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A systematic, empirically based research approach that combines environmental monitoring and field experimentation was previously proposed to quantify and characterize emissions from testing and training at the National Training Center, Ft. Irwin. The purpose of the research is to assist the Department of Defense in assessing contributions from training activities in a variety of environmental conditions to local and regional PM levels and off-post regional visibility effects.

This document has been assembled to describe the quality assurance plan for data collection for the different components of the proposed research.

Quality control (QC) and quality auditing establish the precision, accuracy, and validity of measured values. Quality assurance integrates quality control, quality auditing, measurement method validation, and sample validation into the measurement process. The results of quality assurance are data values with specified precisions, accuracies, and validities.

Quality control (QC) is intended to prevent, identify, correct, and define the consequences of difficulties that might affect the precision and accuracy, and or validity of the measurements.

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QUALITY ASSURANCE PLAN FOR DATA COLLECTION

CHARACTERIZING AND QUANTIFYING LOCAL AND REGIONAL PARTICULATE MATTER EMISSIONS FROM DEPARTMENT OF DEFENSE INSTALLATIONS

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Table of Contents

Q/A Plan:

CHARACTERIZING AND QUANTIFYING LOCAL AND REGIONAL PARTICULATE MATTER EMISSIONS FROM DEPARTMENT OF DEFENSE INSTALLATIONS.

A systematic, empirically based research approach that combines environmental monitoring and field experimentation was previously proposed to quantify and characterize emissions from testing and training at the National Training Center, Ft. Irwin. The purpose of the research is to assist the Department of Defense in assessing contributions from training activities in a variety of environmental conditions to local and regional PM levels and off-post regional visibility effects. The following research components were proposed to meet objectives stated within Statement of Need CPSON-01-03:

- Contributions from dust and other sources will be measured during a 1-year ambient air quality monitoring program at upwind and downwind boundary flux sites, combined with 14 days of intensive monitoring during periods of active training. Selected samples (~30%) will be chemically analyzed and relative contributions from identified sources will be apportioned using the Chemical Mass Balance (CMB) receptor model.
- An emission factor database will be developed using upwind-downwind monitoring methods to measure vehicle-generated emissions using fast-response instrumentation. These tests will be carried out for select vehicles on a variety of surface types. In addition, a newly developed on-vehicle measurement technique for characterizing dust plumes will be used to establish a relationship between these measurements and the upwind-downwind flux measurements, thereby allowing on-vehicle measurements to be used as a surrogate for upwind-downwind monitoring. This will provide an economical means to expand the spatial coverage for defining surface emission potential and estimating emission levels.
- Potential long-range transport of the emitted PM will be assessed from field experiments designed to establish the relationship between the horizontal flux of dust emitted by vehicles in the near-field and its vertical flux component. Accurate estimation of vertical flux is required for dispersion modeling. This will be accomplished using upwind and near- and far-downwind sampling with towers instrumented with real-time monitors to measure vertical concentration profiles, particle size distributions, meteorological conditions, and the deposition flux between the towers. A mass balance approach will be used to define the ratio of the horizontal to vertical flux.
- A complimentary NSF-funded research project will allow us to identify a suitable algorithm for wind-blown dust. In addition, a portable wind tunnel study will be carried out to define military vehicle disturbance effects on soil and surface properties and quantify the effects on dust emission potential. Disturbance effects will be quantified by comparing wind tunnel derived vertical dust emission fluxes measured on a control plot against those measured on the disturbance plots. Comparing dust fluxes measured post-disturbance in the first and third year will assess recovery potential.

- Potential visibility degradation off-post will be determined with an intensive field measurement campaign utilizing *in situ* sensors to measure the light-absorption (photoacoustic method), light scattering (nephelometer), and the total extinction (cavity ring extinction meter) caused by aerosols exiting the post. This will be combined with lidar (light detection and ranging) measurements to describe the vertical and horizontal characteristics and flux of the aerosol plume exiting the installation. These data can be used to reconcile the emission inventory estimates with dispersion model estimates.

This document has been assembled to describe the quality assurance plan for data collection for the different components of the proposed research.

Quality control (QC) and quality auditing establish the precision, accuracy, and validity of measured values. Quality assurance integrates quality control, quality auditing, measurement method validation, and sample validation into the measurement process. The results of quality assurance are data values with specified precisions, accuracies, and validities.

Quality control (QC) is intended to prevent, identify, correct, and define the consequences of difficulties that might affect the precision and accuracy, and or validity of the measurements.

The quality auditing function consists of systems and performance audits. The systems audit includes a review of the operational and QC procedures to assess whether they are adequate to assure valid data that meet the specified levels of accuracy and precision. It also examines all phases of the measurement activity to determine that procedures are followed and that operators are properly trained. Performance audits establish whether the predetermined specifications are achieved in practice. For analytical procedures (e.g., identification of particulate chemistry using x-ray fluorescence) the performance audits challenge the measurement/analysis systems with known transfer standards traceable to primary standards. For instruments that operate *in situ* to measure the quantities of interest (e.g., light absorption by photoacoustic methods) individual calibration is required in the field or the lab with a standard prior to, and again, following recovery from the field.

