

1

THE COPY

ESL-TR-87-71

AD-A208 813

# ENVIRONMENTAL EFFECTS OF SPACE SHUTTLE EXHAUST ON MATERIALS

W.H. ABBOTT

BATTELLE, COLUMBUS DIVISION  
505 KING AVENUE  
COLUMBUS OH 43201-2693

JANUARY 1989

FINAL REPORT

APRIL 1986 — AUGUST 1987

SDTICD  
ELECTE  
JUN 12 1989

CB H

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED



ENGINEERING & SERVICES LABORATORY  
AIR FORCE ENGINEERING & SERVICES CENTER  
TYNDALL AIR FORCE BASE, FLORIDA 32403

89 6 12 034

NOTICE

PLEASE DO NOT REQUEST COPIES OF THIS REPORT FROM  
HQ AFESC/RD (ENGINEERING AND SERVICES LABORATORY).

ADDITIONAL COPIES MAY BE PURCHASED FROM:

NATIONAL TECHNICAL INFORMATION SERVICE  
5285 PORT ROYAL ROAD  
SPRINGFIELD, VIRGINIA 22161

FEDERAL GOVERNMENT AGENCIES AND THEIR CONTRACTORS  
REGISTERED WITH DEFENSE TECHNICAL INFORMATION CENTER  
SHOULD DIRECT REQUESTS FOR COPIES OF THIS REPORT TO:

DEFENSE TECHNICAL INFORMATION CENTER  
CAMERON STATION  
ALEXANDRIA, VIRGINIA 22314

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED			1b. RESTRICTIVE MARKINGS		
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release Distribution Unlimited		
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE					
4. PERFORMING ORGANIZATION REPORT NUMBER(S) N/A			5. MONITORING ORGANIZATION REPORT NUMBER(S) ESL-TR-87-71		
6a. NAME OF PERFORMING ORGANIZATION Battelle, Columbus Division		6b. OFFICE SYMBOL (if applicable)	7a. NAME OF MONITORING ORGANIZATION Headquarters, Air Force Engineering and Services Center		
6c. ADDRESS (City, State, and ZIP Code) 505 King Avenue Columbus OH 43201-2693			7b. ADDRESS (City, State, and ZIP Code) Tyndall AFB FL 32403-6001		
8a. NAME OF FUNDING / SPONSORING ORGANIZATION HQ, Air Force Engineering & Services Center		8b. OFFICE SYMBOL (if applicable) RDVS	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER F08635-85-C0122		
8c. ADDRESS (City, State, and ZIP Code) Tyndall AFB FL 32403-6001			10. SOURCE OF FUNDING NUMBERS		
		PROGRAM ELEMENT NO. 62206 F	PROJECT NO. 1900	TASK NO. 20	WORK UNIT ACCESSION NO. 89
11. TITLE (Include Security Classification) Environmental Effects of Space Shuttle Exhaust on Materials (U)					
12. PERSONAL AUTHOR(S) W.H. Abbott					
13a. TYPE OF REPORT Final		13b. TIME COVERED FROM Apr 86 TO Aug 87		14. DATE OF REPORT (Year, Month, Day) January 1989	15. PAGE COUNT
16. SUPPLEMENTARY NOTATION Availability of this report is specified on reverse of front cover.					
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP	Corrosive monitoring, indoor pollution, corrosive rates on electronic components. (JES)		
19. ABSTRACT (Continue on reverse if necessary and identify by block number) Studies were conducted at Vandenberg Air Force Base to monitor the indoor environments associated with ground-based electronics at Shuttle Launch Complex 6 (SLC-6). Phase I, which is summarized in this report, was designed to determine baseline data prior to first launch of the space shuttle from this facility. During the course of the program, additional but similar studies were made at Vandenberg SLC-4 and Sunnyvale Air-Force Station. Results at SLC-6 showed very low indoor pollutant levels, particularly with respect to reactive chlorides. Severity levels, as defined by corrosion monitoring, were exceptionally low at all locations, indicating that baseline conditions were very satisfactory for modern electronics. However, humidity and humidity cycling problems associated with HVAC operations were demonstrated at several locations. This raised the possibility for high corrosion rates on electronic components where reactive chloride infiltration occurred. Significantly higher chloride levels were detected at SLC-4 for both prelaunch and postlaunch environments. This site was considered marginal with respect to both analyzed and potential corrosion phenomena on electronics.					
20. DISTRIBUTION / AVAILABILITY OF ABSTRACT <input type="checkbox"/> UNCLASSIFIED / UNLIMITED <input checked="" type="checkbox"/> SAME AS RPT <input type="checkbox"/> DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED		
22a. NAME OF RESPONSIBLE INDIVIDUAL Capt Lawrence E. Key			22b. TELEPHONE (Include Area Code) (904) 283-4234		22c. OFFICE SYMBOL HQ AFESC/RDVS

DD Form 1473, JUN 86

Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

(The reverse of this page is blank.)

UNCLASSIFIED



## TABLE OF CONTENTS

Section	Title	Page
I	INTRODUCTION.....	1
	A. OBJECTIVE.....	1
	B. BACKGROUND.....	1
	C. SCOPE.....	1
II	EXPERIMENTAL PROGRAM.....	3
	A. TEST SITES.....	3
	B. DEFINITIONS.....	4
	C. EXPERIMENTAL PROCEDURES.....	4
	1. Reactivity Monitoring.....	4
	2. Air Pollution Analysis.....	5
	3. Temperature-Humidity Monitoring.....	6
III	EXPERIMENTAL RESULTS.....	7
	A. REACTIVITY MONITORING - SIC-6.....	7
	B. AIR POLLUTION MONITORING.....	16
	C. TEMPERATURE-HUMIDITY MONITORING.....	16
	D. MONITORING AT SIC-4.....	18
	E. SUNNYVALE MONITORING.....	29
IV	CONCLUSIONS.....	34
	REFERENCES.....	35

## LIST OF TABLES

Table	Title	Page
1	DEFINITION OF SITES AND TERMS.....	4
2	RESULTS OF COPPER REACTIVITY MONITORING AT VANDENBERG AFB; SLC-6.....	8
3	RESULTS OF SILVER REACTIVITY MONITORING AT VANDENBERG AFB; SLC-6.....	12
4	RESULTS OF AIR POLLUTION MONITORING AT VANDENBERG AFB.....	17
5	TEMPERATURE AND HUMIDITY STATISTICS FROM VANDENBERG AFB.....	18
6	RESULTS OF COPPER REACTIVITY MONITORING AT VANDENBERG AFB; SLC-4.....	24
7	RESULTS OF SILVER REACTIVITY MONITORING AT VANDENBERG AFB; SLC-4.....	25
8	RESULTS OF COPPER REACTIVITY MONITORING AT SUNNYVALE AFS.....	31
9	RESULTS OF SILVER REACTIVITY MONITORING AT SUNNYVALE AFS.....	32

LIST OF FIGURES

Figure	Title	Page
1	Temperature and Relative Humidity Versus Time for Room 125.....	19
2	Temperature and Relative Humidity Versus Time for Room 104.....	20
3	Temperature and Relative Humidity Versus Time for SEB 1st Floor.....	21
4	Temperature and Relative Humidity Versus Time for LCC 118 and 119.....	22
5	Temperature and Relative Humidity Versus Time for MST Electrical Room.....	23
6	Temperature Versus Time for LCC 118, Room 125, and Room 104 at SLC-6.....	26
7	Temperature Versus Time for SEB 1st Floor and MST Electrical Room at SLC-6.....	27
8	Relative Humidity Versus Time for SEB 1st Floor and MSI Electrical Room at SLC-6.....	28
9	Relative Humidity Versus Time for Room 125, Room 104, and MSI Electrical Room at SLC-6.....	30
10	Temperature and Relative Humidity Versus Time at Vandenberg SLC-4.....	33

SECTION I  
INTRODUCTION

A. OBJECTIVE

This study was designed to evaluate the potential effects of the space shuttle exhaust on ground-based electronics, specifically the effects of HCl infiltration (possibly in combination with other pollutants) on short- and long-term electronics reliability.

B. BACKGROUND

Studies at Battelle and elsewhere have established that modern electronic components are highly susceptible to degradation by subtle corrosion reactions produced by ambient environments. Tolerable levels of critical pollutants are often in the range of no more than 1 to 3 parts per billion (ppb). However, these limits are sharply affected by the synergistic effects of other pollutants and humidity. For example, at high humidity (60 to 70 percent RH) and/or with considerable humidity cycling, the threshold levels for corrosion may be reduced by an order of magnitude or more.

The critical pollutants for electronics corrosion have been identified as: (1) reactive chlorides, and (2) reactive or reduced sulfides. Of these, the reactive chlorides may produce the most damaging corrosion reactions and at very low levels of gaseous concentration. In consideration of these facts, concern was expressed about the potential effects of HCl infiltration into ground-based electronics from the shuttle exhaust.

The objective of this report is to present the results and conclusion from baseline studies at SLC-6. These studies were initiated in July, 1985. The final samples were removed in January, 1986. The work was designed to study a variety of indoor electronics operating environments at SLC-6.

C. SCOPE

The problem presented in this work was to describe the operating environments in quantitative yet meaningful terms. Earlier work clearly demonstrated the synergistic effects of a multitude of environmental variables affecting corrosion. These include the most important items of:

1. Relative humidity
2. Gaseous pollutant concentrations
3. Humidity Cycling
4. Temperature
5. Air exchange rate

The relationship among these variables is so complex that measurements of any one or even all of these variables usually cannot be used to predict corrosion effects.

