APPENDIX AVAILABLE ON REQUEST

Research Report 118

Controlled Exposures of Healthy and Asthmatic Volunteers to Concentrated Ambient Particles in Metropolitan Los Angeles

Appendix D. Concentrated Particle Exposures: Additional Details of Methodology and Results

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APPENDIX D. CONCENTRATED PARTICLE EXPOSURES: ADDITIONAL DETAILS OF METHODOLOGY AND RESULTS

CONCENTRATOR AND EXPOSURE CHAMBER

The concentrator was manufactured and installed under the direction of Harvard School of Public Health staff, with components like those employed at Harvard. Figure D-1 presents a schematic illustration of the concentrator, exposure chamber, and monitoring instruments. The first element of the concentrator system is a model TE-6001 size-selective inlet (Tisch Environmental, Inc., Cleveland, OH), mounted on the outside of the laboratory structure just above roof level. This unit, similar to those used on high-volume air samplers, is designed to exclude particles >2.5 μm in aerodynamic diameter. Ambient air is drawn in at 5000 L/min by a single high-capacity main pump. The air then passes through a stainless-steel duct to the laboratory interior, and through a tapered stainless-steel transition piece into concentrator stage 1, consisting of 5 virtual impactors (slits) in parallel (see Figure D-2). The major flow (800 L/min from each impactor), depleted of particles, is drawn off laterally by the main pump. The minor flow (200 L/min each slit, 1000 L/min total), enriched in particles, proceeds longitudinally to concentrator stage 2, which consists of one slit like those of stage 1. Here again, the major flow of approximately 800 L/min is drawn off laterally by the main pump, and the particle-enriched minor flow (170-200 L/min, typically 180 L/min) is drawn through a straight 3-inch (7.6-mm) diameter pipe (chamber inlet pipe), into the front and out the rear of the exposure chamber. An auxiliary pump downstream of the exposure chamber, along with 4 small pumps to supply air sampling instruments, provides this minor flow. The chamber inlet pipe is interrupted by a gate valve that can divert any proportion of the flow through a parallel path incorporating a high-efficiency particulate (HEPA) filter. For filtered-air (FA) exposure studies, the gate valve is fully closed and the entire air flow to the chamber passes through the HEPA filter. For concentrated ambient particle (CAP) exposure studies at times of relatively low ambient pollution, the gate valve is fully open and the entire output of the concentrator flows directly through the chamber. At times of moderate to high ambient pollution, the gate valve is partially closed so that part of the air flow is filtered, sufficient to keep the particle concentration delivered to the chamber near the target of 200 $\mu g/m^3$, 2-hr time-weighted average (TWA). Valve adjustment is guided by real-time concentration readings from the Data RAM nephelometer sampling chamber air, taking account of artifacts related to relative humidity. (Both ambient and in-chamber temperature and relative humidity are monitored during exposure periods with portable electronic instruments.) During typical morning exposures, the in-chamber concentration profile is allowed to follow (roughly speaking) that in ambient air. Accordingly, the chamber concentration may be well above 200 $\mu g/m^3$ early in the exposure (400 $\mu g/m^3$ is considered the short-term exposure limit) and well below 200 $\mu g/m^3$ later. This approach is necessary to approximate the correct TWA consistently, given that ambient particle concentrations may decline appreciably during midmorning.

The only major problem encountered with concentrator operation has been fouling of impactor slits with particles, resulting in increased pressure drop across the slits and decreased concentration efficiency. As was the case in the Harvard dog studies (Godleski et al 2000), this tended to occur during periods of high particulate pollution combined with high humidity. Although the fouling observed in the Harvard environment was a more gradual process, in our circumstances it sometimes became noticeable within one hour of starting the concentrator, even though slits were cleaned prior to every study. To deal with the problem, whenever pressure drop in the chamber/downstream of stage 2 reached 18 in H_2O (46 cm H_2O) - twice its optimum value - major flow was decreased as necessary, up to 25%, to decrease the pressure drop. The impactors' lower 50% cutpoint thereby increased from about 0.15 to as much as 0.25 μm - still adequate to concentrate the majority of ambient fine (accumulation-mode) particles. If pressure drop again increased, the major flow from stage 2 was stopped and the hoses disconnected for 1 to 2 min. This tended to cause release of impacted particles, resulting in a brief concentration spike in the chamber, and a return to more normal operation once major flow was restored. On a few occasions, however, these interventions were ultimately unsuccessful, and exposures had to be terminated early (see main report).

