than expected for ATM internal pressure to stabilize in the 10^{-5} Torr range, this time span was available because of the meteoroid shield problem, and the resulting delay of the manned mission.

Internal canister pressure was measured in the ATM Quadrant II by means of a dual-range pressure gauge. The pressure range of 30 to 10^{-4} Torr at the start of the mission was measured by a Parani gauge. As canister pressure drops into the lower range (from 10^{-4} Torr down to 10^{-6} Torr) it was measured by a cold cathode ionization gauge, the other half of the dual-range gauge.

From DOY 134 through DOY 139, there were random pressure increases from the low 10^{-5} to 10^{-6} Torr steady state level. Periodically, pressure transients up to 8×10^{-5} and occasionally up to 1×10^{-4} Torr were observed. These pressure fluctuations apparently were caused by sources internal to the ATM canister, i.e., pockets of trapped outgassing from within the many layers of insulation. No correlation with external events such as TACS firing, RCS thruster activity, or workshop venting was established to indicate any of these external sources contributed to internal ATM canister pressure readings. After the canister pressure reached steady state in the 10^{-5} to 10^{-6} Torr range, ATM Experiments high voltages were turned on. No problems due to the pressure were noted.

Early in the mission, internal temperatures were about $10^{\circ}C$ colder than the nominal $20^{\circ}C$ due to the thermal control system being off to conserve power. When the thermal control system active temperatures returned to nominal no effects from internal deposition from this thermal cycle were noted.

It was concluded that internal pressure and deposition rates from external contamination throughout the mission were within nominal values, causing no degradation of experiment hardware or data.

Internal pressures increased in the ATM canister due to heating from the 250 amp short circuit in the Power Transfer Distributor Assembly (PTDA) that occurred on DOY 216. Starting at DOY 216 at 04:10 the pressure increased from approximately 1×10^{-6} Torr to approximately 6×10^{-5} Torr in about 2 1/2 hours. This caused termination of unmanned ATM operations and postponement of all further ATM operations until the primary problem (the electrical short) could be identified and resolved and the secondary effect (high canister pressure) could be relieved. By DOY 217 at 21:17, the ATM canister pressures had returned to nominal values and pressure constraints on ATM operations were released. With the concurrent resolution of the electrical problem, unmanned ATM operations resumed on DOY 217 followed (after the EVA) by manned operation resumption at DOY 218 at 15:00. To date, no deposition effects from the increased pressures have been noted, but a final conclusion awaits P.I. evaluation of their respective photographic data.

ATM canister pressures remained at nominal values for the remainder of the mission. Moderate canister pressure excursions up to 10^{-6} and 10^{-5} Torr range during during EVA (suit venting) presented no contamination threat to the ATM Experiments.

With the exception of the S056 mirror which approached $75^{\circ}F$ on DOY 230 (7 hrs 48 min of scheduled ATM operations at 57.2° beta angle), all component temperatures remained at nominal values. The S056 mirror temperature was of concern only for thermal gradient operational characteristics. To date, it can be concluded that pressures and temperatures monitored throughout the mission showed no evidence of deposition within the ATM canister.

1.3.2.3 Mass Column Density and Deposition Rates - Mass Column densities have been calculated and deposition rates were monitored during the mission. These parameters are a measure of potential contamination from sources external to the ATM. There were no significant changes in the external environment on SL-4 over SL-1/2 and SL-3 and those values calculated reflect what is considered to be the external environment. Specific ATM QCM data is presented in Section 1.2 on Induced Atmosphere and brightness ratios of scattered light from the calculated mass column densities are presented in Table 1.0.5-I.

As indicated before, telemetry data from ATM QCMs show no deposition. In fact, the data show a very slow (essentially a zero rate) cleaning trend throughout the mission.

1.3.3 Corollary Experiments - Analysis of contamination impacts on the Corollary Experiments, based upon QCM data, T027/S073 photometric data, math modeling and P.I. data reductions, reveal various degrees of contamination but only moderate effects to most experiment data. The D024 Sample Trays returned on SL-2 and SL-3 were sufficiently contaminated so that analysis for degradation due to radiation impacts could not be performed. SL-4 D024 samples appear to indicate a more highly localized discoloration with the deposition thickness in the process of being analyzed. Major objectives of the D024 experiment were still effected by contamination. Experiments S019, S149, and S230 were noticeably impacted by contaminant deposits, but their data can still be used to obtain primary experiment objectives.

Experiments S063, S073, and T025 were impacted by a camera mechanical failure during SL-4 EVA Kohoutek photography which focused the camera at approximately five feet. The S063 and S073 P.I.'s commented that no contamination impact was evident but the T025 P.I. feels that there may be useful contamination information regarding particle size and density on some of the photographs. Experiment S201 had indications of corona while being operated through the A-SAL. It is felt that a leak may have occurred in one of the canister's interface causing increased pressures which caused the corona. However, any further impact on the data due to contamination is presently unavailable.

The S020 X-ray experiment lost 50% of its data (below 111Å) and the P.I. feels it is a contamination related problem. Tests on the S020 filters are being made to determine if deposits are the cause.

Assessments made by the M487 and T003 P.I. organizations indicate that the internal Cluster environment had remained relatively free of particles. Based upon crew comments the environment was relatively free of condensibles. Therefore, there is little reason at this time to believe that the internal environment has contributed to any contamination conditions. The only exception to this has been physical contact of optics by the crew. The following presentation is in four sections: the first three sections discuss SL-1/2, 3 and 4 mission events which might have contaminated experiments. The last section deals with contamination effects on experiment data.

1.3.3.1 <u>Astrophysical Experiments</u> - Experiments included in this category are: S019, S020, S063, S073, S149, S150, S201, S230, S232, and S233.

a. <u>S019 UV Stellar Astronomy</u> - The S019 experiment was operated on SL-2, 3 and 4. The approximate times of operation or exposure are shown in Table B-1 of Appendix B.

During the initial deployment of the Articulated Mirror System (AMS) on DOY 150, a malfunction occurred resulting in approximately one hour exposure of the mirror [illegible] cab[illegible] air during the subsequent malfunction p[illegible]dure. During the execution of the malfunction, a finger[illegible] was noticed on the mirror. The P.I. was informed of this condition and chose not to attempt cleaning for removal of the fingerprint.

Early in the second mission (SL-3), the S019 AMS was deployed (DOY 222 and 225) when the EREP QCMs showed a relatively high deposition rate (lower, however, than the mission rule red line value) apparently due to the CSM RCS leak discussed in Section 1.2.3.2 of this report. Also during SL-3, a mission rule was violated on DOY 228 to 229 when the condensate holding tank gas side was vented through the anti-solar SAL vent while S019 was installed resulting in possible deposition on the S019 optics.

On DOY 232 the AMS was jammed in the deployed position for more than 28 hours, reaching a calculated minimum temperature of -30°C. A prism change had been made to the S019 on DOY 232 shortly before the jamming occurred allowing cabin air into the experiment and possibly contributing to condensation. When the mirror was removed on DOY 233 condensation was seen on the surface. On DOY 233 during the malfunction procedure to fix the jamming, the mirror's temperature was lower than cabin ambient when exposed to cabin air for many hours causing it to collect condensation. Again, the P.I. elected not to attempt to clean the mirror. Crew comments and photographs indicated that by the end of SL-3 the AMS had some scratches and abrasions and apparent contamination particles on it.

A replacement AMS mirror was resupplied on SL-4 and during the changeout of the AMS the crew commented that there appeared to be more dust or lint on the replacement mirror than on the old one. Three faint, narrow, white strips could be seen on the replacement mirror. Based upon crew visual inspection, the apparent reflectivity of the two mirrors was nearly the same. While removing the replacement mirror from its storage container, the crewman's hand contacted the mirror surface, leaving a 3/4" x 3/16" smudge near the edge. The original AMS was exposed on SL-2 for about 10 hours and on SL-3 for about 65 hours. The replacement mirror was exposed for about 75 hours during SL-4. This contrasts with the premission plan of less than 25 hours of total mirror exposure during SL-2, 3 and 4.

b. S020 X-ray/UV Solar Photography - With the OWS thermal shield blocking the solar scientific Airlock, it was not possible to operate S020 as planned for the mission. However, on SL-4 bracketry was supplied and mounted external to the OWS such that S020 could be operated during EVA. The approximate times of S020 operation or exposure are shown in Table B-II of Appendix B.

During the Christmas EVA (DOY 359), large amounts of apparent yellowish ice particles were observed due to an unanticipated leak in Commander's (CDR's) EVA suit. The Pressure Control Unit (PCU) deflector was not present during the EVA's on DOY 363 and 034 when S020 was again operated. An unanticipated water leak in the Science Pilot (SPT's) suit occurred on the DOY 034 EVA resulting in large amounts of ice particles. The removal of the PCU deflector and leakage of the CDR's suit on DOY 363 and the SPT's on DOY 034 could have resulted in a significant increase in the particulate or molecular densities around S020 during its operation.

c. <u>S063 UV Airglow Horizon Photography</u> - In accordance with premission plans this experiment was not performed during SL-2. S063 periods of operation and exposure during SL-3 and SL-4 are shown in Table B-III of Appendix B. S063 was used in three modes: EA-I (Ozone) which used the S063 ultraviolet transmissive SAL window; EA-II or 2U (Airglow) which used the S019 AMS and Kohoutek observation on SL-4 which also used the S019 AMS.

S063 was first operated early in SL-3 (DOY 222) during a period of high EREP QCM deposition readings (lower, however, than the mission rule red line value) and relatively high T027/S073 Photometer brightness indications. These readings were most likely due to the CSM RCS leak discussed in Section 1.2.3.2. The condition of the AMS, including deposits of contaminants which probably reduced ultraviolet reflectivity, is discussed in Sections 1.3.3.1a and 1.3.3.4 of this report.

The S063 ultraviolet transmissive SAL window was stowed in an uncontrolled manner (exposed to cabin air) for a period of about two days (DOY 250 to DOY 252) during SL-3. The Wardroom window, used for S063 EA-I Ozone data take visible photography, often had ice and condensation on it. The window condition is described in Section 1.3.4. The window section also discusses the condition of the STS windows which were used during SL-3 and SL-4 for S063 handheld photography. Photos and crew comments indicate particulate and film contaminants on the outer surface of these windows.

d. <u>S073 Gegenschein/Zodiacal Light</u> - Two different optical systems were used in obtaining S073 data: the T027/S073 Photometer and an optical system consisting of the S063 camera/T025 canister/S019 AMS. The T027/S073 Photometer was used on SL-2 and SL-3 up to the time of jettison on DOY 216. The S063/T025/S019 hardware was used on SL-3 (DOY 247) and all S073 operation on SL-4. The approximate times of operation or exposure are shown in Table B-IV of Appendix B.

One of the SL-2 Photometer runs on DOY 166 occurred at nearly the same time as an S052 White Light Coronagraph (see Section 1.2.3.1) sighting of a particle shower. The particle shower is thought to have been due to CSM H_2 and/or O_2 venting. Also during SL-2 on DOY 167 the condensate holding tank gas side was vented while the Photometer was in the SAL possibly leading to condensation. The Photometer was extended seven rods and pointed away from the Cluster to minimize the possibility of deposit formation due to this vent. During another data take on DOY 168 the Photometer was deployed during a CSM RCS trim burn which was a violation of mission rules. This could have led to deposition of RCS effluents.

During the data takes on SL-3 with the Photometer (DOY 213 through DOY 215), the CSM RCS system was leaking oxidizer. Sufficient oxidizer was leaked to be measured by the QCMs in the EREP area and could have affected S073 data by leading to increased cloud brightness.

The S073 configuration used during the latter part of SL-3 and during SL-4 employed the S019 AMS, T025 canister, and S063 camera. Therefore, the information concerning particulate deposits and condensation on the AMS, and resulting reflectivity losses, contained in Sections 1.3.3.1a and 1.3.3.4a are pertinent, as well as any indications of slight deposition on T025 or S063 optics.

e. S149 Particle Collection - The S149 Particle Collection experiment was exposed to the Cluster external environment through the anti-solar SAL and at the ATM Sun shield. It could not be deployed through the solar SAL as intended because this port was blocked by the addition of the thermal sail required due to the loss of the Meteoroid Shield. Table B-V of Appendix B shows the exposure times for various S149 cassettes.

During and after the docking of the SL-3 CSM, oxidizer was leaked from the CSM RCS Quadrant D (see Section 1.2.3.1). The leakage began on DOY 209 and continued until DOY 215 when it reached its maximum and began to decrease. Some of this oxidizer could have impinged on the S149 samples which were mounted to the anti-solar SAL until DOY 212, with possible deposition or oxidation resulting.

During the SL-4 Christmas EVA (DOY 359) large amounts of apparent yellowish ice particles were observed due to an unanticipated leak in CDR's EVA suit. The Pressure Control Unit deflector was not present during the EVA on DOY 034 when S149 was installed on the ATM Sun shield. An unanticipated water leak in the SPT's suit occurred on the DOY 034 EVA resulting in large amounts of ice particles. The removal of the PCU deflector and leakage of SPT's suit on DOY 034 could have resulted in a significant increase in the particulate or molecular flux on S149 surfaces and increased deposition. The final S149 cassettes were deployed on DOY 034 at the ATM Sun shield where they will remain for a tentative Apollo/Soyuz retrieval. These samples have been exposed to the EVA (DOY 034) environment discussed above, M479 venting, and the environment due to CSM fly-around.

f. S150 X-Ray Galactic Mapping - This experiment operated from the SL-3 launch vehicle Instrument Unit (IU) on DOY 209. Its period of performance was reduced from the premission plan apparently due to a leak in the S150 proportional counter window.

g. S183 UV Panorama - The S183 experiment which operated on all three missions used the S019 AMS. The approximate times of exposure and operation are shown in Table B-VI of Appendix B.

The impact of particulate contamination and condensation on the AMS, which could have reduced its ultraviolet reflectivity, are discussed in Sections 1.3.3.1a and 1.3.3.4. In addition, near one of the S183 passes on DOY 154 particles were seen by the S052 experiment (see Section 1.2.3.1). At this time, the Moon was near full providing a light source to illuminate any particles present. The Star Tracker experienced a failure to acquire on DOY 170 possibly due to lunar illumination of a contaminant particle just prior to an S183 pass. On a subsequent pass on DOY 170, another apparent moonlit particle was photographed using the Data Acquisition Camera (DAC).

For SL-3, S183 DAC photography only was taken of star fields since the spectrograph film was fogged and not supplied on SL-3. The film fogging was probably due to internal experiment contaminants from the S183 film carrousel itself. Fogging of the SL-2 and SL-4 spectrograph film was significantly less.

During the early portion of SL-4, the S183/DAC optics were replaced. The old optics were inspected and no contamination was observed. On DOY 334, difficulties were encountered in S183 operations. A principal problem was the breakage of at least one film plate, probably in the spectrograph assembly. Any broken glass which was in the optical path could have affected the data by attenuation or scattering, or could have affected optical surfaces by scratching or depositing. Malfunction procedures such as on DOY 346 were run on S183 during SL-4, increasing significantly the exposure of the S183 spectrograph assembly to cabin atmosphere and increasing the probability of deposit formation on S183 optics. Since all indications are that the cabin atmosphere is very clean, this should have resulted in little or no deposition.

h. S201 UV Electronographic Camera - This experiment was on the SL-4 CSM to increase the coverage of the Comet Kohoutek. Photographic data was obtained from anti-solar SAL operations and EVA operations. The approximate time periods of operation and exposure are shown in Table B-VII of Appendix B.

The S019 AMS was used in conjunction with S201 for anti-solar SAL operation. The particulate contaminants and condensation on the AMS, which could reduce its ultraviolet reflectivity, are discussed in Sections 1.3.3.1a and 1.3.3.4.

During the Christmas EVA (DOY 359), large amounts of apparent yellowish ice particles were observed due to an unanticipated leak in CDR's EVA suit. The Pressure Control Unit deflector was not present during the EVA on DOY 363 when S201 was again operated. The removal of the PCU deflector and leakage of the CDR's suit on DOY 359 could have resulted in a significant increase in the particulate or molecular densities around S201.

i. S230 Magnetospheric Particle Composition - Five different collector cuffs were deployed on Skylab. The approximate times of exposure are shown in Table B-VIII of Appendix B.

During EVAs on both SL-2 (DOY 170) and SL-3 (DOY 265), crew comments were made indicating darkening and discoloration of the S230 cuffs. During SL-2 and SL-3 CSM rendezvous, fly-around, SL-1/2 stand-up EVA (SEVA) and docking activities CSM RCS was used. Due to the plume expansion of the RCS engines there could have been impingement and deposition on S230 surfaces. During the first SL-4 EVA, a new cuff which had a calibration strip over part of the collecting surface was deployed. This calibration strip was accidently knocked off prior to or during the Christmas EVA, but its loss will not significantly compromise experiment results.

During the Christmas EVA (DOY 359), large amounts of apparent yellowish ice particles were observed due to an unanticipated leak in CDR's EVA suit. The Pressure Control Unit deflector was not present during the EVAs on DOY 363 and 034. An unanticipated water leak in the SPT's suit occurred on the DOY 034 EVA resulting in large amounts of ice particles. The removal of the PCU deflector and leakage of the CDR's suit on DOY 363 and the SPT's on DOY 034 could have resulted in a significant increase in the particulate or molecular flux on S230 surfaces and increased deposition.

j. S232 Barium Plasma Observations - Photographs of the man-made Barium cloud which was formed by a rocket launched Barium plasma for study of the earth's geomagnetic characteristics were taken on SL-4 on DOY 331 through the Wardroom window. The description of the Wardroom window ice and condensation contained in Section 1.3.4 of this report is pertinent. Crew comments during S232 operation indicated that there was ice on it and a "glow" on the window. Crew comments indicated, however, that the Barium cloud was easily visible to the unaided eye.

k. S233 Kohoutek Photometric Photography - Photographs of the Comet Kohoutek were taken through the STS-3 and the CM-1 windows. Comments received early in the SL-4 mission indicate that the CM windows may have been smeared by the crew. SL-2 and SL-3 crew comments and photography indicate some contamination of the STS windows. Section 1.3.4 discusses further the condition of the windows used by S233.

1.3.3.2 Earth Resources Experiments - Included under this category of experiments are: S190A, S190B, S191, S192, S193, S194, and visual observations and handheld photography. In this section the on-orbit events which are thought to be pertinent to contamination impacts on these experiments are discussed. Approximate times of EREP operations are shown in Table B-IX of Appendix B.

A total of 91 EREP passes were performed; 13 on SL-2, 39 on SL-3, and 39 on SL-4. The EREP data take pass numbers used above are part of the sequential number of planned passes. Since some planned passes were cancelled, the number of passes actually performed (39 on SL-4) is less than the number of planned passes (50 on SL-4). Also, various calibration and single instrument operations have occurred. Numerous handheld Earth photographs were taken on Skylab.

During the SL-2 mission particles were observed by the crew (DOY 160) due to the opening of the S190A/MDA window; however, based upon P.S. responses to date, they do not seem to have affected EREP data.

a. S190A Multispectral Photographic Camera - The SL-2 crew reported some brownish spots, possible condensation residue, on the S190A optical filters on DOY 149. Early in SL-2 on DOY 149 the S190A dessicants were observed to be white indicating the presence of moisture. Specks due to either dust on the lenses or bubbles in the lens elements were noticed on DOY 160, but were inaccessible for cleaning. On SL-2, a filter was cleaned on DOY 171 with distilled water only and the platens were cleaned on DOY 171 using an Orvus detergent.

During SL-3, the platens were dusted (DOY 215) and cleaned with water only (DOY 258). Smudges were removed from the S190A window using lens tissues also on DOY 215. On DOY 259 the SL-3 crew inspected the specks associated with the lenses and they appeared as grey, fine metallic particles. These particles are possibly from the shutter blades, or are possible bubbles in the lens elements.

On SL-4, the crew described noticeable deposits on DOY 08 on the number 1 and number 3 film platens of S190A. The S190A platens were cleaned on DOY 08 using distilled water. The cleaning was apparently successful based upon visual inspection. A few smudges were removed from the S190A/MDA window using lens tissue. The S190A/MDA window, which has remained very clean, is discussed more fully in Section 1.3.4.

b. <u>S190B Earth Terrain Camera</u> - No on-orbit events have occurred which posed a contamination threat to S190B.

c. <u>S191 Infrared Spectrometer</u> - During the first mission on DOY 162, V/TS Television pictures contained numerous dark spots. As V/TS magnification changed, particle density and clarity did not, indicating that the spots were not part of the S191 V/TS optical train, but were due to the TV camera. The subject TV camera was returned and inspection of it verified that large numbers of particulates were present on the vidicon faceplate. Upon inspection of the V/TS DAC window, a few particles were seen and were brushed away, but most of the particles, which were located in the TV camera, could not be removed.

During the SL-3 mission about DOY 223, it was observed that the S191 aperture door closure time was increasing. To preclude the possibility of the door failing closed, it was left open from DOY 224 to 264. The onset of the door closure difficulties was observed shortly after EREP QCMs and the T027/S073 Photometer recorded an increased contamination environment, probably due to the CSM RCS oxidizer leaks discussed in Section 1.2.3.2 of this report. There is a possibility that the oxidizer may have contributed to the door opening problems by oxidizing the lubricant and resulting in a decrease in lubricity.

There is a possibility, considering the EREP +Z QCM date, that there has been some deposition on the S191 external optics due to reflections of Cluster outgassants by the ambient atmosphere. This possibility is discussed in detail in Section 1.2.3.2. If a significant amount of deposition has occurred due to the increased exposure time of S191 external optics, it will be determined by analysis of the S191 calibration data from the three missions.

The opening of the S191 door on DOY 325 was watched through the S190A/MDA window and through the V/TS. The door opened slowly but steadily. On DOY 341 a peculiar pattern was seen through the V/TS just prior to passing from darkness into sunlight. The pattern was a dark region and a light region sharply delineated. Starlike specks or blinking lights could be seen in both regions. The crew suggested that reflections or scattering was occurring. The crew also suggested condensation as the cause. It is possible that this was actually the appearance of the sunlit horizon scene in the V/TS field-of-view at that moment.

The S191 P.I. feels that further data reduction using their computer program is necessary before any comments are made regarding contamination effects.

d. <u>S192 Multispectral Scanner</u> - During the SL-3 mission the S192 aperture door inadvertently remained open for a two day period (DOY 229 to 231), more than doubling the exposure of the S192 optics to external environment. Since the S192 optics are well protected from a line-of-sight to contamination sources even with the door open, it is not expected that the increased open door time will cause detectable contamination effects to S192.

The S192 Dewar detector system was changed out on DOY 015 during SL-4 since the initial detector's signal-to-noise ratio was low. It was replaced with a detector of improved signal to noise characteristics.

e. <u>S193 Microwave Radiometer Altimeter/Scatterometer</u> - Antenna pitch and yaw control difficulties appeared during SL-3 on DOY 258. Contamination build-up on potentiometers, which are exposed to the external environment, was considered a possible cause. On the first SL-4 EVA on DOY 326, the crew inspected the S193 antenna. The only foreign material observed was the antenna's own aluminized mylar insulation. This was photographed by the crew. No contamination, such as outgassing deposits, was observed; however, photographs of the underside of the MDA do show some discoloration of surfaces. This discoloration is felt to be the result of contamination. During SL-2 and SL-3 CSM rendezvous, fly-around, SL-1/2 SEVA and docking activities, CSM RCS was used and deposition could have occurred. This could account for the observed discoloration.

The SL-3 CSM leaked significant amounts of oxidizer from Quadrant D during the early portion of that mission, as indicated by EREP QCM reading and T027/S073 Photometer data (see Section 1.2.3.2 for details). These occurrences could have resulted in deposition on or oxidation of S193 surfaces.

f. S194 L Band Radiometer - During the SL-2 and SL-3 CSM rendezvous, fly-around, SL-1/2 SEVA and docking activities, CSM RCS was used. The SL-3 CSM leaked significant amounts of oxidizer during the early portion of that mission, as indicated by EREP QCM readings and T027/S073 Photometer data. These occurrences could have resulted in deposition or oxidation of S194 surfaces.

1.3.3.3 Engineering Technology Experiments - Included under this category are: D024, M415, T025, T027, T053 and Skylab Optics Cleaning Kits.

a. D024 Thermal Control Coatings - Sets of thermal control samples and polymeric strips, mounted on trays, were deployed at various times on Skylab for different duration exposures. Exposure times of the D024 samples are given in Table B-X of Appendix B.

Crew comments during EVA activity on SL-2 (DOY 170) and SL-3 (DOY 265) indicated that the sample trays had been darkened and discolored. During SL-2 and SL-3 CSM rendezvous fly-around, SL-1/2 SEVA and docking activities CSM RCS was used. At least some of those firings were such that there could have been impingement and deposition on D024 surfaces.

During the deployment of the replacement samples on DOY 326, the gloved thumb of a crewman contacted a sample tray in the process of snapping the tray in position. Physical damage to the samples or contamination from his glove could have resulted.

During the Christmas EVA (DOY 359), large amounts of apparent yellowish ice particles were observed due to an unanticipated leak in CDR's EVA suit. The Pressure Control Unit deflector was not present during the EVAs on DOY 363 and 034. An unanticipated water leak in the SPT's suit occurred on the DOY 034 EVA resulting in large amounts of ice particles. The removal of the PCU deflector and leakage of the CDR's suit on DOY 359 and the SPT's on DOY 034 could have resulted in a significant increase in the particulate or molecular flux on D024 surfaces and increased deposition.

b. M415 Thermal Control Coatings - These samples were flown on the SL-2 IU to study the effects of launch and ascent phenomena on thermal control paints. One set of samples were exposed to: launch site environments, Launch Escape System (LES) firing, retrofirings and post-insertion environments. Other samples were covered at the launch site, but uncovered for the LES firing and thereafter. A third group of samples experienced only the retrofire and post-insertion environments. The fourth sample group experienced only the post-insertion environment.

c. T025 Coronagraph Contamination Measurement - This experiment was performed only on SL-4 during four EVAs. The hardware, however, was used in conjunction with S019 and S063 equipment to obtain S073 data from the anti-solar SAL. Table B-IV (Appendix B) shows the times (DOY 246) that the T025 canister was used to obtain S073 data. The usage of the T025 equipment for T025 objectives is shown in Table B-XI of Appendix B.

During the Christmas EVA (DOY 359), large amounts of apparent yellowish ice particles were observed due to an unanticipated leak in CDR's EVA suit. The Pressure Control Unit deflector was not present during the EVAs on DOY 363 and 034 when T025 was again operated. An unanticipated water leak on the SPT's suit occurred on the DOY 034 EVA resulting in large amounts of ice particles. The removal of the PCU deflector and leakage of the CDR's suit on DOY 363 and the SPT's on DOY 034 could have resulted in a significant increase in the particulate or molecular densities around T025.

d. T027 Contamination Measurement - The T027/S073 Photometer system was used to obtain Gegenschein/Zodiacal light and contamination data during SL-2 and SL-3 before being ejected. The potentially degrading on-orbit events are detailed in Section 1.3.3.1d concerning S073.

The Sample Array system (T027A) was exposed at the anti-solar SAL for about 45 hours near the end of SL-2 (DOY 168 to DOY 170). When retracted, the upper carrousel did not close properly, exposing the cold upper carrousel samples to cabin air and the probability of subsequent condensation.

e. T053 Skylab Earth Laser Beacon Experiment - Visual sightings and photography were performed through the Wardroom window during SL-3 and SL-4. The Wardroom window frequently plagued by ice and condensation is described in Section 1.3.4.

f. Skylab Optics Cleaning Kits - Two optical cleaning kits were supplied on Skylab for use in cleaning optical surfaces, such as experiment optics, windows, and operational camera lenses. These kits were: the Skylab Optics Cleaning Kit and the S190A Optics Cleaning Kit. Both kits contained cotton swabs, air bellows, brush, distilled water, lens tissues and gloves. In addition, the Skylab Optics Cleaning Kit contained a diluted Orvus detergent.

During SL-2, the kits were used to clean S190A optics, the Wardroom window, the S052 occulting disc and the S191 V/TS adapter. The Orvus detergent from the Skylab Optics Cleaning Kit was, according to crew comments, used in an attempt to remove film emulsion residue from the S190A film platens. The crew indicated that a visible residue remained after the cleaning procedure. The fact that later rinsing, using only distilled water from the S190A Optics Cleaning Kit, was successful indicates that repeated rinses at the time of this cleaning would have resulted in a residue-free platen. S190A filter AA was cleaned using the distilled water only from the S190A Optics Cleaning Kit. The filter was apparently visibly clean after the operation.

When spots were noticed on S191 V/TS television transmission, the few particles observed were removed from the V/TS to TV adapter by using a brush. This action did not noticeably reduce the amount of spots seen on subsequent S191 V/TS TV. It has been concluded by inspection of the returned TV camera that these spots were in it and inaccessible to cleaning.

The SL-2 crew apparently tried to clean the Wardroom window using the Skylab Optics Cleaning Kit. Their chief objection was that the kit contents were difficult to use on large surfaces. The kit was designed for cleaning limited optical surfaces and was not intended to clean operational windows. Other cleaning materials were requested and procedures supplied for the cleaning of this window.

On the final EVA of SL-2, thread-like material resting on the S052 occulting disc was reported by the crew to have been removed using a brush from the Skylab Optics Cleaning Kits. Observable TV symptoms persisted, however.

On the SL-3 mission, the S190A Optics Cleaning Kit was used on the S190A film platens and the S190A/MDA window. The S190A platens were cleaned using the distilled water. This cleaning removed the residue remaining after the S190A platen cleaning performed on SL-2. A few smudges on the S190A/MDA window were removed using lens tissues. Both operations apparently left the surfaces visibly clean.

A brush was again used during the final SL-3 EVA in an attempt to remove material from the S052 occulting disc. Some material was removed but this cleaning did not fully solve the observed S052 problems.

On SL-4, the S190A platens were again cleaned with only distilled water from the S190A Optics Cleaning Kit. These surfaces were apparently visibly clean after the operation.

Optics Cleaning Kits on Skylab saw limited use. Their principal use was with the S190A camera. The S190A Optics Cleaning Kit was used to clean S190A camera optics and the S190A/MDA window. It was apparently successful in rendering surfaces visibly clean.

The Skylab Optics Cleaning Kit was apparently never used to clean Scientific Airlock or OWS experiment optical surfaces, for which it was primarily intended. It was difficult to remove residues left on the S190A film platens from cleaning with Orvus detergent. To remove the residues required repeated rinses with distilled water. Based upon crew visual observations and comment, the cleaning kits were generally successful in reducing or eliminating the effects of contaminants deposited on surfaces accessible for cleaning.

1.3.3.4 P.I. Data Updates - The following summarizes significant experiment data presently available and how they relate in describing the external Skylab contamination environment. Included are data from communications with the Principal Investigators (P.I.s) and other sources from available SL-1/2, SL-3, and SL-4 experiment reports. These data were coordinated with the contamination cloud and deposition math models, flight QCM data, Star Tracker data, experiment data, and any observed or known anomalies in an attempt to describe what occurred in the external environment and how it may have affected various scientific and technical experiments. Analyses of these experiment data were continuing at the time this report was published. For additional data, it is suggested that the pertinent PI's be contacted.

a. P.I. Comments on Corollary Experiment Data

1) T027 Contamination Measurement (Dr. Joseph Muscari, P.I.) - The T027/S073 Photometer was used to measure contamination cloud brightness ($B_{\odot}$) as well as gegenschein and zodiacal light on Skylab. Preliminary T027/S073 Photometer data taken during SL-1/2 (DOY 163) indicated a scattering brightness level of from 1.5×10^{-14} to 3.6×10^{-13} $B/B_{\odot}$. During SL-3 (DOY 215), a Photometer reading was taken which indicated a brightness level of about 2×10^{-12} $B/B_{\odot}$. These scattering brightness level readings are considerably below the ATM/Corollary EREP Experiment sensitivity limits for measurements made on Skylab. Since ground site coverage during both SL-1/2 and SL-3 was minimal during Photometer operation, only limited strip chart data are available for near real time quick look contamination assessment. The total data available on magnetic tapes and correlation to vehicle attitude and operational activities during T027/S073 Photometer operation has yet to be processed in detail such that the temporal and spatial variations concerning the measured brightness scattering levels of the induced atmosphere can be established. Scattering brightness levels of about two orders of

magnitude above Zodiacal Light were measured in some instances and in some instances the scattering levels were determined to be transient since the intensity levels observed had changed in minutes while the Photometer was in a fixed position (shaft and trunnion angles were stationary). It is unknown at this time why the intensity levels changed over a relatively short time since the induced environment should appear static over a short period of time and the angular dependence of the scattering function should not change rapidly for normal changes in vehicle orientation over a few minutes of measurements. No active vents which could contribute to this variation in light scattering were operating at the time of the T027/S073 data measurements. Complete data analysis of all of the T027/S073 Photometer data may help resolve this.

T027/S073 SL-1/2 flight data which were obtained were from DOY 163, 166, 167, and 168 operations. Based on DOY 163 data, the scattered $B/B_\odot$ level (where $B/B_\odot$ is the solar surface brightness ratio) at a wavelength of 5081 Å was 1.5×10^{-13}. This 10^{-13} value is also representative of the $B/B_\odot$ level at other Photometer wavelengths (from 4765 to 8225 Å). The possibility exists that on some occasions the brightness may have been slightly higher due to an active source not counted upon in preflight evaluation. For example, the Photometer was again operated on DOY 215 from 17:28 to 17:42 GMT in the sunlight at approximately 85° scattering angle. T027/S073 data shows differences of 1.5×10^{-12} $B/B_\odot$ to 2.5×10^{-12} $B/B_\odot$ between dark and sunlit data takes. Since preflight evaluations depend strongly upon ascertaining particle size and distribution, the variation between predicted and measured values has not been ascertained. Both predicted and measured scattering levels are low enough and therefore not considered a problem from preflight evaluations and this has essentially been born out by the T027/S073 Photometer.

The T027 Sample Array did not collect any significant contaminants. Only trace amounts of surface deposition have been measured. In many cases contaminant measurements were near the limiting sensitivity of the measuring instrumentation.

Residual gas analysis (RGA) of the anti-solar SAL exposed Sample Array system showed that all the upper carrousel samples had no outstanding contamination peaks. Also reflectance and transmittance measurements from 2.75 Å to 20μ indicated no significant changes in the samples and that insignificant deposition had occurred. Selected samples (gold and germanium) indicated contaminant deposition thicknesses ranged from 3 to $\approx$24 Å which are felt to be within the measuring instrumentation sensitivity range.

Select samples were examined for contaminants by using a solvent rinse technique and analyzed by a mass spectrometer for chemical identification. A quick look analysis indicated a large number of high mass peaks up to 560 amu. Dioctylphthalate (a plasticizer) and hydrocarbons were identified. Two of the six exposed ATR samples (KRS-5 crystals) showed infrared absorption bands of 1050 cm^{-1}. However, there was a lack of sufficient key bands to positively identify the contaminant composition by infrared spectra alone. The 1050 cm^{-1} band is typical of silicones. However, other equally strong silicon bands are missing.

As part of evaluating the induced atmosphere on Skylab, select samples were flown as guest samples on the T027 Sample Array. These samples were from the Space Sciences Laboratory at the Marshall Space Flight Center, Ala. Preliminary analysis of these samples (each sample consisted of a nickel and gold specimen mounted in a stainless steel holder with a removable stainless mask) using Auger spectroscopy has indicated that the flight samples appear to have more carbon than the ground based control samples. Also, the distribution across the exposed surfaces appeared nonuniform. The expected step function between the masked and unmasked portions was not obvious in most cases. The peaked nature seems to indicate more of a particulate or localized type distribution. It was apparent that no reasonable permanent contaminant film covered the surfaces to any significant depth (definitely less than 50 Å). This is consistent with data determined from the T027 P.I. measurements.

In addition to the nickel and gold samples, two electrets and one neutral control sample were also flown on the Sample Array. The purpose of these was to test the efficiency of electrets in a space environment as contaminant traps and to determine if the effective electric field was in any way diminished by the space environment. Postflight checks of the samples indicated a loss of 82.5% in the effective field strength on one sample while the control samples showed a loss of 41%. The lower field on the flight sample possibly could be accounted for by the deposition of a contaminant on the electret. Both flight units showed contaminant films appearing to be a residue from a liquid covering the surface.

Possible explanation for this was that the carrousel valve was not fully closed when the T027 Sample Array was retrieved from the ASAL. Also, the experiment was at an estimated -20°F and it is possible that cabin air condensed upon the electrets. If so, the appearance of the contaminant films may be explained as a residue left by the evaporation of the cabin atmosphere condensation. This is also true for all samples on the Sample Array although they have shown very little if any changes in optical properties. Some question exists as to whether or not the carrousels rotated and the number of samples exposed to the external environment for differing periods of time is unknown at present. However, since very little contamination was measured, this should not be a significant factor.

