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TEST METHOD EVALUATIONS AND EMISSIONS TESTING FOR RATING WOOD STOVES

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ABSTRACT

The U. S. Environmental Protection Agency has decided to develop a New Source Performance Standard (NSPS) for wood burning stoves. During the development process several issues must be resolved. One of the more critical issues is the selection of an emission sampling method and stove operating procedure. This report addresses the comparison of three candidate sampling methods: the EPA Modified Method 5 (MM5), the Oregon Method 7 (OM7), and the ASTM proposed Method P180. It also addresses the effect emission format (g/hr, g/kg wood burned, ug/J heat output) has on the intermethod correlations.

Five stoves (i.e., two catalytic, one noncatalytic generic, one noncatalytic high efficiency, and one catalytic fireplace insert) were tested. The stoves were nominally operated according to the State of Oregon's certification procedure. Simultaneous tests were conducted using MM5 and OM7 in the stove flue and MM5, OM7, and ASTM in the (ASTM) dilution tunnel. Quality assurance tests using duplicate sampling trains were also conducted. Proportional sampling, using SO2 as a tracer gas, was conducted in the flue, and isokinetic sampling was conducted in the dilution tunnel.

Results showed good correlations between the total train emissions obtained with each method. The strength of the correlations varied with the emission format; the grams per hour format showed the strongest correlation. POM emissions showed a general (but weak) correlation with total emissions when the grams per hour format was used; there were no correlations when the emissions were expressed in either of the other two formats.

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SECTION 1

INTRODUCTION

The purpose of this test program was to collect emission testing data for the Environmental Protection Agency (EPA) to evaluate emission measurement procedures that have been applied to certification of woodstoves and to develop an acceptable procedure for application to a New Source Performance Standard (NSPS) for the woodstove source category.

The primary objectives of the project as defined by EPA were:

- To collect emission testing data for evaluating the effectiveness of the Oregon Department of Environmental Quality (DEQ) emission sampling method (OM7) in distinguishing between low and high emissions of total particulate matter, condensible organic matter, and polycyclic organic matter POM, using EPA Modified Method 5 (MM5) as the reference.

- To collect emission testing data for evaluating the accuracy and precision of the Oregon DEQ (OM7) sampling method and the applicability of the dilution tunnel emission sampling approach (as used with the American Society for Testing Materials (ASTM) home heating appliance emission sampling method) to the Oregon DEQ OM7 sampling method.

- To collect emission testing data for evaluating the representativeness of the ASTM emission sampling method using MM5 as the reference.

SAMPLING METHODS

The three sampling methods (MM5, OM7, and ASTM) have slightly different objectives which may account for slight differences in the actual emissions measured. EPA MM5 was designed to collect isokinetic samples of particulate and condensible and semi-volatile organic components. The method captures the semi-volatile organic fraction on a sorbent resin.

The Oregon sampling method was designed for the collection of particles and condensible organic matter. Isokinetic sampling is not required for sampling woodstove emissions, but the method does require proportional sampling.

The ASTM method makes the assumption that the particles in the diluted gas stream are small and behave as a gas. The sample rate is held constant (± 2%) throughout the test and gas measurements are taken at varying time intervals depending on the burn rate. Since the sample is collected at basically ambient temperature and moisture conditions the sample train filter is not heated. The ASTM method specifies that the sample rate be based on the filter loading and the filter face velocity (2 to 30 ft/min). During these tests, all sampling trains were operated at fixed points in the stack or dilution tunnel as appropriate.

DESCRIPTION OF FACILITIES

The five stoves tested included three catalytic stoves (a Timber-eze Model 477, a Blaze King Catalyst Stove - King Model KEJ-1101, and a Fisher-Tech IV fireplace insert), one conventional non-catalytic stove (Lakewood), and one low emission non-catalytic stove (BOSCA).

PROJECT PARTICIPANTS

Project participants and their goals and responsibilities included:

- EPA AEERL - to evaluate stove emissions and available control strategies for the purpose of standards development.
- EPA OAQPS - to evaluate the procedures used in the collection of existing data and select a representative and reliable procedure for future testing of woodstove emissions.
- Radian Corporation - to specify woodstove design and operating parameters that should be tested in order to provide the necessary information for this program and to perform analyses on all samples collected by the MM5, OM7, and ASTM sampling methods.
- Engineering-Science - to develop a detailed stove operation and emission test and quality assurance approach to fulfill the goals of AEERL and OAQPS; to operate the woodstoves and collect emission samples according to those plans; and, to summarize the conditions, methodologies, and results of the test program.

TEST LOCATION

All tests were conducted at the ES test facility in Research Triangle Park, North Carolina. An air conditioned trailer was used to house the continuous analyzers and data recorders.

SECTION 2

SUMMARY OF RESULTS

Sampling problems and inconsistencies (discussed in Section 5) resulted in each data point being calculated using three different approaches. Briefly, those approaches are as follows:

Tables 1a, 1b and 1c: The stove heat outputs and stack flows were calculated using the Oregon woodstove test method of carbon, hydrogen, oxygen balance (CHO balance). The dilution tunnel flows and moisture contents were determined for each of the samples collected at that location. Possible problems with the CEMS data and definite problems with the tracer gas method made the CHO balance results suspect. Differences in the methods for measuring dilution tunnel flows and moisture specified by the different sampling methods introduced minor differences in calculations of the emission rates measured simultaneously in the dilution tunnel.

Tables 2a, 2b and 2c: The stove heat outputs and stack flows were calculated as described for Tables 1a, 1b and 1c. The dilution tunnel flows and moisture contents were standardized to those results of the OM7 train, which uses EPA Reference Method 4 for moisture measurements.

Tables 3a, 3b and 3c: The stove heat input was determined from the kilograms of dry wood burned per hour and the analyzed heat content of the fuel. The stack flow rate was calculated using F_C, and F factor for wood (40 CFR 60.45, July 1985). Dilution tunnel flows and moisture contents were standardized to the OM7 train as in Tables 2a, 2b and 2c.

The results of the 22 test burns are presented in three emission formats: grams per hour (Tables 1a, 2a and 3a, grams per kilogram of wood burned (Tables 1b, 2b and 3b) and micrograms per joule (Tables 1c, 2c and 3c). Duplicate sample results are included below the matching sample run.

Some of the data have been qualified in the summary tables. Those data include the following:

- All sample runs conducted during test burns "Blaze King" 3 and "BOSCA" -3 (High Efficiency -3). These burns could not be sampled to completion. This prohibited calculations according to the Oregon woodstove test procedure and did not provide an emission measurement representative of a complete burn. Results were calculated using the F_C factor and are reported in Tables 3a, 3b and 3c.

TABLE 1a. SUMMARY OF WOODSTOVE EMISSION TEST RESULTS USING OREGON WOODSTOVE COMBUSTION PROGRAM AND ACTUAL DILUTION TUNNEL GAS FLOWS DETERMINED BY EACH SAMPLE TRAIN - GRAMS PER HOUR

Stove Burn Number	Heat Output (Btu/hr)	Burn Rate (dry kg/hr)	Particulate: Stack Emissions MM5	Particulate: Stack Emissions OM7	Particulate: Dilution Tunnel Emissions MM5	Particulate: Dilution Tunnel Emissions OM7	Particulate: Dilution Tunnel Emissions ASTM	TCO Stack	TCO Dilution Tunnel	Phenol Stack	Phenol Dilution Tunnel	POM Stack	POM Dilution Tunnel
Timbereze													
1A	10,772	0.90	9.38	4.43	11.5L	6.17L	[illegible]	3.39	4.17L	0.0567	0.0510L	0.0537	0.0822L
2A	15,006	1.22	20.2	10.4	12.8	4.90	[illegible]	6.29	3.36	0.154	0.0288	0.112	0.0365
2A*	15,006	1.22					[illegible]						
Blaze King													
4	7,220	0.60	17.4	6.02	10.7	7.98Q	[illegible]	9.55	4.22	0.0762	0.0906	0.0240	0.0473
4*	7,220	0.60				3.95							
1	11,185	1.09	5.75	3.71X	11.0	4.13	[illegible]	2.15	3.40	0.0467	0.0575	0.0206	0.0384
1*	11,185	1.09		3.36			[illegible]						
5	22,281	1.64	9.76	3.00XQ	13.3	9.30Q	[illegible]	4.17	3.54	0.145	0.0990	0.0817	0.0726
5*	22,281	1.64	8.49		15.2			2.99	3.63	0.140	0.111	0.0798	0.0785
2	32,170	2.77	15.6	8.07	23.7	10.7	[illegible]	4.98	6.62	0.178	0.255	0.104	0.173
2*	32,170	2.77		7.64Q									
3A													
Lakewood													
1	9,812	0.89	44.5	23.8Q	53.9	24.3Q	[illegible]	15.7	19.4	0.335	0.460	0.121	0.185
3	13,277	1.17	42.9	24.5Q	75.3	27.0	[illegible]	20.0	29.5	0.338	0.747	0.174	0.539
3*	13,277	1.17		26.7	53.5				24.9		0.659		0.505
2	16,587?	1.51	32.9	19.6Q	54.4	28.5	[illegible]	13.8	23.9	0.569	1.10	0.245	0.492
4	96,474	7.17	184.	52.0Q	168.0	54.5	[illegible]	92.5	80.8	7.73	3.86	16.4	12.6
4*	96,474	7.17	184.			88.3H		80.8		5.49		14.4	

(continued)

TABLE 1a (continued)

Stove Burn Number	Heat Output (Btu/hr)	Burn Rate (dry kg/hr)	Particulate: Stack Emissions MM5	Particulate: Stack Emissions OM7	Particulate: Dilution Tunnel Emissions MM5	Particulate: Dilution Tunnel Emissions OM7	Particulate: Dilution Tunnel Emissions ASTM	TCO Stack	TCO Dilution Tunnel	Phenol Stack	Phenol Dilution Tunnel	POM Stack	POM Dilution Tunnel
Bosca													
2	7,972	0.54	30.5	21.2	18.5	8.26	12.3	12.1	6.21	0.194	0.0557	0.0923	0.0342
2*	7,972	0.54				12.8Q							
4	13,999	1.08	16.0	9.26	28.4	8.66Q	9.93	6.55	7.76	0.383	0.249	0.432	0.384
1	19,511	1.46	20.6	15.4	33.0	10.7	10.1	9.36	5.94	0.327	0.225	0.833	0.801
1*	19,511	1.46		11.6			8.98						
5	40,591	3.10	56.3	25.9	67.1	37.1	20.5	24.2	21.3	2.32	1.48	4.50	4.48
3A													
3*A													
Fisher													
2	8,752	0.55	9.94	5.38	22.6L	10.7	4.17	2.97	3.22L	0.0637	0.0371L	0.0202	0.0815
2*	8,752	0.55			14.9				2.68		0.0220		0.0641
4	14,273	0.95	17.3	11.8	23.8H	13.1	6.12	5.13	3.99H	0.140	0.0246H	0.0451	0.0750H
4*	14,273	0.95			27.5				3.81		0.0312		0.105
3	23,570	1.58	19.6	16.0	47.7	21.4	13.6	5.53	6.67	0.183	0.123	0.0833	0.238
1	29,223	2.02	40.5	30.4	71.9	37.1	31.2	12.6	13.0	0.432	0.146	0.155	0.415

