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# RELIABILITY ANALYSIS OF THE SYSTEM MAINTENANCE MONITOR CONSOLE

Arthur R. Moss

MARCH 1975

FINAL REPORT

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Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington, D. C. 20590

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F.A.A., National Aviation Facilities Experimental Center
Reliability Analysis of the System Maintenance Monitor Console, by Arthur R. Moss. Final Report. Atlantic City, N.J., March 1975.

97 p. (RD-75-3)
(NA-74-53)

Project No. 121-101-050

1. System Maintenance Monitor Console. 2. Reliability Analysis. 3. Projection Readout Indicators.
I. Moss, Arthur R.

**Technical Report Documentation Page**

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| FAA-RD-75-3 | | |

| 4. Title and Subtitle | 5. Report Date |
|---|---|
| RELIABILITY ANALYSIS OF THE SYSTEM MAINTENANCE MONITOR CONSOLE | March 1975 |
| | 6. Performing Organization Code |
| 7. Author(s) Arthur R. Moss | 8. Performing Organization Report No. FAA-NA-74-53 |
| 9. Performing Organization Name and Address Federal Aviation Administration National Aviation Facilities Experimental Center Atlantic City, New Jersey 08405 | 10. Work Unit No. (TRAIS) |
| | 11. Contract or Grant No. 121-101-050 |
| 12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, D.C. 20590 | 13. Type of Report and Period Covered Final September 1972-December 1974 |
| | 14. Sponsoring Agency Code |

15. Supplementary Notes

16. Abstract


The specification for the system maintenance monitor console (SMMC) calls for a minimum mean uptime (MUT) of 5,000 hours and a maximum mean downtime (MDT) of 1 hour for each SMMC module type. Formal MUT and MDT tests were performed in accordance with approved test plans. All module types passed the tests. An independent MUT analysis covering 3.75 equipment years of observation showed, with an 80-percent degree of confidence, that the true MUT's of all module types except the 9020E-1 are greater than 9,000 hours. The corresponding MUT for the 9020E-1 may be as low as 4,500 hours. A total of 18 hard failures occurred over this 3.75-equipment-year period. Six of these involved blower motor failures in the power supplies.

A major cause of concern has been the high replacement rate and limited availability of the type 247 subminiature lamps used in the projection readout indicators (PRI's). Detailed replacement studies of these lamp failures brought out that an average of two lamps per day per SMMC failed. Comparative life tests were performed between the type 247 and three alternative type lamps, types 6180, 714, and 685. Types 714 and 685 showed significantly greater mean lives but lower luminosities than the 247. Human factors studies are being planned to determine the suitability of using lamps of lower luminosity.


| 17. Key Words | 18. Distribution Statement |
|---|---|
| System Maintenance Monitor Console (SMMC)<br>Reliability<br>Maintainability<br>Projection Readout Indicators (PRI's)<br>Subminiature Lamps | Document is available to the public through the National Technical Information Service, Springfield, Virginia 22151 |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price |
|---|---|---|---|
| Unclassified | Unclassified | 97 | |

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

# PREFACE

The author wishes to express his appreciation to the systems engineers and maintenance personnel at the Washington, Jacksonville, Indianapolis, Denver, Los Angeles, Oakland, and New York air route traffic control centers, and the National Aviation Facilities Experimental Center (NAFEC) for their cooperation in providing the failure data on the modules of the system maintenance monitor console and the detailed replacement data on the type 247 incandescent lamps used in the projection readout indicators (PRI's) thereof.

Acknowledgement is made to Messrs. Lane Hinkley and Donald Fisher, ANA-140 at NAFEC, who conceived and designed the accelerated life tests described herein. Acknowledgement is also made to Mr. John Wojciech, ANA-140, who provided valuable assistance in some of the statistical aspects of this study. Finally, appreciation is expressed to Mr. Francis J. Valleley and the other personnel at the NAFEC photographic section for their support of the accelerated life tests of the PRI lamps.

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# INTRODUCTION

## PURPOSE.

This report summarizes the reliability and maintainability tests and studies performed on the system maintenance monitor console (SMMC). This report also discusses the various categories of part failures which were observed in the SMMC. Foremost among these is the high failure rate of the type 247 incandescent lamps used for indicating purposes within the SMMC. This report describes detailed replacement studies of this type lamp made at selected sites, as well as comparative life tests between the 247 and several alternative type lamps.

## BACKGROUND.

DESCRIPTION OF SMMC. The SMMC monitors and displays the status, configuration, and performance of the various elements, equipments, and subsystems comprising the National Airspace System (NAS). The SMMC, shown in figure 1, is located in the operations room of each of the 20 air route traffic control centers (ARTCC's), as well as at the National Aviation Facilities Experimental Center (NAFEC) and the Federal Aviation Administration (FAA) Academy.

The monitored information, which is continuously updated, is presented by the SMMC both visually and electronically. The visual presentation is by means of several types of display devices. The electronic presentation is in the form of digitized report messages which the SMMC generates and sends to the central computer complex (CCC) subsystem of the NAS for processing.

Physically and functionally, the SMMC is organized into modules, the types and numbers of which are site-adaptable. Figure 1 shows these various modules in an SMMC. These modules monitor specific subsystems of the NAS which are located within the ARTCC or in the geographic area served by it. These modules include the following:

Central Computer Complex Module (CCCM). This module monitors the various elements of the 9020 central computer complex, which comprises the data processing subsystem of the NAS. There is one of these modules per SMMC.

Computer Display Channel Module (CDCM). This module is present in those SMMC's which are located at ARTCC's which utilize the computer display channel (CDC) as the data entry and display subsystem of the NAS. Due to the many elements of the CDC which are monitored, the CDCM physically consists of four drawers (CDCM-1, -2, -3, and -4).

9020E Module. This module, consisting of two drawers (9020E-1 and -2), is present in those SMMC's which are located at ARTCC's which utilize the 9020E rather than the CDC for the data entry and display subsystem of the NAS. The SMMC's at NAFEC and the FAA Academy, however, contain both CDCM and 9020E modules.

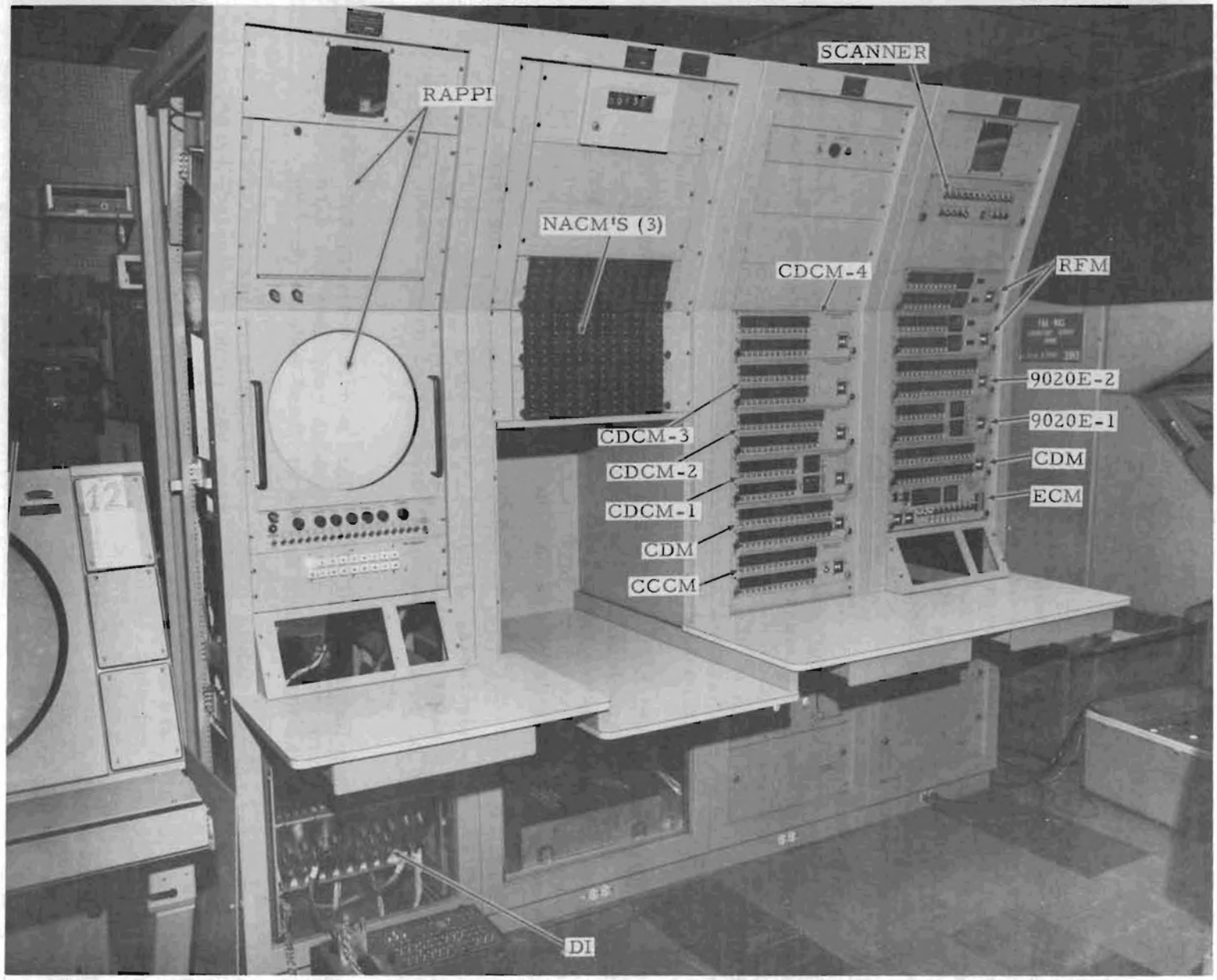


FIGURE 1. SYSTEM MAINTENANCE MONITOR CONSOLE

Controller's Display Module (CDM). This module provides monitoring capability for up to 90 radar display consoles and 12 training consoles (R-Controller positions) at an ARTCC. Physically, this module may consist of up to three drawers (CDM-1, -2, and -3), each of which can monitor 34 radar or radar and training consoles.

Environmental and Controls Module (ECM). This module monitors various physical conditions within the ARTCC. It also has several internal reset and test controls. There is one ECM per SMMC.

Remote Facilities Module (RFM). This module provides monitoring capability for two remote radar facilities. As seen in figure 2, the online and standby radars, beacons, and common digitizers (CD's) of each radar facility, as well as the associated modems and data receiver groups (DRG's), are monitored. As seen in figure 2, the upper row of indicators monitors the elements of one remote radar facility, while the lower row monitors the elements of the other facility. Corresponding indicators in each row are identical. An SMMC can accommodate up to nine RFM modules, thereby providing monitoring capability for up to 18 radar facilities.

Interfacility Modem Module (IMM). This module provides monitoring capability for both Interfacility and the Automated Radar Terminal System (ARTS-3) data sets. There is one IMM module per SMMC.

Random Access Plan Position Indicator (RAPPI) Module. This module provides a symbolic visual display of air traffic data on a cathode-ray tube. This data comes to the RAPPI in the form of digitized target report messages from the DRG at a radar site. Up to 18 radar sites may be thus monitored.

Navigation Aids and Communications Module (NACM). The eight monitoring-type modules listed above sense changes in the status or performance of the monitored elements automatically by means of electronic sensors in the elements monitored. The NACM's monitor the status of the various navigation aids (NAVAID's) and communications sites within the area of the ARTCC. The status of these sites is displayed manually by means of toggle switches and red light-emitting diodes. When the toggle switch is set to nonoperational status, the corresponding diode becomes illuminated.

Each NACM module can monitor 72 NAVAID's or communications sites. A SMMC can accommodate up to five NACM modules.

Scanner. The Scanner module provides the communications between the monitoring module types listed above (except the RAPPI) and the CCC. It formats the digitized messages whereby each monitored element in the NAS can send its availability or performance state, or change therein, to the CCC.

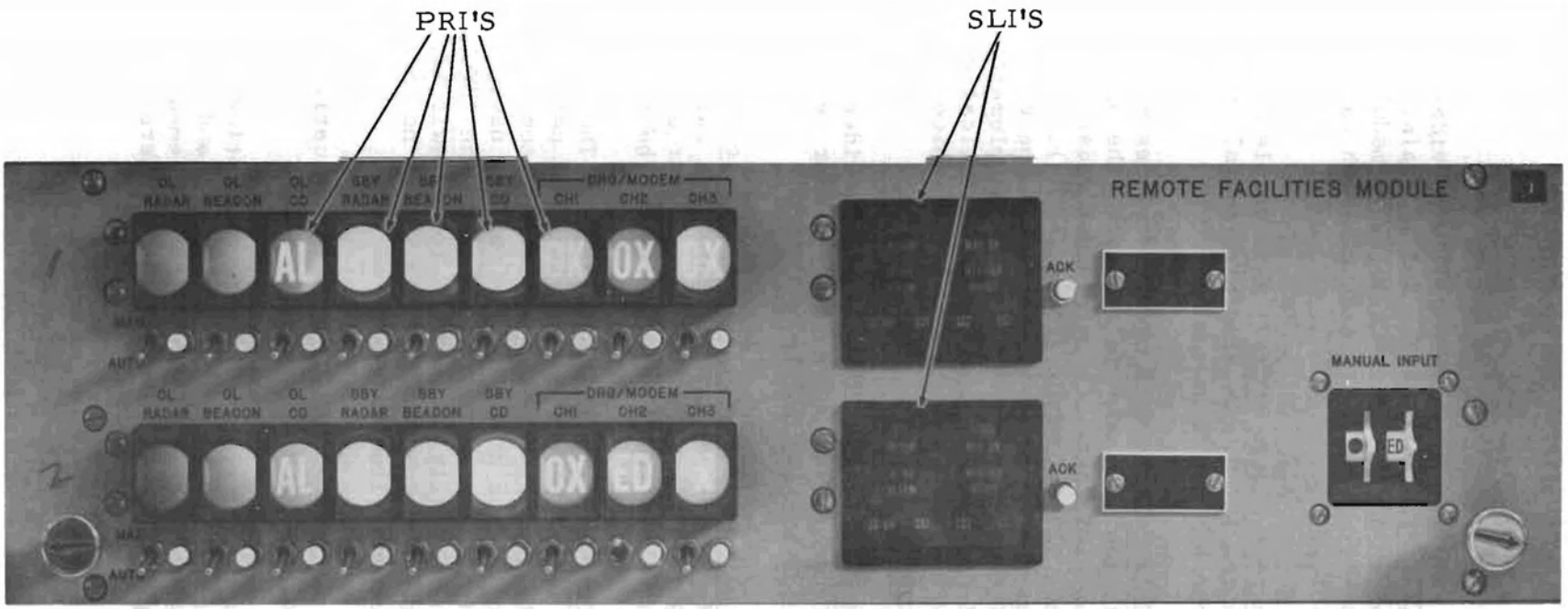


FIGURE 2. TYPICAL SMMC MODULE, REMOTE FACILITIES MODULE

Power Supply Module (PWS). This is not a monitoring type module but provides the necessary power to the other SMMC modules. Each SMMC contains three identical power supply modules, each of which can supply 100 amperes at 5 volts direct current (d.c.). Any two of these three power supplies can maintain the SMMC in full operational condition.

DRG-Interface Module (DI). This is a special module which provides a central collection point for up to 18 DRG's. It outputs data to up to nine RFM's and the RAPPI. It selects any of these 18 DRG's for monitoring by the RAPPI and separates the target and status data of the incoming DRG messages for routing to the RAPPI and RFM's respectively. There is one DI per SMMC.

Visual Displays. One type of visual display, the red light-emitting diode, has been described in connection with the NACM module type. Another type of visual display is the single lamp indicator (SLI). This, like the light-emitting diode, is used when only two status conditions exist for an element. For both these indicator types, the unlighted state is defined as the normal condition and the lighted state is the abnormal or alarm condition. However, while the light-emitting diode is energized manually by means of a toggle switch, the SLI is actuated automatically by electronic circuitry. The SLI's utilize incandescent lamps which are grouped in panel-mounted assemblies, such as shown in the RFM module of figure 2. Each assembly contains up to 12 discrete SLI lamps.

When more than two conditions of a monitored element are to be displayed, a projection readout indicator (PRI) is used. A PRI can display any of four status or availability conditions by means of a discrete color, and any of eight degrees of malfunction (performance) by means of symbols. The PRI's are shown in the remote facilities module (RFM) of figure 2, which contains a total of 18 PRI's.

The PRI consists of a 12-section film located between a matrix of 12 small incandescent lamps and a display screen. A detailed view of a PRI is shown in figure 3. Each section of the film, with its associated lamp, corresponds to one of the four colors and eight symbols. When a particular lamp is energized, its corresponding color or symbol is projected onto the display screen.

The four availability status indications (colors) and their meanings are as follows:

| | | |
|---|---|---|
| GREEN | (G) | On Line |
| AMBER | (A) | Standby |
| RED | (R) | Test/Maintenance (Unavailable) |
| WHITE | (W) | Assignable |

One and only one of the colors must be displayed for each PRI.

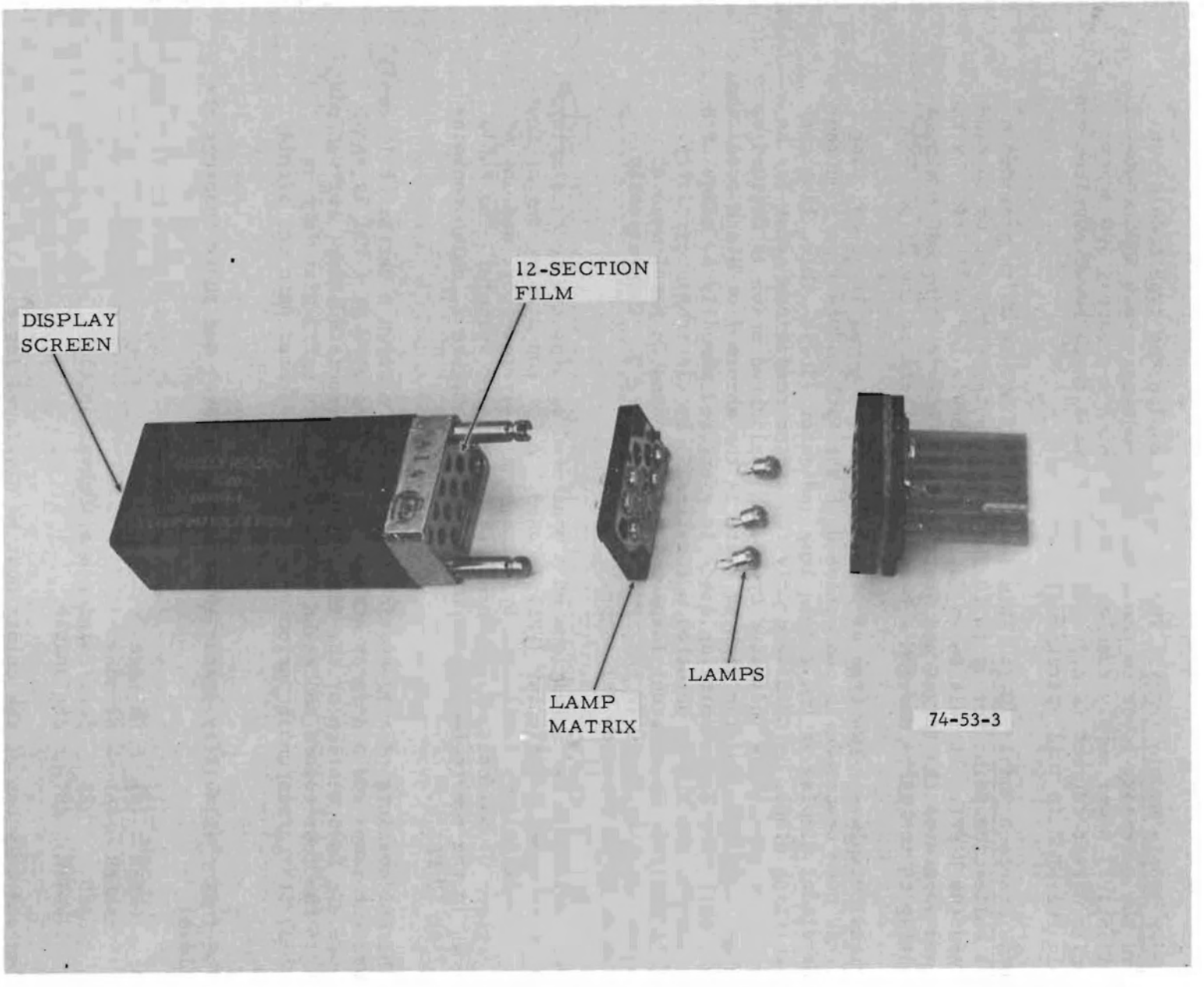


FIGURE 3. PROJECTION READOUT INDICATOR

The eight performance degradation symbols are as follows: D, X, ED, EX, PX, AL, OX, and SS. The meaning of these symbols vary with each module type. No more than one of these symbols may be displayed by a PRI at any time. When no malfunction is present in a PRI-monitored NAS element, no symbol will be displayed on that PRI.