An important aspect of the Sample Array collection of contamination should not be overlooked. The Sample Array was preflight scheduled for exposure 4 days after SL-1 launch; however, the late launch of SL-2 and the resulting low priority of the Sample Array delayed performance until 35 days after SL-1 launch. In addition, only 46.5 hours of exposure were obtained out of the 120 planned hours. All these factors operationally diminished the possibility of the Sample Array detecting any measurable amounts of contamination as indicated by the ±X EREP QCMs which were reading approximately 10 micrograms at the time the T027 Sample Array was deployed. This is essentially 1000 Å of deposition and must be considered as a significant amount of contamination and the lack of contamination as measured by the T027 must not be interpreted as that there is no contamination deposition associated with the Cluster.

Correlation with the deposition math model predictions for the anti-solar SAL T027 Sample Array deployment indicated that a maximum deposition thickness of only 13 Å would occur. This does coincide with the P.I. evaluated data and that obtained from guest samples which for all practical purposes indicated that no significant deposition would occur.

2) D024 Thermal Control Coatings (Dr. William Lehn, P.I.) - The analysis of the D024 samples returned on SL-2 and SL-3 for degradation evaluation due to radiation had been compromised by the amounts of contaminants, principally outgassants, deposited on the samples' surfaces. The SL-1/2 results and preliminary SL-3 analysis of the D0-24 samples have

indicated that amounts of deposition on the flight hardware were in close agreement to the contaminant thickness values calculated by the deposition math model (Figure A-14). However, the high level of discoloration due to long term exposure of solar radiation to the contaminants was not expected. A benefit of this situation has been an increased amount of Skylab contamination data available for analysis.

Exposure times of the D024 samples during the Skylab mission are shown in Table 1.3.3.4-I.

During the 36 days exposure on SL-1/2, the majority of D024 white samples became discolored to a yellow brown. Auger Electron Spectroscopy of selected samples indicated that approximately 700 to 1700 Å of a material containing silicon was deposited on the gold coated quartz crystal

Table 1.3.3.4-I. D024 Thermal Control Coatings Exposure Time

Mission	Sample Direction	Beginning of Exposure (DOY)	End of Exposure (DOY)	Total Exposure (DAYS)
SL-1/2	(-Z); Thermal Coatings	134	170	36
	(+X,-Z); Polymeric Strips			
SL-3	(-Z); Thermal Coatings	134	265	131
	(+X,-Z); Polymeric Strips			
SL-4*	(-Z); Thermal Coatings	326	034	73
	(+X,-Z); Polymeric Strips			

* SL-4 was a resupply of samples since the SL-2 and SL-3 samples were heavily contaminated.

as well as traces of oxygen, carbon, and phosphorous. The silver coated quartz sample showed that between 700 and 2450 Å of a silicon containing material, as well as traces of copper, oxygen, nitrogen, and sulphur, were deposited. Auger analysis made on 3 sections of an aluminum spring from the sample holder also indicated the presence of silicon and carbon contaminants.

Microprobe analysis made on one of the D024 quartz samples indicated silicon was present on the sample. Analysis also indicated that in some isolated areas copper was imbedded or deposited after the silicon layer. In addition, X-ray images showed traces of copper as well as potassium.

The polymeric film strips indicated the same discoloration as the D024 thermal control samples with the areas shaded from sunlight not discolored. This again showed the effect of long term solar irradiation affect on the contaminants. Infrared analysis on each film strip showed an absorption band at approximately 1050 to 1100 cm^{-1} which could be indicative of a siliceous material. Further analysis of a brown spot on the aluminum handle indicated a "strong" band at 1050 cm^{-1} again indicating the material may be siliceous in nature. Infrared analysis has identified other bands from possible outgassing such as methyl silicones, aliphatic amides, low molecular polymides, aliphatic esters, acid carbonyl, and aliphatic hydrocarbons.

Preliminary P.I. analyses from other experiments tend to substantiate the findings of D024. Infrared analysis of a sample from the S230 experiment which is located near the D024 experiment has also shown contaminant deposits of the same nature as D024. Guest samples from the T027 Sample Array flown on SL-1/2 have indicated that the flight samples from this experiment appear to have more carbon than the ground based control samples. Infrared analysis on samples from the T027 Sample Array showed absorption spectra which might indicate silicones. However, other bands typical of silicone were missing and positive identification was not possible. The latter point is significant in that the T027 Sample Array was deployed on the -Z side of the Cluster which was opposite of D024 and indicating that the induced environment is probably similar on both sides of the Cluster. However, due to solar illumination, typical outgassing sources will have a higher rate on the solar side along with possible photo-chemical reactions as most likely observed with the D024 samples.

As previously mentioned, the sample areas on D024 that were "shadowed" from sunlight by objects such as lanyard cable and a pip pin showed no visible discoloration. This tends to substantiate that the cause of the discoloration was a result of a long term solar irradiation of surface contaminants. Astronaut observations have indicated that in general all white thermal surfaces exposed to solar radiation (Saturn Work Shop (SWS) S13G and Z-93 as well as the S13G and Z-93 in D024 samples) have degraded to shades of yellow and brown while similar surfaces not exposed to ultraviolet have remained essentially white. This is not to say that contaminants were not present but to indicate the importance of solar irradiation, in particular the ultraviolet component, to the observed discoloradion.

The results of the deposition math model analysis appear to correlate well with the flight results obtained from the preliminary D024 sample analysis, as shown in Figure A-14, for the 36-day period of exposure on SL-1/2. An accumulated contaminant thickness of 13.0 μ gm/cm^2 or 1300 Å was calculated for the -Z facing samples.

Measured flight values were from 700 Å to 2450 Å. This is shown in Figure A-14 which compares calculated accumulative deposition as a function of mission exposure time with D024 P.I. preliminary data analysis results.

The P.I.s initial tests indicated that the contaminants on the samples returned on SL-3 were darker in their discoloration. Preliminary thickness measurements of these samples are a factor of three or more greater than the SL-1/2 samples. This initial result again appears to compliment the deposition math model calculations shown in Figure A-14 which indicated that the thickness would be approximately 58.0μ gm/cm^2 or 5800 Å for the thermal control paints and 2.2μ for the polymeric strips.

Discoloration of the majority of the thermal control samples has indicated a change in their solar absorptivity (α). Measured changes in white thermal control samples such as Z-93 and S13G have shown changes of approximately 0.08 to 0.09. α changes in black thermal control paint such as 3M Black Velvet were essentially very small if not negligible. These changes were on the order of 0.01.

Figures 1.3.3.4-1 and 1.3.3.4-2 show changes in $\Delta\alpha$ as a function of exposure time and essentially that of accumulative deposition. Comparison of predicted $\Delta\alpha$ changes due to solar irradiation only (obtained from ground test programs) and that measured from D024 are shown indicating good correlation.

A common analysis from thermal control surfaces and polymeric strips on D024 indicates that the observed contaminant is basically siliceous in nature, thus proposing that outgassing of a silicon base material or its derivatives in the S13G and Z-93 and RTV type compounds are strong candidates as sources of this contamination.

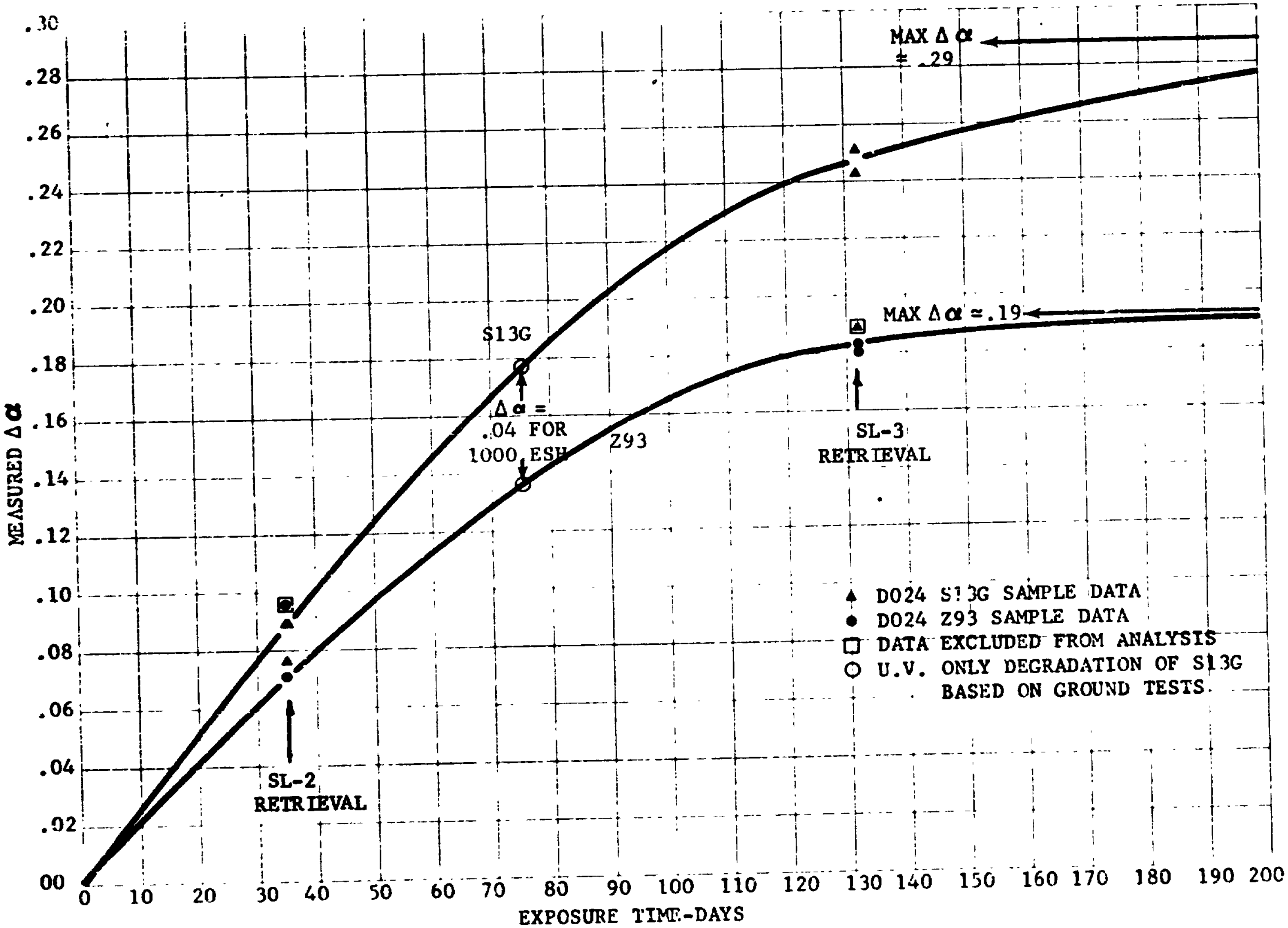

Figure 1.3.3.4-1 Measured D024 Thermal Control Paint Degradation (Δα) as a Function of Exposure Time To Skylab External Environment

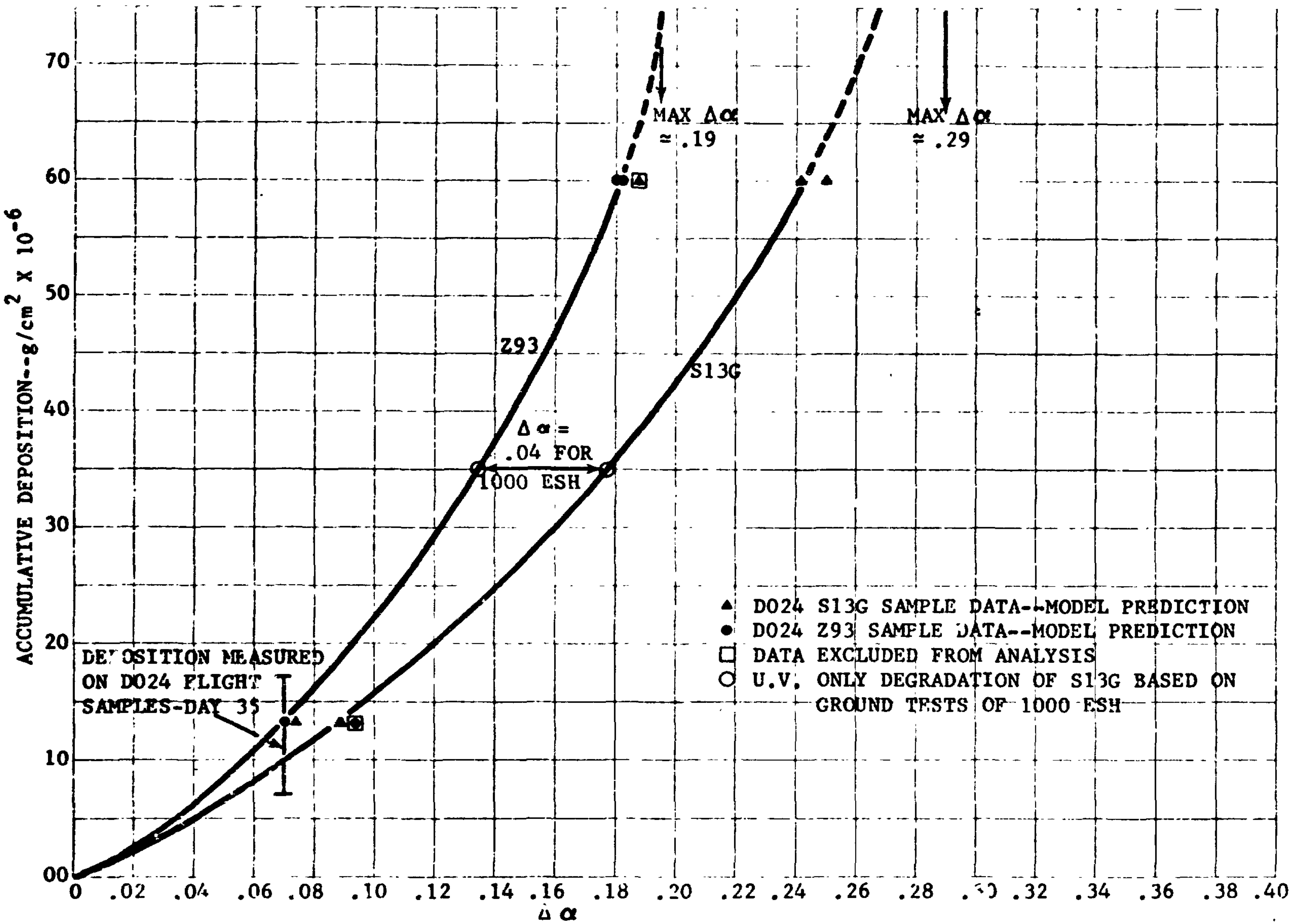

Figure 1.3.3.4-2 Thermal Control Paint Degradation (Δα) as a Function of Accumulative Contaminant Deposition

The P.I. indicated that perhaps a localized leak of coolanol in the EVA area may have some bearing on the contaminant deposits. The presence of carbon and other trace elements observed may indicate that hydrolized coolanol interacting with the solar radiation could have deposited the observed silicon oxide (from the SiO_4 in the coolanol) and turned the surface a yellowish brown color. However, the identified carbon on the samples, along with trace metals and other elements, could also be from the CSM RCS firings, indicating that the RCS may have contributed to the observed deposition.

Reflection curves of the contaminants obtained by Dr. Joe Muscari at MMC are very similar to the silicon oxide reflection curves, which further substantiates the Auger analysis regarding the presence of silicon and oxygen. In evaluating the spectral analysis, the D024 P.I. stated that he found no dimethyl-silicones (which should be present if S13G or Z-93 were responsible for the deposits) makes the coolanol, or some other silicon source, additional candidates. According to the P.I. more information regarding the coolanol leak, its hydrolyzing effects, and solar radiation interaction is needed before any definite conclusions are made.

The observed discoloration of solar oriented Cluster thermal control paints and the majority of D024 samples (as borne out via astronaut observations and the returned samples) is evidence that a combination of contaminant deposits interacting with solar irradiation is responsible. The resulting curves (Figures 1.3.3.4-1 and 2) are felt to be a reliable data source for assessing affects on other Cluster thermal control surfaces. Initial SL-4 "quick-look" analysis by the P.I. indicates the conditions of the thermal control samples and polymeric strips are similarly contaminated as the previous SL-3 samples. The shaded areas across the samples (from the cable, etc.) showed similar defined patterns as on SL-1/2 and SL-2 caused by the lack of solar exposure on the deposited surfaces. This provides further data that the EVA area was again effected by some anomalous source of contamination.

Until further analysis on SL-4 data is completed by the P.I. relating to the similarity of the contaminant to the previous SL-1/2 and SL-3 samples no conclusions can be made at this time.

As additional experimental data becomes available, such as analysis of S230, S149 and the Parasol samples; it should further clarify the overall Skylab contamination environment picture around the EVA hatch area.

3) M415 Thermal Control Surfaces (Mr. Eugene McKannon, P.I. - The M415 experiment was flown on the IU of the SL-2 launch vehicle. Thermal control samples were uncovered at different times during the mission; i.e., at the launch site, during launch and ascent, and on orbit to determine impact of these environments on the thermal control parameters (α, ε and α/ε) of certain thermal control paints and in particular the white thermal control paints S13G and Z-93 (where ε is the emissivity).

The α/ε of a S13G and Z-93 samples covered (but not sealed) was seen to increase over the several hours of experiment operation by over 25% over the α/ε ratios measured in the laboratory prior to installation of the experiment at the launch site. This indicates the degrading effects of the salt-fog environment on reflectivity of the S13G and Z-93 white thermal control paints.

The samples exposed to Launch Escape System (LES) jettison were expected to show noticeable degradation in α/ε due to this event. In fact, the samples showed only a small difference of α/ε when compared to the control samples which were uncovered only after orbital insertion. One possible explanation being considered by the P.I. is that the samples exposed to the LES jettison had only a very short, if any, exposure to the center of the plume. Thus, little material contacted the sample surfaces. However, the heating of the samples due to the LES jettison may have heated the samples sufficiently to drive off moisture which had been picked up by the samples, thus tending to improve the samples' reflectivity.

The M415 samples were located on two panels with different view factors to the retrorockets. However, the α/ϵ degradation was comparable on both sample panels, indicating that the degrading effects of the retrorocket plume were widespread and not highly localized.

After the retrofire, which was the last major event to be experienced by the M415 samples, the samples showed little or no change in α/ϵ. This indicates that the degradation of the samples was primarily due to events which contaminated or damaged the samples. The stability in α/ϵ also indicates that there was little or no further degradation or recovery in the sample's condition.

4) S230 Magnetospheric Particle Composition (Dr. D. Lind/Dr. J. Geiss, P.I.s) - The purpose of this experiment is to measure fluxes and composition of precipitating magnetospheric ions and trapped particles through the use of a foil collection technique. This method will allow the particles to implant themselves in aluminum, aluminum oxide, and platinum foils mounted in the form of two cuffs on the AM deployment assembly near the EVA hatch.

The following exposure times were encountered by the experiment:

Table 1.3.3.4-II S230 Exposure Times

Collector	Beginning of Exposure (DOY)	End of Exposure (DOY)	Exposure Duration (DAYS)
SL-3 Outer Cuff #1	135	218	83
Outer Cuff #2	135	218	83
SL-4 Inner Cuff #1	218	265	47
Inner Cuff #2	218	034	181
Resupplied Inner Cuff	326	034	73

The major interest in the collectors are the surface contaminants they acquired during their various exposure times. The analysis of surface contaminants is currently in progress with no results available at this time. Since they are located close to the D024 experiment, which became badly discolored and contaminated by deposition (see Section 1.3.3.2), any correlation with deposits found on the collector foils will be most useful.

Discussions with the P.I. (Dr. Lind) indicated that pieces of the contaminated foils from SL-3 are being analyzed by Dr. Joseph Muscari at Martin Marietta Aerospace, Denver, Colorado. The SL-3 foils were contaminated to such an extent that they were replaced on SL-4 with the hope that the source of contamination was only inherent to the SL-1/2 and SL-3 missions. Information relating to what the contaminant is, is unknown at the present and will be made available as soon as the infrared spectrometry is analyzed by Dr. Muscari.

Photographs are in the process of being reproduced which will indicate the levels of discoloration and the areas affected. These will be helpful (when compared to the D024 and other Skylab photographs) in determining if the contamination is localized and similar in nature or if this is a general condition occurring throughout the spacecraft.

Math model predictions for the various exposure times are presented in Figure A-16. These values represent deposits from outgassing surfaces and do not consider any anomalous sources. Returned photographs of the S230 SL-4 cuffs have shown considerable deposition as well as an iridescent discoloration (similar to an oily film) on the various sample strips. Pieces of the SL-4 samples were given to Dr. Joseph Muscari for analysis and comparison to the SL-3 contaminated samples. This data indicates that there still was an anomalous source of contamination during SL-4 by the EVA area.

No immediate conclusions, relating to the description of the contaminants or where they came from can be made until the analysis is completed.

5) S149 Particle Collection (Dr. C. L. Hemenway-P.I.) - The S149 Particle Collection experiment was exposed to the Cluster external environment through the anti-solar SAL and at the ATM Sun Shield. It could not be deployed through the solar SAL as intended because this port was blocked by the addition of the thermal parasol required due to the loss of the Meteoroid Shield. It is not clear at this time whether or not contamination contributed to the formation of oxides on the S149 surfaces. Table 1.3.3.4-III shows the exposure times for various S149 cassettes.

Table 1.3.3.4-III S149 Particle Collection Exposure Time

Cassette	Beginning of Exposure (DOY)	End of Exposure (DOY)	Exposure Duration (DAYS)	Exposure Location
Between SL-2 and SL-3	174	212	38	Anti-Solar SAL
SL-3	218	265	47	ATM Sun Shield
SL-4	326	359	33	ATM Sun shield
Post SL-4	034	Intended to be retrieved on Apollo/Soyuz mission		ATM Sun shield

Correspondence with the P.I. has indicated that the S149 cassettes exposed through the anti-solar SAL between SL-1/2 and SL-3 showed little if any particulate contamination. Some dark spots were visible but it is believed only a few could be attributed to particles or deposits while the others are probably tarnished areas which could be caused from several sources (e.g., oxidation due to O^+ ions in the ambient environment or while in storage prior to exposure or in shipping).

Figure 1.3.3.4-3 shows the cassette orientation for the solar and anti-solar positions. The B-1 samples (+Z directions) exposed out of the ASAL during the 34 day SL-1/2 to SL-3 period are shown in Figure 1.3.3.4-4. The dark shattered-like flakes appearing in the lower left sample of the cassette array shows the degree of AgO which occurred on the surface, also the copper oxide coating can be seen in the bottom third from left and the top second from left samples. Two clean stainless steel samples are shown in the bottom second and fourth from left positions indicating no oxidation occurred. The top first position were millipore and lexan guest samples while the top fourth from the left was another guest

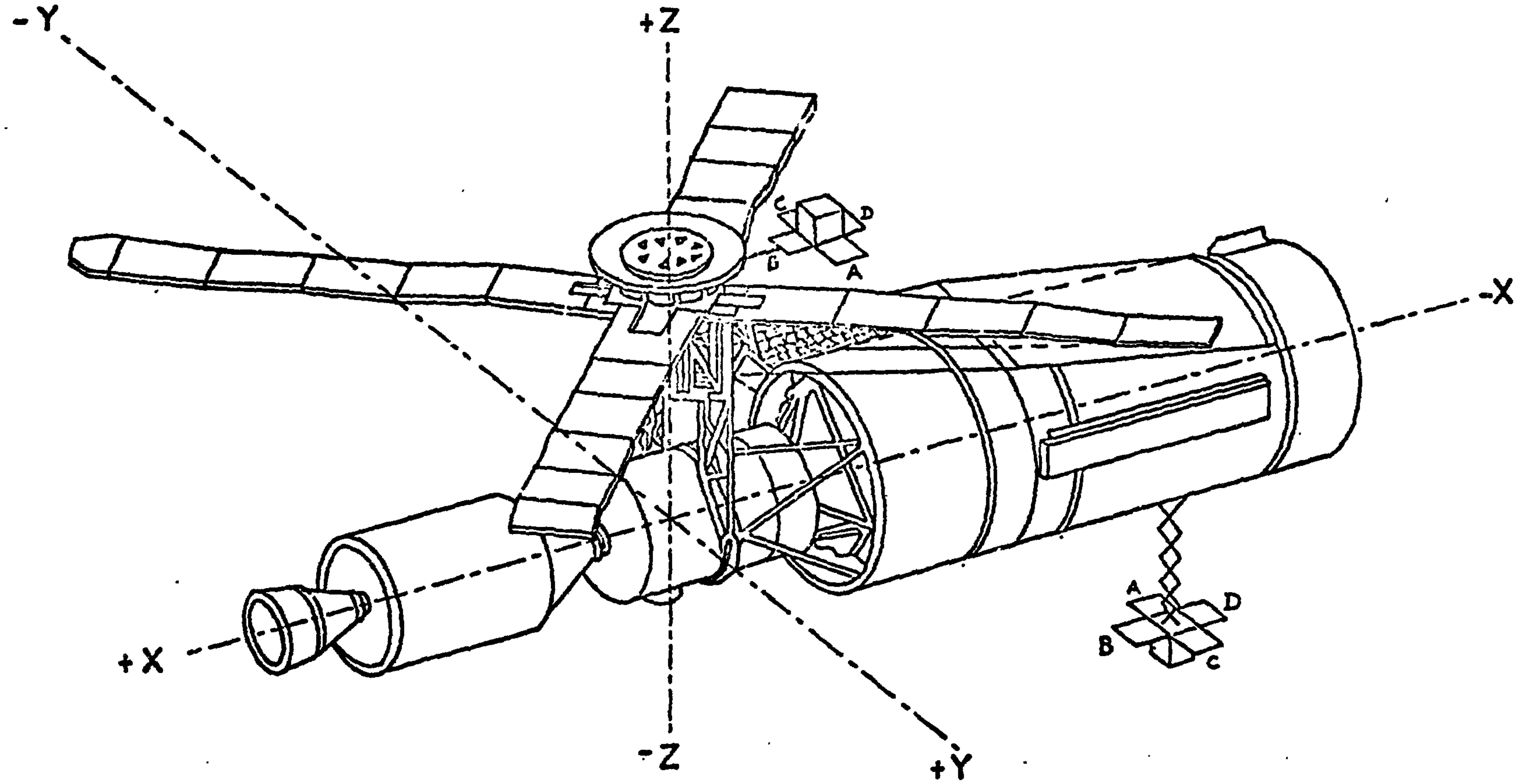

Figure 1.3.3.4-3 S149 Cassette Orientation

Figure 1.3.3.4-4 B-1 Sample (Facing +Z Direction) Exposed Out of the ASAL

sample. The last sample (top third from left) was gold foil.

The cassettes attached to the ATM Sun shield during SL-3 appeared to be more contaminated than the anti-solar cassettes. A discoloration appeared on the cassette surfaces facing the solar and CSM directions. Analysis of the solar facing silver surfaces indicated they were dark grey and that a silver oxide (AgO) was present. The solar facing copper surfaces also appeared corroded and it is expected that a cupric oxide (CuO) is present. The surfaces facing in the +X direction showed the most discoloration with the shielded or shaded areas showing no contamination. This tends to indicate that exposure to the ambient O^+ ions over long periods of time may have been the cause of the discoloration. During any one orbit, the ram effect of the ambient atmosphere and high temperatures are coincident for the $\pm Z$ direction and for high beta angles can provide similar conditions for the +X facing direction. The blue anodized aluminum supporting structure was also darkened where exposed to the Sun, whereas, the areas directly under the samples were not. Less change was noticed on the aluminum, anodized aluminum, stainless steel, and platinum foils than on the silver or copper foils. This is also compatible with O^+ ions impingement since the noble metals will have a higher reaction rate with O^+ ions. Preliminary analysis indicated that particles were also present on the gold foils as was the case with the anti-solar SAL exposed units. A few slides were discolored which reduced their usefulness and made observation for impacting particles difficult. Carbon coated nitrocellulose samples had practically disappeared from the anti-solar SAL exposed cassettes, but the ATM mounted solar exposed samples were not affected.

Data obtained from the OGO No. 6 Satellite indicated that at the Skylab altitude, the O^+ ion has an energy level of approximately 5eV at 10^{-6} Torr. The low 5eV energy level isn't sufficient to cause sputtering but would possibly allow the O^+ ions to interact with silver and copper surfaces, then oxidation could have occurred. The maximum flux rate at 10^{-6} Torr and Skylab altitude is $10^{14} O^+$ ions/sec/cm^2. If the reaction rate were the same for silver as for gold, then the amount of silver atoms reached would be approximately 10^{-5} X 10^{+14} or 10^9 Ag atoms/sec/cm^2 which could be sufficient to cause noticeable degradation with the given exposure time of the samples. If sputtering occurred at any rate, it should have provided for a cleaning effect and would have been noticed because the oxidation effect would not occur. The P.I. feels that it is unlikely that oxidation could have occurred during stowage or shipping.

The EREP QCMs indicated an increased deposition rate which was attributed to a CSM quad D oxidizer leak from DOY 211 through DOY 225. This slow leaking of N_2O_4 may have been deposited on the SL-1/2 to SL-3 exposed cassettes which were opened on DOY 218. It is thought that this oxidizer leak could have provided the extra oxygen for oxidation as noted on the SL-3 samples.

The deposition math model predicted that since no direct line-of-sight with outgassing sources existed there would be no appreciable contamination deposits on the ATM mounted solar facing cassette surfaces. The anti-solar SAL cassettes were predicted to have some deposition from outgassing sources. However, due to the low temperatures at this location the deposition should be minimal.

The deposition math model predicted that the following amounts would accumulate over the 38 day exposure out of the anti-solar SAL (based on a -28°C S149 temperature):

Cassette Direction	Deposition in Angstroms (Å)
+X	65
-X	100
+Y	435
-Y	23
-Z	0

SL-4 quick look observations made by the P.I. indicated that the degree of contamination appeared slightly less than that observed on the SL-3 exposed samples. Oxides on the copper and silver were still evident as well as a similar discoloration on the cassette surface.

The observed oxides have not been detected on other experiments that were exposed to the external environment (as in T027 and D024). Contamination does not appear to have played a major role in affecting the S149 experiment objectives. Continuing analysis such as X-ray diffraction analysis by the P.I. may indicate additional data such as similarities to some of the contaminants observed from the other environments (siliceous material).

6) S019 Ultraviolet Stellar Astronomy (Dr. Karl Henize P.I.) - The primary objective of this experiment was to obtain moderate dispersion stellar spectra from the near ultraviolet region down to 1400 Å, with sufficient spectral resolution to permit the study of ultraviolet line spectra and spectral energy distribution of early type stars. Analyses to date indicate that during SL-1/2 contamination had little impact on S019 data. There

is a strong possibility that contamination deposits degraded the S019 data from SL-3.

Considerable emphasis was placed on evaluating the ultraviolet reflecting Articulated Mirror System (AMS) because it was extensively used not only with S019 but many other experiments (e.g. S183, S063, S201, S073, ED 23 and ED 26).

This extensive use increased the exposure of the initial mirror used on SL-2 and SL-3 to approximately 75 hours. The premission baseline called for about 25 hours of mirror exposure over all three missions.

The deposition math model predicted that due to low temperatures of potential outgassing surfaces during times of mirror exposure, there would be negligible deposition on the AMS surface. Based upon a qualitative review by the P.I., the SL-1/2 photographic data did not indicate any contamination impact and the condition of the film appeared good.

During DOY 232 when the AMS had retraction problems, the mirror reached a calculated temperature of approximately -30°C. The mirror had positive view factors to nearby surfaces which were warmer than itself, setting up the potential for deposition. When the mirror was finally taken out of the SAL, droplets of moisture had condensed on the mirror surface. This was due to the mirror still being cold when it was taken out of the SAL into the OWS. Also, the P.I. commented that it was possible to have had some moisture get to the mirror during the prism change just prior to the malfunction (DOY 232).

The P.I. has indications that data have been affected by AMS degradation but the degree of contamination has yet to be determined. The data indicated that the signal intensity received from a specific star field in the 1500 Å spectral region had degraded approximately 50% when taken during the SL-3 mission as compared to a measurement taken of the same star field at the start of the SL-1/2 mission. Due to this deterioration and the extensive continued use on many other experiments, a new replacement AMS was launched on SL-4.

The SL-3 total, predicted, worst case deposition on the AMS was 2.6 Å which was almost entirely due to outgassing of external surfaces during the malfunction period on DOY 232 when the AMS was continually exposed for over 28 hours. This corresponds to 2.7% attenuation at 1400 Å at a 30° off normal ultraviolet reflection angle on the AMS surface. Such a value is well within tolerance limits of experiment degradation and in itself is not considered serious. However, the degree of degradation due to condensation is unknown and must be considered significant in light of the P.I.s comments concerning the noted signal difference between SL-1/2 and SL-3.

The anti-solar SAL utilized a desiccant system for repressurization after experiment operation. Tests by McDonnell Douglas Aerospace have indicated that the particles which penetrated the filter network downstream of the desiccant and entered the SAL volume during AMS repressurization amounted to 5.8×10^4 particles. This was a total for all repressurizations of the AMS (including S183 operation) and for particles in the 0.3μ size range or greater. If all these particles were electrostatically attached to the S019 AMS surface the density would be the same order of magnitude as the S019 tolerance stated by the P.I. and could create problems from absorption or scattering of the deposited particles. For particles less than 0.3μ in size, the P.I.'s tolerance criteria were met. It is presently thought that this possible source did not contribute significantly to the noted degradation since it is not likely that all the particles would remain on the surface.

The signal attenuation of the star field emissions by the molecular contaminant cloud around the anti-solar SAL was approximated using predicted cloud mass column densities. As a worst case condition, the total column density from all the vents was taken as 17.5 X 10^{-8} gm/cm^2. Utilizing the mass absorption coefficient (approximately 500 cm^{-1} at 500 Å) for molecular oxygen, which constitutes approximately 80% of the cloud, and applying these values in Lambert's Law, an attenuation value of less than 1% was obtained.

This indicated that there was no measurable influence at 1500 Å by the molecular cloud. Spectral regions above the 1500 Å level had smaller mass attenuation coefficients which would therefore attenuate the signal even less.

Since Oxygen (O_2) is the most dominant cloud element, its absorption will be much greater than that of all the other cloud elements. Other molecules which may be in notable abundance (e.g., CO_2, NO_2, NH_3, N_2O_4, etc.) have cross sections no greater than that of O_2, are less abundant, and therefore will attenuate the ultraviolet radiation to a lesser degree and should be no problem.

Uncontrolled anomalies, (e.g., malfunction, procedural errors venting the gas side of the condensate holding tank and not allowing enough warm up time when retracting the mirror at low temperatures), and the extensive usage (approximately 200% above baseline) were greater causes in affecting mirror deterioration than the predicted contaminant cloud or deposition from outgassing.

The P.I. indicated that the quick-look review of the SL-4 data showed no obvious effects due to contamination. Therefore any small loss of sensitivity or degradation would only be discovered after a more thorough analysis of the data has been made. However, with the resupply of a new AMS mirror on SL-4, it would not be expected that it would see considerable contamination when compared to SL-1/2 and SL-3 data since no known anomalies related to the mirror occurred.

7) S063 UV Airglow Horizon Photography (Dr. Donald Packer - P.I.) - The objectives of the experiment were to photograph the ozone in the earth's atmosphere and to obtain representative airglow height and intensity data at twilight over a variety of latitudes and longitudes utilizing the Wardroom, STS, and special ultraviolet SAL windows.

The P.I. has commented that deposits are evident on the four STS window photographs as well as the ice crystal on the Wardroom window. The impact on the data still hasn't been determined, however, initial "quick look" analysis did not indicate any serious anomalies. Future contact with the P.I. will be made as further analysis of the data is completed.

Experiment S063 was operated for the first time during DOY 219. Components which were particularly observed for contamination were the AMS and the ultraviolet SAL window which were utilized in mode 2U or EAII (airglow) and mode EAI (ozone) respectively. During experiment operation on DOY 221 relatively high EREP QCM readings were recorded which indicated an increase in deposition rate. The cause of this increase appeared to stem from the CSM RCS quads B and D oxidizer leaks which occurred in the same time frame. The quad B leak started shortly after launch and was terminated by the crew before docking. The quad D leak commenced after docking and was terminated by DOY 214. However, the EREP QCMs indicated an unusual high deposition rate until DOY 225. Therefore, it is possible that some of the emitted N_2O_4 may have affected this experiment data run.

On DOY 231, a handheld camera was used to obtain data through the STS #243 and #244 windows. This could provide some indication about window contamination when compared to STS window photographs obtained early during SL-1/2 in the performance of the contamination window DTOs.

Deposition math model predictions on the accumulative deposition due to outgassing for the STS #243 window is indicated in Figure A-8 as well as the transmission loss from these deposits at 3000 Å and 6000 Å which would have occurred by DOY 268. A similar prediction is made for the Wardroom window which was used for all the ozone EAI data acquisition (see Figure A-9). Additional contamination occurred on the STS and Wardroom windows and is discussed in Section 1.3.4. Dust particles, lint, and moisture (between the Wardroom window panes) may have an influence on the data but its severity can only be determined after the P.I. completes his analysis.

