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# Quality Assurance for RESOLVE—A Visibility Study in the California Desert

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**JANUARY 1985**

**NAVAL WEAPONS CENTER  
CHINA LAKE, CA 93555-6001**



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## FOREWORD

The study described in this report was supported by Interagency Agreement No. RW-930-243-01-4 with funds derived from Naval Weapons Center Work Requests N60530-84-WR-30171 and N60530-84-WR-30172. The study is part of a continuing effort to study the status of visibility in the R2508 airspace. This report focuses on the role and effect of quality assurance activities in the routine monitoring portion of the project.

The report has not been subjected to the Environmental Protection Agency's peer and administrative review, and, therefore, may not necessarily reflect the views of the Agency and no official endorsement should be inferred.

Because of the continuing nature of the research, refinements and modifications may later be made in this study.

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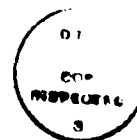
(U) *Quality Assurance for RESOLVE: A Visibility Study in the California Desert*, by Ann Pitchford, Marc Pitchford, Environmental Monitoring Systems Laboratory Las Vegas, Deb Chaloud, Lockheed Engineering and Management Services Company, Inc., and Patrick Feeney, Air Quality Group, University of California, Davis, China Lake, Calif., Naval Weapons Center, January 1985, 20 pp. (NWC TP 6591, publication UNCLASSIFIED.)

(U) The Department of Defense (DOD) and the Environmental Protection Agency (EPA) are conducting a visibility study in the California desert RESOLVE, Research on Operations-Limiting Visual Extinction. The objectives of RESOLVE are: (1) to understand the effect of air pollution sources on visibility in the study region; and (2) to determine spatial and temporal visibility levels, aerosol characteristics, and related meteorological parameters. Instrumentation used in the eight-station network includes nephelometers, teleradiometers, cameras, particle samplers, meteorological sensors, and satellite telemetry for data collection. Quality assurance considerations have been integrated into all phases of the study, including choice of instrumentation, pre-deployment testing, operations, and processing and review of data. For example, choice of satellite telemetry was essential to attain better than 90% data recovery while minimizing operating costs. Modification of nephelometers increased reliability and sensitivity. Predeployment tests of newly developed particle samplers provided operation and quality control information. Standard operating and quality control procedures were developed for all instruments. Data processing procedures were designed to minimize errors and provide data for review within 3 days of collection. Preliminary results of this integrated approach to quality assurance are summarized in this report in terms of data recovery and, for selected instruments, measurement precision and accuracy.

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## INTRODUCTION

The Research on Operations-Limiting Visual Extinction (RESOLVE) project is sponsored by the Department of Defense (DOD) and stems from a concern that visibility in the areas of the China Lake Naval Weapons Center (NWC), Edwards Air Force Base (AFB), and Fort Irwin National Training Center has declined over the years since these bases were established. Since NWC and Edwards are major and unique national weapons and aircraft test areas that rely on optical tracking as part of the test process, further degradation of visibility has the potential to hamper test activities affecting national security (Reference 1).

The objectives of RESOLVE are

- To understand the effect of present air pollution sources on visibility in the testing region airspace (R2508 airspace) and to identify the major pollutant sources and transport routes that contribute to visibility degradation.
- To determine baseline and spatial and temporal variability and trends for atmospheric visibility, aerosol characteristics, and related meteorological parameters in the study area, with special emphasis on selected locations at the military facilities.

These objectives will be met by conducting a monitoring program in the study area with both continuous and short-term (special study) activities. Continuous monitoring began in 1983 and will continue into 1985. The data collected will be analyzed to meet the above objectives.

Quality assurance concerns have been key factors in planning and implementing RESOLVE. From the project's initial conception, decisions have been guided by the requirements of many aspects of quality assurance. These aspects included (1) project organization, (2) network design and planning, (3) preliminary equipment preparation and testing, (4) network operation (data collection and processing), (5) internal quality control, and (6) external audit procedures.

This report focuses on the role and effect of quality assurance activities in the routine monitoring portion of the project. Data recovery statistics for the initial 10 months of operation are presented, along with precision and stability estimates for nephelometers and teloradiometers.

**PROJECT DESCRIPTION**

**ORGANIZATION**

The organization chart (Figure 1) indicates the roles of the many cooperating groups and interested parties participating in RESOLVE. DOD has assigned project coordination to NWC. The routine monitoring and some of the other aspects of RESOLVE are being managed by the Environmental Protection Agency's (EPA) Environmental Monitoring Systems Laboratory in Las Vegas (EMSL-LV). Much of the actual work is being performed by EMSL-LV or DOD contractors, subcontractors, and consultants, including Lockheed Engineering and Management Services Co., Inc. (LEMSCO), the University of California at Davis (UCD), Global Geochemistry Corporation (GGC), Rockwell International, Sonoma Technology, Inc., and Santa Fe Research, Inc.