Both system and performance audits are performed on the analytical instruments (e.g., x-ray fluorescence, automated colorimeter) in DRI's Environmental Analysis Facility on an annual basis to assure data quality. Auditors acquire and review the standard operating procedures and examine all phases of measurement activities to assure that procedures are followed and that operators are properly trained.

For laboratory performance audits, both thin-film standards and laboratory-spiked filters are submitted to independent laboratories for x-ray fluorescence, ion chromatographic, automated colorimetric, and carbon analyses.

1 CHARACTERIZATION AND QUANTIFICATION OF REGIONAL PARTICULATE MATTER TRANSPORT.

The Desert Research Institute has performed numerous air quality research projects that require the implementation and usage of a rigorous Quality Assurance – Quality Control program. The programmatic approach used by the DRI is presented here in brief, but detailed format. Full documentation, such as Standard Operating Procedure Manuals are available upon request for standard monitoring and analytical instruments.

1.1 Ambient Sampling and Analysis

Standard Operating Procedures (SOPs)

Standard operating procedures (SOPs) codify the actions that are taken to implement a measurement process over a specified time period. State-of-the-art scientific information is incorporated into the SOP with each revision. SOPs include the following elements:

1. A brief summary of the measurement method, its principles of operation, its expected accuracy and precision, and the assumptions that must be met for it to be valid.
2. A list of material, equipment, reagents, and suppliers. Specifications are given for each expendable item and its storage location.
3. A general traceability path, the designation of primary standards or reference material, tolerances for transfer standards, and a schedule for transfer standard verification.
4. Start up, routine, and shut down operating procedures and an abbreviated checklist.
5. Copies of data forms with examples of filled out forms.
6. Routine maintenance schedules, maintenance procedures, and troubleshooting tips.
7. Internal calibration and performance testing procedures and schedules.
8. External performance audit schedules.
9. References to relevant literature and related standard operating procedures.

Samplers: The Sequential Gas Sampler

The instrument proposed for ambient particulate matter sampling is the Sequential Gas Sampler (SGS). Air enters the size selective inlet of the SGS, and flows into the conical plenum where filter holders are inserted into the base. The air flows through two of twelve possible filter packs, then through open solenoid valves, differential pressure flow controllers, ball valves, and flow rate indicator orifices to a GAST carbon vane pump. This type of pump has sufficient capacity to pull between 50 to 60 lpm through most filter packs and enough additional flow through the makeup-air port to produce a total flow rate of 113 lpm.

The differential pressure flow controllers maintain constant pressure, and therefore a constant flow rate, across ball valves for the sampling ports containing filters. This is needed because of the increased resistance caused by filter loading during sampling. As the filter loads up, the pressure drop across this valve decreases which sends a signal to the valve to open further and allow more air to pass through. This then equalizes the pressure across the valve. A separate valve controls the makeup-air flow rate.

The filter holders (Savillex-style) are open-faced and accommodate 47 mm diameter filters. Labels with ID numbers for the filters are attached to the filter holders when the filters are loaded. Plugs for the holders are provided to block the flow when holders are not used.

Passive deposition occurs when particles deposit on and gases are absorbed by filters prior to and after sampling. Field blanks are used to quantify this bias, which is usually less than 30 μg of particle mass per filter.

A Dwyer 0 to 100 SCFH rotameter is used to set and verify flow rates through the filter packs. It is fitted with Tygon tubing and a number 9.5 rubber stopper adapter that fits into filter holder receptacle. A Dwyer 0 to 400 SCFH rotameter is used to measure the makeup-air flow rate and to verify the total flow rate into the inlet.

The transfer standards for flow rates are the rotameters. They are all calibrated before use against a positive displacement Roots meter, model 1.5M125. Elapsed time indicators are checked against a stopwatch.

Flow rate performance checks are made monthly.

An independent auditor performs audits of flow rates with independent standards on a regular schedule, usually twice a year.

Maintenance

1. Pump exhaust stream filters are replaced every six months.
2. Size selective inlets are cleaned every six months or as needed.
3. Plenums are cleaned at the beginning and end of the sampling program.
4. Replace the "O"-rings in the filter ports of the plenum base annually.

Filters

The filter holders are made by Savillex of PFA Teflon to minimize their reaction with the sample and contain redesigned filter backing trays that reduced flow restriction and provide uniform deposition. Filters that are used include PTFE Teflon membranes (e.g., Gelman (Ann Arbor, MI) polyolefin ringed, 2.0 μm pore size, (#R2PJ047)) for gravimetric and x-ray fluorescence analysis); pre-fired quartz fiber filters (e.g., Pallflex (#2500QAOT-UP)) for soluble ion and carbon analyses.

Filter Sample Custody

A sample is considered in custody when it is received by the DRI-EAF receiving department from an official package courier or DRI staff member. At this time it is logged into the log book, a chain-of-custody form is initiated, and the samples are stored appropriately. Before storage a visual inspection is carried out to note any signs of damage and/or tampering, etc. If necessary, a review will be initiated to determine if the damage compromised the integrity and/or quality of the sample.