The 2U airglow sequences (DOY 239 through 244) are of particular interest since the AMS was used with S063 (replacing the solar SAL sequences) and may provide some information about mirror degradation or deposition when compared to before and after photographs from experiments S019 and S183. Contact will be made with P.I.s for a quick look review of the returned photographic data for any anomalies which may have been caused by contamination or may indicate contamination.

The stowage procedure following data acquisition on DOY 250, 251, and 252 was of particular interest to contamination. The cameras were removed from the mounting assembly and placed in the film vault, but the assemblies with the optical sight and UV transmitting window attached were simply strapped to the top of the S063 storage container. The window was thereby exposed to internal atmosphere without the normal protection of the enclosure for a period of about 2 days (DOY 250:1920 to DOY 252: 1415). Analysis of data will establish whether any harmful dust or other materials were deposited on its surface. The mounting assemblies, including optical sight and window were stowed normally on DOY 252.

Preliminary analysis has indicated that contamination of the STS and Wardroom windows, utilized by S063, has occurred, but further P.I. analysis will be required to determine the effect of this contamination.

Predictions obtained from the deposition math model indicated that the transmission loss, due to outgassing sources, through the STS and Wardroom windows would reach a level of 0.15% at 3000 Å and 0.095% at 6000 Å, and 5.8% at 3000 Å and 0.155% at 6000 Å, respectively, at the end of DOY 039. However, dust, lint, and moisture on the windows coupled with the above discussed deposition could have degrading effects on S063 data. The total S063 deposition/attenuation prediction for the AMS data, obtained at 2600 Å, is 2.6 Å/1.0%. This is well below the acceptable contamination level for the experiment (Table 1.0.5-I).

The P.I. review of SL-3 data has indicated that no serious degradation to the data has presently been found. The SL-4 SAL data was out of focus, possibly due to a camera pressure plate problem, and it may be difficult to interpret if there was any contamination effects. Kohoutek EVA data however did come out correctly but the P.I. does not anticipate any serious degradation from contamination.

8) S183 UV Panorama (Dr. G. Courtes, P.I. and Mr. Harry Atkins, Co-P.I.) - The primary objective of this experiment was to study hot stars and their color indices which are distributed in different regions of the sky in relation to the milky-way.

The S183 experiment utilized the S019 Articulated Mirror System to reflect the ultraviolet from these stars into its optical system. The Co-P.I. has stated that there is an apparent loss of sensitivity between the SL-3 DAC photography and the SL-2 DAC photography. This loss appears compatible with that experienced by the S019 P.I., indicating that the old AMS, the only optical element common to both experiments, might have experienced a loss in reflectivity. However this reflectivity loss has not compromised the main objectives of the experiment.

A Principal Investigator's representative indicated that although there was some film degradation due to the initial SL-1 OWS environment, there is no reason to suspect any contamination impact on the data.

With only one instance of anomalous particle sightings (DOY 120) on the S183 film, the analysis of the S183 contamination related anomaly is inconclusive at this time. It could have been caused by a large piece of tumbling space debris or a small particle in the instruments field-of-view.

The Co-P.I. said that the SL-4 data showed no anomalous tracks and initial observations indicate no impact due to contamination. Any indications of sensitivity loss or degradation will be made by comparing the same star fields taken on the SL-3 or SL-4 mission to those taken during SL-1/2, however, this data will not be available for several months.

9) S150 X-Ray Galactic Mapping (Dr. William Kaushaar, P.I.) - The S150 Galactic X-Ray Mapping Experiment which was on the SL-3 launch vehicle surveyed the sky for X-ray sources in 200 to 12,000 electron-volt range.

The P.I. has indicated that there are no indications at this time of contamination impacts on S150 data. The breakage of the S150 proportional counter window, which could have conceivably been caused by contamination, correlates closely to times when sunlight was shining on it. Therefore the P.I. thinks that it is very unlikely that contamination was responsible. Other possible contamination effects, such as star sensor indications of false stars or change in the low energy cut-off of the spectral data, has not been analyzed by the P.I. at this time.

10) S073 Gegenschein/Zodiacal Light (Dr. Gerald Weinberg, P.I.) - The S073 Experiment was used to measure brightness and polarization of night flow in the visible spectrum.

The P.I. data reduction has not proceeded far enough to assess contamination effects. Contamination related data for this experiment is contained in the T027 contamination Section 1.3.3.4.a.1.

11) S020 X-Ray/UV Solar Photography (Dr. Richard Tousey P.I. and Mr. David Garrett, Co-P.I.) - The S020 was used to photograph external UV and X-ray emissions of the Sun in the 10 to 200 Angstrom wavelengths.

The instrument was operated during the last three SL-4 EVA's by being mounted externally on an EVA truss taking 60, 30, 15 and 7.5 minute exposures of the sun. The first data run (DOY 359) showed all data below 111Å was non-existent but having good data above 111Å, the second data run (DOY 363) indicated a few very faint lines below 111Å (around 44Å) with good data above 111Å; the last run (DOY 034) indicated triple lines only on the 60 minute exposure but again very faint lines below 111Å on all exposures. All data below 111Å was exceptionally poor on all runs.

The Co-P.I. feels that some possible causes may be H_2O vapor (or moisture) effecting the incoming data or that there may be deposition on the Indium, Beryllium, or Boron filters. Analysis by the P.I. on checking the transmission through the returned filters is continuing. Preliminary observation of the filters indicate some deposition on the surface (perhaps an oxide); however, further analysis will have to be performed to determine what the deposits are and how it is effecting the data. Additional filters are being produced and will be utilized in laboratory tests which will be compared to the effects on the returned flight filter data.

A water leak from the CDR's and SPT's EVA suit occurred on DOY 359 and 034 respectively. Also, the PCU deflector was not attached during the last two EVA's (see Section 1.3.3b for more details). These two factors may have had an effect on the data.

12) <u>T025 Coronagraph Contamination Measurement (Dr. Mayo Greenberg, P.I.)</u> - The T025 was used to obtain visible light data from the Comet Kohoutek and in support of the S073 Experiment. Preliminary indications are that a camera malfunction focused T025 data runs at approximately five feet. Some of the frames indicate particles floating within the field-of-view of the instrument which may help in determining particle size or intensity after further analysis by the P.I. has been completed.

13) <u>S232 Barium Plasma Observations (Dr. Eugene Wescott, P.I.)</u> - The purpose of this experiment was to determine geomagnetic field line configuration, plasma conductivity and space observation of a cold metal plasma.

No contamination related data is available from P.I. analysis at this time.

14) <u>S233 Kohoutek Photometeric Photography (Dr. C. Lundquist, P.I.)</u> - The purpose of this experiment was to obtain photographs of Kohoutek to provide a synoptic history of the Comet.

No contamination related data is available from P.I. analysis at this time.

15) <u>S201 XUV Electronographic Camera (Dr. G. Carruthers, P.I.)</u> - The purpose of this experiment was to study earth's tropical airglow and polar auroral zones, lunar atmospheric hydrogen, interstellar and intergalactic material, and the Comet Kohoutek.

The P.I. reports that there are indications of Corona occurring during approximately 25% of the data runs taken from the A-SAL. The film also indicated some moisture spots. These spots were more likely acquired during their return after splashdown.

Initial evaluations indicated there would not be any Corona problems during EVA or in the A-SAL. However, this was based on a specified experiment leak rate and no outgassing from the instrument. The flight attachments to the S019 and S063 equipment for A-SAL usage could have increased the instruments leak rate causing the higher pressures which allowed Corona to occur. No Corona problems were observed during the EVA data runs which tend to indicate the possibility of higher leak rates than anticipated for the A-SAL exposures.

16) T053 Skylab Earth Laser Beacon (Dr. Louis Caudill, P.I.) - The purpose of this experiment was to evaluate the use of Lasers for navigation and communications in near earth orbits.

The P.I. has indicated that Skylab contamination such as the ice or condensation on the Wardroom window, did not cause any problems to T053 operations.

b. Principal Scientist (P.S.) Comments on Earth Resources and Experiment Packages

1) S190A Multispectral Photographic Camera (Mr. Ken Demel, P.S.) - The S190A was used to obtain high quality repetitive visible and near infrared multispectral photography from space.

The S190A P.S. has noticed that some minute areas of photographed ground scenes were lost. This was apparently due to dust and possibly a slight amount of other materials on the S190A lens platens. This condition has had no substantive impact on the S190A data.

2) S190B Earth Terrain Camera (Mr. Ken Demel, P.S.) - The S190B was used to obtain high resolution medium format color photography from space.

No evidence of contamination impacts has been reported by the P.S.

3) S191 Infrared Spectrometer (Dr. Thomas Barnett, P.S.) - The S191 was used to produce multi-spectral imaging of visible, solar infrared and thermal infrared spectra in assessing earth surface composition and condition.

From preliminary reduction and review of SL-1/2 S191 data to date some indication of possible contamination has been noticed. Using the lunar calibration data, it has been noticed that the signal intensity at about 4000 Å has decreased. Since, in general, contamination deposits attenuate more strongly at shorter wavelengths, this could be evidence of contamination. However, since this signal decrease is very close to the low wavelength cut-off of the instrument, this effect could well be a change in instrument response.

Also SL-2 data in the thermal region taken during deep space runs indicated several anomalous I.R. peaks having considerably higher intensities than anticipated. Some of these peaks could possibly be emitted by H_2O vapor, ozone (O_3), or silicon but until further checks in the data reduction process are made no substantiated contamination related conclusions can be made at this time.

4) S192 Multispectral Scanner (Mr. William Hensley, P.S.) - The S192 was used to obtain quantitative radiance values simultaneously in 13 spectral bands for evaluation of multispectral data and automatic data processing techniques.

No evidence of contamination impacts on S192 data have been noticed. The signal to noise ratio of the initial detector in the thermal band led to the replacement of this detector by one of higher signal to noise characteristics. This condition is an intrinsic characteristic of the detector and not related to contamination.

5) S193 Radiometer Altimeter/Scatterometer (Mr. Doug La Pointe, Experiment Developer) - The S193 was used to obtain data for simultaneous evaluation of radar backscattering-cross-section and passive microwave emissitivity of land and sea (K-Band radar).

Foreign material from instrument insulation was removed from the potentiometer and gimbal area on the first EVA of SL-4 on DOY 326. This restored S193 controlled motion in the yaw direction. From onboard sensors and ground sensors, an apparent minor decrease in S193 power output has been observed. However, since ground sensor data shows little or no change in antenna pattern, it is unlikely that contamination is responsible.

6) S194 L-Band Radiometer (Mr. Harold Nichke, Experiment Developer) - The S194 was used to measure thermal radiation in the microwaver (L-Band range).

Data analysis and performance evaluation to date do not show any contamination impacts on S194 data.

1.3.4 Windows - Analysis of window contamination was derived almost entirely from astronaut comments, the time of occurrence, appearance of the deposits, and photographs taken of the Wardroom and STS during each mission phase. Comments were obtained from Tape Dump and Real Time Transcripts of astronaut conversations and from debriefing interviews. Except for the Wardroom window, which was heavily contaminated on surfaces that could not be cleaned and thereby restricted photography through it, window contamination presented no problems to the astronauts. It appears that window heaters and covers are an effective means of window contamination control when properly used providing the cover does not contact surfaces that will erode and produce contamination particles. Cluster window locations are indicated in Figure 1.3.4-1 and -2.

The S190A/MDA window external surface remained visibly clean throughout all missions. However, the inner surface required removal of two smudges during the SL-3 mission, and the complete inner surface was cleaned during SL-4 using the Optical Cleaning Kit. Condensation of cabin atmosphere on the CSM windows was reported on SL-1/2 and SL-4. The external surfaces of all STS windows became contaminated to some degree with particles and a boot mark was imprinted on the outer surface of window number 2 during the SL-1/2 EVA to deploy the OWS solar wing. Inner surfaces of the STS windows were contaminated by astronaut breath and cabin atmosphere condensation and were cleaned about every three weeks by the crew. An ice spot was observed on the inner surface of the Wardroom window outer pane when the cover was first removed during SL-1/2 activation. Later, this ice spot alternately melted and refroze as the window heater was turned on and off, and eventually spread to a 4-inch diameter. The exterior surface of the Wardroom window outer pane was reported shortly after SL-1/2 activation to have a greasy looking surface with what appeared to be water streaks across it. The interior surface of the Wardroom window became contaminated repeatedly with condensation of astronaut breath and cabin atmosphere and from physical contact by the astronaut during the many observations made through it. These conditions required repeated cleanings. Attempts to remove the ice and condensation from between the panes of the Wardroom window by connecting the window volume to a vacuum and then refilling with dry air were only partly successful. This window has no external cover and its heater was energized only sporadically.

1.3.4.1 S190A/MDA Window - Four reported inspections of the S190A window, two on SL-1/2 and one each on SL-3 and SL-4, indicated that the exterior window surface remained visibly clean throughout all missions. During SL-3, however, two smudges appeared on the inner surface, evidently from inadvertent contact

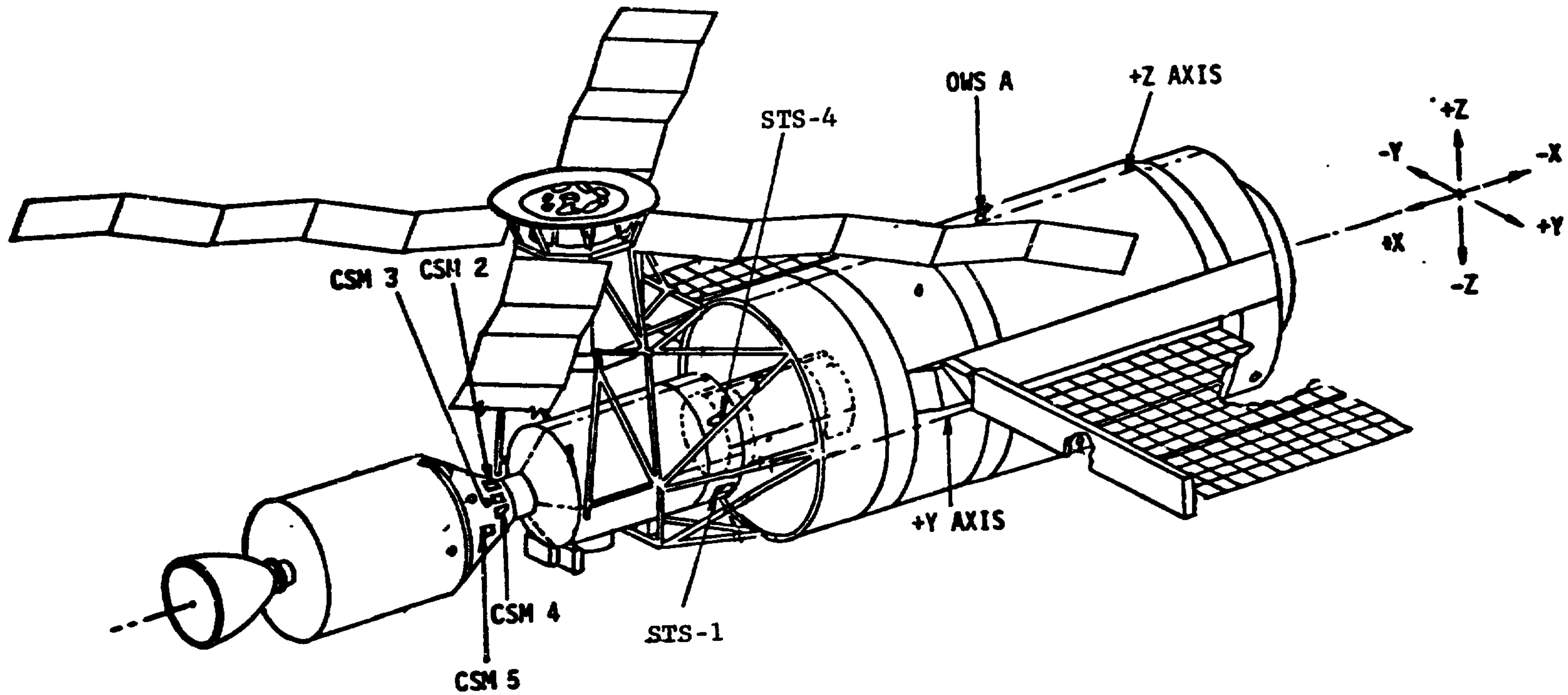

Figure 1.3.4-1 OA Window Locations

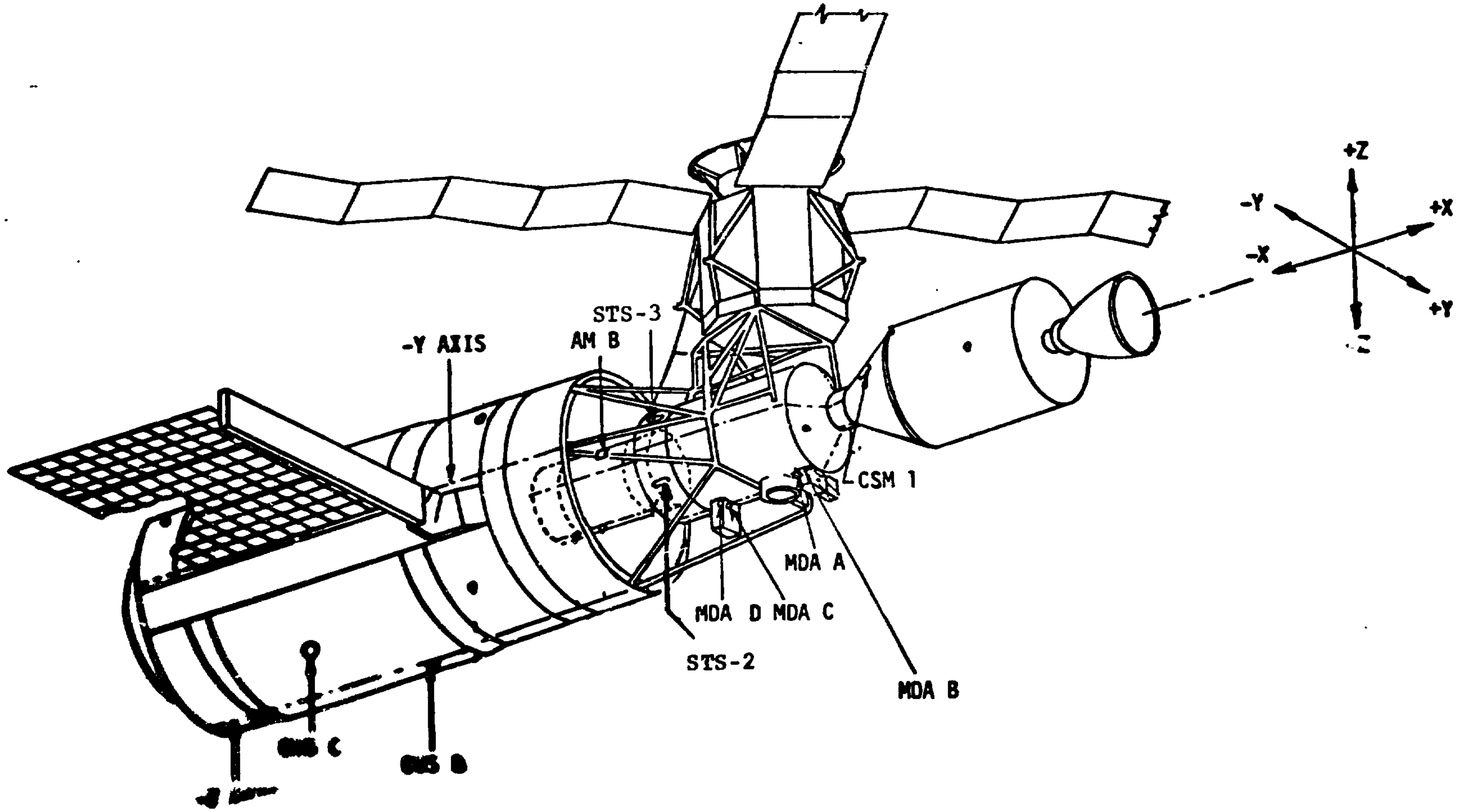

Figure 1.3.4-2 C.\ Window Locations

by one of the astronauts or a piece of equipment being handled by them. These smudges were removed using Zephiran wipes. The inner surface, although reported as visually clean during SL-4, was cleaned using the optical cleaning kit. The heater and covers for this window appear to be quite effective in preventing condensation on the window surfaces.

1.3.4.2 STS Windows - During the initial inspection made shortly after SL-1/2 activation, the STS windows were reported as very clean. A week later, the crew reported several leafy particles on the exterior surface of STS window 4 and also indicated that particles were present to a lesser degree on the other STS windows. As the missions progressed, more particles appeared. It is suspected that these particles were generated by frictional erosion between the window cover and the thermal insulation surrounding the window. The astronauts reported that these two made contact during window cover opening and closing operations. During SL-1/2, the solar-side window covers were left open, on the average, 6 hours a day, to improve lighting conditions in the STS. As a result of this exposure to widely varying external thermal conditions, cabin atmosphere repeatedly condensed on the innermost surfaces during orbit nighttime and evaporated during orbit daytime. Because biological byproducts and other organic contaminants were present in the cabin atmosphere, each of these cycles left more residue on the window surfaces and they eventually required periodic cleaning.

On SL-1/2 DOY 158, covers of windows 2 and 3 were opened to permit the third crewman to observe the EVA operations to free the OWS solar wing. During these operations, one of the astronauts inadvertently placed his boot sole against window number 2. This action left a bootprint on the window which remained throughout subsequent missions. The anti-solar windows showed periodic condensation on the inner surfaces when the covers were left open, which would clear up when the covers were closed. Closing the covers stopped the heat loss to space from the panes and permitted them to attain cabin temperature. Condensation residue and contact contamination on the inner surface of STS windows were cleaned off using water and Zephiran wipes. The crew indicated that this was a very effective cleaning technique. Figure 1.3.4.2-1 and 2 are photographs taken on SL-3 of STS windows 2 and 3, the most contaminated and least contaminated of the four. Nearly all the contamination to be seen is on the exterior surfaces as the photographs were taken shortly after the inner surfaces had been cleaned.

During SL-3, STS window covers were opened for a maximum of only one hour per day for each window. This crew preferred the

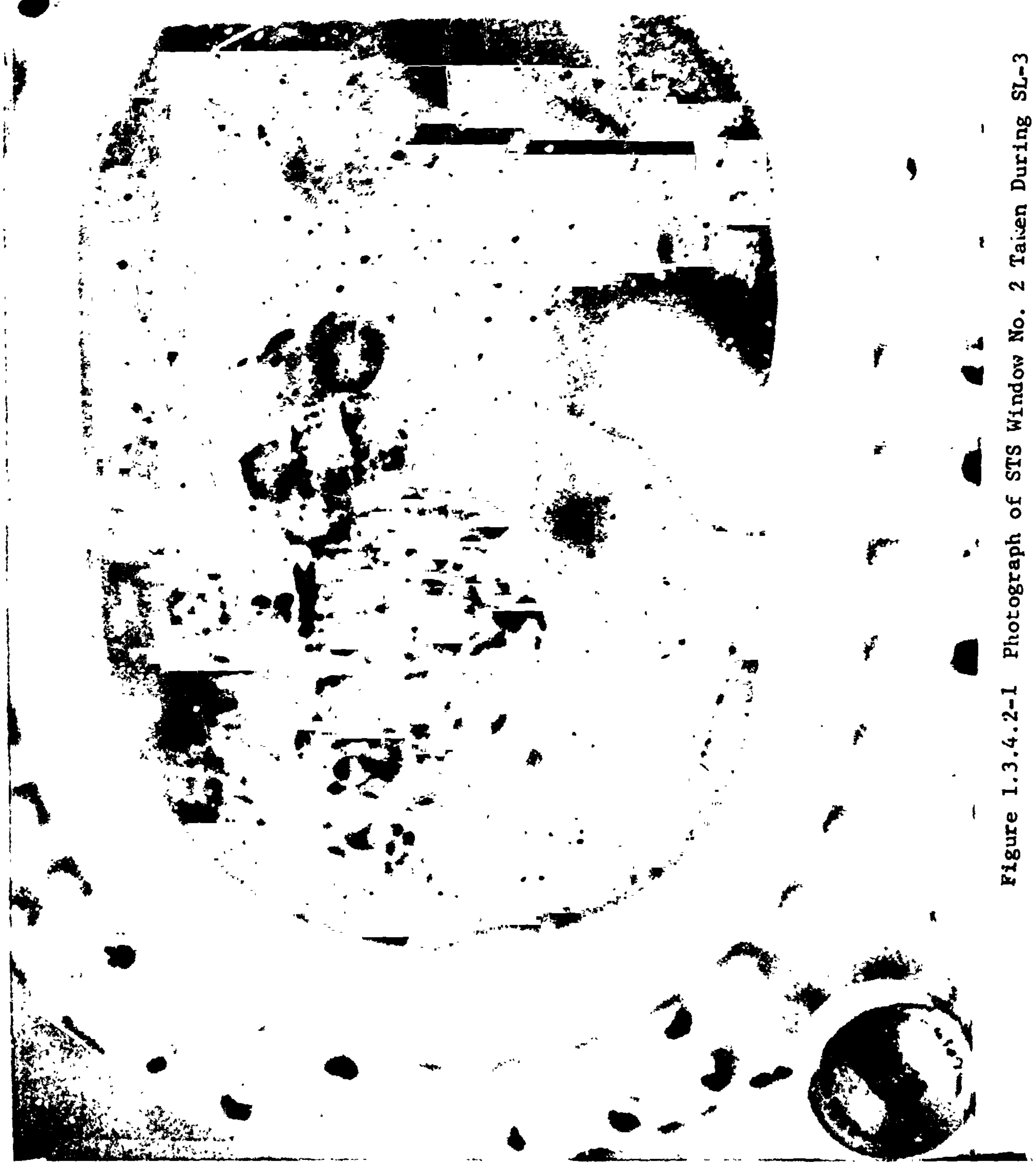

Figure 1.3.4.2-1 Photograph of STS Window No. 2 Taken During SL-3

Figure 1.3.4.2-2 Photograph of STS Window No. 3 Taken During SL-3

covers closed for better observation of the ATM console TV presentations. This shorter exposure to external thermal conditions also reduced the amount of condensation occurring on the inner surfaces. During SL-4, usage was such that the inner surfaces required cleaning approximately every three weeks.

1.3.4.3 Wardroom Window - When the Wardroom window was first activated, the crew reported a small ice particle about the size of a dime in the center of the inner surface of the outer pane. A more critical inspection later revealed an oily appearing film on the outer surface with streaks running across it in an aft direction. It is thought that both of these affects resulted from conditions existing on the pad prior to launch. As the mission progressed the ice spot alternately melted and refroze as the window heater was cycled on and off and also as the effects of earth albedo increased and decreased. It eventually spread to nearly 4 inches in diameter. The volume between the panes was evacuated and refilled with dry air through the SAL dessicators, approximately every two weeks on SL-3 and every 3 weeks on SL-4, but the spot and internal streaking never completely disappeared. Crew reports indicated that the vent from between the panes to the cabin apparently leaked and permitted cabin atmosphere to reenter after evacuation process. This was evidenced by condensation streaks running from the vent orifice toward the center of the window. Even immediately after complete evacuation and dry air filling some solid residue remained. These conditions resulted in some difficulty with operational photography through the window.

This window was used extensively for general viewing, photography, and television. Those operations resulted in condensation of the crew's breath on the inner surface along with hand, nose, and camera prints. When the heater was turned off, cabin atmosphere often condensed on the inner surface. This surface was repeatedly cleaned with dry Zephiran wipes. Television pictures taken through the window during SL-1/2 revealed particles which the astronauts reported as being on the outermost surface. Those particles are thought to have evolved from paint and insulation scraped loose, during the Meteoroid Shield accidental removal and from the subsequent solar array deployment, which adhered to the outer surface. Figure 1.3.4.3-1 is a photograph of the window taken during SL-3 showing the central ice mass, streaking from the vent, and various particles clinging to the outer surface.

1.3.4.4 CSM Windows - Condensation occurred sporadically on the inner surface of the CSM windows; especially, during SL-4, on the right side window farthest from the Sun line when docked. These

Figure 1.3.4.3-1 Photograph of Wardroom Window Taken During SL-3

windows have no exterior covers and, because of the low heat absorption characteristics of the relatively clean glass, they remained cooler than most of the other spacecraft inner surfaces. This condition encouraged condensation of cabin atmosphere on their surfaces when not in direct sunlight. During SL-4 rendezvous operations, the crew commander reported that the crew, including himself, could hardly take their eyes away from the windows and there were nose smears all over them from repeated physical contact. However, no observational difficulties were reported as a result of these smears. During SL-4 undocking, the crew noticed that all CSM windows had visible deposits on the external surfaces. Window number 1 had a fairly smooth layer over its entire surface while window number 2 was streaked with definite lines as if shielded in some areas from the contaminant source. After SL-4 splashdown, the crew say some of these surface films wrinkle up, tear loose, and wash away in the ocean due to wave action.

Analysis was being conducted on samples of this film at the time this report was published. Results thus far indicate that the film was a silicon material whose thickness was approximately 1.7 microns. It is noted that the SL-4 preflight math model deposition prediction for film thickness on this CSM window was 1.5 microns. For information concerning the final results of this investigation, Mr. Charles Davis of MSFC S&E should be contacted.

1.4 THERMAL CONTROL SURFACES

1.4.1 General Discussion - Nearly all external surfaces of Skylab were coated with selected materials to help control both the internal and external temperatures. All temperatures have remained within nominal expected ranges considering exposure conditions. Principal Cluster outer surfaces, such as those of the ATM, AM radiator, and the OWS aft skirt were monitored for degradation resulting from contaminant deposition by measuring longterm temperature changes and evaluating the changes in their solar absorptivity and infrared emissivity characteristics. Analysis of OWS Meteoroid Shield thermal characteristics were eliminated with the loss of the shield and its associated temperature transducers. As a backup process, the astronauts were requested to report on the appearance of and photograph the various surfaces during rendezvous, EVA, and separation operations.

In order to separate the effects of contamination from those of high energy radiation damage, it was necessary to compare the degradation effects on areas having similar surface material and radiation exposure but different contaminant exposure due to location (i.e., being different distances from sources such as vents and outgassing surfaces and being shielded or unshielded from line-of-sight to these sources). Furthermore, astronaut observations and photographs could identify recognizable contaminant deposition patterns.

During the progress of the three missions, various white surfaces on the Cluster slowly darkened turning yellow, then tan, and finally, in some locations, dark brown. Most of this discoloration was in areas exposed to direct solar radiation and can be attributed in part to radiation damage to the S13G paint. According to the findings of the D024 P.I. and other supportive analysis, certain elements of this paint appear to have outgassed and recondensed on other surfaces which were bare or used different paint such as Z-93 which, in time, also darkened under the effects of radiation. Darkening in three areas of the Cluster can definitely be attributed to contaminant deposits. One of these areas is on the aft side of the ATM and the under side of the ATM solar panels near the EVA quadrant. These areas are not subjected to direct solar radiation. The EVA quadrant is a heavy effluent emitter and its emissions are directed toward the affected areas. See Skylab Contamination Sources Report, ED-2002-879, Volume I, for a listing of the many materials located within the OWS forward dome area. Also, during the first SL-4 EVA, the SPT reported discolorations on the OWS outer gold skin that were not uniform along lines having equal radiation exposure. This gold coated plastic film was left exposed when the Meteoroid Shield was torn off and, in the present configuration, two strips running longitudinally along the solar side of the Workshop Y-axis lines (parallel to the X-axis) are still unshaded by the crew deployed Sun shields. The color variations along these strips are indicative of varying thicknesses of deposition. The third area is on the OWS aft skirt and Solar Array beam fairing. In no case though have the deposits or radiation damage appeared to cause adverse thermal conditions in the Skylab cabin or any of the exterior components.

1.4.2 S-IVB Stage Thermal Surfaces

a. Refrigeration System Radiator - Very early in the flight, the radiator ran somewhat hotter than predicted. This was eventually attributed to the high temperature conditions existing in the Workshop following the loss of the Meteoroid Shield and prior to deploying the umbrella type Sun shade. Shortly after the SL-1/2 mission, the radiator was operating at predicted conditions for the particular flowrates, orbital conditions, etc. The radiator continued to operate nominally for the given conditions for the remaining mission phases.

b. Aft Skirt - Based upon temperature of electronics mounted to the interior of the Workshop aft skirt, it is thought that substantial degradation of the S13G on the skirt exterior has occurred. It is estimated from thermal analyses performed by the Skylab thermal group, that the solar absorptivity changed from between 0.21 and 0.25 to about 0.38 during SL-1/2. This change is thought to be due to firing of the solid propellant retro motors on the S-II stage during vehicle staging. Photographs of the Workshop aft surfaces obtained during SL-3 separation fly-around show a grey coating on areas of the aft skirt, with a white "shadow" where it was covered by the SAS beam fairing during boost. This color is what can be expected of the Al_2O_3 by-product of the solid propellant retro-motors of the S-II stage.

c. Sun Shades - The first "umbrella" deployed to alleviate the effects of the missing meteoroid shield was an orange color and was reported, via crew transcriptions, to have faded under the intense solar radiation. The second sun-shade was painted with S13G white paint and this paint, according to crew comments and photographs, has darkened in all areas exposed to solar radiation. It is still effective as a Sun shield though and no observations have indicated that contaminant depositions have occurred. The discoloration appears to be due mostly to solar radiation damage because it varies only where wrinkles and folds vary the solar exposure.

d. Pressure Vessel Thermal Control Film - Loss of the Meteoroid Shield and subsequent deployment of the sun shades left longitudinal strips of the gold coated Kapton film covering the OWS pressure vessel exposed to solar radiation. These areas run along the solar side of the Workshop Y-axis lines (parallel to the X-axis). The temperature of these areas attained temperatures warmer than 60°F on Fin* two and warmer than 95°F on Fin four. As a result, they are cooler and permit condensation of exhaust and vented products and those outgassed from hotter surfaces such as the back side of the ATM solar arrays which were typically 170°F maximum. On the first SL-4 EVA, the SPT reported discolorations along these unshaded areas that varied in color along lines having equal solar exposure. Transcriptions of astronaut comments indicate that these discolorations varied between green, yellow, and red as if either a deposit thickness had varied, causing interference filter effects, or varying degrees of chemical reaction had taken place. Solar radiation on this longitudinal strip would have had an equal effect along its entire length, but according to crew observations, this is not the case. It is suspected that the varying discoloration is the result of effluent deposition from the S-II stage separation rockets, the SM RCS thrusters during the early Meteoroid Shield damage inspection and outgassing from hotter surfaces.

* Refers to Saturn V stage I Fin orientation

1.4.3 ATM Surfaces - Areas of the ATM show definite discoloration patterns on surfaces not directly exposed to solar radiation and, therefore, the result of contaminant deposits. These areas are facing the EVA quadrant surrounding the Airlock and this quadrant is a relatively heavy effluent emitter, directing its emissions toward the affected areas. Most of the outgassing and leakage from the OWS forward dome, EVA hatch area, forward skirt, IU, and AM is directed out this quadrant. During EVA, the Airlock section of the AM is vented through this quadrant and outgassing from equipment located within the Airlock follows. Figures 1.4.3-1, taken after SL-1/2 and 1.4.3-2, taken after SL-3, illustrate the resulting discoloration pattern and its progressive darkening. The discoloration is quite pronounced in color photos but much of the contrast is lost in a black and white presentation. Thermal measurements plotted during the Skylab operations by the Contamination Mission Support Group indicate a gradual temperature rise in the areas exposed to these emissions. (See Figures 1.4.3-3 and 4.) These changes could also be influenced by parasol degradation and subsequent reflection changes and changes in the solar adsorbtivity and emissivity characteristics. This trend is not exhibited by measurements from shaded surfaces on the opposite side of the ATM that do not have line-of-sight exposure to the EVA quadrant. The solar exposed surface of the ATM Sun Shield (S13G paint) exhibited significant radiation degradation. Thermal analyses indicate that the absorptivity changed from an initial value of approximately 0.2 to a value between 0.46 and 0.57 at the end of SL-4. For further details see the report of the ATM Thermal Control System Mission Support Group. However, the degraded surfaces and resultant temperature rises have not been sufficient to compromise operations and all temperatures have remained well within tolerance limits.

1.4.4 Airlock Module Radiator - Slight degradation of the Z-93 coating on the Airlock Module radiator exposed to solar radiation and the EVA quadrant is thought to have occurred. The verage value of solar absorptivity around the entire radiator was approximately 0.22 after the first manned Skylab mission and approximately 0.28 after the first half of SL-4 (as determined from radiator thermal analysis). The original value was approximately 0.14. The degradation was initially thought to be due mainly to ultraviolet radiation damage to the Z-93 paint only, but the discoloration pattern shown in Figure 1.4.3-2 indicates that it could also be due to contamination and interaction between a contaminant and solar ultraviolet.

