OPERATIONAL ASSESSMENT

of

OPTEC NGN-2 NEPHELOMETERS

Prepared for

William C. Malm, Ph.D.
NATIONAL PARK SERVICE
CIRA-Foothills Campus
Fort Collins, Colorado 80523

Prepared by

AIR RESOURCE SPECIALISTS, INC.
1901 Sharp Point Drive
Suite E
Fort Collins, Colorado 80525

Under
Contact CX-0001-1-0025

July 1, 1994

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES

1.0 INTRODUCTION

This report summarizes Air Resource Specialists' (ARS) operational experience with the OPTEC Next Generation Nephelometer (NGN) from 1992 to 1994.

The prototype NGN-1 and 4 production NGN-2 nephelometers were first operationally deployed in 1992 during the winter and summer Project MOHAVE intensive monitoring periods. The characteristics of the instrument, while operating in a dry desert climate, were very encouraging.

During 1993, twenty NGN-2 nephelometers were installed at IMPROVE (11), U.S. Forest Service (5), and CASTNET (4) monitoring sites (Table 1). These locations exposed the instrument to a wide range of ambient temperatures and humidities. Overall the instruments have operated reasonably well; however, several design, manufacturing, and operating deficiencies were discovered. In addition to the ongoing field experience, ARS has continued laboratory research into the operating characteristics of the NGN-2. As a result of this work, ARS has tested, fabricated, and implemented instrument design upgrades and instituted extensive new field operating procedures.

Although operational challenges still exist, current modifications and enhancements will greatly improve data quality during the next operational year. A point by point description of NGN-2 problems and ARS' responses and recommendations are presented in the following sections. A description of associated costs is listed in Appendix A. Data from the first monitoring year (1993) is currently being processed and will be delivered in August 1994.

Table 1-1

NGN-2 Monitoring Locations

Location	Installation Date	Notes
IMPROVE		
Acadia NP	6-10-93	High moisture, salt air
Boundary Waters W	5- 7-93	Intense cold < -30°F
Dolly Sods W	5-13-93	High moisture
Edwin B. Forsythe NWR	4-14-93	High moisture, salt air
Great Smoky Mts. NP	4-29-93	High moisture
Jarbidge W	4- 9-93	Dry desert
Lye Brook W	9- 3-93	Extreme snow & temperature
Mammoth Cave NP	3-11-93	High moisture
Mount Rainier NP	2-10-93	High moisture
Okefenokee NWR	2-12-93	High moisture
Upper Buffalo W	2-26-93	High moisture
U.S. FOREST SERVICE		
Columbia River Gorge NSA	8-24-93	Occasional high moisture, strong winds
Lone Peak W	11-11-93	Extreme snow conditions
Mt. Zirkel W	11-9-93	Extreme snow conditions
Snoqualmie Pass, (Alpine Lakes W) Washington	8-26-93	Extreme snow conditions
Three Sisters W	7-25-93	Extreme snow conditions
CASTNET		
Arendtsville, Pennsylvania	6-26-93	High moisture
Connecticut Hill, New York	6-28-93	High moisture
Quaker City, Ohio	7-23-93	High moisture
Sikes, Louisiana	6-10-93	High moisture

NP: National Park
W: Wilderness
NWR: National Wildlife Refuge
NSA: National Scenic Area

2.0 HARDWARE DESIGN CONSIDERATIONS

2.1 LIGHT TRAP

The design of the original light trap allows it to act as a water trap when the optical chamber becomes wet (Figure 2-1). The collected water reflects light directly into the scattered light detector causing extremely high and erratic zero, span, and ambient readings. Additionally, the flocking paper, glued to the base of the trap, separates from the metal surface after becoming saturated with water (Figure 2-2). ARS has designed, manufactured, and installed a new light trap at all operational sites, replacing the original traps. These traps have no glued parts and employ a wicked drain to quickly remove water from the trap (Figures 2-3, 2-4, and 2-5). Laboratory and field tests have proven the new light traps to be very effective in greatly reducing the adverse effects of water inside the optical chamber (Figures 2-6 and 2-7).

2.2 CLEAN AIR FILTER

The original clean air filter system is highly susceptible to collecting and holding moisture in wet environments (Figure 2-8). Saturated filters greatly effect zero calibrations in the field. High humidity sites, such as Lye Brook and Acadia, have had unacceptable zero fluctuations due in part to these filters. Several filters, returned from the field and dismantled for evaluation, have been saturated with water and covered with mold (Figure 2-9). Additionally, the filter design requires that the entire filter assembly be returned to Optec for filter replacement at a cost of $55 plus shipping. ARS modified of the filter holder to allow for easy field replacement of the filter element at a cost of approximately $4 per element. The new filter canisters have been installed at all operational sites (Figures 2-10. 2-11, 2-12, and 2-13). On-site operators are now replacing the clean air filters at two week intervals just prior to performing a manual span calibration. The IMPROVE sites have been programmed to perform an automatic clean air calibration every six hours in order to monitor performance of the system. The new filter units appear to have minimized erratic zeros previously caused by filter contamination (Filter 2-14).

2.3 PRECIPITATION SENSOR

The original precipitation sensor proved ineffective in closing the instrument door quickly enough to keep moisture out of the optical chamber. Optec supplied retrofit kits to increase the sensitivity of the precipitation sensor. ARS has installed these kits in all available instruments. Though more sensitive, the sensor still misses many precipitation events and is practically ineffective in sensing snow; therefore, this change has not solved the problem of precipitation entering the optical chamber. ARS is now investigating two possible alternatives:

1. An independent wetness sensor to close the nephelometer door during precipitation events; and
2. A rain/snow shield retrofit that can be installed over the door to shed these elements.

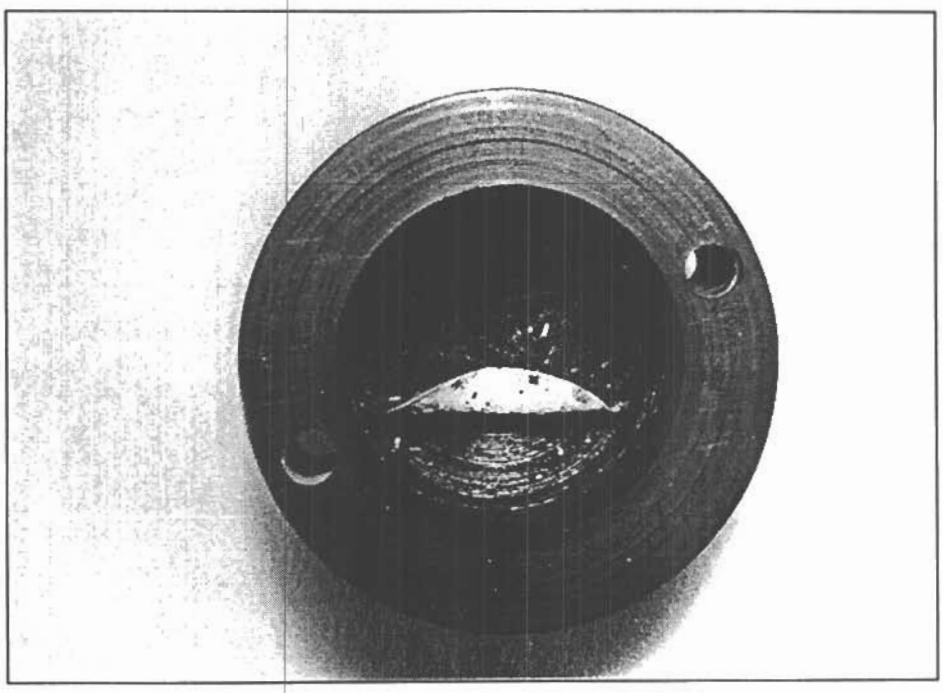


Figure 2-1.
Peeling Optical Surface
Due To Moisture
(Original Light Trap).

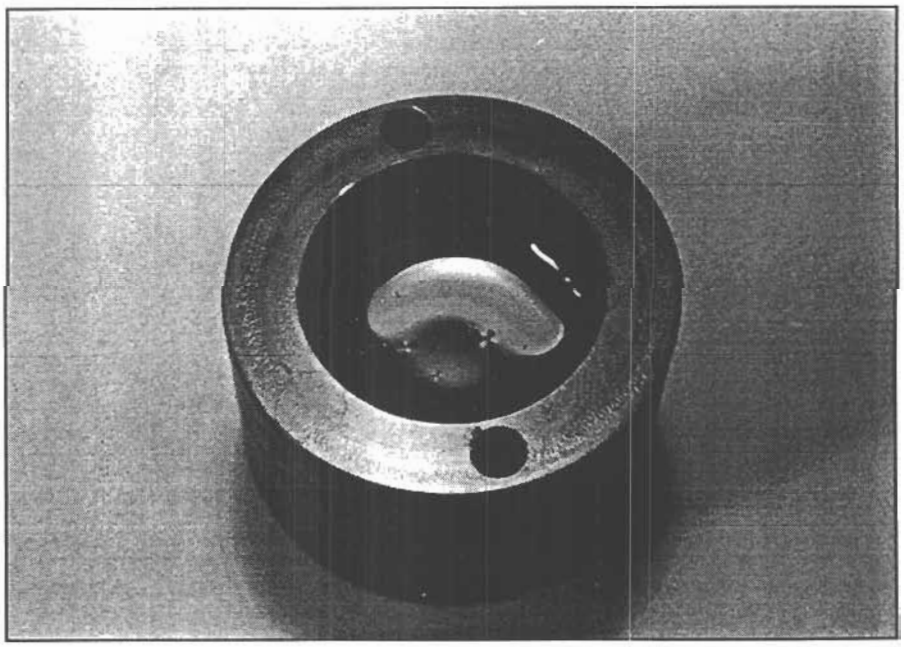


Figure 2-2.
Water-filled Light Trap.