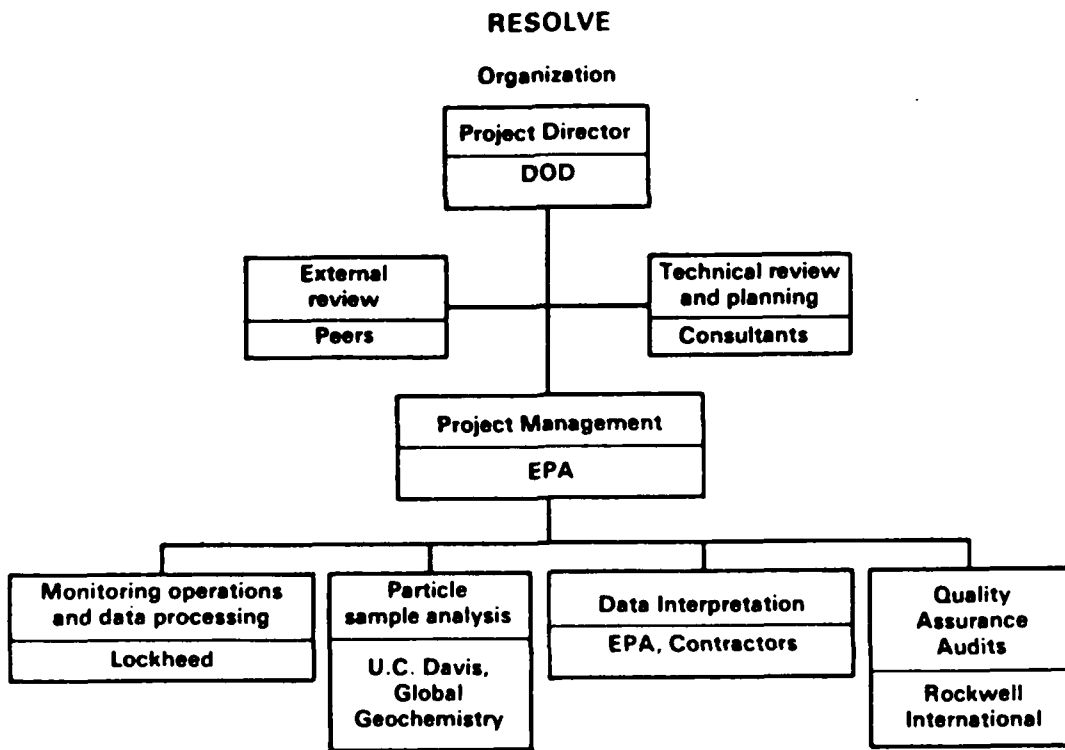


FIGURE 1. RESOLVE Organization.

A key feature of the project organization is the broad base of input for decision making. NWC has provided mechanisms for the technical consultants, EPA, UCD, and the research and technical community in general to be involved in

project planning. The project plan, distributed to the technical community for review in the early planning stages of the project, received numerous comments from the technical community and was revised accordingly. While the study is in process, NWC plans to issue a series of reports on a number of topics including preliminary data analysis results, quality assurance and standard operating procedures, and synoptic and historical meteorological analyses, among others.

## NETWORK DESIGN AND PLANNING

An appreciation of the geographic and air pollution characteristics on the project area (Figure 2) is important to understanding the monitoring approach. The southern California desert area, in the rain shadow of the Sierra Nevada and transverse mountain ranges, consists of low desert valleys separated by mountains. Mining, tourism, and military activities, with supporting residential and commercial activities centered in scattered small towns, characterize this generally unpopulated area. Except for the mining and tourism mentioned, the area has few local air pollution sources. However, due to their proximity, the Los Angeles urban area and the San Joaquin Valley agricultural and industrial areas influence visibility and air quality in the R2508 airspace (References 2 and 3). The mountains that form the western and southern borders of the desert serve to control the spread of pollutants from these areas. Polluted air masses must flow through the passes or go over the mountain tops as they move into the desert. Land to the north and east of the military facilities is largely vacant, and not expected to be a source of polluted air masses. However, dry lakes in the desert regions are a source of wind-blown dust and can contribute to localized visibility impairment under high wind conditions.

The design of the RESOLVE monitoring network is compatible both with networks proposed by the California Air Resources Board (CARB) and to the network being implemented by the multi-organization Subregional Cooperative Electric Utility, National Park Service, and Environmental Protection Agency Study (SCENES) in the desert southwest. In choosing monitoring station locations, study objectives, siting criteria, and budget restrictions were considered. Siting criteria require the site to be (1) representative of an area a minimum of 20 to 30 kilometers in radius, (2) either source or receptor oriented, (3) remote from local sources of particles, (4) on good access roads, and (5) near commercial power. A total of eight sites, listed in Table 1, and shown on Figure 2, were selected. Four of these China Lake NWC, Randsburg Wash NWC, Edwards AFB, and Fort Irwin are considered primary sites though they do not have identical instrumentation. The four primary, receptor-oriented sites will establish baseline visibility for the military facilities. Each of the primary sites has a history of earlier measurements.