For this reason, an alternative form of monitoring has been extensively applied at Battelle to this type of problem. This has been termed reactivity monitoring. In principle, it involves the use of specially-prepared metallic sensors to detect, on an integrated basis, all factors in an operating environment which can produce corrosion. In effect, such integrated sensors are classical corrosion coupons.

Data from such sensors taken alone are relatively meaningless. However, extensive studies have been conducted at Battelle in a variety of operating environments to relate such data to probable effects on electronics reliability. Therefore, the same techniques were applied in this program and conclusions were reached by comparison to the Battelle data bases.

The primary sensor surface used in this work was copper. It has been demonstrated that this material can effectively be used to classify operating environments in terms of both absolute severity levels and chemistry. Details concerning these procedures have already been published (References 1 and 2). However, for the purposes of this study, the following characteristics for a truly benign (Class I) environment are as follows:

1. A film thickness less than 300 Angstroms after 1 to 3 months exposure.
2. A film chemistry consisting of only  $\text{Cu}_2\text{O}$ .

In environments of this type there is no precedent for expecting environmentally-related effects on reliability.

A second sensor material, silver, was also included in this work. Silver has proved useful as a very sensitive reactive chloride detector. The significance of data from this material is as follows. If no chlorides are detected in the operating environment it may generally indicate that higher, absolute reactivity levels (from copper) may be tolerated before equipment problems are encountered. Conversely, the detection of chloride may not guarantee that problems will occur, but it does serve as a warning of potential corrosion problems if humidity is not carefully controlled.

These techniques were applied throughout this program and at all sites. Data should, therefore, be analyzed relative to the criterion just given.

## SECTION II

### EXPERIMENTAL PROGRAM

The original intent of this program was to conduct the studies in three phases, as follows:

- Phase I - Background: This work would begin shortly after contract award and extend until approximately 2 weeks before first launch.
- Phase II - Launch/Post-Launch: This would start at the conclusion of Phase I and extend for a period of approximately 3 months.
- Phase III - Parallel Monitoring: This would start at the conclusion of Phase I and extend for a period of up to 6 months. Only the Phase I studies were conducted, beginning in July, 1985.

#### A. TEST SITES

The original program plan was to survey multiple sites throughout SLC-6. For this report, a site will be considered as a physical location of sample placement. For example, two sites might represent two sample sets at different locations within a given room or a single set in each of two rooms.

A total of 19 sites were monitored at SLC-6. Fifteen installations were made on July 17, 1985. Four additional installations were made on October 17, 1985. Finally, four of the original locations were resurveyed, beginning on January 17, 1986, to check for seasonal and/or time effects.

During the program interest also developed for similar monitoring at two other locations. The first was at the Sunnyvale Air Force Station, Sunnyvale, California. Two locations were monitored. The reason for this work originated in a high failure rate on some of the electronic equipment one location. This may have been a corrosion problem involving the outgassing of chlorinated products from PVC.

The final series of tests was at SLC-4 at Vandenberg Air Force Base. This site was of interest since it is an active launch site for the Titan vehicle, when using a solid fuel and can produce emissions similar to those from the shuttle solid fuel booster. Therefore, it was of interest to determine whether background levels of pollutants, and particularly chlorides, might be significantly different than those at SLC-6.

This work at SLC-4 began in March, 1986 and was completed in May, 1986. It is interesting to note that these data include the Titan launch and explosion of the vehicle from this facility.

## B. DEFINITIONS

More detailed descriptions of the physical sites will be associated with the actual data. This will indicate facility, room number, and location within rooms. However, a number of abbreviations will be used, as summarized in Table 1.

TABLE 1. DEFINITION OF SITES AND TERMS

LCC	Launch Control Center
SEB	Support Equipment Building
LMT	Launch Mount Tower
PCR	Payload Changeout Room
PPR	Payload Preparation Room
RAP	Return Air Plenum
SUB	Electrical Substation
S10B	Electrical Substation 10B
HIMS	Hardware Interface Module
i	Indicates Inside of Cabinet
t	Indicates on Top of Cabinet

## C. EXPERIMENTAL PROCEDURES

Although primary emphasis was placed on coupon/reactivity monitoring, measurements were made at some locations of individual environmental variables. These included temperature, humidity, and low-level air pollutants.

### 1. Reactivity Monitoring

The samples used for reactivity monitoring - silver and copper - were prepared at Battelle in the form of solid metal coupons. These had dimensions of 0.025 by 0.50 by 3.0 inches. Each coupon had a 1/8-inch diameter hole at either end. These were used to mount the coupons rigidly onto plastic cards using nylon screws, nuts, and standoffs. The standoffs provided a vertical elevation above the cards of about 0.4 inches to allow air circulation. One set of two samples was mounted on a plastic card, which in turn had dimensions of 4 inches by 5 inches.

The coupons were cleaned and prepared to a standard surface finish, using a modified metallographic abrasion procedure. Details of this procedure can be found in Reference 2.

Individual sample cards were wrapped in plastic film and enclosed in Ziploc polyethylene bags for transport. The samples were removed from this protection only at the point of installation. This process was reversed when the sample cards were removed from exposure.

Two cards were installed at each location, obtain two exposure periods, tentatively set at 3 and 6 months, respectively.

The test cards were held in a vertical orientation in a small, plastic card guide, also provided by Battelle. This free-standing package allowed free and realistic air circulation around the samples. This package was placed either in rooms or inside cabinets.

As samples were removed from exposure and returned to Battelle, analyses were conducted to determine amounts of surface film and film chemistries. The analytical technique was an electrochemical procedure known as cathodic reduction. Details of this procedure may also be found in Reference 2.

For purposes of comparison, data were extrapolated to a standard exposure period of 1 year. The basis for extrapolation was as follows. If the analyzed film thickness was  $< 300$  angstroms, and if the film was exclusively  $\text{Cu}_2\text{O}$ , no extrapolation was required. Experience had shown that such conditions were characteristic of a limiting film thickness, i.e., no further growth would occur. If, however, the film thickness on copper exceeded 300 angstroms at any point beyond 3 months, the data were extrapolated on the basis of parabolic kinetics, i.e., film thickness would increase proportional to the square root of time.

Data for silver were also extrapolated although, as indicated earlier, the real significance of the silver data related to the presence or absence of chlorides. Earlier work had shown that silver is unique in that it will form surface films (sulfides and chlorides) according to linear kinetics. This was the basis for the data extrapolation.

## 2. Air Pollution Analysis

Four items were studied in the pollution monitoring. These included three gas species and particulates. The gas species included: (1) reactive sulfides (primarily  $\text{H}_2\text{S}$ ), (2) reactive chlorides, and (3) sulfur dioxide. An integrated monitoring technique similar to that described by Lorenzen (Reference 3) was used in this work. This utilized a small plastic cartridge (Millipore) containing a series of four filters. The first was a Nucleopore 3.0-micron membrane filter for particulate removal. The remaining three filters selectively removed: (1) reactive chlorides, (2) reactive sulfides, and (3)  $\text{SO}_2$ .

Particulate filters were analyzed gravimetrically to determine mass loading. The chemical filters were analyzed at Battelle using X-ray fluorescence techniques. The amount of material collected on each filter was determined and compared to known standards.

The filter cartridges were used in conjunction with a small pumping system provided by Battelle. This system maintained a constant air flow rate through the cartridge of 1 liter per minute through a standard 1/4-inch diameter inlet orifice. Therefore, from a knowledge of the sampling time, the total air volume drawn through the cartridge was known. This was used to calculate average concentrations in the gas phase for the four items mentioned above.

This type of pollution monitoring was conducted only at selected sites. The standard monitoring period was tentatively planned as 1 week. However, in some locations this was extended considerably. This was due to the low levels of pollutants found from initial monitoring resulting in a need for a longer sampling period.

### 3. Temperature-Humidity Monitoring

A small data acquisition system was provided by Battelle to obtain temperature-humidity data at selected sites. The data acquisition system used was a grant SQ2 meter/logger. The sensors used included a thermistor temperature probe and a humidity probe (Vaisala, Model HMP 230). These were calibrated at Battelle. Accuracy was estimated at  $\pm 0.2^{\circ}\text{C}$  and  $\pm 0.5$  percent RH.

These units were programmed to take readings at 1-hour intervals and store the results in memory. Sufficient memory was available to obtain about 2 months worth of data. The typical operating sequence was to commit the system to monitoring for 1 month at the first location, then move the system to a second location for an additional month. At this point, the system was returned to Battelle for data readout, analysis, and recalibration.

SECTION III  
EXPERIMENTAL RESULTS

A. REACTIVITY MONITORING - SLC-6

The results for baseline monitoring at SLC-6 are summarized in Tables 2 and 3. On the basis of copper reactivity data, and in consideration of the criterion given earlier, all of the indoor locations showed exceptionally low reactivity levels. All of the environments studied qualified as Class I conditions. This means that, for the operating conditions being experienced at SLC-6, total environmental control was excellent and no basis could be expected for equipment degradation under those conditions. These results may have broad implications for other locations, since experience has shown that it is somewhat unusual to find a large facility such as this to have all locations qualifying as benign.