Upon analysis the sample identification number is recorded both in the written log book for each instrument and in a coded file created for that analysis. The sample number serves as a tracking number, as does the file code.

1.2 Chemical Mass Balance (CMB) Receptor Model Application and Validation Protocols

The DRI has used the CMB receptor model to identify and apportion the relative contributions of particulate matter to observed ambient levels for a host of air quality studies. The DRI applies in all cases a well-established series of validation protocols to the receptor modeling process. These protocols are briefly reviewed in this plan. The full discussions upon which the DRI protocols are based are presented in Watson *et al.* (1991).

Initial tests with different combinations of source profiles are performed to determine which profiles best explain the ambient data and the robustness of the results with respect to choice of source profiles. The tests are done using the average mass concentrations of each species based on the samples collected and their root mean squared uncertainties. CMB performance measurements are examined to determine how well the ambient concentrations are explained by the CMB source contribution estimates. The results of these initial trials are used as guidance in CMB analysis of the entire sample set. The results of the test source apportionments are presented as a series of trials representing different combinations of source profiles.

Three performance measures generated by the CMB model, the R SQUARE, the CHI SQUARE, and the PERCENT MASS are examined from each CMB model run to assess the applicability of the chosen source profiles. The R SQUARE is the fraction of the variance in the measured concentrations accounted for by the variance in the calculated species concentrations. Values of R SQUARE greater than 0.9 indicate a good fit to the measured data. CHI SQUARE represents the weighted sum of the squares of the differences between calculated and measured species concentrations. Values between one and two indicate acceptable fits; values less than one indicates very good fits to the data. PERCENT MASS is the total mass accounted for by the source contribution estimates. Values between 80 and 120% are considered acceptable.

One of the most important assumptions of the CMB model (Watson *et al.* 1984) is that the source profiles are linearly independent (i.e., they are statistically different). The degree to which this assumption can be met in practice depends to a large extent on the types and quality of chemical measurements made at the sources and receptor. The CMB model has been subjected to a number of tests to determine its ability to tolerate deviations from the model assumptions (e.g., Watson 1979, Gordon *et al.* 1981, Henry 1982 1992, Currie *et al.* 1984, Dzubay *et al.* 1984, DeCesar *et al.* 1985, Lowenthal *et al.* 1992). The impacts of collinearities among source profiles vary from case to case. These collinearities tend to inflate the variances of the source contribution estimates. The sensitivity analysis is used to determine if there are significant collinearity problems.

2 REGIONAL VISIBILITY DEGRADATION DUE TO THE EMISSION OF VISIBILITY DEGRADING AEROSOL (VDA).

2.1 Measurement of the Emission of Visibility Degrading Aerosol (VDA)

The measurement of the emissions of VDA is accomplished by measuring VDA concentrations and wind velocity vectors in both upwind and downwind flux planes. Thereby, VDA fluxes into and out of the post can be determined, their difference corresponds to the VDA flux originating within the NTC area.

VDA optical properties including light absorption, scattering, and extinction are measured at one point within the flux plane by real time, point-measurement instruments. While these instruments yield time-resolved data with good accuracy and precision, one measurement location does not adequately represent the whole flux plane. Remote Measurements of VDA optical properties can provide coverage of the complete flux plane, but generally lack adequate absolute calibration. As our remote measurements include the location of our point-measurement instrumentation, they can be accurately calibrated with the *in situ* data, yielding quality assured optical data over the complete flux plane. Quality assurance of the individual measurement components is discussed in the following sections.

Point Measurements

While the point measurement of the light absorption and scattering components of optical extinction is routinely performed, the accuracy of scattering measurements is often poorly defined and the accuracy of light absorption measurements is practically unknown. To improve this situation our group at DRI has very recently developed a cluster of three instruments for the measurement of light absorption, scattering and extinction under sponsorship from NSF's Major Research Instrumentation program. The essential quality assurance feature of this instrument cluster is the point measurement of optical extinction down to the Rayleigh level. This allows us, for the first time, to check if measured scattering and absorption add up to the measured extinction, providing a stringent test of instrument accuracy. Measurement precision is obtained by analyzing the statistics of the calibration measurements. In addition, each of the three instruments incorporates significant advances in measurement accuracy and precision over the previous state-of-the-art. Well-trained DRI personnel will operate all three *in situ* instruments in accordance to their standard operating procedures (SOPs) to assure data integrity and accuracy.

<u>Aerosol Light Absorption</u>

Aerosol light absorption is measured by the DRI photoacoustic (PA) instrument (Arnott *et al.* 1999). This instrument performs a direct, first principle, *in situ* measurement of aerosol light absorption, completely avoiding the many artifacts inherent in the measurement of light absorption on filter-collected aerosol particles. The DRI PA instrument has successfully been used in several field studies (e.g., Moosmüller *et al.* 1998). Its accuracy is established by absolute calibration with a light absorbing gas. The details of this calibration procedure have been described by Arnott *et al.* (2000). Once the instrument is calibrated, the quality of the field data can be evaluated by making sure that the instrument is operating correctly. Correct operation is indicated when the phase of the signal is close to zero. The instrument can also be evaluated for alignment accuracy by placing a particle filter over the inlet and confirming that the aerosol light absorption signal is a random value with magnitude less than the equivalent light absorption produced by background sound and electronic noise. The magnitude of the noise-equivalent light absorption signal can also be evaluated to ensure that noise coupling is minimized. The instrument is housed in an acoustically-quiet enclosure, and the sample lines are equipped with acoustic bandstop filters to reduce ambient noise coupling.