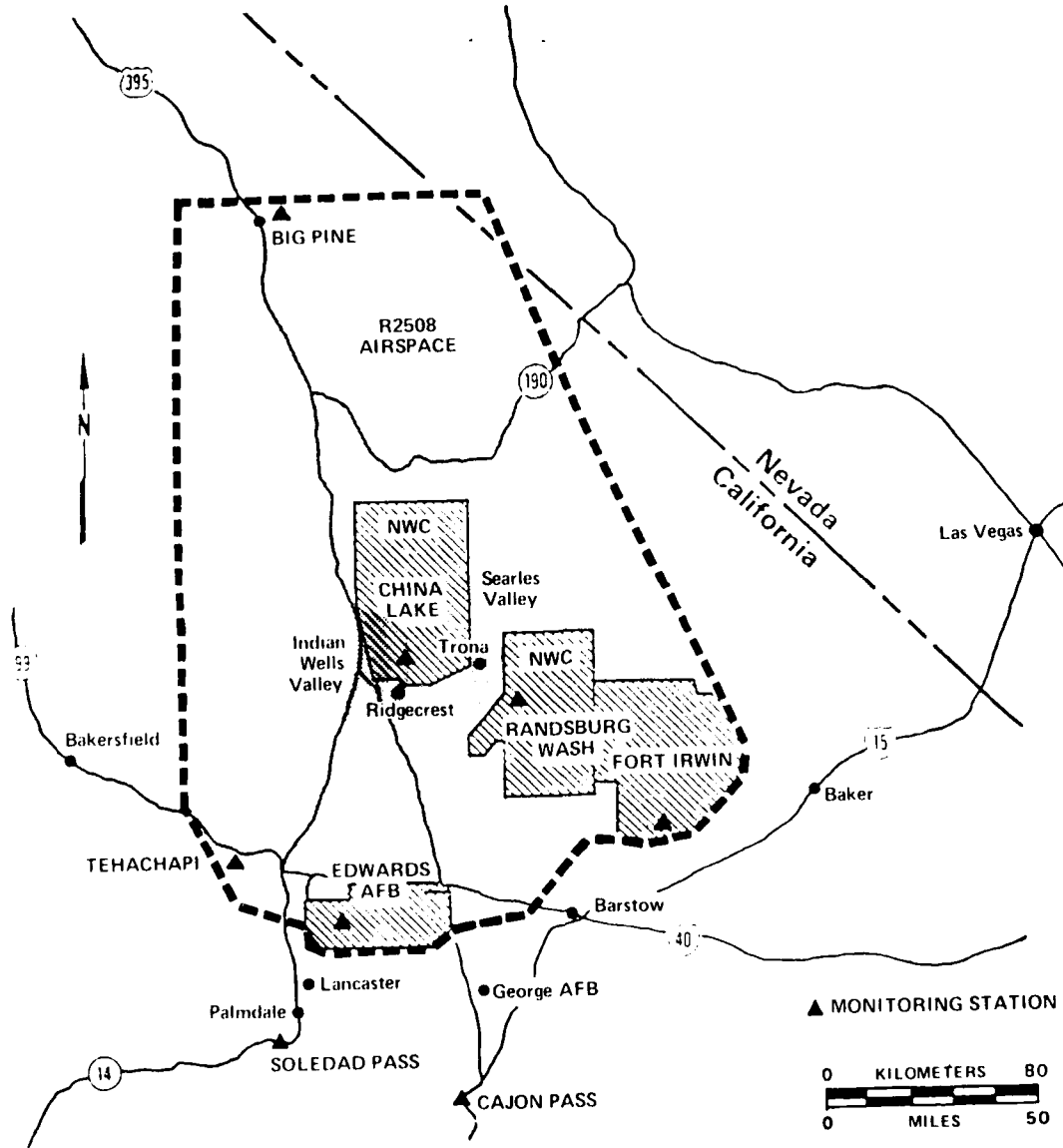


FIGURE 2. Map of RESOLVE Stations.

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TABLE 1. RESOLVE Monitoring Stations and Equipment.

| Equipment  | Monitoring stations |                |                           |            |          |                |              |            |       |
|--|---------------------|----------------|---------------------------|------------|----------|----------------|--------------|------------|-------|
|  | Edwards AFB         | China Lake NWC | Randsburg Wash NWC        | Fort Irwin | Big Pine | Tehachapi Pass | Soledad Pass | Cajon Pass | Total |
| Nephelometer   | 1                   | 1              | 1                         | 1          | 1        | 1              | 1            | 1          | 8     |
| Heated nephelometer  | 1 <sup>a</sup>      | 1 <sup>a</sup> |                           |            |          |                |              |            | 2     |
| Continuous teleradiometer  | 2                   | 1              |                           | 3          |          |                |              |            | 6     |
| Camera   | 2                   | 1              | 1                         | 3          |          |                |              |            | 7     |
| RESOLVE 2x4 particle sampler <sup>b</sup>                              | 1                   | 1              | 1                         | 1          |          | 1              | 1            | 1          | 7     |
| Dichotomous sampler  |                     | 1              |                           |            | 1        |                |              |            | 2     |
| DRUM <sup>c</sup> particle sampler                                     |                     |                | To be moved between sites |            |          |                |              |            | 4     |
| Wind speed, wind direction, temperature                                | 1                   | 1              | 1                         | 1          | 1        | 1              | 1            | 1          | 8     |
| Dewpoint   | 1                   | 1              | 1                         | 1          |          |                |              |            | 4     |
| Relative humidity  |                     |                |                           |            | 1        | 1              | 1            | 1          | 4     |
| Solar radiation  | 1 <sup>d</sup>      | 1 <sup>d</sup> |                           |            |          |                |              |            | 2     |
| Satellite data system  | 1                   | 1              | 1                         | 1          |          | 1              | 1            | 1          | 7     |
| Cassette tape data system  | 1                   | 1              | 1                         | 1          |          |                |              |            | 4     |
| Strip chart recorders  | 1                   | 1              | 1                         | 1          | 3        | 1              | 1            | 1          | 10    |
| Radiosonde (upper air wind speed, wind direction, temperature, and RH) | 1 <sup>d</sup>      | 1 <sup>d</sup> |                           |            |          |                |              |            | 2     |

<sup>a</sup> To be switched automatically between heated and ambient temperature inlets. These have been funded and provided to the study by the Western Oil and Gas Association (WOGA). Planned installation: August 1984.

<sup>b</sup> 2x4 refers to collection in two size ranges of a total of 4 simultaneous samples (1 total,  $d < 10 \mu\text{m}$ ; 3 fine,  $d < 2.5 \mu\text{m}$ ).

<sup>c</sup> Multistage rotating DRUM impactor.

<sup>d</sup> Not collocated with monitoring site. Operated by DOD personnel.

The other four sites are secondary, or source-oriented, with three located in key passes and one in the northern portion of the R2508 airspace. The three passes are Tehachapi Pass, to represent airflow from San Joaquin Valley, and Soledad and Cajon Passes, to represent the airflows from the Los Angeles basin. Two passes were selected to characterize the Los Angeles urban area aerosols because of the area's large size and inhomogeneous distribution of pollutant sources. In contrast, the southern part of the San Joaquin Valley contains fewer types of sources. The purpose of the Big Pine site is to determine visibility conditions and particulate characteristics in the northern portion of the R2508 airspace.

**EQUIPMENT, PREPARATION, AND TESTING**

Table 1 lists the monitoring equipment operating at each station. All sites have nephelometers, RESOLVE 2x4 (a collection in two size ranges of a total of four simultaneous samples (1 coarse,  $< 10 \mu\text{m}$ ; 3 fine,  $< 2.5 \mu\text{m}$ )) or Sierra dichotomous particle samplers, and meteorological sensors. The receptor sites have a second means of monitoring visibility, i.e., teleradiometer and/or camera. A number

of other measurements using heated nephelometers and Davis Rotating Universal Multistage (DRUM) samplers, radiosondes, and solar radiometers are made routinely at selected sites. In February 1984, DRUM samplers were placed at Soledad, Tehachapi, and Edwards. The fourth one will be used for special studies until the fall of 1984.