These results apply strictly to the indoor or in-equipment environments, which are totally different than the outdoor environments. In fact, the data were accidentally obtained to demonstrate that the outdoor environments at Vandenberg, or at least at SLC-6 may be considered corrosive towards electronics. Such results were associated with the sampling at S10B. Originally the samples were placed in the facility as they were at Sub 5. At the 3-month point for sample retrieval it was learned that the samples had been moved to a location outside of the substation, which effectively provided an outdoor exposure. The effective period of the outdoor exposure was unknown, but was estimated by Lockheed personnel to be no more than about 1 month. Because the similarity of Sub 5 and S10B, the indoor data would probably be the same at both locations; therefore, it is reasonable to assume that the data shown for S10B are entirely the result of the outdoor exposure. These data qualify as a relatively corrosive environment. In fact, the data for silver also show a high chloride content, as might be expected for this sea coast location. These results are important since they clearly demonstrate the large degree of natural environmental attenuation that can occur within buildings or other structures.

The indoor results for silver at SLC-6 proved particularly interesting during the latter stages of sampling. The initial results for July through October, 1985, show little or no indoor chloride. Subsequent samples at some locations after January, 1986, did show detectable levels at values which could be potentially significant. Indoor reactive chlorides are generally not associated with outdoor aerosol sources, such as NaCl. Instead, they are usually internally generated from a variety of organic and inorganic sources. This may include such diverse sources such as outgassing products, floor cleaning solutions, etc. Unfortunately, there is not sufficient documentation to determine the most probable sources.

TABLE 2. RESULTS OF COPPER REACTIVITY MONITORING AT VANDENBERG AFB; SLC-6

Location	Date Installed	Date Removed	Sample ID	Actual Film Thickness, Å			Projected 1-year Film Thickness, Å
				Unknown	Oxide	Sulfide	
LCC 118/119 iVSI-C1	7/17/85	10/17/85	1570	--	171	--	171
	7/17/85	1/17/86	1575	--	190	--	190
	1/17/86	1/29/87	2245	--	152	--	152
	1/17/86	1/29/87	2246	--	179	--	179
LCC 118/119 tVSI-C1	7/17/85	10/17/85	309	--	141	--	141
	7/17/85	1/17/86	534	--	171	--	171
	1/17/86	1/29/87	2241	--	200	--	200
LCC 125 t494A5	1/17/86	1/29/87	2242	--	171	--	171
	7/17/85	10/17/85	590	--	171	--	171
	7/17/85	1/17/86	537	--	206	--	206
	1/17/86	1/29/87	2253	--	171	--	171
	1/17/86	1/29/87	2254	--	171	--	171

TABLE 2. RESULTS OF COPPER REACTIVITY MONITORING AT VANDENBERG AFB; SLC-6  
(CONTINUED)

Location	Date Installed	Date Removed	Sample ID	Actual Film Thickness, Å			Projected 1-year Film Thickness, Å
				Unknown	Oxide	Sulfide	
LCC 104 t02.3	7/17/85	10/17/85	1342	--	179	--	179
	7/17/85	1/17/85	1342	--	162	--	162
	1/17/86	1/29/87	2252	--	152	--	152
	1/17/86	1/29/87	1663	--	155	--	155
LCC 205 iTD Console	7/17/85	10/17/85	310	--	133	--	133
	7/17/85	1/17/86	320	--	152	--	152
LCC 205 t Halon Box	7/17/85	10/17/85	748	--	152	--	152
	7/17/85	1/17/86	395	--	114	--	114
LCC 202 t 4401A3	1/17/86	1/29/87	2244	--	209	--	209
	7/17/85	10/17/85	451	--	133	--	133
	7/17/85	1/17/86	368	--	143	--	143
	1/17/86	Lost	2243	--	--	--	--
LCC 216 t J008	1/17/86	Lost	2255	--	--	--	--
	7/17/85	10/17/85	1572	--	205	--	205
	7/17/85	1/17/86	1574	--	190	--	190
	1/17/86	1/29/87	2256	--	205	--	209
	1/17/86	1/29/87	2257	--	219	--	219

TABLE 2. RESULTS OF COPPER REACTIVITY MONITORING AT VANDEMBERG AFB; SLC-6  
(CONTINUED)

Location	Date Installed	Date Removed	Sample ID	Actual Film Thickness, Å			Projected 1-year Film Thickness, Å
				Unknown	Oxide	Sulfide	
SEB, 1st Flr, t 6671	7/17/85	10/17/85	306	--	171	--	171
	7/17/85	1/17/86	492	--	238	--	238
	1/17/86	1/29/87	2239	--	209	--	209
	1/17/86	1/29/87	2240	--	200	--	200
MST, LV1, HIMS 4276A1	7/17/85	10/17/85	1569	--	114	--	114
	7/17/85	1/17/86	1567	--	171	--	171
LMT, LV2, t 6889	1/17/86	1/29/87	2258	--	152	--	152
	7/17/85	Lost	586	--	--	--	--
PCR, LV5, HIMS t TD303	7/17/85	Lost	19	--	--	--	--
	7/17/85	Lost	495	--	--	--	--
	7/17/85	Lost	390	--	--	--	--
SUB 5, tw. Rail	7/17/85	10/17/87	1347	--	162	--	162
	7/17/85	1/17/86	1364	--	171	--	171
	1/17/86	1/29/87	1667	--	190	--	190
S10B, tn. Rail	1/17/86	1/29/87	2247	--	238	--	238
	7/17/85	?(1)	378	2186	--	--	2186
	7/17/85	?(a)	505	1395	--	--	1395

TABLE 2. RESULTS OF COPPER REACTIVITY MONITORING AT VANDENBERG AFB; SLC-6  
(CONCLUDED)

Location	Date Installed	Date Removed	Sample ID	Unknown	Oxide	Sulfide	Total	Projected 1-year Film Thickness, Å
PPR, Cell 3, R.A.P.	10/17/85	1/29/87	739	--	291	--	291	291
	10/17/85	1/29/87	58	--	283	--	283	283
PPR, Cell 2, R.A.P.	10/17/85	1/29/87	1355	--	374	--	374	374
	10/17/85	1/29/87	308	--	296	--	296	296
PPR, Cell 1, R.A.P.	10/17/85	Lost	305	--	--	--	--	--
	10/17/85	Lost	813	--	--	--	--	--
PPR, Tunnel Inlet	10/17/85	Lost	300	--	--	--	--	--
	10/17/85	Lost	301	--	--	--	--	--

(a) Samples found outdoors 10/17/85; effective outdoor exposure time unknown.

TABLE 3. RESULTS OF SILVER REACTIVITY MONITORING AT VANDENBERG AFB; SLC-6

Location	Date Installed	Date Removed	Sample ID	Actual Film Thickness, Å		Projected 1-year Film Thickness, Å
				Chloride	Sulfide Total	
LCC 118/119 iVSI-C1	7/17/85	10/17/85	1570	--	24	24
	7/17/85	1/17/86	1575	--	43	43
	1/17/86	1/29/87	2245	38	40	78
	1/17/86	1/29/87	2246	67	38	105
LCC 118/119 tVSI-C1	7/17/85	10/17/85	309	--	32	32
	7/17/85	1/17/86	534	--	43	43
	1/17/86	1/29/87	2241	25	98	123
	1/17/86	1/29/87	2242	42	98	140
LCC 125 t494A5	7/17/85	10/17/85	590	--	8	8
	7/17/85	1/17/86	537	--	21	21
	1/17/86	1/29/87	2253	29	21	50
	1/17/86	1/29/87	2254	38	40	78
LCC 104 t02.3	7/17/85	10/17/85	1342	--	21	21
	7/17/85	1/17/86	1343	--	38	38
	1/17/86	1/29/87	2252	38	76	114
	1/17/86	1/29/87	1663	46	81	127

TABLE 3. RESULTS OF SILVER REACTIVITY MONITORING AT VANDENBERG AFB; SLC-6  
(CONTINUED)

Location	Date Installed	Date Removed	Sample ID	Actual Film Thickness, Å			Projected 1-year Film Thickness, Å
				Chloride	Sulfide	Total	
LCC 205 iTD Console	7/17/85	10/17/85	310	33	38	71	287
	7/17/85	1/17/86	320	--	95	95	192
LCC 205 t Halon Box	7/17/85	10/17/85	748	--	21	21	85
	7/17/85	1/17/86	395	33	43	76	154
	1/17/86	1/29/87	2244	59	103	162	162
LCC 202 t 4401A3	7/17/85	10/17/85	451	0	21	21	85
	7/17/85	1/17/86	368	25	98	123	249
	1/17/86	Lost	2243	--	--	--	--
	1/17/86	Lost	2255	--	--	--	--
LCC 216 tJ008	7/17/85	10/17/85	1572	25	40	65	263
	7/17/85	1/17/86	1574	--	177	177	358
	1/17/86	1/29/87	2256	110	117	127	227
	1/17/86	1/29/87	2257	76	110	186	186
SEB, 1st Flr, t 6671	7/17/85	10/17/85	306	253	27	280	1133
	7/17/85	1/17/86	492	105	68	173	350
	1/17/86	1/29/87	2239	126	40	166	166
	1/17/86	1/29/87	2240	126	40	166	166

TABLE 3. RESULTS OF SILVER REACTIVITY MONITORING AT VANDENBERG AFB; SLC-6  
(CONTINUED)