* Indicates results of duplicate runs
Q - Data presented but quality is uncertain due to low filter box temperatures
X - Back filter torn
L - Sample rate below 90% isokinetics
H - Sample rate above 110% isokinetics
A - Test burn was not consistent with specified stove operating procedures

TABLE 1b. SUMMARY OF WOODSTOVE EMISSION TEST RESULTS USING OREGON WOODSTOVE COMBUSTION PROGRAM AND ACTUAL DILUTION TUNNEL GAS FLOWS DETERMINED BY EACH SAMPLE TRAIN - GRAMS/KILOGRAMS

Stove Burn Number	Heat Output (Btu/hr)	Burn Rate (dry kg/hr)	Particulate: Stack Emissions		Particulate: Dilution Tunnel Emissions			TCO		Phenol		POM	
			MM5	OM7	MM5	OM7	ASTM	Stack	Dilution Tunnel	Stack Stack	Dilution Tunnel	Stack	Dilution Tunnel
Timbereze													
1A	10,772	0.90	10.4	4.92	12.8L	6.85L	4.79	3.76	4.64L	0.0630	0.0567L	0.0596	0.0913L
2A	15,006	1.22	16.6	8.55	10.5	4.02	2.57	5.16	2.75	0.126	0.0236	0.0921	0.0299
2A*	15,006	1.22					0.781						
Blaze King													
4	7,220	0.60	29.0	10.0	17.8	13.3Q	6.80	15.9	7.03	0.127	0.151	0.0400	0.0788
4*	7,220	0.60				6.58							
1	11,185	1.09	5.28	3.40X	10.1	3.79	2.33	1.97	3.12	0.0428	0.0527	0.0263	0.0352
1*	11,185	1.09		3.08			2.29						
5	22,281	1.64	5.95	1.83XQ	8.13	5.67Q	2.99	2.54	2.16	0.0887	0.0604	0.0498	0.0443
5*	22,281	1.64	5.18		9.24			1.82	2.21	0.0852	0.0678	0.0487	0.0479
2	32,170	2.77	5.62	2.91	8.56	3.87	2.88	1.80	2.39	0.0644	0.0919	0.0376	0.0625
2*	32,170	2.77		2.76Q									
3A													
Lakewood													
1	9,812	0.89	50.0	26.7Q	60.6	27.3Q	30.8	17.6	21.8	0.376	0.517	0.136	0.208
3	13,277	1.17	36.7	20.9Q	64.4	23.1	28.2	17.1	25.2	0.289	0.639	0.149	0.460
3*	13,277	1.17		22.9	45.7				21.2		0.563		0.432
2	16,587	1.51	21.8	13.0Q	36.0	18.9	14.8	9.12	15.8	0.377	0.729	0.162	0.326
4	96,474	7.17	25.6	7.26Q	23.5	7.60	13.8	12.9	11.3	1.08	0.538	2.28	1.76
4*	96,474	7.17	25.6			12.3H		11.3		0.765		2.01	

(continued)

TABLE 1b (continued)

Stove Burn Number	Heat Output (Btu/hr)	Burn Rate (dry kg/hr)	Particulate: Stack Emissions MM5	Particulate: Stack Emissions OM7	Particulate: Dilution Tunnel Emissions MM5	Particulate: Dilution Tunnel Emissions OM7	Particulate: Dilution Tunnel Emissions ASTM	TCO Stack	TCO Dilution Tunnel	Phenol Stack Stack	Phenol Dilution Tunnel	POM Stack	POM Dilution Tunnel
Bosca													
2	7,972	0.54	56.4	39.3	34.2	15.3	22.8	22.4	11.5	0.359	0.103	0.171	0.0633
2*	7,972	0.54				23.7Q							
4	13,999	1.08	14.8	8.58	26.3	8.02Q	9.20	6.06	7.18	0.355	0.231	0.400	0.355
1	19,511	1.46	14.1	10.6	22.6	7.30	6.90	6.41	4.07	0.224	0.154	0.571	0.549
1*	19,511	1.46		7.98			6.15						
5	40,591	3.10	16.2	8.37	21.7	12.0	6.63	7.80	6.86	0.747	0.476	1.45	1.44
3A													
3*A													
Fisher													
2	8,752	0.55	18.1	9.79	41.2L	19.5	7.59	5.40	5.86L	0.116	0.0674L	0.0367	0.148L
2*	8,752	0.55			27.1				4.87		0.0401		0.117
4	14,273	0.95	18.2	12.4	25.1H	13.8	6.45	5.40	4.20H	0.147	0.0259H	0.0475	0.0789H
4*	14,273	0.95			29.0				4.01		0.0328		0.110
3	23,570	1.58	12.4	10.1	30.2	13.5	8.58	3.50	4.22	0.116	0.0780	0.0527	0.151
1	29,223	2.02	20.1	15.1	35.6	18.3	15.4	6.22	6.42	0.214	0.0724	0.0767	0.205

* Indicates results of duplicate runs
Q - Data presented but quality is uncertain due to low filter box temperatures
X - Back filter torn
L - Sample rate below 90% isokinetics
H - Sample rate above 110% isokinetics
A - Test burn was not consistent with specified stove operating procedures

TABLE 1c. SUMMARY OF WOODSTOVE EMISSION TEST RESULTS USING OREGON WOODSTOVE COMBUSTION PROGRAM AND ACTUAL DILUTION TUNNEL GAS FLOWS DETERMINED BY EACH SAMPLE TRAIN - MICROGRAMS/JOULE

Stove Burn Number	Heat Output (Btu/hr)	Burn Rate (dry kg/hr)	Particulate: Stack Emissions MM5	Particulate: Stack Emissions OM7	Particulate: Dilution Tunnel Emissions MM5	Particulate: Dilution Tunnel Emissions OM7	Particulate: Dilution Tunnel Emissions ASTM	TCO Stack	TCO Dilution Tunnel	Phenol Stack Stack	Phenol Dilution Tunnel	POM Stack	POM Dilution Tunnel
Timbereze													
1A	10,772	0.90	0.826	0.390	1.01L	0.543L	0.379	0.298	0.367L	0.00499	0.00449L	0.00472	0.00724L
2A	15,006	1.22	1.287	0.659	0.811	0.310	0.198	0.398	0.212	0.00973	0.00182	0.00710	0.00231
2*A	15,006	1.22					0.0603						
Blaze King													
4	7,220	0.60	2.29	0.790	1.40	1.05Q	0.536	1.26	0.554	0.0100	0.0119	0.00315	0.00621
4*	7,220	0.60				0.518							
1	11,185	1.09	0.488	0.314X	0.935	0.350	0.215	0.182	0.288	0.00396	0.00487	0.00243	0.00325
1*	11,185	1.09		0.285			0.212						
5	22,281	1.64	0.415	0.128XQ	0.568	0.396Q	0.209	0.177	0.151	0.00619	0.00422	0.00348	0.00309
5*	22,281	1.64	0.361		0.645			0.127	0.154	0.00595	0.00473	0.00340	0.00334
2	32,170	2.77	0.459	0.238	0.699	0.316	0.235	0.147	0.195	0.00526	0.00751	0.00307	0.00510
2*	32,170	2.77		0.225Q									
3A													
Lakewood													
1	9,812	0.89	4.31	2.30Q	5.21	2.35Q	2.65	1.52	1.88	0.0324	0.0444	0.0117	0.0179
3	13,277	1.17	3.07	1.75Q	5.38	1.93	2.36	1.43	2.11	0.0241	0.0534	0.0124	0.0385
3*	13,277	1.17		1.91	3.82				1.78		0.0471		0.0361
2	16,587	1.51	1.88	1.12Q	3.11	1.64	1.29	0.787	1.36	0.0325	0.0630	0.0140	0.0281
4	96,474	7.17	1.81	0.512Q	1.65	0.536	0.973	0.910	0.794	0.0760	0.0379	0.161	0.124
4*	96,474	7.17	1.81			0.868H		0.795		0.0539		0.141	

(continued)

TABLE 1c (continued)

Stove Burn Number	Heat Output (Btu/ hr)	Burn Rate (dry kg/ hr)	Particulate: Stack Emissions MM5	Particulate: Stack Emissions OM7	Particulate: Dilution Tunnel Emissions MM5	Particulate: Dilution Tunnel Emissions OM7	Particulate: Dilution Tunnel Emissions ASTM	TCO Stack	TCO Dilution Tunnel	Phenol Stack Stack	Phenol Dilution Tunnel	POM Stack	POM Dilution Tunnel
Bosca													
2	7,972	0.54	3.62	2.53	2.20	0.982	1.47	1.44	0.739	0.0231	0.00663	0.0110	0.00406
2*	7,972	0.54				1.52Q							
4	13,999	1.08	1.09	0.628	1.92	0.587Q	0.673	0.444	0.526	0.0260	0.0169	0.0292	0.0260
1	19,511	1.46	1.00	0.749	1.60	0.518	0.490	0.455	0.289	0.0159	0.0109	0.0405	0.0390
1*	19,511	1.46		0.566			0.437						
5	40,591	3.10	1.18	0.606	1.57	0.868	0.480	0.565	0.497	0.0541	0.0345	0.105	0.105
3A													
3*A													
Fisher													
2	8,752	0.55	1.08	0.583	2.45L	1.16	0.452	0.322	0.349L	0.00690	0.00402L	0.00219	0.00883L
2*	8,752	0.55			1.62				0.290		0.00239		0.00695
4	14,273	0.95	1.15	0.783	1.58H	0.868	0.407	0.341	0.265H	0.00928	0.00164H	0.00300	0.00498H
4*	14,273	0.95			1.83				0.253		0.00207		0.00696
3	23,570	1.58	0.789	0.643	1.92	0.860	0.546	0.222	0.268	0.00738	0.00496	0.00335	0.00959
1	29,223	2.02	1.32	0.988	2.34	1.20	1.01	0.407	0.421	0.0140	0.00474	0.00503	0.0135

* Indicates results of duplicate runs
Q - Data presented but quality is uncertain due to low filter box temperatures
X - Back filter torn
L - Sample rate below 90% isokinetics
H - Sample rate above 110% isokinetics
A - Test burn was not consistent with specified stove operating procedures

