Letter Report

Yucca Mountain Environmental Monitoring Systems Initiative
Air Quality Scoping Study for Rachel, Nevada

prepared by

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INTRODUCTION

The Desert Research Institute (DRI) is performing a scoping study as part of the U.S. Department of Energy's Yucca Mountain Environmental Monitoring Systems Initiative (EMSI). The main objective is to obtain baseline air quality information for Yucca Mountain and an area surrounding the Nevada Test Site (NTS).

Air quality and meteorological monitoring and sampling equipment housed in a mobile trailer (shelter) is collecting data at seven sites outside the NTS, including Ash Meadows National Wildlife Refuge, Sarcobatus Flat, Beatty, Rachel, Caliente, Pahrnagat National Wildlife Refuge, and Crater Flat, and at four sites on the NTS. The trailer is stationed at any one site for approximately eight weeks at a time.

Letter reports provide summaries of air quality and meteorological data, on completion of each site's sampling program.

SITE LOCATION AND CHARACTERISTICS

Site #4 was located at Rachel, Nevada. Rachel is located on the southeastern edge of the Sand Spring Valley. The current population is about 70 inhabitants and their major occupational activities include two alfalfa farms, a few ranches, and two gas station/restaurant stores. Rachel is about 60 to 70 miles northeast of the Yucca Mountain repository facility (Figure 1).

Figure 1. Southern Nevada map showing the location of Site #4 (at Rachel), Nevada Test Site, and Yucca Mountain. The map background is land use and land cover obtained from the 2001 National Land Cover Database.

The location of the trailer is shown in Figure 2. Monitoring of PM₁₀, PM_{2.5} and meteorological conditions was carried out from September 7, 2006, to December 4, 2006.

Table 1. Longitude, latitude, and elevation of the mobile trailer location at Site #4 (Rachel).

Site	Rachel
Latitude	37° 17' 10"
Longitude	117° 2' 4"

Figure 2. Location of the mobile trailer in Rachel, NV. Image obtained from Google Earth.

AEROSOL SAMPLING AND MONITORING

Filter Sampling

Sampler Description and Procedures

BGI, Inc., PQ100 and PQ200 Ambient PM_{2.5} Federal Reference Method (FRM) samplers were used to collect 24-h integrated PM₁₀ and PM_{2.5} samples. Figure 3 shows the PQ100 and PQ200 in the mobile trailer (left) and the PM₁₀ sampling inlets on the top of the trailer (right). Both PQ100 (Designation No. RFPS-1298-124) and PQ200 (Designation No. RFPS-0498-116) are designed to meet the criteria for collecting 24-h samples of ambient aerosol according to the U.S. National Ambient Air Quality Standards (NAAQS).

Figure 3. Photographs of PQ100 (green/gray box in left photo), PQ200 (white box in left photo) and their sampling inlet (right photo).

Figure 4 shows a schematic drawing of the samplers. Briefly, particles with aerodynamic diameter larger than $10\ \mu\text{m}$ were removed by impaction at the size selective inlet, while the remaining particles remained airborne. For the PM_{10} fraction, particles were then collected by a filter located downstream of the size selective inlet. For the collection of $\text{PM}_{2.5}$, particles in the range between 2.5 and $10\ \mu\text{m}$ were removed by the Very Sharp Cut Cyclone (VSCC) (U.S. Environmental Protection Agency [EPA] Equivalent Designation No. EQPM-0202-142), then collected by a filter.

Figure 4. A diagrammatic representation of the BGI $\text{PM}_{2.5}$ sampler showing the PM_{10} size selective impactor head as the first stage followed by a $\text{PM}_{2.5}$ VSCC. This configuration can be readily modified to a PM_{10} sampler by removal of the VSCC.

For both PQ100 and PQ200, samples were collected at a volumetric flow rate of 16.67 liters/min. The flow rate is controlled to ± 2 percent precision with a mass flow meter. True volumetric flow control is achieved in the PQ200 by continuous compensation of the mass flow rate for ambient pressure and temperature. The actual ambient temperature and barometric pressure, filter temperature and pressure, and anomalies (if any) were recorded (and controlled) by a microprocessor. The sampler was equipped to operate from an internal 12-volt DC battery. The battery was recharged by a battery charger from 120-volt AC. Alternatively, a 32-watt solar panel with an additional external ballast battery was installed to provide power for days without electricity. Two sets of PQ100 and PQ200 samplers were installed in the mobile trailer. PM_{10} and $PM_{2.5}$ samples were collected on filters in numbered cassettes, labeled TT (for PM_{10} Teflon), FT (for $PM_{2.5}$ Teflon), TQ (for PM_{10} Quartz), FQ (for $PM_{2.5}$ Quartz). Each filter cassette was loaded with a pre-weighed 46.2-mm-diameter PTFE (Teflon) membrane filter (Whatman # 7592-004) or 47-mm quartz fiber (Pallflex #2500QAT-UP) filter. The Teflon membrane collected particles for measurement of mass by gravimetric analysis, light absorption by densitometry, and elements by x-ray fluorescence spectrometry. Quartz fiber filters were used for measurement of water-soluble ions by atomic absorption spectrometry, ion chromatography, and automated colorimetry, and also for measurement of carbon species by thermal optical reflectance.