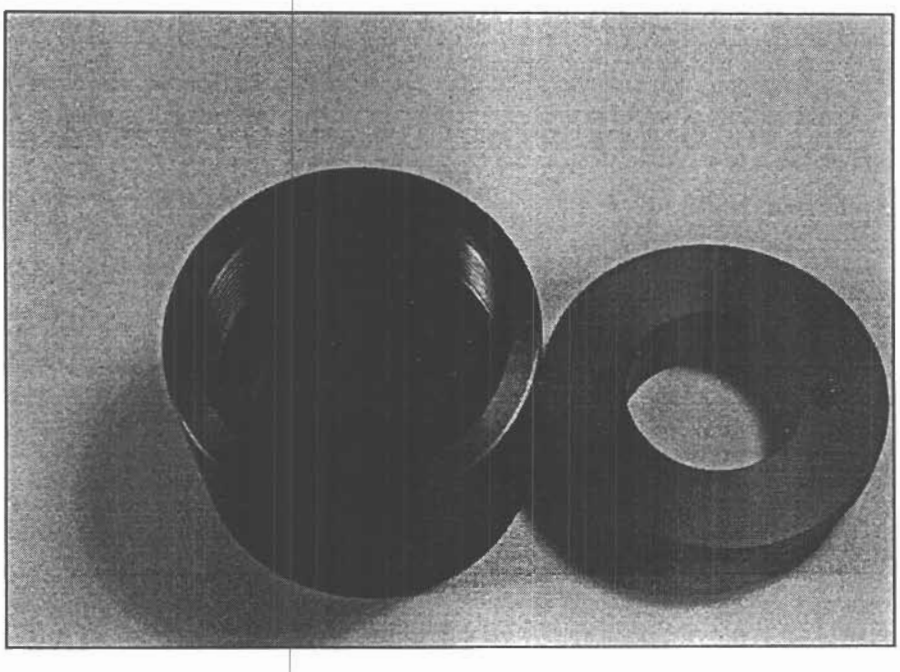


Figure 2-3.
ARS Cone Style Light
Trap With Threaded Base.

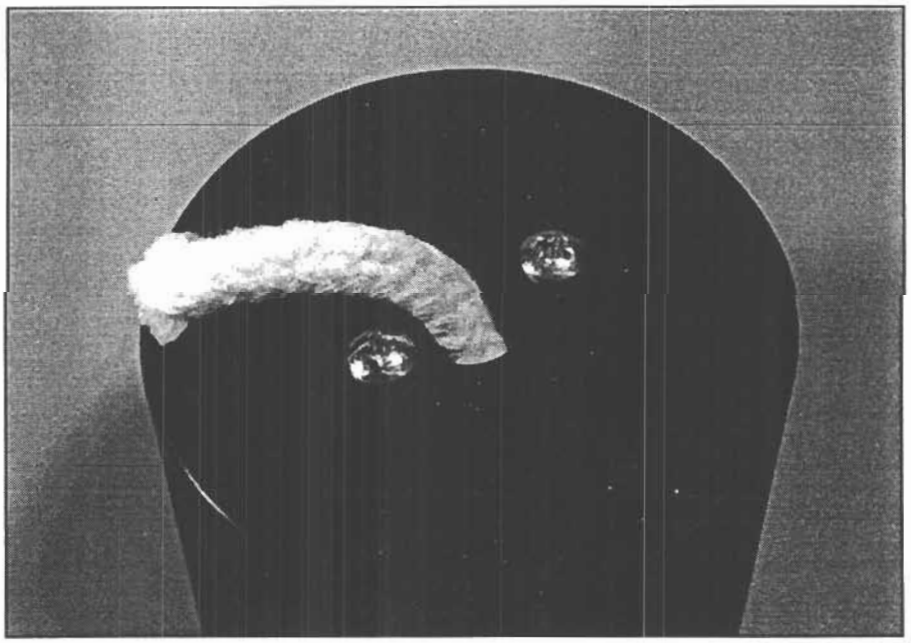


Figure 2-4.
Bottom Surface of ARS
Light Trap Showing
Cotton Wicking.

REPLACEMENT LIGHT TRAP

NGN-2 NEPHELOMETER MODIFICATION

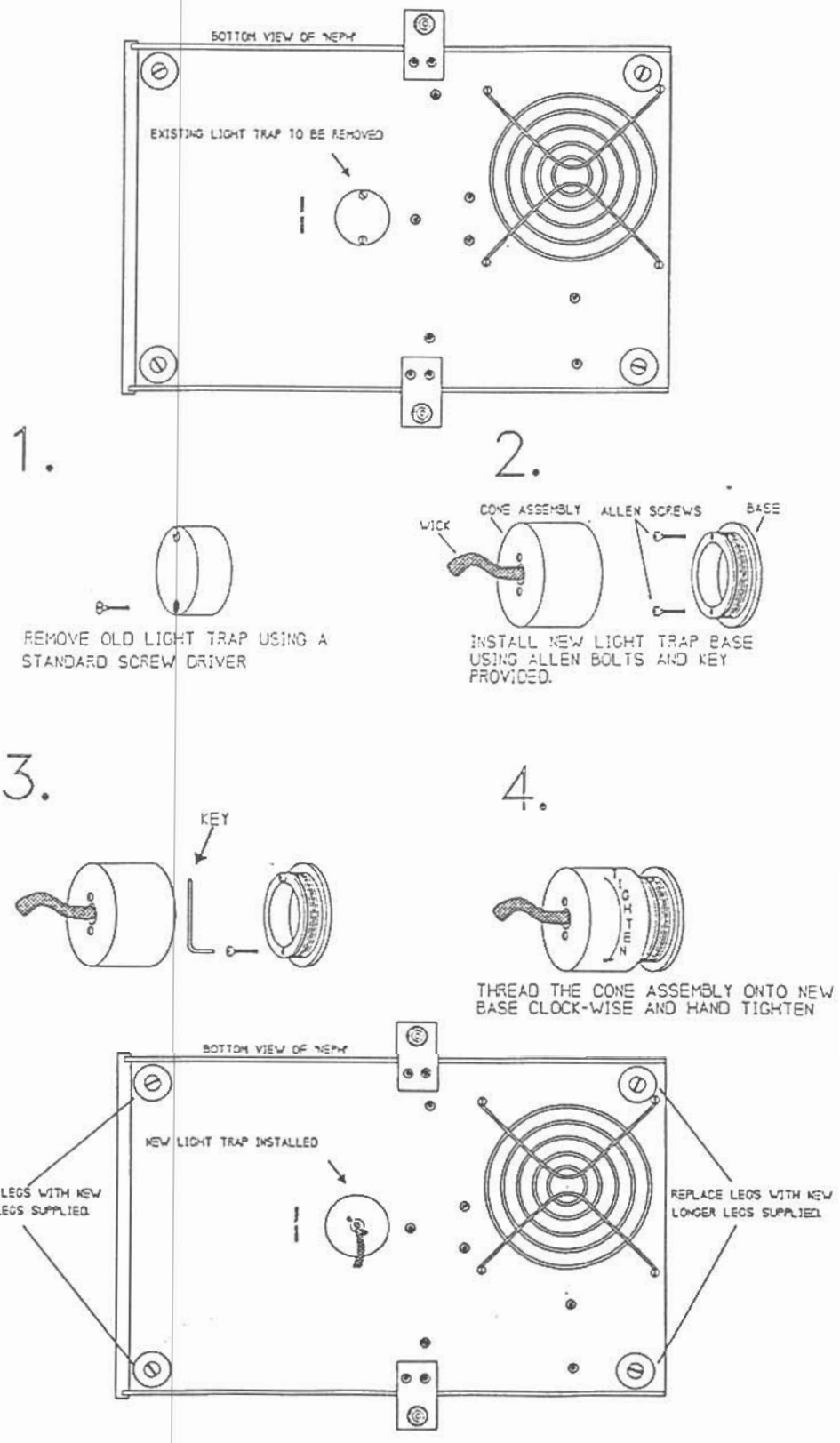


Figure 2-5. Diagram of ARS NGN-2 Nephelometer Modification.

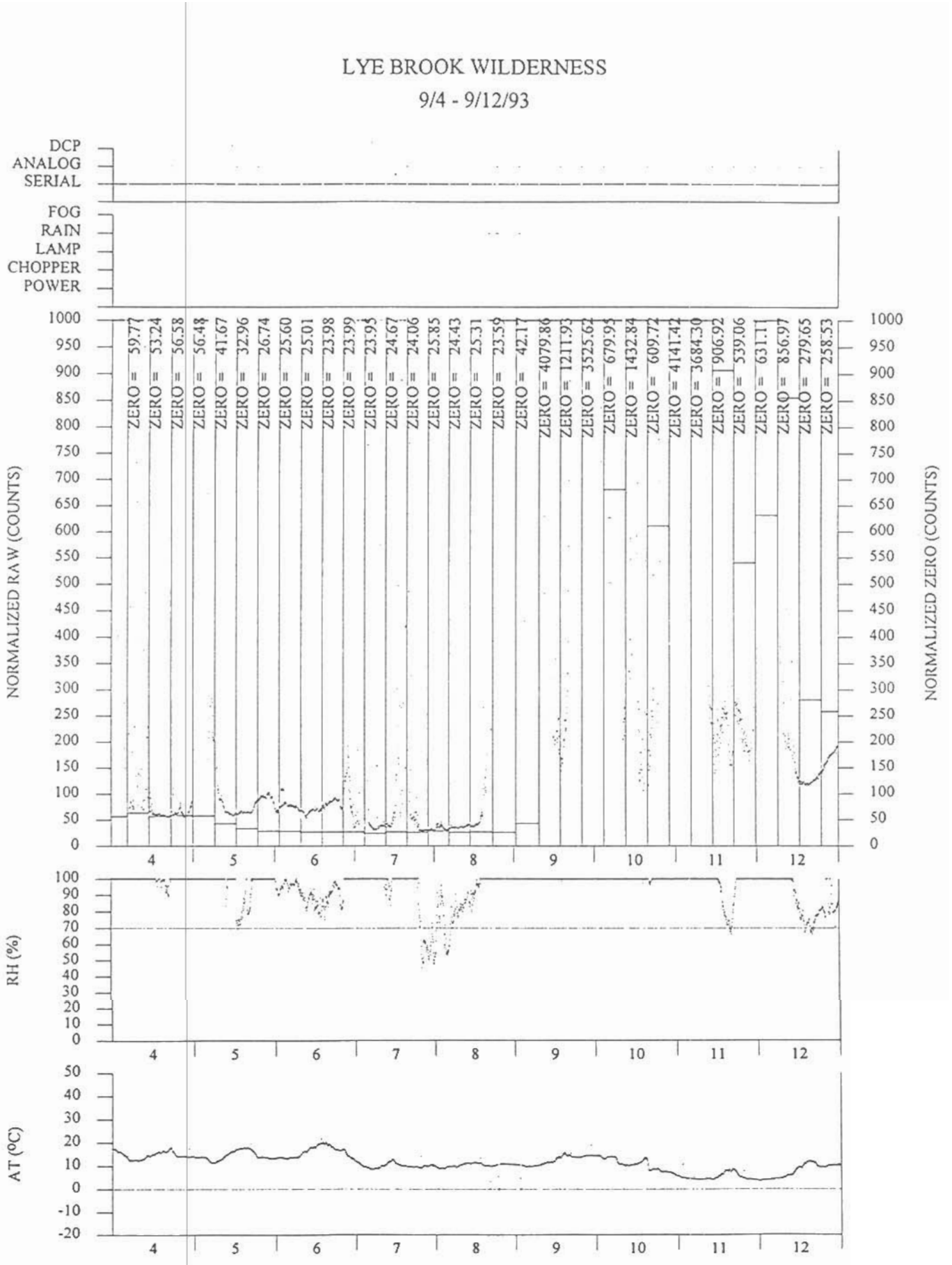


Figure 2-6. Instrument Malfunction After Precipitation Event on September 8-9, 1993.