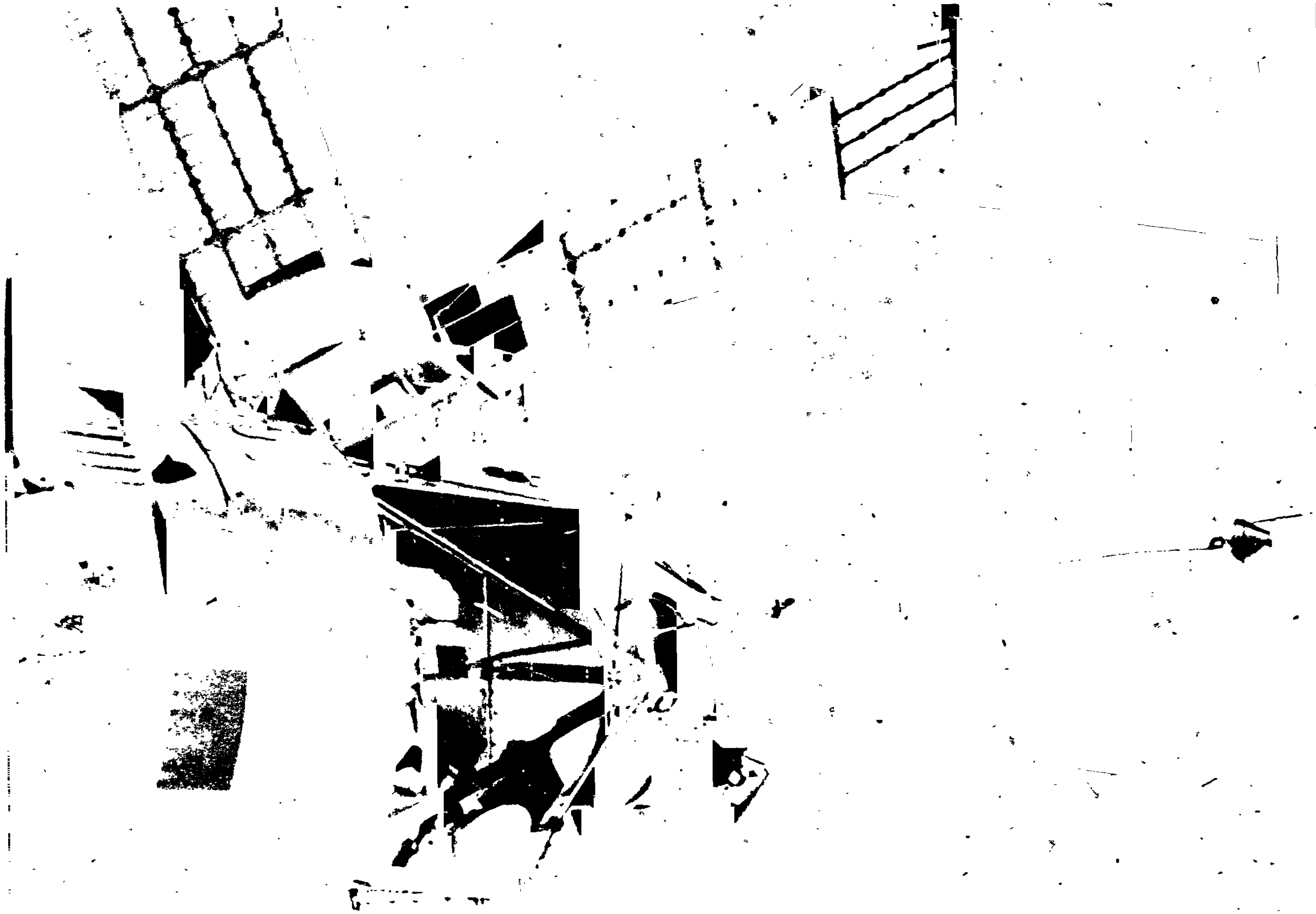

Figure 1.4.3-1 ATM and AM/MDA Surface Discoloration, Forward of EVA Quadrant, Photographed at the beginning of SL-1/2

Figure 1.4.3-2 ATM and AM/MDA Surface Discoloration, Forward of EVA Quadrant, Photographed at end of SL-3

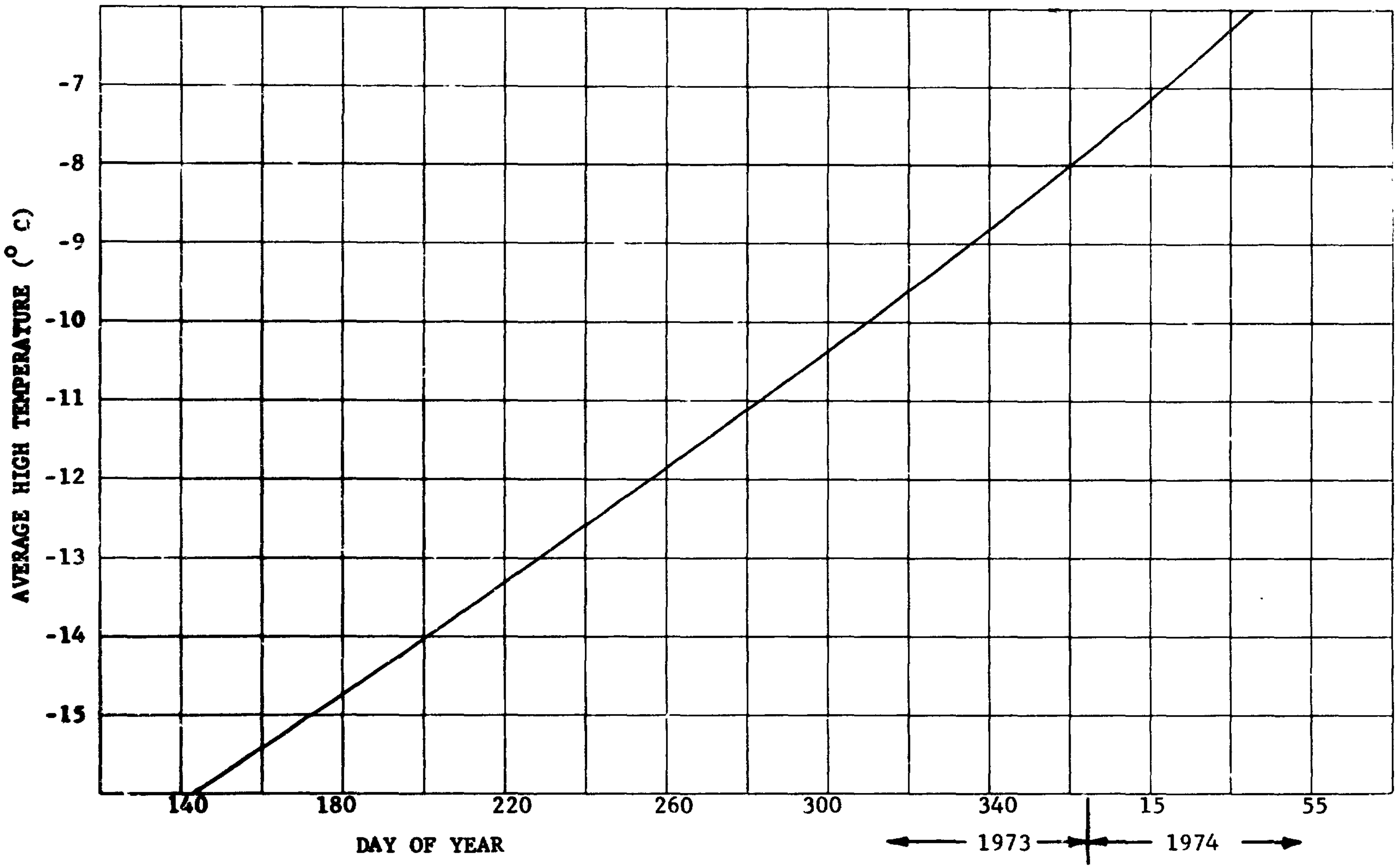

Figure 1.4.3-3 Variation in Average High Temperature of ATM Canister Cover, MDA End, On Side Exposed to EVA Quadrant Emissions - Measurement No. C0454

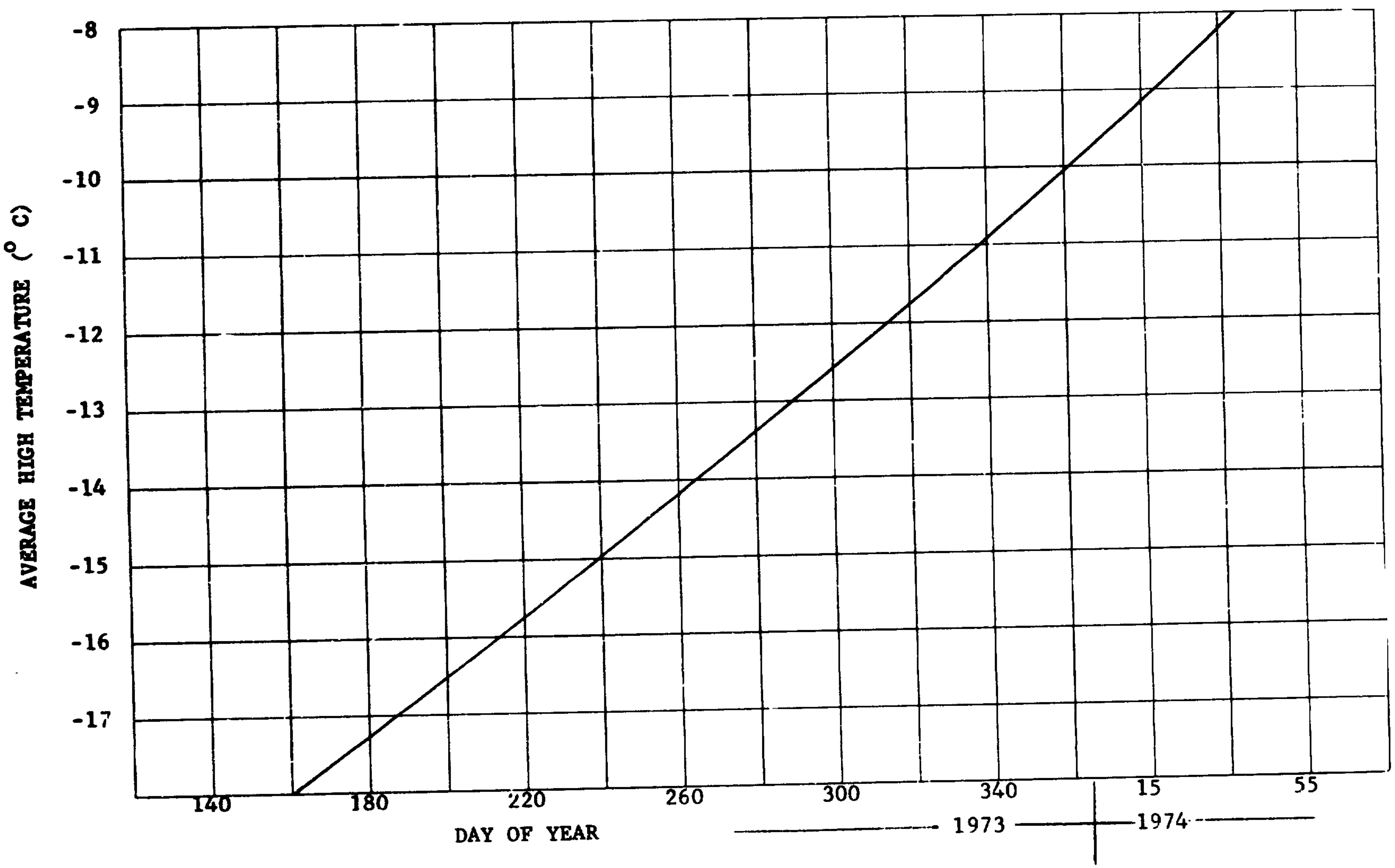

Figure 1.4.3-4 Variation in Average High Temperature of Location on ATM Solar Array Ring Exposed to EVA Quadrant Emissions - Measurement No. C0344

1.4.5 Thermal Surface Data Correlation - Results from the D024 Thermal Control Coatings and Polymeric Films Experiment Principal Investigator analyses have shown an effect which has been considered the result of contamination plus radiation damage. This experiment is positioned on the OWS forward dome taper adjacent to the EVA quadrant. This location is basically in the area of the Airlock Module Radiators. The D024 Experiment and samples face such that the thermal control samples are solar oriented and the polymeric films are facing normal to the OWS forward dome taper but facing essentially solar.

Through samples returned from SL-1/2, it was established by the D024 P.I. that the thermal control samples had a contaminant coating composed primarily of silicates and hydrocarbons. These products are characteristic of S13G outgassing, coolanol, and RCS exhaust. The contaminant thickness was assessed to be approximately 700 to 2450 Å thick. The contaminants appear as a tan or brownish color and this coloration characteristic was consistent among the different types of thermal control samples, such as S13G and Z-93, and reflecting surfaces such as aluminum, gold, and the anodized, experiment pallet surfaces.

The main intent of this experiment was to establish the solar degradation of the exposed samples. However, currently the D024 P.I. feels that the described contaminant effect has masked any attempt to establish the solar radiation degradation of his samples. This is not to say that the brownish or tan appearance of all the samples is due to contamination only but could be due to an interaction between the contaminants and high energy solar radiation.

Measurements by the D024 P.I. of solar absorptivity on selected thermal control paints returned after SL-1/2 indicated a change of about 0.076 to 0.088 for S13G, and approximately 0.071 for Z-93 paint during the SL-1/2 mission only. Samples returned after SL-3, having been exposed for 132 days, exhibit changes in solar absorptivity of from 0.242 to 0.251 for S13G paint and approximately 0.182 for Z-93.

Changes in solar absorptivity of S13G, calculated by the Thermal Control Mission Support Group, on the solar side of the ATM Sun Shield are somewhat less. The change at that location was 0.044 at the end of SL-1/2, 0.16 at the end of SL-3, and 0.27 to 0.37 at the end of SL-4. The reasons for these differences are various and debatable. S13G paint manufactured by different organizations can be slightly different according to which sources supplied the basic constituents and to the environmental history of the paint from the time the paint was made up until its exposure in orbit. The D024 samples were located where they were subject to possible deposition from outgassing, leakage, venting, and RCS exhaust products, whereas, the solar side of the Sun Shield is shielded from line-of-sight to these sources. Finally, the D024 sample absorptivities were measured directly whereas the Sun Shield values were calculated using particular assumptions.

1.5 SOLAR ARRAY SYSTEMS/STAR TRACKER

1.5.1 General Discussion - Neither of the Skylab Solar Array Systems has shown any significant electrical degradation that can be attributed to contamination. Panel temperatures were monitored, as well as power output, because of the effect of temperature on power output and because temperature might prove to be a more sensitive indicator of contamination degradation. Of the four ATM panel temperatures plotted and analyzed throughout all the missions, two panels show a gradual increase in average orbital sunrise temperature. These two panels are in the area affected by emissions from the AM EVA quadrant. However, the average increase of these temperatures was only six to seven degrees and therefore did not significantly affect thermal control or power output.

1.5.2 OWS Solar Array System - Evaluation of the Solar Array Systems were based on the premise that radiation degradation would be equal over the entire surface, but because of the size of the arrays, contaminant deposits would vary with distance from contaminant sources. Also, some array surfaces would be shielded from emission sources. Anti-solar surfaces would not be affected by direct solar radiation but could collect contaminant deposits which could change thermal characteristics of the array. This change in the thermal characteristics over a long time period could cause performance degradation.

Analysis of the contribution of contaminant deposits to degradation was based on comparing the amount of variation occurring at widely separated locations. Also, comparisons were made of temperature variations occurring during the low contaminant emissive unmanned periods with these occurring during manned periods. Other degradation effects should be fairly constant during these two periods. Such comparisons should indicate the presence and magnitude of the contribution of contamination to power variation trends. However, temperature variation trends were so small and gradual that only a full mission trend can be discerned and this only on some panels.

The various solar cell modules making up each OWS SAS group are intermixed spatially on the solar array wing so that comparison of telemetered data from separated locations is not practical except in a very general fashion. Modules 1 through 4 are, on the average, located nearer the OWS skin; whereas, modules 5 through 8 are located farther from the OWS skin. Temperature transducers are not associated with any complete group because of the intermixing of modules. Since the deposition model predictions indicate higher deposition rates on those modules closer to the OWS and consequently larger possible power degradation, the telemetered power and temperature variations of the 1 through 4 groups were compared with those of the 5 through 8 groups using inflight data.

At present there has not been sufficient long term analysis performed on the various OWS Solar Array modules, power and temperature characteristics to determine whether there have been contaminant deposit effects. However, if any effect is noted it should be very small.

1.5.3 ATM Solar Array System - Four ATM panels were selected for contamination analysis. These panels were: 710A5, 711A3, 712A3, and 713A3 feeding CBRMs 18, 7, 10, and 2, respectively. Figure 1.5.3-1 shows their locations. These panels were selected because continuous data were available from them and they were sufficiently widely located, one on each wing, to indicate the spatial effects of contamination if it occurred to a detectable extent. Daily average maximum power output from each panel was computed and plotted to determine trends and possible degradation that could be attributed to contamination. Average orbital sunrise temperatures were determined for the same periods during which the power was averaged.

Results of the power plot analyses indicate no appreciable power degradation trends. Actually, what is indicated is the orbital sunrise power demand or, more properly perhaps, the depth of battery discharge during the preceding shadow period. This condition results from the fact that the panels were seldom called upon to supply the maximum of which they were capable; at least, not during the first six minutes of orbital sunrise. Two of the panels, 711A3 and 712A3 show trends indicating a slight degradation of thermal characteristics. These two panels are on the side affected by the AM EVA quadrant emissions (see Figure 1.4.3-2). This trend might be interpreted as resulting from the increasing solar intensity during the majority of the mission (see Figure 1.5.3-2) if it were not for the fact that the other two panels do not show the trend and the trend continues after the solar intensity starts decreasing. These trends are shown in Figure 1.5.3-3. The curves represent the temperature of the Solar Array backside averaged over the first 5½ minutes of solar exposure after leaving the Earth's shadow and during the early period of heavy battery charge. The curves have been smoothed to remove the effects of Sun angle variations and retain only the gradual temperature rise. However, the small thermal characteristic degradation, which could be the result of contaminant influence upon the thermal control surfaces of the panel backsides, does not appear to have affected the capability of the panels to meet power demands.

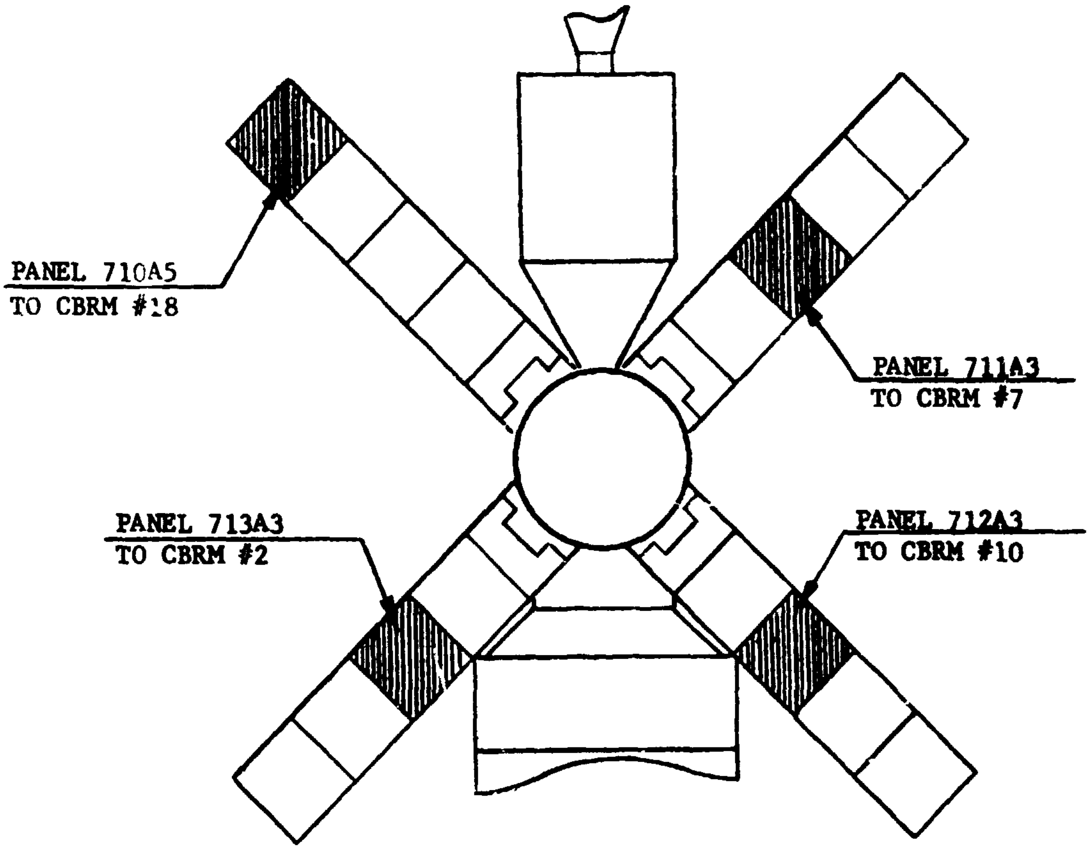

Figure 1.5.3-1 **Location of ATM Solar Array Panels Monitored.**

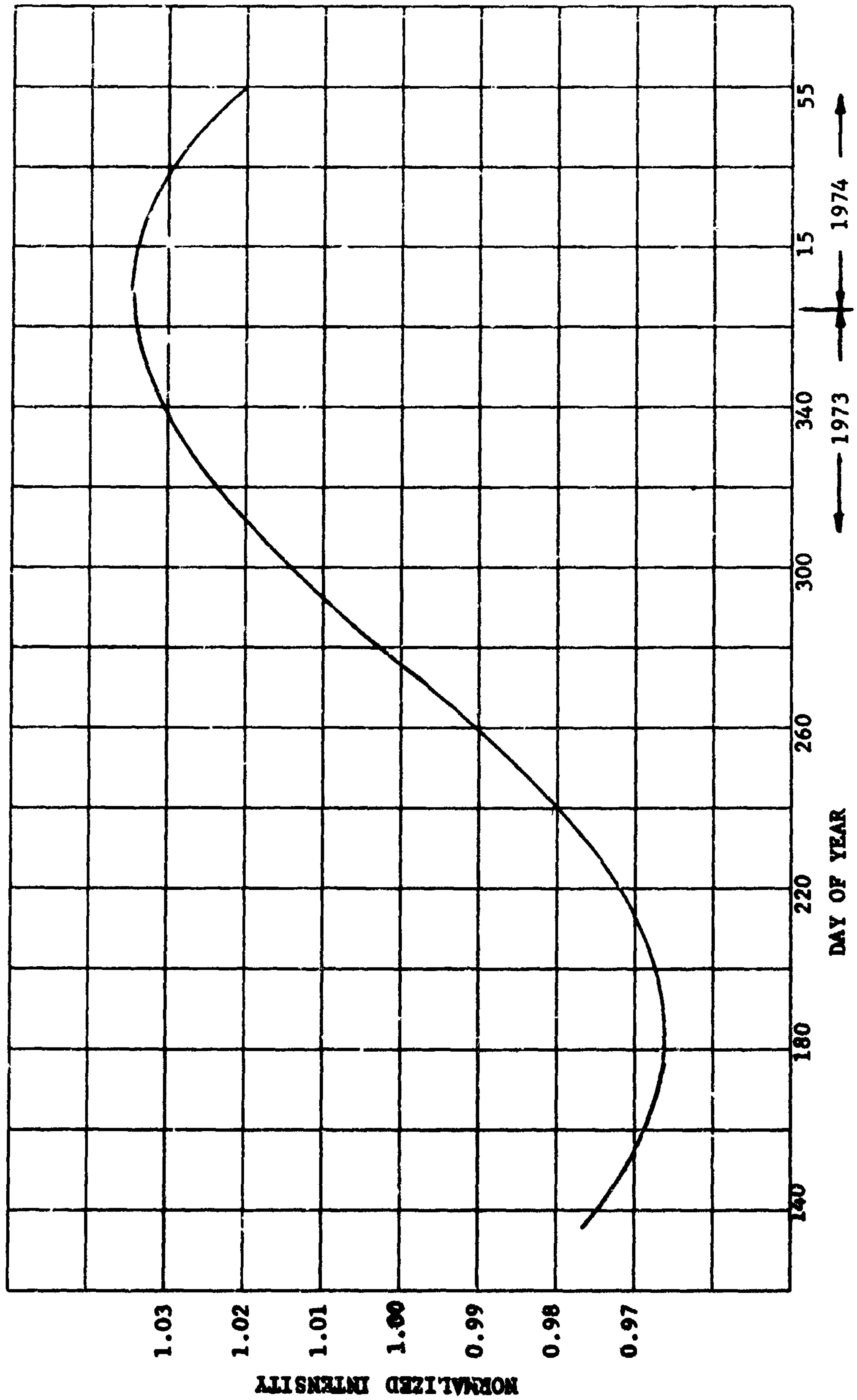

Figure 1.5.3-2 Solar Intensity Variation During Skylab Mission

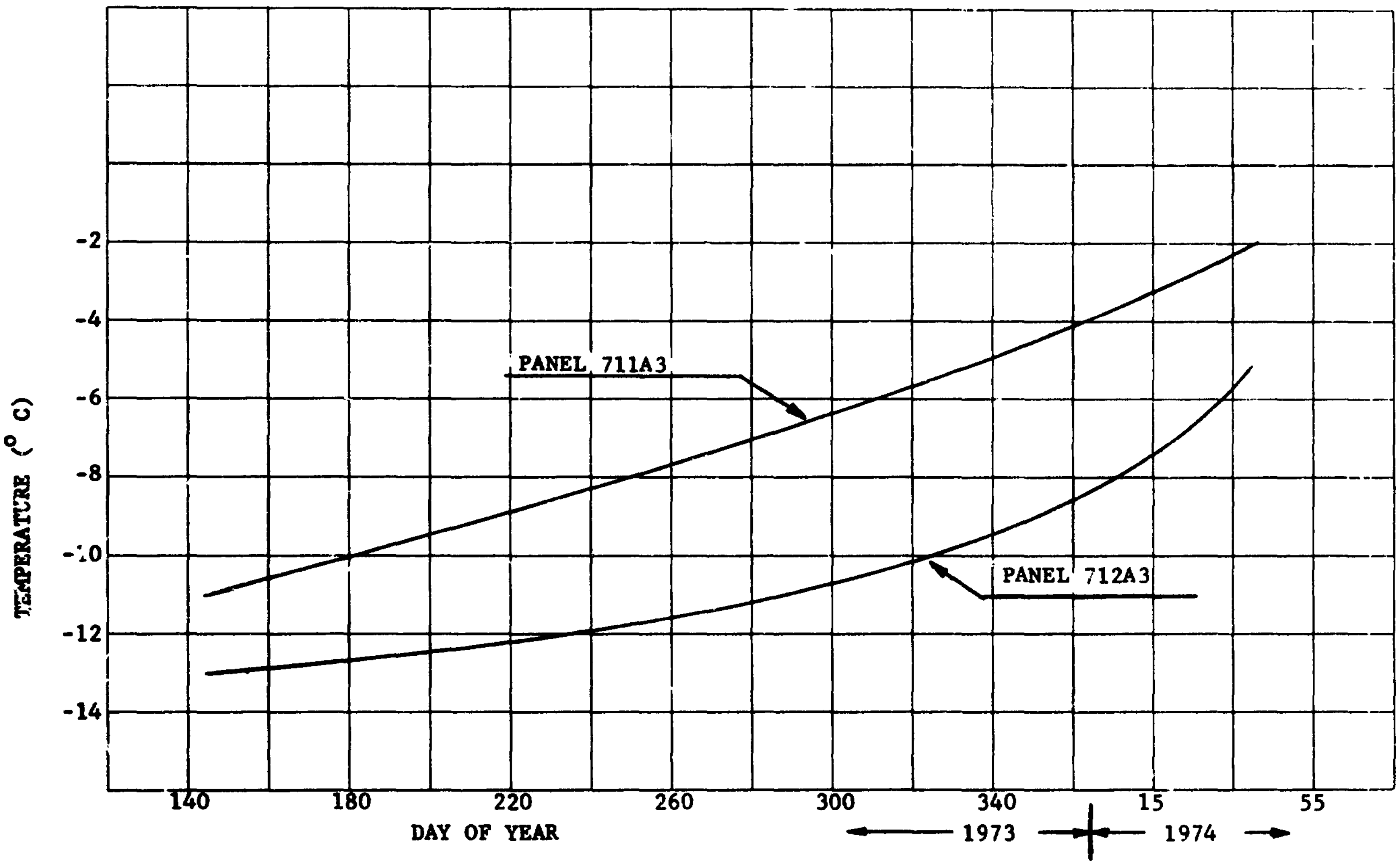

Figure 1.5.3-3 Variation in Average Dawn Temperature of Solar Arrays Exposed to EVA Quadrant Emissions

1.5.4 Star Tracker - During the first Skylab manned mission, (SL-1/2), Star Tracker anomalies were of concern to the program. There were far fewer Star Tracker anomalies on SL-3 and none on SL-4 although on DOY 361 (during SL-4) the Star Tracker failed. Basically, this reduction in and subsequent absence of anomalies was due to the tracking of brighter target stars and a change in Star Tracker operational procedures introduced at the start of the SL-3 manned mission. To ascertain the degree of which contamination contributed to these observed anomalies during SL-1/2 and SL-3, a listing of all Star Tracker anomalies has been compiled and time correlated to potential sources of contamination. Based on observing Star Tracker gimbal rates, approximately thirty-nine Star Tracker anomalies were detected. Of this total, 35 were seen during SL-1/2, four were observed on SL-3, and none observed on SL-4. Based upon the aerodynamic drag influence of the ambient atmosphere on particles and Star Tracker gimbal rate evaluation, eleven of these anomalies have been established as probably being caused by tracking contaminant particles. Of these eleven, nine were observed on SL-1/2 and two on SL-3. The remaining 28 Star Tracker anomalies cannot be analyzed due to the lack of Star Tracker tracking data for those periods of recorded anomalies. Table 1.5.4-I presents a Star Tracker anomaly list indicating occurrence time, possible contamination source event correlation, and particulate possibility.

TABLE 1.5.4-I SL-1/2 & 3 Star Tracker Contamination Related Anomaly List

Anomaly Occurrence Time DOY GMT	Possible Contaminant Source Event Correlation	Potential Particle Tracking (Based on High ST Gimbal Rates)	Probable Particle Tracking (Based on High ST Gimbal Rates & Aero Drag Correlation
152/00:41	AM Primary Coolant 100 P Inverter on	X	
154/02:27	AM Primary Coolant 100 P Inverter on	X	
154/02:27	Squeezer Bag Dump	X	
154/04:01	TAL Dump Terminated	X	
154/04:22	Orbital Sunset	X	
156/16:25	None		X
157/00:19	Pre-sleep Activities	X	

TABLE 1.5.4-I (Continued)

Anomaly Occurrence Time DOY GMT	Possible Contaminant Source Event Correlation	Potential Particle Tracking (Based on High ST Gimbal Rates)	Probable Particle Tracking (Based on High ST Gimbal Rates & Aero Drag Correlation
157/03:18	Pre-sleep Activities	X	
157/03:27	Pre-sleep Activities	X	
157/21:45	Pre-sleep Activities	X	
157/22:02	S055 Door Opened		X
157/23:36	S055 Door Closed	X	
158/01:17	None	X	
158/04:47	None	X	
159/19:02	None	X	
159/22:18	M171 Vent	X	
161/13:12	TACS Firing (69 MIBS of TACS Used This Orbit)		X
162/03:28	None	X	
164/00:21	Pre-sleep	X	
164/17:01	M553, M131		X
164/18:34	TAL Vent, M131	X	
165/16:21	H_2 Fuel Cell Purge	X	
165/19:22	M092 Vent @ 19:15, H_2 Fuel Cell Purge		X
166/18:41	M131, H_2 Fuel Cell Purge		X
166/19:62	H_2 Fuel Cell Purge		X
167/21:05	Condensate Holding Tank Evacuated Through SAL	X	
169/13:26	M092 Vent	X	
169/18:05	None		X
169/21:15	Pre-sleep	X	
170/15:48	None		X
171/01:44	None	X	
171/10:42	AMS Out of SAL	X	
171/14:08	TAL Vent	X	
171/15:04	Physical Training	X	
171/16:41	Deactivation of Medical Experiments	X	
171/23:26	None	X	
215/18:00	ETC, TAL Vent	X	
220/12:52	TAL Vent		X
222/12:46	TAL Vent		X
227/14:10	M092 Vent, S190 Dessicant Bakeout	X	
275	No Further Anomalies Observed		

Available data from the Mission Operation Planning System (MOPS) and Data Books were utilized to confirm the time of anomalies and to provide star presence and gimbal position histories. The Star Tracker anomalies were time correlated with the As-Flown Flight Plans and the Mission Events Lists. These correlations were not established as the specific source of the particles except in a few cases. However, a number of correlations with the same event may indicate a possible source of contamination.

The Star Tracker would lose acquisition of the target star and lock onto a particle if the particle was in the Star Tracker field-of-view and if the apparent magnitude of the particle was brighter than the Star Tracker minimum threshold (the Star Tracker minimum threshold was preset at a magnitude of 1.16 which is one-half magnitude below the dimmest target star, Alpha Crux). Signals dimmer than this would be rejected by the Automatic Gain Control in the video amplifier. The higher threshold determined by the Automatic Gain Control when tracking a brighter star would therefore provide for fewer anomalies. This was substantiated during SL-3 by the reduction in the number of anomalies when tracking the brighter target stars Canopus and Rigil Kent and the increase in anomaly occurrences when tracking the dimmer target star Achernar.

In addition to tracking brighter stars during SL-3, two changes in Star Tracker operational procedures were implemented during SL-3 to minimize the impact on the crew timeline in responding to Star Tracker anomalies. First, vehicle attitude (NU Z) updating was inhibited except when needed. The second change involved closing the Star Tracker shutter except for the 10 second intervals needed for (NU Z) updating. The closed shutter assured that the Star Tracker would not be exposed to any contamination or high level light sources which could saturate the phototube. These changes were implemented on DOY 220 and DOY 239, respectively. Since the length of time in the tracking mode was cut from approximately 12 hours a day to only minutes a day, the anomalies were all but eliminated as a result of these operational changes. Only three probable contamination related anomalies were observed between DOY 220 and 227 and no contamination related Star Tracker anomalies have been observed since DOY 227. This is not to say that no particles were present during these periods and subsequently through the remaining portion of the mission. The probability of acquiring any particles was drastically reduced through these operational changes. In fact, crew comments concerning observing particles during SL-4 were as frequent as during SL-1/2 and SL-3.

During SL-3, degradation of Star Tracker threshold sensitivity was observed when the crew was unable to acquire the star Alpha Crux. The Star Tracker threshold was initially set at one-half magnitude dimmer than Alpha Crux. The crew were able to acquire Achernar the next brightest star. The difference in brightness between the initial threshold setting and Achernar was 0.76 magnitude. The Attitude and Pointing Control Mission Support Group believes that the degradation in Star Tracker sensitivity was due to deterioration in the Star Tracker photocathode caused by exposure to the Earth's limb occurring during SL-1/2 anomalous operation. This concurred with deposition math modeling since worst case deposition analyses could not account for this amount of sensitivity degradation.

To differentiate between whether Cluster attitude changes and not contaminant particles were the cause of Star Tracker gimbal position changes, the tracking rates of suspected particles were calculated and compared to the maximum rates attributable to various vehicle attitude changes. It is possible that some Star Tracker anomalies (e.g., DOY 169, 21:15 GMT) were caused by vehicle attitude changes but the majority of analyzed anomalies have tracking rates from 0.09 to 0.74 degree/second which is characteristic of drag influence particles. When compared to the maximum vehicle attitude angular rate of 0.08 degree/second, it appeared that the majority of Star Tracker anomalies exhibited too great an angular velocity to be caused by vehicle attitude changes and were classified as possible particles.

A number of Star Tracker anomalies which occurred on SL-1/2 and SL-3 can be directly attributed to the tracking of contaminant particles associated with specific events on Skylab. The major source of particles seems to be in the general area of the OWS, where blistered paint and loose insulation could have possibly been loosened by molecular venting, TACS firing, OWS Waste Tank NPV pressure flow, and vehicle vibration or the result of slower effects of sun, drag of the ambient atmosphere, and temperature variations.

Venting of cabin atmosphere has been shown to form particles by condensation and transport particles already present in the flow field of the vent. This latter point is also valid for all vent flow fields. This type venting was related to Star Tracker anomalies during M092 and M171 activity. Mechanical activities such as use of the Articulated Mirror System, ATM door operations, or installation of the Earth Terrain Camera could also have generated particles. The influence of the drag of the ambient atmosphere on the curvature of particles trajectories was verified by the curved trajectories observed in the Star Tracker data and is discussed in Section 1.2.3.1 of the Cloud Model update.