Operation, calibration, and maintenance of PQ100 and PQ200 are described in standard operation procedure (SOP) “BGI PQ100 PM_{10} and PQ200 $PM_{2.5}$ REFERENCE SAMPLERS FOR THE YUCCA MOUNTAIN AIR QUALITY PROGRAM.” Flow calibration and leak tests were performed on the day of installation (September 6, 2006). The leak check was performed according to the manufacturer’s operational instruction manual only for PQ200; no procedure exists for the PQ100. The flow rate was calibrated using a BGI Tri-Cal flow meter. The sampler was then placed in calibration or “run” mode and a one-point calibration verification or one-point flow-rate verification was performed. Aerosol samples were collected on a 1-in-6-day schedule. Audits of the flow and leak tests were done onsite at the beginning and end of the monitoring campaign. Teflon and quartz filters were prepared and assembled in their filter holders in the Desert Research Institute’s (DRI) Environmental Analysis Facility (EAF) in Reno and shipped to DRI’s facilities in Las Vegas. The filters were kept at -4°C and transported to the field in a cryo-cooler. Exposed filters were also stored at -4°C in Las Vegas. Upon completion of the monitoring period at the site, all filters were shipped to the EAF in Reno.

Gravimetry

Table 2 shows mass concentrations (and uncertainty) for filters collected at Rachel. PM_{10} mass concentrations varied from $1.08\ \mu\text{g}/\text{m}^3$ to $13.02\ \mu\text{g}/\text{m}^3$, while $PM_{2.5}$ mass concentrations ranged from $0.74\ \mu\text{g}/\text{m}^3$ to $6.49\ \mu\text{g}/\text{m}^3$. Similar temporal trends were observed for both PM_{10} and $PM_{2.5}$. In all cases, 24-h PM_{10} and $PM_{2.5}$ levels were substantially lower than the daily and annual NAAQS as recently revised by EPA (24-h PM_{10} : $150\ \mu\text{g}/\text{m}^3$, 24-h $PM_{2.5}$: $35\ \mu\text{g}/\text{m}^3$; Annual $PM_{2.5}$: $15\ \mu\text{g}/\text{m}^3$) (Figure 5). Fine particles ($PM_{2.5}$) accounted for approximately 40 percent of PM_{10} ($PM_{2.5}/PM_{10}$ ratio of 43) (Figure 6). Note that PM_{10} and $PM_{2.5}$ concentration levels are quite low, which indicates the moderate-to-low contribution of windblown dust sources in Rachel for the monitoring period.

Table 2. Collection day, filter number, mass, and uncertainty determined by gravimetric analysis and associated flags of samples at Site #4 (Rachel).

Date	No	Type	Mass ($\mu\text{g}/\text{m}^3$)	Uncertainty ($\mu\text{g}/\text{m}^3$)	Flags
9/08/2006	038	PM ₁₀	11.0649	0.5344	
		PM _{2.5}	4.5379	0.4952	
9/14/2006	039	PM ₁₀	9.7338	0.5240	f2: Filter damaged, within analysis area.
		PM _{2.5}	6.4919	0.5037	
9/20/2006	040	PM ₁₀	13.0200	0.5518	
		PM _{2.5}	3.8285	0.4926	
9/26/2006	041	PM ₁₀	8.6522	0.5163	
		PM _{2.5}	4.2447	0.4940	
10/02/2006	043	PM ₁₀	4.1597	0.4935	
		PM _{2.5}	1.2484	0.4873	
10/08/2006	044	PM ₁₀	5.5324	0.4989	
		PM _{2.5}	2.7050	0.4896	
10/14/2006	045	PM ₁₀	1.0815	0.4869	
		PM _{2.5}	0.7491	0.2438	
10/20/2006	046	PM ₁₀	2.4126	0.4888	
		PM _{2.5}	0.8323	0.4869	
11/1/2006	049	PM ₁₀	5.9484	0.5008	f2: Filter damaged, within analysis area.
		PM _{2.5}	3.0379	0.4904	
11/7/2006	051	PM ₁₀	3.2446	0.4908	
		PM _{2.5}	1.2484	0.4873	
11/13/2006	052	PM ₁₀	4.2845	0.4939	
		PM _{2.5}	1.9975	0.4883	
11/19/2006	053	PM ₁₀	3.6190	0.4918	f2: Filter damaged, within analysis area.
		PM _{2.5}	1.7471	0.4877	
11/25/2006	054	PM ₁₀	6.9052	0.5057	
		PM _{2.5}	2.5790	0.4892	
12/1/2006	013	PM ₁₀	3.0782	0.4903	
		PM _{2.5}	1.2901	0.4873

Figure 5. Time series of PM₁₀ and PM_{2.5} mass concentrations (mean $\pm$ uncertainty) at Site #4 (Rachel).

Figure 6. Relationship between mean ($\pm$ uncertainty) daily PM_{2.5} and PM₁₀ at Rachel.