Figure D-3 illustrates the exposure chamber, a body plethysmograph modified by adding an extended footwell to accommodate a small pedal-crank exercise device. The chamber was constructed of Formica-sheathed plywood with a clear plastic door and windows, sealed by closed-cell foam strips. The inlet pipe faces the subject approximately at chest height. The main sampling port, through which air is drawn into a MOUDI at 30 L/min, is just above the inlet. Additional ports to the left and right of the inlet, not visible in the illustration, supply air to a HDS sampler and filter cassettes for carbon and elemental analysis, each drawing 10 L/min. A pump behind the chamber exhausts air, typically at 120 L/min, through 5 small ports at regular intervals in a pipe extending across the chamber just above/behind the subject's head. Through a port in the ceiling directly

above the subject's head, a Data RAM nephelometer draws air at 2 L/min for continuous concentration monitoring. To maintain the nephelometer sampling circuit at the same pressure as the chamber, the nephelometer exhaust air is returned to the chamber through another port in the upper front wall. Prior to exposure studies, the chamber was leak-checked by sealing the inlet and sampling ports, reducing the interior air pressure by briefly operating the exhaust pump. Leaks were then traced by sound, and sealed with silicone-based adhesive. Particle distribution inside the chamber was tested by a staff member inside holding a Data RAM nephelometer, moving the inlet systematically to different positions within, above, below, and to the side of the breathing zone, in randomized order to avoid confounding temporal with spatial variation. No statistically significant vertical concentration gradients were found. In one experiment with the concentrator disconnected and ultrasonically nebulized saline aerosol introduced to the chamber at a mean concentration of 1769 $\mu g/m^3$ by Data RAM, a statistically significant horizontal gradient was found, with an average 13% excess concentration on the right (door) side compared to the rest of the chamber. On two occasions with the concentrator operating normally and average in-chamber concentrations near 350 $\mu g/m^3$, significant horizontal gradients were found, with less than 10% excess concentration on the left side compared to the rest of the chamber. Given that observed gradients were small in magnitude, and inconsistent in direction in different experiments, the distribution of fine particles in the chamber was considered to be uniform for practical purposes.

AIR SAMPLING AND ANALYSIS

In addition to in-chamber monitoring by MOUDI and HDS (described in the main report), comparable MOUDI and HDS samplers were operated concurrently to sample air in the concentrator upstream of stage 1, downstream of the size-selective inlet. These samples were considered to represent the fine-particle content of ambient air during exposure studies. Table D-1 summarizes results of ambient sampling.

Each MOUDI employed seven 47-mm Teflon filters (Teflo, Fisher Scientific, 2 µm pore size) in the upper stages, and one 37-mm Teflon filter as the backup. Each HDS employed an upstream sodium-carbonate-coated honeycomb denuder to remove acidic gases (which was not analyzed in this study), a 47-mm Teflon main filter, and a 47-mm sodium-carbonate-coated glass fiber backup filter to capture that portion of particulate nitrate volatilized from the main filter. The nitrate measured on the backup was assumed to be ammonium nitrate, and the appropriate equivalent mass was added to the mass measured on the main filter to obtain the HDS measurement of total mass concentration. All filters were pre- and post-weighed to determine mass concentrations, as described in the main report. Temperature/humidity equilibration for 24 hr preceded each weighing. The weighing room was maintained between 21 and 27 degrees C, 40% and 60% relative humidity. The limit of detection (LOD) for the balance, defined as 3 times the standard deviation of repeated weighings of a blank Teflon filter, was <= 8 µg , yielding a concentration LOD near 2 $\mu g/m^3$ for any stage of the MOUDI and 7 $\mu g/m^3$ for the HDS. After weighing, filters were wetted with 200 µl ethanol, then extracted with 10 mL of ultra-pure water and sonicated 30 min. Sulfate and nitrate content of the extracts was determined by ion chromatography, as described in the main report. A three-point calibration of the ion chromatograph was performed immediately before analyzing each batch of filters. (A batch typically included all filters from two exposure studies.) Five percent of samples were analyzed twice to verify reproducibility (relative mean deviation of the two measurements < 10%). The LOD, redetermined every 6 months, were defined as 3 times the standard deviation of 7 to 9 repeated measurements of a prepared standard, with concentration approximately 5 times the expected LOD. For nitrate, the highest observed LOD was 0.7 µg, equivalent to a concentration of 1.6 $\mu g/m^3$ for the MOUDI (all stages) or 1.2 $\mu g/m^3$ for the HDS. For sulfate, the highest observed LOD was 0.9 µg, equivalent to a concentration of 2 $\mu g/m^3$ for the MOUDI or 1.5 $\mu g/m^3$ for the HDS. Nitrate and sulfate values below the LOD were recorded as zero.