State-of-the-art satellite telemetry systems are used to process the continuous monitoring data at each site to hourly averages and standard deviations. These processed data are available and updated at least every 3 hours through the National Environmental Satellite facilities. The choice of satellite telemetry as the main data collection system with a cassette tape collection system as back up was a key decision with a number of ramifications. These ramifications include (1) data availability for review by a project scientist the day after they are collected, (2) processing of data at stations reducing work performed by data personnel, and (3) collection of data redundancy minimizing data loss caused by data system malfunction. Because instrument failures can be detected quickly, and a technician to remedy the situation, data recovery is improved.

In choosing equipment, the desirable qualities of standardization among sites and reliability were balanced against budget and equipment on hand from previous studies. In a number of cases, instruments were modified and then tested extensively before deployment to ensure reliable operation. For example, numerous Meteorology Research, Inc. (MRI) Model 1560 series and 1590 series nephelometers were on hand from earlier studies. To ensure uniform operating characteristics, all were rebuilt including the addition of 10-turn potentiometers to adjust zero and gain and a mechanical test device to provide a reliable check of instrument drift within the normal operating range. Modifications to the teleradiometers (MRI model 3030) eliminated data loss associated with filter turret wheel failure. These modifications were accomplished by anchoring the turret wheel so that only the green filter (550 nanometers) is in the light path. In addition, baffles were installed to minimize flare.

Considerable effort went into preparation of the RISOLVE 2x4 particle samplers that were found to be unreliable in initial tests. The 2x4 is a newly designed sampler that uses a group of previously well-tested components. The wind-insensitive 10-micrometer particle diameter inlet systems are commercially available. Cyclones provide the fine sample (diameter <2.5 micrometers) size cut. A total of four samples are collected simultaneously for each sampling period in these two size ranges (three fine samples and one total sample). Multiple fine samples were desired to provide simultaneous use of different filter materials to allow for elemental analysis and carbon analysis, and to provide a duplicate for quality assurance checking. Removable filter cassettes secure the filter in the samplers and are used to ship filters to and from the field, thus minimizing contamination resulting from handling under field conditions. The sampler is designed to operate for up to nine predetermined sample periods by rotating unused filters into the flow system. The sampler uses electronic pressure transducers and filter

position indicators to measure flow and filter information that is relayed with other data via satellite telemetry to EMSL-LV. Particle sampler operating status is then reviewed with other data. After some redesign and extensive modifications, because of earlier operational problems, the seven 2x4 samplers were operated side-by-side in a comparison test with two virtual impactors (Sierra Instruments Model 244 Dichotomous Sampler). These tests were used to evaluate sampler performance, eliminate defects, develop standard operating procedures, and develop precision information. A report that discusses the intercomparison results in detail is in preparation. To summarize, mass and elemental measurements have been inter-compared and found to agree satisfactorily, typically within 10% for the total samples and within 12% for the fine samples. Plans call for the evaluation of the 2x4 sampler to continue in the field, at China Lake NWC, where the 2x4 sampler will be operated routinely side-by-side with a CARB-operated dichotomous sampler.

### NETWORK OPERATION

With the exception of the 2x4 and DRUM particle samplers, network operations began in August 1983. The stations became fully operational in April 1984 and will continue operation through April 1985. After that date, operation of the stations will continue, but at a reduced level of effort, with emphasis on maintaining high data recovery at the primary stations. The data recovery target is 90%, computed for each site and instrument on a quarterly basis. The primary stations are expected to continue operating indefinitely. The secondary stations will be removed when they are no longer needed.

With the exception of the Big Pine site, the EMSL-LV support contractor, LEMSCO, is responsible for the routine operation of the monitoring network. This operation includes equipment and particle sampler servicing, calibrations, maintenance, repairs, data processing, quality control, and regular reporting. The Big Pine site is operated by Great Basin Unified Air Pollution Control District, with data processing for this site arranged by NWC. Because Big Pine's operation, data collection, and data processing are different from the other sites, it will not be included in the discussions that follow.

All LEMSCO and EPA personnel assigned to this project, except for the field operators, are located in Las Vegas. A full-time field operator is responsible for routine servicing and maintenance of the five southernmost stations. A part-time operator maintains the China Lake and Randsburg Wash stations.

The chemical analyses being performed on the 2x4 particle samples are described in Table 2. Gravimetric mass is determined for all but the quartz (carbon) analysis substrate filters. Every third day, for three primary sites, the total 2x4 particle samples and one of the fine filters are analyzed using proton-induced x-ray emissions (PIXE) and optical absorption (OAT). Analyses being performed for other sites, for the DRUM samples and the methods for selecting 35 days for which the

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optical analyses are to be performed are discussed elsewhere (Reference 1). UCD prepares the filters for elemental and mass analysis and performs particle sample analysis. GGC prepares the quartz filters and performs total and organic carbon analyses. The samples from the Big Pine and China Lake dichotomous samplers are weighed and analyzed by x-ray fluorescence (XRF) by CARB.