Location	Date Installed	Date Removed	Sample ID	Actual Film Thickness, Å		Projected 1-year Film Thickness, Å
				Chloride	Sulfide	
MST, LV1, HIMS 4276A1	7/17/85	10/17/85	1569	118	19	137
	7/17/85	1/17/86	1567	42	32	74
	1/17/86	1/29/87	2258	38	40	78
LMT, LV2, t 6889	7/17/85	Lost	586	--	--	--
	7/17/85	Lost	19	--	--	--
PCR LV5 HIMS t TD303	7/17/85	Lost	495	--	--	--
	7/17/85	Lost	390	--	--	--
SUB 5, tw. Rai1	7/17/85	10/17/85	1347	50	13	63
	7/17/85	1/17/86	1364	148	16	164
	1/17/86	1/29/87	1667	253	27	280
S10B, tn. Rai1	1/17/86	1/29/87	2247	338	49	387
	7/17/85	?(a)	378	186	10	196
	7/17/85	?(a)	505	486	27	513

TABLE 3. RESULTS OF SILVER REACTIVITY MONITORING AT VANDENBERG AFB; SLC-6  
(CONCLUDED)

Location	Date Installed	Date Removed	Sample ID	Actual Film Thickness, Å		Projected 1-year Film Thickness, Å
				Chloride	Sulfide	
PPR, Cell 3, R.A.P.	10/17/85	1/29/87	739	156	115	271
	10/17/85	1/29/87	58	177	92	269
PPR, Cell 2, R.A.P.	10/17/85	1/29/87	1355	296	109	405
	10/17/85	1/29/87	308	317	136	453
PPR, Cell 1, R.A.P.	10/17/85	Lost	305	--	--	--
	10/17/85	Lost	813	--	--	--
PPR, Tunnel Inlet	10/17/85	Lost	301	--	--	--

(a) Samples Found Outdoors 10/17/85; effective outdoor exposure time unknown.

The latter data are important because they may illustrate important changes that can occur with the aging and/or operation of a facility. The results become particularly significant when combined with the humidity data to be discussed in the following section on temperature-humidity monitoring.

#### B. AIR POLLUTION MONITORING

The results for SLC-6 and SLC-4 are summarized in Table 4. The latter results will be discussed separately.

The pollution monitoring results are quite consistent with the reactivity data. In general, the background levels at SLC-6 were found to be quite low, particularly during the early stages of monitoring. However, consistent with the silver data, these values did appear to increase with time. This was particularly noticeable in the LCC for the monitoring period towards the end of 1985. Similar increases to detectable levels were found in the SEB, LMT, and PCR. The most significant increases were for reactive chlorides expressed as a chlorine equivalent. This does not imply that the reactive species is chlorine, either wholly or in part. Values at LCC 125 were considered to approach a level of concern if humidity levels were not closely controlled.

#### C. TEMPERATURE-HUMIDITY MONITORING

The statistics for those sites monitored at SLC-6 and SLC-4 are summarized in Table 5. These results, however, may not adequately depict a critical element associated with humidity. This is the degree of humidity cycling/stability. Empirical findings have indicated that humidity cycling may be at least as important as other measures of humidity, such as average or median. It is well-established that as average levels of humidity increase, corrosion rates will increase in an exponential manner. Studies at Battelle however have indicated that, as the degree of humidity cycling increases, corrosion rates will also increase sharply, as both the time rate of change humidity increases and the frequency of occurrence of humidity cycling increases.

TABLE 4. RESULTS OF AIR POLLUTION MONITORING AT VANDENBERG AFB

Location	Date Installed	Date Removed	Cartridge ID	Particulates	Concentration, $\mu\text{g}/\text{m}^3$		
					Cl <sub>2</sub>	H <sub>2</sub> S	SO <sub>2</sub>
<b>SLC-6</b>							
LCC 118/119	7/17	7/25	412	2.6	<.02	<.02	<.02
LCC 125	7/25	8/1	416	3.9	<.02	<.02	<.02
LCC 125	9/30	11/6	440	1.9	.096	.039	.19
LCC 104	8/1	8/8	414	3.5	<.02	<.02	<.02
SEB 1st Flr	8/8	8/30	411	12.7	.036	.028	.031
LMT LVL 1	8/30	9/20	441	3.3	.066	.021	.032
PCR LV5	11/6	1/20/86	6.5	.046	.10	.09	
<b>SLC-4</b>							
Comp. Rm LOB	3/6	4/11	444	1.9	.074	.058	.04
Comp. Rm LOB	4/11	5/15	442	2.0	.092	.058	.04

TABLE 5. TEMPERATURE AND HUMIDITY STATISTICS  
FROM VANDENBERG AFB

<u>Location</u>	<u>Temperature, °C</u>			<u>Relative Humidity</u>		
	<u>Max.</u>	<u>Min.</u>	<u>T<sup>(a)</sup></u>	<u>Max.</u>	<u>Min.</u>	<u>RH<sup>(a)</sup></u>
SLC-6						
LCC 118	23.	16.	- 3.8	66.	42.	13.
LCC 125	18.8	17.8	- 3.6	75.	62.5	21.
LCC 104	28.	25.4	8.8	44.5	36.	-21.5
SEB 1st Floor	24.	14.2	-12.	79.5	32.5	34.5
MST Elec. Rm	28.6	14.6	2.8	81.	21.	20.5
SLC-4						
Comp. Rm	23.2	18.2	- 3	47.	25.	8.5

(a) Maximum Rate of Change °C/Hr or %RH/Hr.

The results from four locations at SLC-6 are shown in Figures 1 through 5. These data confirm findings at many other indoor locations within the United States. They indicate that, in general, temperature is well-controlled. However, in many locations humidity is not.

The results from LCC 125 are particularly interesting. They show high, but stable, humidity during the period monitored. This could be attributed to the mode of air-conditioning operation which maintained this room relatively cool, together with the fact that there was a small heat load. This level of humidity, if it were maintained, is believed to approach values which could significantly increase corrosion rates for the levels of indoor chlorides found in the latter stages of monitoring. It is unfortunate, therefore, that temperature-humidity data were not obtained during early 1986 to coincide with the other forms of monitoring. The data may therefore be important to illustrate the subtle effects which operating conditions such as those associated with air conditioning can potentially have on equipment performance. Additional data can be found in Figures 5 through 8, which compare results at different sites.

#### D. MONITORING AT SLC-4

All of the available data for SLC-4 are summarized in Tables 6 and 7 and Figure 10. Additional samples and monitoring equipment had been placed at this facility, but were lost following the Titan mishap. Reference should also be made to Tables 4 and 5 for air pollution and temperature-humidity statistics.