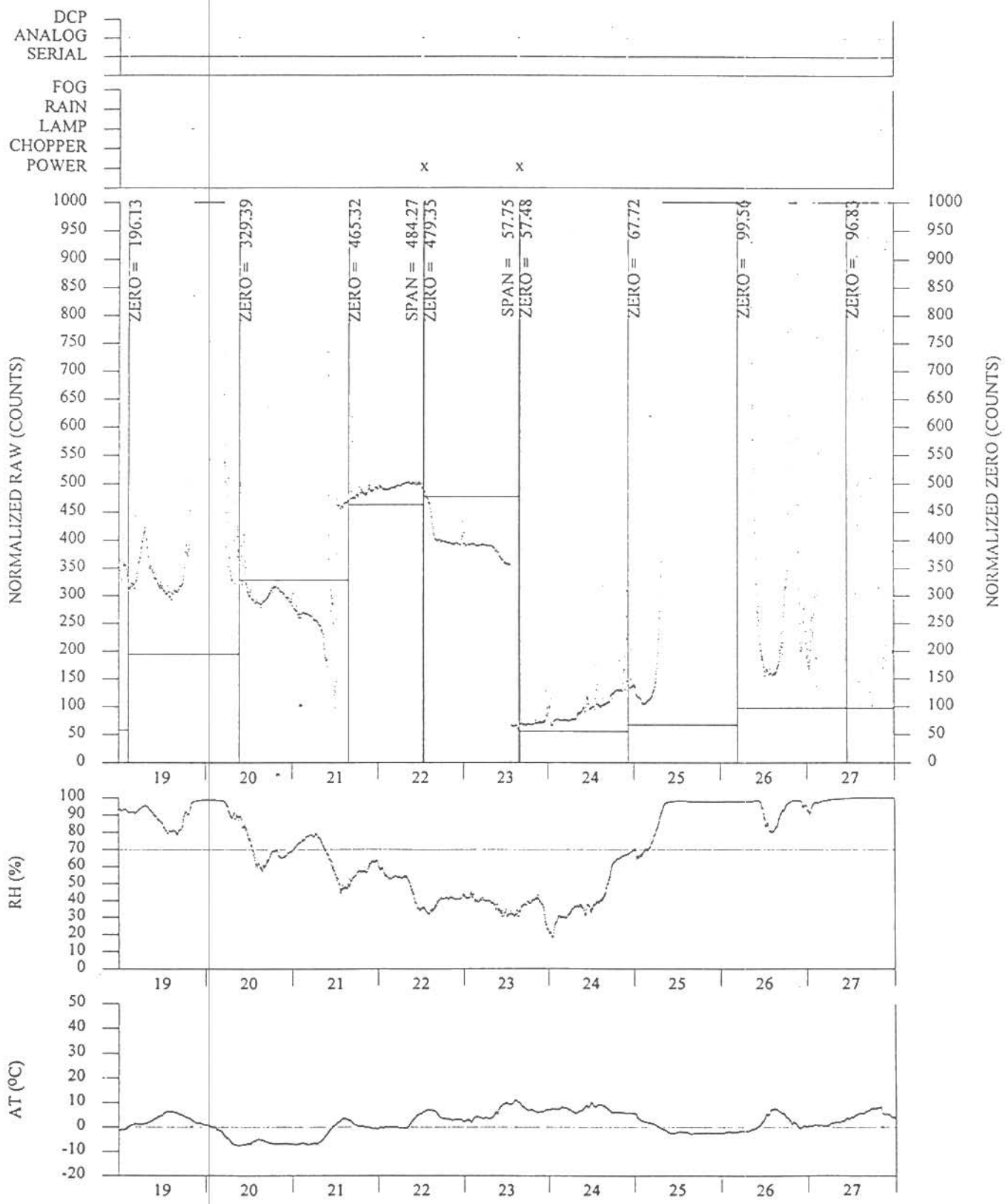


Figure 2-7. Improvement in Instrument Response After Installation of New ARS Light Trap on 11/23/93.

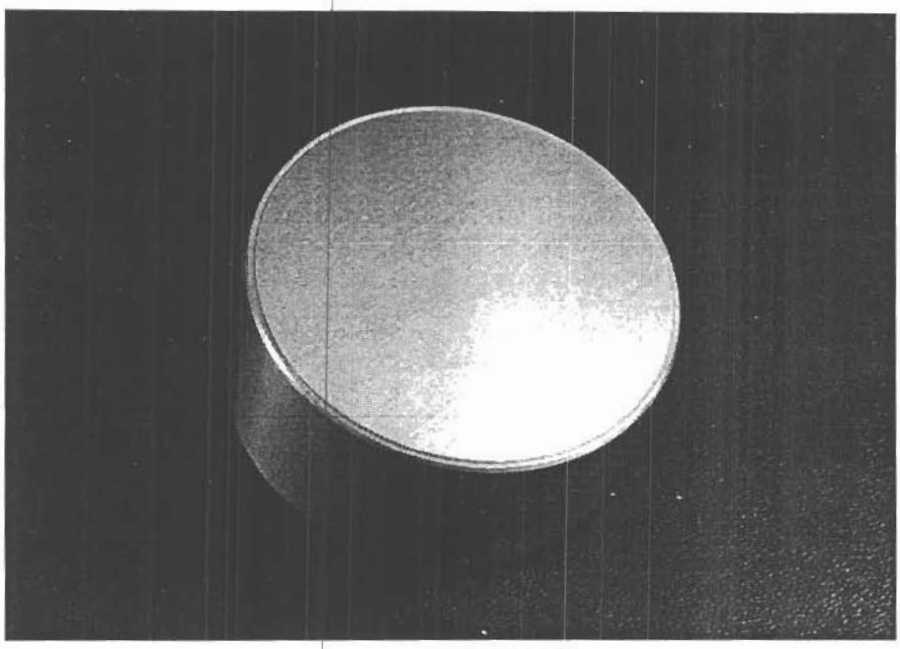


Figure 2-8.
Sealed Clean Air Filter
as Supplied by Optec.

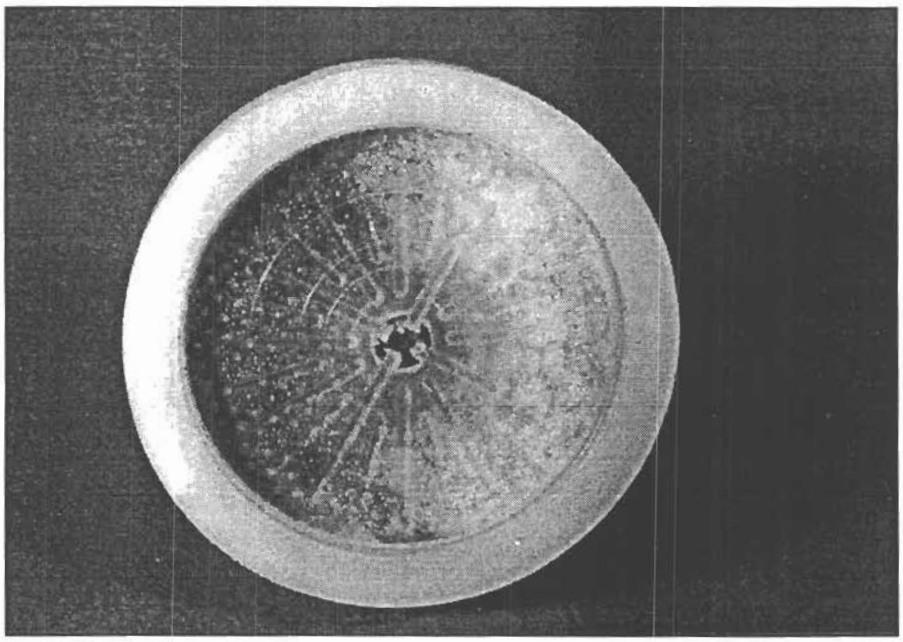


Figure 2-9.
Filter Element
Removed from Optec
Style Filter Showing
Growth of Mold on
Element Surface.

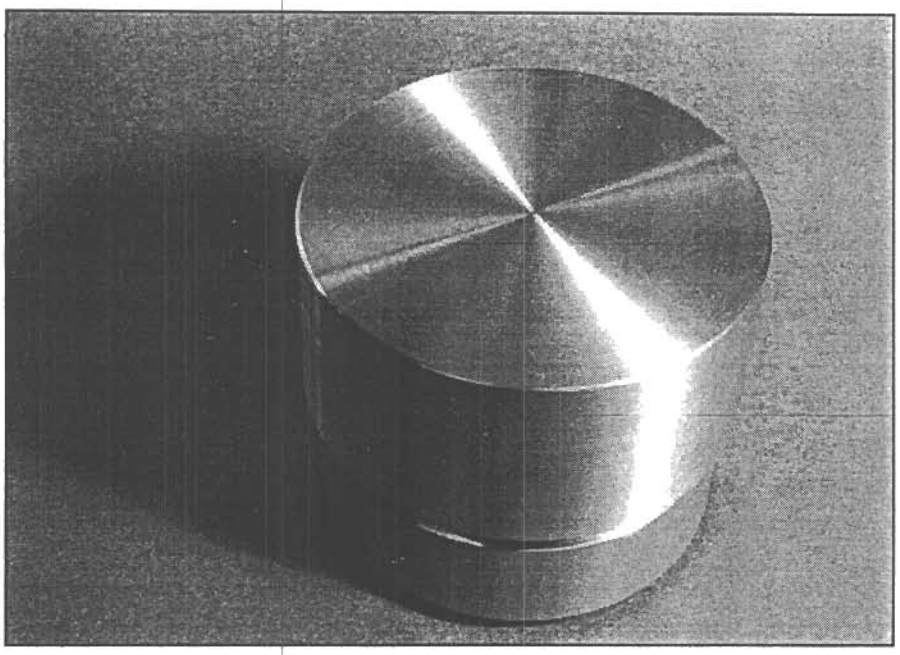
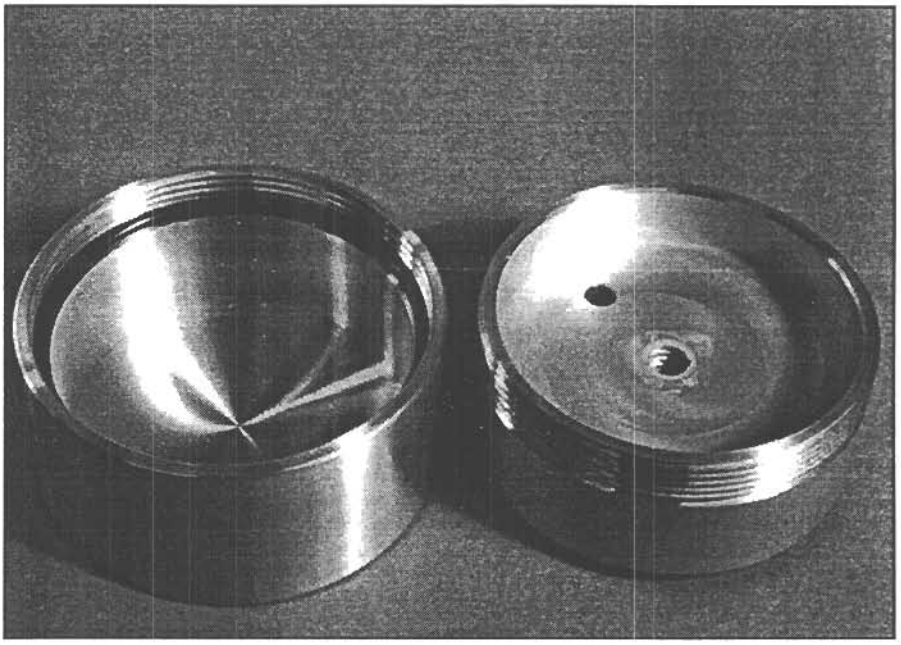


Figure 2-10.
ARS Style Clean Air Filter Holder.