TABLE 2. RESOLVE 2x4 Sampler Filter Analyses.

| Filter number                                       | Size of particles on filter, $\mu\text{m}$ | Gravimetric mass | PIXE, <sup>a</sup> OAT <sup>b</sup>                              | Carbon <sup>c</sup>  | Quality control and special studies |
|---|--|------------------|--|--|-------------------------------------|
| China Lake NWC, Edwards AFB, Fort Irwin             |  |                  |  |  |                                     |
| 1   | > 10                                       | All filters      | Every third filter (day) plus 35 additional filters <sup>d</sup> |  |                                     |
| 2   | > 2.5                                      | All filters      | Every third filter (day) plus 35 additional filters <sup>d</sup> |  |                                     |
| 3   | > 2.5                                      |                  |  | Every third filter (day) plus 35 additional filters <sup>d</sup> |                                     |
| 4   | > 2.5                                      | All filters      |  |  | Selected filters                    |
| Tehachapi, Soledad Pass, Cajon Pass, Rambsburg Wash |  |                  |  |  |                                     |
| 1   | > 10                                       | All filters      | 75 filters <sup>d</sup>  |  |                                     |
| 2   | > 2.5                                      | All filters      | 75 filters <sup>d</sup>  |  |                                     |
| 3   | > 2.5                                      |                  |  | 75 filters <sup>d</sup>  |                                     |
| 4   | > 2.5                                      | All filters      |  |  | Selected filters                    |

<sup>a</sup> PIXE: Elemental analysis by proton induced x-ray emission technique.

<sup>b</sup> OAT: Light absorption and elemental carbon by optical absorption technique.

<sup>c</sup> Organic, elemental, and total.

<sup>d</sup> To be selected later based on the results of the routine analyses.

**INTERNAL QUALITY ASSURANCE**

Quality assurance activities are described in documents prepared by the various contractors. LEMSCO is responsible for monitoring and data processing, UCD is responsible for sample analysis for gravimetric mass and by PIXE and OAT, and GGC is responsible for sample analysis for total and organic carbon.

LEMSCO has prepared a detailed monitoring quality assurance manual including a standard operating procedures section. Topics of discussion include instrument operational checks, calibrations, zero checks, and preventive maintenance, logs and

other forms of documentation: chain of custody; and data control and validation. LEMSCO is responsible for processing data to engineering units and providing statistical and graphic summaries of the data. Data traceability and the validity of computer algorithms are also discussed in the quality assurance manual.

Instrument operational checks are performed on a weekly basis. Results from the checks are compared to warning and control limits specified for each instrument type. (These values typically are warning  $\pm 3$  to 10% and control  $\pm 10$  to 25%, depending on instrument type.) If a single value exceeds the warning limit, the instrument is adjusted. If two consecutive values exceed the warning limit or any value exceeds the control limit, the instrument is checked for malfunction and calibrated, and data are invalidated back to the last successful check. Summaries of some of the operational checks for nephelometer and teloradiometer are presented in the results section of this report.

Each particle sample analysis contractor has also provided a detailed analytical procedures manual including a quality control procedures section. Included in these manuals are discussions of the following: repeat analyses, laboratory and field blanks, analysis-system calibration, filter handling and storage procedures and environment, logs and other forms of documentation, and data control and validation. Analysis contractors will process data to engineering units. The elemental and gravimetric analysis contractor (UCD) also provides statistical and graphic summaries of these data. EMSL-LV provides these data for the other particle analysis data. The responsible organizations have prepared procedures that allow evaluation of data traceability and the validity of computer algorithms.

UCD has performed elemental analysis by x-ray methods, primarily by PIXE but including XRF since 1973. Of key importance is how to ensure that the quoted value for any element, sodium or heavier, can be traced back to an adequate standard. The process used has three components:

1. **System Design.** From the published values of x-ray cross sections, the areal density of elements can be established to  $\pm 15\%$ .
2. **System Calibration.** Thirty-two elements are available commercially in thin, weighed foils for calibration. Ten of these are analyzed in each run, calibrating the system to within  $\pm 15\%$ . Calibration to many standards reduces this to  $\pm 3\%$ , absolute.
3. **System Verifications.** (The numbers in parentheses give the number of samples involved in the last year.)
  - a. Internal
    - (1) Comparison with National Bureau of Standards and U.S. Geological Survey standards (20).

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- (2) PIXE to XRF comparisons (21).
  - (3) Comparison of same sample run each month (200)
  - (4) Sum of all elements versus mass (including H, C, and O) (45).
  - (5) Comparison of same sample run repeatedly (50).
- b. External
- (1) Informal intercomparisons (i.e., analytical and chemical) (40).
  - (2) Formal third party (i.e., Rockwell) (40).
  - (3) Published studies (x-ray spectrometer, EPA/Department of Energy, Visibility Impairment due to Sulphur Transport and Transformation in the atmosphere) (36).

In summary, over the past decade, an absolute accuracy to  $\pm 6\%$  over 42 elements has been achieved.

Determination of the gravimetric mass of samples collected on filters is non-trivial because it involves the comparison of pre- and post-weights differing by only a few percent. This difference is particularly true when the pre- and post-measurements occur 30 days apart (at UCD), and mass loadings in clean regions of the West often go below  $1 \mu\text{g}/\text{m}^3$  for the sub-2.5 micrometer size range.

UCD has developed an extensive 22-step protocol from filter manufacture to archiving samples, including three electrostatic de-excitations, 2-week mechanical relaxations, and other innovative techniques described in detail in the UCD quality assurance manual and summarized elsewhere (Reference 4). About 3500 tests were performed in the past 3 years as part of these protocols (14% of all samples), showing the following precisions in weighing.

|  |                         |
|--|-------------------------|
| Nuclepore 8.0 micrometer (apiezon coated),<br>47-millimeter diameter | 0.0 $\pm$ 5.7 microgram |
| Nuclepore 0.3 micrometer (uncoated),<br>47-millimeter diameter       | 0.2 $\pm$ 6.0 microgram |
| Teflon 3.0 micrometer (ringed),<br>25-millimeter diameter            | 0.7 $\pm$ 3.7 microgram |

These average to be about 0.0012% of the mass of the blank filter.