TABLE 2a. SUMMARY OF WOODSTOVE EMISSION TEST RESULTS USING OREGON METHOD 7 TO STANDARDIZE DILUTION TUNNEL FLOW & MOISTURE CONTENT GRAMS PER HOUR

Stove Burn Number	Heat Output (Btu/hr)	Burn Rate (dry kg/hr)	Particulate: Stack Emissions MM5	Particulate: Stack Emissions OM7	Particulate: Dilution Tunnel Emissions MM5	Particulate: Dilution Tunnel Emissions OM7	Particulate: Dilution Tunnel Emissions ASTM	TCO Stack	TCO Dilution Tunnel	Phenol Stack	Phenol Dilution Tunnel	POM Stack	POM Dilution Tunnel
Timbereze													
1A	10.772	0.90	9.38	4.43	11.4L	6.16L	4.26	3.39	4.12	0.0567	0.0507	0.0537	0.0816
2A	15,006	1.22	20.2	10.4	13.2	4.89	3.37	6.29	3.44	0.154	0.0298	0.112	0.0376
2A*	15,006	1.22					0.999						
Blaze King													
4	7,220	0.60	17.4	6.02	10.7	7.99Q	4.50	9.55	4.22	0.0762	0.0908	0.0240	0.0474
4*	7,220	0.60				3.96							
1	11,185	1.09	5.75	3.71X	10.9	4.15	2.66	2.15	3.39	0.0467	0.0570	0.0286	0.0381
1*	11,185	1.09		3.36			2.34						
5	22,281	1.64	9.76	3.00XQ	13.4	9.27Q	4.96	4.17	3.56	0.145	0.0996	0.0817	0.0731
5*	22,281	1.64	8.49		15.3			2.99	3.65	0.140	0.112	0.0798	0.0790
2	32,170	2.77	15.6	8.07	24.1	10.7	8.55	4.98	6.75	0.178	0.258	0.104	0.176
2*	32,170	2.77		7.64Q									
Lakewood													
1	9,812	0.89	44.5	23.8Q	54.1	24.4Q	27.2	15.7	19.4	0.335	0.461	0.121	0.186
3	13,277	1.17	42.9	24.5Q	74.8	27.0	33.1	20.0	29.2	0.338	0.741	0.174	0.5341
3*	13,277	1.17		26.7	53.2				24.8		0.655		0.503
2	16,587	1.51	32.9	19.6Q	54.5	28.5	22.1	13.8	23.9	0.569	1.10	0.245	0.492
4	96,474	7.17	184.	52.0Q	170.	54.6	97.1	92.5	81.8	7.73	3.90	16.4	12.8
4*	96,474	7.17	184.			89.0H		80.8		5.49		14.4	

(continued)

TABLE 2a (continued)

Stove Burn Number	Heat Output (Btu/hr)	Burn Rate (dry kg/hr)	Particulate: Stack Emissions MM5	Particulate: Stack Emissions OM7	Particulate: Dilution Tunnel Emissions MM5	Particulate: Dilution Tunnel Emissions OM7	Particulate: Dilution Tunnel Emissions ASTM	TCO Stack	TCO Dilution Tunnel	Phenol Stack	Phenol Dilution Tunnel	POM Stack	POM Dilution Tunnel
Bosca													
2	7,972	0.54	30.5	21.2	18.5	8.27	12.2	12.1	6.21	0.194	0.0558	0.0923	0.0343
2*	7,972	0.54				12.8Q							
4	13,999	1.08	16.0	9.26	28.6	8.66Q	9.10	6.55	7.85	0.383	0.251	0.432	0.385
1	19,511	1.46	20.6	15.4	32.7	10.7	9.85	9.36	5.90	0.327	0.222	0.833	0.791
1*	19,511	1.46		11.6			8.76						
5	40,591	3.10	50.3	25.9	68.3	37.2	20.4	24.2	21.6	2.32	1.50	4.50	4.55
Fisher													
2	8,752	0.55	9.94	5.38	22.6L	10.7	4.17	2.97	3.25	0.0637	0.0815	0.0202	0.0371
2*	8,752	0.55			14.9				2.70		0.0641		0.0220
4	14,273	0.95	17.3	11.8	23.9H	13.0	6.23	5.13	4.03	0.140	0.0753	0.0451	0.0247
4*	14,273	0.95			28.3				3.94		0.108		0.0320
3	23,570	1.58	19.6	16.0	48.0	21.3	13.4	5.53	6.73	0.183	0.240	0.0833	0.124
1	29,223	2.02	40.5	30.4	71.6	37.0	30.3	12.6	12.9	0.432	0.413	0.155	0.146

* Indicates results of duplicate runs
Q - Data presented but quality is uncertain due to low filter box temperatures
X - Back filter torn
L - Sample rate below 90% isokinetics
H - Sample rate above 110% isokinetics
A - Test burn was not consistent with specified stove operating procedures

TABLE 2b. SUMMARY OF WOODSTOVE EMISSION TEST RESULTS USING OREGON METHOD 7 TO STANDARDIZE DILUTION TUNNEL FLOW & MOISTURE CONTENT GRAMS PER KILOGRAM

Stove Burn Number	Heat Output (Btu/hr)	Burn Rate (dry) (kg/hr)	Particulate: Stack Emissions MM5	Particulate: Stack Emissions OM7	Particulate: Dilution Tunnel Emissions MM5	Particulate: Dilution Tunnel Emissions OM7	Particulate: Dilution Tunnel Emissions ASTM	TCO Stack	TCO Dilution Tunnel	Phenol Stack	Phenol Dilution Tunnel	POM Stack	POM Dilution Tunnel
Timbereze													
1A	10,772	0.90	10.4	4.92	12.6	6.84	4.73	3.76	4.58	0.0630	0.0563	0.0596	0.0906
2A	15,006	1.22	16.6	8.55	10.9	4.01	2.76	5.16	2.82	0.126	0.0244	0.0921	0.0308
2A*	15,006	1.22					0.818						
Blaze King													
4	7,220	0.60	29.0	10.0	17.8	13.3	7.50	15.9	7.04	0.127	0.151	0.0400	0.0790
4*	7,220	0.60				6.61							
1	11,185	1.09	5.28	3.40X	10.0	3.81	2.44	1.97	3.11	0.0428	0.0523	0.0263	0.0350
1*	11,185	1.09		3.08			2.15						
5	22,281	1.64	5.95	1.83XQ	8.17	5.66	3.03	2.54	2.17	0.0887	0.0607	0.0498	0.0446
5*	22,281	1.64	5.18		9.31			1.82	2.22	0.0852	0.0682	0.0487	0.0482
2	32,170	2.77	5.62	2.91	8.72	3.87	3.09	1.80	2.44	0.0644	0.0931	0.0376	0.0635
2*	32,170	2.77		2.76Q									
Lakewood													
1	9,812	0.89	50.0	26.70	60.7	27.4	30.6	17.6	21.8	0.376	0.518	0.136	0.209
3	13,277	1.17	36.7	20.90	63.9	23.1	28.3	17.1	25.0	0.289	0.633	0.149	0.457
3*	13,277	1.17		22.9	45.5				21.2		0.560		0.430
2	16,587	1.51	21.8	13.0Q	36.1	18.8	14.6	9.12	15.9	0.377	0.730	0.162	0.326
4	96,474	7.17	25.6	7.26Q	23.7	7.61	13.5	12.9	11.4	1.08	0.545	2.28	1.78
4*	96,474	7.17	25.6			12.4		11.3		0.765		2.01	

(continued)

TABLE 2b (continued)

Stove Burn Number	Heat Output (Btu/hr)	Burn Rate (dry) (kg/hr)	Particulate Stack Emissions MM5	Particulate Stack Emissions OM7	Particulate Dilution Tunnel Emissions MM5	Particulate Dilution Tunnel Emissions OM7	Particulate Dilution Tunnel Emissions ASTM	TCO Stack	TCO Dilution Tunnel	Phenol Stack	Phenol Dilution Tunnel	POM Stack	POM Dilution Tunnel
Bosca													
2	7,972	0.54	56.4	39.3	34.3	15.3	22.5	22.4	11.5	0.359	0.103	0.171	0.0635
2*	7,972	0.54				23.7							
4	13,999	1.08	14.8	8.58	26.4	8.02	8.43	6.06	7.27	0.355	0.232	0.400	0.357
1	19,511	1.46	14.1	10.6	22.4	7.30	6.75	6.41	4.04	0.224	0.152	0.571	0.542
1*	19,511	1.46		7.98			6.00						
5	40,591	3.10	16.2	8.37	22.0	12.0	6.59	7.80	6.97	0.747	0.483	1.45	1.47
Fisher													
2	8,752	0.55	18.1	9.79	41.0	19.5	7.58	5.40	5.91	0.116	0.148	0.0367	0.0675
2*	8,752	0.55			27.1				4.91		0.117		0.0400
4	14,273	0.95	18.2	21.4	25.2	13.7	6.57	5.40	4.24	0.147	0.0792	0.0475	0.0260
4*	14,273	0.95			29.8				4.15		0.114		0.0337
3	23,570	1.58	12.4	10.1	30.4	13.5	8.45	3.50	4.26	0.116	0.152	0.0527	0.0783
1	29,223	2.02	20.1	15.1	35.4	18.3	15.0	6.22	6.38	0.214	0.204	0.0767	0.0721

* Indicates results of duplicate runs
Q - Data presented but quality is uncertain due to low filter box temperatures
X - Back filter torn
L - Sample rate below 90% isokinetics
H - Sample rate above 110% isokinetics
A - Test burn was not consistent with specified stove operating procedures

TABLE 2c. SUMMARY OF WOODSTOVE EMISSION TEST RESULTS USING OREGON METHOD 7 TO STANDARDIZE DILUTION TUNNEL FLOW & MOISTURE CONTENT PER MICROGRAMS/JOULE