Aerosol Light Scattering

Aerosol light scattering is measured with an integrating nephelometer. This instrument is calibrated with two calibration gases with well-known scattering properties (Horvath and Kaller 1994). This calibration yields both instrument offset and gain, thereby directly relating nephelometer raw signal to aerosol scattering (e.g., Charlson *et al.* 1967, Anderson *et al.* 1996). As the calibration process is fully automated and computer controlled it will be repeated at least daily for quality assurance and possibly re-calibration purposes.

Aerosol Light Extinction

Aerosol light extinction is measured with a novel extinction instrument that folds several tens of kilometers of optical path into a one-meter length optical cavity. It determines extinction by measuring the exponential decay of the optical power contained in the cavity. Calibration of the instrument is achieved by introducing a gas with well-known scattering extinction into the cavity. This calibration procedure determines the contribution of the instrument mirrors to the measured extinction yielding the offset of atmospheric extinction measurements. As the calibration process is fully automated and computer controlled it will be repeated at least daily for quality assurance and possibly re-calibration purposes.

Remote Measurements

Holographic Airborne Rotating Lidar (HARLIE) VDA Measurements

HARLIE measures range resolved atmospheric backscatter profile along a 45° (half angle) conical scan at a wavelength of 1064 nm. A 100 nanosec pulsed laser runs at a 5 kHz repetition rate. A photon-counting receiver sums counts for 100 milliseconds (500 laser shots) into 1000 × 200 nanosecond (30 m) range bins or 1000 × 500 nanosecond (75 m) bins. Each data record is recorded on removable magnetic media as a string of floating point values with 100 bytes of header information including all system settings, detector temperature, GPS data, and scan angle. The azimuth scan angle is adjustable from 0 to 30 r.p.m. Identification of aerosol plumes, background aerosols and their velocity vectors are the most important of this project's objectives along with quantifying the spatial (horizontal and vertical) extent of aerosol features. Quantifying aerosol extinction is also desired.

Prior to further analysis data are displayed both in real-time as well as in post-processing as false color 2-D images of range-square corrected, background corrected subtracted signals as a functions of range versus time (azimuth or scan angle). This display provides a convenient and quick method to screen for obvious errors or defects including:

1. Missing or blank data (dropouts) are seen as black areas. Small dropouts are expected occasionally due to operation of the safety radar interlock and the asynchronous operation of the data system I/O operations. Large dropouts would indicate problems such as a cover in place or obstruction to the laser beam or other system malfunction.
2. Detector saturation, which is indicated by missing or very weak signal following a very strong signal spike, usually in the near field or from optically thick low clouds. Saturation is distinguishable from shadows (caused by optically thick clouds) because the detector will recover from saturation within several microseconds.
3. Ringing that occurs after strong signal spikes is caused by an impedence mismatch in the detector electronics.
4. Laser after-pulsing is seen as atmospheric structure repeated with range, typically ~100 μsec following the first occurrence. This indicates an improperly adjusted laser.
5. Grounds loops can be seen as artificially constant or repeating structures, either in the vertical or horizontal axis, and may drift with time causing diagonal features on the display.

Having a real-time interpretable display means that most problems can be identified and corrected early, thus avoiding large detrimental data voids.

The instrument location is determined using the embedded GPS receiver. This provides a 10 m accuracy.

Instrument pointing knowledge has several components. One is the accuracy in pointing the rotation axis. The axis is aligned with one axis of the instrument housing (approximately a cube) to approximately 1 mrad accuracy. The instrument is first positioned with the rotation axis vertical by using a bubble level mounted on the instrument to an accuracy of approximately 1°.

The azimuth pointing knowledge has two components, alignment of the instrument 0° heading with true north, and calibration of the scan angle home position marker with the instrument housing along with placement of the holographic optical element (HOE) within the scanner assembly. Manual alignment of the USGS magnetic declination data gives about a 1° accuracy. Higher accuracy if required can be achieved using a theodolite with existing geographic target or manually placed targets located with a differential GPS system and optical reflectors placed on HARLIE. This can improve azimuthal pointing to 1 mrad accuracy. The scanner home location is established at the beginning of each continuous data acquisition run, to a measured accuracy of 10 μrad. Having no encoder, position is established by counting motor steps and calculating the angles from the known gear ratio. Accuracy to one part in 65 million (of 360°) over a 24-hour period has been established through laboratory testing.

Range errors have a constant offset error of ±1 range bin (30 m) and a relative (bin to bin) accuracy determined by the crystal quartz time base in the data system clock. This accuracy is better than 1 part in 10^7 over each profile, or 3 mm.