Tissue quartz filters for carbon sampling (Pall Gelman Sciences, 47 mm) were preheated and coated at the analytical laboratory (AtmAA Inc., Calabasas CA) before shipment to our laboratory, where they covered with aluminum foil, sealed in plastic bags, and stored in a vacuum desiccator until use. After exposure, they were stored in Petri dishes sealed with Teflon tape, covered with aluminum foil, placed in sealed plastic bags inside larger sealed plastic bags, and refrigerated before and during shipment back to the analytical laboratory.

Filters for elemental analysis (Teflon 47 mm) were stored and weighed before and after exposure in the climate-controlled weighing room, like the similar MOUDI filters. They were shipped to Chester LabNet, Tigard, OR, for analysis by X-ray fluorescence. Table D-2 presents detailed elemental analysis results not included in the main report.

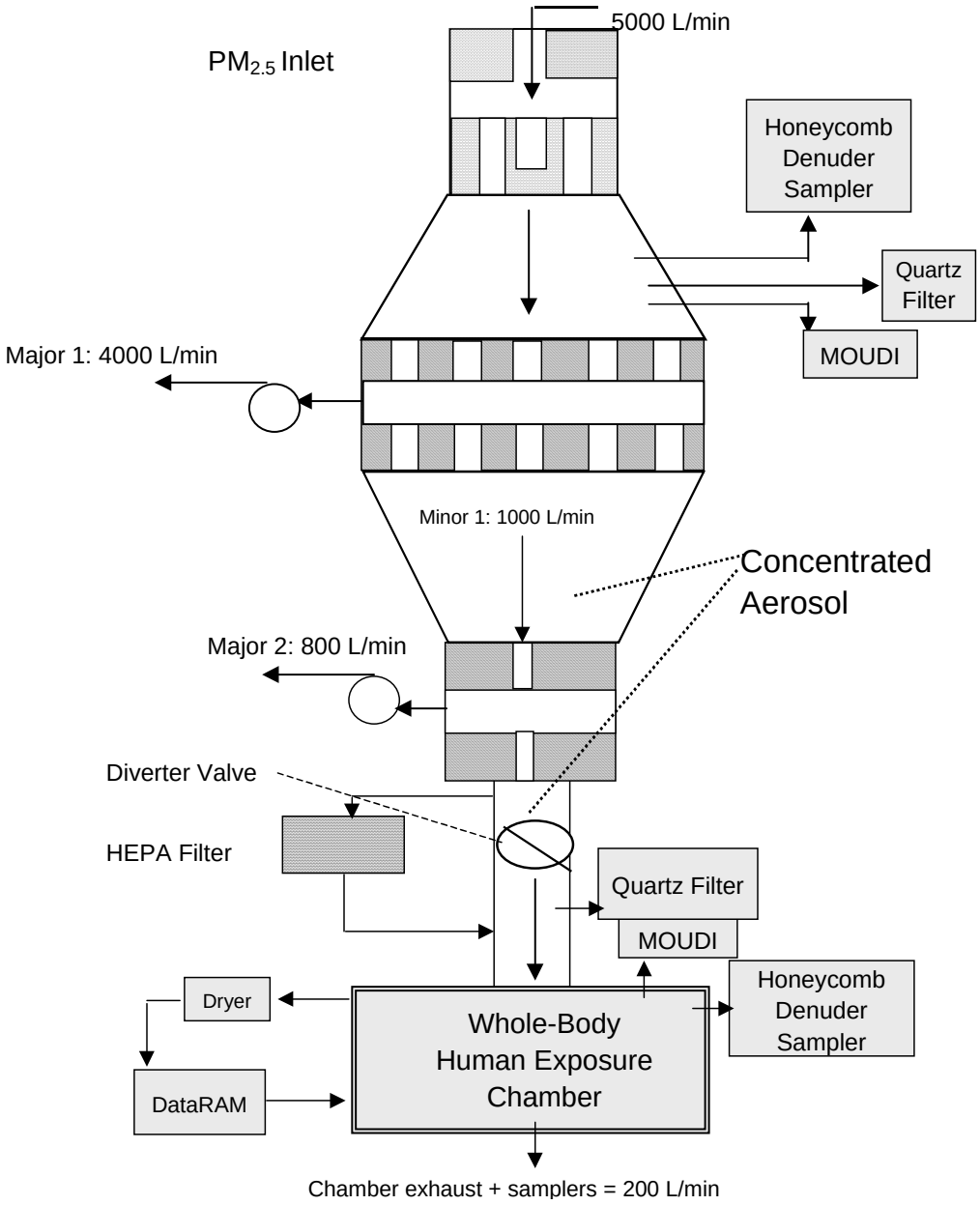

Figure D-1. Schematic diagram of ambient fine particle concentrator, exposure chamber, and monitoring instruments (filter sampling for elemental analysis not shown).

Figure D-2. Concentrator stage 1, viewed from upstream side with access hatch removed to show 5 impactor slits in parallel. Major flow exhaust hoses are visible to left of impactor slits.