Stove Burn Number	Heat Output (Btu/hr)	Burn Rate (dry) (kg/hr)	Particulate: Stack Emissions MM5	Particulate: Stack Emissions OM7	Particulate: Dilution Tunnel Emissions MM5	Particulate: Dilution Tunnel Emissions OM7	Particulate: Dilution Tunnel Emissions ASTM	TCO Stack	TCO Dilution Tunnel	Phenol Stack	Phenol Dilution Tunnel	POM Stack	POM Dilution Tunnel
Timbereze													
1A	10,772	0.90	0.826	0.390	1.00	0.542	0.375	0.298	0.363	0.00499	0.00446	0.00472	0.00718
2A	15,006	1.22	1.287	0.659	0.837	0.309	0.213	0.398	0.217	0.00973	0.00188	0.00710	0.00237
2A*	15,006	1.22					0.0631						
Blaze King													
4	7,220	0.60	2.29	0.790	1.41	1.05	0.591	1.26	0.555	0.0100	0.0119	0.00315	0.00623
4*	7,220	0.60				0.521							
1	11,185	1.09	0.468	0.314X	0.928	0.352	0.226	0.182	0.287	0.00396	0.00483	0.00243	0.00323
1*	11,185	1.09		0.285			0.199						
5	22,281	1.64	0.415	0.128XQ	0.571	0.395	0.211	0.177	0.151	0.00619	0.00424	0.00348	0.00311
5*	22,281	1.64	0.361		0.650			0.127	0.155	0.00595	0.00476	0.00340	0.00336
2	32,170	2.77	0.459	0.238	0.712	0.316	0.252	0.147	0.199	0.00526	0.00761	0.00307	0.00518
2*	32,170	2.77		0.225Q									
Lakewood													
1	9,812	0.89	4.31	2.30Q	5.23	2.36	2.63	1.52	1.88	0.0324	0.0445	0.0117	0.0180
3	13,277	1.17	3.07	1.75Q	5.34	1.93	2.37	1.43	2.09	0.0241	0.0529	0.0124	0.0382
3*	13,277	1.17		1.91	3.80				1.77		0.0468		0.0359
2	16,587	1.51	1.88	1.12Q	3.12	1.63	1.26	0.787	1.37	0.0325	0.0631	0.0140	0.0281
4	96,474	7.17	1.81	0.512Q	1.67	0.537	0.955	0.910	0.804	0.0760	0.0384	0.161	0.126
4*	96,474	7.17	1.81			0.875		0.795		0.0539		0.141	

(continued)

TABLE 2c (continued)

Stove Burn Number	Heat Output (Btu/hr)	Burn Rate (dry) (kg/hr)	Particulate: Stack Emissions MM5	Particulate: Stack Emissions OM7	Particulate: Dilution Tunnel Emissions MM5	Particulate: Dilution Tunnel Emissions OM7	Particulate: Dilution Tunnel Emissions ASTM	TCO Stack	TCO Dilution Tunnel	Phenol Stack	Phenol Dilution Tunnel	POM Stack	POM 'ilu-'.on Tunnel
Bosca													
2	7,972	0.54	3.62	2.53	2.20	0.983	1.45	1.44	0.739	0.0231	0.00664	0.0110	0.00408
2*	7,972	0.54				1.52							
4	13,999	1.08	1.09	0.628	1.94	0.587	0.617	0.444	0.532	0.0260	0.0170	0.0292	0.0261
1	19,511	1.46	1.00	0.749	1.59	0.518	0.479	0.455	0.287	0.0159	0.0108	0.0405	0.0385
1*	19,511	1.46		0.566			0.426						
5	40,591	3.10	1.18	0.606	1.60	0.870	0.478	0.565	0.505	0.0541	0.0350	0.105	0.106
Fisher													
2	8,752	0.55	1.08	0.583	2.45	1.16	0.452	0.322	0.352	0.00690	0.00883	0.00219	0.00402
2*	8,752	0.55			1.62				0.292		0.00695		0.00238
4	14,273	0.95	1.15	0.783	1.59	0.867	0.415	0.341	0.268	0.00928	0.00500	0.00300	0.00164
4*	14,273	0.95			1.89				0.262		0.00717		0.00213
3	23,570	1.58	0.789	0.643	1.93	0.859	0.537	0.222	0.271	0.00738	0.00965	0.00335	0.00498
1	29,223	2.02	1.32	0.988	2.32	1.20	0.982	0.407	0.418	0.0140	0.0134	0.00503	0.00472

* Indicates results of duplicate runs
Q - Data presented but quality is uncertain due to low filter box temperatures
X - Back filter torn
L - Sample rate below 90% isokinetics
H - Sample rate above 110% isokinetics
A - Test burn was not consistent with specified stove operating procedures

TABLE 3a. SUMMARY OF WOODSTOVE EMISSION TEST RESULTS USING ORSAT DATA AND F_C - GRAMS PER HOUR

Burn Number	F Factor Heat Input (Btu/hr)	Burn Rate (dry kg/hr)	Particulate: Stack Emissions MM5	Particulate: Stack Emissions OM7	Particulate: Dilution Tunnel Emissions MM5	Particulate: Dilution Tunnel Emissions OM7	Particulate: Dilution Tunnel Emissions ASTM	TCO Stack	TCO Dilution Tunnel	Phenol Stack	Phenol Dilution Tunnel	POM Stack	POM Dilution Tunnel
Timbereze													
1A	17,285	0.90	17.0	8.01	11.4L	6.16L	4.26	6.13	4.12L	0.103	0.0507L	0.0971	0.0816L
2A	23,218	1.22	14.6	7.55	13.2	4.89	3.37	4.55	3.44	0.111	0.0298	0.0813	0.0376
2A*	23,218	1.22					0.999						
Blaze King													
4	11,607	0.60	23.1	7.99	10.7	7.99Q	4.50	12.7	4.22	0.101	0.0908	0.0319	0.0474
4*	11,607	0.60				3.96							
1	20,898	1.09	7.13	4.59X	10.9	4.15	2.66	2.66	3.39	0.0576	0.0570	0.0355	0.0381
1*	20,898	1.09		4.16			2.34						
5F	31,964	1.64	10.5	3.22XQ	13.4	9.27Q	4.96	4.47	3.56	0.156	0.0996	0.0877	0.0731
5F*	31,964	1.64	9.11		15.3			3.21	3.65	0.150	0.112	0.0856	0.0790
2	53,615	2.77	20.8	10.8	24.1	10.7	8.55	6.66	6.75	0.239	0.258	0.139	0.176
2*	53,615	2.77		10.3Q									
3A F	6,620	0.34	5.45	2.50	15.8H	9.43	2.91	2.18	2.99H	0.0223	0.0493H	0.0316	0.0404H
Lakewood													
1	17,148	0.89	54.7	29.2Q	54.1	24.4Q	27.2	19.3	19.4	0.411	0.461	0.148	0.186
3	22,667	1.17	56.4	32.1Q	74.8	27.0	33.1	26.3	29.2	0.444	0.741	0.228	0.5341
3*	22,667	1.17		35.0	53.2				24.8		0.655		0.503
2	29,004	1.51	45.3	26.9Q	54.5	28.5	22.1	18.9	23.9	0.782	1.10	0.337	0.492
4	139,443	17.17	216.	61.3Q	170.	54.6	97.1	109.	81.8	9.11	3.90	19.3	12.8
4*	139,443	17.17	216.			89.0H		95.1		6.46		16.9	

(continued)

TABLE 3a (continued)

Burn Number	F Factor Heat Input (Btu/hr)	Burn Rate (dry kg/hr)	Particulate: Stack Emissions MM5	Particulate: Stack Emissions OM7	Particulate: Dilution Tunnel Emissions MM5	Particulate: Dilution Tunnel Emissions OM7	Particulate: Dilution Tunnel Emissions ASTM	TCO Stack	TCO Dilution Tunnel	Phenol Stack	Phenol Dilution Tunnel	POM Stack	POM Dilution Tunnel
Bosca													
2	10,466	0.54	27.3	19.0	18.5	8.27	12.2	10.9	6.21	1.74	0.0558	0.0827	0.0343
2*	10,466	0.54				12.8Q							
4	21,299	1.08	14.7	8.49	28.6	8.66Q	9.10	6.00	7.85	0.351	0.251	0.396	0.385
1	28,082	1.46	12.6	9.39	32.7	10.7	9.85	5.70	5.90	0.199	0.222	0.508	0.791
1*	28,082	1.46		7.10			8.76						
5	64,001	3.10	22.3	11.5	68.3	37.2	20.4	10.7	21.6	1.02	1.50	1.98	4.55
3AF	11,447	0.60	17.2	6.97	56.4	20.2H	19.7	7.50	14.0	0.402	0.549	0.476	1.06
3*AF	11,447	0.60	16.7Q		59.6Q			7.05Q	20.4Q	0.252Q	0.815Q	0.252Q	1.47Q
Fisher													
2	10,621	0.55	8.54	4.63	22.6L	10.7	4.17	2.55	3.25L	0.0547	0.0815L	0.0173	0.0371L
2*	10,621	0.55			14.9				2.70		0.0641		0.0220
4	18,501	0.95	15.9	10.8	23.9H	13.1	6.24	4.72	4.03H	0.128	0.0753H	0.0415	0.0247H
4*	18,501	0.95			28.3				3.94		0.108		0.0320
3	30,279	1.58	19.7	16.1	48.0	21.3	13.4	5.55	6.73	0.184	0.240	0.0836	0.124
1	38,911	2.02	38.9	29.2	71.6	37.0	30.3	12.0	12.9	0.415	0.413	0.149	0.146

* Indicates results of duplicate runs
Q - Data presented but quality is uncertain due to low filter temperatures
X - Second filter torn
H - Sample rate in excess of 110 percent isokinetic
L - Sample rate below 90 percent isokinetic
A - Test burn was not consistant with specified stove operating procedures
F - F_c calculated using CEMS data because of bad orsat

TABLE 3b. SUMMARY OF WOODSTOVE EMISSION TEST RESULTS CALCULATED AND F_c - GRAMS PER KILOGRAMS

Burn Number	F Factor Heat Input (Btu/hr)	Burn Rate (dry) (kg/hr)	Particulate Stack Emissions MM5	Particulate Stack Emissions OM7	Particulate Dilution Tunnel Emissions MM5	Particulate Dilution Tunnel Emissions OM7	Particulate Dilution Tunnel Emissions ASTM	TCO Stack	TCO Dilution Tunnel	Phenol Stack	Phenol Dilution Tunnel	POM Stack	POM Dilution Tunnel
Timbereze													
1A	17,285	0.90	18.9	8.90	12.6L	6.84L	4.73	6.81	4.58L	0.114	0.0563L	0.108	0.0906L
2A	23,218	1.22	12.0	6.19	10.9	4.01	2.76	3.73	2.82	0.0913	0.0244	0.0667	0.0308
2A*	23,218	1.22					0.818						
Blaze King													
4	11,607	0.60	38.5	13.3	17.8	13.3Q	7.50	21.2	7.04	0.169	0.151	0.0332	0.0790
4*	11,607	0.60				6.61							
1	20,898	1.09	6.54	4.21X	10.0	3.81	2.44	2.44	3.11	0.0530	0.0523	0.0325	0.0350
1*	20,898	1.09		3.82			2.15						
5F	31,964	1.64	6.39	1.97QX	8.17	5.66Q	3.03	2.73	2.17	0.0952	0.0607	0.0534	0.0446
5F*	31,964	1.64	5.55		9.31			1.95	2.22	0.0914	0.0682	0.0522	0.0482
2	53,615	2.77	7.52	3.90	8.72	3.87	3.09	2.41	2.44	0.0861	0.0931	0.0503	0.0635
2*	53,615	2.77		3.69Q									
3A	6,620	0.34	16.0	7.34	46.6H	27.7	8.56	6.41	8.79H	0.0656	0.145H	0.0929	0.119H
Lakewood													
1	17,148	0.89	61.4	32.8Q	60.7	27.4Q	30.6	21.6	21.8	0.461	0.518	0.167	0.209
3	22,667	1.17	48.2	27.5Q	63.9	23.1	28.8	22.5	25.0	0.379	0.633	0.195	0.457
3*	22,667	1.17		30.0	45.5				21.2		0.560		0.430
2	29,004	1.51	30.0	17.8Q	36.1	18.8	14.6	12.5	15.9	0.518	0.730	0.223	0.326
4	139,443	7.17	30.2	8.55Q	23.7	7.61	13.5	15.2	11.4	1.27	0.545	2.69	1.78
4*	139,443	7.17	30.2			12.4A		13.3		0.901		2.36	