Aerosol backscatter coefficient calibration will be established prior to and after field measurements by comparison to simultaneous 355 nm lidar measurements of cirrus clouds under otherwise clear tropospheric conditions at NASA-Goddard Space Flight Center. Cirrus clouds are spectrally very flat and 355 nm lidar is easily calibrated using the strong Rayleigh scattering returns inherent in its signals. Both the 355 nm and the 1064 nm signal need to be corrected for Rayleigh and aerosol extinction to obtain calibrated aerosol backscatter coefficients at their respective wavelengths. Rayleigh coefficients are calculated using temperature profiles measured by radiosonde at nearby BW1 airport. This process should yield accuracies of ~5% based on previous experience with other lidars at NASA-Goddard.

Aerosol extinction coefficients will be calibrated against *in situ* extinction meter, nephelometer, and photoacoustic instrument at the field site. Extinction to backscatter ratios will be assumed constant over the field site and during periods between calibrations.

Random error bars will be assigned to data based solely on Poison statistics inherent in the photon counting process of the lidar receiver.

Lidar Wind Velocity Measurements

In addition to the detection and measurement of aerosols by the analysis of lidar backscatter, the rotary scan feature of HARLIE's operation tracks the motion of clouds and clumps of aerosol-laden air across the conical "field of regard" of the instrument. Two systems of data analysis have been developed at NASA-Goddard and Utah State University (Sanders *et al.* 2000) for visualizing wind motion, and determining the wind velocity and direction at any altitude where clouds and aerosols are present. The general technique of cross-beam lidar tracking of aerosols and clouds has been used by many researchers since its introduction at the University of Wisconsin in the 1970s (Eloranta *et al.* 1975). The uniqueness of the HARLIE method lies in the periodic conical scan, which enables successive images of water and aerosol clouds to be analyzed in terms of wind direction and speed. Wind velocities in the range of 1 m s^{-1} to 30 m s^{-1} are measured with an accuracy of 0.5 m s^{-1} by HARLIE, at lidar ranges as great as 15 kilometers in the case of vertical orientation of the HARLIE cone. Substantially greater ranges will be reached in the proposed program, by virtue of the "tilt-scan" mode in which the HARLIE axis is tilted to an elevation angle of 45°. This provides access to both the vertical and near-horizontal lines of sight and all angles in between. It enables quantitative wind velocity measurements close to the ground, and thereby provides direct comparison with *in situ* wind velocity monitors (i.e., anemometers) that will be mounted on towers for this study.

In addition, vertical wind profiles will be measured with a collocated Remtech PA1-LRNT SODAR (sound detection and ranging) and compared with the lidar-derived data. The SODAR is an independent measure of the 3 dimensional flow of air above the instrument and collects wind speed and direction information at 100 m intervals up to 2500 m a.g.l. every half hour.

Sun/Star Photometer VDA measurements

Total optical extinction along atmospheric slant paths is measured with a sun/star photometer. Absolute calibration of this instrument is achieved by means of Langley plots of solar (daytime) and starlight (nighttime) optical transmission. The analysis of these data will proceed by methods similar to those used at the U.S Army Atmospheric Sciences Laboratory at White Sands (Gutman *et al.* 1990) and at the Max Planck Institut for Meteorology in Hamburg, Germany (Matthias and Bösenberg 2000). Rigorous calculations that take account of the earth's curvature provide values of the air mass that are insensitive to the details of the vertical profile of optical extinction. By logarithmically plotting the optical signal strength against air mass, one obtains the vertical optical depth τ_{90} from the slope of a linear regression of the data. A consistency check against significant atmospheric variability during any given data set is obtained by comparing the regression intercepts observed over many periods of atmospheric stability. Typically τ_{90} will be of order 0.1 or less, and the vertical transmittance, exp $(-\tau_{90})$, will be determined with better than 1% accuracy. The transmittance at all angles will be an important consistency check on the data from other instruments that are measuring VDA concentrations in the study area.

3 DETERMINING EMISSION FACTORS FROM TRAINING AND OPERATIONAL ACTIVITIES AT DOD INSTALLATIONS AND DISTURBANCE EFFECTS.

3.1 Military Vehicle Emission Factors and Horizontal to Vertical Flux Measurements

The tower monitoring methods described in the proposal to estimate horizontal flux emission factors for military vehicles and define the relationship between horizontal and vertical flux require the utilization of the following instruments deployed on 9 and 15 meter high meteorological towers:

- TSI model 8520 DustTraks
- Grimm Aerosol Particle Sizers
- Anemometers
- Wind vanes
- Frisbee-style dust deposition traps

The following subsections describe the precision, accuracy, and measurement range of each of the instruments.

TSI model 8520 DustTrak (TSI Inc., St. Paul MN)

The DustTrak is a portable, battery-operated, laser-photometer that uses light scattering from particles to estimate particle mass concentrations. The instrument is calibrated by the manufacturer to accurately reproduce the mass concentrations of NIST Arizona Road Dust. When properly maintained, the manufacturer specifies an instrument resolution of 0.1% or 1 $\mu g\ m^{-3}$ which ever is larger. The range of mass concentration measurements is specified to be between 1 $\mu g\ m^{-3}$ and 100 mg m^{-3}. Since the instrument is calibrated with a particular type of dust, the accuracy of particle concentrations measurements for other types of dust cannot be assured without an independent measurement.