Star Tracker gimbal position changes as a result of potential particle tracking are illustrated by a plot on a Star Tracker field-of-view "window" for a specific time of interest for which data was available. Tracking data was not sufficient to determine the exact origin of the particulates, as they were not tracked until they came near the target star vicinity, but certain observations were possible. Figure 1.5.4-1 (DOY 220 @ 12:54) illustrates one of the few anomalies on SL-3 thought to be caused by a particle. A TAL dump terminated 2 minutes prior to this anomaly which added weight to the correlation between increased pressures in the Waste Tank NPV flow field and sightings and or anomalies related to contaminant particles.

In conclusion there are indications that a particulate environment does exist around Skylab and that, in general, this particulate environment is the result of day to day operations and not from any one controllable source. Star Tracker operational procedures which were introduced early in the SL-3 mission nearly eliminated the effect of these contaminants upon Star Tracker operation as evidenced by the absence of Star Tracker anomalies (with the exception of the three early in SL-3).

Legend:

Time Increments: 30 Seconds
Desired Target: Canopus
Suspected Cause of Anomaly: Particle Transported into Field of View @ approximately 12:55

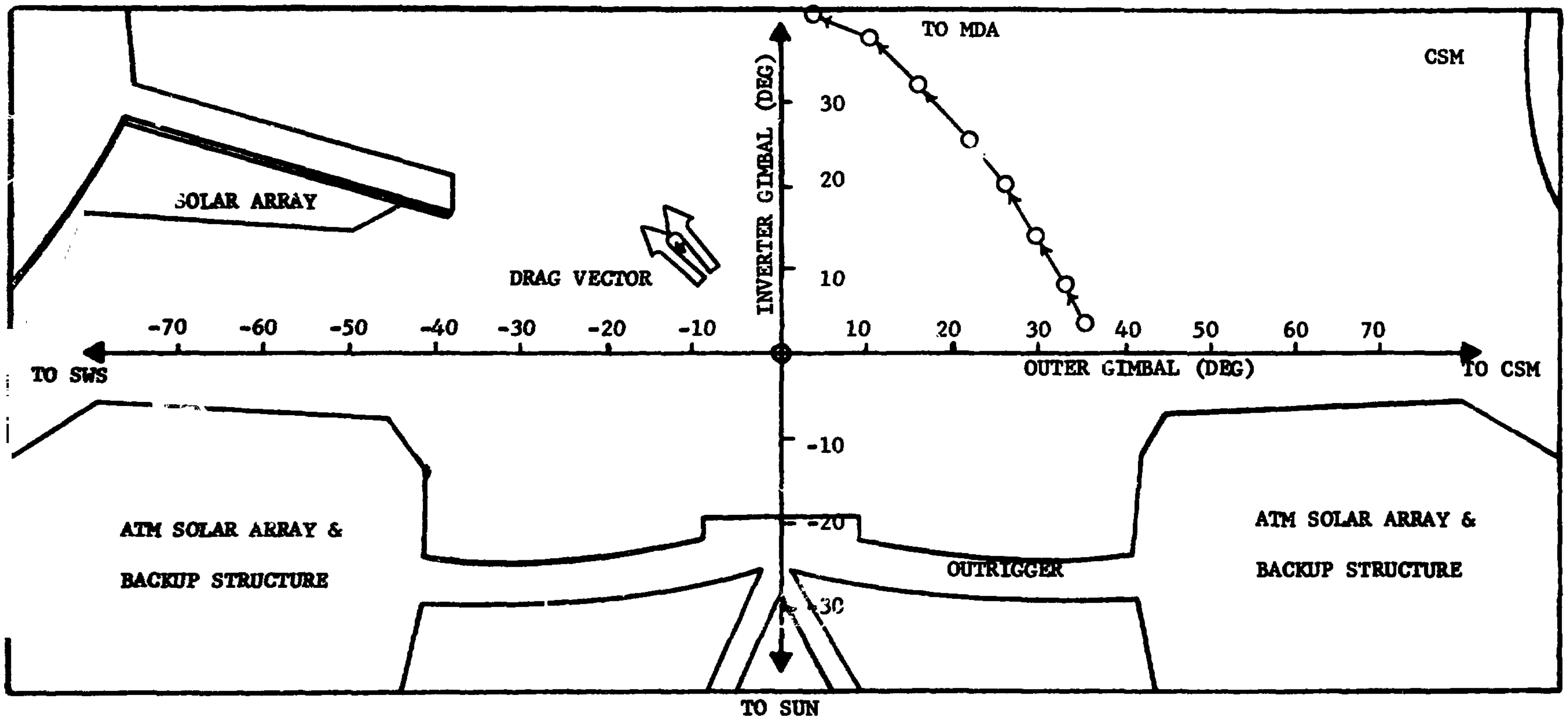

Figure 1.5.4-1 Star Tracker Tracking Data
Start: 220/12:54

1.6 <u>Recommendations</u> - The Skylab program was the first major manned space program that incorporated an intensive contamination control activity. Based on the experiences gained in this control effort, recommendations for what should have been done better on Skylab and what should be done on future spacecraft programs are listed below:

a. <u>Skylab</u>

1) All operational windows should have had exterior covers, i.e., a cover on the Wardroom Window.

2) An effective gas seal should have been incorporated between panes on the Wardroom Window.

3) Covers should have been installed on passive experiments such as D024.

4) A mass spectrometer should have been included that could have been deployed to space to detect contaminants that affect experiments.

b. <u>Future Space Vehicles</u>

1) Develop early in the program a contamination prediction math model. This math model can be used continuously for making spacecraft hardware and design decisions, trade studies, and later as required, for on-orbit operational control and assessment of contamination.

2) Contamination control should be operated as a technical discipline such as structural, electrical, etc. Areas to be considered include:

- design, where the identification of sensitive elements and sources of contaminants are critical and resolutions of design conflicts;

- cleanliness control during component and system fabrications;
- ground handling cleanliness;
- transportation;
- and on orbit activities.

3) Contamination detectors and monitors should be located at strategic positions on space vehicles and be chosen to measure specific contaminants that cause deposition or contribute to the induced environment of the specific vehicle.

4) Incorporate a closed loop EVA system for operational use for manned systems.

1.7 Bibliography - Additional publications pertinent to the Skylab contamination assessment program efforts are delineated below. Copies of these documents are on file in the NASA MSFC repository.

MMC Report No.	Title	Date
ED-2002-1567	Skylab Contamination Prediction Report	Nov. 1972
ED-2002-1567A	(Update)	April 1973
ED-2002-1428	Skylab Surface Effects Empirical Model GSFC Outgassing	Jan. 1972
ED-2002-1359	Topic Report - Tribo - Electric Series Report	Aug. 1971
ED-2002-1370	Topic Report: Trapping Matrix Report	Sept. 1971
ED-2002-1391A	Topic Report: Spacecraft Charging Report (Update)	Jan. 1972
ED-2002-1358	Topic Report: Fluid Venting Problems	Aug. 1971
ED-2002-879-I	Skylab Contamination Sources Analysis	Feb. 1970
ED-2002-879-IA	(Update)	Jan. 1972
ED-2002-879-II	Skylab Contamination Improvement Study	Mar. 1970
ED-2002-1439	(Update)	Feb. 1972
ED-2002-1373	Small Chamber Test Plan	Sept. 1971
ED-2002-1373A	(Update)	Nov. 1971
ED-2002-1369	Ground Base Observations Apollo 14 and Salyut	Sept. 1971
ED-2002-879-V	Miscellaneous Flight Test Plan	Aug. 1971
ED-2002-1386	Topic Report: Test/Parameter Matrix	Oct. 1971
ED-2002-1372	Skylab Cloud Effects Math Model Report	Sept. 1971
ED-2002-1372A	(Update)	Sept. 1972
ED-2002-1440	Skylab Surface Effects Empirical Model Report	Feb. 1972
ED-2002-1440A	(Update)	Sept. 1972

MMC Report No.	Title	Date
ED-2002-1534A	Skylab Design Confirmation	Nov. 1972
ED-2002-1360	Skylab Mission Contamination Evaluation Report - Objectives	Aug. 1971
ED-2002-1360A	(Updates)	Dec. 1971
ED-2002-1360B		Sept. 1972
ED-2002-1360C		Dec. 1972
ED-2002-1572	Skylab Mission Contamination Evaluation Report Operational	Dec. 1972
ED-2002-1701 SL-1/2	Skylab Mission Contamination Evaluation Report - Assessment	Aug. 1973
ED-2002-1701A SL-3	(Updates)	Nov. 1973
ED-2002-1701B SL-4		(May 1974)
ED-2002-1382	SWS Experiment Optical Cleaning Technique Plan Evaluation Report	Oct. 1971
ED-2002-1568A	(Update)	Mar. 1973
ED-2002-1565	Skylab Contamination Mission Support Plan	Nov. 1972
ED-2002-1565A	(Update)	Mar. 1973
BD-18011	Steady State Solutions Concerning the Lox Tank Venting System	Dec. 1971
BD-18012	Transient Pressures in the Lox Tank Venting System	Feb. 1972
ED-2002-879 Vol. IV	Skylab External Thermal Coating Contamination	Mar. 1970
ED-2002-1081	Skylab I Windows and Vents Study	June 1970
DC-003M0020-V	AAP System Contamination Criteria	June 1969
ED-2002-1314-2	Skylab Experiment Contamination Data Pack	Sept. 1971
BD-13013	Dynamics of the Skylab Waste Tank System	July 1973
ED-2002-1495 (NASA 10M33114)	SCGTP Test Report	July 1972

MMC Report No.	Title	Date
ED-2002-1495 Attach I	Nozzle Panel Electrode Test	July 1972
ED-2002-1451	Condensate Nozzle Verification Test	Feb. 1972
ED-2002-1654	Sublimation of Ice Particles in Space	Mar. 1973

1.8 **ABBREVIATIONS**

Å	Angstrom
α	adsorbtivity
Ag_2O	Silver Oxide
AlO_3	Aluminum Oxide
AM	Airlock Module
AMB	ambient
amu	atomic mass unit
AMS	articulating mirror system
ASAL	anti-scientific airlock
$\approx$	approximately
ATM	Apollo Telescope Mount
$B/B_{\odot}$	background brightness to brightness on sun
$^{\circ}C$	degree centigrade
CBRM	charger battery regulator module
CCWG	Contamination Control Working Group
C&D	control & display
CDR	Commander
CMSG	Contamination Mission Support Group
CO_2	carbon dioxide
CRS	Cluster Requirements Specification
CSM	Command and Service Module
CuO	cupric oxide
DAC	data acquisition camera
δ	delta
DOY	day of year
EDDU	experiment digital data unit
ϵ	emissivity
EREP	Earth Resources Experiment Package

1.8	<u>ABBREVIATIONS</u> (Cont.)
ETC	earth terrain camera
eV	electron volt
EVA	extra vehicular activity
^oF	degrees fahrenheit
GMT	Greenwich mean time
H_2	hydrogen
H_2O	water
HCO	Harvard College Observatory
HOSC	Huntsville Operations Support Center
IU	Instrument Unit
JSC	Johnson Space Center
kg	kilogram
Kcal	kilocaloric
KHz	kilohertz
KSC	Kennedy Space Center
LES	Launch Escape System
λ	wavelength
μgcm^2	microgram per square centimeter
MDA	Multiple Docking Adapter
MSFC	Marshall Space Flight Center
MOPS	Mission Operation Planning System
N/A	not applicable
N_2O_4	nitrogen tetroxide
NH_3	ammonia
NO_2	nitrogen dioxide
NPV	nonpropulsive vent
NRL	Naval Research Laboratory
NU Z	vehicle attitude
O_2	oxygen
OA	Orbital Assembly

1.8	Abbreviations (Cont.)
OWS	Orbital Work Shop
PCU	pressure control unit
P.I.	Principal Investigator
P.S.	Principal Scientist
PTDA	power transfer distributor assembly
QCM	quartz crystal microbalance
Quad	quadrant
RCS	reaction control system
RGA	residual gas analysis
SAL	scientific air lock
SAS	solar array system
SCGTP	Skylab Contamination Ground Test Program
SEVA	standup extravehicular activity
SPT	Science Pilot
STS	Structural Transition Section
TACS	thrust attitude control system
TAL	trash airlock
TDM	Technical Discipline Manager
TV	television
UV	ultraviolet
V/TS	viewfinder tracking system

APPENDIX A

Correlations of deposition model predictions and flight data. Also predictions for contamination susceptible surfaces.