(continued)

TABLE 3b (continued)

Burn Number	F Factor Heat Input (Btu/hr)	Burn Rate (dry) (kg/hr)	Particulate: Stack Emissions MM5	Particulate: Stack Emissions OM7	Particulate: Dilution Tunnel Emissions MM5	Particulate: Dilution Tunnel Emissions OM7	Particulate: Dilution Tunnel Emissions ASTM	TCO Stack	TCO Dilution Tunnel	Phenol Stack	Phenol Dilution Tunnel	POM Stack	POM Dilution Tunnel
Bosca													
2	10,466	0.54	50.5	35.2	34.3	15.3	22.5	20.1	11.5	0.322	0.103	0.153	0.0635
2*	10,466	0.54				23.7							
4	21,299	1.08	13.6	7.86	26.4	8.02Q	8.43	5.56	7.27	0.325	0.232	0.366	0.357
1	28,082	1.46	8.61	6.43	22.4	7.30	6.75	3.91	4.04	0.137	0.152	0.348	0.542
1*	28,082	1.46		4.86			6.00						
5	64,001	3.10	7.18	3.70	22.0	12.0	6.59	3.45	6.97	0.330	0.483	0.639	1.47
3A	11,447	0.60	28.7	11.6	94.0	33.7H	32.8	12.5	23.3	0.669	0.915	0.793	1.76
3*A	11,447	0.60	27.9Q		99.3Q			11.7Q	34.0Q	0.420Q	1.36Q	0.420Q	2.45Q
Fisher													
2	10,621	0.55	15.5	8.41	41.0L	19.5	7.58	4.64	5.91L	0.0995	0.148L	0.0315	0.0675L
2*	10,621	0.55			27.1				4.91		0.117		0.0400
4	18,501	0.95	16.8	11.4	25.2A	13.7	6.57	4.96	4.24H	0.135	0.0792H	0.0437	0.0260H
4*	18,501	0.95			29.8				4.15		0.114		0.0337
3	30,279	1.58	12.5	10.2	30.4	13.5	8.45	3.51	4.26	0.117	0.152	0.0529	0.0783
1	38,911	2.02	19.2	14.4	35.4	18.3	15.0	5.96	6.38	0.205	0.204	0.0736	0.0721

* Indicates results of duplicate runs
Q - Data presented but quality is uncertain due to low filter temperatures
X - Second filter torn
H - Sample rate in excess of 110% isokinetic
L - Sample rate below 90% isokinetic
A - Test burn was not consistent with specified stove operating procedures

TABLE 3c. SUMMARY OF WOODSTOVE EMISSION TEST RESULTS CALCULATED ORSAT DATA & F_c - MICROGRAMS PER JOULE

Burn Number	F Factor Heat Input (Btu/hr)	Burn Rate (dry) (kg/hr)	Particulate: Stack Emissions MM5	Particulate: Stack Emissions OM7	Particulate: Dilution Tunnel Emissions MM5	Particulate: Dilution Tunnel Emissions OM7	Particulate: Dilution Tunnel Emissions ASTM	TCO Stack	TCO Dilution Tunnel	Phenol Stack	Phenol Dilution Tunnel	POM Stack	POM Dilution Tunnel
Timbereze													
1A	17,285	0.90	0.932	0.440	0.624	0.338L	0.234	0.336	0.226L	0.00563	0.00278L	0.00533	0.00448
2A	23,218	1.22	0.597	0.308	0.541	0.200	0.137	0.186	0.141	0.00455	0.00122	0.00332	0.00153
2A*	23,218	1.22					0.041						
Blaze King													
4	11,607	0.60	1.89	0.653	0.874	0.653Q	0.368	1.04	0.345	0.00828	0.00742	0.00261	0.00387
4*	11,607	0.60				0.324							
1	20,898	1.09	0.323	0.208X	0.497	0.188	0.121	0.121	0.154	0.00262	0.00259	0.00161	0.00173
1*	20,898	1.09		0.189			0.106						
5F	31,964	1.64	0.311	0.0956XQ	0.398	0.275Q	0.147						
5F*	31,964	1.64	0.270		0.453			0.0953	0.108	0.00445	0.00332	0.00254	0.00234
2	53,615	2.77	0.369	0.191	0.427	0.190	0.151	0.118	0.119	0.00422	0.00456	0.00246	0.00311
2*	53,615	2.77		0.181Q									
3A	6,620	0.34	0.781	0.358	2.27H	1.35	0.417	0.312	0.428H	0.00319	0.00706H	0.00452	0.00578H
Lakewood													
1	17,148	0.89	3.02	1.62Q	2.99	1.35Q	1.51	1.07	1.07	0.0227	0.0255	0.00821	0.0103
3	22,667	1.17	2.36	1.34Q	3.13	1.13	1.39	1.10	1.22	0.0186	0.0310	0.00956	0.0224
3*	22,667	1.17		1.47	2.23				1.04		0.0274		0.0210
2	29,004	1.51	1.48	0.880Q	1.78	0.931	0.721	0.619	0.783	0.0256	0.0361	0.0110	0.0161
4	139,443	7.17	1.47	0.417Q	1.16	0.371	0.661	0.741	0.556	0.0619	0.0266	0.131	0.0868
4*	139,443	7.17	1.47			0.605H		0.647		0.0439		0.115	

(continued)

TABLE 3c (continued)

Burn Number	F Factor Heat Input (Btu/hr)	Burn Rate (dry) (kg/hr)	Particulate: Stack Emissions MM5	Particulate: Stack Emissions OM7	Particulate: Dilution Tunnel Emissions MM5	Particulate: Dilution Tunnel Emissions OM7	Particulate: Dilution Tunnel Emissions ASTM	TCO Stack	TCO Dilution Tunnel	Phenol Stack	Phenol Dilution Tunnel	POM Stack	POM Dilution Tunnel
Bosca													
2	10,466	0.54	2.47	1.72	1.68	0.749	1.10	0.984	0.563	0.0158	0.00506	0.00749	0.00311
2*	10,466	0.54				1.16Q							
4	21,299	1.08	0.654	0.378	1.27	0.386Q	0.405	0.267	0.350	0.0156	0.0112	0.0176	0.0172
1	28,082	1.46	0.425	0.317	1.10	0.360	0.333	0.193	0.199	0.00674	0.00750	0.0171	0.0267
1*	28,082	1.46		0.240			0.296						
5	64,001	3.10	0.330	0.170	1.01	0.552	0.303	0.158	0.320	0.0152	0.0222	0.0293	0.0674
3A	11,447	0.60	1.43	0.578	4.67	1.68H	1.63	0.622	1.16	0.0333	0.0455	0.0394	0.0877
3*A	11,447	0.60	1.39Q		4.94Q			0.584Q	1.69Q	0.0209Q	0.0675Q	0.0209Q	0.122Q
Fisher													
2	10,621	0.55	0.762	0.413	2.02L	0.957	0.372	0.228	0.290L	0.00489	0.00728L	0.00155	0.00331L
2*	10,621	0.55			1.33				0.241		0.00572		0.00196
4	18,501	0.95	0.816	0.556	1.23H	0.669	0.320	0.242	0.207H	0.00658	0.00386H	0.00213	0.00126H
4*	18,501	0.95			1.45				0.202		0.00553		0.00164
3	30,279	1.58	0.617	0.503	1.50	0.669	0.418	0.174	0.211	0.00577	0.00751	0.00262	0.00388
1	38,911	2.02	0.947	0.711	1.74	0.902	0.738	0.293	0.314	0.0101	0.0101	0.00362	0.00355

* Indicates results of duplicate runs
Q - Data presented but quality is uncertain due to low filter temperatures
X - Second filter torn
H - Sample rate in excess of 110% isokinetic
L - Sample rate below 90% isokinetic
A - Test burn was not consistent with specified stove operating procedures

- Anisokinetic sampling conducted for OM7 and MM5 sample runs in the dilution tunnel were designated with an "H" when sample rates were over 110 percent of isokinetic and an "L" when sampling rates were below 90 percent of isokinetic.

- Two torn second filters in OM7 sample trains (located between the third and fourth impingers) were identified with an "X".

- Two test burns were not adequately conducted under the Oregon woodstove test procedure stove operating guidelines. The doors were opened during sampling and the coals and woodpieces stirred during two Timber-eze test burns.

- Several OM7 and MM5 sample runs were conducted with the heated filter box temperature below the specified lower limit of 223°F. In all of those cases except BD-OM7-5 the average temperatures were between 200 and 223°F.

These conditions are discussed in greater detail in Section 5.

Total gravimetric emissions for each of the sampling methods are comprised of the combined individual analyses of the following fractions:

- MM5 - front half $MeCl_2$ rinse drydown residue
  filter catch
  XAD extraction
  semi-volatile organics (extracted from back-half water) by GC plus water drydown residue
  semi-volatile organics (in rinse solvent) by GC plus solvent drydown residue condensate extraction semi-volatile organics by GC plus drydown residue

- OM7 - front half solvent rinse drydown residue
  front filter catch
  back half extraction drydown residue
  back half water drydown residue
  back half rinse drydown residue
  back filter catch

- ASTM - front half and between-filter solvent rinse drydown residue
  front filter catch
  back filter catch

The summary tables also include results of organic sampling and analyses conducted on MM5 samples for total chromatographable organics (TCO), phenol and POM. TCO were determined on the combined back half fractions of the MM5 samples. POM and phenol were analyzed in combined aliquots from all front and back half fractions of the MM5 samples.