SMMC RELIABILITY AND MAINTAINABILITY TESTS. Section 3.8.1.1 of the SMMC specification FAA-E-2347 of April 23, 1968, calls for a minimum mean uptime (MUT) of 5,000 hours for each SMMC module and a corresponding maximum mean downtime (MDT) of 1 hour. Contract DOT-FA69NS-177 required that these parameters be demonstrated by suitable tests. In accordance with these requirements, a reliability test demonstration plan was generated by the contractor (Electronic Laboratories, Inc., of Houston, Texas) for demonstrating the MUT requirement. A maintainability demonstration plan was likewise drawn up by the contractor for demonstrating the MDT requirement. Both test plans were approved by the FAA and subsequently performed. This report will describe these reliability and maintainability tests and their results, along with additional reliability observations made on the SMMC at NAFEC.

INCANDESCENT LAMP INVESTIGATIONS. The reliability test demonstration plan did not consider incandescent lamp failures as chargeable failures against the modules being tested; however, various installations using the SMMC have reported a high failure rate of the small type 247 incandescent lamps used in the PRI's. In addition, supply problems with these lamps exist, since they are manufactured in a foreign country. Since these lamps play an important part in the function of the SMMC (i.e., indication), it was decided to investigate the failures of these lamps to determine whether they meet the manufacturer's specifications concerning life expectancy. The Systems and Equipment Engineering Branch (ANA-140) at NAFEC was assigned to investigate the replacement of these lamps at NAFEC and at three field sites. ANA-140 was also assigned the task of comparing the life of the lamps used in the PRI's (type 247 lamps) with that of several alternative type lamps. Human factors tests are also to be performed on several lamp types in an effort to find an optimum combination of life, cost, availability, and luminosity characteristics.

## DISCUSSION

### MEAN UPTIME TESTS.

CONTRACTUAL TEST. The reliability demonstration test plan generated by the contractor was based on a time-terminated test, wherein each module type was observed over a total period of 2 unit-years, or 17,280 unit-hours. This total observation time was obtained by observing the SMMC for a 6-month

(4,320-hour) period at each of four ARTCC's, recording failures on a module-by-module basis as they occurred. The four ARTCC's were Jacksonville, Washington, Indianapolis, and Denver. The module types tested were the types described in the introduction with the exception of the DI. They are repeated below for convenience.

- Central Computer Complex Module (CCCM)
- Computer Display Channel Module (CDCM)
- Controller's Display Module (CDM)
- Environmental Control Module (ECM)
- Navigation Aids and Communications Module (NACM)
- Remote Facilities Module (RFM)
- Scanner Module
- Interfacility Modem Module (IMM)
- Random Access Plan Position Indicator (RAPPI)
- 9020E Module
- SMMC Power Supply

Each module type, with the exception of the CDCM, was to demonstrate a specified MUT of 5,000 hours. In the case of the CDCM, the four discrete physical units CDCM-1, CDCM-2, CDCM-3, and CDCM-4 were considered as one unit for the purpose of the reliability test. Due to this corresponding increase in hardware included in the CDCM module type, the MUT required to be demonstrated was reduced to 2,800 hours.

In the case where a module type consists of two or more similar units, only one unit per site was selected for reliability observation. These module types were the CDM, NACM, and RFM. In the case of the 9020E module type, the two physical units comprising it (9020E-1 and 9020E-2) were considered as one unit for the purpose of the test. In the case of the power supplies, three redundant units are contained in the SMMC. Two of these will sustain the SMMC at full operational capability. Therefore, the power supply module type is considered in an uptime status at each site as long as at least two of the power supply units in each SMMC are functional.

The test ran for 6 months at each of the four sites. This provided a total uptime of 17,280 hours (4,320 X 4) per module type, with the exception of the CDCM and 9020E types. Since there were a total of only three CDCM's and one 9020E module among the four ARTCC's selected for observation, supplementary observation of these two module types was performed at NAFEC to provide a total of 17,280 hours (2 years) of test time for each of these two module types. In the case of the CDCM, since three of the ARTCC's had the computer display channel (CDC), 6 months of supplementary data on the CDCM were taken at NAFEC. This was done from November 1, 1973, through April 30, 1974, coincidental with the period of observation at the four ARTCC's. In the case of the 9020E, since only one of the ARTCC's (Washington) utilized the 9020E, 18 months of

supplemental observations on this module type were performed at NAFEC. One year of reliability observation on the SMMC (January 1, 1973, through December 31, 1973) had been performed and documented at NAFEC. The 18 months of supplemental observation on the 9020E module type consisted of this documented year plus an additional 6 months at NAFEC from January 1, 1974, through June 30, 1974.

MUT is determined by the number of independent hard failures which occur in a module type during the period of observation. A hard failure is a malfunction in a module which is caused by a defective component or part, other than an incandescent lamp. Correction of a hard failure must be accomplished by maintenance effort and must involve replacement or repair of the faulty component. A hard failure is considered independent when it is not related to any failure which had occurred previously.

In accordance with the test plan, two or more independent hard failures in any module type except the CDCM and power supply during the 17,280 hours of test time would constitute a reject decision for that module type. Therefore, with one allowable independent failure in a module type (except CDCM and power supply), and given a 20-percent consumer's risk as specified in the test plan, it can be stated with an 80-percent degree of confidence that the true MUT of the module type concerned would be greater than 5,769 hours. This satisfies the 5,000-hour contractual requirement for a module type.

In the case of the CDCM module type, four or more independent failures during the 17,280 hours of test time would constitute a reject decision. Therefore, with three allowable failures, one can be 80-percent confident that the true MUT of the CDCM would be greater than 3,141 hours. This satisfies the 2,800 hours specified for the CDCM by the test plan.

In the case of the power supplies, two simultaneous failures of two power supplies would provide a reject decision. As in the case of the other module types, with the exception of the CDCM, one simultaneous failure of two power supplies would indicate with an 80-percent degree of confidence that the true MUT of the three-unit redundant power supply system is greater than 5,769 hours.

During the period of observation, failures were documented on a failure report form, a copy of which is shown in figure 4. In addition, information concerning these failures was documented in the Facility Maintenance Log Form 6030-1.

OBSERVATION AT NAFEC. In addition to the contractually required MUT observations at the four ARTCC's, an independent reliability observation was performed on the SMMC at NAFEC. This observation was performed during the 21-month period from January 1, 1973, through September 30, 1974. The first 12 months of this observation (January 1 to December 31, 1973) were documented in the form of four quarterly reliability bulletins, each of which analyzed the data for the quarter concerned, as well as cumulatively.

SMMC FAILURE/MAINTENANCE REPORT

1. Site _____

2. Report number _____

3. Module type _____

4. Module serial number _____

5. Date reliability observation on module started _____

6. Date of failure

| Day | Month | Year | Time |
|---|---|---|---|

7. Description of failure symptoms:

8. Comments on apparent cause of failure:

9. Description of maintenance actions:

10. Defective circuit board or major subassembly

| Number | Type | Location |
|---|---|---|

11. Defective component

| Number | Type | Location |
|---|---|---|

12. Date module returned to service

| Day | Month | Year | Time |
|---|---|---|---|

13. Signature of approving authority

_____

FIGURE 4. SMMC FAILURE/MAINTENANCE REPORT FORM

In the NAFEC analysis, all modules of a given type, such as NACM and RFM, were included in the analysis, rather than just one of each type, as was done in the contractual test. In the NAFEC analysis, the discrete physical units which comprise a module type, such as CDCM-1, CDCM-2, etc., are considered as individual modules rather than a composite CDCM module, as was done in the contractual test. The power supplies are likewise considered as discrete units rather than as a two-out-of-three redundant system. The module types tested at NAFEC and the number of module units per type are listed below.

| Module Name | Acronym | Quantity |
|---|---|---|
| Navigation Aids and Communications Module | NACM | 3 |
| Computer Display Channel Modules | CDCM-1 | 1 |
| | CDCM-2 | 1 |
| | CDCM-3 | 1 |
| | CDCM-4 | 1 |
| Controllers Display Module | CDM | 2 |
| Remote Facilities Module | RFM | 2 |
| 9020E | 9020E-1 | 1 |
| | 9020E-2 | 1 |
| Central Computer Complex | CCCM | 1 |
| Environmental and Control Module | ECM | 1 |
| Scanner Module | SCAN | 1 |
| Random Access Plan Position Indicator | RAPPI | 1 |
| Power Supplies | PWS | 3 |
| Interfacility Modem Module | IMM | 1 |
| DRG Interface | DI | 1 |

MEAN DOWNTIME TESTS.

CONTRACTUAL TEST. The maintainability demonstration test plan is a modification of method 1, appendix B of MIL-STD-471 of February 15, 1966. This is a sequential test based upon an assumed log-normal underlying distribution. The test consisted of inserting a number of artificially induced failures into the module under test. Only one induced failure was inserted at a time. A team of maintenance personnel using prescribed maintenance procedures would then isolate the failure, correct it, and bring the module back to an operational condition. The time in minutes required for the maintenance team to accomplish this was recorded. The number of observations greater than and less than the required mean corrective maintenance downtime (Mct), which is 60 minutes, was cumulated and compared with the running values shown in table 1. An accept/reject decision was then made on each module tested in accordance with table 1. For example, if after 12 induced failures or tasks have been executed, each task was completed in less than the required 60 minutes, an "accept" decision was made for the module concerned.

TABLE 1. ACCEPT/REJECT CRITERIA FOR MEAN DOWNTIME TEST

Executions Exceeding 1 Hr.

| # of Tasks OBSR (N) | Accept | Reject | # of Tasks OBSR (N) | Accept | Reject |
|---|---|---|---|---|---|
| 5 | | 5 | 55 | 12 | |
| 6 | | 6 | 56 | 13 | 20 |
| 7 | | ↕ | 57 | ↕ | 21 |
| 8 | | 6 | 58 | 13 | ↕ |
| 9 | | 7 | 59 | 14 | 21 |
| 10 | | ↑ | 60 | ↑ | 22 |
| 11 | | ↓ | 61 | ↓ | ↕ |
| 12 | 0 | 7 | 62 | 14 | 22 |
| 13 | ↕ | 8 | 63 | 15 | 23 |
| 14 | 0 | ↕ | 64 | ↕ | ↑ |
| 15 | 1 | 8 | 65 | 15 | ↓ |
| 16 | ↑ | 9 | 66 | 16 | 23 |
| 17 | ↓ | ↑ | 67 | ↕ | 24 |
| 18 | 1 | ↓ | 68 | 16 | ↕ |
| 19 | 2 | 9 | 69 | 17 | 24 |
| 20 | ↕ | 10 | 70 | ↑ | 25 |
| 21 | 2 | ↕ | 71 | ↓ | ↑ |
| 22 | 3 | 10 | 72 | 17 | ↓ |
| 23 | ↑ | 11 | 73 | 18 | 25 |
| 24 | 3 | ↕ | 74 | ↑ | 26 |
| 25 | 4 | 11 | 75 | 18 | ↕ |
| 26 | ↑ | 12 | 76 | 19 | 26 |
| 27 | ↓ | ↑ | 77 | ↕ | 27 |
| 28 | 4 | ↓ | 78 | 19 | ↑ |
| 29 | 5 | 12 | 79 | 20 | 27 |
| 30 | ↕ | 13 | 80 | ↑ | 28 |
| 31 | 5 | ↑ | 81 | ↓ | ↑ |
| 32 | 6 | 13 | 82 | 20 | ↓ |
| 33 | ↕ | 14 | 83 | 21 | 28 |
| 34 | 6 | ↑ | 84 | ↕ | 29 |
| 35 | 7 | 14 | 85 | 21 | ↕ |
| 36 | ↑ | 15 | 86 | 22 | 29 |
| 37 | ↓ | ↑ | 87 | ↑ | 30 |
| 38 | 7 | ↓ | 88 | ↓ | ↕ |
| 39 | 8 | 15 | 89 | 22 | 30 |
| 40 | ↕ | 16 | 90 | 23 | 31 |
| 41 | 8 | ↕ | 91 | ↕ | ↑ |
| 42 | 9 | 16 | 92 | 23 | ↓ |
| 43 | ↑ | 17 | 93 | 24 | 31 |
| 44 | ↓ | ↑ | 94 | ↕ | 32 |
| 45 | 9 | ↓ | 95 | 24 | ↕ |
| 46 | 10 | 17 | 96 | 25 | 32 |
| 47 | ↕ | 18 | 97 | ↑ | 33 |
| 48 | 10 | ↕ | 98 | ↓ | |
| 49 | 11 | 18 | 99 | 25 | |
| 50 | ↑ | 19 | 100 | 26 | |
| 51 | 11 | ↕ | | | |
| 52 | 12 | 19 | | | |
| 53 | | 20 | | | |
| 54 | | | | | |

There were 100 different tasks available for each module type. A sample of some of the available tasks for the RAPPI module is shown in figure 5. Each task was randomly selected by the reading of the last two digits of an electronic counter which had been running for 5 seconds or more. After execution, the task number was returned to the pool and made available for reselection. If a task was reselected, it was not re-executed, but the results of its first execution were recorded for the reselected task.

The mean downtime test was performed at the contractor's plant in Houston, Texas, between the period September 5 through 8, 1972. The test was performed on seven representative modules: A RAPPI module, a DI module, a NACM, a scanner, a CDCM-1 module, an RFM, and the CCCM.

NAFEC AND FIELD. The downtimes, or times required to repair the hard failures which had occurred in the NAFEC SMMC during the 21-month period of observation, were ascertained from the SMMC log. In a few cases where the downtimes were not too apparent, they were estimated.

Downtimes are also included where available for the hard failures which had occurred during the contractual mean uptime test at the four ARTCC's. From the downtimes of these hard failures experienced both at NAFEC and the field, the overall MDT's of the module types can be determined. These downtimes do not represent controlled conditions, such as prevailed during the contractual test in Houston, and may reflect waiting and other time in addition to the actual time expended in true maintenance effort.

PRI LAMP FAILURES.

The reliability and maintainability tests (MUT and MDT) described above did not consider incandescent lamps in their analyses. However, since several installations have reported a high failure rate of the incandescent lamps used in the PRI's, special effort was addressed to this problem. The PRI's are manufactured by Shelly Associates of El Segundo, California. They are model SRO-600 of this manufacturer and utilize type 247 miniature lamps obtained from Lamps Incorporated of Torrance, California.

The first phase of this PRI lamp study consisted of an investigation of the replacements of the type 247 lamp at NAFEC plus three field sites. This was followed by life tests at NAFEC of the type 247 versus several other types of miniature lamps. One of these life tests is still in progress at the time of this writing.

The alternate lamps which were life-tested against the type 247 lamp were the types 6180, 714, and 685. Their comparative characteristics are listed in table 2.

+5 VOLTS d.c. POWER SUPPLY (PROCESSOR)

TASK 1

a) Turn OFF RAPPI power.

b) Remove the bottom cover from the processor.

c) Use a 3- to 4-inch length of 16-AWG bus wire to short across the terminals of capacitor C10.

d) Replace the bottom cover.

e) Turn ON RAPPI power.

TASK 2

a) Turn OFF RAPPI power.

b) Remove the 2732-p.c. board.

c) Solder a 22-AWG black wire across zener diode CR3 on the board.

d) Replace the card.

e) Turn ON RAPPI power.

TASK 3

a) Turn OFF RAPPI power.

b) Remove the 2732-p.c. board.

c) Solder a 22-AWG black wire across zener diode CR1 on the board.

d) Replace the card.

e) Turn ON RAPPI power.

TASK 4

a) Turn OFF RAPPI power.

b) Remove the 2732-p.c. board.

c) Solder a 22-AWG black wire across capacitor C1 on the board.

d) Replace the card.

e) Turn ON RAPPI power.

FIGURE 5. SAMPLE OF AVAILABLE INDUCED FAILURE TASKS FOR RAPPI MODULE

TABLE 2. COMPARATIVE CHARACTERISTICS OF PRI LAMPS

| Lamp | Specified Life (Hours) | Current Drain (Milliamperes) | Luminous Intensity in Mean Spherical Candle Power (MSCP) |
|---|---|---|---|
| 247 | 6,500 | 60 | .150 |
| 6180 | 6,500 | 60 | .150 |
| 714 | 25,000 | 75 | .090 |
| 685 | 100,000 | 60 | .050 |

As seen from table 2, the types 714 and 685 have a much greater specified lifetime than does the 247, however, their luminosities in mean spherical candlepower (MSCP) are less. At the time of this writing, a human factors study is being planned at NAFEC to determine whether the 714 or 685 could be used as a satisfactory substitute for the 247, considering the reduced lighting intensity. As the results of these human factors studies become available, they will be disseminated.

DETAILED REPLACEMENT STUDY OF TYPE 247 LAMPS. The replacement study of the type 247 lamps was conducted at NAFEC plus the ARTCC's at Los Angeles, Oakland, and New York. In order to more accurately study the life expectancy or MUT of these lamps, each lamp replaced was uniquely identified within the SMMC in terms of the specific SMMC module, the PRI location within the module, and the color or symbol position within the PRI. In addition, the date and time of replacement were provided for each replaced lamp. From this data, specific information concerning the distribution of the replaced lamps with respect to their locations within the SMMC was obtained, as well as a determination of the overall effective MUT and daily replacement rates of the lamps at each site.

Replacement information on failed PRI lamps was recorded at the sites on a lamp replacement log, a sample of which is shown in figure 6. In the leftmost column, marked "MODULE," the name of the SMMC module concerned was entered. Where more than one module of the same type is present, as in the case of the remote facilities module (RFM), designation of the specific module concerned was made by affixing a number after the module designation. The numbers run in descending order from the top downward. RMF-2, for example, is located above RFM-1. In the particular case of NAFEC, where there are two identical controller's display modules number one (CDM-1's), the module on the left was designated CDM-1A while that on the right was called CDM-1B.

In the next column, marked "PRI," the name of the NAS element monitored by the PRI concerned was entered. In the case of the RFM's, where two identical rows of PRI's on each module monitor the elements of two radar sites, the row concerned was designated by use of the letter "U" or "L" for upper or lower, respectively.

FACILITY LAX ARTCC

| | MODULE | PRI | LAMP | DATE REPL. | TIME REPL. | REMARKS (UPTIME HOURS) |
|---|---|---|---|---|---|---|
| (a) | RFM No. 1 | SBY CD (U) | A | 9/14 | 1430 | 1070.5 |
| | RFM No. 2 | DRG CH 3 (U) | A | 9/14 | 1430 | 1070.5 |
| | RFM No. 2 | DRG CH 3 (U) | OX | 9/14 | 1430 | 1070.5 |
| | CDCM No. 3 | RKM 3 | A | 9/15 | 0820 | 1088.33 |
| | CDM No. 1 | RC 12 | W | 9/15 | 0820 | 1088.33 |
| | CDM No. 2 | RC 29 | AL | 9/15 | 0820 | 1088.33 |
| | CDM No 2 | RC 29 | W | 9/15 | 0820 | 1088.33 |
| | CCCM | TCU-1 | G | 9/15 | 0820 | 1088.33 |
| | CDCM No. 4 | DGU 7 | G | 9/15 | 2150 | 1101.83 |
| | CDCM No. 4 | DGU 4 | G | 9/16 | 0815 | 1112.25 |
| | CDCM No. 4 | DGU 4 | W | 9/16 | 0815 | 1112.25 |
| | RFM No. 4 | OL BCN (U) | G | 9/16 | 0815 | 1112.25 |
| | RFM No. 2 | SBY BCN (U) | A | 9/17 | 0940 | 1137.67 |
| | CCCM | CE-1 | G | 9.17 | 1030 | 1138.5 |
| | CCCM | CE-1 | W | 9/17 | 1030 | 1138.5 |
| | CDM | RC 17 | A | 9/17 | 1450 | 1142.83 |
| | CDM | RC 17 | AL | 9/17 | 1450 | 1142.83 |
| | CDM | RC 17 | W | 9/17 | 1450 | 1142.83 |
| (b) | CDCM No. 3 | RKM 2 | G | 9/17 | 1925 | 404.00 |
| | CCCM | CE 1 | W | 9/18 | 0835 | 22 |
| | CDCM No. 1 | NRKM 1 | X | 9/18 | 0945 | 1161.75 |
| | CDCM No. 1 | NRKM 1 | R | 9/18 | 0945 | 1161.75 |
| | CDM No. 1 | RC 13 | AL | 9/18 | 1245 | 1164.75 |
| | RFM No. 4 | OL RADAR (U) | G | 9/18 | 1430 | 1166.5 |
| | RFM No. 3 | SBY BCN (U) | A | 9/19 | 0848 | 1184.8 |

FIGURE 6. SMMC PRI LAMP REPLACEMENT LOG

In the next column, marked "LAMP," the color or symbol designation for the lamp concerned was entered. The four color designations used were as follows: A - amber, R - red, G - green, and W - white. The eight symbol designations were the actual symbols displayed: SS, X, AL, PX, EX, ED, OX, and D.