Figure 2-11.
Two Piece Design Allowing for Easy Field Replacement of Filter Element.



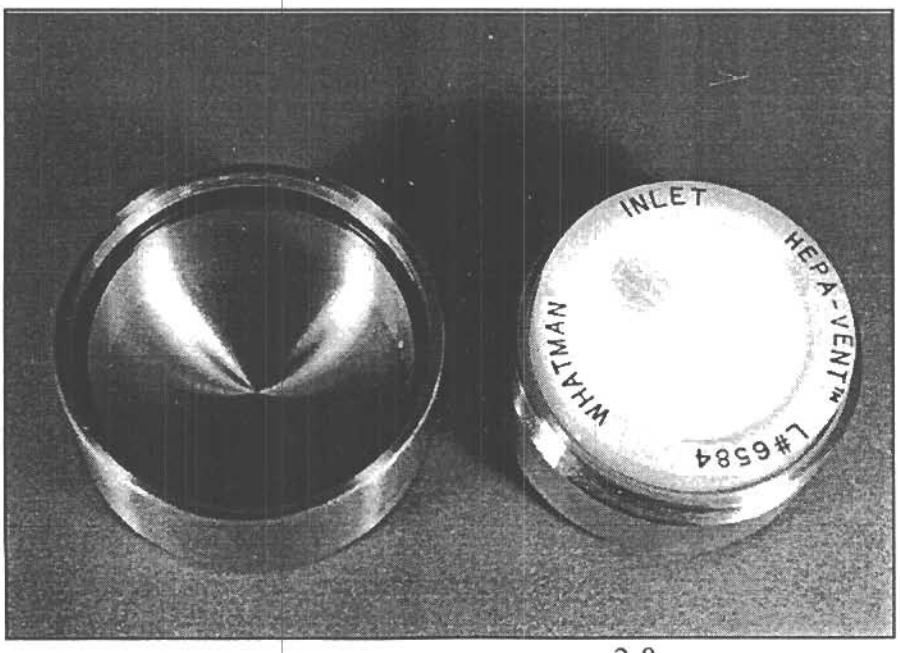


Figure 2-12.
ARS Style Clean Air Filter with Filter Element Threaded in Place.

IMPROVED CLEAN AIR FILTER HOUSING

NGN-2 NEPHELOMETER MODIFICATION

- The modified clean air filter holder supplied for use with the NGN-2 nephelometer will allow for easy replacement of the filter element by the site operator.

- As shown below, the modified filter holder consists of three parts: a filter base which threads onto the nephelometer just like the old style filter, a replaceable filter element that threads onto the base, and a cap that threads over the base and filter element assembly.

- To replace a filter element, simply unscrew the cap, unscrew the old element and thread in the replacement, then replace the threaded cap.

- Check inside the filter holder for moisture while the assembly is open during the filter element replacement. Note this on the log sheet an dry off the assembly before installing the new element.

- Do not use any tools to tighten any of the assembly parts; hand tighten only.

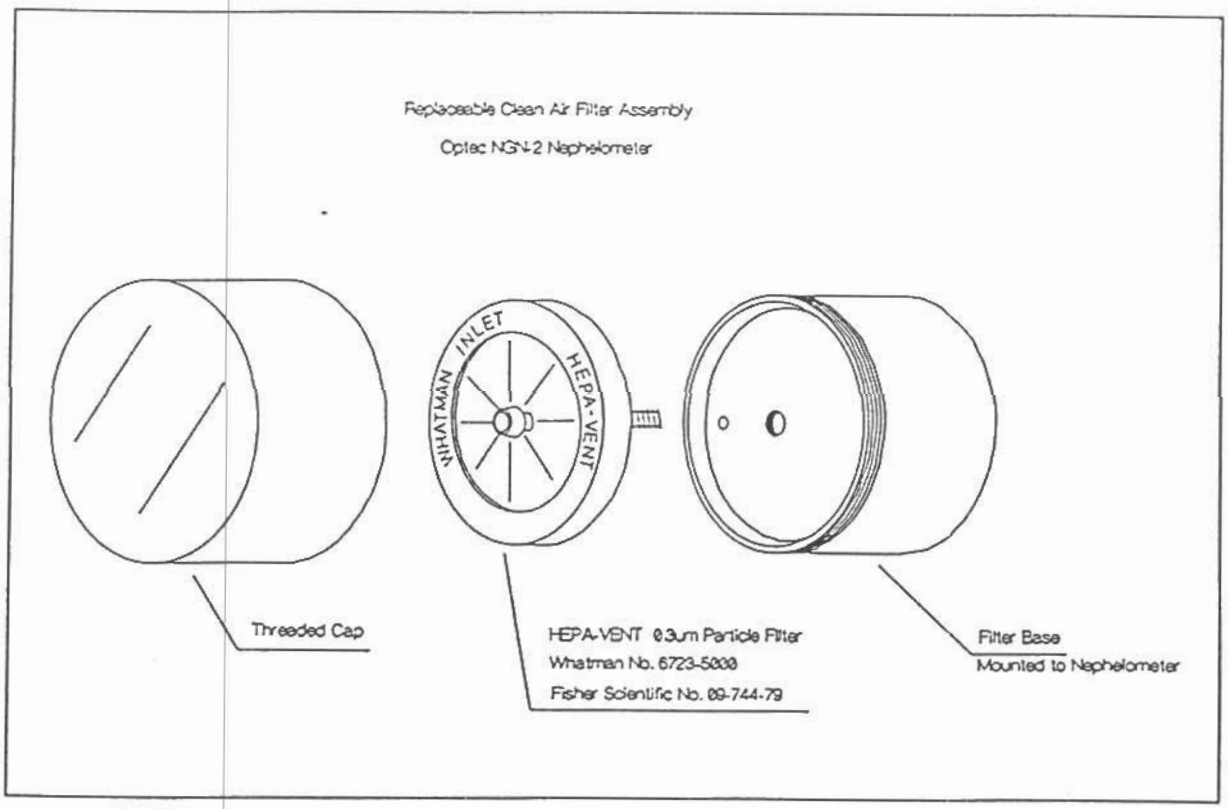


Figure 2-13. Schematic of Improved Clean Air Filter.

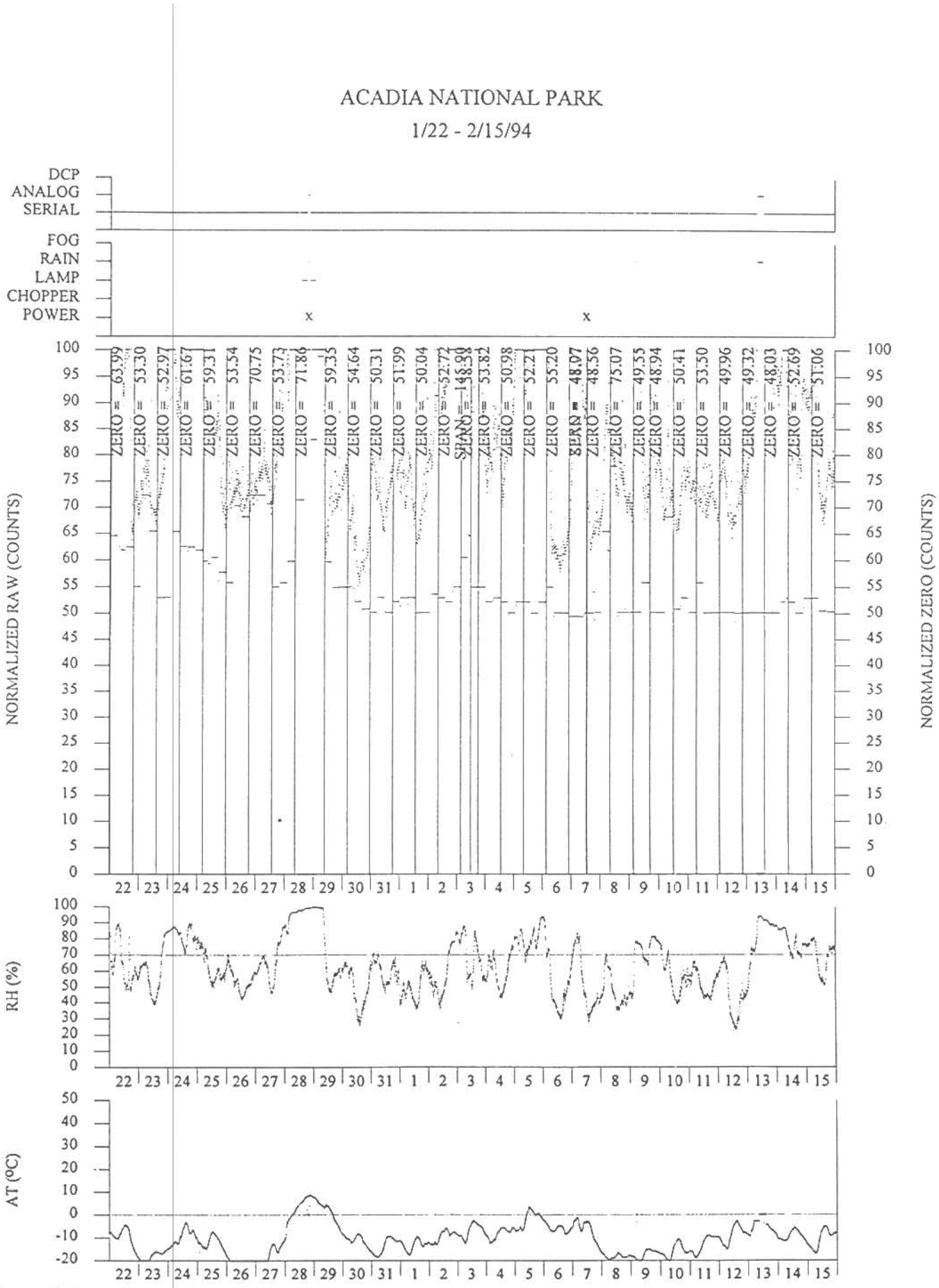


Figure 2-14. Improvement in Instrument Response After Installation of New ARS Clean Air Filter on 2/3/94.