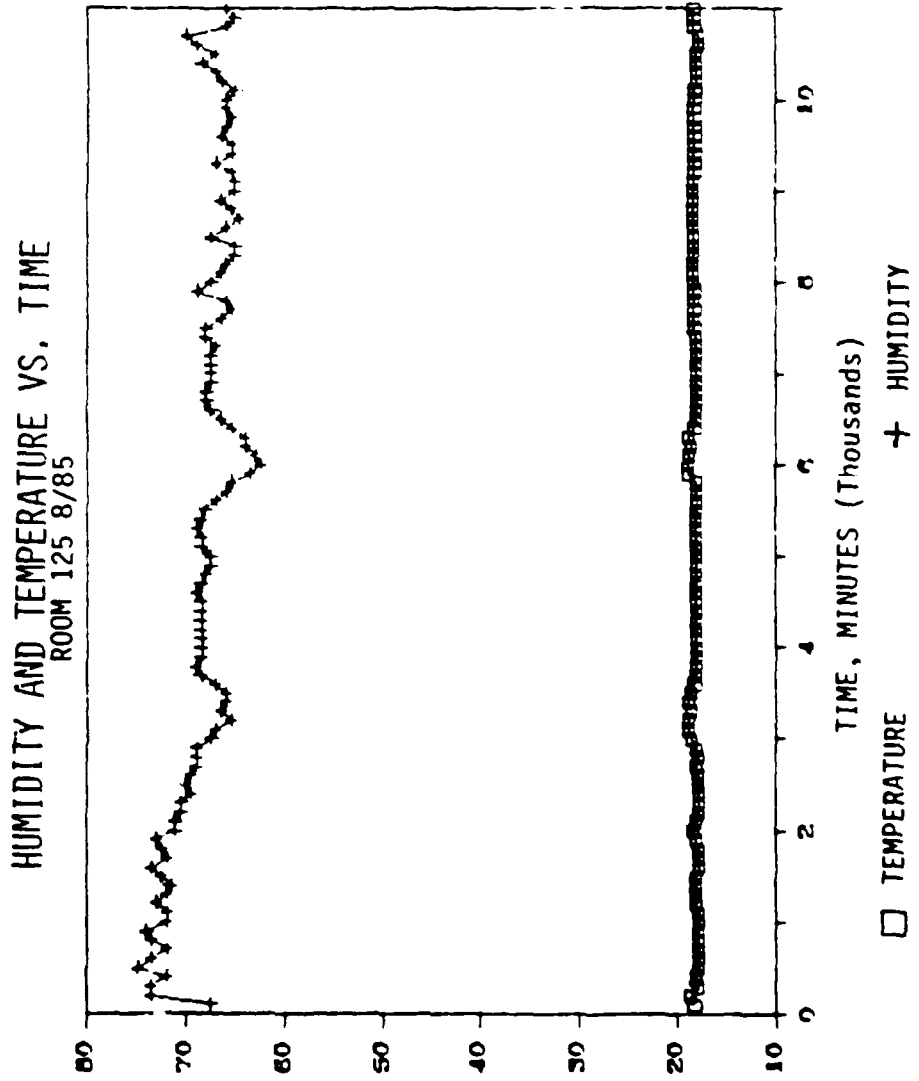


Figure 1. Temperature and Relative Humidity Versus Time for Room 125

TEMPERATURE OR HUMIDITY

HUMIDITY AND TEMPERATURE VS. TIME  
ROOM 104 8/85

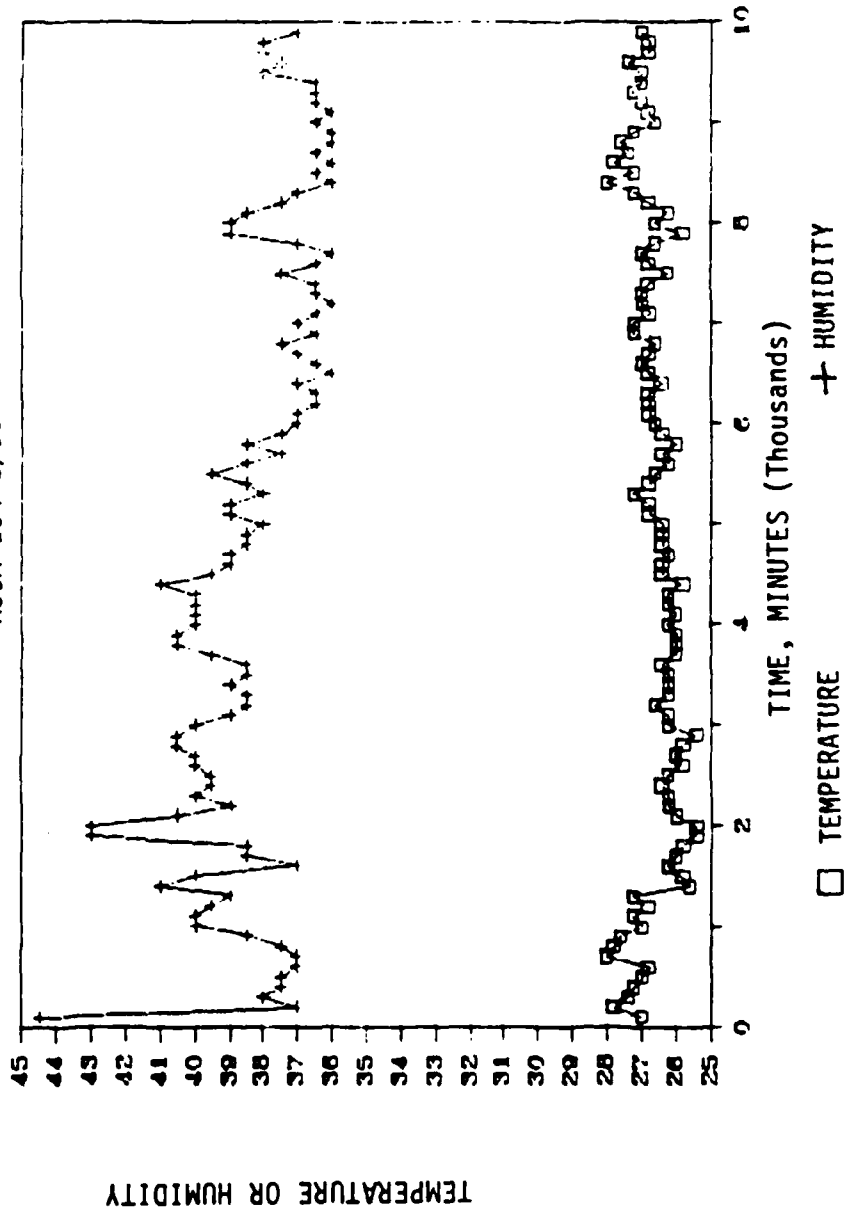


Figure 2. Temperature and Relative Humidity Versus Time for Room 104

HUMIDITY AND TEMPERATURE VS. TIME  
SEB 1st FLOOR 8/85

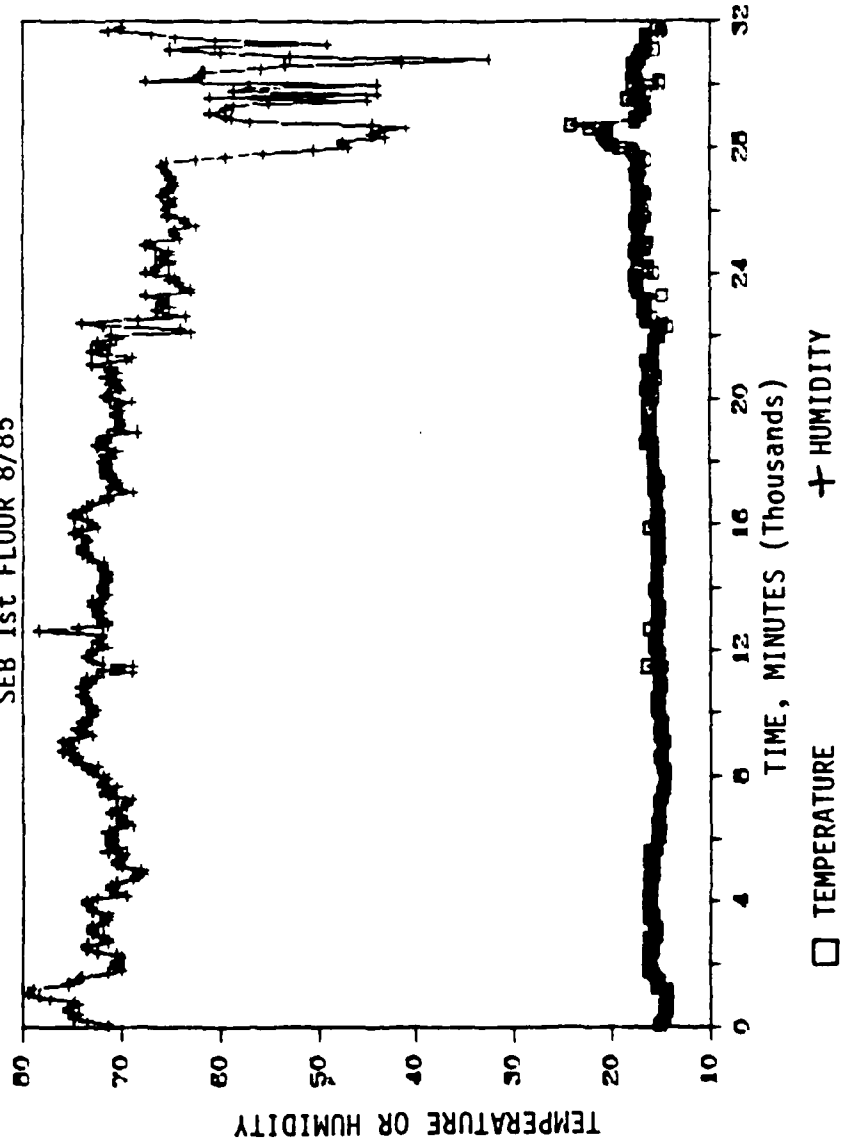


Figure 3. Temperature and Relative Humidity Versus Time for SEB 1st Floor

HUMIDITY AND TEMPERATURE VS. TIME  
LCC 118,119 7/85

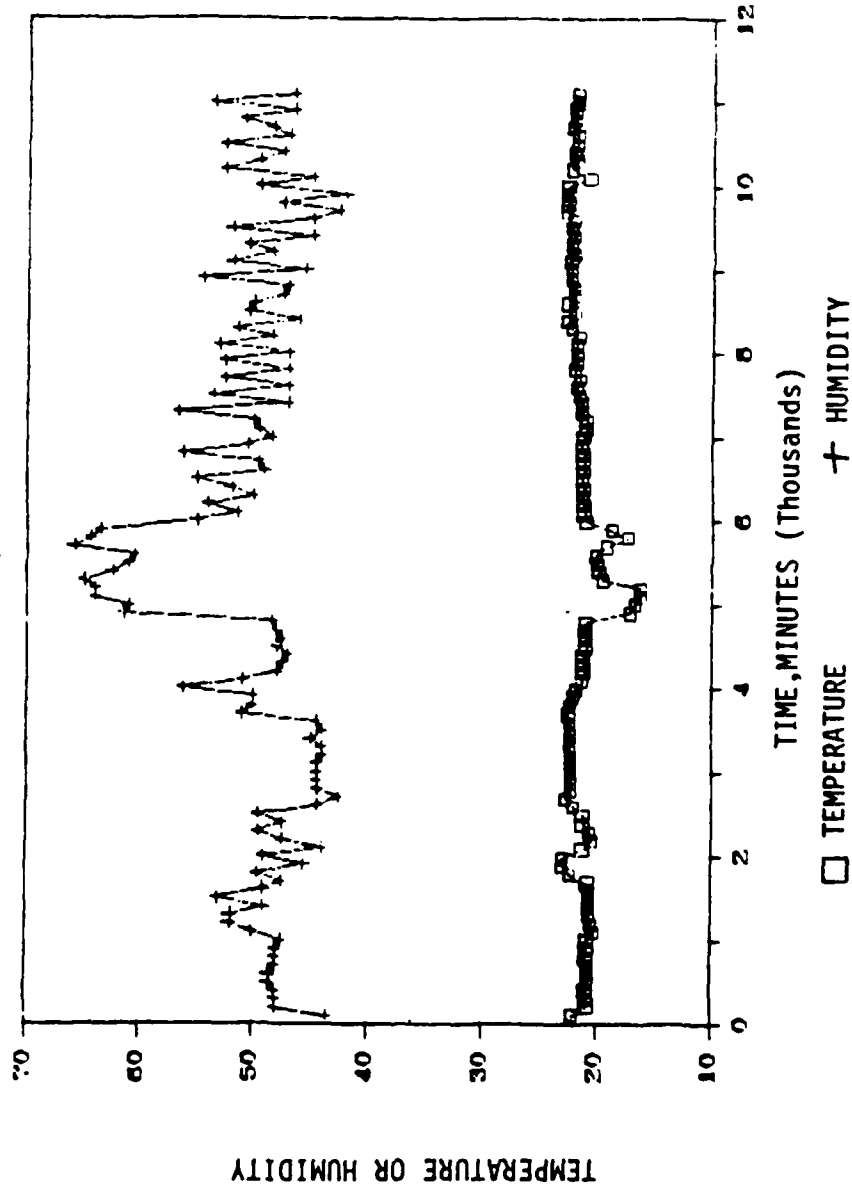


Figure 4. Temperature and Relative Humidity Versus Time for LCC 118 and 119

HUMIDITY AND TEMPERATURE VS. TIME  
MST ELECTRICAL ROOM 8/85-9/85

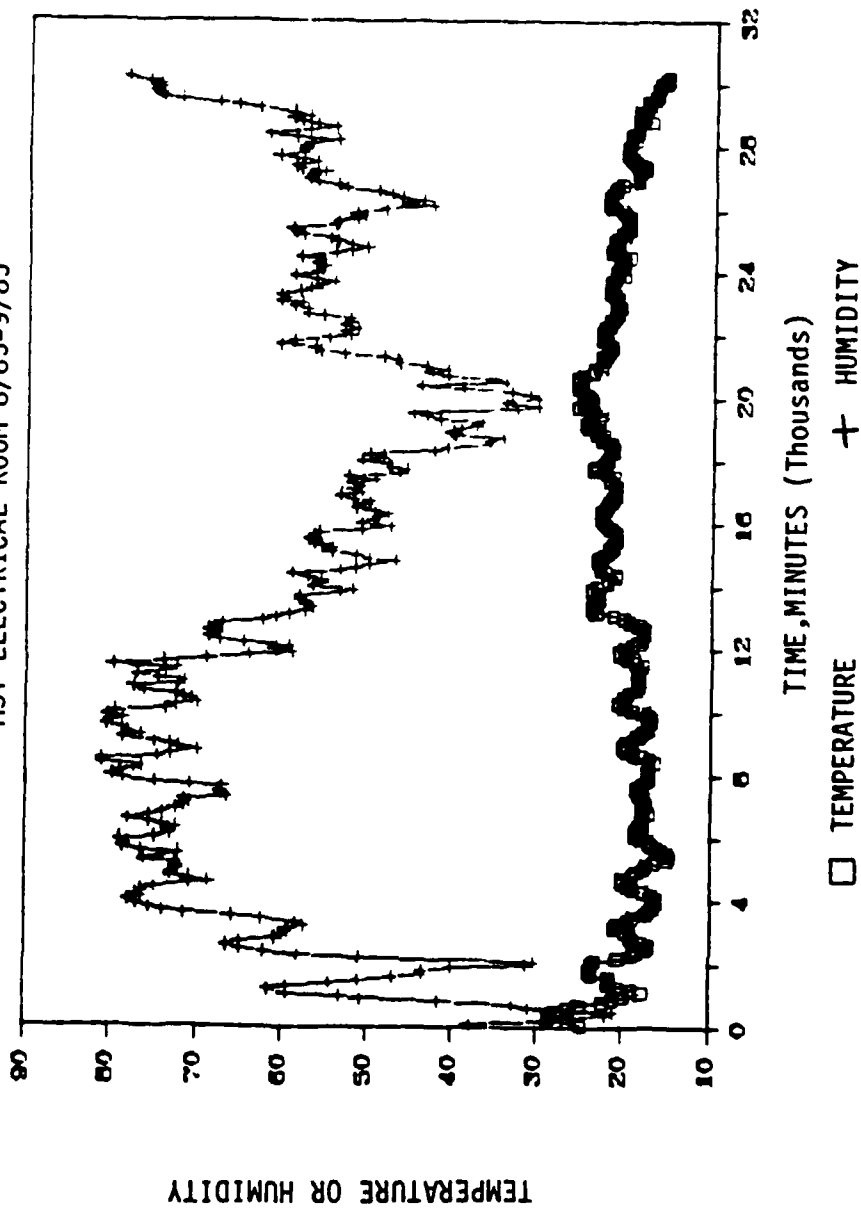


Figure 5. Temperature and Relative Humidity Versus Time for MST Electrical Room