With the "DATE REPLACED" and "TIME REPLACED" columns filled out, each replaced lamp was uniquely identified as to location within the SMMC and the date and time of replacement. From this information, the uptime, or time interval in hours between the current lamp replacement and the next previous replacement for the location concerned was computed. This was entered in the rightmost column of the log called "REMARKS." In the case where a lamp replacement was the first for the location concerned, the uptime was computed from the date and time that observation for the site concerned started, unless the date and time of the last replacement prior to the start of observation was known. For example, the first line of figure 6, (a), shows that the lamp in the amber position of the PRI monitoring the standby common digitizer failed in the upper row of RFM-1 (the bottommost RFM) and was replaced at 1430 hours (2:30 p.m.) on September 14, 1973. This was the first replacement of the lamp in this specific location and occurred 1,070.5 hours after the start of observation at the site concerned (Los Angeles). Observation for this site started at 0000 hours on August 1, 1973. The uptime for the replaced lamp is therefore 1,070.5 hours or greater, since the lamp was in operation at the start of the period of observation.

In the line shown as (b) in figure 6, it is seen that the lamp in the green position of the PRI monitoring CDC element RKM2, in the CDCM-3 module, was replaced at 1,925 hours on September 17. This is the second lamp failure in this location, and it occurred 404 hours after the previous (first) failure. This first failure had occurred at 2,315 hours on August 31. Therefore, the uptime for this subsequent (second) replacement was 404 hours.

From the information on these log forms, the uptimes for each replaced lamp was computed. The results are shown in terms of initial and subsequent replacements. An initial replacement is the first lamp in any given location replaced after the start of observation for the particular site. Subsequent replacements are the second, third, etc., lamps replaced in any given location after the start of observation. The uptime obtained for the initial replacement must be interpreted as so many hours <u>or greater</u>, since it is not known how long the lamp had been in operation before the start of the observation period. Subsequently replaced lamps had been put into operation and had failed entirely within the time duration of the test, hence their uptimes, or hours between replacements, can be considered as absolute, even though they may not have been energized for the full uptime period.

The underlying statistical distributions for the uptimes for the subsequent replacements were then ascertained, using a Kolmogorov-Smirnov Goodness-of-Fit test. Using a WANG 700C minicomputer, the subsequent uptimes for each of the

four colors at each site was checked to ascertain which of three statistical distributions provided the closest fit. The three statistical distributions were the exponential, normal, and log-normal. The same was done for all symbols combined at each site. An example of the goodness-of-fit test is shown in tables A-1 through A-3 of appendix A. This example shows the test applied to all subsequent lamp replacements in the amber position of the PRI's in the NAFEC SMMC. The 18 subsequent uptimes ranged from 411 to 3,818 hours. Tables A-1 through A-3 show these uptimes checked against the normal, log-normal, and exponential distributions respectively. The test shows that the underlying distribution of these uptimes fits the normal distribution the closest, since the observed maximum cumulative difference between observed and theoretical probabilities (observed d-max) was smaller for the normal distribution (.108, table A-1) than it was for the other two (.146 for the log-normal and .252 for the exponential, tables A-2 and A-3).

The distribution of lamp replacements with respect to lamp location within the SMMC, together with some statistical summaries, is tabulated and discussed for each site observed in the RESULTS section of this report.

ACCELERATED LIFE TESTS. Table 2 includes several lamp types which could be used as substitutes for the type 247 in the SMMC PRI's. One of these, the 6180, while showing the same specified life as the 247, is more readily available. The other two lamps listed, i.e., the 714 and 685, have much longer specified lifetimes than the 247; 25,000 and 100,000 hours respectively.

A series of life tests of these four lamp types was run to obtain comparative life data under simulated SMMC conditions. This included operation inside PRI's at d.c. voltage, which is used in the SMMC, rather than the alternating current (a.c.) voltage operation which the lamp specifications call for. In order to reduce the time necessary to conduct the life tests, the lamps were operated at higher voltages, thereby accelerating or shortening their lives, since the life of a miniature lamp is inversely proportional to the 12th power of the applied voltage. The lamps are normally rated at 5.0 volts. The life tests were performed with the lamps operated at 6.06 and 7.30 volts. When operated at 6.06 volts, the lamp lives were accelerated (or shortened) by a factor of 10; when operated at 7.30 volts, the acceleration factor was 93.8. This is to say that when operated at 7.30 volts, the 100,000-hour specified life of the type 685 lamp could theoretically be simulated by 100,000/93.8 or 1,066 real hours, or about 1.5 months.

In performing the life tests, a number of lamps of a given type would be initially energized at either of the two voltages described above, noting the date and time that the lamps were energized. As each lamp failed, the date and time of failure would again be noted. From this information and the acceleration factor corresponding to the voltage used, the MUT of the lamps could be determined.

For performing the life tests, a special test jig shown in figure 7 was used. This test jig accommodated 40 PRI's. The jig was wired so as to energize the OX symbol position of the PRI's; consequently, the lamps to be tested were inserted in the OX positions. The lamps were energized by a Sorenson d.c. power supply, the output of which could be varied. The voltage applied to the lamps was measured by means of a Fluke digital voltmeter. Time was measured by means of a camera with a built-in Accutron clock. The camera was actuated by an automatic timer. The test setup is shown in figure 8. The timer was set to take one frame every 4 minutes and approximately 6 seconds. Each frame contains the number of illuminated PRI's along with the time and voltage at the instant of exposure. Each failed lamp was assumed to have burned out midway between the two consecutive frames concerned. This can be seen for example in figure 9, which shows two consecutive frames. The upper frame, No. (1) 1108, showed all 40 lamps illuminated at 01:10:41 hours (on September 9). The following frame, No. (1) 1109, occurring at 01:14:49, shows the lamp occupying the D3 position (reference figure 7) extinguished. This lamp is therefore presumed to have failed at a time midway between the two frames, or at 01:12:45.

The film was then analyzed, and the dates and times of the appropriate frames where lamp failures and/or variations in the average voltage level occurred were noted. Using a WANG 700 minicomputer, the lifetimes of the lamps in equivalent hours were calculated. An example is shown in figure 10, where 10 type 247 lamps were tested at a life acceleration factor of 93.8. Using a Kolmogorov-Smirnov goodness-of-fit test, the underlying statistical distributions (normal or log-normal) of the lamp life times were determined.

Sequence of Accelerated Life Tests. The following accelerated life tests were run:

Test 1. - July 8 to 10, 1974. In this test, 10 lamps apiece of types 247, 6180, 714, and 685 were tested at an acceleration factor of 93.8. The test ran to completion on the types 247 and 6180, thereby providing a successful test on these two lamp types. However, a thunderstorm on July 10 destroyed nine of the ten 714's and seven of the ten 685's, thereby aborting the test for these two lamp types.

Test 2. - July 17 to 19, 1974. In this test, 20 lamps apiece of types 6180 and 247 were tested at an acceleration factor of 10. Two 247's and two 6180's failed in a natural manner, but on the morning of July 19, a thunderstorm destroyed all the remaining lamps, hence this test was considered aborted.

Test 3. - July 22 to August 5, 1974. This was a repeat of test No. 2, which had been aborted due to the thunderstorm. This test ran to completion, thereby providing a successful life test of the type 247 and 6180 lamps at an acceleration factor of 10.

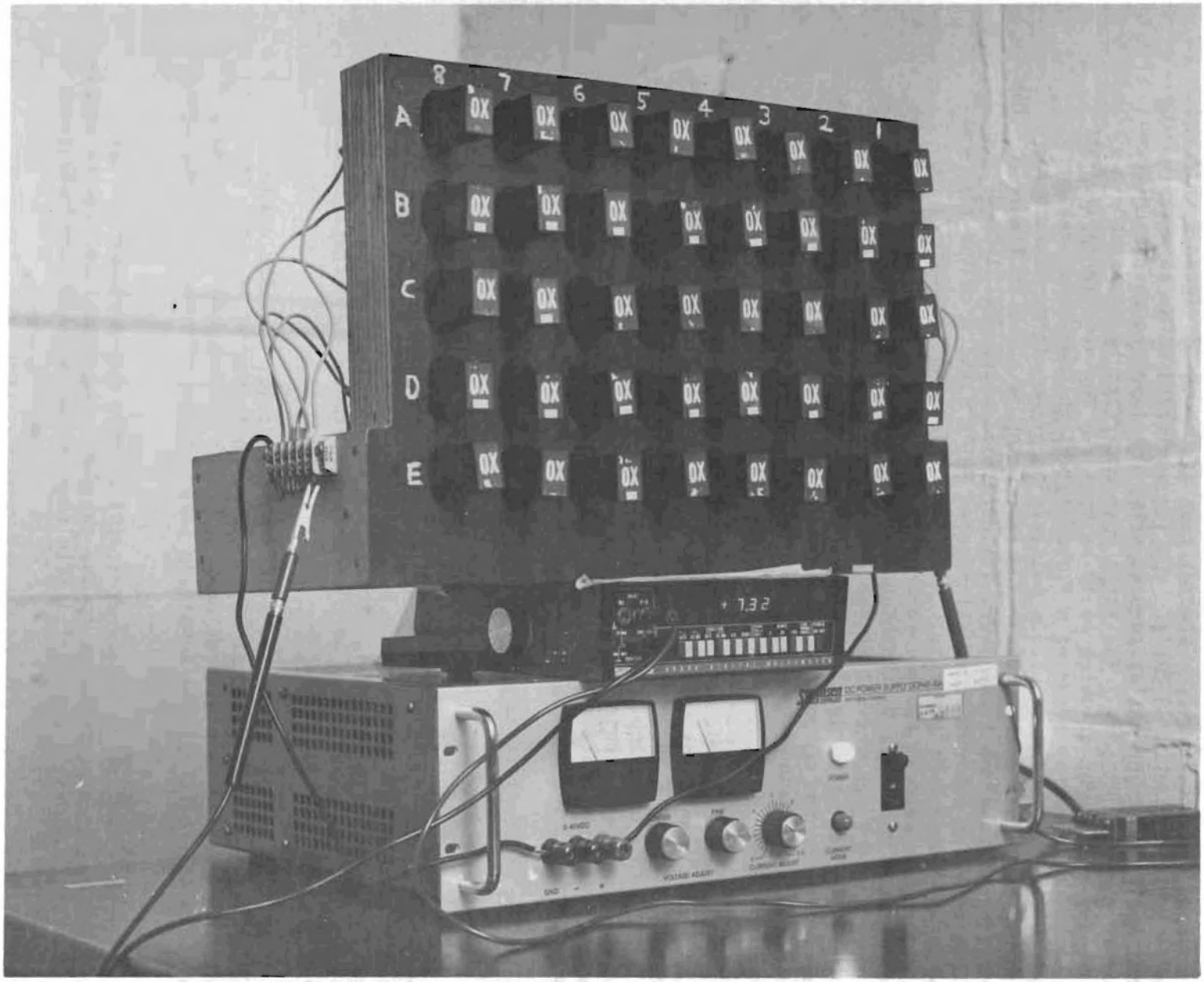


FIGURE 7. TEST JIG, POWER SUPPLY, AND DIGITAL VOLTMETER USED IN ACCELERATED LIFE TESTS

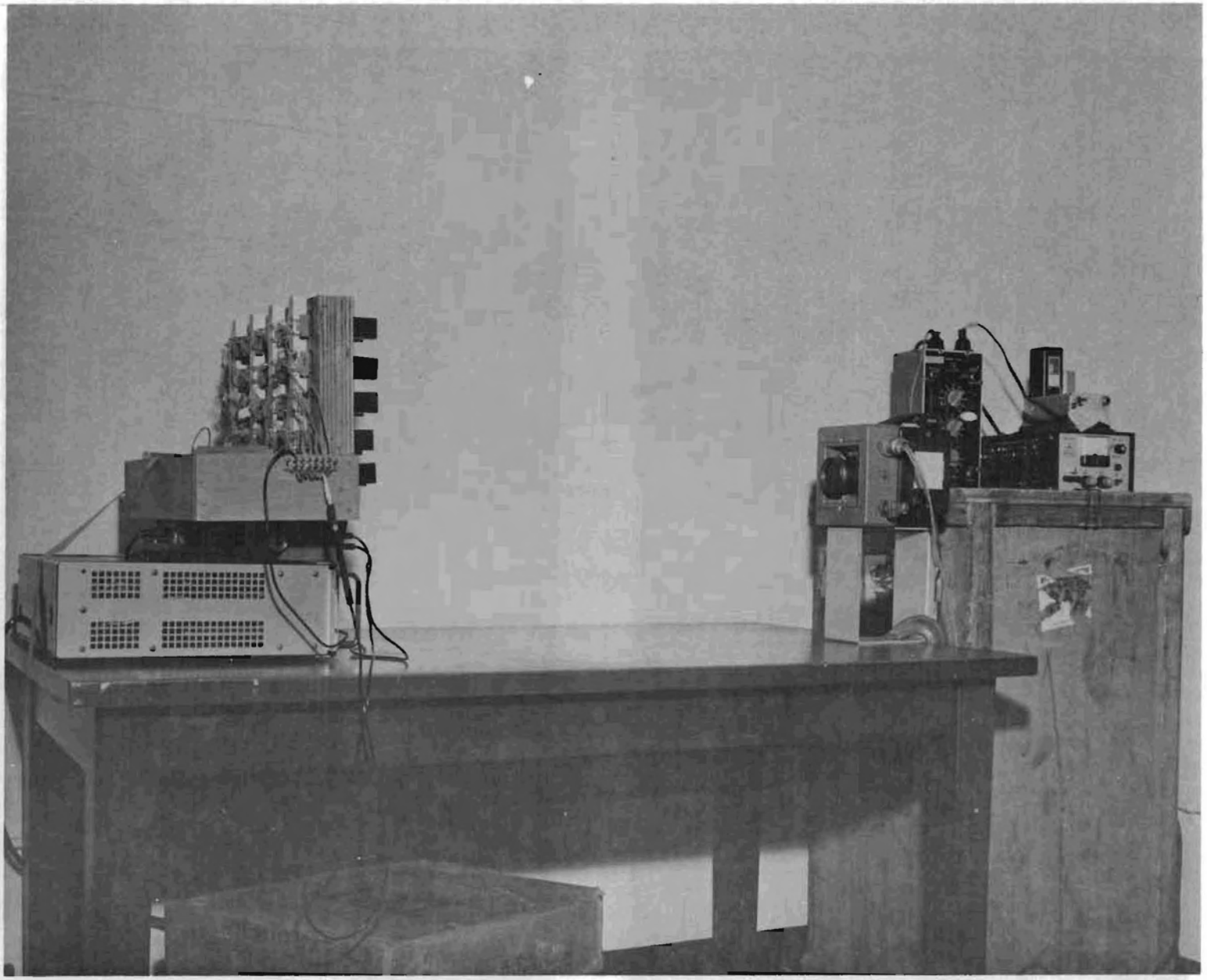

FIGURE 8. PHOTOGRAPHIC INSTRUMENTATION USED IN ACCELERATED LIFE TESTS

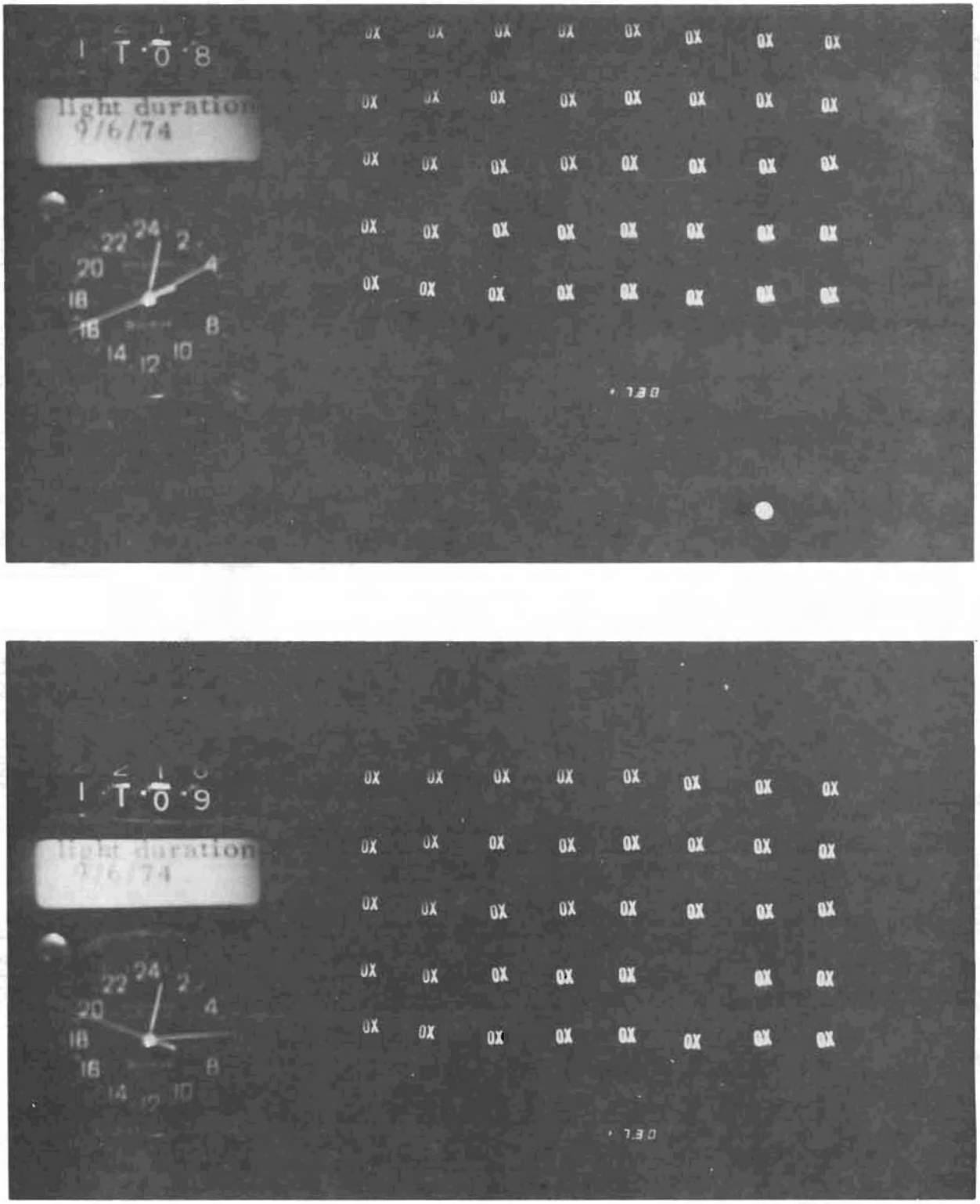


FIGURE 9. TWO CONSECUTIVE FRAMES SHOWING LAMP FAILURE

TEST No. 1 July 8, 1974 Accelerated Life Test of TYPE 247 Lamps

Acceleration Factor = 93.8

| | | | | | | |
|---|---|---|---|---|---|---|
| date time; | 8.100735 | volts; | 7.300 | | | |
| date time; | 8.105051 | volts; | 7.290 | | | |
| date time; | 8.110716 | volts; | 7.280 | | | |
| date time; | 8.111123 | volts; | 7.290 | | | |
| date time; | 8.111529 | volts; | 7.300 | | | |
| date time; | 8.112342 | volts; | 7.310 | | | |
| date time; | 8.112748 | volts; | 7.300 | | | |
| date time; | 8.115659 | volts; | 7.300 | | | |
| date time; | 8.120109 | volts; | 7.300 | life | 173.7 | hrs |
| date time; | 8.122113 | volts; | 7.300 | | | |
| date time; | 8.122925 | volts; | 7.300 | life | 214.7 | hrs |
| date time; | 8.125258 | volts; | 7.300 | | | |
| date time; | 8.130111 | volts; | 7.300 | life | 264.4 | hrs |
| date time; | 8.131336 | volts; | 7.300 | | | |
| date time; | 8.131742 | volts; | 7.300 | life | 293.4 | hrs |
| date time; | 8.132556 | volts; | 7.310 | | | |
| date time; | 8.133409 | volts; | 7.300 | | | |
| date time; | 8.141918 | volts; | 7.300 | | | |
| date time; | 8.142325 | volts; | 7.300 | life | 396.4 | hrs |
| date time; | 8.144357 | volts; | 7.310 | | | |
| date time; | 8.144801 | volts; | 7.300 | | | |
| date time; | 8.151213 | volts; | 7.300 | | | |
| date time; | 8.151620 | volts; | 7.300 | life | 479.2 | hrs |
| date time; | 8.152026 | volts; | 7.310 | | | |
| date time; | 8.153652 | volts; | 7.300 | | | |
| date time; | 8.154058 | volts; | 7.310 | | | |
| date time; | 8.155317 | volts; | 7.290 | | | |
| date time; | 8.160129 | volts; | 7.300 | | | |
| date time; | 8.160941 | volts; | 7.290 | | | |
| date time; | 8.162200 | volts; | 7.300 | | | |
| date time; | 8.162606 | volts; | 7.300 | | | |
| date time; | 8.163011 | volts; | 7.290 | life | 594.9 | hrs |
| date time; | 8.171113 | volts; | 7.300 | | | |
| date time; | 8.172331 | volts; | 7.290 | | | |
| date time; | 8.173144 | volts; | 7.290 | | | |
| date time; | 8.173550 | volts; | 7.290 | life | 696.2 | hrs |
| date time; | 8.204028 | volts; | 7.310 | | | |
| date time; | 8.204435 | volts; | 7.300 | | | |
| date time; | 8.225957 | volts; | 7.310 | | | |
| date time; | 8.230404 | volts; | 7.310 | life | 1204.8 | hrs |
| date time; | 9.013951 | volts; | 7.310 | | | |
| date time; | 9.014357 | volts; | 7.310 | life | 1458.9 | hrs |

Mean Uptime for Type 247 Lamp = 577.7 hours (with Normal distribution)
= 457.1 hours (with Log-normal distribution)

FIGURE 10. SAMPLE PRI LAMP LIFE DETERMINATION

Test 4. - August 8 to October 22, 1974. In this test, 20 lamps apiece of types 714 and 685 were tested at an acceleration factor of 93.8. On August 17, 9 days after the test started, a thunderstorm destroyed all 20 type 714's, but left the 685's undamaged. A second sample of 20 type 714's was inserted on August 19 and ran till September 3. On that day, the remaining six 714's were simultaneously destroyed by a voltage surge, while all 20 type 685's still remained intact. On September 6, a third sample of 20 type 714's was inserted. This sample ran to completion; the final 714 lamp failed on October 17.