2.4 DOOR SEAL PROBLEMS

Occasionally the optical chamber door fails to seal properly. Insects and debris that become lodged between the door and the nephelometer case can usually be removed by the site operator. Ice and snow, too, have been observed to accumulate under the door seal and impede proper door closure. These door closure problems are inherent in this design of nephelometer; however, the weather related issues could be minimized with the installation of a more effective precipitation sensor or a rain/snow shield as mentioned above.

Figures 2-15 through 2-17 show snow and ice buildup on the Mount Zirkel instrument. The Optec precipitation sensor did not close the door correctly and allowed precipitation to collect on the inlet screen and door seals as well as inside the optical chamber.

2.5 APERTURE RING

An aperture ring precisely defines the illumination cone of the light source. Originally, Optec mounted the ring to the manifold in the optical chamber with glue. Under field conditions, the glue joint fails and the aperture ring falls off. Missing aperture rings allow direct lamp light to reach the detector. When a ring falls off, the instrument must be returned for servicing. Five rings have failed either in the field or during shipping. ARS constructed a jig which allows for precise alignment of the aperture ring for the drilling of mounting screws. All instruments that have not already been repaired by ARS will be repaired when they are returned from the field for annual servicing. New instruments from Optec will have the aperture ring more firmly attached. It is strongly suggested that *no glue joints* be used in any field instrument.

2.6 OPTICAL CHAMBER PAINT

A number of instruments have had the black paint on the light baffle peel off after instrument installation in the field. This caused the zero, span, and ambient readings to become extremely erratic. ARS pulled the instruments from the field, located the problem, and shipped the equipment to Optec for evaluation. Optec repaired these instruments under warrantee. Optec has varied their light baffle manufacturing and painting procedures over time but has not solved all of the problems. The last six (6) nephelometers received from Optec had paint peeling from the aperture rings ARS is continuing to work closely with Optec to resolve this issue. Figures 2-18, 2-19 and 2-20 depict this issue.

2.7 SPAN GAS VALVE

The original span gas valve is mounted in the instrument using Loc-Tite to glue a 10-32 threaded fitting into a 1/4" female elbow (Figure 2-21). This joint not only provides a pneumatic seal but acts as the sole mechanical support for the valve. ARS is currently soldering this joint after a failure occurs. Proper fittings are being ordered by ARS for replacement of the glued joints. The factory valve has failed on two occasions and may not

be suitable for long term field use or for automatic span calibrations. A more standard type valve has been ordered by ARS for evaluation as a replacement. It is strongly recommended that *no glue joints* be used in any field instrument.

2.8 LINE SURGE PROBLEMS

The NGN-2 nephelometer required additional protection from power surges and lightning damage to the AC power line and the telephone line. ARS purchased and shipped uninterruptible power supplies (UPS) to most IMPROVE and USFS sites. UPS will help protect the system from power surges as well as provide temporary power during momentary AC power failures and brown-outs. The remaining IMPROVE sites will require more complicated installation procedures which will be completed by ARS during site visits in the coming year. Telephone line surge protectors will also be installed at the same time.

2.9 BULB HOLDER

The NGN-2 light source bulb holder (Figure 2-22) is cumbersome and allows the operator to install a new bulb in an improper orientation. Even experienced operators have installed bulbs improperly due to the design of the holder (Figures 2-23 and 2-24). An improperly installed lamp can cause low chamber illumination, which in turn causes erratic zeros and readings. An operator logging only analog readings will not be able to detect this problem.

Due to problems associated with the original factory installed lamp tray system, ARS has developed and is implementing design modifications to correct the inadequacies. An external wiring configuration for the lamp is now being used which will alleviate the wire chafing and lamp holder bending, major problems with the original design (Figures 2-25 and 2-26). In addition to preventing damage to the system, the new design makes it much easier for an operator to replace a lamp. The entire lamp tray can now be removed (Figure 2-27) from the instrument, allowing the operator to replace the lamp while on the ground and in a sheltered environment if desired. Misalignment of the lamp due to improper installation will be greatly reduced by the removable lamp tray. In addition lamp tray mounting nuts are now secured directly to the tray.

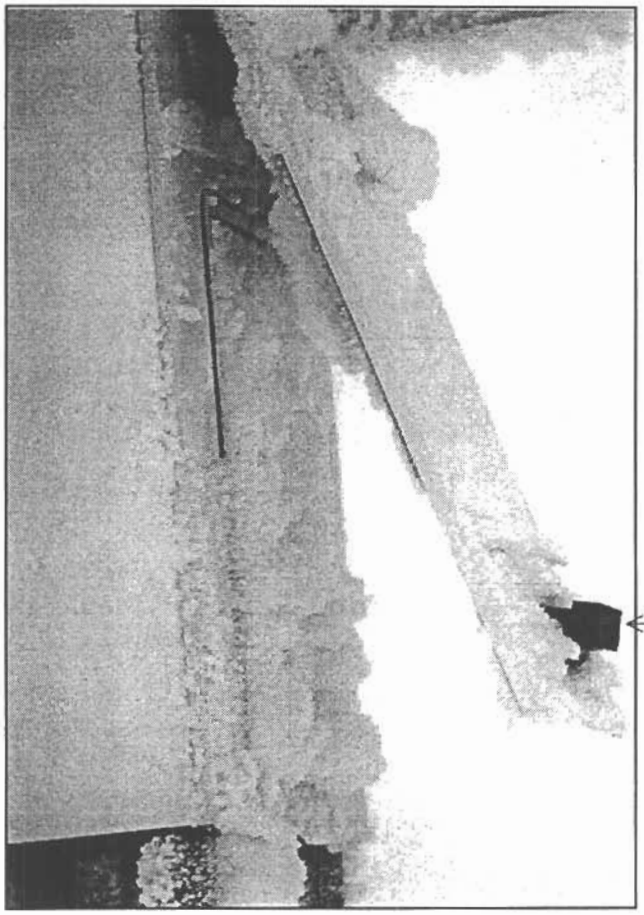
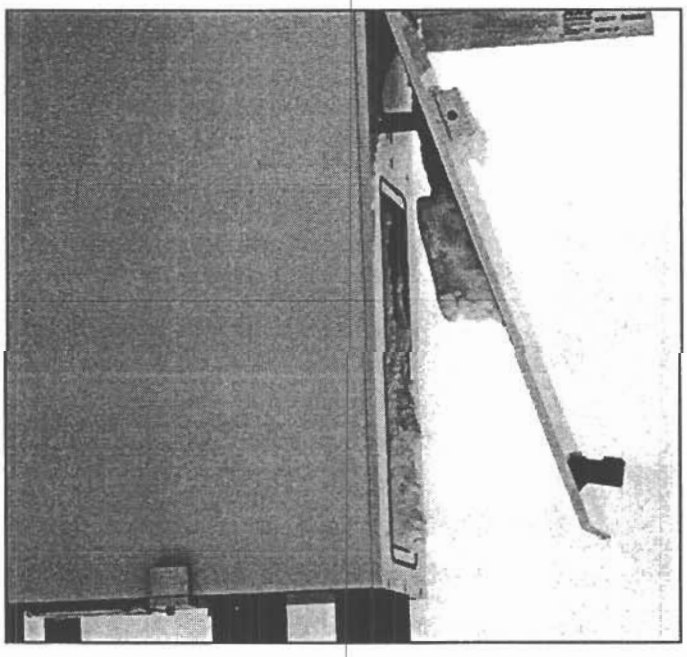
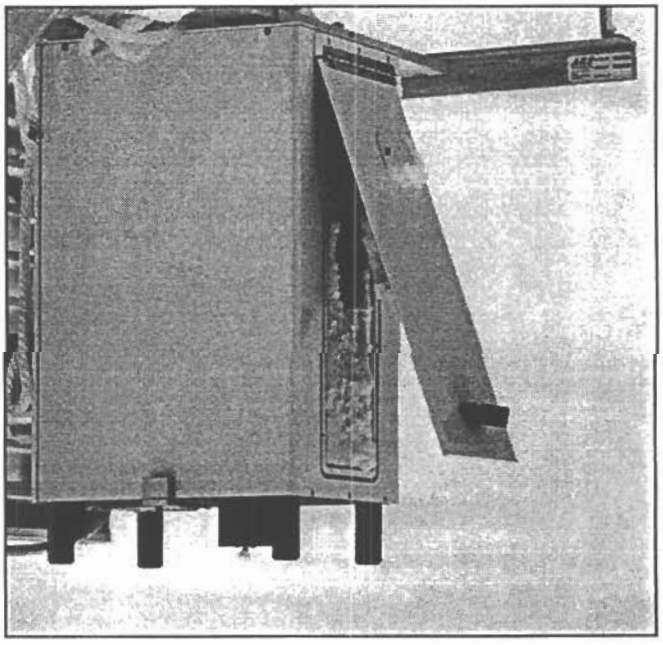


Figure 2-15. Optec Precipitation Sensor.





Figures 2-16 and 2-17. Snow and Ice Build-up on the NGN-2 Nephelometer at Mount Zirkel Wilderness. (Note that the Optec heated precipitation sensor is free of snow yet does not provide proper protection from the elements.)