Chemical Analysis

Table 3 shows the chemical content of PM₁₀ and PM_{2.5} samples collected on 9/20/2006 and 11/25/2006. Chemical analysis included elements (from sodium to uranium) with x-ray fluorescence spectrometry, major anions (sulfate, nitrate, and chloride) by ion chromatography, major cations (sodium, potassium) by atomic absorption, particulate ammonium by colorimetry, and elemental and organic carbon by thermal optical reflectance (TOR).

Table 3. Results of the chemical analysis for selected filters from Rachel. Chemical components with concentration higher than two times the uncertainty are in bold, while those with concentrations lower than two times the uncertainty are in italics. Concentrations are in $\mu\text{g}/\text{m}^3$.

DATE	9/20/2006				11/25/2006			
SIZE	PM ₁₀		PM _{2.5}		PM ₁₀		PM _{2.5}	
	Conc.	Uncer.	Conc.	Uncer.	Conc.	Uncer.	Conc.	Uncer.
Chloride, Cl ⁻	<i>0.0454</i>	<i>0.0297</i>	<i>0.0105</i>	<i>0.0294</i>	<i>0.0216</i>	<i>0.0295</i>	<i>0.0077</i>	<i>0.0294</i>
Nitrate, NO ₃ ⁻	0.2024	0.0297	0.0825	0.0295	0.1711	0.0296	0.0592	0.0294
Sulfate, SO ₄ ²⁻	0.4974	0.0311	0.4454	0.0308	0.4519	0.0308	0.2858	0.03
Ammonium, NH ₄ ⁺	0.1693	0.0302	0.1628	0.0302	0.1067	0.0298	0.1037	0.0298
Sodium, Na ⁺	0.1019	0.0028	0.0363	0.0019	0.1126	0.003	0.0153	0.0018
Potassium, K ⁺	0.0714	0.0045	0.0362	0.0034	0.0394	0.0035	0.0142	0.003
OC1	0.3301	0.0549	0.7317	0.1146	0.1178	0.0276	0.1954	0.0366
OC2	0.541	0.1145	0.505	0.1083	0.1384	0.052	0.2243	0.0632
OC3	0.5204	0.1727	0.5158	0.1725	0.1307	0.1577	0.2117	0.1599
OC4	0.413	0.1182	0.2237	0.077	0.1854	0.0699	0.1056	0.0577
Pyrolyzed OC-TT	0.4073	0.0899	0.3328	0.0765	0.0413	0.0379	0.0417	0.038
Pyrolyzed OC-Op	0.3408	0.0735	0	0.037	0	0.037	0	0.037
Total OC	2.1429	0.3153	1.9738	0.3012	0.5701	0.2081	0.7347	0.2157
EC1	0.4046	0.0867	0.2613	0.0599	0.0547	0.0299	0.0417	0.029
EC2	0.0941	0.0385	0.0715	0.037	0.0358	0.0353	0.1272	0.0414
EC3	0.0191	0.0117	0	0.0116	0	0.0116	0.0833	0.0146
Total EC	0.177	0.0722	0.3328	0.1163	0.0905	0.0528	0.2522	0.0927
Total Carbon	2.3198	0.2687	2.3066	0.2683	0.6606	0.2223	0.9868	0.2283
Sodium, Na	<i>0.0975</i>	<i>0.1507</i>	<i>0.1544</i>	<i>0.1516</i>	<i>0</i>	<i>0.149</i>	<i>0</i>	<i>0.1492</i>
Magnesium, Mg	<i>0.1914</i>	<i>0.0456</i>	<i>0.0596</i>	<i>0.0448</i>	<i>0.0679</i>	<i>0.0448</i>	<i>0.0621</i>	<i>0.0448</i>
Aluminum, Al	0.6976	0.0248	0.1572	0.0186	0.3198	0.02	0.1321	0.0184
Silicon, Si	1.6086	0.0387	0.4111	0.0177	0.7829	0.0233	0.3027	0.0164
Phosphorous, P	<i>0.0075</i>	<i>0.0045</i>	<i>0.0114</i>	<i>0.0045</i>	<i>0.0011</i>	<i>0.0045</i>	<i>0.0041</i>	<i>0.0045</i>
Sulfur, S	0.2086	0.0207	0.1999	0.0206	0.1331	0.0204	0.1189	0.0203
Chlorine, Cl	<i>0.0232</i>	<i>0.0038</i>	<i>0.0031</i>	<i>0.0037</i>	<i>0.006</i>	<i>0.0037</i>	<i>0</i>	<i>0.0037</i>
Potassium, K	0.2734	0.0059	0.0892	0.0027	0.1303	0.0033	0.0495	0.0022
Calcium, Ca	0.5243	0.011	0.1221	0.0038	0.3572	0.0078	0.124	0.0038
Scandium, Sc	<i>0</i>	<i>0.0074</i>	<i>0</i>	<i>0.0074</i>	<i>0</i>	<i>0.0074</i>	<i>0.0003</i>	<i>0.0074</i>
Titanium, Ti	0.041	0.0016	0.0077	0.0013	0.0165	0.0013	0.0047	0.0013
Vanadium, V	<i>0.0021</i>	<i>0.0003</i>	<i>0</i>	<i>0.0003</i>	<i>0</i>	<i>0.0003</i>	<i>0</i>	<i>0.0003</i>
Chromium, Cr	<i>0.0007</i>	<i>0.0015</i>	<i>0.0002</i>	<i>0.0015</i>	<i>0.0007</i>	<i>0.0015</i>	<i>0.0002</i>	<i>0.0015</i>
Manganese, Mn	<i>0.0101</i>	<i>0.0032</i>	<i>0.0023</i>	<i>0.0032</i>	<i>0.0042</i>	<i>0.0032</i>	<i>0.0008</i>	<i>0.0032</i>