Grimm Aerosol Particle Sizer (Grimm Tech. Inc., Atlanta GA)

The Grimm Aerosol Particle Sizer (model 1.108) also uses laser light to estimate mass concentrations of airborne particles. Air with multiple particle sizes passes through a flat laser beam produced by a laser diode. A 15-channel pulse height analyzer for size classification detects the scattering signals. The Grimm instrument also collects all sample air on a backup Teflon filter that may be submitted for gravimetric and chemical analysis. The Grimm reports aerosol number size distributions for particles ranging from 0.3 μm to 20 μm optical diameter. The instrument is specified to measure particle mass concentrations ranging from 1 $\mu g/m^3$ to 100 mg/m^3. Accuracy of the real-time mass measurement can be improved by using the mass on the backup filter to calculate particle density for all measured particles between filter changes.

R.M Young 3-cup Anemometers

Vertical wind speed profiles will be measured using R.M Young wind sentry anemometers on boom arms affixed to the meteorological towers. The anemometers will be calibrated according to the manufacturers specifications prior to deployment in the field. Bearings will be inspected and replaced as necessary. The manufacturer specifies an instrument precision of ± 0.01 m s^{-1}.

R.M Young Wind Vanes

Wind direction will be measured using R.M Young wind vanes. The vanes will be calibrated according to the manufacturers specifications prior to deployment in the field. Bearings will be inspected and replaced as necessary. The manufacturer specifies an instrument precision of $\pm 1°$.

Frisbee-style Dust Fall Traps

The dust deposition gauges used to measure the deposition flux of particles downwind of the vehicle-generated emissions will be based on the design of Hall and Upton (1988). The basic design is an inverted commercially-available Frisbee mounted on a pole such that the bowl and bottom of the Frisbee are parallel to the ground surface. This design has proved to be resistant to re-entrainment of the settled dust up to a maximum wind speed of 5-6 m s^{-1} in wind tunnel tests. The performance of this sampler was evaluated and found to perform satisfactorily by Vallack (1995). The precision of the dust deposition traps will be established from collocated measurements.

Field Sampling Quality Assurance Requirements for Particle Measurements

To ensure consistent and accurate results, the following procedures will be followed for all experiments that utilize the DustTrak and Grim instruments (i.e., dust emission factor measurements, relationship of horizontal to vertical flux, TRAKER, and the wind tunnel disturbance effect tests).

These activities will be followed in addition to the recommended maintenance schedule defined by the equipment manufacturers.

- Synchronize field computer with network timeserver each day.
- Synchronize instrument clocks with field computer each day.

- Measure flow rates on all DustTrak samplers using the same calibrated rotometer. If instrument flows differ more than 5% from the specified 1.7 lpm, adjust flow rates to restore proper flow.
- Check the zero on all DustTrak samplers using the zero air filter prior to a sampling day, re-zero if necessary.
- Compare particle concentrations between at least 3 collocated DustTrak samplers. If particle concentrations differ by more than 10%, replace one or more samplers until they are in agreement.
- Measure and if necessary adjust the flow rate of the Grimm 1.108 aerosol sizer.

During the experiments, all particle measurement data will be logged on the internal memory storage of the instruments. After the experiments are completed for the day, the following procedures will be followed.

- Check and record the final flow rate on all particle instruments.
- Check and record the instrument clocks on all pieces of equipment. Note any discrepancies.
- Check and record the zero-offsets on all DustTraks. Note any changes.
- Download all stored DustTrak and Grimm data files to the field computer.
- Backup each days files to a ZIP disk.

For the dust deposition gauges the accumulated sediment in each trap will be collected after each testing period and stored in sealed containers labeled with the appropriate date, time, position, and test sequence number. These containers will be returned to the Desert Research Institute for subsequent weighing of the collected dust.

Data Representativeness for Emission Factor and Flux Measurements

Particle Measurements

The two instruments used to measure particle mass concentrations use light scattering intensity as a proxy to represent mass concentrations. For cases in which the particles measured do not vary in size distribution or chemical composition, light scattering intensity has been shown to vary proportionally with particle mass. Light scattering may not be a stable proxy of particle mass in environments where multiple sources may influence a monitor with varying proportions of impact.

For this research component the dominant source of emissions is expected to be fugitive dust emissions generated from vehicle movement on selected surfaces. The size distribution of fugitive dust particles less than 10 μm is expected to remain constant for the upwind-downwind measurements. In order to ensure the light scattering measurements are representative of particle mass concentrations, the DustTrak, Grimm 1.108, and a low volume PM_{10} sampler will be collocated in a source dominated environment beside the travel surface. These collocated measurements will be made in conjunction with the efforts of Dr. John Veranth of University of Utah. Dr. Veranth's team will be responsible for the collection of PM mass measurements with the low-volume samplers. Repeated measurements will be made to establish a quantitative calibration linking the DustTrak and Grimm 1.108 to an accepted measure of PM.

To provide an estimate for the precision of the Frisbee-style dust deposition traps, two traps will be collocated during each test sequence. The collocated precision is defined as the standard deviation of the paired differences, and the root means squared (RMS) precision (the square root of the mean squared precisions), which is essentially the average measurement uncertainty between the two samplers.