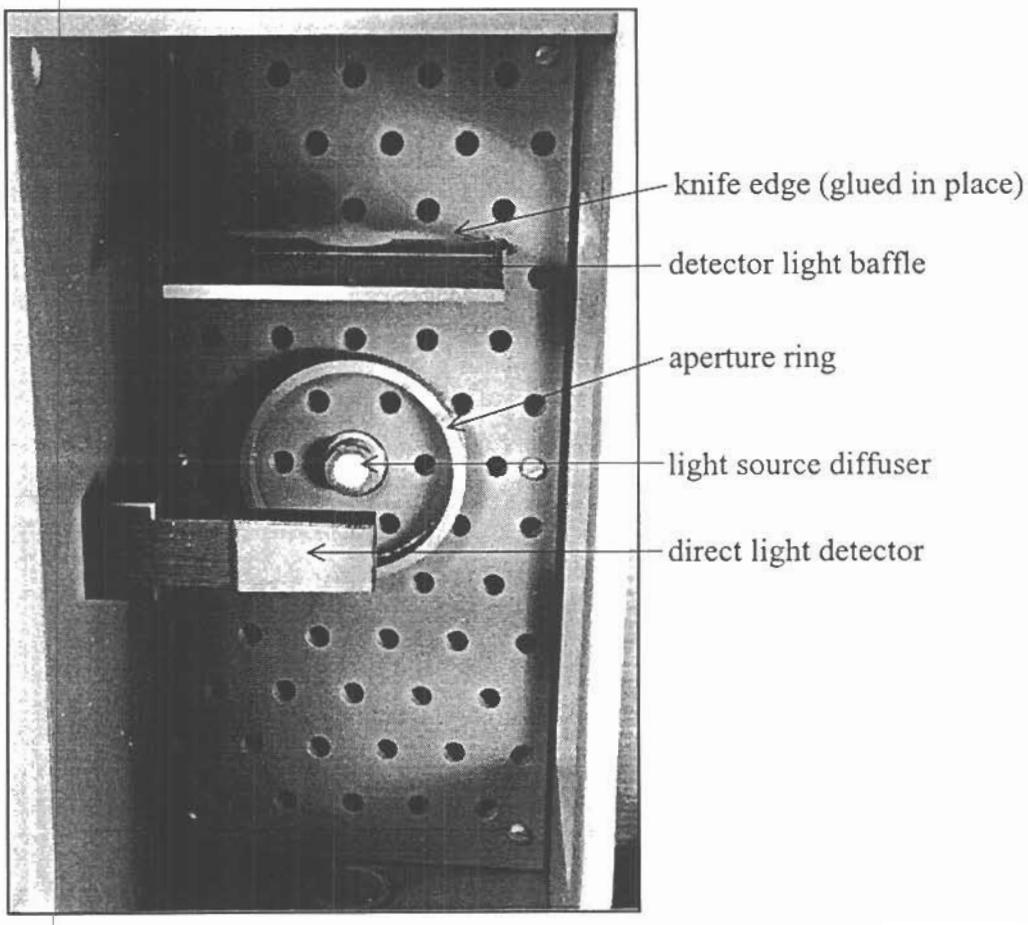


Figure 2-18. Inside View of NGN-2 Optical Chamber.

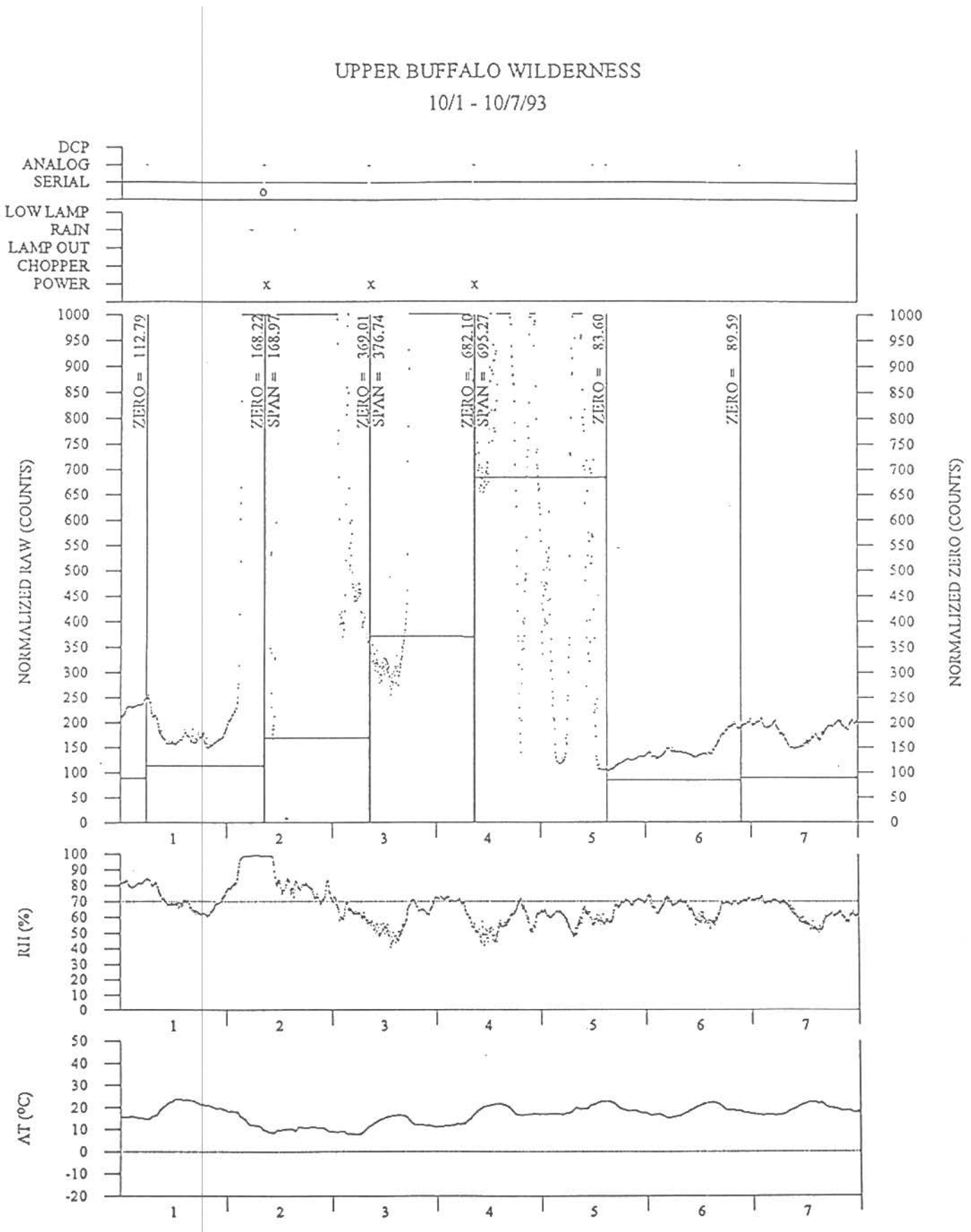


Figure 2-19. Effect of Peeling Paint on Upper Buffalo Instrument.

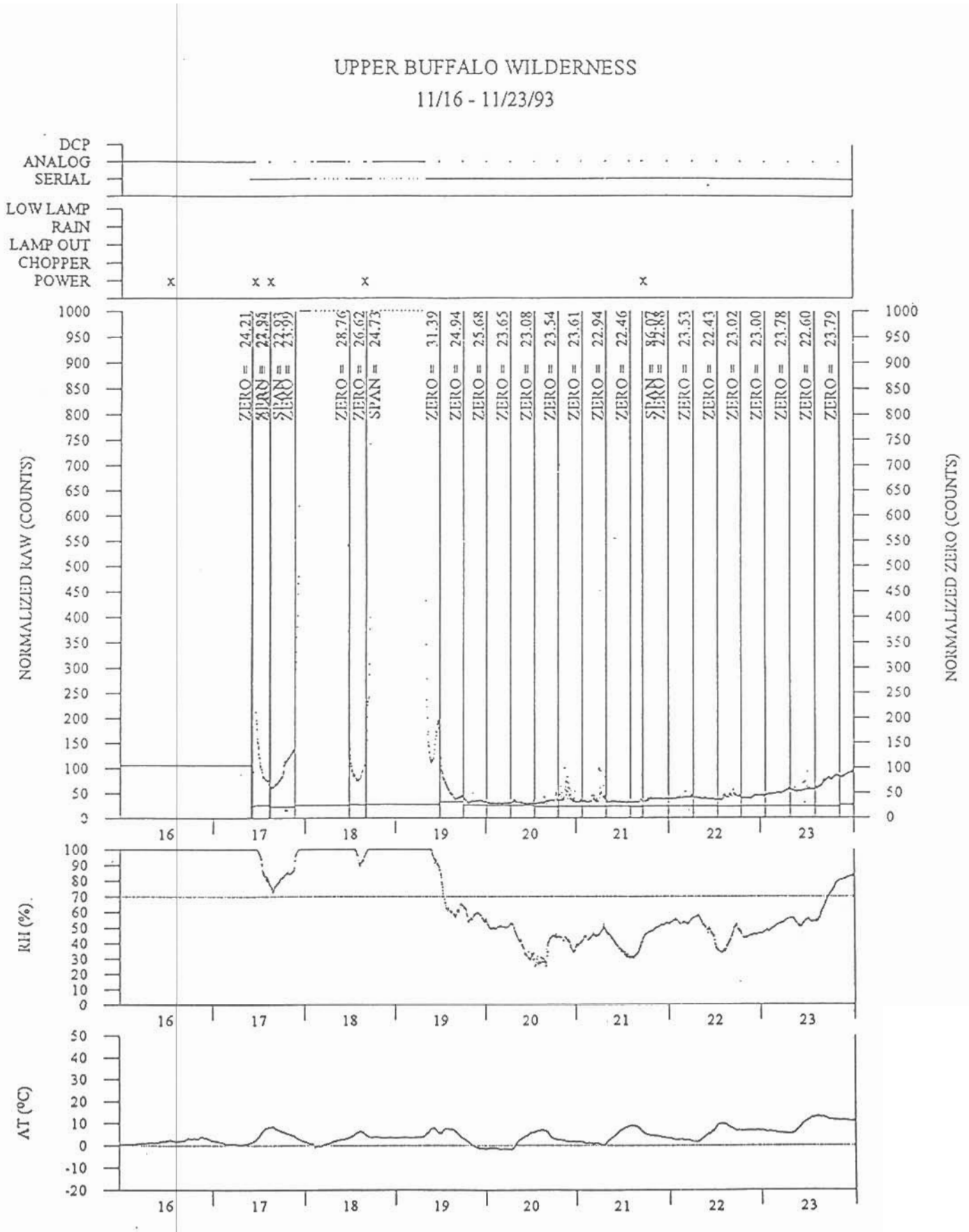


Figure 2-20. Improved Instrument Response After Repair of Peeling Paint. Re-installation on 11/17/93.