Table 4 presents arithmetic averages on a per stove basis for the results presented in Tables 3a through 3c. Averages were calculated for all

TABLE 4. AVERAGE EMISSION RATES PER STOVE ARITHMETIC AVERAGE

Burn Number	Stove	Particulate: Stack Emissions MM5	Particulate: Stack Emissions OM7	Particulate: Dilution Tunnel Emissions MM5	Particulate: Dilution Tunnel Emissions OM7	Particulate: Dilution Tunnel Emissions ASTM	TCO Stack	TCO Dilution Tunnel	Phenol Stack	Phenol Dilution Tunnel	POM Stack	POM Dilution Tunnel
		AVERAGE GRAMS PER HOUR							GRAMS PER HOUR			
4	Blaze King	14.1 (5)	7.65(3)	14.9 (5)	6.27(3)	4.60(5)	3.54(5)	4.31(5)	0.141(5)	0.123(5)	0.0759(5)	0.0827
4	Lakewood	117. (5)	35.0 (1)	81.3 (5)	36.7 (3)	44.9 (4)	53.7 (5)	35.8 (5)	3.44 (5)	1.37 (5)	7.38 (5)	2.90 (5)
4	Bosca	19.2 (4)	11.1 (5)	37.0 (4)	18.7 (3)	12.1 (5)	[illegible]	10.4 (4)	0.828(4)	0.507(4)	0.742 (4)	1.44 (4)
4	Fisher	20.8 (4)	15.2 (4)	40.7 (4)	20.5 (4)	13.5 (4)	6.2 (4)	6.57(4)	0.195(4)	0.206(4)	0.0729(4)	0.0810(4)
		AVERAGE GRAMS PER KILOGRAM OF DRY WOOD BURNED										
4	Blaze King	12.9 (5)	8.15(3)	10.8 (5)	4.76(3)	3.94(4)	6.15(5)	3.40(5)	0.0989(5)	0.0851(5)	0.0483(5)	0.0541(5)
4	Lakewood	40.0 (5)	30.0 (1)	46.0 (5)	16.5 (3)	21.9 (4)	17.0 (5)	19.1 (5)	0.706 (5)	0.597 (5)	1.13 (5)	0.640 (5)
4	Bosca	20.0 (5)	11.6 (5)	26.5 (4)	14.6 (4)	13.9 (6)	8.26(4)	7.45(4)	0.279 (4)	0.243 (4)	0.377 (4)	0.608 (4)
4	Fisher	16.0 (4)	11.10(4)	30.7 (4)	16.3 (4)	9.4 (4)	4.77(4)	4.93(4)	0.139 (4)	0.147 (4)	0.0504(4)	0.0560(4)
		AVERAGE MICROGRAMS PER JOULE							MICROGRAMS PER JOULE			
4	Blaze King	0.633(5)	0.344(3)	0.530(5)	0.234 (3)	0.179(5)	0.344(4)	0.182(4)	0.00489(4)	0.00447(4)	0.00231(4)	0.00276(4)
4	Lakewood	1.96 (5)	1.47 (1)	2.27 (4)	0.811 (3)	1.07 (4)	0.835(5)	0.934(5)	0.0345 (5)	0.0293 (5)	0.0549 (5)	0.0313 (5)
4	Bosca	0.970(4)	0.565(5)	1.27 (4)	0.554 (3)	0.487(5)	0.401(4)	0.358(4)	0.0133 (4)	0.0115 (4)	0.0179 (4)	0.0286 (4)
4	Fisher	0.786(4)	0.546(4)	1.51 (4)	0.799 (4)	0.462(4)	0.234(4)	0.242(4)	0.00684(4)	0.0072 (4)	0.00248(4)	0.0276 (4)

catalytic

* non catalytic

[illegible] 22% [illegible] g/kg)wet · g/kg dry /(1-.22) pollutants measured by each method. None of the data qualified with Q, X, H, L or A in Tables 3a through 3c were used in calculating the arithmetic average. The number of samples used to determine each average is in parentheses in the table.

SECTION 3

TEST FACILITY AND STOVE DESCRIPTIONS

The test facility was designed to conform as closely as practicable to both the Oregon and ASTM facility requirements (Figure 3). The test stove was mounted on a platform scale. The accuracy of the scale used for most of these tests was 0.2 pounds. The 8-inch stove pipe was equipped with a water seal which isolated the sampling location from the stove and scale. This minimized interference with the weight measurements by sampling activities in the stack.

The ASTM dilution hood was located above the stove pipe exit. The draft was measured on several occasions at the top of the stack to insure that less than 0.005 inches of water draft was induced on the stack with no fire in the stove. The dilution tunnel was constructed of 8-inch stove pipe. Sampling was conducted in a downcomer upstream of the blower. The blower was operated at a constant rate during the test program.

APPLICANCE TESTED AND TEST CONDITIONS

Five stoves were tested under this test program. The units are identified below:

- Timber-eze Model 477 Catalytic Heater
- Blaze King Catalyst Stove - King Model KEJ-1101
- Lakewood Cottager (non-catalytic)
- Bosca - Model 500 (high efficiency noncatalyst stove)
- Fisher Tech IV Fireplace Insert (catalytic)

Test charges for the Timber-eze were approximately 8.2 kg, Blaze King 13.7 kg, Lakewood 7.9 kg, Bosca 4.2 kg, and Fisher 7.6 kg. Fuel moisture was checked prior to each test. Air dried Douglas fir having a moisture content between 19 and 25% on a dry basis was used for all tests.

Stove operation followed the Oregon procedures with a few exceptions. Those exceptions are presented in Section 5 under "Other Considerations".

SELECTION OF SAMPLING LOCATION

The test locations were selected according to the OM7 and ASTM criteria. The stove pipe test location was 8 feet above the scale platform (Figure 3). The MM5 and the OM7 trains sampling in the stack were located at the same

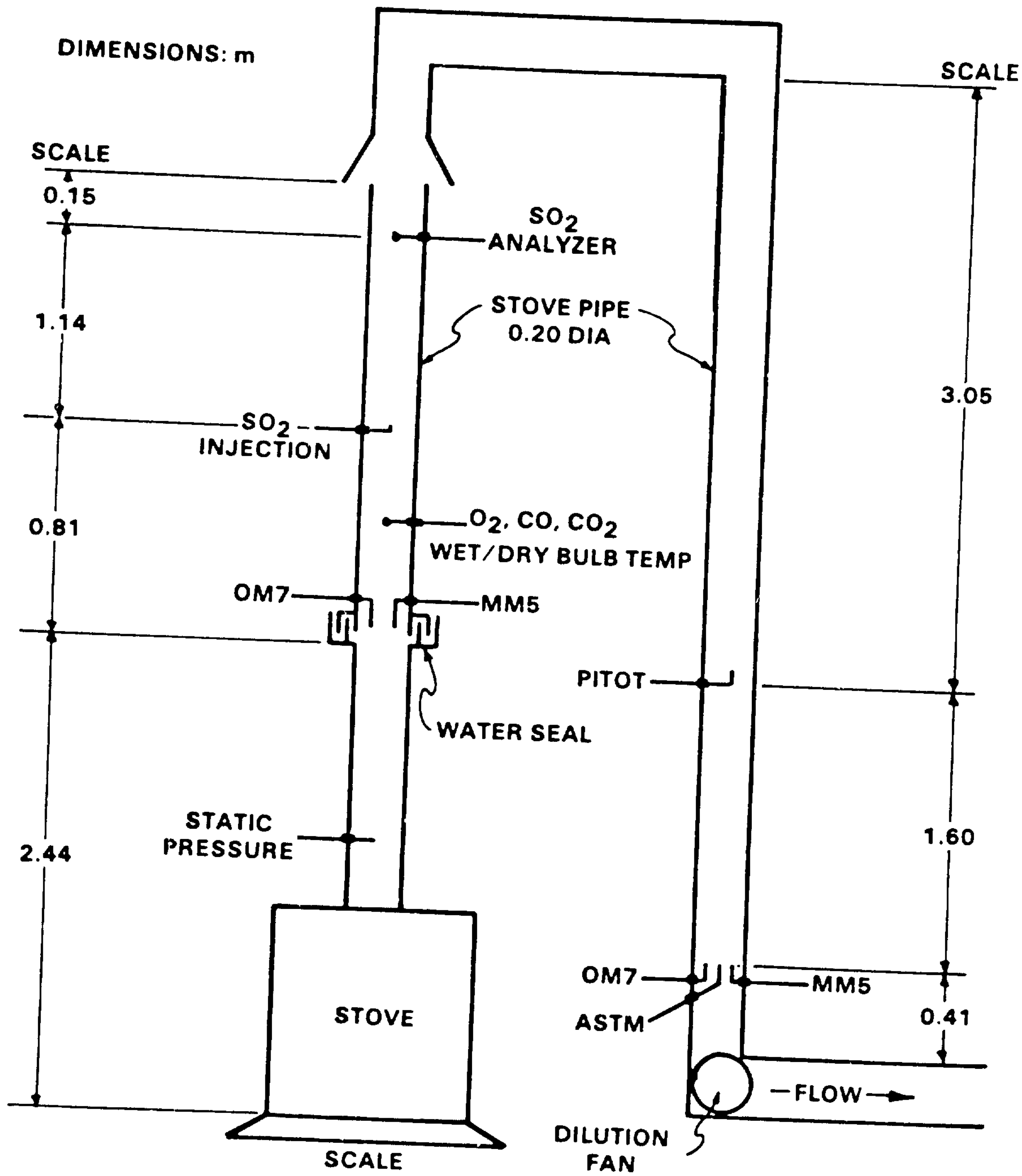

Figure 1. Schematic of stove exhaust and dilution system with sample locations.

elevation to avoid any possible discrepancies in results because of loss of particulate on the stack wall or other reasons. No traverse was attempted due to the small duct diameter and multiple sample probes (OM7 and MM5) being located at the same elevation.

The wet bulb and dry bulb thermometers were located approximately 10 inches downstream of the sampling probes. The continuous analyzer sample probe was at the same elevation as the thermocouples.

The SO_2 tracer gas injection was 36 inches downstream of the OM7 and MM5 sampling points as specified in the method. The stack height allowed the SO_2 gas sample to be extracted at a point 46 inches downstream of the injection point which does not meet the 8 duct diameters criteria of the method.

The test location in the dilution tunnel was selected to meet ASTM criteria except that the sampling trains were 8 duct diameters downstream of the pitot tube. Three sample probes were at the same elevation (ASTM, OM7, and MM5) in the tunnel. The ASTM method specifies that the pitot tube be located approximately 2 tunnel diameters (16 inches) downstream of the pitot tube. The various draft EPA procedures (1A, 2C, 5C) which deal with sampling small ducts dictate 8 duct diameters of undisturbed flow upstream of both the pitot and probe locations. EPA criteria were followed for selecting the dilution tunnel test points. The sample probes were inserted at 90° angles to each other. Nozzles were inserted 2 inches into the stack. The thermocouple was inserted 6 inches downstream of the sample probe.