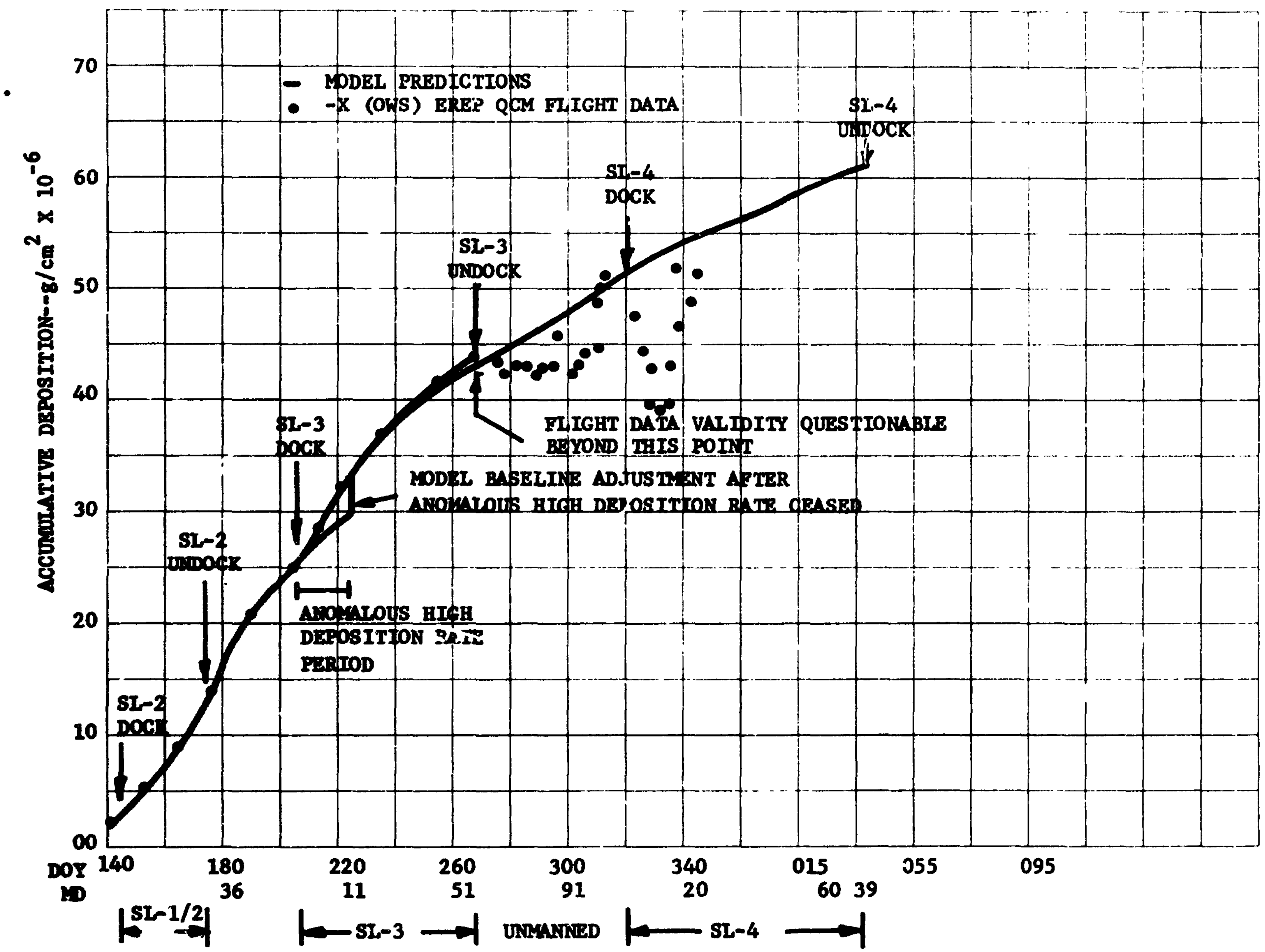

Figure A-1 Correlation of Model Update Predictions with -X (OWS) QCM Flight Data

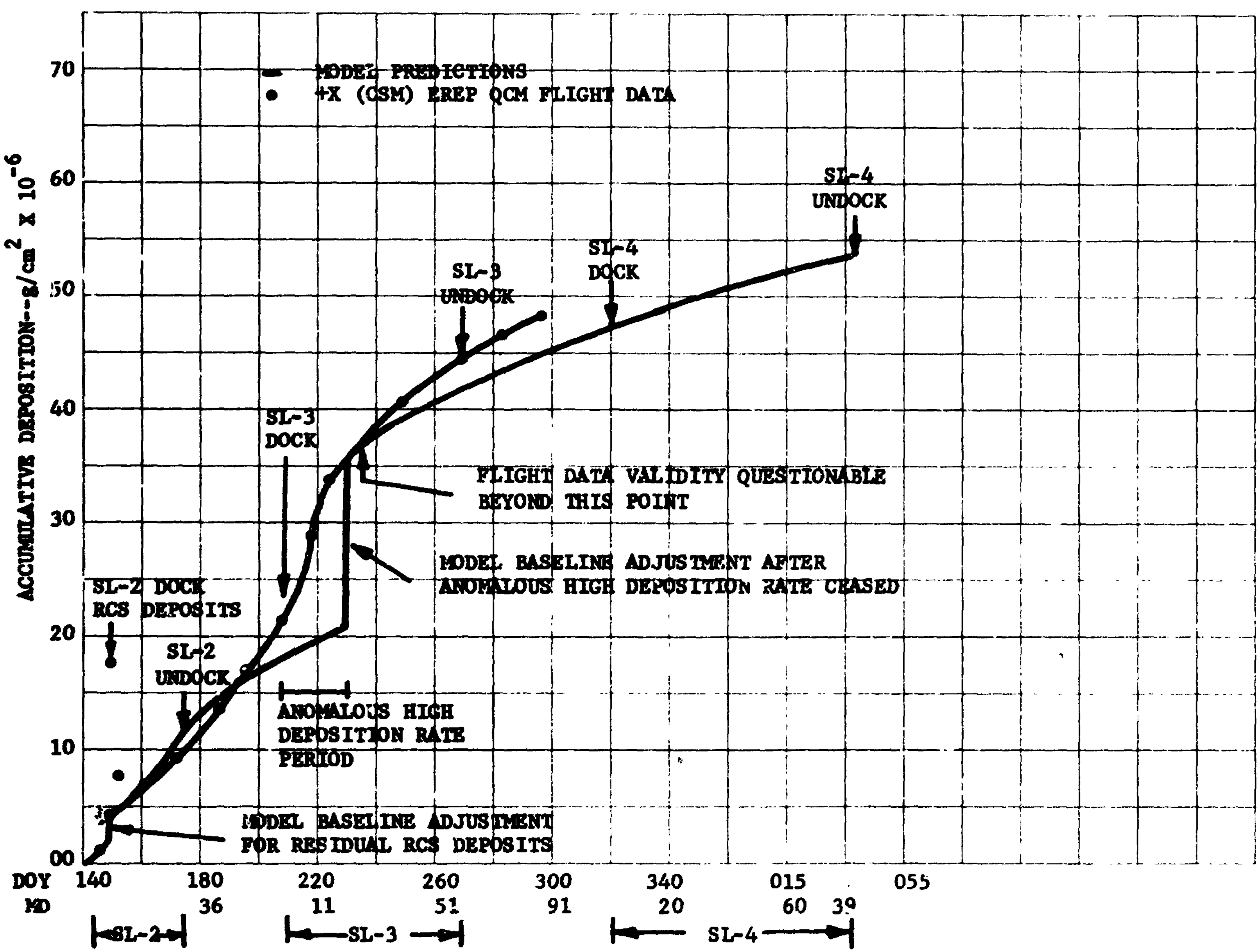

Figure A-2 Correlation of Model Update Predictions with +X (CSM) QCM Flight Data

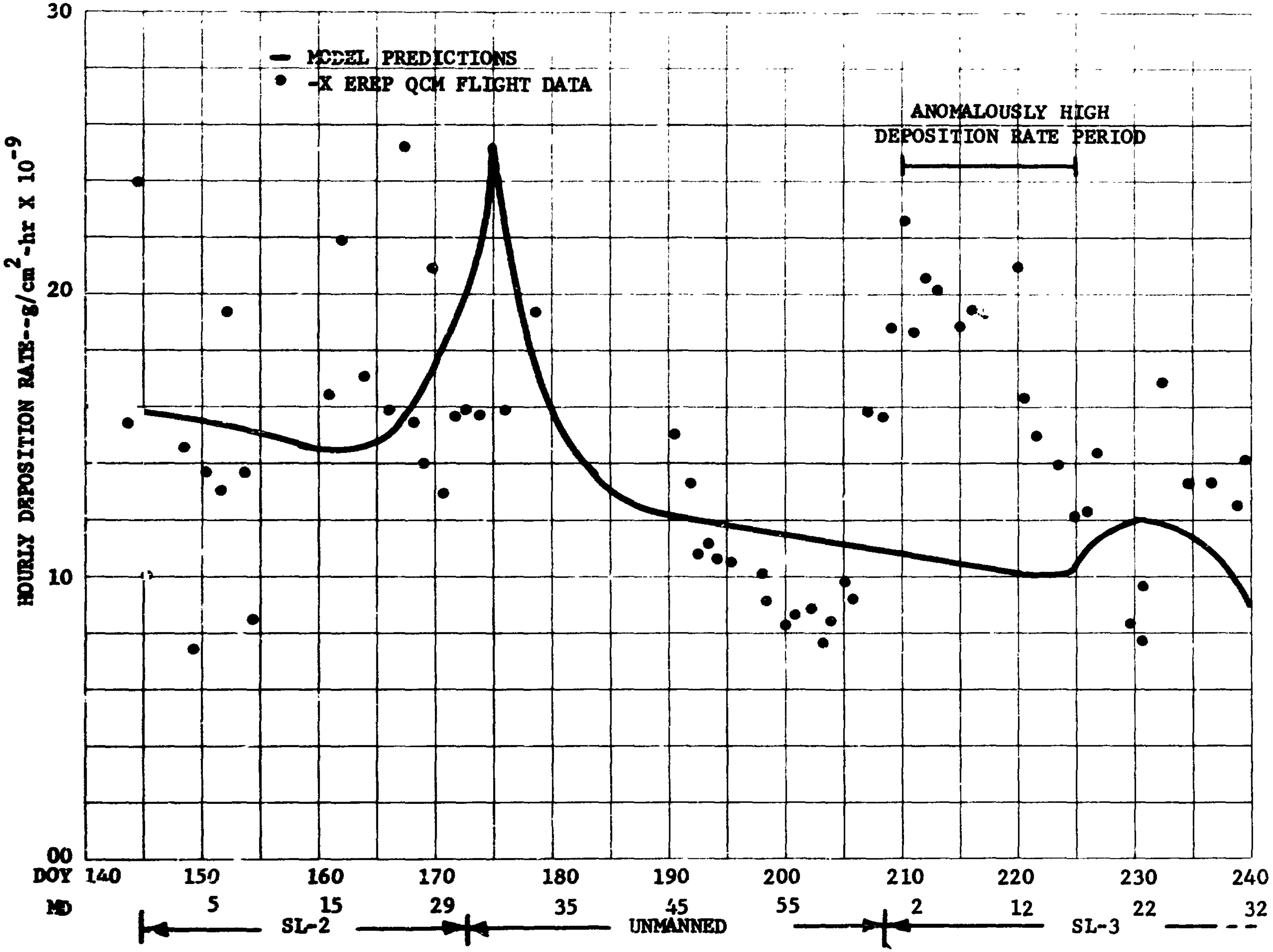

Figure A-3 Correlation of Model Update with -X (OWS) QCM Hourly Rate Flight Data

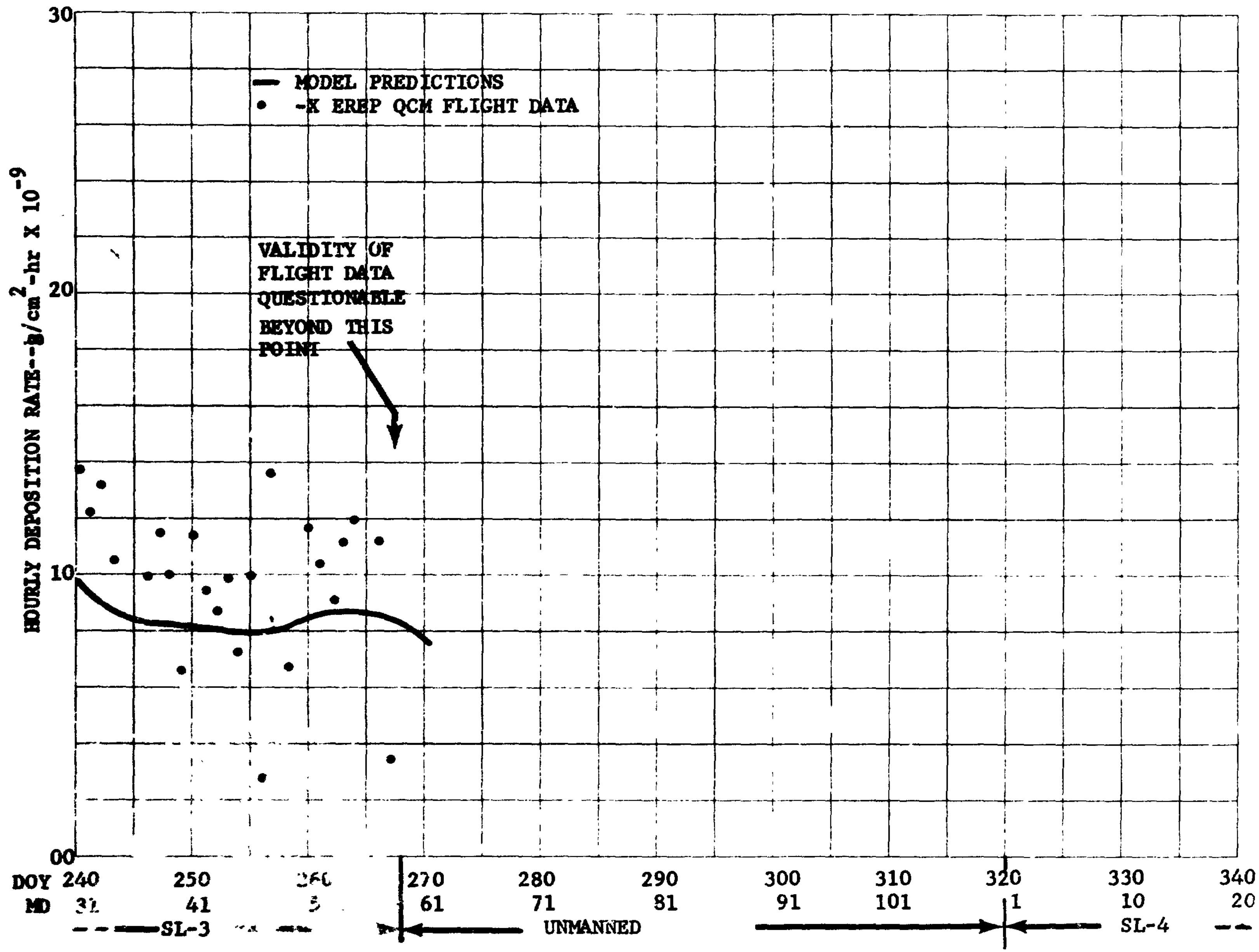

Figure A-4 Correlation of Model Update with -X(OWS) QCM Hourly Rate Flight Data

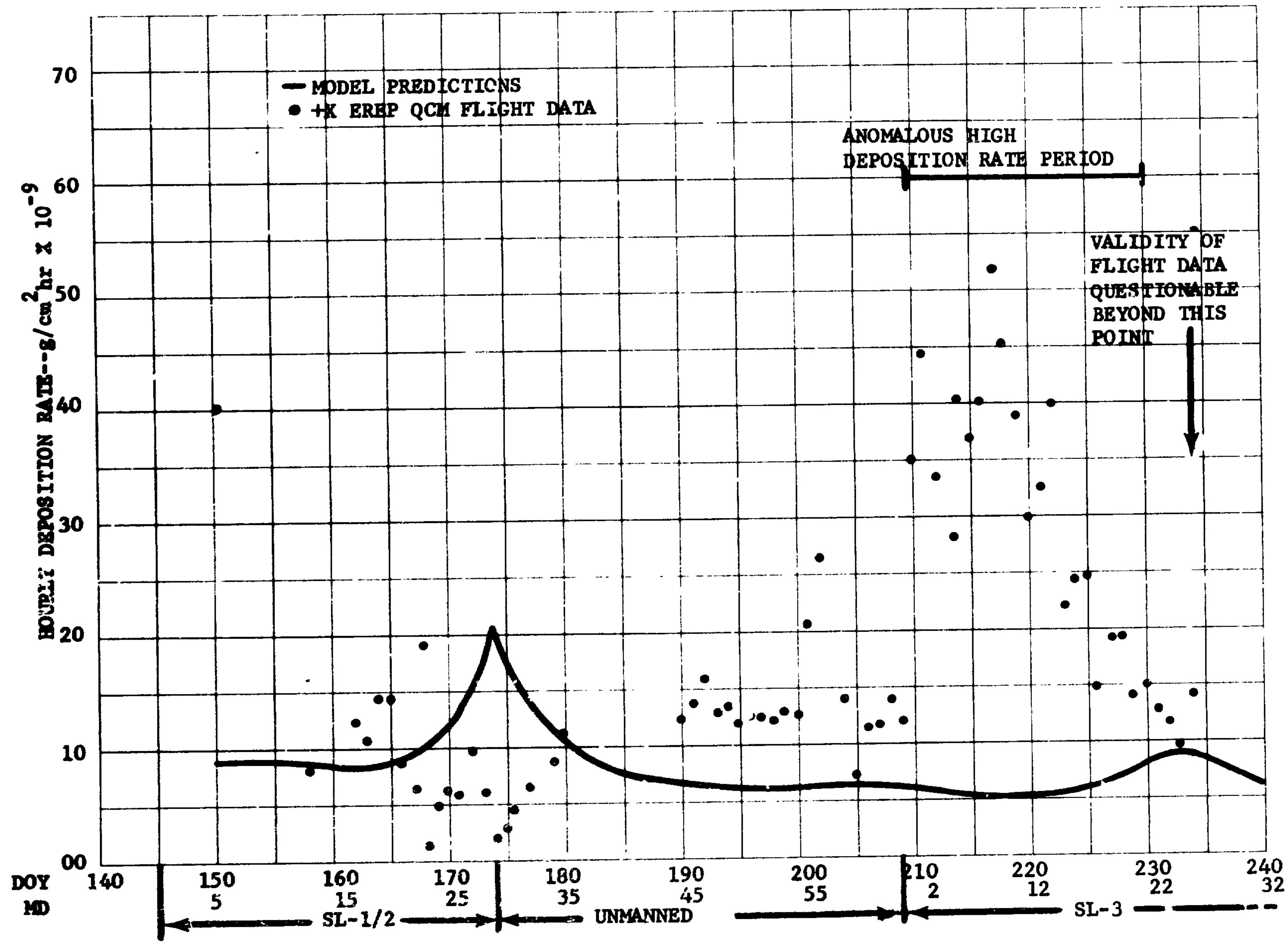

Figure A-5 Correlation of Model Update with +X(CSM) QCM Hourly Flight Data

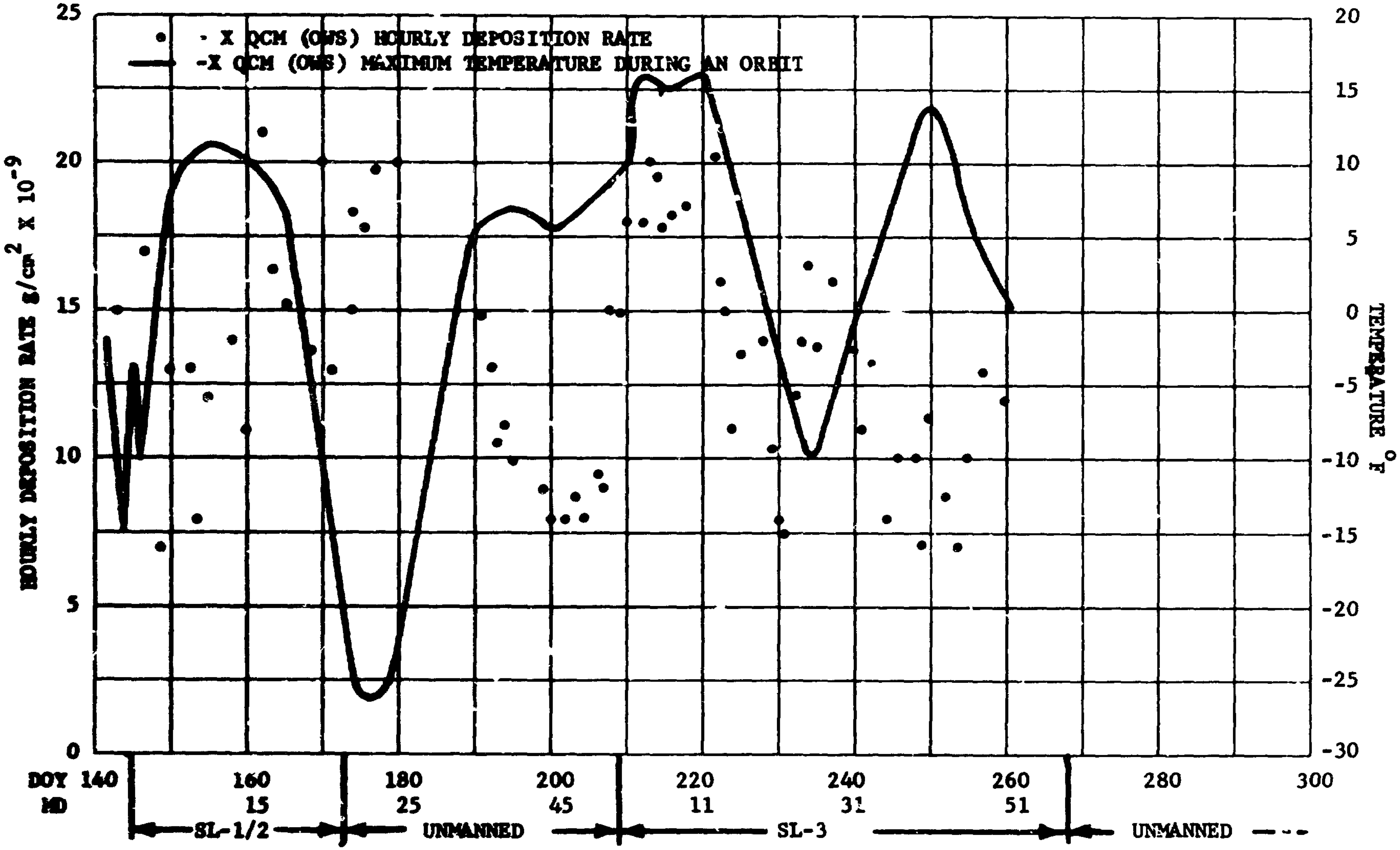

Figure A-6 Temperature - Mass Deposition Rate Behavior of -X (OWS) QCM

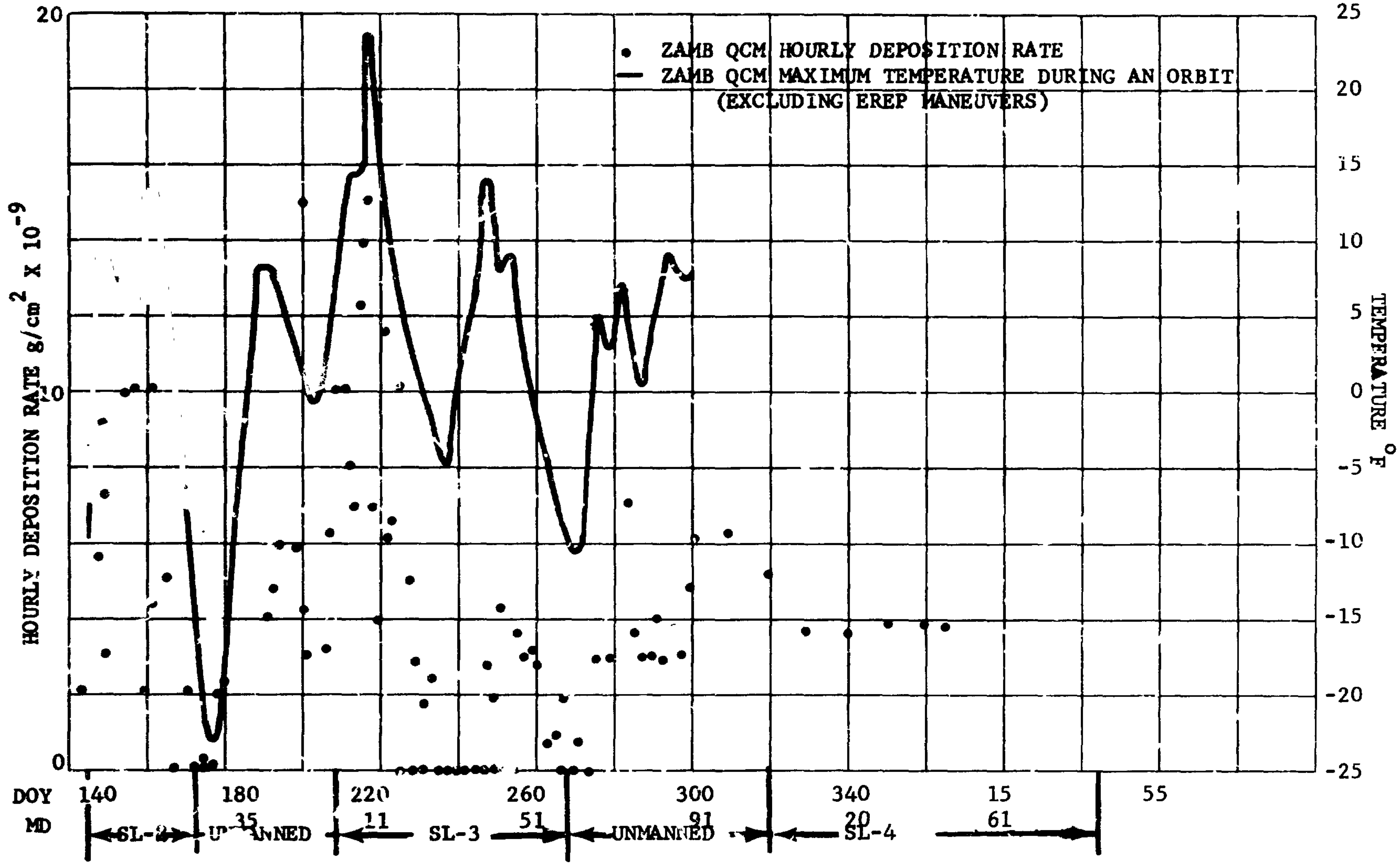

Figure A-7 Temperature-Mass Deposition Rate Behavior of ZAMB QCM

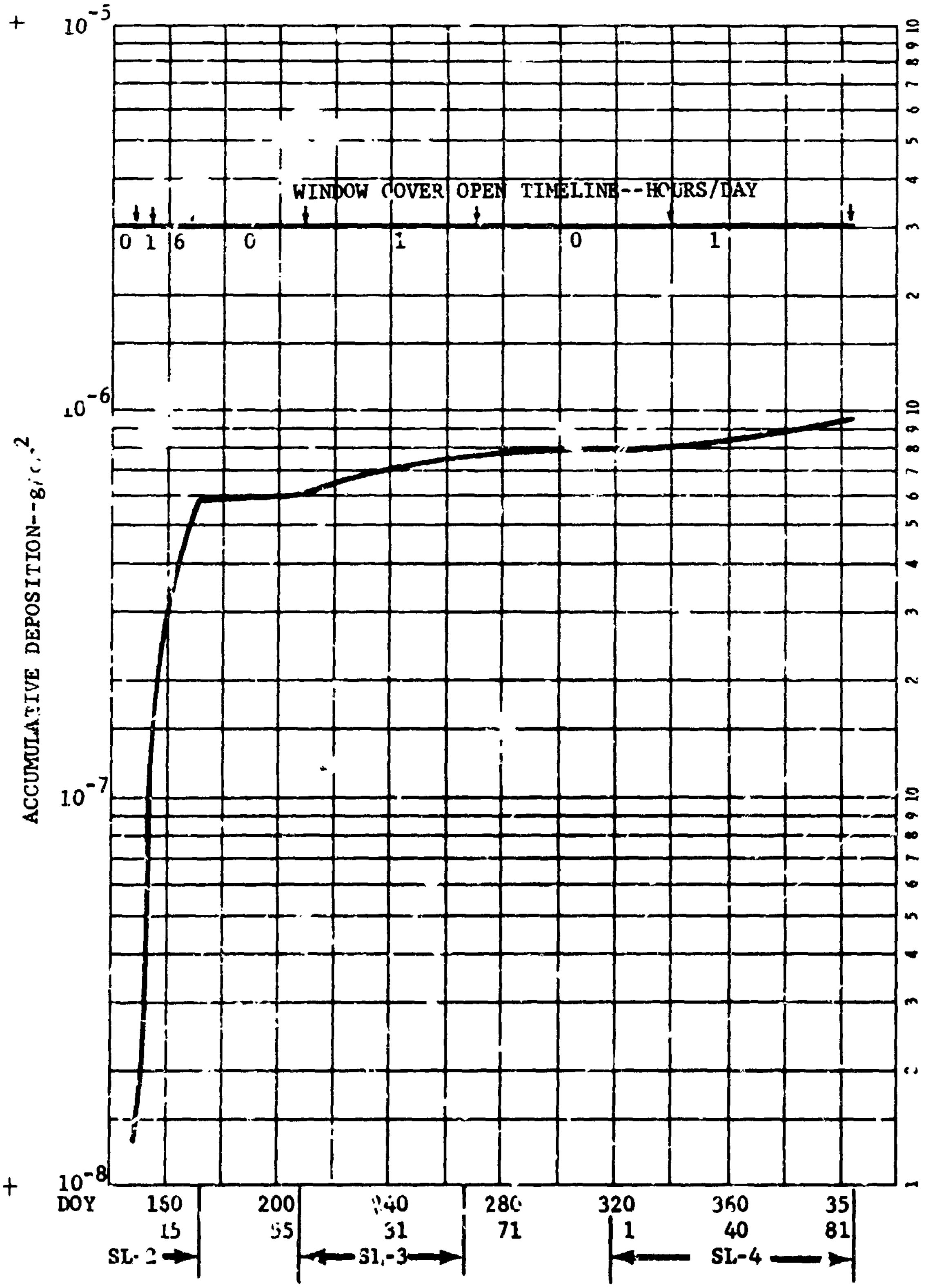

Figure A-8 STS Window 243 As Flown Deposition Predictions DOY 147 to 039

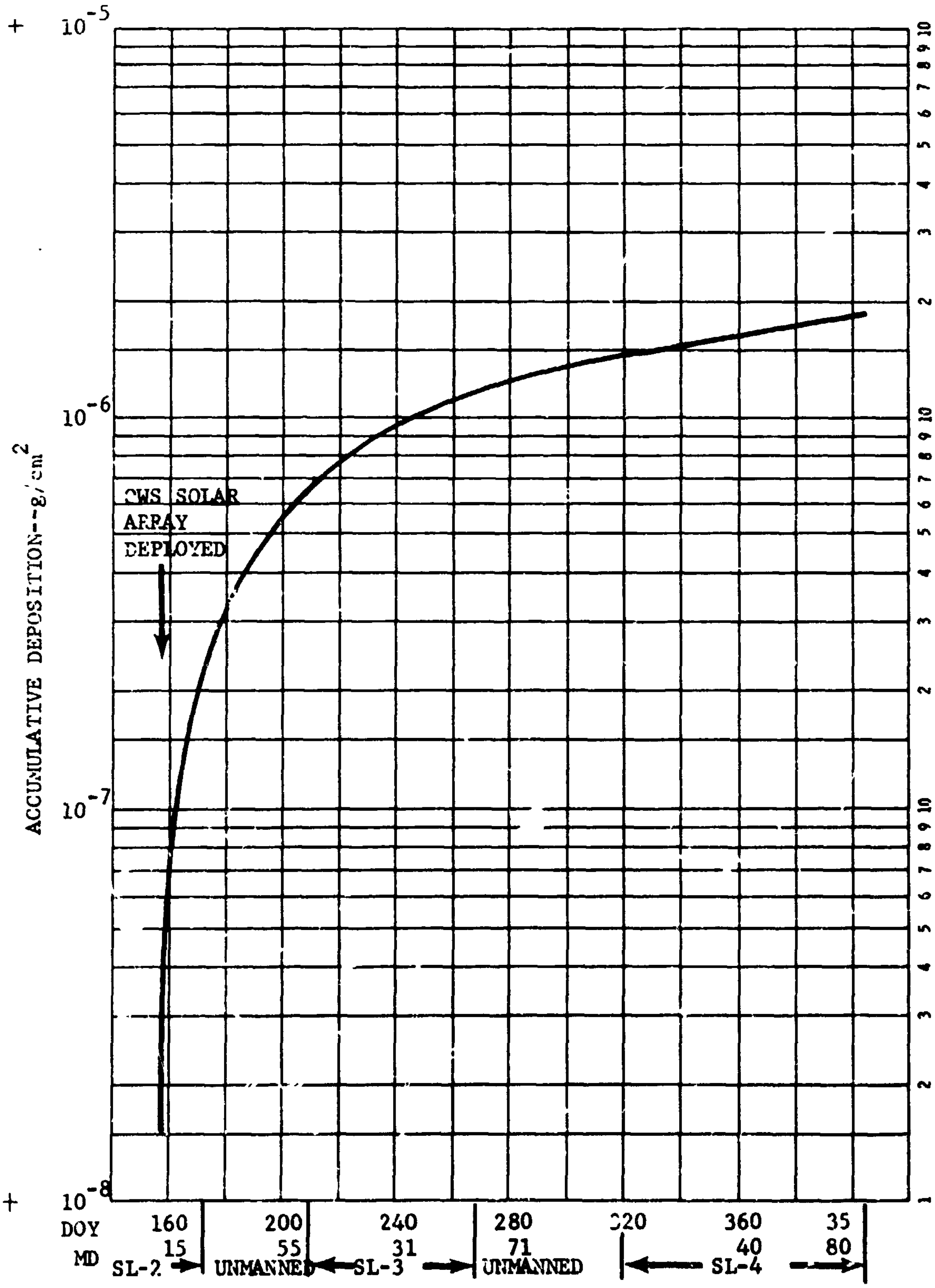

Figure A-9 CWS Wardroom Window As Flown Deposition Predictions DOY 159 to 039

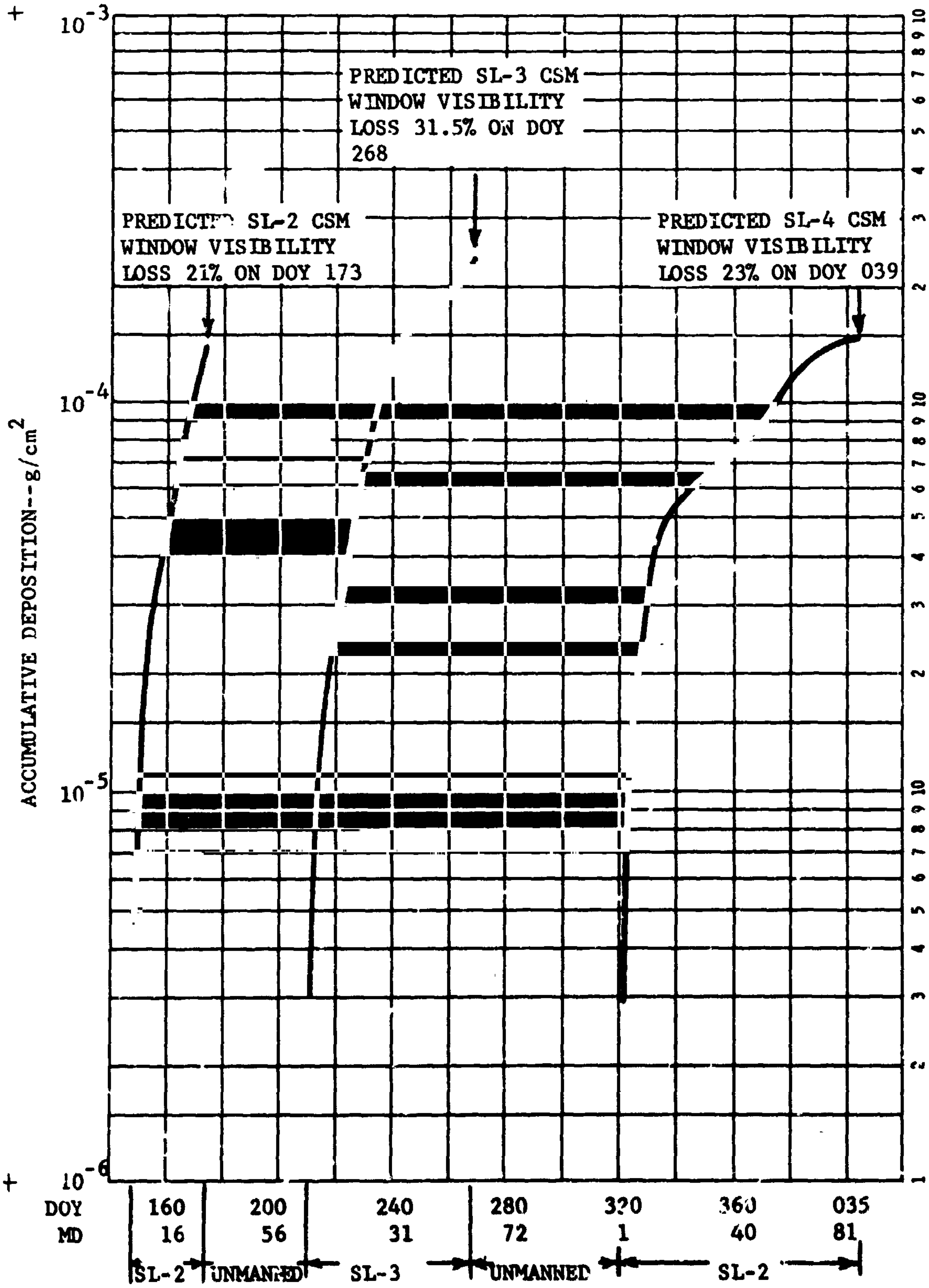

Figure A-10 CSM Window As Flown Deposition Predictions DOY 147 to 039

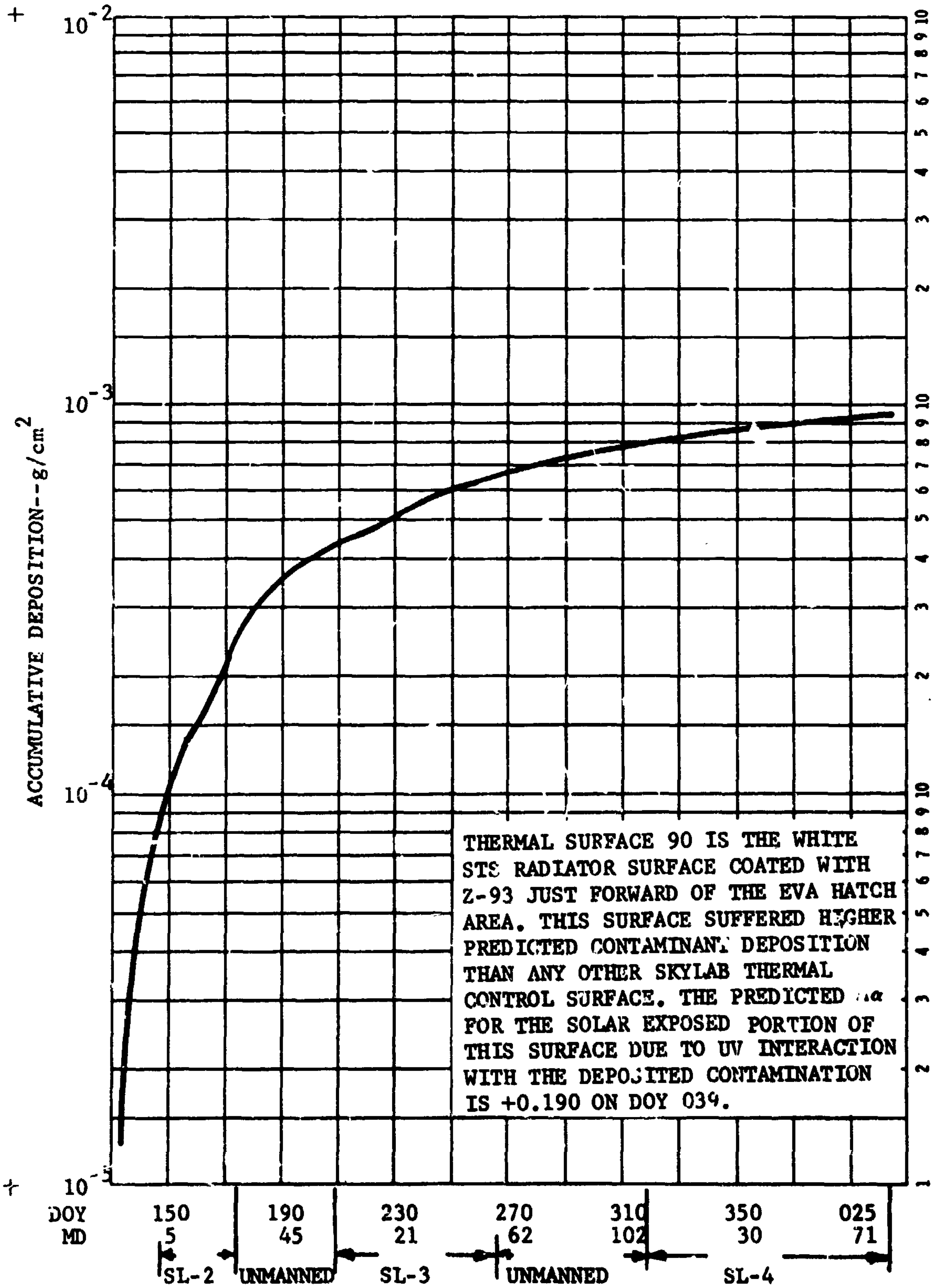

Figure A-11 Thermal Surface 90 As Flown Deposition Predictions DOY 134 to 039

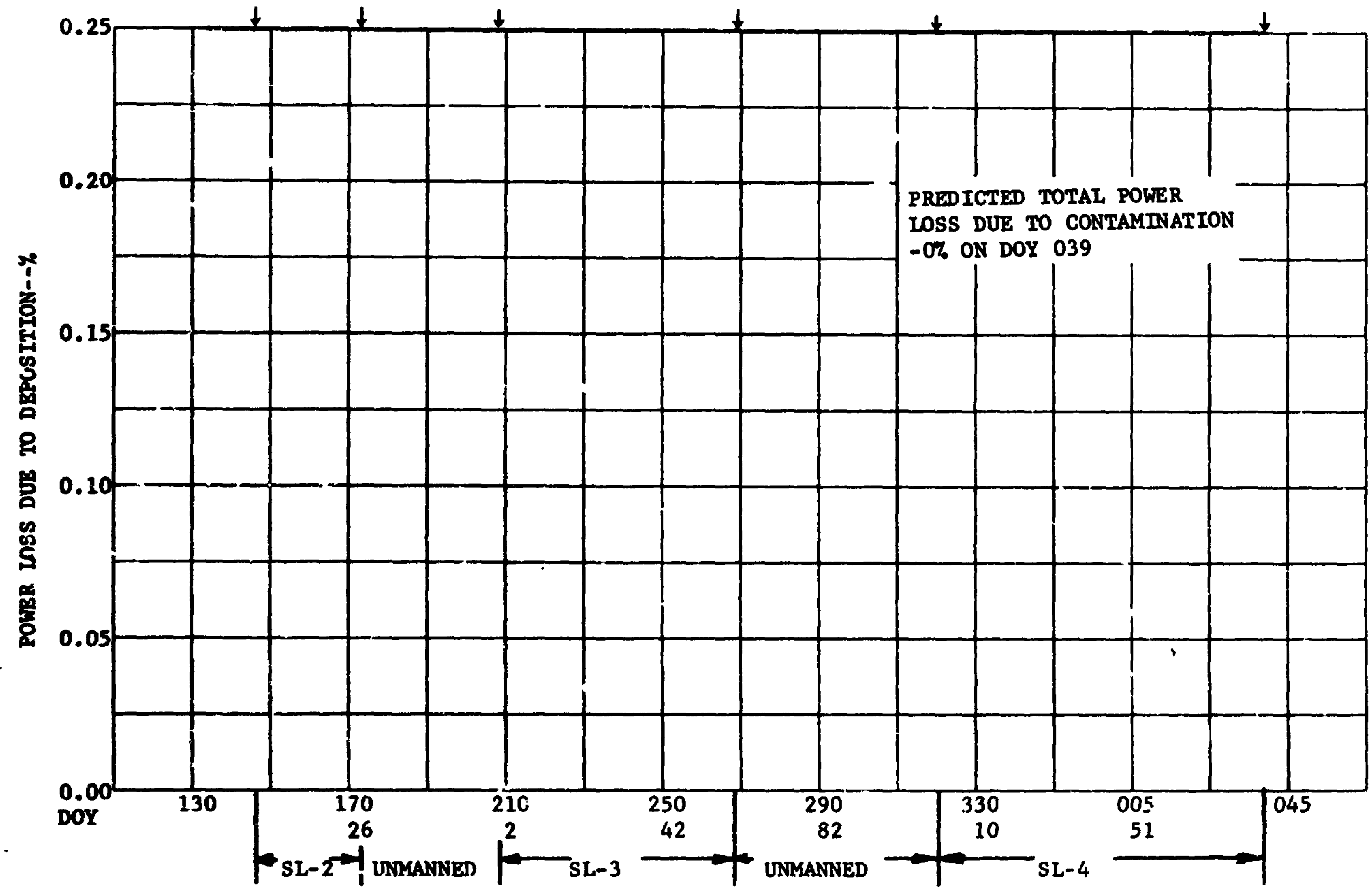

Figure A-12 ATM Solar Array System As [illegible]own Power Loss Predictions
DOY 134 to 039

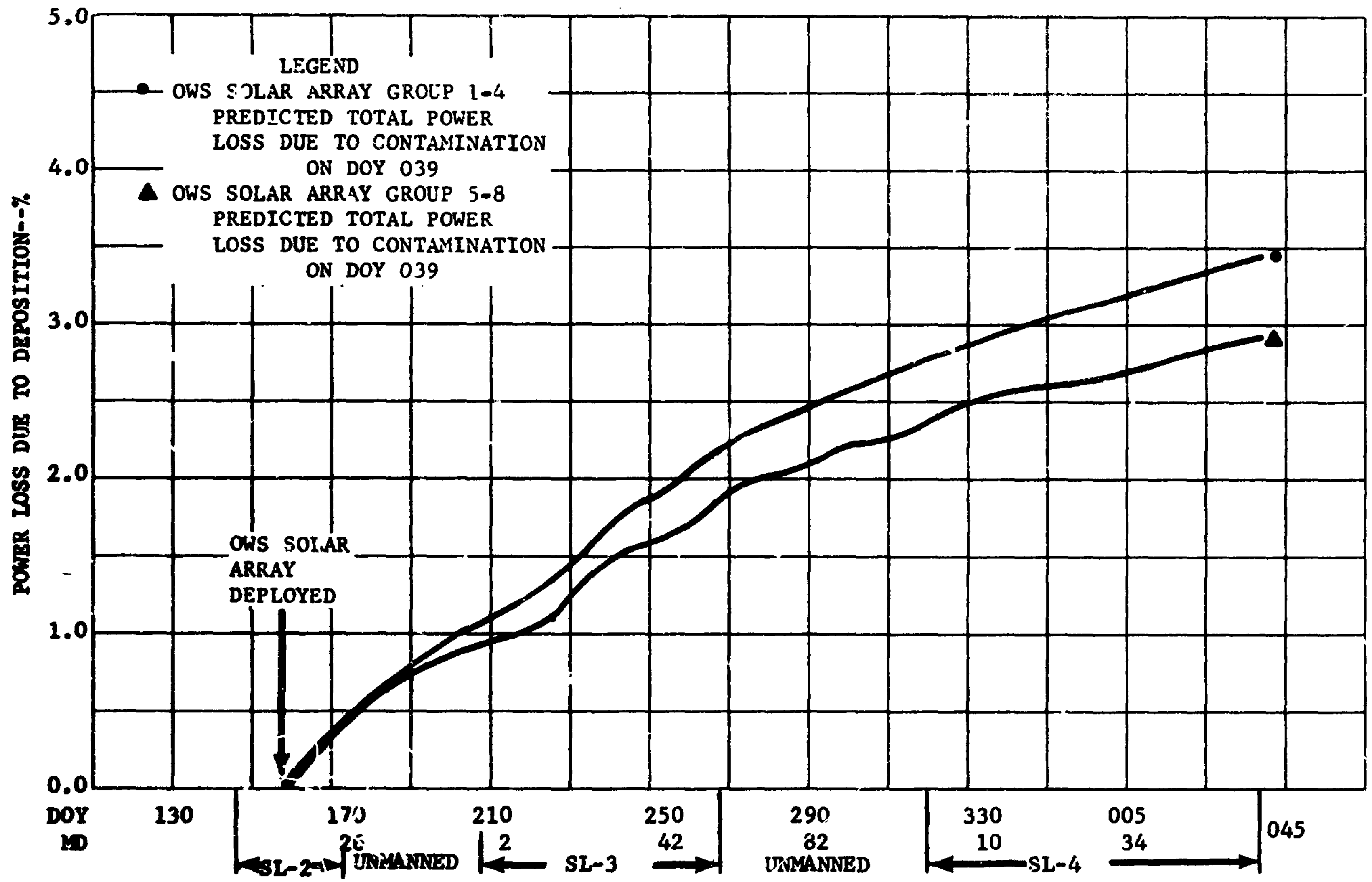

Figure A-13 OWS Solar Array System As Flown Power Loss Predictions DOY 159 to 039

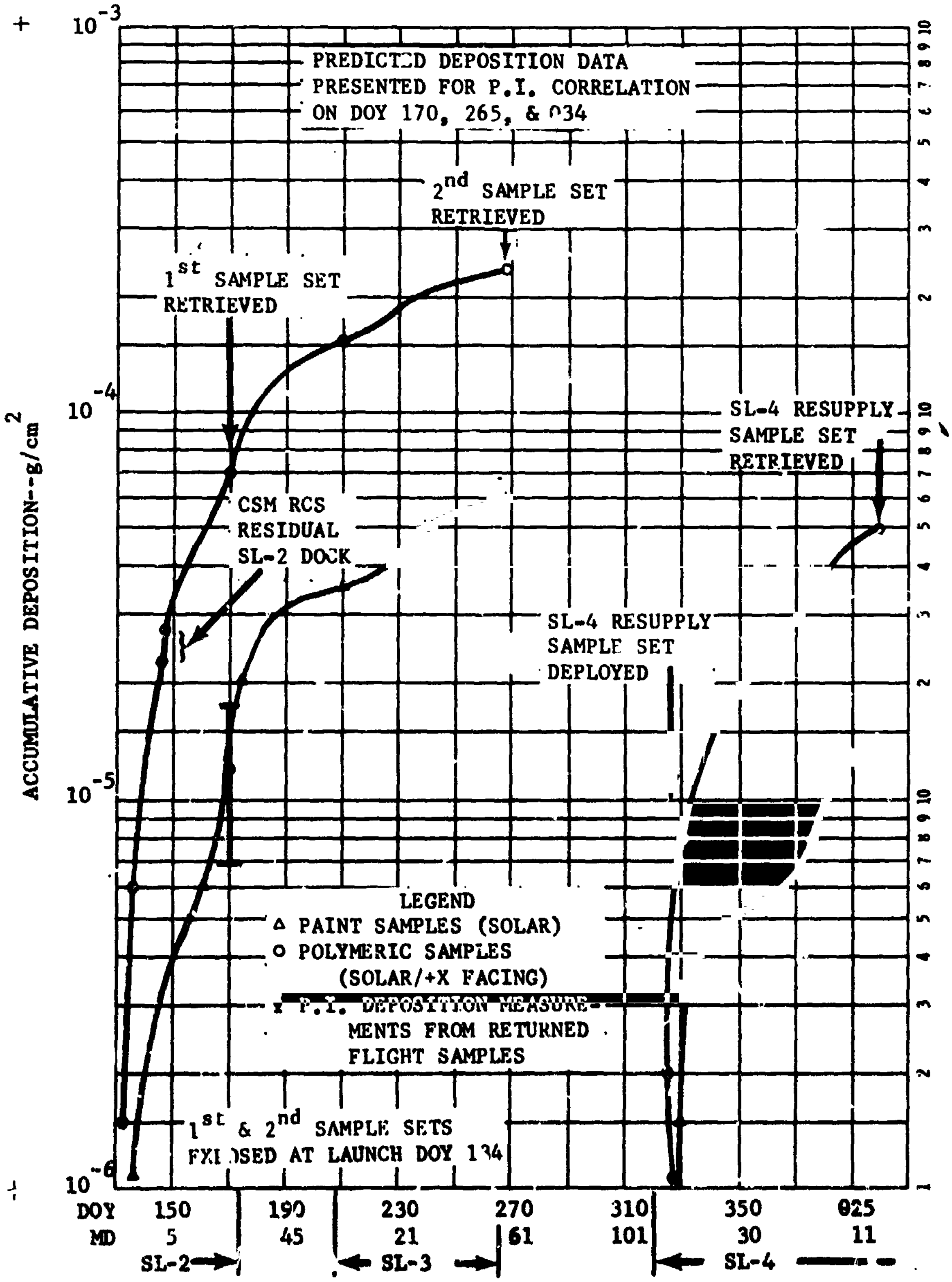

Figure A-14 Experiment D024 As Flown Deposition Predictions DOY 134 to 034

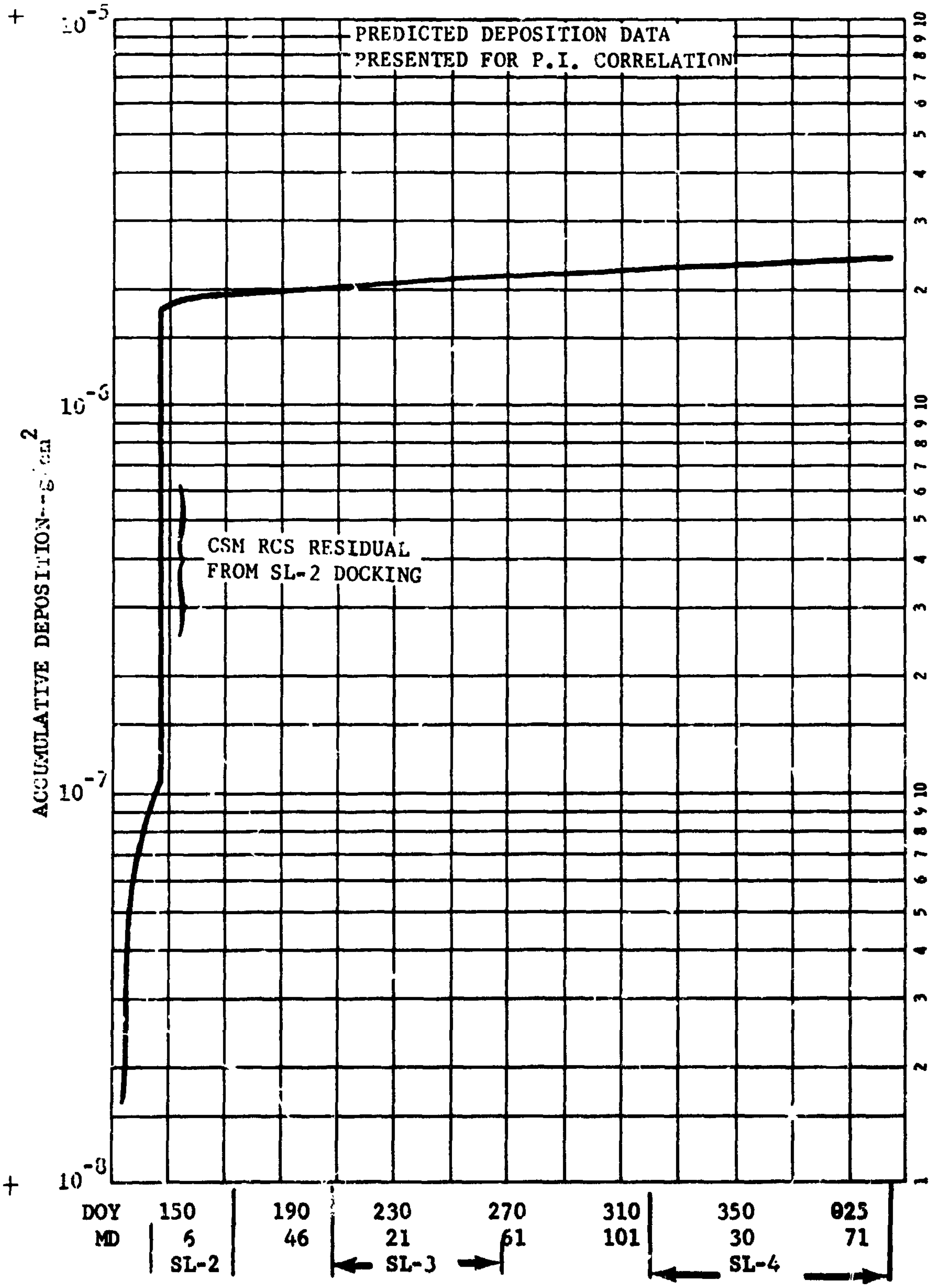

Figure A-15 S193 Feed Horn As Flown Deposition Predictions DOY 134 to 039

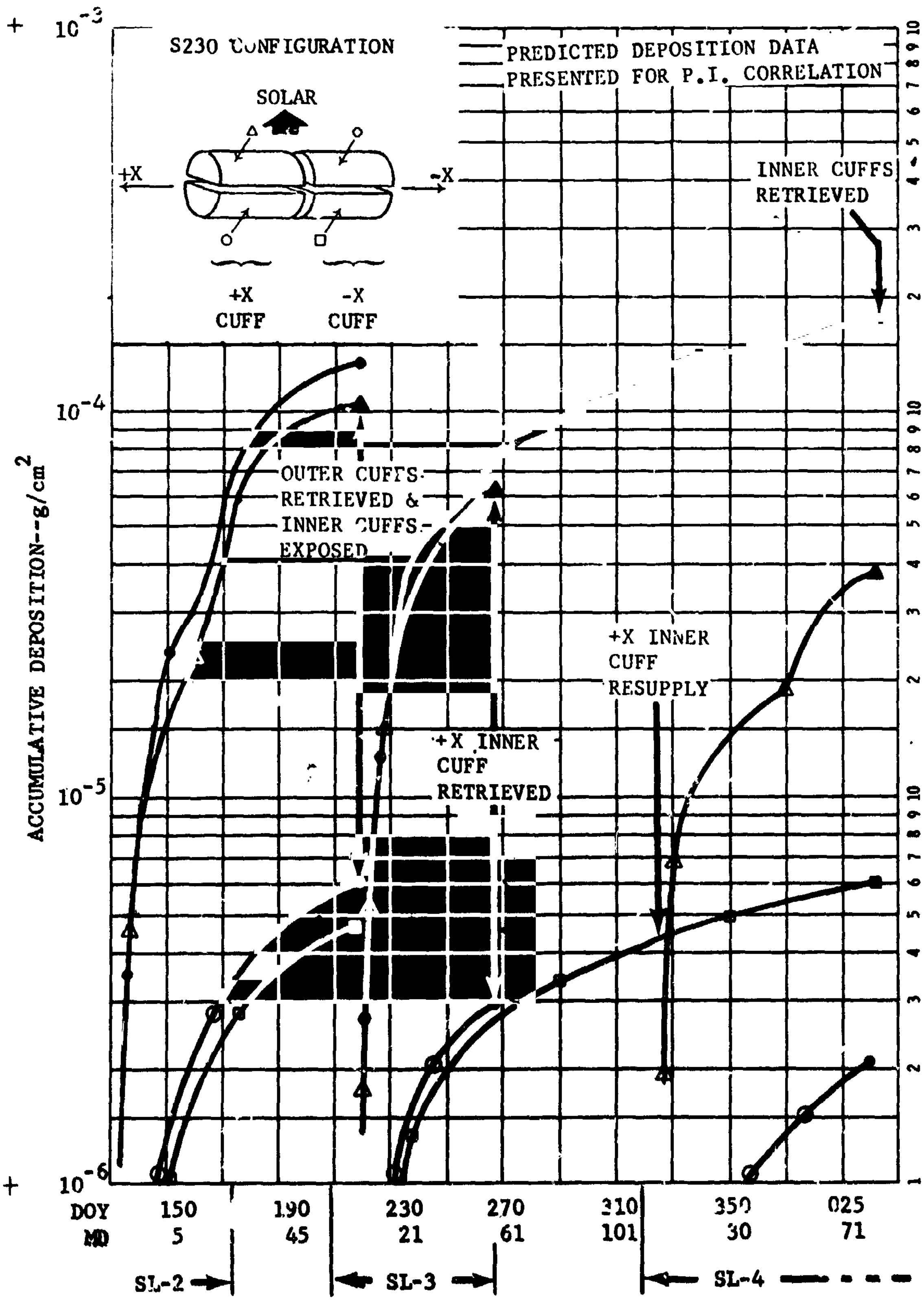

Figure A-16 Experiment S230 As Flown Deposition Predictions DOY 134 to 034

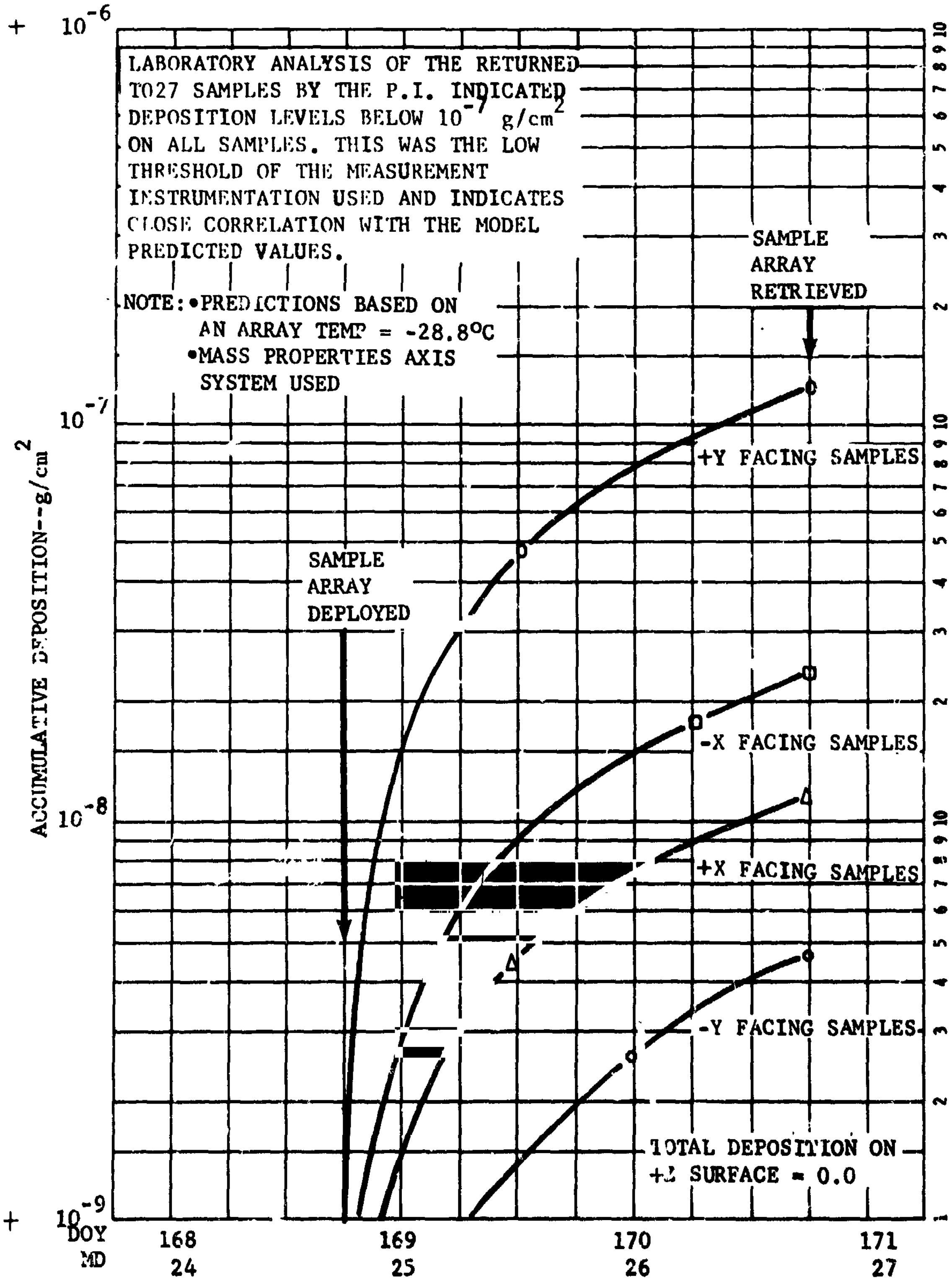

Figure A-17 T027 Sample Array Deposition Predictions DOY 168 to 170 (SL-2)

APPENDIX B

A compilation of approximate times of operation and exposure of Astrophysical, Earth Resource, and Engineering Technology Experiments.