### EXTERNAL QUALITY ASSURANCE

The purpose of an external audit program is to provide an independent check on the adequacy of equipment, supplies, personnel, and procedures; to evaluate the

degree to which procedures are followed; and to provide an opportunity for remedial action when problems are identified. Rockwell International will perform five field audits for the seven southernmost sites and laboratory and overall system audits for LEMSCO, UCD, and GGC during the course of RESOLVE. Activities performed by Rockwell include sampler flow audits, calibrations, filter analysis audits, inspection of logs and other documents, review of procedures, and interviews of personnel. Details of these activities are discussed in Rockwell's audit protocols. Results from these activities are summarized in audit reports. For the first field audit, the mean percent difference for nephelometer accuracies at the seven sites was 1%. The teleradiometer mean percent difference for apparent contrast was -16%. Results from the subsequent audits are not yet available.

## RESULTS

Results of operational checks for nephelometer and teleradiometer are presented in this section. In the case of the nephelometer, the operational checks are analogous to determining precision by making repeated measurements of a standard of fixed value. Percent precision and accuracy are defined similarly using the equation

$$\text{Precision (or Accuracy)} = \left[ (Y_i - X_i) / X_i \right] \times 100$$

where

$Y_i$  = indicated value from  $i$ th check

$X_i$  = known value of check

For precision determination, the standards (clean air and Freon-12) may be the same as used in the calibration process. For an accuracy determination, the standard must be different from that used in the routine calibration (Freon-12 for the RESOLVE nephelometers). Thus, Freon-22 or a second bottle of Freon-12 and ideally a person other than the regular station operator would be used to establish nephelometer accuracy. It is not always practical to determine accuracy with separate personnel. However, Freon-22 is used routinely to check the performance of the RESOLVE nephelometers. This procedure has been termed a Freon-22 accuracy check.

Figures 3, 4, and 5 are plots of the mean and standard deviation of precision (or accuracy) calculated seasonally for each site for nephelometer-measured filtered clean air, Freon-12, and Freon-22. The precision values are determined for periods of valid data only. In addition, outliers were identified by Chauvenet's criterion and removed to avoid errors caused by transcription on other non-instrument-related problems. Clean air mean precisions (Figure 3) have a positive bias of 3 to 4%.

with typical standard deviations of about 5%. For Freon-12 (Figure 4) there is virtually no bias overall with standard deviations ranging from 1 to nearly 8% but typically less than 5%. There is a negative bias of approximately 8% for Freon-22 (Figure 5) with standard deviations ranging from 1 to 12%, though typically less than 5%. In many seasons, only one Freon-22 check was performed at each site (indicated on the graphs by a dot only).

These data indicate that the nephelometers tend to slightly overestimate scattering coefficient (by 3 to 4%) when it is near Rayleigh conditions, and that for conditions of high scattering coefficient there is little bias (i.e., excellent repeatability on a week-to-week basis) overall. Since data of most interest in RESOLVE are for days with visibilities ranging from average to highly impaired, these precision values are satisfactory. The accuracy data indicate a tendency to underestimate scattering coefficients by approximately 8% for days of somewhat worse than average visibility, but this tendency is nearly uniform on a site-to-site basis. Thus, though times of somewhat-worse-than-average visibility are underestimated slightly, variability from site to site is not large. This variability is consistent with Rockwell's audit results mentioned earlier.

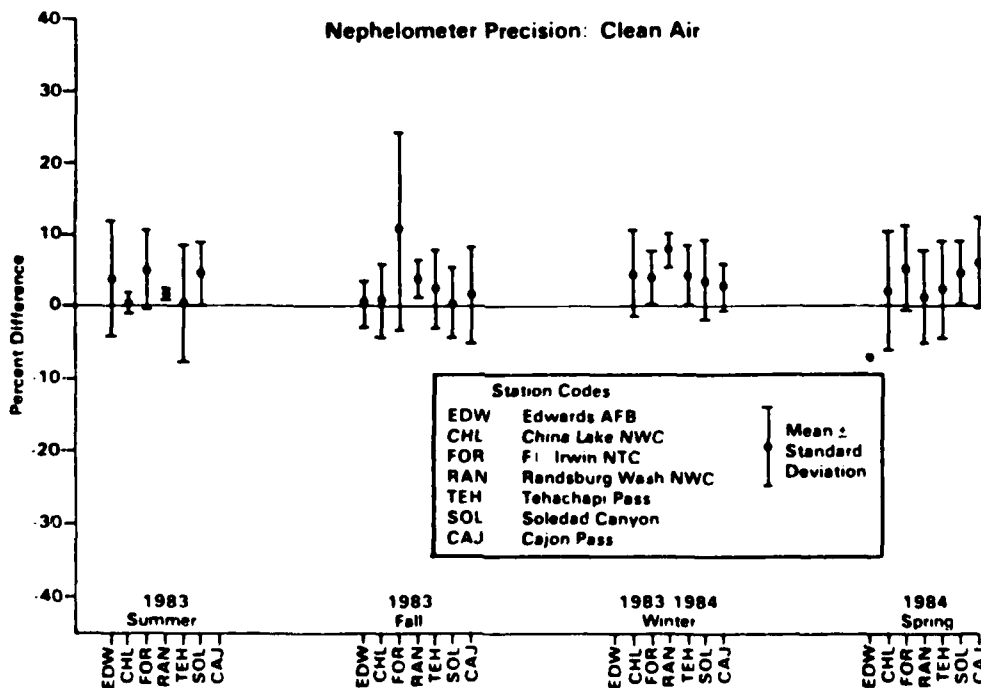


FIGURE 3. Nephelometer Precision Based on Clean Air.

