United States
Environmental Protection
Agency

Office of Air Quality
Planning and Standards
Research Triangle Park NC 27711

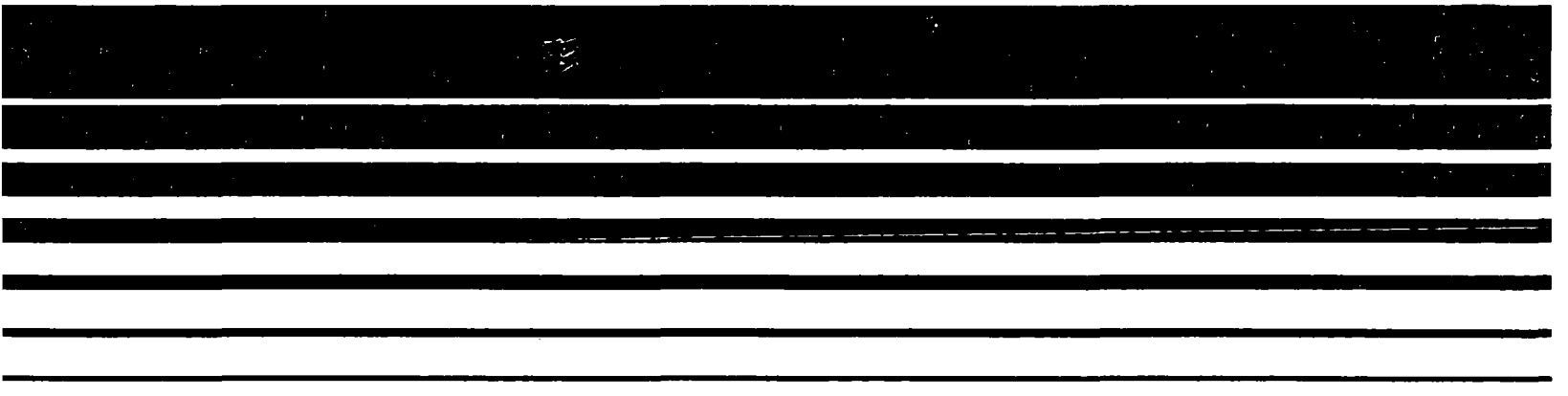
EMB Report 85-CCT-1
October 1986

Air

EPA

Cooling Towers Drift Methods Study Chromium

Method Development And Evaluation Report Munters Corporation Fort Myers, Florida



METHOD DEVELOPMENT AND EVALUATION FOR CHROMIUM AIR EMISSIONS FROM COOLING TOWERS

MUNTERS CORPORATION
FORT MYERS, FLORIDA

ESED 85/2b

EMB Contract No. 68-02-4336
Work Assignment Nos. 3 and 5

Submitted by:

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Submitted to:

United States Enviromental Protection Agency
Office of Air Quality Planning and Standards
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DECEMBER 1986

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1.0 INTRODUCTION

The U. S. Environmental Protection Agency has a program plan to provide data to characterize chromium (Cr) emissions from existing cooling towers nationwide. This includes emissions from cooling towers equipped with both average and high-efficiency drift eliminators. Together with other information, emission test data gathered will be used to develop a National Emissions Standard for Hazardous Air Pollutants (NESHAP) for this source category: cooling towers. At present, the EPA is considering an equipment standard, an air emission limit standard, or combination of both. In response to the program plan, the Emission Measurement Branch has been given the responsibility to develop and evaluate a method for the sampling and analysis of chromium emissions from cooling towers.

In developing standardized methods, EPA encourages, whenever possible, the use of existing EPA Reference Methods and/or industry accepted or standardized methods. In this case, however, none of the current EPA Reference Methods can be used for cooling towers without some procedural modifications because of the presence of cyclonic flow and large water droplets.