This test was terminated on October 22, 1974 with 18 of the original 20 type 685 lamps still illuminated.

Test 5. - October 18 to 19, 1974. This was a repeat of test 1 as applied to the types 247 and 6180 lamps. Ten apiece of these two lamp types were inserted in the 20 places which had been occupied by the third sample of type 714's from test 4.

REAL LIFE TEST. This test started on October 25, 1974 and is still in progress as of the time of this writing. The purpose of this test is to compare the MUT's of the types 247 and 6180 lamps under realtime conditions with no time compression. The same test jig shown in figure 7 is being used in this test. Twenty apiece of each of the two lamp types are being tested and operated at the nominal 5 volts. For this realtime life test, the lamps are observed visually several times a day rather than photographically every 4.1 minutes as was done in the accelerated life tests. The time a lamp failure occurs will be assumed to be midway between the successive observations before and after occurrence of the failure.

HUMAN FACTORS TESTS. At the time of this writing, plans are underway for comparative testing of the types 247, 714, and 685 lamps from a standpoint of relative readability. While the types 714 and 685 lamps have much longer lives than the 247, they are less brilliant. Consequently, test procedures are being developed for determining whether either the 714 or 685 can be considered as a satisfactory substitute for the 247 as far as lighting intensity is concerned. As the results of these tests become available they will be published.

## RESULTS

### MEAN UPTIME TESTS.

CONTRACTUAL TEST. The independent hard failures experienced at each test site during its period of observation are shown in table 3. The results of the

TABLE 3. INDEPENDENT HARD FAILURES EXPERIENCED BY OBSERVED SITES DURING CONTRACTUAL SMMC MUT TEST

| SITE | MODULE | SERIAL NUMBER | DATE OF FAILURE | TIME OF FAILURE | DESCRIPTION OF FAILURE |
|---|---|---|---|---|---|
| Jacksonville | RAPPI | 12 | Dec 6, 74 | --- | R63 and Q15 (2N3714) failed in Deflection Amplifier. |
| Washington | 9020E-1 * | 4 | Oct 31, 73 | 1500 | All 9020E PRI's were flashing at random. Replaced IC# Z-14 on Scanner Interface Card. |
| | NACM | 11 | Nov 9, 73 | --- | Defective Switch Assembly. |
| | Power Supply | 13 | Jan 7, 74 | 0845 | Defective Blower Motor, Dirt in Bearings. |
| | RFM | 10 | Jan 29, 74 | 0500 | False status reports. Defective RFM Selector Printed Circuit Board. |
| Indianapolis | NACM | 39 | Feb 10, 74 | 2305 | Defective Switch Assembly |
| | Power Supply | 26 | Feb 11, 74 | 1930 | Defective Blower Motor |
| Denver | None | -- | ---- | --- | ----- |
| NAFEC | 9020E-1 | 3 | Mar 4, 74 | 1015 | Erratic Blink or Absence of Blink on SLIL Indicators. Defective IC# Z-14 on SLIL Printed Circuit Board. |

*This failure occurred 9 hours prior to the official start of the observation period.

MUT test as they relate to the requirements of the test plan are shown in table 4. The ground rules for the test plan provide for observation on only one unit of each module type except the power supplies. No more than one failure is allowed for any module type except for the CDCM, for which three failures are allowed, and for the power supplies, for which one simultaneous failure of two power supplies in any one of the SMMC's may be allowed. Table 4 accordingly shows the accept/reject decision on each module tested.

TABLE 4. FAILURE SUMMARY OF SMMC MODULE TYPES (CONTRACTUAL TEST)

| Module Type | Number of Failures | Accept or Reject |
|---|---|---|
| CCCM | 0 | Accept |
| CDCM | 0 | Accept |
| CDM | 0 | Accept |
| ECM | 0 | Accept |
| NACM | 2 | Accept |
| RFM | 1 | Accept |
| Scanner | 0 | Accept |
| IMM | 0 | Accept |
| RAPPI | 1 | Accept |
| 9020E | 1 | Accept |
| Power Supplies | 2* | Accept |

*These were failures of individual power supply units. There were no simultaneous failures of two or more units at any one SMMC.

Since the 9020E failure of October 31, 1973, at the Washington ARTCC occurred before the official start of the reliability test, it is not included in considering an accept/reject decision, hence table 4 shows an accept decision for this module type. However, this October 31, 9020E failure will be used in the overall point-estimate and 80 percent lower confidence limit MUT determinations.

Table 4 shows two failures for the NACM module type. In accordance with the test plan, only one NACM from each site was to be chosen for the reliability demonstration. Two or more failures in the four NACM's under observation would constitute a reject decision. As seen in table 3, a failure occurred in NACM module No. 11 at the Washington ARTCC and in NACM module No. 39 at Indianapolis. If these two modules were chosen for inclusion in the test, this would constitute a reject decision for the NACM's. But there are four NACM's at Indianapolis and five at Washington, thereby providing a possibility of 20 NACM combinations for these two sites. Only one of these would be a reject combination. With one failing combination out of 20 overall possible

combinations, there is a 5-percent chance that the NACM's would incur a reject decision, depending upon which NACM was selected for observation at Indianapolis and Washington. However, when all NACM modules in the four sites are considered, table 5 shows a point-estimate MUT for the NACM module type of 36,720 hours and an 80 percent lower confidence limit of 17,159 hours, well above the 5,000-hour specified value. Therefore, the NACM module type is considered to have passed the MUT test.

Table 5 provides the point estimate and 80 percent lower confidence values of MUT for the SMMC modules as obtained from the failures listed in table 3, considering all the units of a module type in the SMMC's. In this table, the discrete physical units which comprise a module type, such as CDCM-1, CDCM-2, etc., are considered as individual modules. The power supplies are likewise considered as discrete units rather than a two-out-of-three redundant system. In the case of the CDM's, since the three possible units in each of the CDCM-CDM and the 9020E-CDM module types are sufficiently similar, they will be grouped and listed as CDM in table 5. Sample calculations for the point estimate and 80 percent lower confidence levels of MUT determinations are shown in appendix B. The power supply module type is used as the example. An 80 percent lower confidence level is used in this and subsequent MUT analyses because this corresponds to the 20-percent consumer's risk given in the contractor-generated reliability demonstration test plan.

NAFEC TEST. A total of 11 hard failures were encountered in the various modules of the NAFEC SMMC during the 21-month period of observation there. These failures are tabulated in table 6.

The results of the MUT observations on the NAFEC SMMC are shown in table 7. The number of failures, unit-hours of uptime, point estimate, and 80-percent lower confidence levels of MUT's are provided for each module type observed.

OVERALL MUT. The overall MUT of the SMMC module types can be determined by combining the 21-month period of observation at NAFEC with the 6-month periods of observation at each of the four ARTCC's. Since the NAFEC and ARTCC observations were mutually exclusive for all module types except the 9020E and CDCM, the uptimes and failures per module type, as shown in tables 5 and 7, can be added to produce a grand total.

In the case of the CDCM, 4,320 of the 17,280 uptime hours called for in the contractual test (table 7) were actually done at NAFEC, since only three of the four ARTCC's had the CDC. Likewise, in the case of the 9020E, 12,960 of the 17,280 contractual uptime hours shown in table 7 were actually done at NAFEC, since only one of the four ARTCC's used the 9020E. Table 8 shows the overall MUT results for each module type.

Table 8 enables one to state with an 80-percent degree of confidence that the true MUT's of the 16 SMMC module types observed are greater than 9,000 hours, with the exception of the 9020E-1 module type, for which the MUT may be as low as 4,500 hours. The SMMC specification calls for a MUT of 5,000 hours for each module type.

TABLE 5. POINT ESTIMATE AND 80 PERCENT LOWER-CONFIDENCE LEVEL MUT's FOR SMMC MODULE TYPES (CONTRACTUAL TEST)

| MODULE TYPE | TOTAL No. of MODULES | TOTAL EQUIPMENT UP-TIME (MODULE-HOURS) | No. of HARD FAILURES | POINT-ESTIMATE MUT (HOURS) | 80% LOWER CONF. LIMIT of MUT (HOURS) |
|---|---|---|---|---|---|
| CCM | 4 | 17,280 | 0 | --- | 10,733 |
| CDCM-1 | 4 | 17,280 | 0 | --- | 10,733 |
| CDCM-2 | 4 | 17,280 | 0 | --- | 10,733 |
| CDCM-3 | 4 | 17,280 | 0 | --- | 10,733 |
| CDCM-4 | 4 | 17,280 | 0 | --- | 10,733 |
| CDM | 8 | 34,560 | 0 | --- | 21,466 |
| ECM | 4 | 17,280 | 0 | --- | 10,733 |
| NACM | 17 | 73,440 | 2 | 36,720 | 17,159 |
| RFM | 13 | 56,160 | 1 | 56,160 | 18,751 |
| SCANNER | 4 | 17,280 | 0 | --- | 10,733 |
| IMM | 4 | 17,280 | 0 | --- | 10,733 |
| RAPPI | 4 | 16,300 | 1 | 16,300 | 5,442 |
| 9020E-1 | 2 | 17,280 | 2 | 8,640 | 4,037 |
| 9020E-2 | 2 | 17,280 | 0 | --- | 10,733 |
| POWER SUPPLIES | 12 | 51,839 | 2 | 25,920 | 12,112 |

TABLE 6. HARD FAILURES IN NAFEC SMMC (JANUARY 1, 1973, THROUGH SEPTEMBER 30, 1974)

| Module Type | Date of Failure | Description of Failure |
|---|---|---|
| NACM | 2/2/73 | Bent pin caused short circuit in pin assembly. |
| CDM | 3/5/73 | Unable to set red or amber status indication in manual mode for radar console 21 PRI. Defective IC (SN74L-74N238) on SRDL card 10. |
| CDM | 5/2/73 | Defective SRDL card, radar console No. 21 PRI. |
| CDM | 9/13/73 | Replaced SRDL card in training console No. 5 PRI position. Defective lamp operation. |
| RFM | 6/28/73 | No alphanumerics on OL-radar (top) PRI. Defective IC (gate Z32) on SRDL card. |
| RFM | 9/13/73 | Replaced SRDL card in standby CD PRI position. Defective lamp operation. |
| 9020E-1 | 3/4/74 | Erratic blinks on SLIL indicators. Defective IC No. Z-14 on SLIL printed circuit board. |
| Power Supply (PWS) S.N.10 | 3/14/73 | Overheated. Defective blower motor, type B-1. |
| PWS S.N.10 | 9/6/73 | Muffin fan failure, type B-1. |
| PWS S.N.11 | 1/29/74 | Blower motor B-1 failed. Overtemperature sensor S-101 failed to shut down power supply. |
| PWS S.N.12 | 3/20/74 | Defective blower motor, type B-1. |

TABLE 7. CUMULATIVE RELIABILITY DATA FOR NAFEC SMMC MODULE TYPES (JANUARY 1, 1973, THROUGH SEPTEMBER 30, 1974)

| Module Type | No. of Hard Failures | Uptime (Unit-Hours) | Point-Estimate MUT (Hours) | 80-Percent Lower Confidence Level of MUT (Hours) |
|---|---|---|---|---|
| NACM | 1 | 45,000 | 45,000 | 15,000 |
| CDCM-1 | 0 | 15,000 | - | 9,300 |
| CDCM-2 | 0 | 15,000 | - | 9,300 |
| CDCM-3 | 0 | 15,000 | - | 9,300 |
| CDCM-4 | 0 | 15,000 | - | 9,300 |
| CDM | 3 | 30,000 | 10,000 | 5,450 |
| RFM | 2 | 30,000 | 15,000 | 7,000 |
| 9020E-1 | 1 | 15,000 | 15,000 | 5,000 |
| 9020E-2 | 0 | 15,000 | - | 9,300 |
| CCCM | 0 | 15,000 | - | 9,300 |
| ECM | 0 | 15,000 | - | 9,300 |
| Scanner | 0 | 15,000 | - | 9,300 |
| RAPPI | 0 | 15,000 | - | 9,300 |
| DRGI | 0 | 15,000 | - | 9,300 |
| PWS | 4 | 45,000 | 11,250 | 6,725 |
| IMM | 0 | 8,700 | - | 5,400 |

TABLE 8. OVERALL RELIABILITY DATA FOR SMMC MODULE TYPES AT FOUR ARTCC's PLUS NAFEC

| Module Type | No. of Hard Failures | Uptime (Unit-Hours) | Point-Estimate MUT (Hours) | 80-Percent Lower Confidence Level of MUT (Hours) |
|---|---|---|---|---|
| CCCM | 0 | 32,280 | - | 20,000 |
| CDCM-1 | 0 | 27,960 | - | 17,366 |
| CDCM-2 | 0 | 27,960 | - | 17,366 |
| CDCM-3 | 0 | 27,960 | - | 17,366 |
| CDCM-4 | 0 | 27,960 | - | 17,366 |
| CDM | 3 | 64,560 | 21,520 | 11,750 |
| ECM | 0 | 32,280 | - | 20,000 |
| NACM | 3 | 88,440 | 29,480 | 16,000 |
| RFM | 3 | 86,160 | 28,720 | 15,700 |
| Scanner | 0 | 32,280 | - | 20,000 |
| DRGI | 0 | 15,000 | - | 9,300 |
| RAPPI | 1 | 31,300 | 31,300 | 10,400 |
| IMM | 0 | 25,980 | - | 16,135 |
| 9020E-1 | 2 | 19,320 | 9,660 | 4,500 |
| 9020E-2 | 0 | 19,320 | - | 12,000 |
| PWS | 6 | 96,840 | 16,140 | 10,640 |

MEAN DOWNTIME TESTS.

CONTRACTUAL TEST. In the maintainability demonstration (MDT test) conducted at the contractor's plant, all seven representative module types tested passed the test. All induced failures were resolved in less than an hour; most of them in less than 10 minutes. Table 9 shows the results of the maintainability demonstration on one of these modules, the RAPPI. This module was tested during the afternoon of September 5, 1972.

TABLE 9. RESULTS OF MDT TEST ON RAPPI MODULE AT ELI PLANT, HOUSTON, TEXAS (SEPTEMBER 5, 1972)

| Task Sequence | Task Number | Time Started | Time Ended | Duration of Task (Minutes) |
|---|---|---|---|---|
| 1 | 5 | 1415 | 1421 | 6 |
| 2 | 43 | 1432 | 1434 | 2 |
| 3 | 63 | 1456 | 1511 | 15 |
| 4 | 14 | 1522 | 1527 | 5 |
| 5 | 88 | 1535 | 1539 | 4 |
| 6 | 49 | 1555 | 1635 | 40 |
| 7 | 56 | 1703 | 1707 | 4 |
| 8 | 14 | Repeat (Sequence 4) | | 5 |
| 9 | 75 | 1731 | 1750 | 19 |
| 10 | 35 | 1800 | 1805 | 5 |
| 11 | 80 | 1814 | 1817 | 3 |
| 12 | 85 | 1835 | 1854 | 19 |

NAFEC AND FIELD. A total of 18 hard failures occurred during the 21-month period of observation at NAFEC plus the MUT tests performed on the SMMC modules at the four ARTCC's. These failures, together with downtimes, are shown in table 10. In some cases, the downtimes are estimated when they are not apparent from the logs or failure reports.

The MDT's for the various module types are given, assuming a log-normal underlying distribution. Inasmuch as the downtimes were not obtained under controlled conditions, and as considerable estimation was done in determining them, the downtimes and MDT's should not be taken as absolute but are provided for general information. It will be noted that of the six module types where hard failures were experienced, only one (the power supplies) incurred more than three failures.

DISTRIBUTION OF HARD FAILURES.

Table 10 shows the 18 hard failures which had occurred in the reliability observations at NAFEC and the five ARTCC's. The failures generally consisted

TABLE 10. HARD FAILURES ENCOUNTERED DURING OVERALL SMMC RELIABILITY OBSERVATION AT FOUR ARTCC's AND NAFEC

| Module | Location | Failure Description | Downtime (Hours) |
|---|---|---|---|
| CDM | NAFEC | Defective IC on SRDL card | 2.0 |
| CDM | NAFEC | Defective SRDL card | 1.0 |
| CDM | NAFEC | Defective SRDL card | 0.5* |
| | | MDT = 1.0 hours (log-normal) | |
| NACM | NAFEC | Bent pin | 3.5 |
| NACM | Washington | Defective switch assembly | 1.0* |
| NACM | Indianapolis | Defective switch assembly | 1.0* |
| | | MDT = 1.52 hours (log-normal) | |
| RFM | NAFEC | Defective IC on SRDL card | 2.0 |
| RFM | NAFEC | Defective SRDL card | 0.5* |
| RFM | Washington | Defective RFM selector card | 0.0 |
| | | MDT = 0.25 hours (log-normal) | |
| RAPPI | Jacksonville | Deflection ampl. failure | 4.0* |
| 9020E-1 | NAFEC | Defective IC on SRDL card | 1.0* |
| 9020E-1 | Washington | Defective IC on scanner interface card | 0.0 |
| | | MDT = 0.5 hours (log-normal) | |
| PWS | NAFEC | Defective blower motor | 4.0 |
| PWS | NAFEC | Muffin fan failure | 1.25 |
| PWS | NAFEC | Defective blower motor | 1.83 |
| PWS | NAFEC | Defective blower motor | 2.0 |
| PWS | Washington | Defective blower motor | 1.5* |
| PWS | Indianapolis | Defective blower motor | 1.4 |
| | | MDT = 1.84 hours (log-normal) | |

*Estimated

of defective NACM switch assemblies, defective printed circuit boards, and defective blower motors in the power supplies; this latter comprised the largest category of hard failures. There were six power supply failures noted, all of which involved defective blower or muffin fan motors. These were all item B-1, fan, part No. 4500A, manufactured by Pamotor, Inc., of Burlingame, California. This manufacturer has superceded the 4500A with an improved model No. 4500C.

PRI LAMP FAILURES.

While there were only 18 hard failures in approximately 3.75 equipment-years of SMMC observation, the high replacement rate of the type 247 incandescent lamps in the PRI's is of much greater concern. The detailed lamp replacement study at NAFEC plus the three field sites of New York, Los Angeles, and Oakland was made to ascertain the magnitude of this problem. The life tests and human factors studies to be made on the alternative lamp types are being done to investigate the use of suitable alternative lamps to replace the type 247. The results of these studies as completed to date are shown below.

DETAILED REPLACEMENT STUDY OF TYPE 247 LAMP. NAFEC (July 1, 1973 through April 15, 1974. During the 281 days of observations a total of 694 type 247 PRI lamps were replaced. The distribution of these lamps with respect to their location within the SMMC (module, NAS element, and color or symbol) is shown in appendix C.

Some replacement statistics revealed in appendix C are as follows:

Number of PRI's in NAFEC SMMC - 230.

206 PRI's (89.5 percent) underwent at least one lamp replacement.

201 PRI's (87.4 percent) underwent at least one lamp replacement in one or more status (color) positions.

110 PRI's (48 percent) underwent at least one lamp replacement in two or more status (color) positions.

44 PRI's (19.1 percent) underwent at least one lamp replacement in three or more status (color) positions.

14 PRI's (6.1 percent) underwent at least one lamp replacement in all four status (color) positions.

104 PRI's (45 percent) underwent at least one lamp replacement in one or more performance (symbol) positions.

26 PRI's (11.3 percent) underwent at least one lamp replacement in two or more performance (symbol) positions.

7 PRI's (3 percent) underwent at least one lamp replacement in three performance (symbol) positions.

| | | |
|---|---|---|
| Total number of lamps replaced in GREEN positions of PRI's | - | 135 |
| Total number of lamps replaced in WHITE positions of PRI's | - | 221 |
| Total number of lamps replaced in AMBER positions of PRI's | - | 81 |
| Total number of lamps replaced in RED positions of PRI's | - | 106 |
| Total number of lamps replaced in color (status) positions of PRI's | - | 543 |
| Total number of lamps replaced in symbol (performance) positions of PRI's | - | 151 |
| Total number of type 247 lamps replaced at NAFEC (July 1, 1973, through April 15, 1974) | - | 694 |

Of these 694 lamps, 506 were INITIAL replacements (first lamps replaced since July 1, 1973) while 188 were SUBSEQUENT replacements (second, third, etc., lamps replaced since July 1, 1973) for each lamp position.