Figure D-3. Side view of exposure chamber with staff member inside in subject's usual position. (Actual subjects wore clean-room clothing when inside.) Inlet pipe (larger opening) and main (MOUDI) sampling port (smaller opening) are visible in front wall below window. Sampling instrument platform and hoses of HEPA-filter-containing bypass circuit are visible outside upper front of chamber.

TABLE D-1. AMBIENT FINE PARTICLE CONCENTRATION MEASUREMENTS (MICROGRAMS/CUBIC METER) DURING CONCENTRATED PARTICLE EXPOSURES

GROUP	ID #	< MOUDI >			< HDS >		
		MASS	NO3	SO4	MASS	NO3	SO4
Healthy	1082	93.1	4.8	5.0	42.2	4.4	6.1
Healthy	2172	71.9	18.8	2.2	87.4	20.4	1.7
Healthy	2324	74.4	12.6	4.3	81.0	15.6	5.3
Healthy	2325	41.0	5.2	3.9	54.4	5.0	2.6
Healthy	2340	49.4	5.8	2.7	96.0	7.2	4.4
Healthy	2459	85.6	24.5	9.2	79.5	25.4	9.7
Healthy	2461	63.9	10.4	5.8	84.6	13.6	5.7
Healthy	2465	74.4	14.2	3.8	103.1	15.7	3.2
Healthy	2476	82.5	21.6	2.2	103.4	23.8	2.7
Healthy	2503	65.8	9.4	1.0	70.0	11.8	1.2
Healthy	2505	34.2	4.0	0.1	36.5	6.1	0.0
Healthy	2508	115.2	32.4	2.8	167.3	34.8	3.0
Asthma	1656	51.4	7.5	1.1	22.5	10.9	0.0
Asthma	1750	60.4	3.0	0.0	53.3	3.8	0.0
Asthma	1808	64.7	12.1	3.5	55.3	11.7	3.3
Asthma	2216	59.2	10.8	6.8	86.2	15.6	6.2
Asthma	2433	44.4	4.0	4.0	68.3	2.6	4.7
Asthma	2525	35.0	5.3	4.7	70.2	8.7	5.3
Asthma	2528	62.5	6.1	2.9	52.6	8.3	4.4
Asthma	2541	75.9	0.0	0.0	4.2	3.2	0.0
Asthma	2543	32.5	5.6	0.3	37.3	8.3	0.0
Asthma	2550	69.6	0.7	4.0	53.1	4.1	3.7
Asthma	2551	49.4	11.7	1.1	44.5	14.2	1.4
Asthma	2563	43.3	0.9	9.6	43.4	2.6	8.3