Documentation and Record Keeping

Notation of field activities for the emission measurements will be entered on the field computer. All data collected by the instruments are joined with the field notations as a series of tables within a single Microsoft Access Database. Traceability of the data stream is preserved by maintaining all raw data files in a subdirectory on the field computer.

The database will contain the following information:

- Experiment description, start time, stop time, location, and other pertinent information for each specific test.
- Time series data from particle instruments.
- Instrument flow rates, zero values, and time of measurement checks.
- Meteorological data from anemometers and wind vanes.
- Dust deposition data (after gravimetric analysis, post field measurements).
- Dust concentration data from filter samplers (from University of Utah data collection).

3.2 Testing Re-entrained Aerosol Kinetic Emissions from Roads (TRAKER)

Testing Re-entrained Aerosol Kinetic Emissions from Roads (TRAKER) will be used to measure the potential of a travel surface to emit particles while a vehicle is driving over the surface. The measurement approach uses real-time particle sensors to measure simultaneously the concentrations and size distribution of particles in front of and in the dust plume behind a vehicle in motion (Kuhns and Etymezian 1999). Simultaneously with the dust concentration and particle size data, a GPS records the position and velocity of the vehicle every second. The difference in particle concentrations between the plume and the front of the vehicle is assumed to be quantitatively related to the emissions of particles due to vehicle movement over the travel surface. The GPS provides position information corresponding to the differential concentration measurements allowing a map to be drawn of the emissions potential of the travel surface for all areas visited by the test vehicle.

As part of the proposed project, the TRAKER system will be installed on light-, medium- and heavy-duty vehicles during military training maneuvers. In addition to collecting data from vehicles in routine operation, the test vehicle will be operated in a special test area where particulate emissions will be measured directly using an upwind-downwind technique (Gillies *et al.* 1999). Simultaneous collection of TRAKER and upwind-downwind datasets will permit the TRAKER measurement to be calibrated to a direct emissions measurement. Once the TRAKER signal has been calibrated, emissions of a particular vehicle can be estimated on all surfaces surveyed by the TRAKER vehicle. This approach will enable the estimation of emissions from numerous vehicles operating on a variety of travel surfaces.

Measurement Quality Objectives:

The instruments used to conduct the TRAKER measurements are listed below:

- TSI model 8520 DustTrak
- Grimm Aerosol Particle Sizer
- Ashtech Promark X GPS

Refer to Section 3.1 regarding the procedures to be followed for all experiments with the DustTrak and Grim instruments. The procedures to be used to insure quality data for the Global Positioning System are provided in the following subsection.

Ashtech Promark X GPS

The Global Positioning System (GPS) is a well-developed technology that has been used for surveying, orienting, and navigating for nearly 2 decades. GPS permits the recording of an instrument's position at any location on Earth with a clear view of the sky. On May 20, 2000, the DoD ended the use of "Selective Availability" errors that were used to maintain optimum military effectiveness by U.S. and allied forces. This has resulted in large improvements in the accuracy of the raw GPS position signal. At present, the accuracy of the raw GPS position signal is typically 15 m. Using differential GPS post processing of the position data, the accuracy may be improved to less than 10 m and frequently less than 5 m. In order to use differential GPS corrections, a base station must be located within 50 km of the study area. Hundreds of base stations are in operation throughout the United States. In most cases, computer files used to correct the raw GPS data can be obtained free of charge over the internet. The Ashtech Promark X GPS produces data in a format suitable for differential correction post processing.

Data Representativeness for TRAKER

Particle Measurements

The same considerations for particle mass measurements that were discussed in Section 3.1 also apply for particle measurements for the TRAKER-based experiments. One additional check on the representativeness of the light scattering measurements as they relate to particle mass concentrations will be to collocate a DustTrak, a Grimm 1.108, and a medium volume PM_{10} sampler in a source dominated environment beside the travel surface. Repeated measurements will be made to establish a quantitative calibration linking the DustTrak and Grimm 1.108 to a Federal reference equivalent method for measurement of PM_{10}.

GPS Measurements

GPS velocity measurements will be compared with vehicle speedometer readings. Several controlled tests will be performed in which the vehicle is operating at a constant speed. The sampling speed will be regulated based on the vehicle's speedometer. The GPS speed will be compared with the speed as measured on the speedometer as a means of verifying the two independently measured signals.

Instrument Timing

Accurate timing stamping of the data streams from the multiple instruments is essential to the success of this project component. Representative instrument timing will be ensured by simultaneously logging all instrument data onto a single laptop computer. The computer's clock will be synchronized with the true time using a program that accesses a network time-server. The internal clocks of all of the instruments will then be synchronized with the computer's clock each day. The instrument's clocks will be compared with computer clock at the end of each day to ensure consistent time stamping has occurred.

Documentation and Record Keeping

Notation of field activities for these measurements will be entered on the field computer inside the TRAKER vehicle. All data collected by the instruments are joined with the field notations as a series of tables within a single Microsoft Access Database. Traceability of the data stream is preserved by maintaining all raw data files in a subdirectory on the field computer.