From the replacement logs, the following uptime summaries are listed:

Of the 506 INITIAL replacements:

483 (95.5 percent) operated for 1,000 hours or more before replacement.

376 (74.4 percent) operated for 2,000 hours or more before replacement.

277 (54.7 percent) operated for 3,000 hours or more before replacement.

188 (37 percent) operated for 4,000 hours or more before replacement.

113 (22.3 percent) operated for 5,000 hours or more before replacement.

78 (15.4 percent) operated for 6,000 hours or more before replacement.

17 (3.36 percent) operated for 6,500 hours or more before replacement.

NOTE: The INITIAL replacement percentage listings are not mutually exclusive, since each listing is contained in all the listings above it.

The SUBSEQUENT replacement percentage listings are mutually exclusive, and hence add up to 100 percent.

Of the 188 SUBSEQUENT replacements:

41 (21.8 percent) were replaced before 1,000 hours of operation.

59 (31.4 percent) were replaced between 1,000 and 2,000 hours of operation.

54 (28.7 percent) were replaced between 2,000 and 3,000 hours of operation.

22 (11.7 percent) were replaced between 3,000 and 4,000 hours of operation.

12 (6.4 percent) were replaced after 4,000 hours of operation.

The results of the Kolmogorov-Smirnov test on the SUBSEQUENT replacements indicated the following:

| Category | Number of SUBSEQUENT Replacements | Underlying Distribution | MUT (hours) | Standard Deviation (hours) |
|---|---|---|---|---|
| GREEN | 39 | NORMAL | 2,144 | 1,231 |
| WHITE | 93 | NORMAL | 1,906 | 1,121 |
| AMBER | 18 | NORMAL | 1,865 | 1,071 |
| RED | 24 | LOG-NORMAL | 1,791 | .232* |
| SYMBOLS | 14 | LOG-NORMAL | 1,866 | .250* |

* - Standard Deviation of Logs (10) of Uptimes.

LOS ANGELES (AUGUST 1, 1973 THROUGH JANUARY 31, 1974). During the 184 days of observation at Los Angeles, a total of 409 type 247 lamps were replaced. The distribution of these lamps with respect to their location with the SMMC is given in appendix D, and some replacement statistics are summarized as follows:

Estimated number of PRI's in Los Angeles SMMC - 223.

169 PRI's (76 percent) underwent at least one lamp replacement.

167 PRI's (75 percent) underwent at least one lamp replacement in one or more status (color) positions.

48 PRI's (21.5 percent) underwent at least one lamp replacement in two or more status (color) positions.

11 PRI's (4.9 percent) underwent at least one lamp replacement in three status (color) positions.

57 PRI's (25.5 percent) underwent at least one lamp replacement in one or more performance (symbol) positions.

13 PRI's (5.8 percent) underwent at least one lamp replacement in two performance (symbol) positions.

| | | |
|---|---|---|
| Total number of lamps replaced in GREEN positions of PRI's | - | 115 |
| Total number of lamps replaced in WHITE positions of PRI's | - | 103 |
| Total number of lamps replaced in AMBER positions of PRI's | - | 72 |
| Total number of lamps replaced in RED positions of PRI's | - | 26 |
| Total number of lamps replaced in color (status) positions of PRI's | - | 316 |
| Total number of lamps replaced in symbol (performance) positions of PRI's | - | 93 |
| Total number of type 247 lamps replaced at Los Angeles (August 1, 1973, through January 31, 1974) | - | 409 |

Of these 409 lamps, 296 were INITIAL replacements (first lamps replaced since August 1, 1973) while 113 were SUBSEQUENT replacements (second, third, etc., lamps replaced since August 1, 1973) for each lamp position.

From the replacement logs, the following uptime summaries are listed:

Of the 296 INITIAL replacements:

212 (71.5 percent) operated for 1,000 hours or more before replacement.

124 (42 percent) operated for 2,000 hours or more before replacement.

63 (21.3 percent) operated for 3,000 hours or more before replacement.

8 (2.7 percent) operated for 4,000 hours or more before replacement.

Of the 113 SUBSEQUENT replacements:

19 (16.8 percent) were replaced before 500 hours of operation.

29 (25.7 percent) were replaced between 500 and 1,000 hours of operation.

24 (21.2 percent) were replaced between 1,000 and 1,500 hours of operation.

21 (18.6 percent) were replaced between 1,500 and 2,000 hours of operation.

10 (8.8 percent) were replaced before 2,000 and 2,500 hours of operation.

5 (4.4 percent) were replaced before 2,500 and 3,000 hours of operation.

5 (4.4 percent) were replaced after 3,000 hours of operation.

The results of the Kolmogorov-Smirnov test on the SUBSEQUENT replacements indicated the following:

| Category | Number of SUBSEQUENT Replacements | Underlying Distribution | MUT (hours) | Standard Deviation (hours) |
|---|---|---|---|---|
| GREEN | 42 | NORMAL | 1,403 | 936 |
| WHITE | 31 | NORMAL | 1,013 | 624 |
| AMBER | 10 | NORMAL | 1,408 | 1,103 |
| RED | 7 | NORMAL | 1,090 | 553 |
| SYMBOLS | 23 | NORMAL | 1,361 | 742 |

NEW YORK (NOVEMBER 1, 1973, THROUGH APRIL 27, 1974). During the 178 days of observation at New York, a total of 348 type 247 lamps were replaced. The distribution of these lamps with respect to their location within the SMMC is shown in appendix E, and some replacement statistics are summarized as follows:

Estimated number of PRI's in New York SMMC - 218.

148 PRI's (68 percent) underwent at least one lamp replacement.

134 PRI's (61.5 percent) underwent at least one lamp replacement in one or more status (color) positions.

53 PRI's (24.3 percent) underwent at least one lamp replacement in two or more status (color) positions.

11 PRI's (5 percent) underwent at least one lamp replacement in three status (color) positions.

58 PRI's (26.6 percent) underwent at least one lamp replacement in one or more performance (symbol) positions.

10 PRI's (4.6 percent) underwent at least one lamp replacement in two or more performance (symbol) positions.

1 PRI (0.5 percent) underwent at least one lamp replacement in three performance (symbol) positions.

Total number of lamps replaced in GREEN positions of PRI's - 60

Total number of lamps replaced in WHITE positions of PRI's - 109

Total number of lamps replaced in AMBER positions of PRI's - 78

| | | |
|---|---|---|
| Total number of lamps replaced in RED positions of PRI's | - | 24 |
| Total number of lamps replaced in color (status) positions of PRI's | - | 271 |
| Total number of lamps replaced in symbol (performance) positions of PRI's | - | 77 |
| Total number of type 247 lamps replaced at New York (November 1, 1973, through April 27, 1974) | - | 348 |

Of these 348 lamps, 267 were INITIAL replacements (first lamps replaced since November 1, 1973) while 81 were SUBSEQUENT replacements (second, third, etc., lamps replaced since November 1, 1973) for each lamp position.

From the replacement logs, the following uptime summaries are listed:

Of the 267 INITIAL replacements:

190 (71 percent) operated for 1,000 hours or more before replacement.

122 (45.6 percent) operated for 2,000 hours or more before replacement.

85 (31.8 percent) operated for 3,000 hours or more before replacement.

32 (12 percent) operated for 4,000 hours or more before replacement.

Of the 81 SUBSEQUENT replacements:

10 (12.3 percent) were replaced before 500 hours of operation.

13 (16 percent) were replaced between 500 and 1,000 hours of operation.

22 (27.2 percent) were replaced between 1,000 and 1,500 hours of operation.

17 (21 percent) were replaced between 1,500 and 2,000 hours of operation.

2 (2.4 percent) were replaced between 2,000 and 2,500 hours of operation.

9 (11.1 percent) were replaced between 2,500 and 3,000 hours of operation.

7 (8.7 percent) were replaced between 3,000 and 3,500 hours of operation.

1 (1.2 percent) were replaced after 3,500 hours of operation.

The results of the Kolmogorov-Smirnov Test on the SUBSEQUENT replacements indicated the following:

| Category | Number of SUBSEQUENT Replacements | Underlying Distribution | MUT (hours) | Standard Deviation (hours) |
|---|---|---|---|---|
| GREEN | 14 | NORMAL | 1,605 | 1,266 |
| WHITE | 36 | NORMAL | 1,366 | 965 |
| AMBER | 21 | LOG-NORMAL | 1,603 | .184* |
| RED | 2 | NORMAL | 1,894 | 586 |
| SYMBOLS | 8 | NORMAL | 1,566 | 1,027 |

* - Standard Deviation of Logs $_{(10)}$ of Uptimes.

OAKLAND (AUGUST 1, 1973, THROUGH FEBRUARY 5, 1974). During the 189 days of observation at Oakland, a total of 143 type 247 lamps were replaced. The distribution of these lamps with respect to their location within the SMMC is shown in appendix F, and some replacement statistics are summarized as follows:

Estimated number of PRI's in Oakland SMMC - 193.

99 PRI's (51 percent) underwent at least one lamp replacement.

96 PRI's (49 percent) underwent at least one lamp replacement in one or more status (color) positions.

15 PRI's (7.8 percent) underwent at least one lamp replacement in two or more status (color) positions.

1 PRI (0.5 percent) underwent at least one lamp replacement in three status (color) positions.

14 PRI's (7.25 percent) underwent at least one lamp replacement in one performance (symbol) position.

Total number of lamps replaced in GREEN positions of PRI's - 58

Total number of lamps replaced in WHITE positions of PRI's - 38

Total number of lamps replaced in AMBER positions of PRI's - 28

Total number of lamps replaced in RED positions of PRI's - 4

| | | |
|---|---|---|
| Total number of lamps replaced in color (status) positions of PRI's | - | 128 |
| Total number of lamps replaced in symbol (performance) positions of PRI's | - | 15 |
| Total number of type 247 lamps replaced at Oakland (August 1, 1973, through February 5, 1974) | - | 143 |

Of these 143 lamps, 126 were INITIAL replacements (first lamps replaced since August 1, 1973) while 17 were SUBSEQUENT replacements (second, third, etc., lamps replaced since August 1, 1973) for each lamp position.

From the replacement logs, the following uptime summaries are listed:

Of the 126 INITIAL replacements:

79 (62.6 percent) operated for 1,000 hours or more before replacement.

33 (26.2 percent) operated for 2,000 hours or more before replacement.

16 (12.7 percent) operated for 3,000 hours or more before replacement.

3 (2.38 percent) operated for 4,000 hours or more before replacement.

Of the 17 SUBSEQUENT replacements:

2 (11.8 percent) were replaced before 500 hours of operation.

4 (23.5 percent) were replaced between 500 and 1,000 hours of operation.

4 (23.5 percent) were replaced between 1,000 and 1,500 hours of operation.

3 (17.6 percent) were replaced between 1,500 and 2,000 hours of operation.

1 (5.9 percent) was replaced between 2,000 and 2,500 hours of operation.

1 (5.9 percent) was replaced between 2,500 and 3,000 hours of operation.

1 (5.9 percent) was replaced between 3,000 and 4,000 hours of operation.

1 (5.9 percent) was replaced after 4,000 hours of operation.

The results of the Kolmogorov-Smirnov test on the SUBSEQUENT green and white replacements are summarized as follows. NOTE: Goodness-of-fit tests were not performed on the other three categories for Oakland because there were less than two uptimes per category.

| Category | Number of SUBSEQUENT Replacements | Underlying Distribution | MUT (hours) | Standard Deviation (hours) |
|---|---|---|---|---|
| GREEN | 13 | LOG-NORMAL | 1,337 | .291* |
| WHITE | 2 | NORMAL | 354 | 446 |

* - Standard Deviation of Logs $_{(10)}$ of Uptimes.

OVERALL MUT OF ALL TYPE 247 PRI LAMPS. The previous discussion concerned the replacement of lamps uniquely identified as to position within the SMMC as well as specific time of replacement. Uptime and replacement summaries were provided for these specific replaced lamps and from the PRI's whence they were replaced. Each PRI contains 12 lamps (four color and eight symbols). Many of these lamps were energized for only a small portion of the period of observation, and some possibly not at all. To arrive at a more meaningful determination of the overall MUT of all the type 247 lamps used in the SMMC, their use within the PRI must be considered.

While each PRI has 12 lamps, one and only one of the four lamps in the color positions will be energized at any time. No more than one of the eight symbol lamps within a PRI may be energized at any time. Observations at NAFEC have indicated that an average of approximately 20 percent of the PRI's have symbols displayed at any time. Since all the PRI's will have one color displayed, and approximately 20 percent of the PRI's will have one symbol displayed at a given time, one can consider that the equivalent number of continuously energized lamps would therefore be equal to 1.2 times the number of PRI's in the SMMC.

Using this approach, the overall MUT's for the type 247 lamps at each site are computed as follows:

NAFEC. Six hundred and ninety four lamps were replaced at NAFEC during the 281 days of observation. The NAFEC SMMC contains approximately 230 PRI's. The overall MUT for the lamps at NAFEC is therefore:

$$\frac{230 \times 1.2 \times 281 \times 24}{694} = 2{,}682 \text{ hours}$$

Los Angeles. Four hundred and nine lamps were replaced at Los Angeles during the 184 days of observation. The Los Angeles SMMC contains an estimated 223 PRI's. The overall MUT for the lamps at Los Angeles is therefore:

$$\frac{223 \times 1.2 \times 184 \times 24}{409} = 2{,}889 \text{ hours}$$

New York. Three hundred and forty eight lamps were replaced at New York during the 178 days of observation. The New York SMMC contains an estimated 218 PRI's. The overall MUT for the lamps at New York is therefore:

$$\frac{218 \times 1.2 \times 178 \times 24}{348} = 3{,}211 \text{ hours}$$

Oakland. One hundred and forty three lamps were replaced at Oakland during the 189 days of observation. The Oakland SMMC contains an estimated 193 PRI's. The overall MUT for the lamps at Oakland is therefore:

$$\frac{193 \times 1.2 \times 189 \times 24}{143} = 7{,}346 \text{ hours}$$

Table 11 provides a summary of the overall MUT's and average daily replacement rates of the type 247 lamps at the four sites observed.

As seen from table 11, the overall MUT's appear in the general area of between 2,700 and 3,200 hours, with the exception of Oakland. Daily replacement rates run from approximately 2 to 2.5 lamps replaced per day, with the exception of Oakland.

As seen from the Kolmogorov-Smirnov summaries of the subsequent replacements, the MUT's of the various categories of colors and symbols tested show a lower range of MUT's than the overall MUT's shown in table 11. The MUT's of the subsequent replacements at New York, for example, range from 1,366 hours (white) to 1,894 hours (red), which is considerably below the overall MUT of 3,211 hours for New York. However, the entire lifetimes of these subsequent replacements were contained within the test interval, which itself was limited to between 178 and 281 days. For an indefinitely long test period, the MUT's of the subsequent replacements would be expected to increase. This can be seen by considering the test period at NAFEC (281 days) which was approximately 50 percent longer than at the other sites. The MUT's of the subsequent replacements at NAFEC were higher than those for the other three sites; ranging from 1,791 hours (red) to 2,144 hours (green).

TABLE 11. OVERALL MUT AND REPLACEMENT RATE SUMMARY OF TYPE 247 LAMPS

| Site | Duration of Study (Days) | No. of Lamps Replaced | MUT (Hours) | Average Daily Replacement Rate |
|---|---|---|---|---|
| NAFEC | 281 | 694 | 2,682 | 2.47 |
| Los Angeles | 184 | 409 | 2,889 | 2.22 |
| New York | 178 | 348 | 3,211 | 1.96 |
| Oakland | 189 | 143 | 7,346 | 0.76 |

The type 247 lamps are manufactured by Lamps, Inc., of Torrance, California. The manufacturer's catalog shows a life of 6,500 hours for the type 247 lamp. This is based upon a.c. voltage. The SMMC uses d.c. voltage for these lamps. The use of d.c. voltage on small-diameter filaments, such as this lamp employs, will generally reduce this figure by 40 to 50 percent. Therefore, the type 247 lamps used in the SMMC with direct current, should exhibit a life of approximately 3,500 hours, rather than the 6,500 hours shown by the specification. The overall MUT's shown by three of the sites studied range from 2,682 to 3,211 hours, which is somewhat below 3,500 hours.

The Kolmogorov-Smirnov tests showed that most of the subsequent replacements tested indicated underlying normal distributions, with a few indicating log-normal. These subsequent replacements were complete lifetimes, since the lamps were put into operation and were replaced entirely within the period of observation. However, in actual use, failures and replacements occur at various times. Over an extended period of time, the failures would tend to approach a random, or constant rate (exponential) distribution rather than a normal or log-normal distribution. Assuming lamp failures at random times then, and considering an average of 265 continuously energized lamps in a SMMC, random failures of the lamps would be expected to occur every 3,500/265, or about 13.2 hours. This would correspond to a theoretical replacement rate of about 1.82 lamps per day. Comparing this theoretical replacement rate with the actual replacement rates shown in table 11, it is seen that the actual replacement rates are somewhat higher than the theoretical rate, with the exception of Oakland.

ACCELERATED LIFE TESTS. The results of the accelerated life tests for the four types of lamps tested are presented below. These equivalent lives should be considered as relative rather than absolute, since the 12th power inverse relationship between life and voltage departs from accuracy as the deviation from the nominal (5 volts) voltage increases.

Type 247 Lamp. Test 3. Acceleration Factor of 10 (6.06 volts). The 20 type 247 lamps tested at 6.06 volts showed the following equivalent lives in hours:

| | | | |
|---|---|---|---|
| 231.7 | 438.6 | 810.0 | 1,719.6 |
| 258.4 | 497.7 | 856.6 | 1,852.7 |
| 258.4 | 535.1 | 972.7 | 1,993.1 |
| 268.8 | 541.9 | 1,114.6 | 2,555.4 |
| 372.4 | 549.9 | 1,340.0 | 2,956.5 |

These lifetimes showed an underlying log-normal distribution with a log-normal mean of 741.3 hours.

Type 247 Lamp. Test 1. Acceleration Factor of 93.8 (7.3 volts). The 10 type 247 lamps tested at 7.3 volts showed the following equivalent lives in hours:

| | |
|---|---|
| 173.7 | 479.2 |
| 214.7 | 594.9 |
| 264.4 | 696.2 |
| 293.4 | 1,204.8 |
| 396.4 | 1,458.9 |

These lifetimes showed an underlying log-normal distribution with a log-normal mean of 457.1 hours.

Type 247 Lamp. Test 5. Acceleration Factor of 93.8 (7.3 volts). The second sample of 10 type 247 lamps tested at 7.3 volts showed the following equivalent lifetimes in hours:

| | |
|---|---|
| 379.4 | 1,205.1 |
| 385.8 | 1,355.0 |
| 417.7 | 1,652.7 |
| 507.3 | 2,034.9 |
| 585.5 | 3,568.7 |

These lifetimes showed an underlying log-normal distribution with a log-normal mean of 902 hours. NOTE: The goodness-of-fit tests performed on each of the three tests above on the type 247 lamp indicated that each fitted a normal as well as a log-normal distribution, however, the log-normal provided the better fit.

Since tests 1 and 5 were conducted at the same acceleration factor (93.8), if the two samples are combined, the resulting 20 type 247 lamp lifetimes show a log-normal distribution with a mean of 642 hours.

Type 6180 Lamp. Test 3. Acceleration Factor of 10 (6.06 volts). The 20 type 6180 lamps tested at 6.06 volts showed the following equivalent lives in hours:

| | | | |
|---|---|---|---|
| 301.0 | 775.0 | 969.4 | 1,398.1 |
| 522.9 | 857.3 | 1,009.4 | 1,402.3 |
| 630.9 | 861.4 | 1,150.9 | 1,407.6 |
| 635.0 | 892.3 | 1,303.9 | 1,532.2 |
| 747.9 | 937.4 | 1,369.4 | 2,037.1 |

These lifetimes showed an underlying normal distribution with a mean of 1,037 hours and a standard deviation of 412 hours.

Type 6180 Lamp. Test 1. Acceleration Factor of 93.8 (7.3 volts). The 10 type 6180 lamps tested at 7.3 volts showed the following equivalent lives in hours:

| | |
|---|---|
| 383.5 | 986.6 |
| 479.2 | 1,159.8 |
| 531.1 | 1,537.1 |
| 708.8 | 1,693.4 |
| 715.2 | 1,840.8 |

These lifetimes showed an underlying normal distribution with a mean of 1,004 hours and a standard deviation of 531 hours.

Type 6180 Lamp. Test 5. Acceleration Factor of 93.8 (7.3 volts). The second sample of 10 type 6180 lamps tested at 7.3 volts showed the following equivalent lifetimes in hours:

| | |
|---|---|
| 128.3 | 883.0 |
| 328.2 | 897.4 |
| 411.3 | 936.0 |
| 820.6 | 1,529.8 |
| 833.4 | 1,582.0 |

These lifetimes showed an underlying normal distribution with a mean of 835 and a standard deviation of 471 hours.