SECTION 4

SAMPLING PROCEDURES

Due to the nature of the test program and the source category to be tested, some compromises were required between the specifics of the various test procedures. The basic procedures followed were:

- Modified Method 5 prepared for EPA, ORD, EPA Project Officer Raymond Merrill.
- Oregon Department of Environmental Quality Standard Method for Measuring the Emissions and Efficiencies of Woodstoves, June 8, 1984.
- ASTM Standard Test Method for Heating Performance and Emissions of Residential Wood-Fired Closed Combustion Chamber Heating Appliances, Revised November 1984.

Those methods are referred to in this document as MM5, OM7, and ASTM, respectively. Certain other reference and draft procedures were used in conjunction with those basic methods. The specific ancillary methods used varied with the test location.

- Stack MM5 - EPA Method 3 - molecular weight
  EPA Method 4 - moisture
  EPA Method 5C - particulate matter in small ducts
- Stack OM7 - OM4 - moisture
  OM5 - particulate matter emissions
  OM7 - condensible matter emissions
  EPA Method 10 - CO, CO_2
  EPA Method 20 - oxygen
  ASTM D3286.77 - higher heating value
  or ASTM D2015.77 - higher heating value
  OM4 - alternate, wet bulb/dry bulb
- Dilution Tunnel MM5 - EPA-2C - velocity in small ducts
  EPA-3 - molecular weight
  EPA-4 - moisture
  EPA-5C - particulate matter in small ducts
- Dilution Tunnel OM7 - OM4 - moisture
  OM5 - particulate emissions
  OM7 - condensible matter emissions

o Dilution Tunnel ASTM - as specified in the method

Figures 2, 3, and 4 illustrate the MM5, OM7, and ASTM sample trains, respectively.

The emissions sampling on the Timber-eze stove began within 5 minutes after the stove was loaded with the fuel charge. This was a deviation from the Oregon procedure and was corrected for all subsequent burns. All other test burns were conducted with the emissions sampling starting one minute or less before the stove test charge was placed in the firebox.

SAMPLE RECOVERY

The solvents specified for OM7 sample recovery are acetone (front half) and acetone and water (back half). For the ASTM method acetone and methanol are specified. Those recoveries were made according to the procedures. In addition, a methylene chloride rinse of the OM7 front and back halves was made and recovered separately.

The MM5 train was recovered using methylene chloride. Methanol was used on runs H-2, H-3, H-4, and H-5 after the $MeCl_2$ rinse because the $MeCl_2$ did not seem to clean the trains satisfactorily. Those fractions were recovered separately.

Following sample recovery, all samples were sealed and safely stored until transported to the laboratory for analysis. Samples were delivered to the lab within 1 week of their collection.

Sample containers were borosilicate glass bottles with Teflon® lined caps. Prior to the test program all sample containers and sample train glassware were washed with soap and water rinsed with distilled water and a final rinse with methylene chloride.

Filters for the test program were tare weighed by ES. Tare weights were given to Radian for determination of final weights.

<u>EPA-MM5</u>

Two front half fractions and four back half fractions were collected for the MM5 sample trains. The fractions were:

- o Front half
  - methylene chloride probe and front half rinse
  - filter
- o Back half
  - condensate, including rinse of all glassware between the filter and the XAD-2 module and the $MeCl_2$ rinse of the condensate impinger bottle