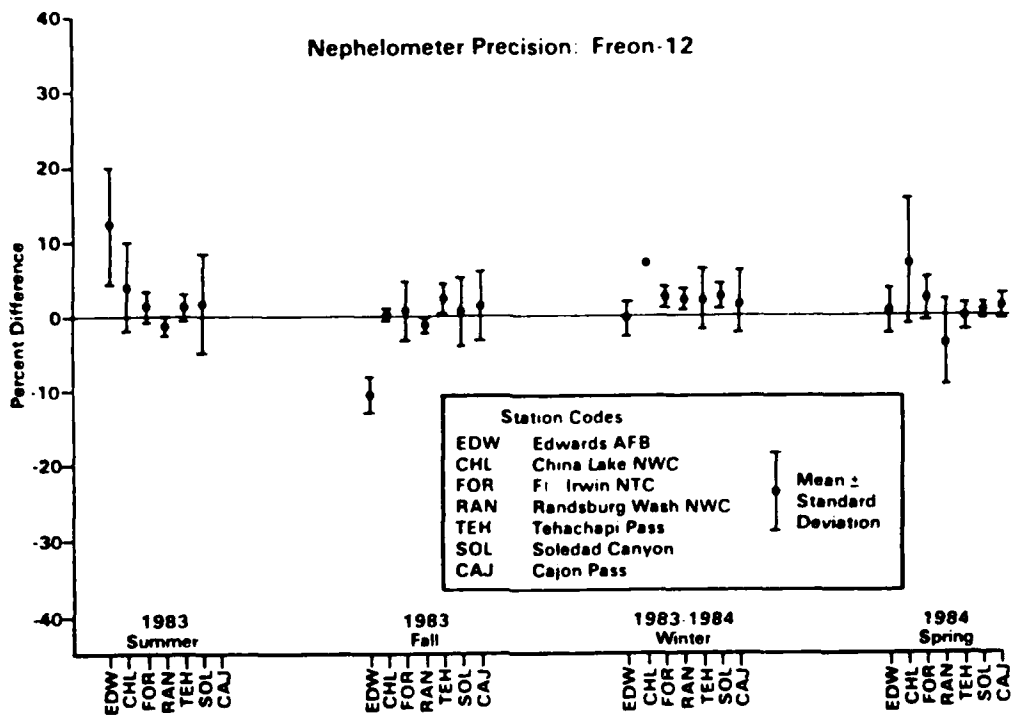


FIGURE 4. Nephelometer Precision Based on Freon-12.

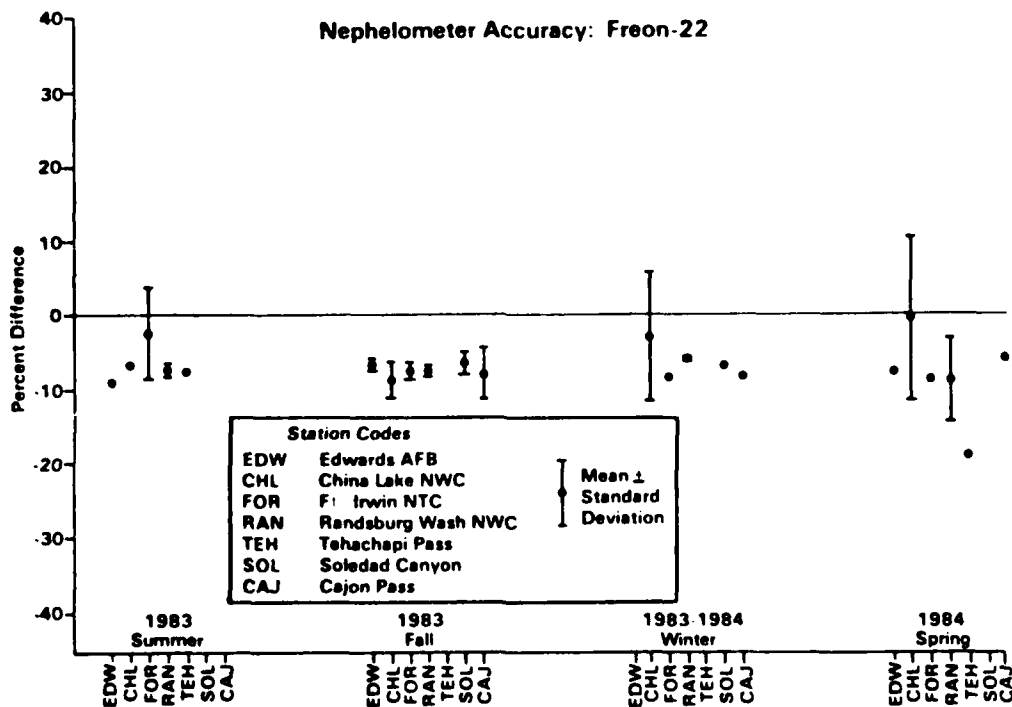


FIGURE 5. Nephelometer Accuracy Based on Freon-22.

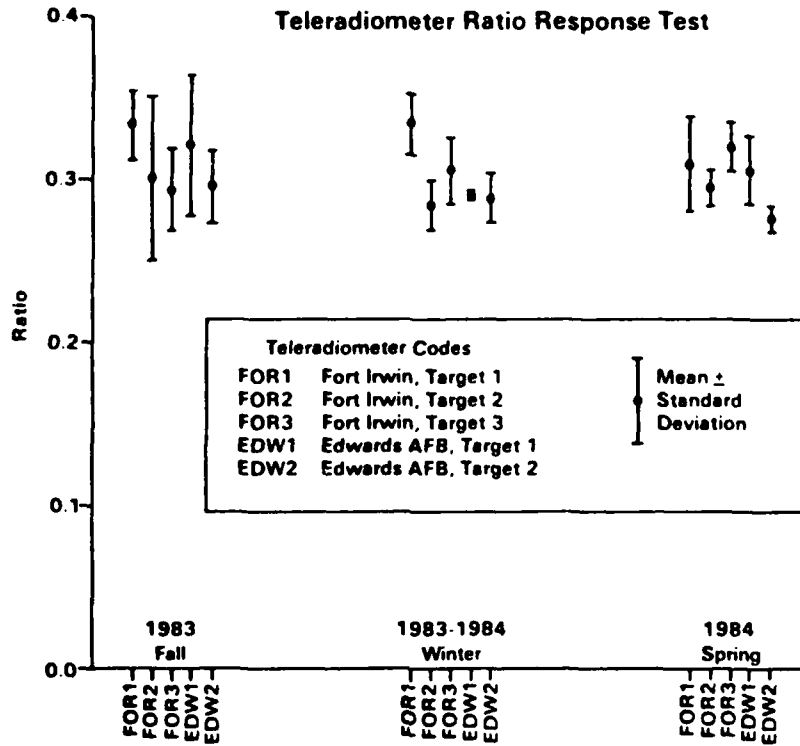


FIGURE 6. Teleradiometer Ratio Test Results.