Since tests 1 and 5 were conducted at the same acceleration factor (93.8), if the two samples are combined, the resulting 20 type 6180 lamp lifetimes show a normal distribution with a mean of 919 hours and a standard deviation of 496 hours.

Type 714 Lamp. Test 4. Acceleration Factor of 93.8 (7.3 volts). The first sample of 20 type 714 lamps was totally destroyed by a voltage surge at an equivalent life of 21,306 hours. The second sample of 20 type 714 lamps showed the following equivalent lives in hours:

| | |
|---|---|
| 503.0 | |
| 8,438.6 | |
| 15,755.4 | |
| 20,675.0 | (Destroyed by a voltage surge) |
| 25,572.7 | |
| 30,466.9 | (Nine destroyed at once by a voltage surge) |
| 34,649.1 | (Six destroyed at once by a voltage surge) |

The third sample of 20 type 714 lamps showed the following equivalent lives in hours:

| | | | |
|---|---|---|---|
| 5,579.0 | 33,867.3 | 44,607.4 | 59,194.6 |
| 24,360.5 | 37,070.5 | 45,152.4 | 62,933.4 |
| 29,584.3 | 39,859.0 | 52,336.9 | 70,109.3 |
| 33,180.9 | 42,341.5 | 52,882.3 | 78,014.0 |
| 33,386.5 | 42,742.6 | 54,660.3 | 93,070.0 |

The first and second samples of 714's were substantially destroyed by voltage surges, hence the lifetimes obtained are shown for relative information purposes. The third sample, having run to completion, was analyzed and showed an underlying normal distribution with a mean of 46,746 hours and a standard deviation of 19,762 hours.

Type 685 Lamp. Test 4. Acceleration Factor of 93.8 (7.3 volts). On October 22, the test was truncated with 2 of the 20 lamps having failed. The times to failure in equivalent real hours were 71,532 and 131,828 hours. The remaining 18 lamps which were still illuminated at the time of truncation had been energized for the equivalent of over 168,000 real hours apiece.

REAL LIFE TEST. The 20 type 247 lamps showed the following lives in hours:

| | | | |
|---|---|---|---|
| 193 | 524 | 724 | 888 |
| 214 | 540 | 780 | 1,156 |
| 408 | 556 | 818 | 1,372 |
| 416 | 596 | 830 | 1,844 |
| 436 | 692 | 840 | 2,004 |

These lifetimes showed an underlying log-normal distribution with a mean of 670 hours.

The type 6180 lamps showed the following lives in hours at an elapsed time of 3,300 hours.

| | | | |
|---|---|---|---|
| 63 | 1,030 | 1,506 | 2,873 |
| 324 | 1,212 | 1,844 | |
| 708 | 1,373 | 1,915 | |
| 732 | 1,431 | 2,368 | |
| 733 | 1,432 | 2,428 | |

These lifetimes showed an underlying normal distribution with a mean of 1,711 hours and a standard deviation of 1,102 hours.

For the type 247, this compares with the results of the accelerated life tests; however, in the case of the 6180, the real life test is showing a higher mean life than was shown in the accelerated life tests. This can probably be explained by the following observation which was noted during the real life test. On several occasions when a PRI was no longer lit, it was discovered that the lamp was not actually burned out. The lamp would become illuminated again by turning it slightly in the PRI matrix (figure 3) or in some cases by merely removing the PRI and reinserting it. When this occurred, time would continue to be counted on the PRI concerned, noting the estimated time, if any, that the PRI was out due to this apparent poor contact. This would then be taken into account when true failure of the lamp finally occurred.

This "contact outage" phenomenon was especially apparent in the 6180's, although it was also noted in the 247's but to a lesser extent. This was substantiated further by continuity checking the failed types 247 and 6180 lamps from the previous accelerated life tests. In the case of the type 6180, of 48 lamps checked, 19 (40 percent) checked good. In the case of the type 247's, of 49 lamps tested, only two (4 percent) checked good.

LIFE TEST SUMMATION. Due to the "contact outage" phenomenon described in the real life tests, the lifetimes of the type 6180 will probably be somewhat higher than those shown for the accelerated life tests. As seen in table 2, the types 6180 and 247 have identical characteristics; however, the type 6180 is generally available throughout the industry, while the 247, which is manufactured in a foreign country, has more restricted availability.

The type 714 has a significantly longer life than the 247, as seen in table 2 and as shown in the accelerated life tests. It will be noted in table 2, however, that the 714 draws more current than the 247 (75 versus 60 milliamperes) and has a lower luminosity (.090 versus .150 MSCP). The increased current drain of the 714 should cause no problem, as can be seen by considering the following: The lamp-driving circuitry was designed to accommodate 80 milliamperes, which is more than the 75 milliamperes drawn by the 714. With an assumed PRI complement of 225 per SMMC, assuming worst-case conditions of one color and one symbol lamp energized per PRI, a maximum of 450 lamps would be energized. The increase in current of one 714 over a 247 is .075 - .060 = .015 ampere. The total worst-case increase in current involved in replacing all 247's with 714's would be 450 X .015 = 6.75 amperes. The maximum current drain on the SMMC power supply system (except for inrush current at turn-on) is approximately 180 amperes. Each of the three power supplies can supply 100 amperes. Hence the increase of less than 7 amperes would still mean a maximum current drain of about 187 amperes, which is still within the capability of two out of the three power supplies as required by the SMMC specification.

Concerning the decreased luminosity of the 714 versus 247, this is currently under investigation by the Human Engineering Branch at NAFEC. The possible use of the 685, which has an even longer life than the 714 but a still lower luminosity, is also being considered by human factors. As results are obtained from the human factors studies of these lamps, they will be published.

## SUMMARY OF RESULTS

Formal MUT and MDT tests were performed on specified module types of the SMMC in accordance with approved test plans. All module types concerned passed the tests.

An independent MUT determination was also performed over an accumulated 3.75-equipment-year period of observation. Fifteen of the 16 module types observed showed with an 80-percent degree of confidence that their true MUT's were at least 9,000 hours. The exception was the 9020E-1 module type, for which the corresponding value was 4,500 hours. The SMMC specification calls for a minimum MUT of 5,000 hours per module type.

Over this 3.75-equipment-years of observation, 18 hard failures occurred, 6 of which consisted of blower motor failures in the power supplies.

A detailed replacement study of the type 247 incandescent lamps used in the PRI's was made at NAFEC and three ARTCC's. This study indicated an average replacement rate per SMMC of about two lamps per day. The overall uptimes of the type 247 lamps as measured at three of the four sites varied between about 2,700 to 3,200 hours.

Real time and accelerated life tests were performed on the type 247 lamp and three alternate lamp types. The results of these tests are summarized in table 12.

As seen from table 12, the MUT of the type 247 lamp obtained from the real time and accelerated life tests appears closely grouped around 700 hours, while the MUT obtained from the lamp replacement studies at NAFEC and the ARTCC's is approximately 3,000 hours. The replacement studies were based on certain assumptions, since the percentage of times that the lamps were energized varied widely. The life tests were performed under controlled conditions, where all lamps were continuously energized. This may account for the lower MUT's obtained in the tests for the type 247 lamp.

Many apparent failures in PRI's employing types 6180 and 247 lamps were actually caused by poor contact. The lamps would become relit by turning slightly in the PRI lamp matrices or by removing and reinserting the PRI. This was particularly noticeable in the type 6180 lamp.

Current replacement costs of the type 247 lamps for the 22 SMMC's, assuming a per-unit cost of 68¢, are nearly $11,000 per year, not counting manpower costs. Based upon the MUT's obtained by the accelerated life tests, the corresponding estimated replacement costs of types 714 and 685 would be as follows:

| | | |
|---|---|---|
| Type 714 (± 25 percent luminosity tolerance) | = | $ 846 per year |
| Type 714 (± 15 percent luminosity tolerance) | = | $ 1,271 per year |
| Type 685 | | $ 177 per year |

TABLE 12. SUMMATION OF REAL AND ACCELERATED LIFE TEST RESULTS

| | | LAMP TYPES | | | |
|---|---|---|---|---|---|
| | | 247 | 6180 | 714 | 685 |
| ACCELERATION FACTOR 93.8 | Number Tested | 20 | 20 | 20 | 20 |
| | Underlying Statistical Distribution | Log-Normal | Normal | Normal | ** |
| | Mean | 642 | 919 | 46,746 | Above 168,000 |
| | Standard Dev. | .353* | 496 | 19,762 | ** |
| ACCELERATION FACTOR 10.0 | Number Tested | 20 | 20 | N/A | N/A |
| | Underlying Statistical Distribution | Log-Normal | Normal | N/A | N/A |
| | Mean | 741 | 1,037 | N/A | N/A |
| | Standard Dev. | .35* | 471 | N/A | N/A |
| REAL TIME | Number Tested | 20 | 20 | N/A | N/A |
| | Underlying Statistical Distribution | Log-Normal | Normal | N/A | N/A |
| | Mean | 670 | 1,711 | N/A | N/A |
| | Standard Dev. | .262* | 1,102 | N/A | N/A |

LEGEND: Mean = Mean lamp life in equivalent real hours.
Standard Dev. = Standard deviation of lamp lives in equivalent real hours (normal distribution).
N/A = Not applicable.
* = Standard deviation of the common logarithms of the lamp lives in equivalent real hours (log-normal distribution).
** = Only two of the 20 type 685 lamps had failed at the time of test termination; therefore, these items could not be determined.

## CONCLUSIONS

It is concluded that:

1. All SMMC module types passed the contractually required mean uptime (reliability) test conducted at four ARTCC's: Washington, Jacksonville, Indianapolis, and Denver.

2. All seven SMMC modules tested passed the mean downtime (maintainability) test conducted at the contractor's plant in Houston, Texas.

3. The MUT's of the type 247 lamp currently in use varied between 642 and 741 hours in both the real time and accelerated life tests. This is almost an order of magnitude less than the specified value of 6,500 hours (adjusted to 3,500 hours for d.c. operation).

4. The MUT of the type 6180 lamp obtained from the real time life test was 1,711 hours, still considerably below the specified value. This lamp type is also fraught with apparent outages due to poor contact; however, it is more readily available than the type 247 and could be used as a satisfactory substitute.

5. The MUT's of the types 714 and 685 lamps as obtained from the accelerated life tests were 46,746 hours and over 168,000 hours respectively. These values are significantly higher than the MUT's obtained for the types 247 and 6180 lamps. The adequacy of the types 685 and 714 for use, considering their lower luminosities, is to be determined by human factors studies.

## RECOMMENDATIONS

It is recommended that:

1. As an interim measure, when supply problems exist, the type 6180 subminiature incandescent lamp may be used as a satisfactory substitute for the type 247 currently used in the PRI's.

2. If the human factors studies indicate that the luminosities of types 685 and 714 lamps are both acceptable, the type 685 should be used as a replacement for the type 247. If these studies indicate that the type 714 has acceptable luminosity and the 685 does not, then type 714 should be used as the replacement for the type 247.

3. When 6180 or 247 PRI lamp outages occur, the PRI lamp should be removed and then reinserted. If the lamp does not relight, the lamp should be turned slightly, in the PRI matrix, and the PRI reinserted.

# APPENDIX A

Kolmogorov-Smirnov Goodness-of-Fit Tests for Subsequent Lamp Replacements in the Amber Positions of the PRI's in the NAFEC SMMC

APPENDIX A

Table A-1

KOLMOGOROV-SMIRNOV GOODNESS-OF-FIT TEST
NORMAL DISTRIBUTION ASSUMED
UP TIMES

EQUIPMENT ELEMENT TYPE: NAFEC SMMC, SUBSEQUENT PRI REPLACEMENTS
SERIAL NUMBER: STATUS (AMBER) LAMPS
TEST PERIOD: JULY 1, 1973 through APRIL 15, 1974

| t | o | P(o) | P(t) | d |
|---|---|---|---|---|
| 0 or more | 18 | 1.000 | 1.000 | .000 |
| 411 or more | 18 | 1.000 | .913 | .087 |
| 480 or more | 17 | .944 | .902 | .042 |
| 341 or more | 16 | .889 | .830 | .059 |
| 852 or more | 15 | .833 | .828 | .005 |
| 852 or more | 14 | .778 | .828 | .050 |
| 981 or more | 13 | .722 | .795 | .073 |
| 1356 or more | 12 | .667 | .682 | .015 |
| 1640 or more | 11 | .611 | .583 | .028 |
| 1768 or more | 10 | .556 | .536 | .020 |
| 1768 or more | 9 | .500 | .536 | .036 |
| 1768 or more | 8 | .444 | .536 | .092 |
| 2021 or more | 7 | .389 | .442 | .053 |
| 2481 or more | 6 | .333 | .282 | .051 |
| 2545 or more | 5 | .278 | .263 | .015 |
| 3158 or more | 4 | .222 | .114 | .108 |
| 3158 or more | 3 | .167 | .114 | .053 |
| 3662 or more | 2 | .111 | .047 | .064 |
| 3818 or more | 1 | .056 | .034 | .022 |

Observed d(max): .108

Tabular d(max): .309 for 95% confidence level

LEGEND:

t = Up time in hours
$\theta$ = Estimated mean of up times = 1864.921
s = Estimated standard deviation of up times = 1071.090
N = Total number of observed failures
o = Observed cumulative failures at time t
P(o) = Observed cumulative probability of survival at time t = o/N
P(t) = Theoretical cumulative probability of survival at time t =

$$(1/\ 2\ )\int_{Z}^{\infty} \exp(-Z\ /2)dZ\ ,\ \text{where } Z = (t - \theta)/s$$

d = Absolute deviation = /P(o)-P(t)/

APPENDIX A

Table A-2

KOLMOGOROV-SMIRNOV GOODNESS-OF-FIT TEST
LOG NORMAL DISTRIBUTION ASSUMED
UP TIMES

EQUIPMENT ELEMENT TYPE: NAFEC SMMC, SUBSEQUENT PRI REPLACEMENTS
SERIAL NUMBER: STATUS (AMBER) LAMPS
TEST PERIOD: JULY 1, 1973 through APRIL 15, 1974

| t | o | P(o) | P(t) | d |
|---|---|---|---|---|
| 0 or more | 18 | 1.000 | 1.000 | .000 |
| 411 or more | 18 | 1.000 | .976 | .024 |
| 480 or more | 17 | .944 | .960 | .016 |
| 841 or more | 16 | .889 | .819 | .070 |
| 852 or more | 15 | .833 | .814 | .019 |
| 852 or more | 14 | .778 | .814 | .036 |
| 981 or more | 13 | .722 | .752 | .030 |
| 1356 or more | 12 | .667 | .578 | .089 |
| 1640 or more | 11 | .611 | .465 | .146 |
| 1768 or more | 10 | .556 | .421 | .135 |
| 1768 or more | 9 | .500 | .421 | .079 |
| 1768 or more | 8 | .444 | .421 | .023 |
| 2021 or more | 7 | .389 | .345 | .044 |
| 2481 or more | 6 | .333 | .240 | .093 |
| 2545 or more | 5 | .278 | .229 | .049 |
| 3158 or more | 4 | .222 | .143 | .079 |
| 3158 or more | 3 | .167 | .143 | .024 |
| 3662 or more | 2 | .111 | .099 | .012 |
| 3818 or more | 1 | .056 | .089 | .033 |

Observed d(max): .146

Tabular d(max): .309 for 95% confidence level

LEGEND:

t = Up time in hours
log $\theta$ = Estimated mean of logs of up times = 3.189
log s = Estimated standard deviation of logs of up times = .290
N = Total number of observed failures
o = Observed cumulative failures at time t
P(o) = Observed cumulative probability of survival at time t = o/N
P(t) = Theoretical cumulative probability of survival at time t =

$$(1/2)\int_{Z}^{\infty} \exp(-Z/2)\,dZ \text{ , where } Z = (\log t - \log \theta)/\log s$$

d = Absolute deviation = /P(o)-P(t)/

APPENDIX A

Table A-3

KOLMOGOROV-SMIRNOV GOODNESS-OF-FIT TEST
EXPONENTIAL DISTRIBUTION ASSUMED
UP TIMES

EQUIPMENT ELEMENT TYPE: NAFEC SMMC, SUBSEQUENT PRI REPLACEMENTS
SERIAL NUMBER: STATUS (AMBER) LAMPS
TEST PERIOD: JULY 1, 1973 through APRIL 15, 1974

| t | o | P(o) | P(t) | d |
|---|---|---|---|---|
| 0 or more | 18 | 1.000 | 1.000 | .000 |
| 411 or more | 18 | 1.000 | .802 | .198 |
| 480 or more | 17 | .944 | .773 | .171 |
| 841 or more | 16 | .889 | .637 | .252 |
| 852 or more | 15 | .833 | .633 | .200 |
| 852 or more | 14 | .778 | .633 | .145 |
| 981 or more | 13 | .722 | .591 | .131 |
| 1356 or more | 12 | .667 | .483 | .184 |
| 1640 or more | 11 | .611 | .415 | .196 |
| 1768 or more | 10 | .556 | .387 | .169 |
| 1768 or more | 9 | .500 | .387 | .113 |
| 1768 or more | 8 | .444 | .387 | .057 |
| 2021 or more | 7 | .389 | .338 | .051 |
| 2481 or more | 6 | .333 | .264 | .069 |
| 2545 or more | 5 | .278 | .255 | .023 |
| 3158 or more | 4 | .222 | .184 | .038 |
| 3158 or more | 3 | .167 | .184 | .017 |
| 3662 or more | 2 | .111 | .140 | .029 |
| 3818 or more | 1 | .056 | .129 | .073 |

Observed d(max): .252

Tabular d(max): .309 for 95% confidence level

LEGEND:

t = Up time in hours
$\theta$ = Estimated mean of up times = 1864.921
N = Total number of observed failures
o = Observed cumulative failures at time t
P(o) = Observed cumulative probability of survival at time t = o/N
P(t) = Theoretical cumulative probability of survival at time t = $\exp(-t/\theta)$
d = Absolute deviation = /P(o)-P(t)/

APPENDIX B

SAMPLE CALCULATIONS

The power supply module is used here as an example. There are three power supplies per SMMC, four SMMC's (sites), and 6 months (180 days) of testing time per site.

1. Total Equipment Up-Time in Module-Hours

   4 sites x 3 modules/site x 180 days x 24 hours/day

   = 51,840 hours minus 1.4 hours downtime

   $\cong$ 51,839 module-hours.

2. Point-Estimate MUT (hours)

   $$= \frac{\text{Module-Hours}}{\text{Number of hard failures}} = \frac{51,839}{2} = 25,920 \text{ hours}$$

3. 80% Lower Confidence Limit of MUT (hours)

   $$= \frac{2T}{\chi^2 (.80,\ 2r + 2)}$$

   where T = Module-Hours = 51,839

   $\chi^2$ = Value from Chi-Square table for .80 confidence level (.20 significance level) and 2r + 2 degrees of freedom, where r = number of failures = 2. Hence, the value of $\chi^2$ (Chi-Square) for .80 confidence level and 2(2) + 2 = 6 degrees of freedom = 8.56.

   Then 80% lower confidence limit of MUT $= \frac{2\ (51,839)}{8.56}$

   = 12,112 hours.