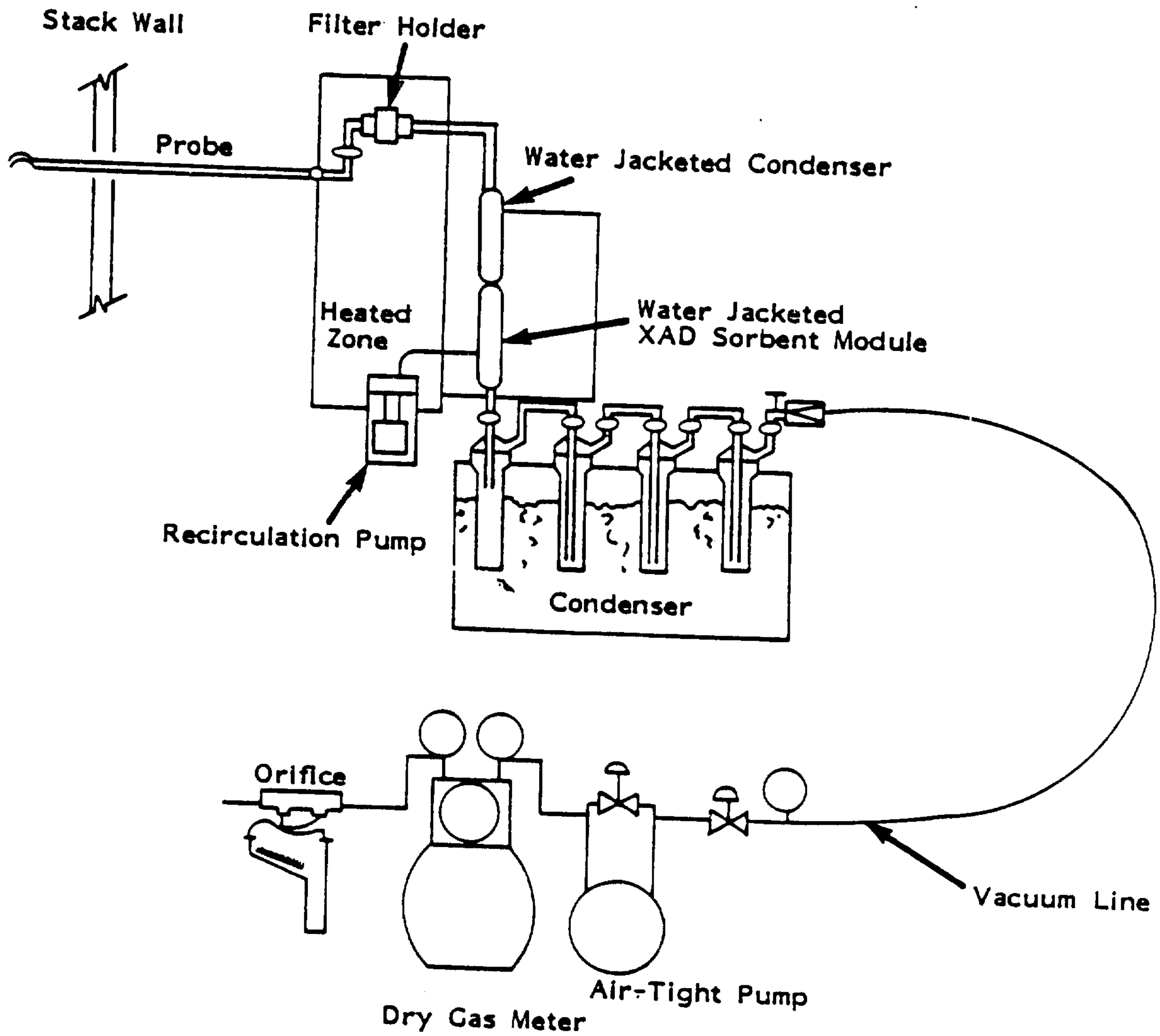

Figure 2. Schematic of Modified Method 5 Sample Train

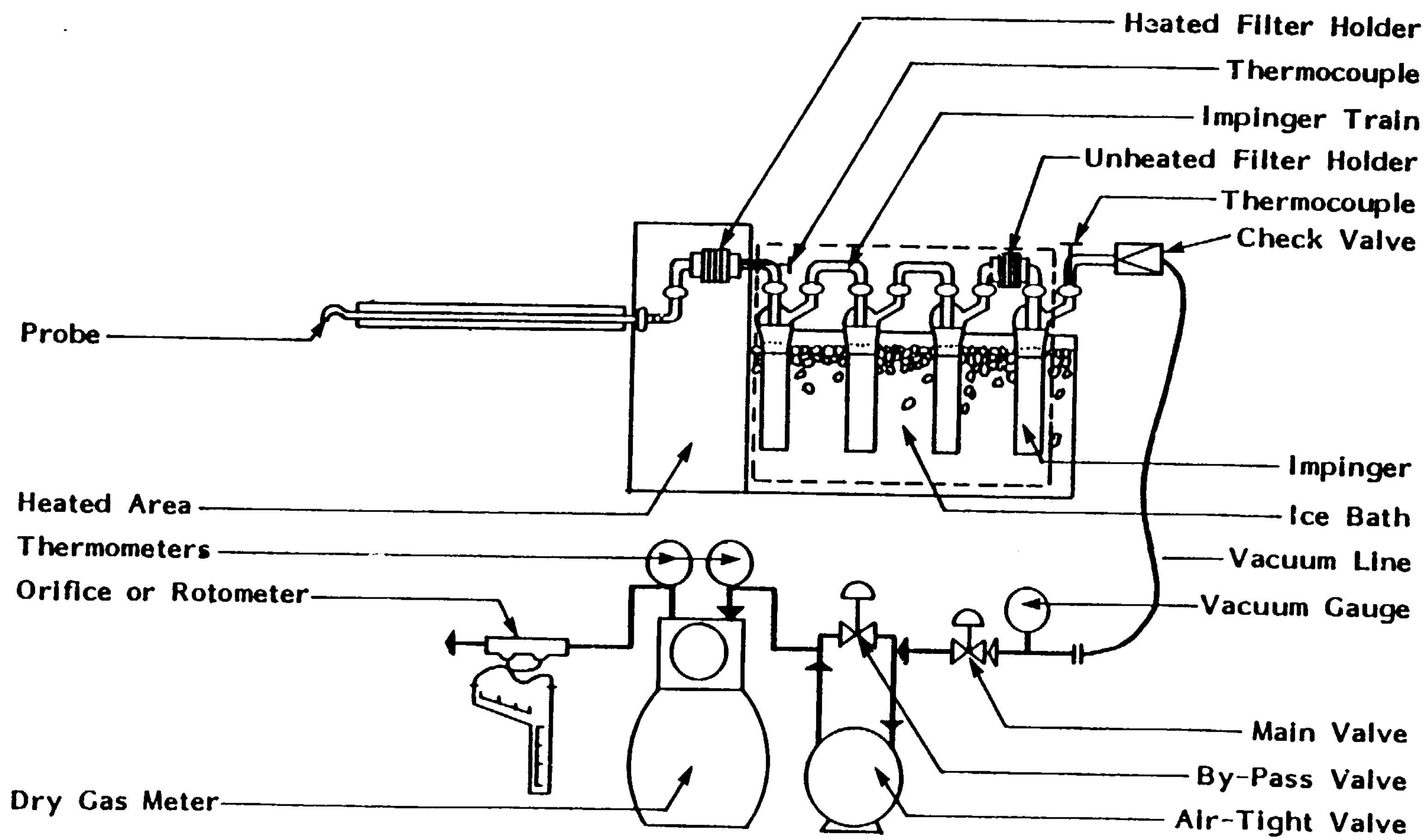

Figure 3. Schematic of OM7 Sampling Train

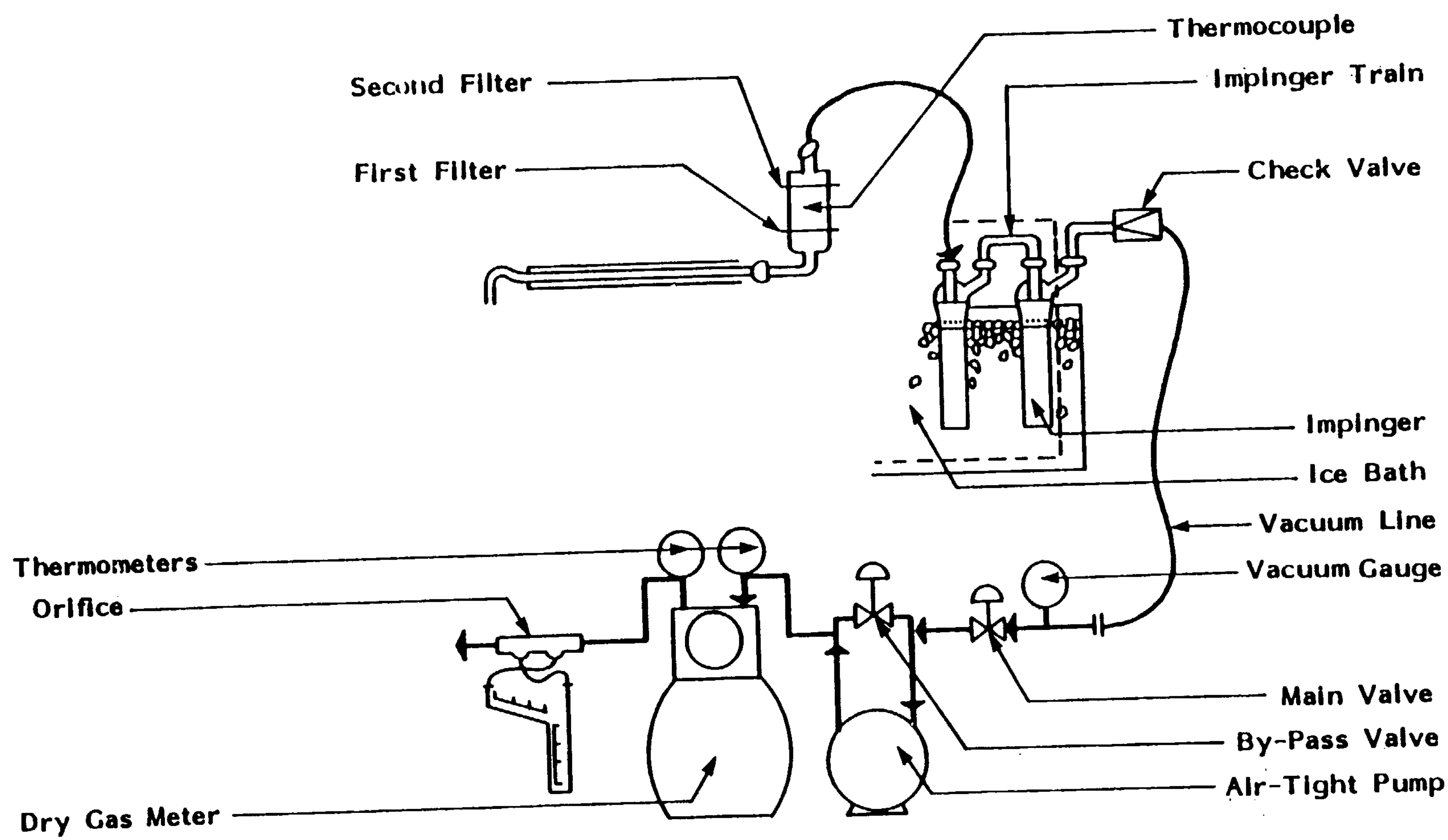

Figure 4. Schematic of ASTM Sample Train

- XAD-2 module
- back half water from the second and third impingers including a rinse
- silica gel

OM7

The OM7 sample recovery resulted in the following fractions (OM7, 8.0):

- o Front half
  - acetone rinse of probe and front half
  - filter
  - $MeCl_2$ rinse of probe and front half (in addition to OM7 procedure)

- o Back half
  - water catch and impinger water wash
  - acetone rinse of back half
  - $MeCl_2$ rinse of back half (in addition to OM7 procedure)
  - filter
  - silica gel

ASTM

Sample fractions from each ASTM train included (ASTM, 10.11, 11.12):

- o Front half:
  - acetone/methanol rinse of probe and front half
  - first filter
  - second filter
  - $MeCl_2$ rinse of front half (in addition to ASTM procedure)

- o Back half
  - none

Although the ASTM method does not specify, the glass surfaces exposed to the sample between the two filters were rinsed with acetone then methanol and both rinses added to the front half acetone/methanol rinse bottle.

SAMPLE IDENTIFICATION AND LOG

Each sample fraction was given an identifying code number which designated the sample location, stove number, method type, sample fraction and run number. Application of the code simplified tracking samples throughout the collection, handling, analysis and reporting processes.

The sample numbering system had 5 components which were applied in the following order:

- o Stove ID - Sample Location - Method - Fraction - Run Number

The specific codes are listed below:

- o Stove ID:
  - B - Blaze King
  - T - Timber-eze
  - G - Generic (Lakewood)
  - H - High Efficiency (Bosca)
  - F - Fisher

- o Sample locations:
  - S - Stack
  - D - Dilution Tunnel

- o Method:
  - MM5 - Modified Method 5
  - OM7 - Oregon Method 7
  - AST - ASTM

- o Fraction:
  - PR - Probe and Front Half Rinse
  - F - Filter
  - F2 - Second Filter (ASTM and OM7)
  - C - Condensate and Glassware Rinse
  - BH - Back Half Water Rinse (with $MeCl_2$ impinger rinse for MM5)
  - BR - Back Half Acetone Rinse (OM7 only)
  - X1 - XAD Module
  - PM - Probe and Front Half $MeCl_2$ Rinse (OM7 only)
  - BM - Back Half $MeCl_2$ Rinse (OM7 only)

- o Run Numbers:
  - 1 - First Burn Rate
  - 2 - Second Burn Rate
  - 3 - Third Burn Rate
  - 4 - Fourth Burn Rate
  - 5 - Fifth Burn Rate
  - B - Blank

SAMPLE ANALYSES

All sample analyses were conducted by the Radian Corporation under a separate contract. A copy of the laboratory report is provided in Appendix D. Analytical Methods are described there.

CO/CO_2, OXYGEN ANALYZERS

Carbon monoxide (CO) and carbon dioxide (CO_2) were monitored using an Anarad Model AR-412 infrared analyzer. The analyzer has a 0 to 5 percent CO range and a 0 to 20 percent CO_2 range. The O_2 analyzer was an MSA stack gas analyzer which uses a fuel cell detector. That instrument has a range of 0 to 20.9 percent. The gas sample was extracted using a stainless steel probe bent into the gas flow. A glass fiber filter was used to remove particulate material. A gas sample conditioner including two impingers with water in an ice bath, was upstream of the filter.

The instruments were calibrated with gases certified to be within $\pm$ 2 percent of the specified cylinder value. The gases were in concentrations to generate analyzer responses of approximately 20-30%, 45-55% and 70-80% of full scale. Daily pre- and post-test calibrations were conducted by direct introduction of the zero and span gases to the analyzers. The analyzer operation was acceptable if the analyzer response was ± 2% of the cylinder value. After the pretest multipoint calibration, a single span gas was introduced at the sample probe according to EPA Method 20, Figure 20-1. This latter calibration check demonstrated performance of the system. If any calibration checks did not comply with the ± 2 percent criteria, corrections to the system were made and the calibrations repeated. Span checks were made using a single gas every 2 to 3 hours during each test and after each test.

An evaluation of the CEMS, CO_2, O_2, and CO data is presented in Section 5. Drift problems did occur during most test burns. Corrections were made for each span or zero drift but the accuracy of the CEMS data remains suspect based upon a fuel factor test as described in EPA Reference Method 3, 40 CFR 60 Appendix A, July 1985. This is discussed further in Section 5.

SO_2 TRACER GAS

SO_2 was injected into the stack 32 inches (4 duct diameters) downstream of the OM7 sample point. The SO_2 was injected at a rate that resulted in a downstream concentration of less than 5000 ppm (OM7 6.3). A critical orifice was used to control the injection rate. The orifice was calibrated using bubble meters prior to the test program.

The procedure followed for the tracer gas analyzer calibration was similar to that followed for CO, CO_2 and O_2. Span gases were on hand to calibrate the instrument to 1000 ppm. Calibration gases were certified by the manufacturer to be ± 2 percent of the cylinder value.

Problems with the tracer gas system were identified after the first test but it was not until an audit was conducted that the problem was determined to be apparent reactions of the SO_2 in the system. The SO_2 was used as a guide for proportional sampling but the accuracy of the actual values collected are suspect.

TEMPERATURES

Type K thermocouples were used to monitor flue gas temperatures in both the stack and the dilution tunnel. The ASTM procedure specifies measuring the stack gas temperature 8 feet above the top of the scale using an array of 5 thermocouples (ASTM 6.12). That array would interfere with the OM7 and MM5 sample systems and was not used for this test program.

Flue gas temperatures were measured at the center of the stack approximately 1 duct diameter downstream of the sampling location. The dilution tunnel temperature was measured at a similar point in that duct.

Thermocouples were calibrated as per EPA Method 2.

MOISTURE MEASUREMENTS

The Oregon test Method specifies use of an alternate moisture determining technique, which is based on wet bulb/dry bulb temperatures. Wet bulb and dry bulb temperatures were monitored and recorded every 5 minutes at a location 1 duct diameter downstream of the stack sample collection point (OM 3.3, 3.8).

Moisture catch in the OM7 and MM5 sample trains were also used to determine stack gas moisture according to EPA Method 4 and Oregon Method 4. A comparison of stack gas moisture measurements resulting from the three methods is presented in Section 5.

The dilution tunnel moisture content was measured using the OM7 and MM5 samples.

FUEL HEAT CONTENT AND DENSITY

The heat content of the fuel was determined for each piece of wood burned during the test program. Sawdust was collected when the wood was cut to build fuel cribs. The shavings were placed in plastic bags and labeled to identify the specific cribs constructed from that particular board. Blocks of wood were also collected at the same time and sealed in plastic bags.

The dust and wood blocks were submitted to a subcontract laboratory for heat content and density analysis respectively. The heat contents for each crib were used in the F_C calculations discussed in Section 2. The laboratory report is provided in Appendix D.