Table B-I S019 Operation and Exposure Times

	DOY	GMT	FUNCTION*
SL-2	149	22:15 - 23:00	Preparation
	150	16:30 - 17:00	Deploy AMS and AMS malfunction
	151	13:45 - 15:00	Malfunction procedure on mirror inside cabin
	151	17:45 - 18:00	Mount optics
	151	22:00 - 22:40	Data Take
	153	13:20 - 13:40	Stow
	156	19:30 - 20:00	Preparation
	156	20:45 - 21:45	Data Take
	157	20:45 - 21:45	Data Take
	159	14:20 - 14:35	Stow
	168	10:50 - 11:25	Preparation
		11:40 - 17:00	Data Takes, include ED23 data
		18:25 - 18:45	Stow
SL-3	217	13:30 - 14:10	Preparation
	222	18:15 - 19:15	Data Take
		19:5[illegible] - 20:50	Data Take
		2[illegible]:20 - 22:2[illegible]	Data Take
	225	00:40 - 01:30	Data Take
		01:30 - 02:10	Stow
	227	13:30 - 13:55	Data Take
		22:40 - 23:15	Data Take
	228	13:45 - 14:10	Stow
		18:20 - 18:55	Preparation
		18:55 - 19:50	Data Take
		23:30 - 00:30	Data Take
	229	19:45 - 20:20	ED26 Data Take
	232	13:10 - 13:50	ED23 Data Take
		13:50 - 14:10	Prism installation
		16:15 - 16:4[illegible]	Data Take (FO 1-12)
		16:45 -	Malfunction
	233	14:10 - 14:50	Data Take (FO 1-12)
		21:05	Malfunction corrected
	234	18:05 - 18:45	Data Take (FO 1-12)
		21:20 - 21:45	Data Take
	235	02:00 - 02:20	Data Take (FO 1-12)
		12:40 - 13:15	Data Take (FO 1-12)

	DOY	GMT	FUNCTION*
SL-3	237	12:50 - 13:00	Prism stow
		13:00 - 13:40	Data Take (FO 1-12)
	240	13:50 - 14:45	S183 Data Take (FO 1-12) using S019
		18:20 - 18:35	Prism install
		18:35 - 19:20	S183 Data Take (FO 1-12) using S019
		23:10 - 00:05	S183 Data Take (FO 1-12) using S019
	241	13:20 - 13:45	Stow
		19:00 - 19:20	Preparation
		19:25 - 20:15	Data Take (FO 1-12)
	242	01:35 - 02:25	Data Take (FO 1-12)
		12:40 - 13:20	Data Take (FO 1-12)
		14:15 - 15:00	Data Take (FO 1-12)
		16:00 - 16:30	Stow
	244	12:35 - 12:50	Stow
		21:30 - 21:60	Preparation with T.V. 47
		21:60 - 22:50	Data Take (FO 1-12)
		23:35 - 00:20	Data Take (FO 1-12)
	245	02:25 - 03:00	Stow
	246	18:20 - 19:05	Preparation
		19:10 - 19:45	S183 Data Take (FO 1-12) using S019
		23:50 - 00:15	Stow
	247	23:10 - 23:40	Preparation with T.V. 47
	248	00:30 - 01:30	S183 Data Take (FO 1-12) using S019
		02:05 - 03:05	S183 Data Take (FO 1-12) using S019
		12:55 - 13:40	S183 Data Take (FO 1-12) using S019
		14:30 - 15:20	S183 Data Take (FO 1-12) using S019
		16:35 - 17:00	Stow
		20:55 - 21:10	Preparation
		21:10 - 21:35	S183 Data Take (FO 1-12) using S019
		22:20 - 22:45	Stow
	249	22:30 - 23:00	Preparation
	250	00:40 - 01:40	S183 Data Take (FO 1-12) using S019
		14:00 - 14:30	Stow

	DOY	GMT	FUNCTION*
SL-3	254	16:15 - 16:35	Preparation
		16:35 - 17:25	Data Take
		17:25 - 17:45	Stow
	257	18:45 - 19:05	Preparation
		19:05 - 19:50	Data Take (FO 1-12)
	258	01:15 - 12:15	Data Take
		13:30 - 14:00	Stow
	264	07:50 - 08:05	Preparation
		08:05 - 08:45	Data Take
		09:05 - 10:20	Data Take
		10:55 - 11:15	Stow
	266	17:30 - 17:40	Preparation
		19:20 - 20:00	Data Take
		20:00 - 20:10	AMS photographs
		20:10 - 20:20	Stow
	2[illegible]6	22:00 - 23:00	Data Take
SL-4	330	14:00 - 14:15	Data Take
		15:20 - 16:00	Data Take
		20:10 - 20:20	Stow
	338	18:30 - 19:15	Preparation
		23:35 - 24:40	Data Take
	339	13:50 - 14:35	Stow
	341	17:05 - 17:35	Preparation
		23:25 - 23:55	Data Take-Kohoutek
	342	14:45 - 15:30	Data Take
		15:30 - 1[illegible]10	Stow
	346	20:50 - 21:15	Preparation
		21:15 - 22:10	Data Take
	347	14:50 - 15:15	Data Take-Kohoutek
		15:15 - 15:35	Stow
	348	14:40 - 15:15	Preparation
		15:30 - 16:05	Data Take-Kohoutek
		16:05 - 16:40	Stow
	351	02:20 - 03:10	Data Take-Kohoutek
		15:20 - 15:40	Stow
	352	23:45 - 24:15	Preparation
	353	22:50 - 23:40	Data Take-Kohoutek
	354	14:20 - 15:00	Data Take
		17:10 - 18:05	Data Take
		18:05 - 18:35	Stow

	DOY	GMT	FUNCTION*
SL-4	357	24:05 - 24:30	Preparation
	358	01:05 - 01:25	Data Take-Kohoutek
		19:30 - 20:00	Stow
	364	15:20 - 15:50	Preparation
		16:45 - 17:45	Data Take
		21:30 - 22:00	Data Take
		22:50 - 23:40	Data Take
	365	24:35 - 01:05	Stow
	04	22:35 - 23:04	Preparation
		23:45 - 24:40	Data Take-Kohoutek
	05	13:50 - 14:30	Data Take
		14:35 - 15:00	Stow
	07	22:40 - 23:25	Preparation
		23:40 - 24:15	Data Take-Kohoutek
	08	12:15 - 12:50	Data Take-Kohoutek
	11	01:05 - 01:35	Preparation
		01:35 - 01:55	Data Take-Kohoutek
		01:55 - 02:20	Stow
	14	19:30 - 20:00	Preparation
		20:35 - 21:10	Data Take-Kohoutek
		21:25 - 21:40	Stow
	24	21:50 - 22:20	Preparation
	25	24:45 - 01:40	Data Take
		13:10 - 14:00	Data Take
		14:50 - 15:20	Stow
	30	22:30 - 23:00	Preparation
		23:40 - 24:35	Data Take-Kohoutek
	31	24:35 - 01:05	Stow

* For details of Functional Objectives and Performance Requirements, see Mission Requirement Document 1-MRD-001F, Volume III, dated August 27, 1973.

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Table B-II S020 Operation and Exposure Times

	DOY	GMT	FUNCTION*
SL-4	358	21:10 - 22:30	Preparation
	359	17:00 - 24:00	EVA Data Take
	360	01:20 - 01:40	Stow
	362	19:30 - 20:15	Preparation
	363	17:30 - 21:00	EVA Data Take
		23:40 - 24:20	Stow
	033	18:20 - 19:10	Preparation
	034	15:20 - 20:40	EVA Data Take

* For details of Functional Objectives and Performance Requirements, see Mission Requirements Document 1-MRD-001F dated August 27, 1973.

Table B-III S063 Operation and Exposure Times

	DOY	GMT	FUNCTION*
SL-3	213	21:45 - 22:00	Preparation
	221	13:15 - 13:30	Preparation
		13:30 - 14:15	EA I Ozone Data Take
		14:15 - 15:05	Stow
	226	13:45 - 14:00	Preparation
		14:05 - 14:30	EA I Ozone Data Take
		14:30 - 14:50	Stow
	231	13:30 - 13:50	Preparation
		13:50 - 14:20	Hand Held Data Take
		14:20 - 14:40	Stow
	235	01:13 - 01:40	Hand Held Data Take
	237	02:10 - 02:20	Preparation
		02:20 - 02:35	Hand Held Data Take
		02:40 - 02:50	Stow
	239	14:30 - 15:30	Preparation
		14:30 - 15:30	EA-II Data Take (AMS)
	240	00:05 - 00:55	EA-II Data Take (AMS)
		01:15 - 02:15	EA-II Data Take (AMS)
		02:15 - 02:30	Stow
	243	22:30 - 23:30	EA-II Data Take (AMS)
	244	01:50 - 02:50	EA-II Data Take (AMS)
		12:10 - 12:50	Stow
	246	13:55 - 15:05	Preparation
		15:05 - 15:20	EA-I Ozone Data Take
		15:20 - 16:10	EA-I Ozone Data Take
		16:10 - 17:10	Stow
	248	22:45 - 23:30	Preparation
	249	11:35 - 14:20	EA-I Ozone Data Take
		19:00 - 20:00	Stow
	250	16:25 - 17:20	Preparation
		18:35 - 19:20	EA-I Data Take
	251	21:00 - 21:15	Preparation
		21:15 - 21:55	EA-I Ozone Data Take
		21:55 - 22:10	Stow (temporary)
	252	13:15 - 14:15	Regular stow
	257	14:50 - 15:50	Preparation
		17:16 - 17:27	EA-I Ozone Data Take
		23:30 - 24:20	Stow

	DOY	GMT	FUNCTION*
SL-3	260	16:23 - 16:52	EA-I Ozone Data Take, using handheld camera viewing through SAL window
	262	19:05 - 19:15	Deactivation
	263	08:30 - 08:35	Photography out STS windows #3 and #4 to determine structural obstructions
		08:35 - 09:00	Deactivation
SL-4	339	22:40 - 23:50	Preparation
	340	02:05 - 02:50	Kohoutek Data Take (AMS)
		02:50 - 03:20	Stow
	342	16:30 - 17:15	Preparation
		18:05 - 18:30	Kohoutek Data Take (AMS)
		19:20 - 20:10	Stow
	343	14:00 - 14:40	Preparation
		20:30 - 21:10	Kohoutek Data Take (AMS)
		21:10 - 21:20	Stow
	344	16:40 - 17:00	Preparation
		17:00 - 17:30	Kohoutek Data Take (AMS)
		20:50 - 21:30	Stow
	345	15:00 - 16:20	Preparation
		17:10 - 18:05	EA-II Data Take (AMS)
		18:50 - 19:30	EA-II Data Take (AMS)
		20:40 - 21:10	Stow
	349	13:55 - 14:35	Preparation
		16:00 - 16:50	EA-II Data Take (AMS)
	350	13:50 - 14:40	EA-II Data Take (AMS)
		14:40 - 15:25	Stow
	351	15:40 - 16:25	Preparation
		16:50 - 17:15	Kohoutek Data Take (AMS)
		20:00 - 20:40	Stow
	354	23:50 - 24:30	Preparation
	355	01:40 - 02:10	Kohoutek Data Take (AMS)
		23:10 - 23:45	Kohoutek Data Take (AMS)
	356	13:55 - 14:05	Preparation
		16:20 - 16:50	Kohoutek Data Take (AMS)
		16:50 - 17:15	Stow
	365	23:20 - 24:10	Preparation

	DOY	GMT	FUNCTION*
SL-4	01	24:20 - 01:15	EA-I Ozone Data Take
		12:55 - 13:50	EA-I Ozone Data Take with EREP
		15:15 - 16:05	Stow
	02	14:10 - 14:30	Preparation
		14:30 - 14:45	Kohoutek Data Take (AMS)
		18:15 - 18:50	Stow
	03	24:45 - 01:50	Preparation
		10:15 - 10:50	EA-I Ozone Data Take
		11:15 - 12:00	EA-I Ozone Data Take
		13:00 - 13:45	Stow
	05	21:00 - 21:45	Preparation
		23:20 - 23:45	Kohoutek Data Take (AMS)
	06	24:00 - 24:20	Stow
		19:30 - 20:15	Preparation
		21:15 - 21:50	EA-II Data Take (AMS)
	07	24:40 - 01:40	Stow
	08	21:40 - 22:25	Preparation
	09	24:30 - 24:35	Kohoutek Data Take (AMS)
		12:00 - 12:20	Stow
		12:20 - 12:40	Malfunction Procedure
		12:40 - 13:25	Preparation
		14:35 - 15:15	EA-II Data Take (AMS)
		17:20 - 18:10	EA-II Data Take (AMS)
		19:30 - 20:15	Preparation
		20:35 - 21:05	Kohoutek Data Take (AMS)
		21:05 - 21:50	Stow
	12	18:50 - 19:45	Preparation
		21:45 - 22:30	Kohoutek Data Take (AMS)
	13	18:05 - 18:50	Preparation
		19:40 - 20:15	EA-I Ozone Data Take
		21:10 - 21:40	Kohoutek Data Take (AMS)
		21:50 - 22:40	Stow
	19	12:00 - 12:40	Preparation
		17:20 - 17:50	EA-II Data Take (AMS)
		18:50 - 19:25	EA-II Data Take (AMS)
		19:25 - 20:00	Stow
	23	16:40 - 17:15	Preparation
		17:45 - 18:40	EA-II Data Take (AMS)
		18:40 - 19:20	Stow

DOY	GMT	FUNCTION*
25	15:40 - 16:30	Preparation
	16:55 - 17:40	EA-I Ozone Data Take
	18:15 - 19:10	Stow
27	21:45 - 22:20	Preparation
29	24:10 - 24:35	Kohoutek Data Take (AMS)
	18:50 - 19:40	Preparation
	19:40 - 20:30	EA-II Data Take (AMS)
30	24:40 - 01:25	Stow
31	13:30 - 14:40	Preparation
	14:40 - 15:10	EA-I Data Take with EREP
	19:20 - 20:10	Stow

* For details of Functional Objectives and Performance Requirements see Mission Requirements Document, 1-MRD-001F, Volume III, dated August 27, 1973.

Table B-IV S073 Operation and Exposure Times

	DOY	GMT	FUNCTION*
SL-2	162	18:52 - 00:05	Mode 0a Cal
	163	00:05 - 11:55	Mode 4a Gegenschein
		13:45 - 14:10	Mode 1e Joint
		19:45 - 21:55	Mode 1a Contamination
	165	18:10 - 01:00	Mode 0a Cal
	166	01:00 - 01:30	Mode 1d Zodiacal
		19:10 - 20:15	Mode 2c Joint
		21:06 - 09:56	Mode 4a Gegenschein
	167	09:56 - 22:30	Mode 3d Contamination
	168	09:00 - 10:30	Mode 3d and Retract/Stow
SL-3	213	23:00 - 02:35	Mode 4a Gegenschein
	214	02:20	Malfunction discovered, shaft could not be turned
	215	13:50 - 14:10	Mode 1b Gegenschein
		16:00 - 16:20	Mode 1a Contamination
		17:25 - 18:50	Mode 1a Contamination
		19:00 - 19:20	Mode 1b Gegenschein
		23:50 - 12:20	Mode 2b Ecliptic
	216	14:02	Photometer Jettisoned
	246	01:15 - 02:20	Preparation - First use of S063/T025/S019 AMS to obtain S073 data
	247	01:00 - 01:30	Data Take
		02:05 - 02:35	Stow
SL-4	343	24:00 - 24:20	Preparation
		24:30 - 01:40	Data Take
	344	01:40 - 01:55	Stow
	355	01:20 - 01:40	Preparation
		02:00 - 02:55	Data Take
	356	13:50 - 14:00	Stow
	361	13:40 - 14:10	Preparation
		18:45 - 19:20	Data Take
		23:15 - 24:05	Data Take
		24:05 - 24:15	Stow
	362	13:35 - 13:45	Preparation
		13:45 - 14:20	Data Take
		18:50 - 19:40	Stow

DOY	GMT	FUNCTION*
01	16:00 - 16:40	Preparation
	16:40 - 17:25	Data Take
	20:30 - 20:45	Lens Change
	21:35 - 22:10	Data Take
19	22:00 - 22:40	Preparation
20	01:00 - 01:50	Data Take
	13:50 - 14:10	Data Take
	15:20 - 15:40	Stow
21	22:10 - 22:25	Preparation
22	01:05 - 02:00	Data Take (without AMS)
	12:10 - 12:45	Data Take (without AMS)
	15:00 - 16:10	Data Take (without AMS)
	16:10 - 16:25	Stow
23	12:35 - 12:55	Preparation
	13:00 - 13:50	Data Take (without AMS)
	14:10 - 14:40	Stow
	20:10 - 20:30	Preparation
	20:45 - 21:20	Data Take (without AMS)
	21:20 - 21:45	Stow
28	11:20 - 12:00	Preparation
	12:40 - 13:10	Data Take
	13:10 - 14:10	Stow
30	18:15 - 19:00	Preparation
	19:00 - 19:50	Data Take
	20:30 - 21:20	Data Take
	21:20 - 22:00	Stow

* For details of Photometer Modes see Mission Requirements Document, 1-MRD-001F, Volume 1, dated February 1, 1973.

Table B-V S149 Particle Collection Exposure Times

Cassette	Beginning of Exposure (DOY)	End of Exposure (DOY)	Exposure Duration (DAYS)	Exposure* Location
Between SL-2 and SL-3	174	212	38	Anti-Solar SAL
SL-3	218	265	47	ATM Sun shield
SL-4	326	359	33	ATM Sun shield
Post SL-4	034	Intended to be retrieved on Apollo/Soyuz mission		ATM Sun shield

* For details of Functional Objectives and Performance Requirements see Mission Requirements Document, 1-MRD-001F, Volume III, dated August 27, 1973.

Table B-VI S183 Operation and Exposure Times

	DOY	GMT	FUNCTION*
SL-2	153	13:45 - 14:20	Preparation
		17:30 - 18:05	Data Takes
	154	13:45 - 14:30	Data Takes
		14:30 - 14:40	Malfunction
		21:20 - 21:30	Malfunction Procedure
	155	13:20 - 13:35	Data Takes
		14:30 - 15:00	Stow
	170	16:10 - 16:30	Preparation
		22:50 - 23:25	Data Takes
SL-3	232	19:05 - 19:20	Preparation
	243	00:45 - 01:50	Data Take
		01:50 - 02:00	DAC Stow
		13:30 - 14:20	AMS Stow
	255	13:05 - 13:25	Preparation
		14:20 - 15:10	Data Take
		15:10 - 15:55	Stow
	260	18:00 - 18:35	Preparation
		18:35 - 19:35	Data Take
		22:00 - 22:30	Stow
	261	11:05 - 11:30	Preparation
		11:30 - 12:30	Data Take
		13:50 - 14:20	Stow
	262	16:50 - 17:20	Preparation
		17:20 - 18:10	Data Take
		18:10 - 18:50	Stow
SL-4	329	22:00 - 22:30	DAC Optics Replacement
	331	16:30 - 17:10	Preparation
		22:10 - 22:45	Stow
	333	20:30 - 21:20	Preparation
		22:20 - 23:30	Data Take
	334	01:30 - 02:20	Stow
		20:30 - 21:30	Preparation and malfunction procedure
		23:05 - 24:05	Data Take
	335	14:30 - 15:30	Stow

DOY	GMT	FUNCTION
340	13:40 - 14:15	Preparation
	14:20 - 15:10	Data Take
	19:10 - 20:05	Data Take
	22:10 - 23:00	Data Take
341	01:40 - 02:20	Kohoutek Data Take
346	24:50 - 01:00	Stow
	15:35 - 15:50	Preparation and malfunction procedure
	19:40 - 21:30	Data Take
347	24:10 - 24:35	Kohoutek Data Take
	24:35 - 01:30	Stow
351	20:45 - 21:10	Preparation and malfunction procedure
352	15:20 - 16:20	Data Take
	21:50 - 22:45	Kohoutek and Starfield Data Take
	22:45 - 23:20	Stow
365	14:05 - 14:45	Preparation
	15:55 - 16:45	Data Take
	17:30 - 18:10	Data Take
	18:10 - 19:00	Stow
03	14:30 - 15:05	Preparation
	15:10 - 16:10	Kohoutek Data Take
	21:20 - 22:10	Data Take
	23:20 - 24:00	Stow
04	14:40 - 15:40	Data Take
	15:40 - 16:25	Stow
05	15:00 - 15:20	Preparation
	18:45 - 19:40	Data Take
	20:10 - 20:40	Stow
09	22:00 - 22:15	Preparation
	23:50 - 24:45	Kohoutek Data Take
10	24:45 - 01:20	Stow
11	18:50 - 19:20	Preparation
	22:30 - 23:15	Kohoutek Data Take
	23:15 - 23:40	Stow
13	22:40 - 23:00	Preparation
14	24:20 - 24:55	Data Take
	24:55 - 01:45	Stow
21	15:05 - 15:05	Preparation
	18:00 - 19:00	Stow

DOY	GMT	FUNCTION
27	20:50 - 21:40	Malfunction Procedure
28	21:00 - 21:40	Preparation
	21:50 - 22:20	Data Take
29	24:50 - 25:50	Data Take
	12:00 - 12:50	Data Take
	13:10 - 14:00	Stow

* For details of Functional Objectives and Performance Requirements see Mission Requirements Document, 1-MRD-001F, Volume III, dated August 27, 1973.

Table B-VII S201 Operation and Exposure Times

	DOY	GMT	FUNCTION*
SL-4	330	20:20 - 20:45	Preparation
		23:00 - 23:45	Kohoutek Data Take
	339	19:45 - 20:20	Preparation
		21:40 - 22:35	Kohoutek Data Take
		22:35 - 22:50	Stow
	345	21:00 - 21:20	Preparation
	346	01:15 - 01:45	Kohoutek Data Take
		05:10 - 06:10	Atmospheric Data Take
	350	15:35 - 15:50	Preparation
		17:00 - 17:40	Kohoutek Data Take
		17:40 - 18:20	Stow
	356	19:30 - 19:50	Preparation
		22:25 - 23:00	Kohoutek Data Take
	357	15:20 - 16:10	Kohoutek Data Take
		20:05 - 20:40	Stow
	358	20:00 - 22:30	Preparation for EVA
	359	17:00 - 24:00	EVA Kohoutek Data Take
	360	01:40 - 02:20	Stow
	362	19:30 - 20:15	Preparation for EVA
	363	17:30 - 21:00	EVA Kohoutek Data Take
		23:40 - 24:20	Stow
	02	20:10 - 20:45	Preparation
		22:25 - 23:20	Kohoutek Data Take
	03	24:00 - 24:45	Stow
	06	12:00 - 12:25	Preparation
		13:15 - 13:45	Kohoutek Data Take
		14:20 - 15:10	Stow
	10	13:55 - 14:30	Preparation
		16:55 - 17:25	Khoutek Data Take
		17:25 - 18:20	Stow
	12	23:40 - 23:55	Preparation
	13	01:00 - 01:35	Kohoutek Data Take
		12:00 - 12:50	Stow
	14	21:35 - 21:55	Preparation
	15	01:15 - 01:50	Kohoutek Data Take
		12:00 - 12:50	Stow
	25	21:40 - 22:00	Preparation
	26	24:05 - 24:55	Kohoutek Data Take
		13:00 - 13:25	Atmospheric Data Take

	DOY	GMT	FUNCTION*
SL-4	32	20:50 - 21:25	Preparation
		23:50 - 24:05	Kohoutek Data Take
	33	24:05 - 24:45	Atmospheric Data Take
		01:00 - 01:30	Stow

* For details of Functional Objectives and Performance Requirements see Mission Requirements Document, 1-MRD-001F, Volume III, dated August 27, 1973.

Table B-VIII S230 Exposure Times

Collector	Beginning of Exposure (DOY)	End of Exposure (DOY)	Exposure Duration (DAYS)
Outer Cuff #1	135	218	83
Outer Cuff #2	135	218	83
Inner Cuff #1	218	265	47
Inner Cuff #2	218	034	181
Resupplied Inner Cuff	326	034	73

Table B-IX EREP Operation Times

	DOY	GMT	FUNCTION
SL-2	146	17:15 - 17:30	S190A/MDA Window Protector Install
	149	21:20 - 21:30	Checkout
	150	18:50 - 20:30	Preparation
		20:30 - 21:00	Data Take
	153	20:00 - 20:15	Data Take
	154	17:50 - 18:08	Data Take
	155	17:00 - 17:15	Data Take
	156	17:50 - 18:10	Data Take
	157	18:55 - 19:00	Data Take
	160	14:45 - 15:25	Data Take
	161	14:00 - 14:45	Data Take
	162	14:55 - 15:40	Data Take
	163	12:55 - 13:20	Data Take
	164	13:35 - 14:00	Data Take
	165	14:35 - 15:20	Data Take
		15:30 - 16:00	Data Take
SL-3	213	14:30 - 15:30	S192 Malfunction Procedure
		19:00 - 20:30	(Alignment)
		20:30 - 23:15	EREP Checkout
	214	21:15 - 23:15	S192 Alignment
	215	18:57 - 19:27	Data Take Pass 1, ETC not used
		13:30 - 13:55	S190A Optics Inspected and cleaned
			S190A Dessicants Replaced
	216	17:04 - 17:41	Data Take Pass 2
	217	14:55 - 15:09	Data Take Pass 3
		16:31 - 17:01	Data Take Pass 4
	219	20:30 - 21:00	S190A Optics cleaned
	220	15:51 - 16:26	Data Take Pass 5
	221	13:41 - 14:01	Data Take Pass 6 ETC not used
	222	20:50 - 21:00	S192 Alignment Checked
	223	15:25 - 15:48	Data Take Pass 7
		15:56 - 16:06	Data Take of Earth Limb S191 Door Appears Sluggish

	DOY	GMT	FUNCTION
SL-3	224	02:24 - 02:51	Data Take Pass 8
		14:44 - 15:11	Data Take Pass 9
		15:36 - 16:04	Lunar Calibration
			S191 Door Left Open
	229	12:30 - 13:15	S192 Test Run, with EDDU
			Downlink, and Live TV.
			Door Left Open Inadvertently
	237	00:45 - 00:55	S191 VTS Test of Mirror Gimbal
			Drive, Recorded on TV
	241	17:10 - 17:30	Data Take with ETC only
	243	18:25 - 18:35	Data Take with ETC only
	244	15:06 - 15:45	Data Take Pass 10
	245	14:20 - 15:00	Data Take Pass 11
		15:50 - 16:20	Data Take ETC Only
		17:54 - 18:02	Data Take Pass 12
	246	15:21 - 15:54	Data Take Pass 13 ETC not used
	247	14:41 - 15:10	Data Take Pass 14
		18:02 - 18:10	Data Take Pass 15 ETC not used
	249	21:19 - 21:33	Data Take Pass 16 (16A)
	250	20:20 - 20:50	Data Take ETC Only
		20:35 - 20:49	Data Take Pass 17
	251	13:05 - 13:30	Data Take ETC Only
	252	18:49 - 19:05	Data Take ETC Only
		19:04 - 19:34	Data Take Pass 18
	253	10:15 - 11:00	Data Take ETC Only
		18:24 - 18:45	Data Take Pass 19
		20:01 - 20:18	Data Take Pass 20
	254	12:50 - 13:06	Data Take ETC Only
		13:06 - 13:19	Data Take Pass 21
		13:46 - 13:59	Lunar Calibration
		20:59 - 21:08	Data Take Pass 23
	255	12:25 - 12:35	Data Take Pass 24
		16:52 - 17:15	Data Take Pass 25
		20:11 - 20:25	Data Take Pass 26
	256	17:53 - 18:13	Data Take Pass 27
		19:27 - 19:53	Data Take Pass 28
	257	17:04 - 17:31	Data Take Pass 29
			S193 Malfunction No ETC
	258	16:23 - 16:49	Data Take Pass 31
		17:58 - 18:22	Data Take Pass 32
		18:55 - 19:10	S190A Film Platens Cleaned
			S193 Antenna Motion Observed

	DOY	GMT	FUNCTION
SL-3	259	15:39 - 16:08	Data Take Pass 33
		17:16 - 17:31	Data Take Pass 34
	260	14:56 - 15:27	Data Take Pass 35
		00:19 - 00:29	Data Take Pass 36
		00:37 - 00:52	Data Take Earth Limb
	261	15:53 - 16:04	Data Take Pass 37
	262	13:53 - 14:05	Data Take Pass 38
		20:01 - 21:21	Data Take Pass 39
	263	14:15 - 14:30	S193 Malfunction Procedure
		20:52 - 21:07	Data Take Pass 40
	264	13:40 - 14:23	Data Take Pass 41
	265	16:37 - 18:37	Deactivation
SL-4	325	17:20 - 17:30	S191 Door Open
	331	18:20 - 18:40	ETC Knob and Clock Replacement
	333	18:54 - 19:17	Data Take Pass 3 (Solar Inertial)
	334	16:30 - 16:50	Data Take Pass 4
	335	17:23 - 17:50	Data Take Pass 5
	336	16:43 - 16:54	Data Take Pass 6
		18:16 - 18:29	Data Take Pass 7
	337	16:03 - 16:13	Data Take Pass 8 (without ETC)
		17:31 - 17:43	Data Take Pass 9 (without ETC)
	338	16:45 - 17:02	Data Take Pass 10
	339	16:05 - 16:25	Data Take Pass 11
	341	14:20 - 15:05	Data Take Pass 12
	342	02:15 - 02:40	Data Take Pass 14
	348	23:35 - 24:20	Data Take Pass 15
	349	12:30 - 12:40	ETC Only in Solar Inertial
	351	12:05 - 02:20	Data Take Pass 16 (without ETC)
	352	11:30 - 11:55	Data Take Pass 17 (without ETC)
	356	18:35 - 19:10	ETC Only
	01	13:10 - 13:50	Data Take Pass 18 (with S063)
	04	19:15 - 19:45	Data Take Pass 20
	06	17:50 - 18:20	Data Take Pass 21
	07	12:00 - 14:10	Calibrations
		17:10 - 17:35	Data Take Pass 22
	08	24:20 - 01:45	Calibrations
		15:20 - 16:50	Data Take Pass 23
		17:35 - 18:50	Data Take Pass 23 (without ETC)
	09	15:40 - 16:05	Data Take Pass 24 (without ETC)

	DOY	GMT	FUNCTION
SL-4	10	01:50 - 02:10	Data Take Pass 25
	11	17:25 - 17:55	Data Take Pass 26
	12	16:45 - 17:10	Data Take Pass 27
	14	15:05 - 15:50	Data Take Pass 29
		16:50 - 17:25	Data Take Pass 29
	15	17:50 - 20:50	S192 Detector Change Out
	16	17:55 - 19:00	S192 Data Take in Solar Inertial
	18	20:30 - 20:50	Data Take Pass 30
	19	21:25 - 21:45	Data Take Pass 31
	20	18:50 - 19:25	Data Take Pass 32
	21	19:45 - 20:40	Data Take Pass 35
	22	19:10 - 19:40	Data Take Pass 37
	24	17:45 - 18:15	Data Take Pass 40
	25	17:00 - 17:35	Data Take Pass 41 (with S063)
	26	19:40 - 20:15	Data Take Pass 42
	27	12:15 - 12:55	Data Take Pass 44
		18:55 - 19:25	Data Take Pass 45
	28	18:10 - 18:45	Data Take Pass 46
	29	17:20 - 17:55	Data Take Pass 47
	30	12:00 - 12:45	S190A and S193 Malfunction Procedures
		16:30 - 17:20	Data Take Pass 48
	31	14:40 - 15:50	Data Take Pass 49 (with S063)
		15:55 - 16:30	Data Take Pass 49 (with S063)
	32	16:40 - 17:15	Data Take Pass 50

* For details of Earth Resources Requirements see Mission Requirements Document, 1-MRD-001, Appendix B, Revision B, dated July 1973.

Table B-X D024 Samples Exposure Times

Samples	Beginning of Exposure (DOY)	End of Exposure (DOY)	Duration of Exposure (DAYS)
SL-2 Return	134	170	36
SL-3 Return	134	265	131
SL-4 Resupply and Return	326	034	73

Table B-XI T025 Operation and Exposure Times*

	DOY	GMT	FUNCTION
SL-4	325	15:20 - 17:00	Preparation for EVA
	326	17:45 - 24:20	Atmospheric Data Take and Malfunction
	353	16:40 - 17:20	Malfunction Procedure
	358	20:00 - 22:30	Preparation for EVA
	359	17:00 - 24:00	EVA Kohoutek Data Take
	360	01:40 - 02:20	Stow
	362	19:30 - 20:15	Preparation for EVA
	363	17:30 - 21:00	EVA Kohoutek Data Take
		23:40 - 24:20	Stow
	33	23:20 - 20:40	Preparation for EVA
	34	15:20 - 20:40	Atmospheric Data Take

*NOTE: Times of T025 uses for S073 data are shown in Table B-IV.

APPENDIX C

Availability of HOSC Contamination Mission Support Data.