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Table D-2. Concentrated Ambient Particle Mass Concentrations from Total Filter, and Element Concentrations from X-Ray Fluorescence Analysis (Chronological Order)

YR	MON	DY	ASTH	SUB	MASS	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Co	Ni	Cu
1999	7	13	0	1082	266.67	6.28	17.63	0.02	6.98	3.78	3.32	10.61	0.99	0.00	0.05	0.13	7.22	0.00	0.05	0.18
1999	7	22	0	2325																
1999	8	17	0	2340	169.17	0.96	2.61	0.00	6.20	1.15	0.84	2.30	0.42	0.02	0.01	0.05	2.15	0.00	0.02	0.07
1999	8	31	0	2461	155.00	1.92	2.80	0.00	6.12	0.58	0.52	1.71	0.17	0.00	0.01	0.04	1.22	0.01	0.01	0.04
1999	9	21	0	2324																
1999	9	28	0	2459	155.00	0.40	1.61	0.00	6.68	0.83	0.44	1.05	0.34	0.02	0.01	0.03	0.97	0.01	0.01	0.12
1999	11	10	0	2476	226.67	0.73	2.32	0.00	3.39	3.90	0.99	1.89	0.17	0.00	0.01	0.03	1.49	0.00	0.02	0.07
1999	12	14	0	2172	270.00	3.55	8.86	0.00	4.10	5.97	2.34	4.39	0.59	0.02	0.04	0.18	4.45	0.00	0.03	0.22
1999	12	20	0	2503	266.67	6.70	13.16	0.13	2.81	8.51	3.88	7.30	0.64	0.00	0.02	0.21	8.77	0.00	0.02	0.17
2000	1	4	0	2505	154.17	1.71	5.03	0.00	1.51	3.02	0.97	2.88	0.37	0.00	0.02	0.17	5.53	0.00	0.02	0.13
2000	1	13	0	2508	298.89	4.30	11.58	0.08	4.57	6.31	2.41	5.57	0.54	0.00	0.01	0.12	5.19	0.00	0.03	0.37
2000	2	8	0	2465	258.33	2.33	6.45	0.00	6.74	4.44	1.69	4.63	0.66	0.07	0.02	0.13	4.39	0.00	0.02	0.13
2000	4	13	1	2216	194.17	1.31	3.57	0.00	7.97	1.13	1.88	1.97	0.28	0.06	0.03	0.07	1.93	0.01	0.05	0.14
2000	5	31	1	2433	228.33	0.00	1.74	0.02	10.74	1.32	0.70	0.88	0.12	0.03	0.02	0.03	0.98	0.00	0.00	0.09
2000	6	6	1	2528	236.67	0.69	3.62	0.00	7.98	1.53	1.10	2.27	0.31	0.06	0.02	0.08	2.09	0.00	0.02	0.09
2000	8	17	1	2525	219.17	2.06	3.63	0.00	10.70	1.51	1.92	3.57	0.41	0.08	0.02	0.08	2.80	0.00	0.02	0.21
2000	11	7	1	2541	122.22	4.63	8.27	0.02	2.16	0.72	1.34	4.24	0.16	0.00	0.03	0.12	5.09	0.00	0.01	0.12
2000	11	14	1	1656	230.83	1.86	3.27	0.07	4.50	3.30	1.40	3.45	0.43	0.06	0.02	0.10	3.77	0.00	0.02	0.17
2000	12	28	1	2543	198.33	3.17	5.10	0.02	2.56	10.40	1.76	3.78	0.39	0.02	0.03	0.12	4.92	0.02	0.01	0.18
2001	1	17	1	1750	173.33	1.98	4.23	0.04	3.14	1.57	1.43	2.86	0.69	0.06	0.09	0.33	7.79	0.02	0.09	0.21
2001	2	15	1	2551	221.67	1.24	2.24	0.01	3.74	1.51	0.98	1.61	0.27	0.03	0.02	0.12	3.13	0.01	0.03	0.14
2001	2	22	1	2550	234.44	0.29	3.42	0.03	14.14	2.51	0.91	1.84	0.41	0.03	0.06	0.06	1.93	0.01	0.03	0.12
2001	3	27	1	1808	240.83	0.52	2.37	0.01	7.66	1.94	0.60	2.03	0.22	0.03	0.02	0.03	1.62	0.01	0.01	0.08
2001	7	10	1	2563	172.50	0.59	2.96	0.00	22.43	0.09	0.77	1.77	0.42	0.11	0.04	0.06	1.64	0.00	0.02	0.06
				Mean	213.32	2.15	5.29	0.02	6.67	3.00	1.46	3.30	0.41	0.03	0.03	0.10	3.59	0.00	0.03	0.14
				SD	46.40	1.89	4.17	0.03	4.72	2.69	0.89	2.26	0.21	0.03	0.02	0.07	2.30	0.01	0.02	0.07