Table 3. Results of the chemical analysis for selected filters from Rachel. Chemical components with concentration higher than two times the uncertainty are in bold, while those with concentrations lower than two times the uncertainty are in italics. Concentrations are in $\mu\text{g}/\text{m}^3$ (continued).

DATE SIZE	9/20/2006				11/25/2006			
	PM ₁₀		PM _{2.5}		PM ₁₀		PM _{2.5}	
	Conc.	Uncer.	Conc.	Uncer.	Conc.	Uncer.	Conc.	Uncer.
Iron, Fe	0.3878	0.0086	0.0913	0.0038	0.1663	0.0047	0.0614	0.0035
Cobalt, Co	0	0.0003	0	0.0003	0	0.0003	0	0.0003
Nickel, Ni	0	0.0008	0.0005	0.0008	0	0.0008	0	0.0008
Copper, Cu	0	0.0017	0.0003	0.0017	0	0.0017	0	0.0017
Zinc, Zn	0.001	0.0015	0.0005	0.0015	0	0.0015	0.0049	0.0015
Gallium, Ga	0.0034	0.0049	0	0.0049	0	0.0049	0.001	0.0049
Arsenic, As	0	0.0006	0	0.0006	0	0.0006	0	0.0006
Selenium, Se	0	0.0011	0	0.0011	0	0.0011	0	0.0011
Bromine, Br	0.0003	0.0021	0.0003	0.0021	0.0003	0.0021	0.0008	0.0021
Rubidium, Rh	0.0016	0.0011	0.0011	0.0011	0	0.001	0.0002	0.0011
Strontium, Sr	0.0039	0.0025	0.0034	0.0025	0.0025	0.0025	0.001	0.0025
Yttrium, Y	0.0016	0.0015	0.0007	0.0015	0	0.0015	0	0.0015
Zirconium, Zr	0.0018	0.0039	0	0.0039	0	0.0039	0	0.0039
Niobium, Nb	0	0.0025	0.0002	0.0025	0	0.0025	0	0.0025
Molybdenum, Mo	0	0.0025	0	0.0025	0	0.0025	0	0.0025
Palladium, Pd	0.0029	0.0059	0.0025	0.0059	0	0.0059	0	0.0059
Silver, Ag	0.0007	0.0056	0	0.0056	0	0.0056	0.0036	0.0056
Cadmium, Cd	0.0008	0.0044	0	0.0044	0.0003	0.0044	0.0018	0.0044
Indium, In	0	0.0049	0	0.0048	0.0008	0.0049	0	0.0049
Tin, Sn	0.0038	0.0053	0	0.0053	0	0.0053	0.0028	0.0053
Antimony, Sb	0.0036	0.008	0	0.008	0.0026	0.008	0	0.008
Cesium, Cs	0	0.0023	0	0.0023	0	0.0023	0	0.0023
Barium, Ba	0	0.0025	0	0.0025	0	0.0025	0.0007	0.0025
Lanthanum, La	0	0.0017	0	0.0017	0	0.0017	0	0.0017
Cerium, Ce	0	0.0016	0	0.0016	0.0003	0.0016	0	0.0016
Samarium, Sa	0	0.0033	0.0015	0.0033	0	0.0033	0	0.0033
Europium, Eu	0	0.0051	0	0.0051	0	0.0051	0	0.0051
Terbium, Tb	0.002	0.0037	0	0.0037	0	0.0038	0	0.0037
Hafnium, Hf	0.0033	0.0152	0.0028	0.0152	0	0.0152	0	0.0152
Tantalum, Ta	0	0.0099	0.0049	0.01	0	0.01	0	0.0099
Tungsten, W	0.0064	0.0164	0.0034	0.0164	0.0108	0.0164	0.0113	0.0164
Iridium, Ir	0	0.0046	0	0.0046	0.0015	0.0046	0	0.0046
Gold, Au	0	0.0075	0.001	0.0075	0	0.0075	0	0.0075
Mercury, Hg	0	0.0037	0	0.0037	0	0.0037	0.0018	0.0037
Thallium, Th	0	0.0025	0	0.0025	0	0.0025	0	0.0025
Lead, Pb	0.0013	0.0036	0.0018	0.0036	0.0013	0.0036	0.0038	0.0036
Uranium, U	0	0.0063	0	0.0063	0	0.0063	0	0.0063