In the performance of direct HOSC Skylab contamination mission support and contamination evaluation and assessment, contamination control data was requested, developed, and obtained by the CMSG. A majority of this data is presently in the custodial files of the Contamination Mission Support Group Leader, Mr. C. M. Davis, SL-EI, Marshall Space Flight Center, Huntsville, Alabama 35812. A supplemental data file is also being maintained by Mr. E. B. Ress, Martin Marietta Aerospace, Box 179, Denver, Colorado. The following is a compilation of the data obtained through various Data Request Forms (DRFs) to support the Skylab mission:

a) Data Book 12 from which EREP Quartz Crystal Microbalance (QCM) flight deposition and temperature plots and tabs were extracted and filed for archival data and future reference. Similar data was extracted from Data Book 4 for the ATM QCMs. (Sample rate - 1/30 sec.) These data are being retained in the supplemental file at MMC-Denver.

b) MOPS tabs of the EREP QCM flight deposition and temperature measurements (sample rate - 1/10 min). These data are being retained in the supplemental file at MMC-Denver. An additional set of these data is being maintained by Mr. W. Moore, S&E-SSL-PO, Marshall Space Flight Center, Huntsville, Alabama 35812.

c) Realtime tabs of the EREP QCM flight deposition and temperature measurements (sample rate - 1/90 min). These data are being retained in the supplemental file at MMC-Denver. An additional set of these data is also being maintained by Mr. W. Moore.

d) Crew comments and debriefing transcripts containing verbal responses to contamination DTOs and additional information pertinent to contamination events and phenomena. Copies of these data are being retained by the CMSG Leader at MSFC and in the supplemental file at MMC-Denver.

e) Wardroom window and STS window photographs in answer to contamination DTO's which indicate Skylab window degradation throughout the mission. These data are being retained in the supplemental file at MMC-Denver. An additional set of photographs was obtained by Mr. P. Craven, S&E-SSL-TT, Marshall Space Flight Center, Huntsville, Alabama 35812.

f) Skylab fly-around photographs in answer to contamination DTOs which indicate external surface contamination and degradation. These data are being retained in the supplemental files at MMC-Denver.

g) Skylab mission events tabulations including such data as experiment operation timelines, vent timelines, times of trim burns, etc. These data are being retained in the supplemental file at MMC-Denver.

h) As Flown Flight Plans which provide a record of the mission activities performed by the crews. These data are being retained by the CMSG at MSFC.

Additional supportive contamination data was developed by the CMSG and/or obtained through experiment principal investigators who furnished data, photographs, and in some cases flight samples for contamination analysis. The CMSG developed data includes a wide variety of Skylab contamination technical reports and the contamination prediction summary reports including:

a) Based on computer math modeling of the contaminant environment of Skylab throughout the entire mission, the contamination prediction summary reports were generated on a daily basis during SL-1/2 and weekly for the remainder of the program. These reports contain contaminant deposition predictions for critical operational surfaces and experiments along with induced environment predictions of particulate and molecular mass column densities and radiant scattering as a function of solar brightness ($B/B_{\odot}$) for experiment lines-of-sight (see Table 1.0.5-I for the final contamination prediction summary report). Where available, susceptible experiment maximum allowable contamination limits are presented to allow comparison with predicted levels which aided in the determination of required operational constraints. All predictions are based on the as-flown exposure timelines of the particular surface or experiment of interest. Copies of all contamination prediction summary reports are being retained by the CMSG at MSFC and in the supplemental file at MMC-Denver.

b) The items listed in Table C-I indicate those additional areas from which analytical contamination data has been obtained from various principal investigators and other miscellaneous sources. Included in the Table are data type, content, and the data supplier to the CMSG.

c) During the mission support phases of the Skylab Program, the CMSG responded to numerous Action Requests (ARs), Mission Action Requests (MARs) and other similar support requirements which required detailed contamination analysis and formal responses to the Huntsville Operations Support Center. Complete files of these contamination oriented action requests along with the CMSG responses are available through Mr. C. M. Davis, MSFC and Mr. E. B. Ress, Martin Marietta Aerospace.

Table C-I Additional Available Skylab Contamination Data

Date Source	Data Content	Where Available
S052 ATM Film	Particle Tracks	Mr. H. Weathers, S&E-SSL-X, Marshall Space Flight Center, Huntsville, Alabama 35812
S183 Photographs	Particle Tracks	Mr. H. Atkins, S&E-SSL-TE, MSFC, Huntsville, Alabama 35812
T027/S073 Tapes & Photographs	Particle Tracks & background scattering	Dr. J. Muscari, Martin Marietta Aerospace, Box 179, Denver, Colorado
T027A Samples & QCM's	External Deposition	↓
D024 Samples	External Deposition	Dr. W. Lehn, AF ML/NE Elastomers & Coating Branch Air Force Materials Lab, WPAFB, Dayton, Ohio
S230 Cuff Samples	External Deposition	Dr. J. Muscari, Martin Marietta Aerospace
S228 Silver Tape	Internal Deposition	Dr. J. Muscari, Martin Marietta Aerospace
Waste Tank Pressure Data	Non-propulsive vent source rates	Mr. E. Ress, Martin Marietta Aerospace
S019 AMS Photos	Mirror particulate & deposition data	Dr. C. Henize, Astronaut Office CB, JSC, Houston, Texas

APPENDIX D

Skylab Contamination Control Approach

D1

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1.0 General Discussion - On many satellite and manned space programs conducted prior to Skylab, it was found that contamination either impacted the mission objectives through degrading performance of experiment critical surfaces or causing major system failures such as shorting out of power supplies. Because of the long duration of the Skylab mission with its many sensitive optical experiments and with man as one of the major contamination sources, there was a significant effort to reduce the potential deleterious affects of contamination.

As a result of this, spacecraft contamination control became a new technical discipline that was developed as a major system on the Skylab program. This activity encompassed the control of optical contamination through identification of contamination sources, sensitive hardware, and levels of contamination that could be tolerated. This was subsequently translated into control requirements.

1.1 Background - The following discussions briefly address the history of optical contamination and the program direction for Skylab contamination control.

a. Discussion - The existence of a debris cloud surrounding a manned spacecraft in orbit was first noted by John Glenn on the MA-6 flight. The origin of these "fireflies" was later traced to ice crystals condensing from the hydrogen peroxide reaction control system. On later Gemini flights, the operation of other subsystems such as water boilers, fuel cells, and liquid water dumps produced noticeable contamination of the local spacecraft environment. Difficulty was reported in observing dim stars through the spacecraft windows that was first attributed to the scattering of sunlight by debris in the cloud that from visual estimates could produce an average optical interference background brightness of about 10^{-9} $(B/B_{\odot})$ of the sun. Further analytical and experimental test activities indicated that a small amount of debris on the spacecraft window surfaces, acquired either in ground handling or from deposition on the windows on orbit, could have produced the background brightness ratio observed on orbit. It became apparent that the observed spacecraft contamination not only could interfere with basic system functions such as reducing window visibility for rendezvous or star sightings but could seriously interfere or degrade any sensitive experiment exposed to such an environment.

On Gemini XII, a series of optical witness samples were flown to obtain quantitative data concerning the deposition effect of contamination during the boost phase, boost and orbit phase, and orbit only phase. These witness samples were returned and analyzed. Although the spectral range of the samples was limited, sufficient quantitative data was obtained to indicate that minute amounts of deposition either in a thin film state or as particulate deposition could present a serious degradation problem to instruments that would be measuring in the ultraviolet through the X-ray portion of the electromagnetic spectrum.

Subsequent manned and unmanned spacecraft flights have revealed a variety of problems that have been traced to contamination.

1.2 Contamination Effects - The atmosphere surrounding the Skylab is composed of the residual earth atmosphere at the Skylab altitude and molecular and particulate matter induced by the spacecraft systems. This induced atmosphere is dynamic and the spatial and temperal nature of it is not only dependent upon material, overboard venting characteristics, and orbital altitude, but is also dependent upon operational requirements, and the design philosophy of the spacecraft.

Deposition of material upon surfaces of a spacecraft from the induced atmosphere is known to alter surface characteristics and becomes a prime concern for extensive space missions with sophisticated ultra sensitive instrumentation. This deposited material is capable of altering transmission and reflection characteristics of optical surfaces, changing the absorptivity/emissivity of thermal control surfaces, and altering the resistance of electrical interfaces.

Additional degradation results from the induced mass column density of material along a given line-of-sight through the induced atmosphere. This mass column density is capable of emitting, absorbing, or scattering electromagnetic energy as a result of its molecular and particulate content. In addition, the induced atmosphere can interact with the residual earth's ambient atmosphere and be reflected back to the spacecraft providing an additional source of contaminants.

1.3 Identification of Sources & Experiments/Critical Surfaces

1.3.1 Sources - The various contaminant producing sources of the Orbital Assembly were identified, and the nature and characteristics of these sources established. The primary sources of concern were only those effective during the boost and orbital phases of the mission. The major sources identified are briefly discussed in this section. In general, the major source categories are:

a. Outgassing of vacuum exposed materials

b. Venting of liquids and gases

c. Cabin atmosphere leakage

d. Motor exhaust contaminants

e. Pyrotechnics

f. Extravehicular Activity (EVA)

a. Outgassing of Vacuum Exposed Materials - The total Cluster non-metallic area exposed to vacuum was approximately 250,000 ft^2. The average Cluster steady state outgassing rate was 200 grams/day assuming an average rate of 10^{-11} grams/cm^2-sec. (based upon material outgassing requirements as set forth in 50M02442). There were approximately 195 different non-metallic vacuum exposed materials with surface areas larger than 1 square foot on the Skylab cluster which were evaluated for contamination impact.

b. <u>Venting of Liquids and Gases</u> - The overboard venting of liquids and gases was a potential source of contamination during Skylab orbital operations. Since venting activities were basically controlled or preplanned activities, these sources and their impact were controlled to a degree by establishing mission rules and constraints to minimize their impact.

c. <u>Cabin Atmosphere Leakage</u> - The maximum specified cluster leakage was 14.7 lbs/day. However, the average leakage observed was approximately 3.75 lbs/day. The leakage products were mostly light gases, and therefore, were not expected to condense on critical surfaces.

d. <u>Motor Exhaust Contaminants</u> - Three engine subsystems were operated in the vicinity of the Skylab cluster; i.e., Service Module Reaction Control System (SM RCS), Thruster Attitude Control System (TACS), and the Stage II (SII) Retro-rockets.

The Service Module has four clusters of four 100 lb. thrust attitude engines each. These engines were used for orientation prior to navigation measurements; prior to Service Propulsion System (SPS) burn for ullage settling; for attitude control during SPS burn; for SM and CM separation; for orbit circularization and matching, and for translation and attitude control during rendezvous and docking.

Plumes from these engines are capable of momentarily interfering with experiment operation by causing transitory degradation of data in the field-of-view. Deposition from impingement of the plumes from these engines was expected to exist.

The Thruster Attitude Control System (TACS) was a cold nitrogen gas blowdown system with 1372 lb of N_2 available for the Skylab Mission. The engines were located on the $\pm Z$ axes at vehicle station number 2759. The thrusters are capable of producing a visible plume of condensed and frozen nitrogen particles, but the clearing times of the plumes are quite short. The visible plumes were calculated to dissipate in less than 3 seconds after thruster shutdown and were not expected to cause any significant data loss.

The four Stage II (SII) retrorocket engines were located on the forward end of the second stage of the Saturn V vehicle. The engines were used for SII/SIVB separation. Each engine provided 35,000 lbs of thrust. It is estimated that each engine expelled 188 lbs of exhaust material during the 1.5 second firing time. This produced an average mass flow rate of 125 lb/second which is capable of depositing upon externally exposed Workshop surfaces.

e. Pyrotechnic Devices - All pyrotechnic devices used on Skylab were the self contained design which precluded the possibility of contaminating the Cluster with products of combustion from this source.

f. EVA - EVAs were scheduled as required throughout the manned missions for Cluster repair, modifications, for the resupply and return of ATM film and specific experiment samples including D024, S230 and S149 and to conduct Kohoutek and Solar experiments.

Pressure suit ventilation exhaust particles were a local source of exterior spacecraft contamination during astronaut EVA but only a small percentage of experiments could be affected. A deflection shield was placed over the EVA suit Pressure Control Unit to deflect any particulate emitted to the rear of the astronaut. During SL-4 this deflector was removed to help reduce Cluster attitude control problems. Other sensitive surfaces were protected or too remote from the astronauts to be affected.

1.3.2 Experiments/Critical Surfaces - All Skylab experiments and systems were reviewed to determine their susceptibility to contamination. Critical items were identified from preliminary analyses and in-depth susceptibility analyses were performed on these items. With the advent of the comet Kohoutek, the experiment data gathering program for SL-4 was expanded. The use of new and existing experiments for observing Kohoutek required the implementation of additional contamination control actions to negate the effects of the major sources of contamination discussed above in Section 1.3.1 of Appendix D.

a. Experiments Susceptibility - Optical experiments were anticipated to be the most sensitive to the effects of contamination.

The Corollary, Earth Resources Experiments Package (EREP) and Apollo Telescope Mount (ATM) experiments were identified as being appreciably susceptible to contamination and are listed below:

Corollary

S019	UV Stellar Astronomy
S183	UV Panorama
S020	X-Ray UV Solar Astronomy
S063	UV Airglow Horizon Photography
S073	Gegenschein/Zodiacal Light
S149	Particle Collection
S150	Galactic X-Ray Mapping
S201	Far UV Electronographic Camera
S233	Kohoutek Photometric Photography
D024	Thermal Control Coatings
M415	Thermal Control Coatings
T025	Coronograph Contamination Measurements
T002	Manual Navigation Sightings

EREP

S190A	Multispectral Photographic Cameras
S190B	Earth Terrain Camera
S191	Infrared Spectrometer
S192	Multispectral Scanner
S193	Microwave Radiometer Scatterometer/Altimeter
S194	L-Band Radiometer

ATM

S052	White Light Coronograph
S054	X-Ray Spectrographic Telescope
S055	XYV Scanning Polychromator Spectroheliometer
S056	X-Ray Telescope
S082A	XUV Coronal Spectroheliograph
S082B	UV Spectrograph

Experiment susceptibility analyses were performed for each experiment. These analyses included detailed hardware analyses, experiment operational analyses, contamination susceptibility analyses, and recommendations for minimizing the contamination impact. Allowable experiment performance degradation limits were obtained from the experiment Principal Investigators and Experiment Managers. These limits were translated into deposition thicknesses, scattering levels, and mass column densities for comparison with contamination predictions.

b. Systems Susceptibility - The major systems identified as being susceptible to contamination were:

1) Thermal Control Surfaces - AM-STS, OWS, MDA and ATM surfaces

2) Solar Array Systems - ATM-SAS, OWS-SAS

3) Windows - OWS Wardroom Window, STS Windows, MDA Window, Scientific Airlock Window, CSM Windows

4) Attitude Pointing and Control System - Startracker

A methodology was developed for predicting the degradation of operational characteristics due to contamination for each of the systems listed. Available ground test data were used to establish the relative magnitudes of the degradation. These data were later used during prediction, and mission support and evaluation phases.

1.4 Contamination Control System Specifications - The following specifications were used to control the design and operational procedures for the Cluster contamination control activities.

1.4.1 Cluster Requirements Specification (CRS) - The Cluster Requirements Specification, RS003M00003, was the governing document for the design of Skylab. All of the Contract End Item Specifications (CEIS) for the design of modules and End Item Specifications (EISs) for the design of experiments were responsive to the requirements of the CRS. Section 3.2.2 of the CRS and the subsequent paragraphs defined the requirements for contamination control of the Skylab Cluster after assembly of the Cluster and continued through the launch and orbit phases. Contamination control of modules and experiments during design, manufacturing, test, and delivery phases was governed by the contamination control plan in the respective specifications which were written with the cognizance of CRS requirements.

1.4.2 Saturn Launch Vehicles and IU Requirements - The Saturn Launch Vehicles for Skylab were not directly governed by the CRS since they were not part of the orbiting assembly. However, Appendix J of the CRS imposed certain requirements on the Instrument Unit (IU) because it was retained with the Cluster. Paragraph 2.1.6 of Appendix J in the CRS specified contamination control for the IU. Subparagraphs governed IU contamination through the same phases of prelaunch and orbital operations as were imposed on basic cluster modules. Procedure and requirements for Flammability and Outgassing Evaluation, Manned Spacecraft Non Metallic Materials document MSC-D-NA-0002 was reviewed and found compatible with the MSFC Spec 101 Rev A. In addition, CSM vents were evaluated with operational recommendations made and accepted.

1.4.3 GSE Cleanliness - GSE required to support the Skylab Cluster during prelaunch activities was governed by Appendix I of the CRS. Paragraph 3.3.4 of the CRS specifies that cleanliness of GSE would be consistent with the cleanliness of the modules it supports.

1.4.4 Manufacturing and Shipping Cleanliness - Since the CRS was specified as effective after manufacture, many of the cleanliness requirements required during manufacturing of modules and experiments were not defined. As a function of Skylab Systems Integration, the Martin Marietta Corporation (MMC) Quality Section maintained surveillance of these requirements and the manner in which the contractor complied with them.

1.4.5 <u>KSC SL-I Stacked Cleanliness Document</u> - This document was used at the launch site to control cleanliness of the major Cluster subassemblies during their assembly and checkout on the launch pad. Included in this document are procedures for working inside the payload fairing without compromising its cleanliness criteria. In addition, it specified the cleanliness level of all fluids used including purge gases.

1.5 <u>Analytical Tool Development</u> - Contamination effects are seen basically in two aspects which are deposition and induced background brightness. Therefore, tools to assess and predict these effects were developed. Computer programs addressing these contamination phenomenon were developed prior to the mission based on the use of state-of-the-art, newly generated, and special test data. These models provided contamination prediction data for continuous mission support and mission evaluation throughout the orbital phase of the program. The models were updated with flight data as it became available. This was to assure that they provided the most accurate prediction data in support of the mission. These models proved to be invaluable during the mission in providing timely contamination prediction inputs to Cluster anomaly resolution.

For a detailed discussion of contamination control prediction modeling, see section 1.2.3 of this report.

1.5.1 <u>Supportive Test Programs</u> - This section contains a summary of large and small vacuum chamber tests conducted at various NASA and contractor locations to evaluate specific Skylab waste disposal and liquid venting systems. These test programs provided basic data for analytical modeling. In addition, they provided data for qualification of cluster systems with respect to contamination.

a. <u>Large Chamber Test</u> - Extensive experimental data were obtained on the major Skylab waste management vents for use in the contamination analytical math models being developed under the Skylab Contamination Assessment Program (SCAP). These models provide the methodology and analytical background to predict and assess the influence of contamination upon Skylab and the contaminant environment during actual Skylab operations.

The Skylab Contamination Ground Test Program (SCGTP) consisted of three specific tests conducted in the Martin Marietta Aerospace, Denver Division, large thermal vacuum chamber to provide explicit data on prototype Skylab waste management systems for contamination modeling. The systems evaluated in these tests were

1) Environmental Control System (ECS), which removes water (condensate) from the cabin atmosphere and normally vents into the Orbital Workshop waste tank or directly overboard in a contingency mode;

2) Molecular Sieve System (Mole Sieve), which removes primarily CO_2 and some water from the cabin atmosphere and vents continuously overboard in 15 minute cycles;

3) Orbital Workshop Waste Tank Non-Propulsive Vents (OWS-NPVs), which are continually open to vacuum and basically vents vapor resulting from the various liquid and gaseous inputs into the waste tank.

For details of this test program, see NASA Skylab Contamination Ground Test Program Test Report 10M33114 dated July 31, 1972.

b. Small Chamber Tests - A series of small chamber tests were conducted as prerequisite tests to the SCGTP for hardware design, test setup and operation, safety and to develop data for the Skylab Contamination Assessment Program and Skylab mission analysis.

The following small chamber tests were conducted:

1) Charging Tests of Liquid Vents - The purpose of this test was to determine the order of magnitude of charge generated when water is vented to vacuum from hardware simulating Skylab hardware and to identify the factors which control the magnitude of the charge.

It was thought that the results of these tests might determine that high voltage problems exist in the atmosphere surrounding the Skylab vehicle during liquid dumps. These problems could influence the deposition mechanisms of contamination on the spacecraft.

It was concluded from this test that nozzle shape had small effect on the magnitude of charge and an increase in pressure of one order of magnitude increased the voltage about 60%.

2) Urine Auto-Pressurization Test - The purpose of this test was to determine the pressure buildup of urine being stored for a period equivalent to the Skylab mission (nine months) in a sealed metal containers. In addition, it was to provide quantitative data under long term storage that the pressure buildup would or would not exceed design limits of urine storage bags (10 psi). It was felt that the bursting of the bags in the Skylab waste tank might provide a source of contamination from the non-propulsive vents.

   The results of this test indicated that the temperature and pressure inside a urine bag would stabilize at a level well below the design limits of the bag.

3) Nozzle Panel Electrode Test - The purpose of this test was to validate the high voltage grid assembly in a vacuum environment prior to committing the hardware to the large chamber tests.

   The results of this test indicated that the high voltage grid, as designed would not perform its intended function. All discharges resulted in an immediate breakdown of the electric potential (high current flow to ground structure and/or corona discharge) and resultant shutdown of the power supply. Based on this test, the high voltage grid assembly was deleted from the SCGTP.

4) OWS Waste Tank Filter Bench Tests; Phase I Verification Tests - The purpose of this test was to determine pressure drop flow of a variety of selected filters under Waste Tank conditions. In addition, this test was to determine filter effectiveness/liquid dump simulation to determine general effectiveness of filter in removing ice particles, along with an assessment of blockage characteristics.

   The results of this test indicated that there would be no excessive increase in the pressure drop across the OWS waste tank screen. This test also provided data to select the screen mesh for use in the Phase II Test.

5) OWS Waste Tank Screen Test; Phase II Verification Test - The purpose of this test was to provide more exact data on Waste Tank filter performance than determined in the Phase I Verification Test.

   The results of this test indicated that no observable particulate existed from the simulated NPV duct. In addition, the full-scale urine dump test confirmed that the OWS-WT pressure would remain well below the triple point during actual mission operations while venting urine into the Waste Tank.

6) Particle/Spray Quality of Nozzles Venting Liquids into Vacuum (Arnold Engineering Development Center (AEDC) - The purpose of this test was to find a nozzle configuration that would eliminate large ice formations when water is dumped into the vacuum of space. Based on the test results, it appeared that a configuration consisting of a quarter-inch diameter tube with either one or two 0.05-inch diameter orifices would perform better than the straight tube Skylab ECS condensate nozzle. These configurations did not completely eliminate ice formations, but provided a significant improvement over the present design.

It was concluded that additional nozzle tests and the SCGTP at MMC-Denver would provide information on nozzle performance.

7) Condensate Nozzle Verification Test - The purpose of this test program was to evaluate a series of prospective ECS condensate vent nozzle configurations and to recommend a nozzle to be used for the SCGTP. The nozzle selection criteria was based on that design which created the least amount of ice buildup at the nozzle assembly.

   Of all designs tested, it was concluded that a double tapered nozzle having an internal angle of 60^{o} and an external angle of 90^{o} performed the most satisfactorily.

   This design provided a sharp (knife) edge at the orifice. Under the test conditions specified in the test report, no ice cones were generated by this nozzle. In addition, this nozzle design produced the smallest size plume of ice particles of all nozzles tested.

8) Sublimation Rate of Ice Particles in Vacuum Simulating Space and Waste Tank Conditions - Bellcomm using SAO observational data had deduced the life-time of ice particles vented from Apollo to be 1000 minutes for particles larger than 750 and has analytically derived the e-folding time using assumed values of the real and imaginary dielectric constant. The predicted lifetime is severely sensitive to the value of imaginary dielectric constant assumed. It was accordingly necessary to determine by test if Skylab contaminants would sublime at a rate that was acceptable or prohibitive if Skylab could learn elsewhere (SCGTP) the size of particles it would be creating by venting.

   The results of these tests were inconclusive. Therefore, an Ice Particle Life Time Test was scheduled at a later date to determine ice sublimation data.

9) Ice Particle Lifetime Tests - The purpose of this test was to devise measures to and to conduct the necessary tests to determine the change in size of ice particles as a function of time under simulated Skylab environments. These environments include external to the cluster and internal to the waste tank.

   Data from this test program provided ice sublimation rates and other criteria pertinent to ice particles in space for use in the math model predictions.

10) Charge to Size Values of Ice Particles in a Vacuum - The purpose of this test was to determine the relationship between ice droplet size and the electrostatic charge the particle generates upon impact with the particle sensor electrode.

   The results of this test were inconclusive.

11) Effects of Urine/RCS Propellants on Solar Arrays - The purpose of this test was to determine the effects of urine/RCS Propellant contamination on the solar arrays.

   The results of the test indicated that the degradation of the solar cells was minimal. Without ultraviolet irradiation the deposited material was removed due to the action of the vacuum. With ultraviolet irradiation both the hydrazine and the urine deposits which were obtained did not pump off as readily. A total of 2 milliliters of the material was deposited at close range which was considered to be a worse case.

   Preliminary analysis of the data indicated that these dumps did not impose any significant degradation in the performance of the solar cell.

12) Molecular Sieve Contamination Test - Individual and mixed gas contaminant tests were performed. The purpose of the individual contaminant tests was to determine bed degradation as well as removal of contaminants by condensing heat exchanger, charcoal bed, and molecular sieve. The mixed gas test determined possible bed degradation with injection of a mixture of gases which simulated conditions expected on Skylab.

For information concerning data results of this test, the NASA-MSFC SSL office should be contacted.

13) LRC RCS Plume Definition Test - The purpose of this test was to determine RCS plume definition. The major contribution of this test was the determination of a sticking coefficient for a bipropellant (MMH/N_2O_4) rocket engine and the surface thermal changes (α/ϵ) resulting from these deposits. The results from this test were used in contamination assessment and evaluation modeling and analysis.

14) M479 Materials Flammability Test - The purpose of this test was to evaluate the potential hazards associated with the operation of the M479 Flammability Experiment. It provided data on toxicity, contamination, cleaning, timeline, and hardware performance.

For information concerning data results of this test, the NASA-MSFC S&E-ASTN-MEV office should be contacted.

1.5.2 Mission Data Acquisition

a. Data Request Forms - All requests for data necessary for contamination analyses were submitted, processed and implemented using the Data Request Forms (DRF). The Contamination Mission Support Group Technical Discipline Members were responsible for obtaining the requested data, processing it as required and providing it to the affected group members for assessment and evaluation. In cases where other organizations had a more basic need for specific data that was also required by the CMSG, such as the thermal group needing temperature data, instead of both organizations requesting the same data, the CMSG was made a secondary recipient of the data by the primary requesting group.

In addition to using DRF to obtain basic on-orbit test data, this form was the basis for obtaining Principal Investigator reduced data.

b. Detailed Test Objectives - Skylab mission functions and operations that were performed were covered in the Mission Requirements Document (MRD), 1-MRD-001. Contamination control related operations which were implemented by a Detailed Test Objective (DTO) were contained in this document. The functional objectives (FO's) of these DTO's which were requested for Skylab support are as follows:

1) Obtain data on the contamination effects of certain Cluster vent plumes and how these vent plumes and associated contamination changed with the duration of the mission.

2) Obtain data concerning the contamination on certain Cluster windows and how this contamination changed with the duration of the mission.

3) Obtain data concerning OWS vent plumes and contaminants deposited on certain Cluster external surfaces as viewed during EVA.

Since the implementation of these FO's were not mandatory, information received on their performance had to be established from crew transcripts and post splashdown briefings. In general, visual observations were made during the mission of specific vents. No plume sightings except TACS were observed. Pictures of the wardroom window and the 4 STS windows were made once during each of the SL-1/2, SL-3 and SL-4 flights.

1.6 Contamination Control Implementation - Based upon the identification of contamination sources, experiment/critical surfaces, contamination control system specifications, and the development of analytical tools; control measures were implemented on Skylab which would reduce the effects of contamination. This was accomplished by elimination of sources, design modifications, and establishing timeline constraints for orbital operations.

1.6.1 Mission Support and Evaluation Activities - The contamination control mission support and evaluation activities were carried out in accordance with a Skylab Contamination Support Plan developed prior to the mission. These activities were implemented by the Contamination Mission Support Group (CMSG) located at MSFC. The group was made up of a technical discipline team including members from the following Skylab technical groups:

Solar Array and Star Tracker
Thermal
Windows
Induced Atmosphere
ATM Experiments
Corollary Experiments

The CMSG Leader, in addition to the above, had a technical staff which was composed of Martin Marietta Aerospace, Denver Division contractor personnel which supported him on a daily basis througnout the missions.

The purpose of the CMSG was to evaluate the effects of the external Cluster contamination sources on selected experiments and sensitive cluster systems. In general, sources and susceptible equipment were designed and operated in a manner such as to minimize contamination effects through diligent application of material specifications and configuration and performance requirements. In special cases, test and analytical studies resulted in source or susceptibility improvement (e.g., relocation of vents and heating of windows). Through effective control measures, Skylab reduced the potential induced atmosphere interference effects and minimized contamination characteristics of sources. Through the use of existing Skylab system and experiment instrumentation, mission evaluation of the contamination effects was accomplished.

The CMSG performed premission, mission and post mission activities. Premission activities included training and mission simulation, technical discipline team coordination, computer model development, contamination prediction formulation and the processing of Data Request Forms (DRF) and Detailed Test Objectives (DTO).

During the mission, the CMSG analyzed data on a continuous basis to provide solution to any anomalous conditions, to determine contamination trends, and to establish contamination source information. For example, based on computer math modeling of the contaminant environment around Skylab, contamination prediction summary reports were generated on a daily basis during SL-1/2 and weekly for the remainder of the mission. The reports contained contamination deposition predictions for critical operational surfaces and experiments along with the induced environment predictions of mass column densities and radiant scattering. See Section 1.0.5 of this report for a detailed discussion of the Skylab contamination prediction summary.

The trend and source data were used to assess design performance and constraint effectiveness, to update mission prediction, and to resolve potential anomalies.

Mission evaluation was a longer term analysis activity which included assessment of all relative data generated during the mission operation activity period and also treated post mission splashdown data. This analysis activity evaluated the overall contamination trends, determined the degree of DTO completion, identified potential anomalies, formulated timely operational constraint recommendations where required and provided periodically mission predictions.

After splashdown of each segment of the mission, an evaluation report was published to provide a section of the Mission Evaluation Working Group Report. At the end of the mission, a final contamination control evaluation report was published that encompassed all pertinent data contained in the two previous evaluation reports.

1.6.2 Design Modifications - Based on studies and tests conducted by the Contamination Control and other affected organizations, a series of hardware and operational changes were implemented on Skylab to help reduce the affects of contamination. Specific areas affected were as follows:

a. Materials - Many material changes were made because of incompatibility between optical surfaces and material outgassing.

b. Vents - In general, effort was made to eliminate all overboard fluid dumps. In addition, where possible vents were relocated to take advantage of the best venting directions. Examples included the mole sieve and the condensate vent. Shielding was put on some vents including the M512, M479, and PCU for sensitive instrumentation protection. The condensate system and the M092 systems were rerouted into the OWS Waste Tank Filter system to reduce overboard contamination.

The contingency condensate primary vent was redesigned to reduce the size of plume and ice particles formed when this system was used.

c. Filters - Based on a ground test program, 2 micron nominal filters were placed in the OWS waste tank to control the size of particles coming out of the non-propulsive vents.

d. Operational Constraint Procedures - A number of operational constraint procedures were implemented as follows:

1) Procedures were instigated to control exposure of sensitive equipment relative to high contamination environments.

2) Experiment data acquisition was timelined to allow for clearing time of programmed vents that could cause loss of data.

3) Restrictions were placed on RCS engine firings to reduce contamination of the Cluster.

4) The condensate system dump procedures were changed such that condensate was stored for several days in a holding tank and then dumped in to the waste tank at an optimum time with respect to external contamination control.

5) The liquid flowrate to the OWS waste tank was controlled to assure that the liquid dumped in the waste tank remained below the triple point.

e. Cover - A cover was placed on the OWS aft radiator to protect it from the Stage II separation retrorocket firings.

f. Pyro-Technics - All pyrotechnic devices were of a self contained design so that no products of combustion could escape and provide a source of contamination.

g. Waste Material Bags - Many waste materials on board the Cluster were bagged prior to being dumped into the waste tank to enhance contamination control.

h. Payload Shroud - The jettisoning of the payload shroud was delayed until after separation of Stage II to protect the SL-1 from Stage II retrorocket contaminants.

i. The water source to the glycol evaporator was turned off at docking to eliminate this evaporated water as a contaminant source.

1.6.3 Operational Rules/Constraints - To minimize the effects of contamination with regard to experiments, it was necessary to impose numerous contamination mission rules and constraints on operational vent activities. These rules and constraints were effective between experiment and vehicle systems. The rules and constraints on each experiment and system were defined in the Mission Requirements Document for the mission.

For SL-1/2 the general contamination management rules were as follows:

Rule No.	Mission Rule
12-2	Deleted
12-3	CSM RCS firings will be minimized during dock/undock operations.
12-4	Where possible, experiments will be scheduled so that experiment contamination limits will not be exceeded.

Rule No.	Mission Rule
12-5	If any of the following contamination levels are experienced, a (ATM, EREP, Corollary) contamination alert will be issued by the indicated position:

Position	Source	Indicated Level	Type Alert
Corollary	ATM QCM	0.02×10^{-6} GMS/CM^2/HR	ATM
Corollary	EREP QCM	0.5×10^{-6} GMS/CM^2/HR	EREP/Corollary
ATM	S052	1×10^{-10} B/BO	ATM/Corollary/EREP
Corollary	T027/S073	1×10^{-14} B/BO	ATM/Corollary/EREP

Definition:

Contamination Alert: A situation where the contamination environment may be sufficiently high so as to consider changes in the nominal flight plan. An alert will be followed by a conference set up by Corollary which includes the Contamination team members, and representatives from the potentially effected discipline.

12-6 Vents will be planned such that there is minimum impact to experiment operation.

12-7 Normally during orbit shaping maneuvers, only the CSM + X thrusters will be used.

12-8 CSM urine and waste water must not be dumped within 1000 ft. of the SWS.

12-9 Deleted.

12-10 Aperture doors and experiment optics covers (including their windows) must be closed except during the data taking periods of the following experiments:

Corollary	EREP	ATM
S019	S190A	S052
S020	S190B	S055A
T027/S073	S191	
S063	S192	S082A
S183	STS Windows	S082B
T002		H-Alpha 1
		H-Alpha 2
		Star Tracker
		S054

Rule No.	Mission Rule
12-11	The contingency trash disposal plan will be utilized in the event of trash airlock malfunction and will be scheduled to have minimum effect in experiment operations.
12-12	Liquid dumps will be inhibited when Waste Tank pressures > 0.08 Psia as indicated by the waste processor outlet pressure or the Waste Tank low pressures. Waste tank pressures above the triple point of water result in the existence of free water in the Waste Tank.
12-13	Simultaneous liquid dumps into the Waste Tank from more than one source (dump nozzles) normally will not be performed to ensure Waste Tank pressures < 0.08 Psia. It may be necessary to inhibit atmosphere dumps into the Waste Tank during liquid dumps from another source. Trash airlock operation is permissible during liquid dumps into the Waste Tank.
12-14	Operational vent/experiment constraints matrix (See Table 1.0.4-I.

During the Skylab mission, Mission support activities identified certain desired modifications to the controls and constraints developed for SL-1/2 as a result of operational changes and assessment of the contamination environment. Changes to the General Contamination Mission Rules listed above are as follows:

1) Mission Rule 12-5: Delete EREP from contamination alert. Rationale-Cloud brightness levels of 10^{-14} B/B_0 as measured by the T027/S073 Photometer is well below the EREP sensitivity level.

2) Mission Rule 12-10: This Mission Rule is waived for S054. Rationale-The S054 do[illegible] was pinned open on SL-2.

3) Mission Rule 12-14: Delete S054 from the Operational Vent/Experiment constraint table. Rationale - The S054 door was pinned open on SL-2.

A prime consideration was to establish constraints to control the contamination effect of various venting operations. To implement this control, vent and operational constraints were established which are delineated in Table 1.0.4-I of this report. This table presents the operational vent/experiment constraints for all Skylab vents which would impact contamination sensitive experiments and systems. This table further indicates the nature of the contaminant effect and whether the vent is a scheduled or contingency vent.

As a result of operational changes on SL-3 and new experiments required for SL-4 Kohoutek observations and the new use of S063 with the AMS, changes were made to the mission rules and operational constraints over those developed at the start of the mission. Table 1.0.4-I contains the mission rules and operational constraints at the end of the Skylab mission and are representative of those operational constraints required to maintain contamination control of the mission.

1.7 <u>Conclusions</u> - Cluster external contamination evaluation made throughout the Skylab mission indicated that contamination control measures instigated during the design, development, and operational phases of this program reduced the contamination environment external to the Cluster in many cases below the threshold sensitivity levels for experiments and affected subsystem except for anomalous conditions. In addition, outgassing appeared to be a near steady state source of contamination as indicated in Figure 1.2.2.3-7.

APPROVAL

MSFC SKYLAB CONTAMINATION CONTROL SYSTEM
MISSION EVALUATION

By Contamination Mission Support Group

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Center. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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*U. S. Government Printing Office:-1974-748-298/184