# APPENDIX C

## DISTRIBUTION OF REPLACED TYPE 247 PRI LAMPS IN NAFEC SMMC

TABLE C-1 NAFEC

Distribution of Replaced Type 247 PRI Lamps in NAFEC SMMC

LEGEND

Colors: W-White, G-Green, A-Amber, R-Red
Symbols: Al, SS, X, PX, ED, EX, OX, D.
NONE: No Lamps Replaced in this PRI

| CCCM | CDCM-1 | CDCM-2 | CDCM-3 | CDCM-4 | CDM-1A | CDM-1B | 9020E-1 | 9020E-2 | RFM-1 | RFM-2 |
|---|---|---|---|---|---|---|---|---|---|---|
| CE-1<br>G-4<br>R-1<br>W-2<br>SS-1 | IOC-1<br>NONE | EMU-1<br>AL-1<br>SS-1<br>W-1 | RMU-1<br>W-2<br>G-1<br>X-1<br>A-1 | DGU-1<br>NONE | RC-1<br>W-3<br>A-1<br>R-1<br>X-1<br>G-1 | RC-1<br>R-1<br>X-2<br>W-1 | SE-1<br>G-1<br>W-1 | DG-1<br>NONE | OL-RAD-U<br>SS-1<br>G-2 | OL-RAD-U<br>G-1 |
| CE-2<br>R-1<br>X-1<br>G-1 | IOC-2<br>W-1<br>G-1<br>A-1<br>D-1 | EMU-2<br>G-1 | RMU-2<br>W-1<br>A-1<br>R-1<br>G-1 | DGU-2<br>W-1 | RC-2<br>W-3<br>G-1<br>OX-1 | RC-2<br>X-1<br>W-1 | SE-2<br>W-1<br>G-2<br>X-1<br>EX-1 | DG-2<br>W-1<br>R-1<br>SS-1 | OL-BEAC-U<br>W-1<br>G-2 | OL-BEAC-U<br>G-1 |
| CE-3<br>R-1 | CFU-1<br>EX-1<br>G-1<br>W-1 | EMU-3<br>G-1 | RMU-3<br>SS-1 | DGU-11<br>SS-1<br>W-2<br>G-1<br>D-1 | RC-3<br>W-2 | RC-3<br>W-1 | SE-3<br>W-1<br>X-2<br>R-1<br>G-1 | DG-3<br>NONE | OL-CD-U<br>G-2<br>AL-1 | OL-CD-U<br>AL-1<br>G-3<br>A-1 |
| CE-4<br>W-3 | CFU-2<br>A-1<br>W-1<br>SS-1 | EMU-4<br>A-1<br>W-1 | RMU-9<br>NONE | DGU-12<br>SS-1 | RC-4<br>W-2 | RC-4<br>W-1<br>X-1<br>R-1 | SE-4<br>A-1<br>R-1<br>X-1<br>G-1 | DG-4<br>NONE | STD-RAD-U<br>A-2 | STD-RAD-U<br>A-2<br>ED-1<br>G-1 |
| IOCE-1<br>R-2<br>W-1<br>G-1 | HSF-1<br>W-1<br>G-1 | EMU-5<br>ED-1<br>EX-1<br>W-2<br>G-1 | RMU-10<br>G-2<br>R-1<br>W-1<br>A-1 | DGU-13<br>R-2<br>W-1<br>G-1<br>A-1 | RC-5<br>W-2 | RC-5<br>W-3<br>X-1<br>EX-1 | SE-5<br>D-1<br>W-1<br>R-1<br>X-1 | RKM-1<br>SS-1 | STD-BEAC-U<br>A-3<br>R-1<br>G-1 | STD-BEAC-U<br>G-1<br>SS-1 |
| IOCE-2<br>NONE | HSF-2<br>W-2<br>G-1<br>SS-1 | EMU-6<br>W-1<br>G-2<br>R-1 | RMU-11<br>X-1<br>R-1 | DGU-14<br>NONE | RC-6<br>W-1 | RC-6<br>W-2<br>EX-2 | DE-1<br>G-1 | RKM-3<br>NONE | STD-CD-U<br>A-2<br>G-1 | STD-CD-U<br>A-1<br>OX-1<br>R-1 |

TABLE C-2 NAFEC Distribution of Replaced Type 247 PRI Lamps in NAFEC SMMC

| CCCM | CDCM-1 | CDCM-2 | CDCM-3 | CDCM-4 | CDM-1A | CDM-1B | 9020E-1 | 9020E-2 | RFM-1 | RFM-2 |
|---|---|---|---|---|---|---|---|---|---|---|
| IOCE-3<br>NONE | RMC-1<br>NONE | RMU-7<br>A-1 | RMU-12<br>W-3<br>X-1<br>R-1<br>G-1<br>D-1<br>A-1 | DGU-23<br>W-1<br>A-1<br>R-1<br>D-1 | RC-7<br>W-2 | RC-7<br>W-2<br>R-1 | DE-2<br>W-1<br>A-1<br>SS-1 | IOCE-1<br>NONE | DRG-1-U<br>R-1 | DRG-1-U<br>R-1<br>SS-1<br>OX-1 |
| PAM-1<br>R-2 | RMC-2<br>G-2<br>R-2<br>SS-1<br>A-1<br>W-1 | RMU-8<br>NONE | RMU-18<br>R-1 | DGU-24<br>SS-1<br>W-2<br>R-3<br>AL-1 | RC-8<br>W-1<br>R-1<br>G-1<br>A-1 | RC-8<br>NONE | DE-3<br>G-1 | IOCE-2<br>W-1<br>R-1 | DRG-2-U<br>SS-1<br>OX-1<br>X-1<br>R-1 | DRG-2-U<br>G-1<br>R-3<br>W-1<br>X-1<br>A-1<br>OX-3 |
| PAM-2<br>G-2 | DPSS-A<br>A-1 | RMU-9<br>R-1 | RKM-1<br>G-1 | | RC-9<br>G-1<br>W-2<br>A-1<br>X-1 | RC-9<br>W-2 | DE-4<br>W-2<br>ED-1 | TCU-1<br>G-1 | DRG-3-U<br>A-1<br>OX-1<br>R-1 | DRG-3-U<br>R-3<br>OX-1 |
| PAM-3<br>NONE | DPSS-B<br>A-1 | RMU-10<br>NONE | RKM-2<br>NONE | | RC-10<br>W-3<br>A-1 | RC-10<br>W-1<br>G-1 | DE-5<br>G-1<br>W-2<br>EX-1<br>A-1 | TCU-2<br>R-1 | OL-RAD-L<br>NONE | OL-RAD-L<br>G-2 |
| TCU-1<br>R-1<br>A-1 | RMIOC-1<br>W-1<br>AL-1 | DI/O-1<br>AL-1<br>R-1<br>W-1<br>G-1<br>SS-1 | RKM-3<br>G-1<br>W-1 | | RC-11<br>R-1<br>X-1<br>W-3 | RC-11<br>W-1 | CE-1<br>G-1<br>AL-1<br>A-1<br>R-1<br>EX-1<br>D-1 | TCU-3<br>A-1<br>ED-1<br>R-1<br>W-1 | OL-BEAC-L<br>G-2<br>OX-1 | OL-BEAC-L<br>G-2 |
| TCU-2<br>G-4<br>W-2 | RMIOC-2<br>SS-1<br>W-1 | DI/O-2<br>W-1<br>ED-1<br>SS-1 | RKM-4<br>NONE | | RC-12<br>W-1<br>G-1 | RC-12<br>R-2<br>A-2<br>G-1<br>X-1<br>W-1 | CE-2<br>W-2<br>R-1<br>A-1<br>X-1 | CCC/IOCE-1<br>R-2<br>OX-1 | OL-CD-L<br>G-2<br>AL-1 | OL-CD-L<br>AL-2<br>G-2 |

TABLE C-3 NAFEC Distribution of Replaced Type 247 PRI Lamps in NAFEC SMMC

| CCCM | CDCM-1 | CDCM-2 | CDCM-3 | ECM | CDM-1A | CDM-1B | 9020E-1 | 9020E-2 | RFM-1 | RFM-2 |
|---|---|---|---|---|---|---|---|---|---|---|
| TCU-3<br>G-1 | RMIOC-3<br>R-1 | BIOCH-A<br>OX-1<br>R-1<br>W-2 | RKM-5<br>NONE | ECM<br>NONE | RC-13<br>R-1<br>SS-1 | RC-13<br>W-1<br>EX-1<br>G-1 | CE-3<br>X-2<br>G-1<br>SS-1<br>AL-1<br>R-1 | CCC/IOCE-2<br>X-1<br>W-2<br>SS-1 | STD-RAD-L<br>A-2 | STD-RAD-L<br>A-1 |
| SCU-1<br>A-1<br>W-1<br>G-2<br>R-1 | RMIOC-4<br>R-3<br>G-1<br>W-3 | BIOCH-B<br>EX-1<br>G-1<br>W-1 | CCM<br>W-1<br>G-2<br>OX-1 | | RC-14<br>A-1<br>W-2<br>R-1 | RC-14<br>G-1<br>R-1<br>A-3<br>X-1<br>W-1 | CE-4<br>W-2 | CCC/IOCE-3<br>R-1 | STD-BEA-L<br>A-2<br>R-1 | STD-BEA-L<br>A-1 |
| SCU-2<br>W-1<br>R-1 | NRKM-1<br>ED-1<br>W-1<br>G-2<br>R-1 | HSF-RMC-1<br>G-2<br>OX-1 | | | RC-15<br>W-1 | RC-15<br>W-1 | NRKM-1<br>R-1 | DAU-1<br>NONE | STD-CD-L<br>A-3 | STD-CD-L<br>A-1 |
| SCU-3<br>G-3<br>W-1 | NRKM-2<br>OX-1<br>X-2<br>R-2<br>G-1<br>SS-1 | HSF-RMC-2<br>W-1<br>SS-1<br>G-1 | | | RC-16<br>W-3 | RC-16<br>A-3 | NRKM-2<br>R-3<br>G-1<br>A-1<br>X-1<br>SS-1 | DAU-2<br>W-2 | DRG-1-L<br>OX-2<br>R-3 | DRG-1-L<br>R-1<br>OX-1 |
| SE-1<br>G-1<br>OX-1 | NRKM-3<br>W-2<br>G-3<br>EX-1<br>R-1<br>X-1 | SELCH-1<br>W-2<br>ED-1<br>G-1 | | | RC-17<br>W-1 | RC-17<br>W-1<br>A-1 | NRKM-3<br>R-3<br>X-3 | | DRG-2-L<br>R-1<br>OX-1 | DRG-2-L<br>R-2<br>OX-1 |
| SE-2<br>G-2 | NRKM-S<br>D-1<br>G-1 | SELCH-2<br>W-2<br>SS-1 | | | RC-18<br>W-4 | RC-18<br>G-1<br>A-2<br>X-1 | NRKM-S<br>X-1 | | DRG-3-L<br>R-1<br>A-1 | DRG-3-L<br>R-1 |

TABLE C-4 NAFEC Distribution of Replaced Type 247 PRI Lamps in NAFEC SMMC

| CCCM | CCCM | CDCM-1 | CDCM-2 | CDM-1A | CDM-1A | CDM-1A | CDM-1B | CDM-1B | CDM-1B | 9020E-1 |
|---|---|---|---|---|---|---|---|---|---|---|
| SE-3<br>R-1<br>W-2<br>G-1 | SE-9<br>W-4<br>G-2 | ERC-1<br>G-2 | SELCH-3<br>W-3<br>R-1 | RC-19<br>W-4<br>G-1<br>A-1 | TC-4<br>G-1<br>W-1<br>A-1<br>PX-1 | TC-10<br>W-1<br>A-1<br>R-2 | RC-19<br>A-1<br>W-1 | TC-4<br>W-5<br>R-1<br>SS-1<br>X-1 | TC-10<br>W-2<br>AL-1<br>EX-1<br>OX-1 | RCU-1<br>R-1<br>X-1 |
| SE-4<br>W-1 | SE-10<br>G-1<br>W-4 | ERC-2<br>W-1<br>A-2 | EMB-IOC/RMC<br>W-1 X-1<br>AL-1 R-1<br>G-1<br>A-1 | RC-20<br>W-5<br>X-2<br>SS-1<br>A-1 R-1 | TC-5<br>W-1<br>G-1<br>X-1 | TC-11<br>PX-1<br>EX-1<br>W-1 | RC-20<br>A-2<br>W-3<br>SS-1<br>ED-1 D-1 | TC-5<br>G-3<br>A-2<br>W-2<br>OX-1 | | RCU-2<br>A-1<br>X-2<br>R-1<br>W-1<br>G-1 |
| SE-5<br>G-1 | SE-11<br>G-3<br>W-3 | | EMB-CFU<br>NONE | RC-21<br>G-1<br>W-1 | TC-6<br>R-1<br>W-1 | TC-12<br>G-1<br>W-2 | RC-21<br>A-1<br>G-1<br>W-2 | TC-6<br>W-1<br>A-1 | | |
| SE-6<br>W-2<br>G-3 | SE-12<br>W-3<br>G-1 | | EMB-HSF<br>OX-1 | RC-22<br>R-1<br>W-2<br>D-1<br>PX-1<br>EX-1 | TC-7<br>W-2<br>ED-1<br>A-1 | | RC-22<br>NONE | TC-7<br>W-1<br>SS-1<br>A-1<br>R-1 | | |
| SE-7<br>W-1<br>G-1 | | | SPARE EMB<br>R-1<br>A-1<br>W-1 | TC-2<br>W-3<br>G-2<br>R-1<br>EX-1<br>A-1 | TC-8<br>G-1 | | TC-2<br>W-4<br>X-1 | TC-8<br>W-2<br>AL-2 | | |
| SE-8<br>W-3 | | | | TC-3<br>PX-1<br>W-5<br>R-1 | TC-9<br>W-2<br>D-1 | | TC-3<br>R-1<br>EX-1<br>W-1 | TC-9<br>R-2<br>W-1<br>G-1 | | |

# APPENDIX D

## DISTRIBUTION OF REPLACED TYPE 247 PRI LAMPS IN LOS ANGELES SMMC

TABLE D-1 LOS ANGELES

Distribution of Replaced Type 247 PRI Lamps in Los Angeles SMMC

LEGEND Colors: W-White, G-Green, A-Amber,
Symbols: Al, SS, X, PX, ED, EX, OX,
NONE: No Lamps Replaced in this PRI

| CCCM | CDCM-1 | CDCM-2 | CDCM-3 | CDCM-4 | CDM-1 | CDM-2 | RFM-1 | RFM-2 | RFM-3 | RFM-4 | RFM-5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CE-1<br>G-1<br>W-2 | IOC-1<br>G-1 | BMU-1<br>G-1 | RMU-1<br>A-1 | DGU-1<br>G-3 | RC-1<br>W-1 | RC-23<br>NONE | OL-RAD-U<br>G-2 | OL-RAD-U<br>G-1 | OL-RAD-U<br>G-2 | OL-RAD-U<br>G-1 | OL-RAD-U<br>G-1<br>R-1<br>EX-1<br>W-1 |
| CE-2<br>G-2<br>W-1<br>AL-1 | IOC-2<br>A-1 | BMU-2<br>A-1<br>G-1 | RMU-2<br>G-2<br>A-1 | DGU-2<br>G-2<br>W-1<br>R-1 | RC-2<br>AL-2<br>W-2 | RC-24<br>W-1 | OL-BEAC-U<br>G-1<br>OX-1 | OL-BEAC-U<br>NONE | OL-BEAC-U<br>NONE | OL-BEAC-U<br>G-2 | OL-BEAC-U<br>NONE |
| CE-3<br>AL-1<br>A-1 | CFU-1<br>NONE | BMU-3<br>NONE | RMU-3<br>G-1 | DGU-3<br>NONE | RC-3<br>AL-3<br>W-2 | RC-25<br>AL-2<br>W-1 | OL-CD-U<br>G-2 | OL-CD-U<br>NONE | OL-CD-U<br>X-1<br>G-2 | OL-CD-U<br>G-1 | OL-CD-U<br>G-1 |
| IOCE-1<br>NONE | CFU-2<br>NONE | BMU-4<br>G-2<br>R-1<br>A-1 | RMU-4<br>W-1<br>G-4 | DGU-4<br>G-2<br>W-1 | RC-4<br>AL-1 | RC-26<br>W-2 | STB-RAD-U<br>A-1 | STD-RAD-U<br>NONE | STD-RAD-U<br>A-1 | STD-RAD-U<br>NONE | STD-RAD-U<br>A-1 |
| IOCE-2<br>AL-1<br>G-2<br>A-1 | HSF-1<br>G-1 | BMU-5<br>G-1 | RMU-5<br>G-2 | DGU-5<br>G-1 | RC-5<br>W-1<br>AL-1 | RC-27<br>W-1 | STD-BEAC-U<br>A-2 | STD-BEAC-U<br>A-1 | STD-BEA-U<br>A-1 | STD-BEAC-U<br>A-1 | STD-BEAC-U<br>NONE |
| IOCE-3<br>AL-1<br>G-1<br>W-1<br>A-1 | HSF-2<br>R-1<br>G-1 | | RMU-6<br>NONE | DGU-6<br>NONE | RC-6<br>W-2<br>AL-1 | RC-28<br>W-1 | STD-CD-U<br>A-1 | STD-CD-U<br>NONE | STD-CD-U<br>NONE | STD-CD-U<br>A-1 | STD-CD-U<br>NONE |

TABLE D-2 LOS ANGELES Distribution of Replaced Type 247 PRI Lamps in Los Angeles SMMC

| CCCM | CDCM-1 | CDCM-2 | CDCM-3 | CDCM-4 | CDM-1 | CDM-2 | RFM-1 | RFM-2 | RFM-3 | RFM-4 | RFM-5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PAM-1<br>G-3 | RMC-1<br>A-1 | BMU-6<br>NONE | RMU-7<br>G-4<br>R-1 | DGU-7<br>G-2 | RC-7<br>AL-2<br>W-1<br>EX-1 | RC-29<br>AL-3<br>W-4<br>EX-1 | DRG-1-U<br>W-1<br>R-1 | DRG-1-U<br>W-1<br>OX-1<br>R-1<br>EX-1 | DRG-1-U<br>W-1 | DRG-1-U<br>W-1 | DRG-1-U<br>R-2<br>X-1 |
| PAM-2<br>G-1 | RMC-2<br>PX-1<br>A-1<br>W-1 | BMU-7<br>G-2<br>R-1 | RMU-8<br>W-1<br>G-2 | DGU-8<br>G-2 | RC-8<br>AL-1 | RC-30<br>W-2<br>AL-2 | DRG-2-U<br>X-1<br>ED-1<br>W-1 | DRG-2-U<br>W-1<br>G-1<br>EX-1 | DRG-2-U<br>W-1 | DRG-2-U<br>R-1 | DRG-2-U<br>NONE |
| PAM-3<br>A-1<br>G-1 | DPSS-A<br>G-2<br>SS-1<br>W-1<br>A-2<br>X-1 | BMU-8<br>G-2 | BMU-9<br>A-1 | DGU-9<br>NONE | RC-9<br>AL-4<br>A-1<br>W-3<br>X-1 | RC-31<br>W-1<br>EX-1 | DRG-3-U<br>W-3 | DRG-3-U<br>A-1<br>OX-1<br>ED-1<br>W-1 | DRG-3-U<br>OX-1<br>R-1 | DRG-3-U<br>W-2 | DRG-3-U<br>NONE |
| TCU-1<br>G-2 | DPSS-B<br>NONE | BMU-9<br>A-1 | RKM-1<br>G-2 | DGU-10<br>G-1 | RC-10<br>W-1<br>AL-1 | RC-32<br>W-1<br>AL-1<br>A-3 | ON-RAD-L<br>NONE | ON-RAD-L<br>AL-1<br>OX-1<br>G-2 | ON-RAD-L<br>NONE | ON-RAD-L<br>G-1 | ON-RAD-L<br>G-1 |
| TCU-2<br>G-1 | RMIOC-1<br>W-1<br>G-2<br>A-1 | BMU-10<br>A-1 | RKM-2<br>G-3<br>D-1<br>A-1<br>W-1 | DGU-11<br>A-1 | RC-11<br>W-2<br>AL-1 | RC-33<br>A-2<br>G-1<br>AL-1<br>W-1 | ON-BEAC-L<br>G-1 | ON-BEAC-L<br>NONE | ON-BEAC-L<br>NONE | ON-BEAC-L<br>G-1 | ON-BEAC-L<br>G-1 |
| TCU-3<br>AL-1<br>A-1<br>W-1 | RMIOC-2<br>AL-1<br>A-1<br>R-1 | SELCH-1<br>A-1<br>W-1 | RKM-3<br>A-3 | DGU-12<br>A-1 | RC-12<br>W-2<br>AL-1 | RC-34<br>A-1 | ON-CD-L<br>G-1 | ON-CD-L<br>NONE | ON-CD-L<br>G-1 | ON-CD-L<br>NONE | ON-CD-L<br>G-1 |

TABLE D-3 LOS ANGELES Distribution of Replaced Type 247 PRI Lamps in Los Angeles SMMC

| CCCM | CDCM-1 | CDCM-2 | CDCM-3 | | CDM-1 | CDM-2 | RFM-1 | RFM-2 | RFM-3 | RFM-4 | RFM-5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SCU-1<br>G-2 | RMIOC-3<br>R-1<br>G-1 | SELCH-2<br>W-1<br>G-1 | CCM<br>NONE | | RC-13<br>W-1<br>AL-1 | RC-35<br>A-1 | STD-RAD-L<br>SS-1<br>A-1 | STD-RAD-L<br>A-1 | STD-RAD-L<br>NONE | STD-RAD-L<br>A-1 | STD-RAD-L<br>NONE |
| SCU-2<br>NONE | RMIOC-4<br>NONE | SELCH-3<br>W-3<br>A-1 | ECM<br>NONE | | RC-14<br>R-1<br>AL-1 | RC-36<br>NONE | STD-BE-L<br>A-1 | ST-BEAC-L<br>G-1<br>A-1 | STD-BEAC-L<br>A-1 | STD-BEA-L<br>NONE | STD-BEA-L<br>NONE |
| SCU-3<br>A-1 | NRKM-1<br>X-2<br>R-2<br>G-1 | BMB-IOC-RMC<br>G-2<br>A-1 | | | RC-15<br>AL-3<br>W-2 | RC-37<br>W-4<br>X-1<br>A-1 | STD-CD-L<br>NONE | STD-CD-L<br>A-1 | STD-CD-L<br>NONE | STD-CD-L<br>A-1 | STD-CD-L<br>A-1 |
| SE-1<br>G-3<br>PX-1 | NRKM-2<br>X-3<br>R-3<br>PX-1<br>G-1 | BMB-CFU<br>NONE | | | RC-16<br>W-2<br>AL-1 | RC-38<br>W-1 | DRG-1-L<br>W-1 | DRG-1-L<br>W-1 | DRG-1-L<br>NONE | DRG-1-L<br>NONE | DRG-1-L<br>NONE |
| SE-2<br>W-1 | NRKM-3<br>R-2<br>W-1<br>X-2<br>G-1 | BMB-HSF<br>G-3<br>W-1<br>A-1 | | | RC-17<br>A-1<br>AL-2<br>W-3 | RC-39<br>A-1<br>W-1 | DRG-2-L<br>W-1<br>ED-1 | DRG-2-L<br>NONE | DRG-2-L<br>R-2<br>OX-1 | DRG-2-L<br>NONE | DRG-2-L<br>NONE |
| SE-3<br>NONE | NRKM-4<br>EX-1<br>R-2<br>X-2<br>A-1 | DI/O-1<br>G-2 | | | RC-18<br>AL-2<br>W-1 | RC-40<br>W-1<br>A-1 | DRG-3-L<br>W-1 | DRG-3-L<br>W-2 | DRG-3-L<br>NONE | DRG-3-L<br>NONE | DRG-3-L<br>NONE |