(Table D-2 continued)

YR	MON	DY	ASTH	SUB	MASS	Zn	As	Se	Br	Rb	Sr	Y	Zr	Mo	Pb
1999	7	13	0	1082	266.67	1.92	0.00	0.01	0.04	0.01	0.08	0.00	0.19	0.00	0.15
1999	7	22	0	2325											
1999	8	17	0	2340	169.17	0.42	0.02	0.03	0.04	0.00	0.01	0.00	0.00	0.04	0.10
1999	8	31	0	2461	155.00	0.14	0.00	0.00	0.02	0.00	0.02	0.00	0.03	0.00	0.06
1999	9	21	0	2324											
1999	9	28	0	2459	155.00	0.20	0.01	0.00	0.03	0.00	0.00	0.00	0.02	0.00	0.10
1999	11	10	0	2476	226.67	0.47	0.02	0.03	0.04	0.01	0.01	0.00	0.02	0.00	0.10
1999	12	14	0	2172	270.00	0.91	0.03	0.02	0.08	0.00	0.05	0.00	0.26	0.00	0.18
1999	12	20	0	2503	266.67	0.94	0.02	0.02	0.05	0.01	0.08	0.00	0.19	0.02	0.22
2000	1	4	0	2505	154.17	1.03	0.02	0.00	0.03	0.00	0.03	0.00	0.20	0.02	0.17
2000	1	13	0	2508	298.89	1.08	0.00	0.00	0.09	0.00	0.07	0.00	0.13	0.00	0.11
2000	2	8	0	2465	258.33	0.76	0.01	0.00	0.07	0.01	0.07	0.00	0.26	0.00	0.11
2000	4	13	1	2216	194.17	0.41	0.01	0.01	0.02	0.00	0.02	0.00	0.47	0.00	0.06
2000	5	31	1	2433	228.33	0.13	0.00	0.01	0.06	0.01	0.02	0.00	0.11	0.03	0.08
2000	6	6	1	2528	236.67	0.47	0.02	0.01	0.03	0.02	0.04	0.01	0.30	0.00	0.03
2000	8	17	1	2525	219.17	0.44	0.02	0.02	0.07	0.00	0.08	0.00	0.16	0.00	0.12
2000	11	7	1	2541	122.22	0.54	0.04	0.03	0.00	0.01	0.02	0.00	0.03	0.00	0.10
2000	11	14	1	1656	230.83	0.61	0.01	0.01	0.12	0.00	0.03	0.00	0.21	0.00	0.14
2000	12	28	1	2543	198.33	1.01	0.02	0.00	0.03	0.00	0.04	0.00	0.06	0.06	0.17
2001	1	17	1	1750	173.33	0.94	0.04	0.00	0.03	0.00	0.06	0.00	0.08	0.01	0.10
2001	2	15	1	2551	221.67	0.40	0.00	0.02	0.06	0.01	0.03	0.00	0.13	0.09	0.12
2001	2	22	1	2550	234.44	0.52	0.00	0.02	0.07	0.01	0.03	0.00	0.02	0.00	0.06
2001	3	27	1	1808	240.83	0.27	0.00	0.00	0.06	0.02	0.02	0.00	0.08	0.00	0.07
2001	7	10	1	2563	172.50	0.19	0.00	0.01	0.04	0.00	0.03	0.00	0.02	0.00	0.03
				Mean	213.32	0.63	0.01	0.01	0.05	0.00	0.04	0.00	0.14	0.01	0.11
				SD	46.40	0.42	0.01	0.01	0.03	0.01	0.02	0.00	0.12	0.02	0.05