OC = organic carbon
EC = elemental carbon
OP = optical pyrolysis
TT = transmittance

With respect to the chemical composition of PM₁₀ and PM_{2.5}, the following patterns are observed:

- Sulfur (S) was mostly in the form of sulfate (SO₄²⁻) with sulfate-to-sulfur ratio of 2.22 to 3.39. Ammonium was almost entirely (96 to 97% for ammonium) associated with fine particles, while less than 50 percent of nitrate (35 to 41%) was measured in PM_{2.5}. On September 28, most of the sulfate (90%) was associated with fine particles, while only two-thirds of sulfate was attached on fine particles on November 11, 2006. This may be due to neutralization of H₂SO₄ by soil dust elements, while ammonium concentrations were half of those measured in September 2006. Ammonium-to-sulfate molar ratios varied from 1.25 to 1.95, suggesting that sulfate aerosols were mostly in the form of ammonium bisulfate, (NH₄)HSO₄ (Malm *et al.*, 2002). Nitrates appeared to be partially neutralized by ammonium in the fine particle mode, while coarse particles nitrates may be the product of the reactions of nitric acid with soil dust elements such as Ca (Lefer and Talbot, 2001).
- Carbonaceous aerosol was predominantly in fine particles. For PM_{2.5}, organic carbon (OC) concentrations accounted for 38 to 68 percent of particle mass and only 10 to 20 percent of PM₁₀ particle mass. The EC/OC ratio values (between 0.08 and 0.34) were indicative of contributions from traffic emissions.
- Soluble potassium (K⁺) accounted for 26 to 40 percent of total potassium in both PM₁₀ and PM_{2.5}. Soluble potassium is a tracer of biomass burning, which suggested the significant impact of emissions from local and/or regional fire (prescribed or wildfire) events. This was further supported by the estimates of nonsoil potassium K_{non-soil} (K_{total} - (0.26 x [Al])) that were comparable to measured water-soluble K⁺.
- The ratios of Al/Si (0.38 to 0.43), Ca/Al (0.75 to 1.11) and K/Fe (0.75 to 1.11) were comparable to those determined for samples collected at the Interagency Monitoring of Protected Visibility Environments (IMPROVE) sites in western United States (Al/Si: 0.31 to 0.43, K/Fe: 0.67 to 0.78, Al/Ca: 1.4 to 1.7) when soil dust was the major component of particulate matter (Kavouras *et al.*, 2006).

The IMPROVE mass estimation scheme is adopted to reconstruct aerosol mass into five major types: sulfate, nitrate, organic, light-absorbing carbon, and soil. For this scheme, sulfate and nitrate are assumed to be in the forms of ammonium sulfate [(NH₄)₂SO₄] and ammonium nitrate [NH₄NO₃], respectively (Malm *et al.*, 2004). Organic mass concentration [OMC] was estimated as [OMC] = 1.4 x [OC], where [OC] is the organic carbon concentration. The 1.4 factor was used to correct for other elements (mainly hydrogen and oxygen) associated with the composition of organic compounds (White and Roberts, 1977). Soil mass concentration [SOIL] was estimated as the sum of the elements present in the soil as oxides (Al₂O₃, SiO₂, CaO, K₂O, FeO, Fe₂O₃, and TiO₂) as follows: [SOIL] = 2.2 x [Al] + 2.49 [Si] + 1.63 x [Ca] + 2.42 x [Fe] + 1.94 x [Ti]. Therefore, the reconstructed aerosol mass was estimated as follows:

$$[\text{Aerosol Mass}] = (128/96) \times [\text{SO}_4] + (80/62) \times [\text{NO}_3] + \text{EC} + [\text{OMC}] + [\text{SOIL}]$$

Figure 7 shows the concentrations of ammonium sulfate, ammonium nitrate, organic carbon mass, elemental carbon, and soil for PM₁₀ and PM_{2.5} collected on 9/06/2006 and 11/25/2006 in Rachel. Considering the positive bias for organic carbon measurements:

- Reconstructed particle mass accounted for 78 to 894 percent of measured PM₁₀ mass and for 122 to 147 percent of PM_{2.5} mass.
- Carbonaceous aerosol (OMC and EC) appeared to account for 16 to 28 percent of PM₁₀ and 41 to 56 percent of PM_{2.5}.
- Soil represented 64 to 68 percent of PM₁₀ and 32 to 45 percent of PM_{2.5} mass, while sulfate contributed between 6 and 11 percent for PM₁₀ and 12 percent for PM_{2.5} (Figure 7).
- The differences of PM₁₀ fractions are entirely due to higher concentration of soil elements in the coarse fraction (particles with diameter between 2.5 and 10 µm).

Figure 7. Reconstructed mass for PM₁₀ and PM_{2.5} based on chemical composition.