TABLE D-4 LOS ANGELES Distribution of Replaced Type 247 PRI Lamps in Los Angeles SMMC

| CCCM | CDCM-1 | CDCM-2 | | | CDM-1 | CDM-2 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SE-4<br>NONE | ERC-1<br>G-1 | DI/O-2<br>A-2<br>W-1 | | | RC-19<br>AL-1<br>W-1 | RC-41<br>W-1 | | | | | |
| SE-5<br>NONE | ERC-2<br>W-1<br>RD-1<br>A-1<br>G-1 | BIOCH-A<br>NONE | | | RC-20<br>AL-2<br>W-1 | RC-42<br>W-1<br>AL-1<br>EX-1 | | | | | |
| SE-6<br>G-1 | | BIOCH-B<br>A-2<br>G-2 | | | RC-21<br>W-4<br>AL-2<br>SS-1 | RC-43<br>W-1 | | | | | |
| | | HSF-RMC-1<br>A-1<br>G-1 | | | RC-22<br>W-3<br>AL-2<br>EX-1 | | | | | | |
| | | HSF-RMC-2<br>A-1 | | | | | | | | | |
| | | BMB-SPARE<br>A-2 | | | | | | | | | |

# APPENDIX E

## DISTRIBUTION OF REPLACED TYPE 247 PRI LAMPS IN NEW YORK SMMC

E-1

TABLE 3 NEW YORK

Distribution of Replaced Type 247 PRI Lamps in New York SMMC

LEGEND Colors: W-White, G-Green, A-Amber,
Symbols: Al, SS, X, PX, ED, EX, OX,
NONE: No Lamps Replaced in this PRI

| CCCM | 9020E-1 | 9020E-2 | CDM-1 | CDM-2 | CDM-3 | RFM-1 | RFM-2 |
|---|---|---|---|---|---|---|---|
| CE-1<br>W-1<br>G-1<br>A-1 | SE-1<br>G-2<br>A-1 | DG-1<br>NONE | RC-1<br>W-2<br>A-1 | RC-23<br>NONE | RC-57<br>A-2<br>W-1<br>G-1 | OL-RAD-U<br>G-2<br>W-2<br>A-1 | OL-RAD-U<br>W-1 |
| CE-2<br>NONE | SE-2<br>G-2 | DG-2<br>NONE | RC-2<br>A-2 | RC-24<br>A-1 | RC-58<br>G-1 | OL-BEAC-U<br>SS-1 | OL-BEAC-U<br>NONE |
| CE-3<br>G-2<br>PX-1<br>SS-1 | SE-3<br>W-1 | DG-3<br>NONE | RC-3<br>R-1<br>W-1 | RC-25<br>W-1 | RC-59<br>G-1<br>A-1 | OL-CD-U<br>G-1 | OL-CD-U<br>NONE |
| IOCE-1<br>NONE | SE-4<br>NONE | DG-4<br>R-1<br>SS-1<br>A-1 | RC-4<br>W-1 | RC-26<br>A-1 | RC-60<br>G-1 | STB-RAD-U<br>A-1<br>G-1 | STB-RAD-U<br>NONE |
| IOCE-2<br>SS-1<br>W-1<br>R-1 | SE-5<br>W-1 | DG-5<br>R-1<br>G-1 | RC-5<br>NONE | RC-27<br>NONE | RC-61<br>NONE | STB-BEAC-U<br>PX-1<br>EX-1<br>A-1<br>W-1 | STB-BEAC-U<br>NONE |
| IOCE-3<br>NONE | DE-1<br>W-2<br>EX-1 | DG-6<br>NONE | RC-6<br>W-1 | RC-28<br>NONE | RC-62<br>A-2 | STB-CD-U<br>A-2 | STB-CD-U<br>A-1 |

TABLE E-2 NEW YORK Distribution of Replaced Type 247 PRI Lamps in New York SMMC

| CCCM | 9020E-1 | 9020E-2 | CDM-1 | CDM-2 | CDM-3 | RFM-1 | RFM-2 |
|---|---|---|---|---|---|---|---|
| PAM-1<br>NONE | DE-2<br>W-1 | DG-7<br>NONE | RC-7<br>W-3 | RC-29<br>W-1<br>G-1<br>SS-1<br>AL-1 | RC-63<br>NONE | DRG-1-U<br>SS-1<br>X-1<br>W-1<br>G-1 | DRG-1-U<br>NONE |
| PAM-2<br>NONE | DE-3<br>G-1<br>EX-1 | DG-8<br>G-1 | RC-8<br>NONE | RC-30<br>W-1<br>EX-1 | RC-64<br>A-1 | DRG-2-U<br>W-1<br>AL-1<br>R-1 | DRG-2-U<br>W-2 |
| PAM-3<br>W-1<br>A-2 | DE-4<br>A-1<br>R-1<br>G-1 | DG-9<br>NONE | RC-9<br>W-2<br>AL-1 | RC-31<br>AL-1 | RC-65<br>A-2 | DRG-3-U<br>NONE | DRG-3-U<br>NONE |
| TCU-1<br>W-1<br>G-3 | DE-5<br>W-5<br>G-2<br>R-1<br>AL-1 | DG-10<br>NONE | RC-10<br>AL-2 | RC-32<br>W-3<br>AL-2<br>EX-1<br>SS-1 | RC-66<br>A-1 | OL-RAD-L<br>G-1 | OL-RAD-L<br>NONE |
| TCU-2<br>NONE | CE-1<br>NONE | DG-11<br>R-1<br>G-1 | RC-11<br>W-1<br>SS-2 | RC-33<br>W-2<br>AL-1 | RC-67<br>A-3 | OL-BEAC-L<br>A-1 | OL-BEAC-L<br>G-1 |
| TCU-3<br>NONE | CE-2<br>G-1 | DG-12<br>W-1 | RC-12<br>AL-1<br>G-1 | RC-34<br>W-3<br>AL-1 | RC-68<br>A-2<br>G-1<br>W-1 | OL-CD-L<br>G-1 | OL-CD-L<br>NONE |

TABLE E-3 NEW YORK Distribution of Replaced Type 247 PRI Lamps in New York SMMC

| CCCM | 9020E-1 | 9020E-2 | CDM-1 | CDM-2 | CDM-3 | RFM-1 | RFM-2 |
|---|---|---|---|---|---|---|---|
| SCU-1<br>NONE | CE-3<br>G-2<br>A-2<br>EX-1 | DG-13<br>G-1 | RC-13<br>AL-2<br>W-2<br>G-1 | RC-35<br>W-1<br>A-1 | RC-69<br>NONE | STB-RAD-L<br>A-1 | STB-RAD-L<br>NONE |
| SCU-2<br>NONE | NRKM-1<br>NONE | DG-14<br>W-2<br>G-2 | RC-14<br>AL-1<br>EX-1<br>W-1 | RC-36<br>EX-1 | RC-70<br>A-1<br>W-1 | STB-BEAC-L<br>A-1<br>G-1 | STB-BEAC-L<br>W-1 |
| SCU-3<br>NONE | NRKM-2<br>NONE | DG-15<br>G-1<br>AL-1 | RC-15<br>W-1<br>G-3<br>AL-1 | RC-37<br>W-3<br>A-1<br>G-1<br>AL-1 | RC-71<br>NONE | STB-CD-L<br>A-2<br>G-1 | STD-CD-L<br>A-1 |
| SE-1<br>NONE | NRKM-3<br>OX-1 | DG-16<br>R-1<br>G-1 | RC-16<br>W-1<br>A-1 | RC-38<br>D-1 | RC-72<br>A-1<br>W-1 | DRG-1-L<br>NONE | DRG-1-L<br>NONE |
| SE-2<br>NONE | NRKM-4<br>A-2 | DG-17<br>OX-1<br>W-2 | RC-17<br>NONE | RC-39<br>AL-2<br>G-1<br>W-1 | RC-73<br>W-1<br>G-2 | DRG-2-L<br>W-2<br>X-1 | DRG-2-L<br>W-1 |
| SE-3<br>G-2 | RCU-1<br>G-2 | RKM-1<br>NONE | RC-18<br>W-1 | RC-40<br>W-1<br>A-2 | RC-74<br>A-1 | DRG-3-L<br>W-1 | DRG-3-L<br>NONE |

TABLE E-4 NEW YORK Distribution of Replaced Type 247 PRI Lamps in New York SMMC

| CCCM | 9020E-1 | 9020E-2 | CDM-1 | CDM-2 | CDM-2 | CBM-3 | CDM-3 |
|---|---|---|---|---|---|---|---|
| SE-4<br>NONE | RCU-2<br>NONE | RKM-2<br>NONE | RC-19<br>A-1<br>W-1<br>R-1<br>EK-1 | RC-41<br>W-3<br>AL-2<br>ED-1 | RC-47<br>A-2<br>W-1 | RC-75<br>NONE | RC-81<br>AL-1 |
| SE-5<br>AL-1 | | RKM-3<br>NONE | RC-20<br>R-1<br>A-1<br>W-1<br>AL-1 | RC-42<br>W-1<br>SS-1 | RC-48<br>AL-2<br>W-2 | RC-76<br>W-1<br>G-1 | RC-82<br>A-2 |
| SE-6<br>G-1<br>A-1<br>W-1 | | RKM-4<br>NONE | RC-21<br>NONE | RC-43<br>W-3<br>ED-1<br>A-1 | RC-49<br>W-1<br>R-1 | RC-77<br>A-2 | RC-83<br>A-1<br>R-1<br>AL-1 |
| SE-7<br>NONE | | RKM-5<br>NONE | RC-22<br>AL-2 | RC-44<br>A-1<br>W-1 | RC-50<br>EK-1<br>SS-1 | RC-78<br>NONE | RC-84<br>AL-1 |
| SE-8<br>G-1<br>R-1 | | IOCE-1<br>A-1 | TC-1<br>R-1<br>SS-1 | RC-45<br>NONE | RC-51<br>NONE | RC-79<br>A-3 | RC-85<br>AL-1 |
| SE-9<br>R-1<br>PX-1<br>ED-1 | | IOCE-2<br>NONE | TC-2<br>R-2<br>W-1 | RC-46<br>SS-1<br>W-1 | RC-52<br>W-2<br>SS-1<br>AL-1 | RC-80<br>A-1 | RC-86<br>NONE |

TABLE E-5 NEW YORK Distribution of Replaced Type 247 PRI Lamps in New York SMMC

| CCCM | 9020E-2 | 9020E-2 | CDM-1 | CDM-1 | CDM-2 | CDM-3 | ECM |
|---|---|---|---|---|---|---|---|
| SE-10<br>W-3<br>G-1<br>ED-1<br>A-1 | IOCE-3<br>NONE | CCC-IOCE-3<br>SS-1 | TC-3<br>W-3 | TC-9<br>NONE | RC-53<br>W-1 | RC-87<br>W-2<br>A-1<br>AL-1 | NONE |
| SE-11<br>W-1 | TCU-1<br>NONE | DAU-1<br>G-1 | TC-4<br>NONE | TC-10<br>W-1 | RC-54<br>W-2 | RC-88<br>A-2 | |
| SE-12<br>W-1 | TCU-2<br>A-1 | DAU-2<br>A-2<br>G-1 | TC-5<br>R-1<br>PX-1 | TC-11<br>NONE | RC-55<br>A-1 | RC-89<br>NONE | |
| | TCU-3<br>R-1 | | TC-6<br>A-1<br>R-1<br>PX-1 | TC-12<br>R-2<br>W-2<br>SS-1 | RC-56<br>NONE | RC-90<br>A-2<br>AL-1 | |
| | CCC-IOCE-1<br>A-1<br>W-2 | | TC-7<br>AL-1<br>R-1 | | | | |
| | CCC-IOCE-2<br>NONE | | TC-8<br>SS-1 | | | | |

# APPENDIX F

## DISTRIBUTION OF REPLACED TYPE 247 PRI LAMPS IN OAKLAND SMMC

TABLE F-1 OAKLAND

Distribution of Replaced Type 247 Lamps in Oakland SMMC

LEGEND
Colors: W-White, G-Green, A-Amber, R-Re
Symbols: Al, SS, X, PX, ED, EX, OX, D.
NONE: No Lamps Replaced in this PRI

| CCCM | CDCM-1 | CDCM-2 | CDCM-3 | CDCM-4 | CDM-1 | CDM-2 | RFM-1 | RFM-2 | RFM-3 |
|---|---|---|---|---|---|---|---|---|---|
| CE-1<br>G-1 | IOC-1<br>NONE | BMU-1<br>NONE | RMU-1<br>G-1 | DGU-1<br>G-2 | RC-1<br>NONE | RC-23<br>W-1 | OL-RAD-U<br>G-1 | OL-RAD-U<br>NONE | OL-RAD-U<br>G-1 |
| CE-2<br>NONE | IOC-2<br>A-1 | BMU-2<br>NONE | RMU-2<br>G-2 | DGU-2<br>G-1 | RC-2<br>NONE | RC-24<br>NONE | OL-BEAC-U<br>W-1<br>G-1 | OL-BEAC-U<br>NONE | OL-BEAC-U<br>NONE |
| CE-3<br>AL-1<br>A-1<br>W-1 | CFU-1<br>G-1 | BMU-3<br>NONE | RMU-3<br>G-1 | DGU-3<br>NONE | RC-3<br>W-1 | RC-25<br>W-1 | OL-CD-U<br>G-1 | OL-CD-U<br>G-1<br>X-1 | OL-CD-U<br>G-1 |
| CE-4<br>PX-1<br>A-1 | CFU-2<br>NONE | BMU-4<br>G-1 | RMU-4<br>NONE | DGU-4<br>G-4 | RC-4<br>W-1 | RC-26<br>PX-1<br>A-1 | STB-RAD-U<br>NONE | STD-RAD-U<br>NONE | STD-RAD-U<br>A-1 |
| IOCE-1<br>G-2 | HSF-1<br>G-1 | BMU-5<br>G-1 | RMU-5<br>G-1 | DGU-5<br>G-2 | RC-5<br>NONE | RC-27<br>NONE | STB-BEAC-U<br>A-1 | STD-BEAC-U<br>A-1 | STD-BEAC-U<br>A-1 |
| IOCE-2<br>NONE | HSF-2<br>NONE | BMU-6<br>NONE | RMU-6<br>G-1 | DGU-6<br>G-1 | RC-6<br>W-1 | RC-28<br>W-2 | STD-CD-U<br>NONE | STD-CD-U<br>NONE | STD-CD-U<br>A-1 |

TABLE F-2 OAKLAND Distribution of Replaced Type 247 PRI Lamps in Oakland SMMC

| CCCM | CDCM-1 | CDCM-2 | CDCM-3 | CDCM-4 | CDM-1 | CDM-2 | RFM-1 | RFM-2 | RFM-3 |
|---|---|---|---|---|---|---|---|---|---|
| IOCE-3<br>D-1<br>A-1 | RMC-1<br>NONE | RMU-7<br>R-1 | RMU-7<br>G-1 | DGU-7<br>W-1 | RC-7<br>W-1 | RC-29<br>W-1 | DRG-1-U<br>W-1 | DRG-1-U<br>NONE | DRG-1-U<br>NONE |
| PAM-1<br>G-1 | RMC-2<br>NONE | RMU-8<br>A-1 | RMU-8<br>NONE | DGU-8<br>NONE | RC-8<br>NONE | RC-30<br>NONE | DRG-2-U<br>NONE | DRG-2-U<br>NONE | DRG-2-U<br>W-1 |
| PAM-2<br>W-1 | DPSS-A<br>G-2 | RMU-9<br>NONE | RMU-9<br>NONE | DGU-9<br>NONE | RC-9<br>NONE | RC-31<br>W-1 | DRG-3-U<br>NONE | DRG-3-U<br>G-1 | DRG-3-U<br>A-1<br>W-1 |
| PAM-3<br>NONE | DPSS-B<br>R-1 | SELCH-1<br>W-1<br>G-1 | RKM-1<br>NONE | DGU-10<br>W-1 | RC-10<br>AL-1<br>G-1 | RC-32<br>W-1 | | | |
| TCU-1<br>NONE | RMIOC-1<br>NONE | SELCH-2<br>NONE | RKM-2<br>NONE | DGU-11<br>A-2 | RC-11<br>NONE | RC-33<br>NONE | OL-RAD-L<br>R-1 | OL-RAD-L<br>NONE | OL-RAD-L<br>NONE |
| TCU-2<br>W-1 | RMIOC-2<br>NONE | SELCH-3<br>G-1 | RKM-3<br>A-1<br>W-1<br>G-1 | DGU-12<br>A-1 | RC-12<br>G-1<br>AL-2<br>W-2 | RC-34<br>NONE | OL-BEAC-L<br>G-1 | OL-BEAC-L<br>NONE | OL-BEAC-L<br>NONE |

TABLE F-3 OAKLAND Distribution of Replaced Type 247 PRI Lamps in Oakland ARTCC

| CCCM | CDCM-1 | CDCM-2 | CDCM-3 | CDCM-4 | CDM-1 | CDM-2 | RFM-1 | RFM-2 | RFM-3 |
|---|---|---|---|---|---|---|---|---|---|
| TCU-3<br>A-1<br>W-1 | NRKM-1<br>NONE | EMB/10C/RMC<br>NONE | CCM<br>G-1 | | RC-13<br>NONE | RC-35<br>A-1 | OL-CD-L<br>NONE | OL-CD-L<br>G-1 | OL-CD-L<br>NONE |
| SCU-1<br>AL-1 | NRKM-2<br>NONE | EMB-CFU<br>NONE | | | RC-14<br>AL-1<br>W-1 | RC-36<br>NONE | STA-RAD-L<br>NONE | STA-RAD-L<br>NONE | STA-RAD-L<br>NONE |
| SCU-2<br>NONE | NRKM-3<br>NONE | EMB-HSF<br>NONE | | | RC-15<br>AL-1 | RC-37<br>NONE | STA-BEA-L<br>A-1 | STA-BEA-L<br>A-1 | STA-BEA-L<br>NONE |
| SCU-3<br>NONE | NRKM-4<br>R-1<br>X-1<br>A-1 | DI/O-1<br>G-1 | | | RC-16<br>W-1 | RC-38<br>NONE | STA-CD-L<br>NONE | STA-CD-L<br>NONE | STA-CD-L<br>A-1 |
| SE-1<br>G-2 | ERC-1<br>NONE | DI/O-2<br>NONE | | | RC-17<br>NONE | RC-39<br>NONE | DRG-1-L<br>W-1 | DRG-1-L<br>NONE | DRG-1-L<br>NONE |
| SE-2<br>G-1 | ERC-2<br>A-1 | BIOCH-A<br>G-2 | | | RC-18<br>NONE | RC-40<br>NONE | DRG-2-L<br>NONE | DRG-2-L<br>NONE | DRG-2-L<br>W-1 |

TABLE F-4 OAKLAND Distribution of Replaced Type 247 PRI Lamps in Oakland SMMC

| CCCM | CCCM | CDCM-2 | CDCM-1 | | CDM-1 | CDM-2 | RFM-1 | RFM-2 | RFM-3 |
|---|---|---|---|---|---|---|---|---|---|
| SE-3<br>A-1<br>X-1<br>G-2 | SE-9<br>NONE | BIOCH-B<br>A-1 | RMIOC-3<br>NONE | ECM<br>NONE | RC-19<br>AL-1 | RC-41<br>NONE | DRG-3-L<br>NONE | DRG-3-L<br>W-1 | DRG-3-L<br>NONE |
| SE-4<br>NONE | SE-10<br>AL-1<br>G-1<br>A-1 | HSF-RMC-1<br>G-1 | RMIOC-4<br>W-1<br>G-1 | | RC-20<br>A-1<br>W-1 | RC-42<br>NONE | | | |
| SE-5<br>W-1<br>G-1 | SE-11<br>A-1 | HSF-RMC-2<br>NONE | | | RC-21<br>NONE | RC-43<br>W-1 | | | |
| SE-6<br>W-1<br>G-1 | SE-12<br>W-1 | BMB-SPARE<br>NONE | | | RC-22<br>W-1 | | | | |
| SE-7<br>G-3<br>W-1 | | | | | | | | | |
| SE-8<br>NONE | | | | | | | | | |