The database will contain the following information:

- Time series data from particle instruments
- Time series data from GPS
- Experiment description, start time, stop time, location, and other pertinent information for each specific test.
- Instrument flow rates, zero values, and time of measurement checks.

At the end of each sampling day, data will be backed up onto ZIP disk and stored in a separate location from the field computer.

Field Sampling Quality Assurance Requirements for TRAKER

Quality assurance requirements for the DustTrak and Grimm instruments are detailed in Section 3.1. For the GPS unit the following procedure will be followed:

- Compare clock on field computer with GPS clock and note any discrepancy at the end of each sampling day.
- Transfer GPS data files to the field computer.
- Backup each days files on a ZIP disk.

Data Validation and Verification for the Particle Measurements

Linear regression can be used to infer equivalence between the two samplers as well as predictability of one sampler's measurement from that of another sampler (King 1977). Regression slope and intercept for each sample pair, along with their standard errors, are easily calculated using modern spreadsheet software. When regression slope equals unity to within three standard errors, the intercept is equal to zero within three standard errors, and the r^2 coefficient of determination exceeds 0.81, the selection of independent and dependent variables is often considered to be equivalent (Berkson 1950; Madansky 1959, Kendall 1951a 1951b). If the correlation coefficient (r) is greater than 0.9 ($r^2 > 0.81$), but the slope and intercept criteria are not met, the compared measurements are said to be "well correlated" with the independent variable.

The particle mass concentrations will be calibrated by collocating the instruments with an independent and direct measurement of PM_{10} mass concentration using a filter sampling system. Since the DustTrak and Grimm 1.108 are calibrated with the filter based PM_{10} mass concentration, the filter measurements cannot be used to truly validate the accuracy of the light scattering instruments. Rather the correlation of DustTrak and Grimm 1.108 signal with the direct PM_{10} mass concentrations measurement will be used to verify that the calibrated light scattering instruments can reproduce PM_{10} mass concentrations.

3.3 Portable Wind Tunnel Testing to Quantify Disturbance Effects on Dust Emissions

The wind tunnel proposed for the disturbance effect research is a suction type, with a cross section of 0.75 × 1.0 m and a working section length of 12 m. The tunnel is sufficiently long to develop a relatively thick boundary layer over natural surfaces (~0.25 m) and is large enough to overcome Froude Number effects that limit the usefulness of smaller portable wind tunnels in experiments involving saltation (White and Mounla, 1991).

Wind speed will be measured with a 6 point Pitot tube rake (0.2 to 30 cm above the bed) mounted just up-wind of a wedge-shaped saltation/creep trap (Nickling and McKenna Neuman, 1997). Sediment entering the trap is continuously weighed on a sensitive load cell positioned under the trap orifice buried beneath the surface. Data from the Pitot tubes and load cell are recorded on a Personal Computer through an A to D board. Suspended sediment concentration will be measured with a vertical array of four streamlined sampling nozzles, positioned from 5 to 50 cm above the surface, upwind and to the side of the saltation trap. A fifth sampling nozzle will be placed in the center of the wind tunnel inlet orifice to record the incoming or background dust concentration. The concentration of the suspended sediment at each sampling height will be determined at 1 s intervals using a DustTrak.

The pressure transducer (Viatran model 219-12, 0-5" water head) used to measure the dynamic pressure in the Pitot tubes is calibrated in the laboratory prior to field measurements against an inclined manometer (Airflow Developments Ltd., 2-Tube Precision Manometer, model M4-5). To calibrate the pressure transducer both the transducer and the manometer are connected to a closed cell. The pressure within the cell is controlled and can be varied over the expected range of dynamic pressure associated with the range of wind velocities used in the wind tunnel testing. A calibration relationship is developed for the millivolt output of the transducer and the pressure head of water (cm of H_2O). The millivolt readings obtained with the pressure transducer during wind tunnel runs are converted to pressure readings with the calibration equation and then to wind velocities using the following equation:

$$v = \sqrt{\frac{2g\,\Delta p}{\rho_a}} \tag{1}$$

where: v = velocity (cm s^{-1})

g = acceleration due to gravity (981 cm s^{-2})

Δp = the height of the water column (cm) (from the calibration equation that converts millivolts to cm of H_2O)

ρ_a = air density (g cm^{-3})

The horizontal mass flux trap (Nickling and McKenna Nueman 1997) is based on measuring the mass of sediment accumulating on a balance (Metler Inc., Model BD 1201, ±0.05 g) during each second of a wind tunnel test. The balance is checked prior to deployment in the field against a series of laboratory-certified calibration weights to establish its accuracy and precision.

The vertical dust concentration profile is measured with 4 DustTraks connected via Tygon tubing to the sampling array of nozzles in the wind tunnel. In addition, a Grimm particle sizer will be collocated with one of the DustTrak sampling points. The same instrument protocols and procedures outlined in Section 3.1 for using the DustTraks and Grimms for the Tower and TRAKER sampling programs will be utilized during the wind tunnel testing. For the wind speed and horizontal flux data recorded on the wind tunnel dedicated personal computer the data files will be transferred to the field computer and then backed up on a ZIP disk.

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