TABLE 6. RESULTS OF COPPER REACTIVITY MONITORING AT VANDENBERG AFB; SLC-4

Location	Dates		Sample ID	Actual Film Thickness, Å			Projected 1-Year Film Thickness, Å	
	Installed	Removed		Unknown	Oxide	Sulfide		Total
Comp. Rm LOB	3/6/86	4/11/86	1353	69	152	0	221	713
LSB Elect. Rm.	3/6/86	4/11/86	736	0	141	0	141	455

TABLE 7. RESULTS OF SILVER REACTIVITY MONITORING AT VANDENBERG AFB; SLC-4

<u>Location</u>	<u>Dates</u>		<u>Sample ID</u>	<u>Actual Film Thickness, Å</u>			<u>Projected 1-Year Film Thickness, Å</u>	
	<u>Installed</u>	<u>Removed</u>		<u>Chloride</u>	<u>Oxide</u>	<u>Sulfide</u>		<u>Total</u>
Comp. Rm. LOB	3/6/86	4/11/86	1353	46	--	21	67	698
LSB Elect. Rm.	3/6/86	4/11/86	736	88	--	35	123	1282

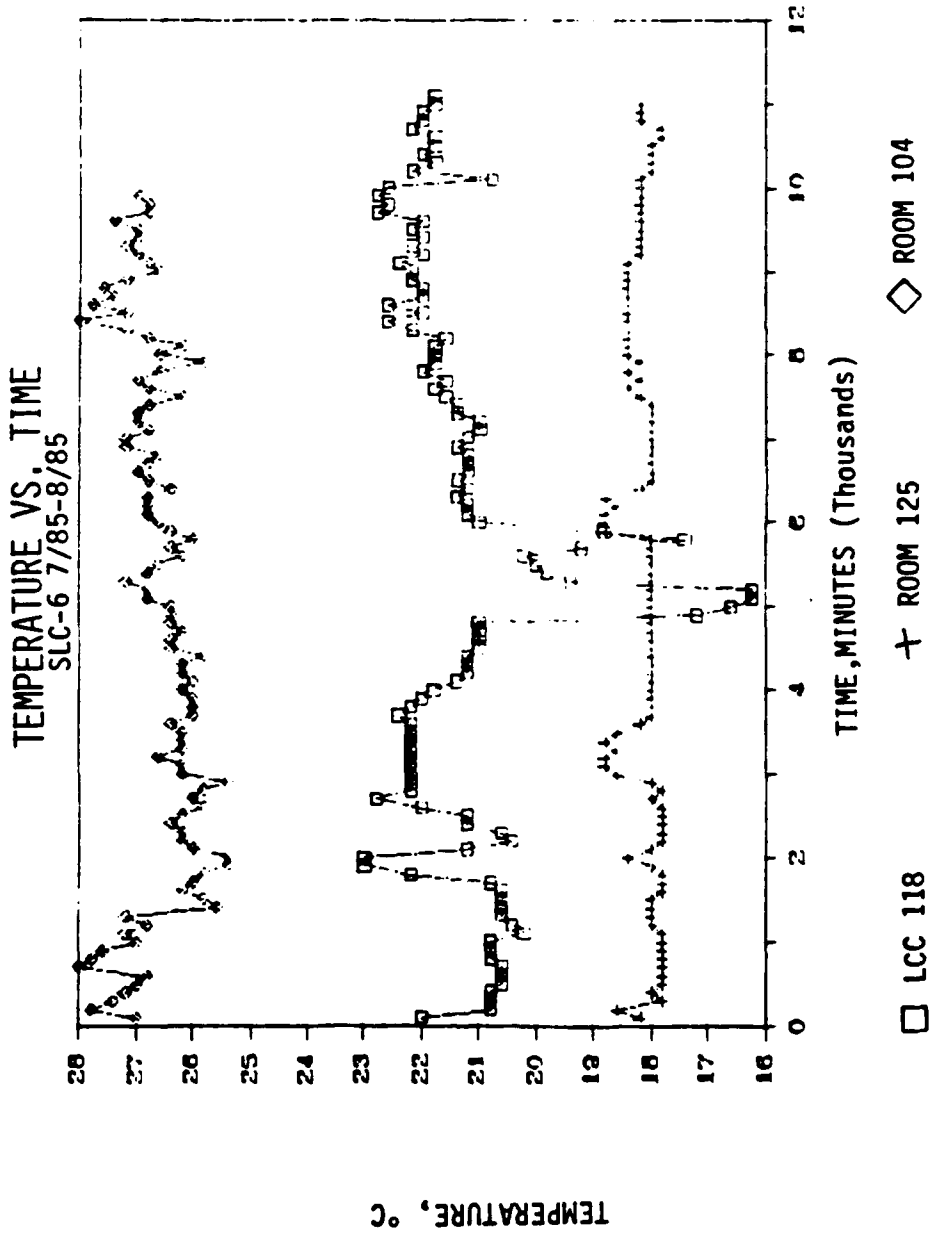


Figure 6. Temperature Versus Time for LCC 118, Room 125 and Room 104 At Shuttle Launch Complex 6