Aerosol Monitoring

Monitor Description and Procedures

The TEOM Series 1400 Ambient Particulate Monitor from Thermo Scientific and the DUSTTRAK™ Aerosol Monitor from TSI were used to continuously measure PM₁₀ and PM_{2.5} mass concentrations (Figure 8). The TEOM Series 1400 monitors the ambient particulate mass concentration of PM₁₀ (EPA certification EQPM-1090-079) (or PM_{2.5}) in real time by direct measurement of particulate mass collected on a filter attached to an

oscillating inertial mass transducer. The mass transducer in the sensor unit has a tapered ceramic tube (element) that is fixed at the downstream end and a Teflon-coated glass fiber filter on the free end. The oscillating frequency of the tube changes proportionally as ambient air is drawn through the filter and the particulate loading thereon increases. The flow-rate through the filter sample is set at a nominal 3.0 l/min. A bypass (auxiliary) flow provides an additional 13.67 l/min for a total flow-rate of 16.67 l/min. An internal datalogger stores mass values, time, and some meteorological data. To eliminate bias caused by humidity, the filter is heated to 50°C. Operation, calibration and maintenance of the TEOM is described in SOP “RUPPRECHT & PATASHNICK (R&P), SERIES 1400A TAPERED ELEMENT OSCILLATING MICROBALANCE (TEOM).” Flow calibration and leak tests were performed on the day of installation (September 6, 2006). Data were downloaded during site visits. Regular checks of time, filter loading, by-pass filter, and flow rates were accomplished during site visits.

Figure 8. Left photograph: The front panels of PM₁₀ (right on the left photograph) and PM_{2.5} (left on the left photograph) of TEOM. Right photograph: The measurement units of TEOM and DUSTTRAK on top of them.

The DUSTTRAK™ Aerosol Monitor is a portable, battery operated laser photometer. The monitor provides measurements of particle mass based on 90° light scattering. Atmospheric aerosol passes through a size selective inlet (either PM₁₀ or PM_{2.5}) and is directed to an optics chamber at a flow rate of 1.7 l/min. The light source is a laser diode that emits light at a wavelength of 780 nm. The aerosol sample is drawn into the sensing chamber where it is illuminated with a narrow beam of laser light. Light scattered by aerosol particles is collected by a set of lenses and focused onto the photodetector. The detector signal is proportional to the amount of scattered light, which is proportional to the mass concentration of the aerosol. Voltage is read by the processor and multiplied by an internal calibration constant to yield mass concentration. The calibration constant is pre-set by the manufacturer for scattering characteristics of the respirable mass of ISO 12103-1, Al test dust. Local variations in aerosol particle size distribution and composition relative to this standard may result in differences in the actual response factor of the instrument. The operation, calibration, and maintenance of TSI is described in SOP “TSI INCORPORATED MODEL 8520 DUSTTRAK AEROSOL MONITOR FOR THE YUCCA MOUNTAIN AIR QUALITY PROGRAM.”

Both PM₁₀ and PM_{2.5} DUSTTRAK inlets were attached on a wide “Y” connector, which was connected to one end of a second “Y” (Figure 9). A funnel was connected to the other end of the second “Y” to achieve fast exchange of ambient air into the sampling line. Flow calibration and zero-tests were performed on the day of installation (September 6, 2006) and subsequent site visits. Deviations in flow were predominantly due to failure of the pump diaphragm. In those cases, the instrument was replaced. Deviations of the zero check were corrected by performing zero calibration according to the manufacturer’s operational instruction manual.

Figure 9. Sampling inlet for DUSTTRAK.

Continuous Measurements of PM₁₀ and PM_{2.5}

Trends and correlations of particle mass are examined using hourly TEOM data integrated for 24 hours (from 0:00 to 23:00). Statistics of 24-h particle mass are presented in Table 4. Twenty-four-h PM₁₀ levels ranged from 3.2 to 41.5 $\mu\text{g}/\text{m}^3$, with a mean of 8.6 ($\sigma = 5.2$) $\mu\text{g}/\text{m}^3$, while PM_{2.5} concentrations varied from 0.0 to 7.0 $\mu\text{g}/\text{m}^3$, with a mean of 1.7 ($\sigma = 2.1$) $\mu\text{g}/\text{m}^3$. Similar temporal trends were found for PM₁₀ and PM_{2.5} at Rachel. Two high PM₁₀ episodes on September 15 and 19, 2006, were observed, with PM_{2.5} mass concentration of approximately 7 $\mu\text{g}/\text{m}^3$ (Figure 10). A consistent relationship between PM fractions was observed during the monitoring period with fine particles being accounted for about one-fourth of PM₁₀ (PM_{2.5}/PM₁₀ ratio of 0.21) (Figure 11). While differences in particle mass for weekdays/weekends were not statistically significant, somewhat higher PM₁₀ levels were measured on Friday (Day #5) (Figure 12).

Table 4. Statistics for 24-h PM_{10} and $PM_{2.5}$ TEOM mass concentrations.

	Mean	Median	Minimum	Maximum	Std. Deviation
PM_{10}	8.6	7.5	3.2	41.5	5.2
$PM_{2.5}$	1.7	1.5	0.0	7.0	1.3

Figure 10. Mean 24-h PM_{10} and $PM_{2.5}$ mass concentrations measured by TEOM at Site #4 (Rachel).