A true precision check for a teleradiometer is not easily accomplished in the field, so a substitute has been devised using identical sets of white and gray cards at two of the teleradiometer sites. Approximately every month, each of the cards in turn is placed in front of the teleradiometers and radiance values recorded. Since lighting conditions vary each time the cards are used, the absolute radiances vary. However, the ratio of the radiances is expected to remain constant. Mean ratios and standard deviations for five teleradiometers and three seasons available are shown in Figure 6. The ratios vary from 0.275 to 0.330 with typical values of 0.3 and standard deviations of approximately 10% of this value. While it does not provide an estimate of precision or accuracy, this technique does indicate gross changes in teleradiometer performance, both from month to month and from site to site.

A simple, overall measure of the internal comparability of the fine particle samples collected by the 2x4 samplers is determined by comparing the gravimetrically measured mass routinely analyzed on two of the three fine samples. Correlation analysis of the fine mass measured on the two samples for each of the seven samplers for the first 2 months of operation results in a mean correlation coefficient,  $r$ , of 0.95 with a range from  $r = 0.90$  to  $r = 1.00$ . Thus, the simultaneous fine samples are highly correlated as desired.

Percent data recovery is an index that, when used in context with precision and accuracy data and data validation procedures, can be used to quantify the overall success of a measurement program. Percent data recovery for a continuous instrument is computed monthly by dividing the number of valid hourly averages by the total number of hours in the month and multiplying by 100. For teleradiometer data, measured during 8 daylight hours only (0800 to 1600 inclusive), data recovery is computed in the same manner, but using daylight measurement hours rather than all hours. For particle samples, collected on a daily basis, data recovery is calculated similarly based on the total number of days in a month. A summary of data recovery values for the first 10 months of RESOLVE is presented in Table 3. The values represent the 10-month averages for each site by parameter, for each site overall, and for each parameter overall. A review of the data recovery values shows them to be generally better than 90% with the grand average of all parameters and all sites at 91%. These high-data recovery values are attributed to thorough quality control and the use of satellite telemetry with rapid data review. At Tehachapi, the site with the lowest data recovery (84%), the reduced data recovery is attributed to unusually high winds blowing the meteorological tower over on two occasions. The tower anchors have since been redesigned. The DRUM particle sampler is unique among the instruments listed, as it is the only one not incorporated in the satellite telemetry system. The data recoveries for the DRUM samplers are the lowest at 80%. The cause of this low-data recovery is attributed to the lack of sufficient replacement drum substrates immediately after deployment and the *problem has since been remedied*. Thus, future DRUM data recoveries are expected to approach 90 to 100% because the sampler has proven to be easy to operate, reliable, and rugged.

TABLE 3. RESOLVE Percent Data Recovery by Instrument and Station for August 1983 Through May 1984.

| Equipment                                 | Edwards AFB | China Lake SWC | Randsburg Wash NWC | Fort Irwin | Tehachapi Pass | Soledad Pass | Cajon Pass | Average |
|---|-------------|----------------|--------------------|------------|----------------|--------------|------------|---------|
| Nephelometer Continuous teleradiometer    | 92          | 91             | 90                 | 90         | 93             | 96           | 93         | 92      |
| RESOLVE 2x4 particle sampler <sup>a</sup> | 97          | 96             | N A                | 95         | N A            | N A          | N A        | 96      |
| DRUM particle sampler <sup>b</sup>        | 78          | 100            | 100                | 77         | 95             | 94           | 98         | 92      |
| Wind speed, wind direction                | 78          | N A            | N A                | N A        | 86             | 75           | N A        | 80      |
| Temperature                               | 94          | 92             | 94                 | 90         | 71             | 98           | 89         | 90      |
| Dew point                                 | 98          | 96             | 98                 | 95         | 91             | 95           | 91         | 95      |
| Relative humidity                         | 96          | 96             | 97                 | 95         | N A            | N A          | N A        | 96      |
| Average                                   | N A         | N A            | N A                | N A        | 70             | 86           | 81         | 83      |
|   | 90          | 95             | 96                 | 90         | 84             | 91           | 90         | 91      |

N A - not applicable.

<sup>a</sup> Operations initiated in April 1984.

<sup>b</sup> Operations initiated in February 1984.

## SUMMARY AND CONCLUSIONS

Quality assurance has been of prime concern for the RESOLVE monitoring program from its inception through each stage of the program. Instruments were selected, and in some cases modified and tested, with the goal of achieving reliable measurements with high-data recovery. In particular, the primary data recording system operates by transmitting data values via satellite many times daily to the project's main computer facilities. This prompt availability allows preliminary review of the previous day's data for instrument malfunctions. Thus far, this monitoring design has resulted in better than 90% data recovery.

Extensive operations and quality control procedure documents were prepared and are being followed for every phase of the program. These include numerous performance checking procedures, the results of which, in most cases, can be interpreted in terms of precision and accuracy. Preliminary results of such tests for the nephelometer indicate results with precision and accuracy of better than 10%. Teleradiometer measurements of contrast show variability of approximately 10%. Overall accuracy for elemental analysis of particle samples is generally better than 10%, as is gravimetrically determined mass on filter samples.

Much remains to be accomplished with regard to assessing the overall precision and accuracy of values measured by this program. The results of flow audits must be incorporated into the sampling precision estimates for particle-related measurements. Where feasible, the bias associated with accuracy checks can be used to adjust data values. Finally, further quality control and external quality assurance audit results must be compiled and evaluated.

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