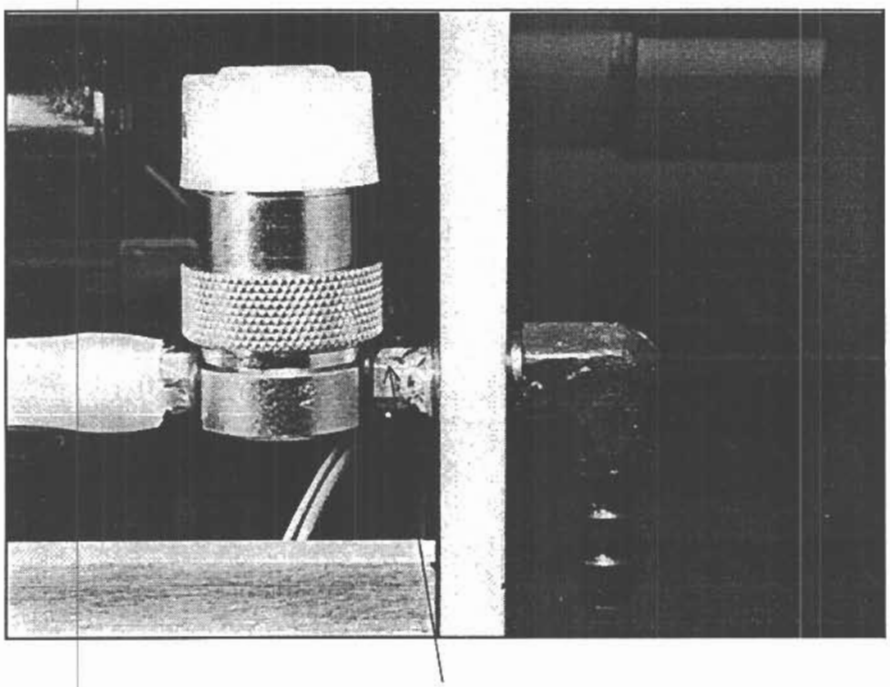


Figure 2-21. NGN-2 Span Gas Valve, Non-standard Fitting that is Glued Together at the Factory. This Joint has been Soldered by ARS After Joint Failure.

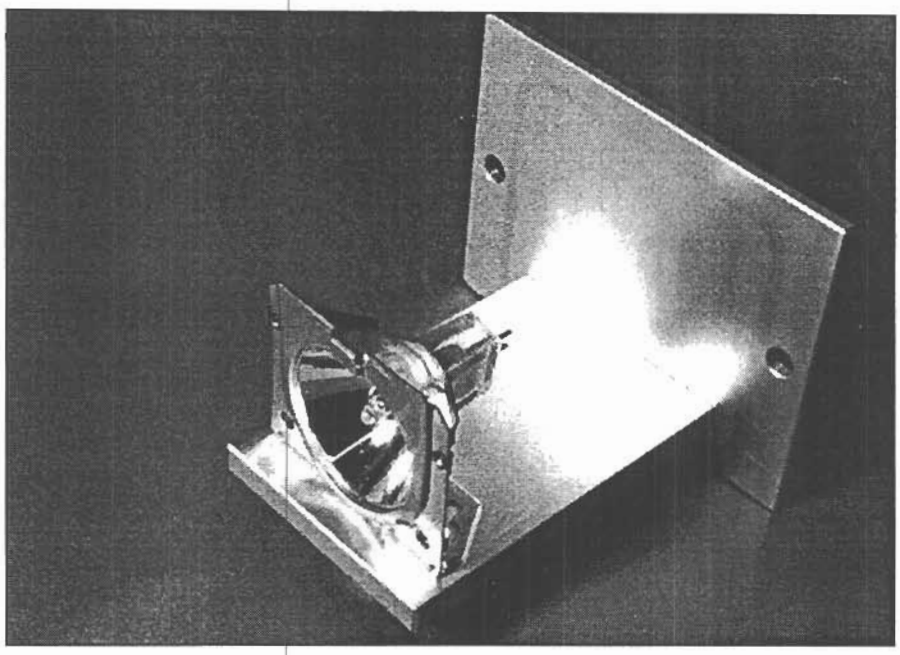


Figure 2-22.
Overall View of Bulb Holder.

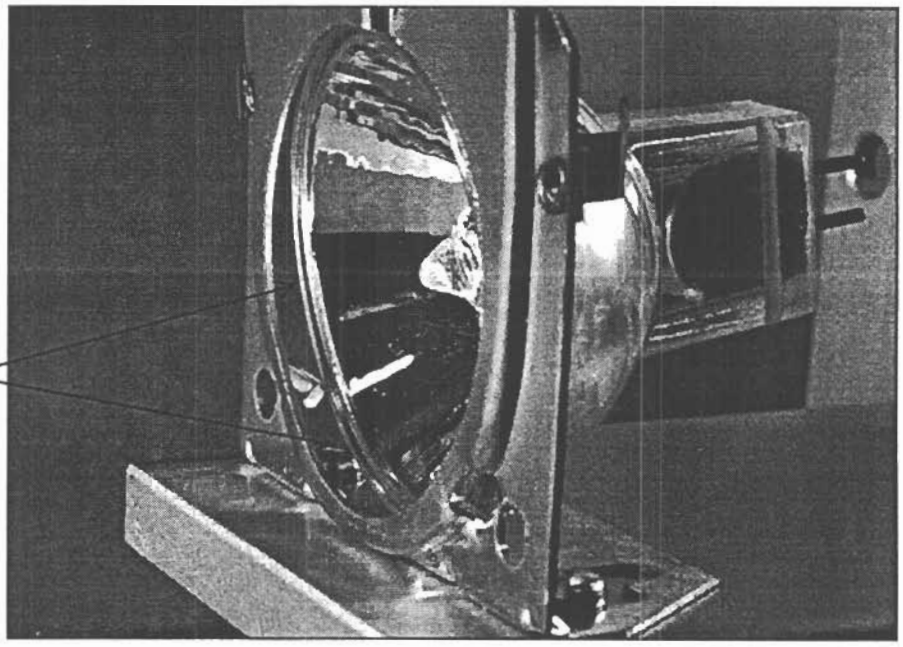


Figure 2-23.
Incorrect Bulb Installation.

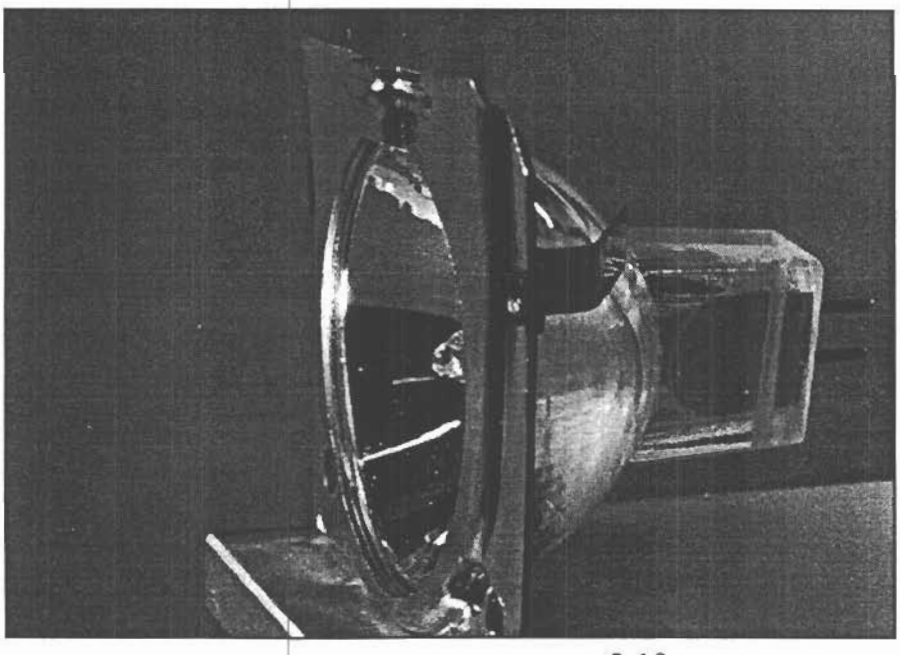


Figure 2-24.
Correct Bulb Installation.

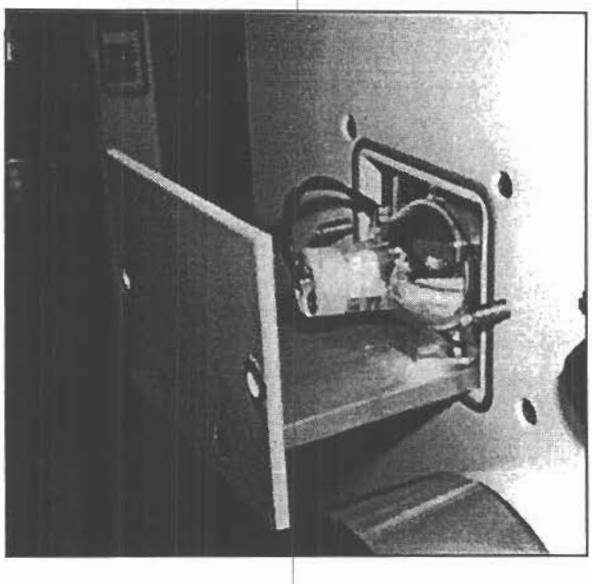


Figure 2-25.
Original Factory Lamp Tray System. Lamp Wire Can Become Caught between Tray and Nephelometer Opening.

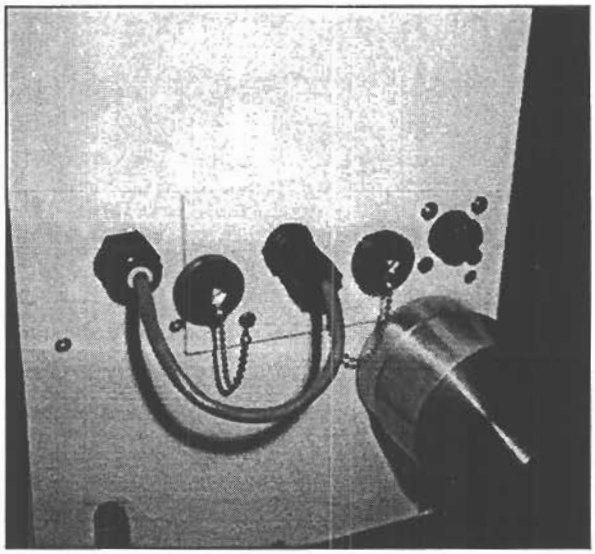


Figure 2-26.
Modified Lamp Tray System Showing External Wiring Configuration.