Figure 11. $PM_{2.5}/PM_{10}$ mass ratios at Site #4 (Rachel). Error bars represent the standard error of the mean.

Figure 12. Variation of mean ($\pm$ st.error) PM_{10} and $PM_{2.5}$ ($\mu g/m^3$) in weekdays and weekends at Site #4 (Rachel) (Monday=1, Tuesday=2, Wednesday=3, Thursday=4, Friday=5, Saturday=6, Sunday=7).

Variations of daily PM_{10} and $PM_{2.5}$ measured with DUSTTRAK and TEOM are presented in Figure 13 and Figure 14. The temporal correlations between DUSTTRAK and TEOM were good ($R=0.71$ to 0.86) (Figure 15). The absolute differences between concentrations measured by DUSTTRAK and TEOM were larger for PM_{10} as compared to those for $PM_{2.5}$. A slope of 0.62636 and an intercept of $-1.34905 \mu\text{g}/\text{m}^3$ (Figure 15) were computed for PM_{10} . This was indicative of the weakness of the light scattering technique to monitor dust particles that represented more than 80 percent of PM_{10} mass in Rachel at very low concentration levels. The daily trends of particle mass concentrations measured by DUSTTRAK and TEOM were comparable for $PM_{2.5}$ mass. Both TEOM and DUSTTRAK were quite comparable, the slope between TEOM and DUSTTRAK $PM_{2.5}$ was 1.16409 with a rather low intercept of $0.42844 \mu\text{g}/\text{m}^3$. This good agreement was due to the fact that light scattering provides more reliable measurements of particle mass in the accumulation mode.

Figure 13. PM_{10} mass ($\mu\text{g}/\text{m}^3$) measured with DUSTTRAK and TEOM at Site #4 (Rachel).

Figure 14. $PM_{2.5}$ mass ($\mu\text{g}/\text{m}^3$) measured with DUSTTRAK and TEOM at Site #4 (Rachel).

Figure 15. Comparison of 24-h PM_{10} and $PM_{2.5}$ mass concentrations measured by TEOM and DUSTTRAK. Error bars represent the standard error of the mean.

Comparison of Filter to Continuous Results

Figure 16 and Figure 17 show the relationships between PM₁₀ and PM_{2.5} measured by TEOM/DUSTTRAK and FRM filter-based methods. The slope for PM_{2.5} measured by TEOM and DUSTTRAK was 0.9817 and 1.40462, respectively, with insignificant intercepts. The agreement between TEOM/DUSTTRAK and filter-based PM₁₀ measurements was acceptable (R=0.72 to 0.90), with a slope of 1.57328 for TEOM and 0.60393 for DUSTTRAK, while low intercepts are computed.

Figure 16. Relationships between PM₁₀ concentrations ($\mu\text{g}/\text{m}^3$) measured by TEOM, DUSTTRAK, and filter-based methods.

Figure 17. Relationships between PM_{2.5} concentrations (µg/m³) measured by TEOM, DUSTTRAK, and filter-based methods.

METEOROLOGY

Variations of hourly data for each meteorological parameter are presented in Figure 18 through Figure 22. Descriptive statistics of hourly data also are presented in Table 5. Solar radiation progressively increased up to 74.8 watts/m² (Figure 18). Ambient temperature varied from 4.0 to 89.2 °F with a mean temperature of 50.2 °F for the monitoring period (Table 5; Figure 19). Relative humidity ranged from 6 to 97 percent (Figure 19), while total precipitation of 14.73 mm was recorded (Figure 20).

Table 5. Descriptive statistics of 1-hour meteorological data.

	Mean	Minimum	Maximum	Sum
Solar Radiation (watts/m ²)	15.0	0.0	74.8	
Wind speed (miles/h)	6.1	0.2	31.6	
Temperature (°F)	50.2	4.0	89.2	
Relative humidity (%)	33	6	97	
Precipitation (mm)				14.73

Figure 18. Solar radiation (in watts/m²) at Site #4 (Rachel).

Figure 19. Temperature (in °F) and relative humidity at Site #4 (Rachel).

Figure 20. Total precipitation (in mm) at Site #4 (Rachel).

Figure 21. Wind speed (in miles/hr) at Site #4 (Rachel).

Figure 22. Wind direction at Site #4 (Rachel).

The wind conditions for the monitoring period were described as northwest winds during the night and southeast winds during the day, with wind speeds mostly in the range of 5 to 30 miles/hour (Figure 21 through Figure 22). The classification of wind conditions was retrieved from the Federal Meteorological Handbook (Table 6). The mean wind speed for each direction bin (16 bins) is presented in Figure 23.

Table 6. Wind condition classifications.

Miles/hour	Specification
<1	Calm; smoke rises vertically.
1 to 5	Direction of wind shown by smoke drift not by wind vanes. Wind felt on face; leaves rustle; vanes moved by wind.
5 to 9	Leaves and small twigs in constant motion; wind extends light flag.
9 to 14	Raises dust, loose paper; small branches moved.
14 to 23	Small trees in leaf begin to sway; crested wavelets form on inland waters. Large branches in motion; whistling heard in overhead wires; umbrellas used with difficulty.
23 to 35	Whole trees in motion; inconvenience felt walking against wind. Breaks twigs off trees; impedes progress.
35 to 48	Slight structural damage occurs. Trees uprooted; considerable damage occurs.
>48	Widespread damage.