TEMPERATURE VS. TIME  
SLC-6 8/85-9/85

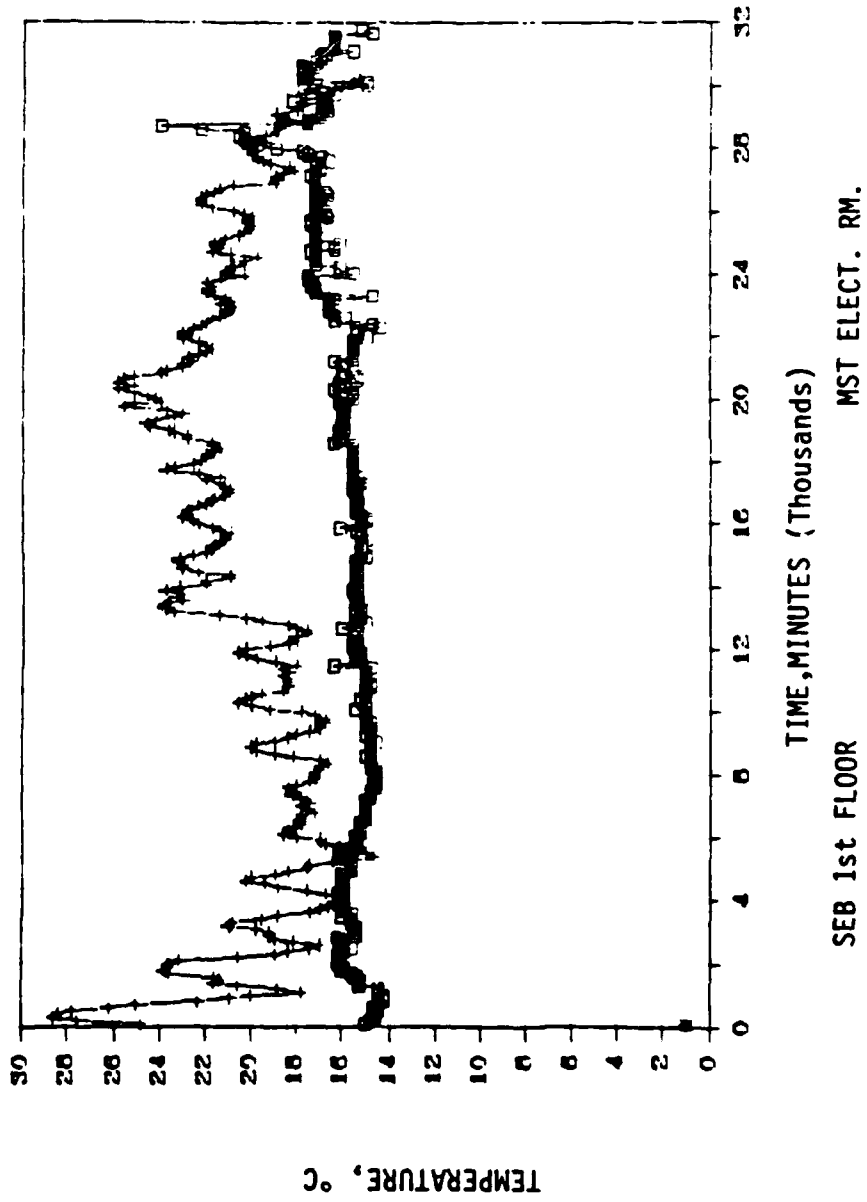


Figure 7. Temperature Versus Time for SEB 1st Floor and MST Electrical Room At Shuttle Launch Complex 6

RELATIVE HUMIDITY VS. TIME  
SLC-6 8/85-9/85

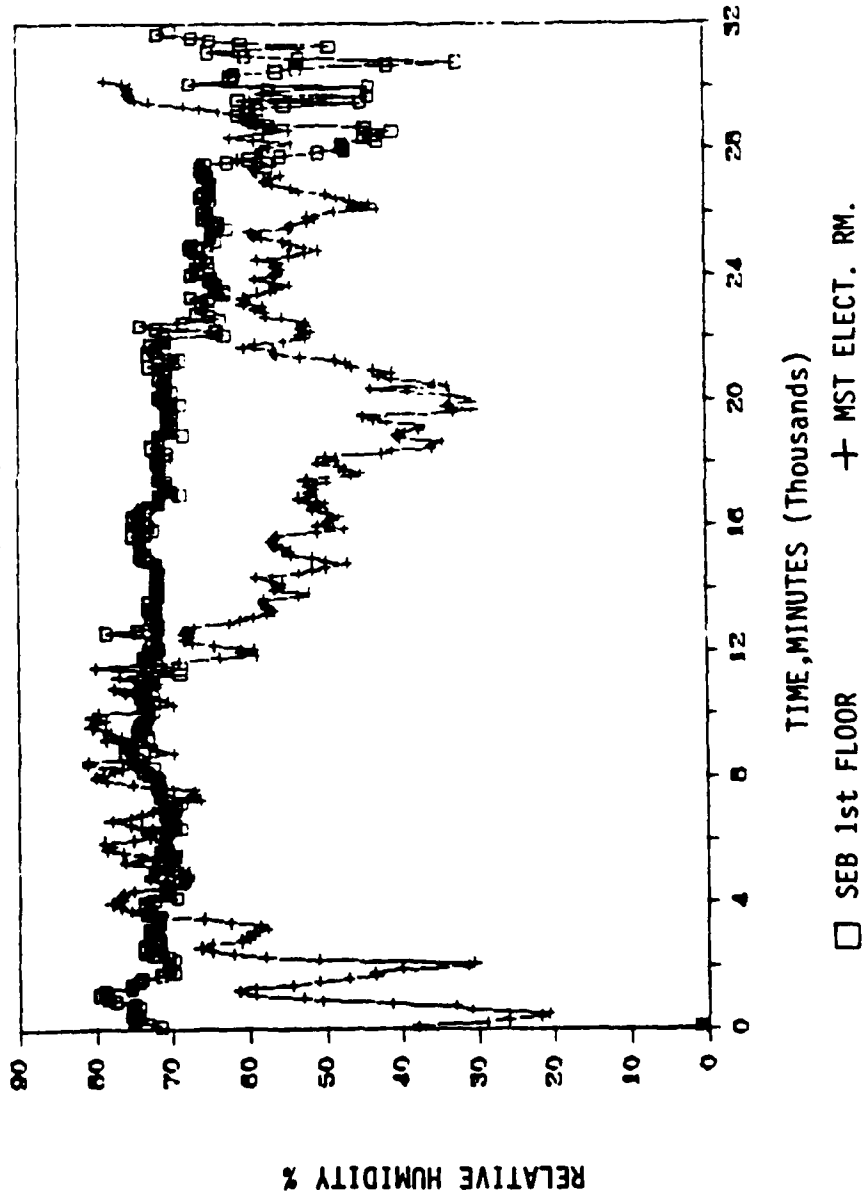


Figure 8. Relative Humidity Versus Time for SEB 1st Floor and MST Electrical Room at Shuttle Launch Complex 6

The results at this facility are quite different than those at SLC-6. Chlorides were detected indoors and at levels somewhat higher than those found at SLC-6. This constituent, together with large humidity variations as shown in Figure 9 for the computer room, had two effects. One was a considerable increase in the corrosion rate of copper. The second was a change in the corrosion chemistry on copper to produce an additional reaction product suspected to be a copper-hydroxy-chloride. The computer room at SLC-4 was considered to be a nonbenign and moderately reactive environment.

The latter conclusion was confirmed with one additional piece of data. For sample cards installed at SLC-4, one additional material was used as a sensor, along with silver and copper. This was a coupon of solid copper which was first electroplated with  $50 \times 10^{-6}$  inch of nickel and then  $30 \times 10^{-6}$  inches of gold. The surface finish and plating conditions were such that a porous gold coating was produced. Porosity levels were comparable to those found on some commercial finishes. This type of sensor has proved useful, even for visual purposes. Typically, it will confirm that if reactivity levels fall outside of the benign region, various degrees of corrosion can be detected around pore sites. These reaction products are typically chloride based.

Pore corrosion was demonstrated on even the 1-month exposure samples at SLC-4, confirming that the environments in the computer room were not benign. Furthermore, it demonstrates that the chloride levels detected were sufficiently high for the humidity conditions that exist to produce corrosion. Similar studies on gold were not conducted on any of the SLC-6 sites; however, it can be concluded that such corrosion would not have been observed, at least for the monitoring period. Such corrosion might have been approached at selected sites as conditions appeared to deteriorate somewhat during 1986.

#### E. SUNNYVALE MONITORING

Only reactivity monitoring with the standard materials was conducted at three locations at Sunnyvale. These monitoring data can be found in Tables 8 and 9.

Chlorides were detected at two locations, and it may be significant to note that, equipment problems were reported in Room 1301. No other documentation is available for this site; no other monitoring was conducted. Therefore, it is impossible to reach conclusions other than two of these locations do not qualify as benign environments. It is likely, however, that if humidity were not controlled at this facility, significant or even higher corrosion rates could be observed.