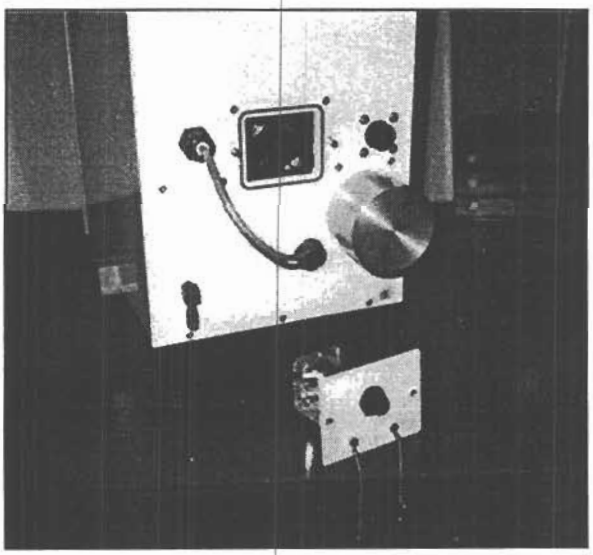


Figure 2-27.
Modified System shown Removed from the Nephelometer.

```
LAMP MISALIGNMENT TEST


RTL CPM VERSION - FOR OPTEC SBC
COPYRIGHT 1992
OPTEC, INC.  NGN-2 OPERATING SYSTEM
VERSION: NEPH1056
SN =   38
RUN MODE =    3
INTERVALS =   72
DATE & TIME (YR-MO-DAY  HR-MIN) = 940112  1418
AUTO SPAN (1 ON / 0 OFF) =    1
STORED BAUD RATE = 1200
AUTO TEST (1 ON / 0 OFF) =    1
TOTAL RUN TIME =   54  HOURS


CSUM=   23    ROMTOP=   23


             LAMP VALUE


1         37    2444      30    1  22.11    940112      1419
1         39    2428      32    1  22.08    940112      1420
1         35    2454      29    1  22.02    940112      1421
1         35    2492      28    1  22.05    940112      1422
1         40    2491      32    1  22.08    940112      1423

*LAMP MISALIGNED (SEE FIGURE ?)

1         17    1052      32    1  22.05    940112      1426
1         17    1087      31    1  21.96    940112      1427
1         20    1091      37    1  21.96    940112      1428
1         20    1090      37    1  21.99    940112      1429
1         14    1090      27    1  21.99    940112      1430
1         17    1090      31    1  21.96    940112      1431
1         17    1090      31    1  21.93    940112      1432


*56% DROP IN LAMP COUNTS DUE TO MISALIGNMENT
```

Figure 2-28. Lamp Misalignment Test.

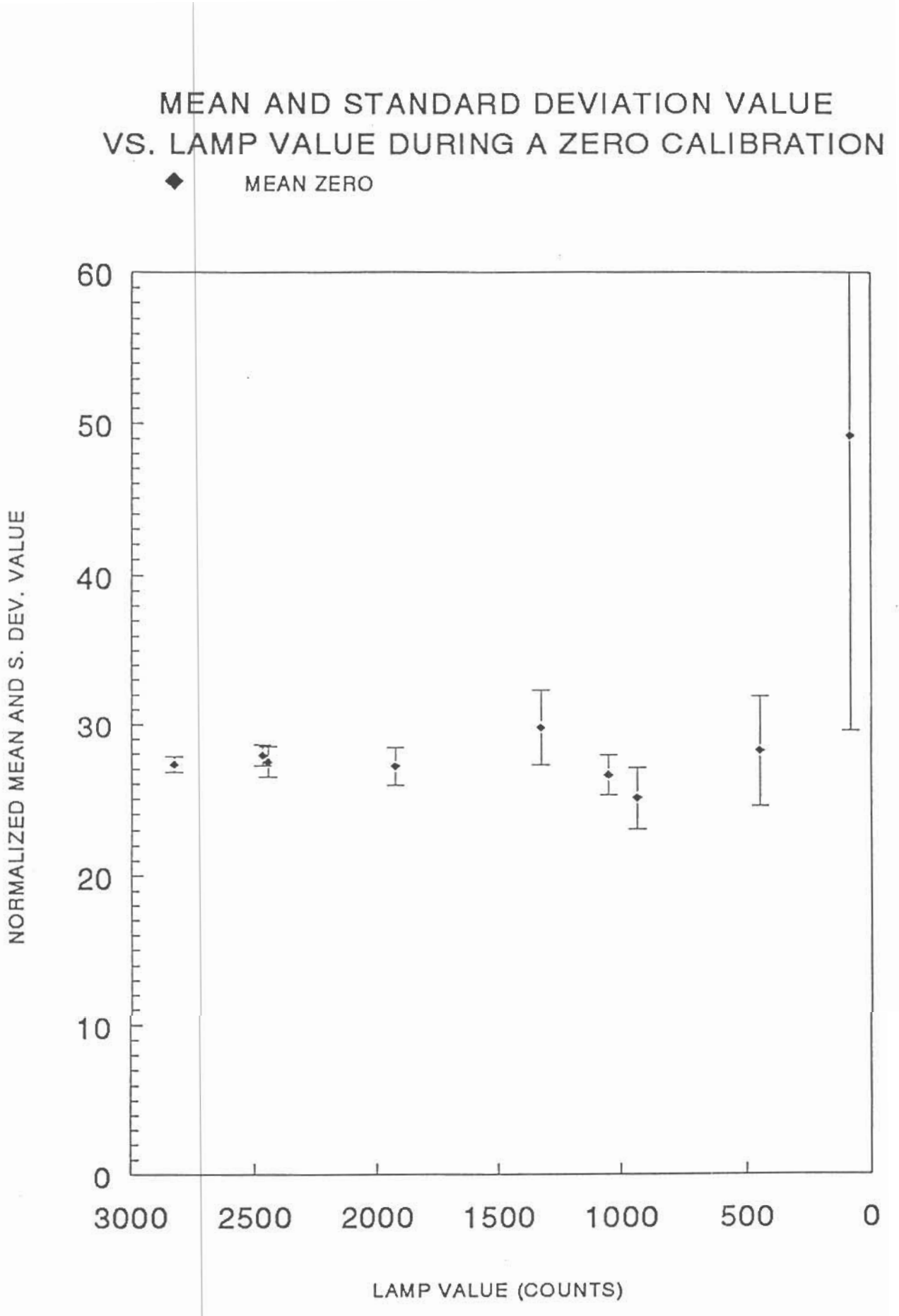


Figure 2-29. Variable of Zero Value, A Function of Lamp Value.

3.0 SOFTWARE/COMMUNICATION CONCERNS

When the next generation ambient nephelometer is designed, several current nephelometer software and communications problems should be addressed.

3.1 ROM MODIFICATIONS

At the request of ARS, Optec made ROM modifications to correct operational errors and to enhance the performance of the NGN-2 under field conditions. The latest modification was delivered from Optec with very little testing

Table 3-1 shows the test results of the NGN-2 using a 1071 ROM. The nephelometer locks up if a lamp fails during a calibration. The instrument will remain locked up until a power failure or operator intervention. This intermittent problem also occurs with earlier ROM versions. The manufacturer has suggested that it may be hardware problem and has provided ARS with a possible fix. No testing of this hypothesis has occurred.

3.2 SERIAL COMMUNICATION

Serial communication between the NGN-2 and dataloggers could be greatly simplified by the addition of a built in serial buffer to allow for proper handshaking between the nephelometer and datalogger. At present a separate micro-controller is required in the data logging system to allow for serial logging of data. Future versions should provide data logging and modem capabilities.

3.3 GROUND LOOPS

Great care must be taken to prevent signal ground loops from occurring due to the internal grounding configuration of the NGN-2. Optically isolated analog and possibly serial outputs would eliminate any ground loop problems that can presently occur.

Table 3-1

NGN-2 Lockup Problem

```
TESTING OF 1071 ROM VERSION


RTL CPM VERSION - FOR OPTEC SBC
COPYRIGHT 1992
OPTEC, INC.  NGN-2 OPERATING SYSTEM
VERSION: NEPH1071
SN =   38
RUN MODE =    3
INTERVALS =   72
DATE & TIME (YR-MO-DAY  HR-MIN) = 940112  0954
AUTO SPAN (1 ON / 0 OFF) =    1
STORED BAUD RATE = 1200
AUTO TEST (1 ON / 0 OFF) =    1
TOTAL RUN TIME =   53  HOURS
LOW LAMP LIMIT = 1000
FOG LIMIT = 10000
ANALOG-1 MULTIPLIER =   17


CSUM=  112    ROMTOP=  112

*CHECK FOR SYSTEM SHUTDOWN WHEN LAMP BLOCKED


>door close
>valve off
>sol off
>lamp on
>pump on
>1 to integ
>1 20 do work loop
1         30    2451      24    1  19.53    940112      0927
1         35    2439      29    1  19.61    940112      0928
1         35    2479      28    1  19.61    940112      0929
1         33    2478      27    1  19.61    940112      0930
1         36    2479      29    1  19.67    940112      0931
4

*WORKS OK DURING WORK LOOP

>lamp on
>1 20 do work loop
1         33    2489      27    1  19.82    940112      0937
1         32    2503      25    1  19.85    940112      0938
1         35    2501      28    1  19.88    940112      0939
1         36    2498      28    1  19.94    940112      0940
4

*WORKS OK REPEATING WORK LOOP

*TESTING FOR SHUTDOWN AFTER POWER UP CAL

1         61    2429      50    1  20.43    940112      0955
3         34    2462      27   10  21.20    940112      1007
2         33    2462      27   10  21.70    940112      1023
4

*WORKS WHEN LIGHT BLOCKED OFF FOLLOWING CAL

*TESTING FOR SHUTDOOWN DURING A CALIBRATION


1         51    2394      43    1  21.81    940112      1042
3         33    2464      27   10  23.51    940112      1054
2         34    2455      27   10  23.69    940112      1231
1         43    2414      36    2  23.28    940112      1250
1         48    2453      39    2  23.25    940112      1255
1         47    2453      38    2  23.10    940112      1300
4

*1042-CALIBRATION BEGINS AFTER POWER UP, LAMP NOT BLOCKED
*1052-LAMP COMES ON FOR TEN MINUTE INTEGRATION, LAMP BLOCKED OFF, NO LIGHT IN CHAMBER
*1210-NO OUTPUT, NEPH IS LOCKED UP;PUMP ON,LAMP ON,ETC. LOOKS JUST LIKE IT IS DOING A
     CALIBRATION BUT NO UPDATES OCCUR
*1213-LAMP LIGHT ALLOWED TO ENTER CHAMBER
*1231-NEPH UPDATES WITH CLEAN AIR VALUE. DOOR OPENS,FAN ON,PUMP OFF,LAMP-CHOPPER OFF
*1249-LAMP AND CHOPPER ON
*1250-LAMP OFF,CHOPPER OFF,UPDATES AMBIENT VALUE
*1255-NORMAL FIVE MINUTE UPDATES BEGIN


*NGN-2 WITH 1071 ROM LOCKS UP IF LAMP GOES OUT DURING A CALIBRATION
```

4.0 CONCLUSIONS

This report summarizes part and equipment specific operational experiences with the NGN-2 nephelometer. A detailed discussion of the overall quality of the IMPROVE network data is being prepared. All current NGN-2 and support system modifications will be fully implemented by ARS personnel during the network site visits which will occur in the spring and summer of 1994.