(retrieved from Federal Meteorological Handbook; Chapter 5. Wind;
<http://www.nws.noaa.gov/oso/oso1/oso12/fmh1/fmh1ch5.htm#chp5link>)

Figure 23. Wind direction and speed at Rachel.

For the entire monitoring period, winds were blowing predominantly from the east-southeast and south, less frequent from the northeast and 25 percent of winds were reported as calm (less than 1 mile/hour). Less than 3 percent of east-southeast winds were associated with wind speeds higher than 14 miles/hour, with a mean wind speed of 8.5 miles/hour. This is consistent with the topography of the region (Figure 2). Lower winds speeds are recorded for winds blowing from the northeast (mean wind speed of 4 miles/hour) (Figure 24).

Figure 24. Average wind speed for each wind direction sector. Error bars represent the standard error of the mean.

Associations of Meteorology with Aerosol Measurements

Trends and correlations of PM mass with meteorological conditions are shown for hourly TEOM data. A bimodal pattern is observed for $PM_{2.5}$ (Figure 25), which is typical of anthropogenic emissions. The first mode is associated with comparatively higher particle mass concentration in early morning (5:00 to 6:00), followed by a gradual decrease. A second, less pronounced, mode can be observed in late afternoon (18:00 to 20:00). A two-mode, but less clear, pattern is observed for PM_{10} . As for $PM_{2.5}$, a peak in early morning was observed; however, an increasing trend was observed as wind speeds increased from 7:00 a.m. to noon. Afterwards, PM_{10} concentrations slightly decreased in early afternoon, followed by a gradual increase in late afternoon (comparable to that observed for $PM_{2.5}$). There are no significant differences of $PM_{2.5}$ concentrations for different wind directions, while somewhat higher PM_{10} levels were determined for south and southwest winds as compared to those blowing from the northeast, providing information on the location of windblown dust area sources (Figure 26 and Figure 27).

Figure 25. Hourly variation of PM₁₀ and PM_{2.5} mass concentrations ($\mu\text{g}/\text{m}^3$) as well as wind speed (miles/hour) at Site #4 (Rachel). Error bars represent the standard error of the mean.

Figure 26. Mean ($\pm$ st.error) of PM₁₀ mass concentrations ($\mu\text{g}/\text{m}^3$) for different wind direction sectors at Site #4 (Rachel).

Figure 27. Mean ($\pm$ st.error) of $\text{PM}_{2.5}$ mass concentrations ($\mu\text{g}/\text{m}^3$) for different wind direction sectors at Site #4 (Rachel).

CONCLUSIONS

PM_{10} and $\text{PM}_{2.5}$ mass concentrations and meteorological conditions were continuously monitored from September 07 to December 04, 2006, in Rachel, with continuous (TEOM and DUSTTRAK) monitors. At the same time, integrated samples of PM_{10} and $\text{PM}_{2.5}$ were collected using FRM samplers on a 1-to-6-day schedule. Two sets of filters (September 20 and November 25, 2006) were analyzed for major anions (sulfate, nitrate, chloride) and cations (sodium and potassium), elements (from sodium to uranium), and elemental and organic carbon. The comparison of PM_{10} and $\text{PM}_{2.5}$ mass concentrations obtained by continuous monitors and filters showed that differences are associated with the limitations of the operating principle. For example, while light scattering (the measurement technique for DUSTTRAK) is not influenced by volatilization losses and is accurate for fine particles, it performs poor for coarse particles, resulting in underestimation of PM_{10} mass. TEOM PM_{10} measurements were subject to volatilization artifacts at relatively high PM_{10} concentrations. $\text{PM}_{2.5}$ mass measurements obtained by TEOM, DUSTTRAK, and filter-based methods were comparable.

Mean 24-h concentrations of PM_{10} and $\text{PM}_{2.5}$ mass were 8.6 and $1.7 \mu\text{g}/\text{m}^3$, which are significantly lower than the 24-h and annual NAAQS standards (24-h PM_{10} : $150 \mu\text{g}/\text{m}^3$, 24-h $\text{PM}_{2.5}$: $35 \mu\text{g}/\text{m}^3$; Annual $\text{PM}_{2.5}$: $15 \mu\text{g}/\text{m}^3$). Higher PM_{10} and $\text{PM}_{2.5}$ mass concentrations occurred in the early morning and late afternoon. Comparatively lower $\text{PM}_{2.5}$ levels were associated with increased wind speeds blowing mostly from the north/northwest in early afternoon, while PM_{10} concentrations increased. The chemical composition of both PM_{10} and

PM_{2.5} samples indicated that soil dust is the major component of PM₁₀, while carbonaceous aerosol contributes approximately 50 percent of PM_{2.5} mass. Sulfate and nitrate account for about 10 percent. Increases in PM₁₀ and PM_{2.5} mass concentrations are associated with higher concentrations of dust.

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