RELATIVE HUMIDITY VS. TIME  
SLC-6 7/85-9/85

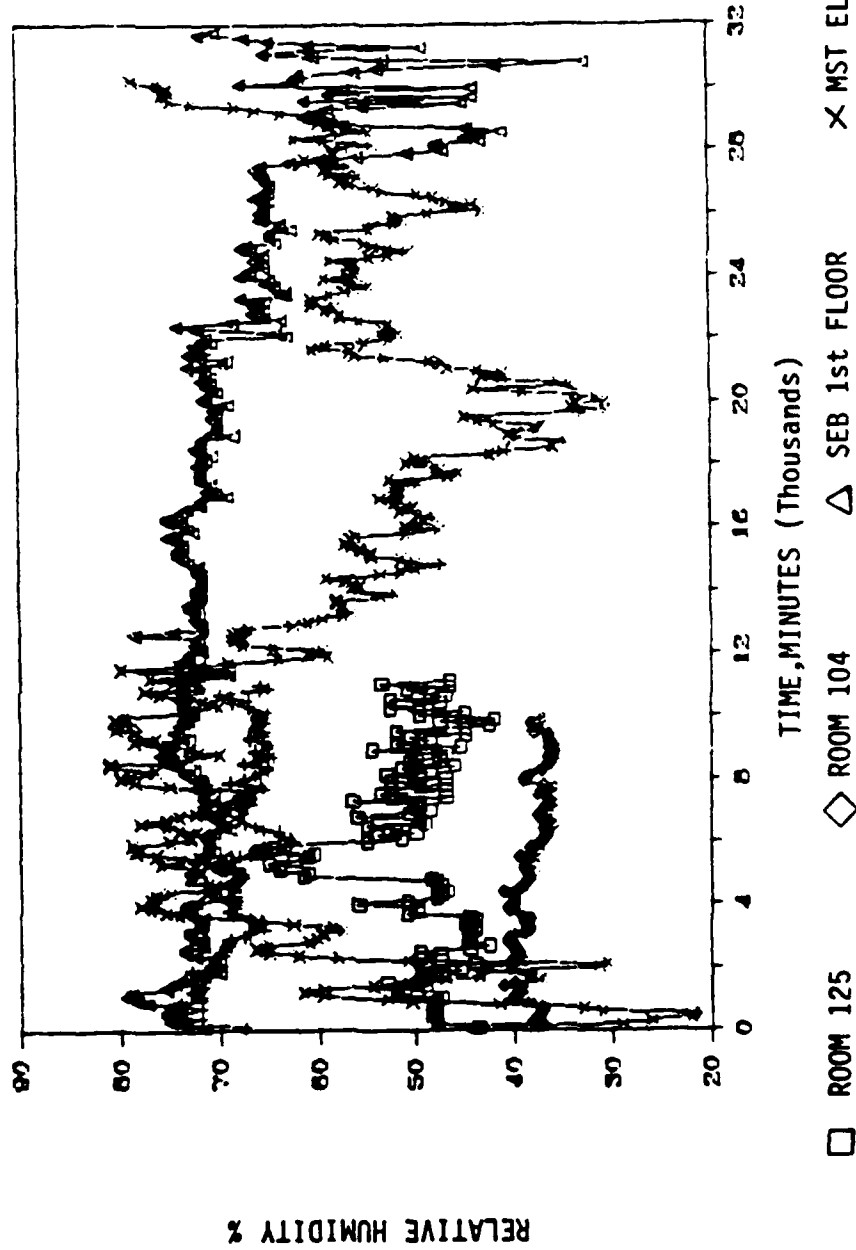


Figure 9. Relative Humidity Versus Time for Room 125, Room 104, SEN 1st Floor and MSI Electrical Room at Shuttle Launch Complex 6

TABLE 8. RESULTS OF COPPER REACTIVITY MONITORING AT SUNNYVALE AFS

Location	Installed	Removed	Sample ID	Actual Film Thickness, Å			Projected 1-Year Film Thickness, Å
				Unknown	Oxide	Sulfide	
Bldg. 1003, Rm. 1301	8/1/85	9/1/85	499	33	190	0	220
	8/1/85	2/1/85	293	46	193	0	239
Bldg. 1003 Rm. 2201	8/1/85	11/1/85	1353	37	152	0	189
	8/1/85	2/1/85	1354	52	162	0	214
Bldg. 1003 Rm. 2164	8/1/85	11/1/85	1360	0	162	0	162
		2/1/85	1350	0	190	0	190

TABLE 9. RESULTS OF SILVER REACTIVITY MONITORING AT SUNNYVALE AFS

Location	Installed	Removed	Sample ID	Actual Film Thickness, Å			Projected 1-Year Film Thickness, Å
				Chloride	Oxide	Sulfide	
Bldg. 1003, Rm. 1301	8/1/85	9/1/85	499	25	--	21	46
	8/1/85	2/1/85	291	84	--	81	165
Bldg. 1003, Rm. 1301	8/1/85	11/1/85	1353	0	--	43	43
	8/1/85	2/1/85	1354	253	--	136	389
Bldg. 1003 Rm. 2164	8/1/85	11/1/85	1360	0	--	382	382
	8/1/85	2/1/85	1350	0	--	1227	1227

TEMPERATURE AND RELATIVE HUMIDITY  
VANDENBERG SLC-4 3/86-5/86

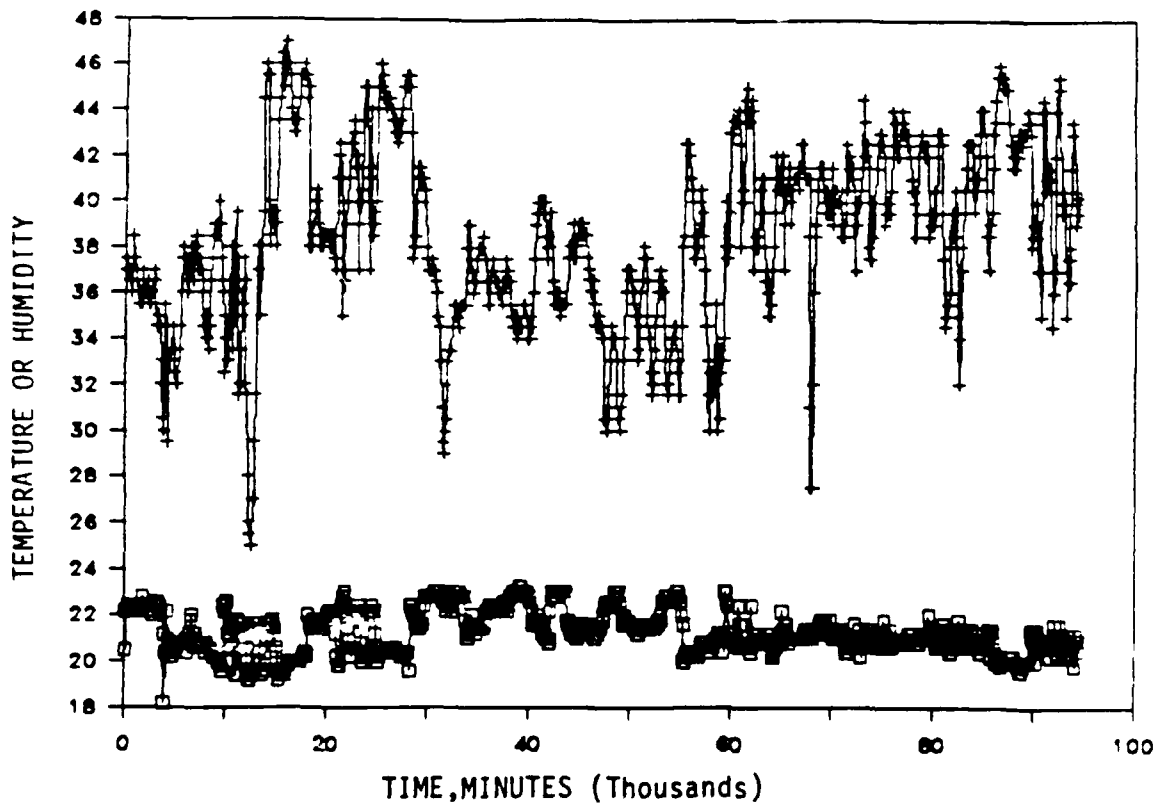


Figure 10. Temperature and Relative Humidity Versus Time at Vandenberg Shuttle Launch Complex 4

## SECTION IV

### CONCLUSIONS

These studies have demonstrated that the indoor baseline environments at SLC-6 have generally qualified as benign environments. This has apparently been achieved by natural attenuation processes and a reasonable degree of humidity control. They have also demonstrated a degradation in environmental quality with age and/or operating mode of the facility. Indoor chloride levels increased with time and potential humidity problems were identified in several rooms. For the combination of conditions identified at this site, the most cost-efficient way of achieving equipment protection would be better humidity control. This refers to a lowering of median humidity levels below 50 percent RH and a decrease in the degree of humidity cycling to the greatest degree possible.

#### REFERENCES

1. Abbott, W.H., "The Corrosion of Porous Gold Platings in Field and Laboratory Environments," 13th Int'l. Conf. on Electric Contacts, Lausanne, Switzerland, (Sept. 1986) pp. 343.
2. Instrument Society of America, Specification ISA-SP71, Environmental Conditions for Process Measurement and Control Systems - Airborne Contaminants, Instrument Society of America, Research Triangle Park, North Carolina.
3. Lorenzen, J., "Environmental Monitoring Device for X-Ray Determination of Atmospheric Chlorine, Reactive Sulfur, and Sulfur Dioxide," Advances in X-Ray Analysis, Vol. 16, Plenum Publishing, New York, pp. 566.