The primary cooling tower national organization or standardization group was contacted to determine if they had a applicable test method for chromium emissions. This group, the Cooling Tower Institute (CTI), does not currently have any standardized emission measurement methods that could be used for evaluating chromium emissions from cooling towers.

The method development and evaluation study concentrated on identifying a source emissions measurement method that would provide results in terms of a mass emission rate of chromium. Particle size distribution methods will be determined during the standards setting test, but particle size is not likely to be part of any proposed emissions standard. This study also considered method accuracy, cost, and complexity. For any method to become an EPA Reference Method, it must have acceptable accuracy, be cost effective, and be useable by the typical emissions measurement organizations.

The initial methods development plan was discussed at the Cooling Tower Institute Conference held January 27-29, 1986. The plan was presented at the subcommittee meeting on drift measurement, and all comments received were incorporated into the revised work plan.

The data generated from the emission test program presented in this report were used to develop a draft reference method for measurement of chromium from cooling towers. This method includes the use of other compounds or elements as surrogates for making measurements on cooling towers with low concentrations of chromium and for sources that do not contain chromium. The methods development and evaluation test program was conducted at The Munters Corporation in Fort Myers Florida during the period of March 3 through 8, 1986. The Munters facility was selected because:

1. The Munters Corporation operates and maintains pilot scale crossflow and counterflow cooling towers that are equipped for product performance testing purposes. The existing equipment configurations would require only minor modifications to accomodate the testing program;
2. The cooling towers are single cell units that could be modified easily to simulate various cooling tower configurations;
3. Surrogate compounds could be added to the recirculating water;
4. The cooling towers could be operated at close to design conditions;
5. The cooling tower operating parameters could be altered to represent the various conditions that were encountered during actual test programs at other locations;
6. The operating parameters could be monitored easily when tests were being performed;
7. Mild meteorological conditions were expected to be present in the Fort Myers area during the test period; and
8. The Munters staff demonstrated a willingness to assist EPA in the methods development program.

Mr. Rodney Gibson of Midwest Research Institute (MRI) monitored the process operations. Mr. Dan Bivins (EPA Task Manager) of the Emission Measurement Branch (EMB) observed the test program. Mr. Steve Adams served as the Munters Corporation contact.

This report is organized into several sections addressing various aspects of the testing program. Immediately following this introduction is the "Technical Approach To Method Development Test" which describes the approach

that EPA used to develop the test plan. Next the "Summary and Discussion of Results" section presents a discussion of the experiments conducted, the results of each experiment and a discussion on how this impacted the recommended draft test method. Following this is the "Process Operation" section which includes a discussion of the process and the operational conditions during testing. The next section, "Sampling Location and Test Methods" describes and illustrates the sampling location for the methods evaluation testing and then explains the sampling strategies used. The "Quality Assurance" section explains the procedures used to ensure the integrity of the sampling program. The Appendices present the complete Test Results and Example Calculations (Appendix A); Sampling and Analytical Procedures (Appendix B); Field Data (Appendix C); Analytical Data (Appendix D); Calibration Data (Appendix E); Test Participants and Observers (Appendix F); and Additional Information (Appendix G). Appendix B will include the "Recommended Draft Test Methods" which describe the test methods that will be used in subsequent testing programs to measure emissions from cooling towers.

2.0 TECHNICAL APPROACH TO METHOD DEVELOPMENT TEST

In general, method development and evaluation studies employ a three phase approach involving (1) a survey of available methods and selection of the best for validation, (2) laboratory evaluation of the method(s), and (3) field validation of the method(s). In this case, extensive methods development and evaluation of chromium emission measurement methods for several other industries has already provided a wealth of supporting laboratory data.[1] For example, the EPA currently has a draft test method for measurement of hexavalent chromium emissions which is presented in Appendix B. Thus, the selection and evaluation of the method for determining chromium emission from cooling towers was be conducted in only two phases. These two phases are:

Phase I - Survey of available field methods and selection of best available field method(s) for validation.

Phase II - Field validation.

2.1 PHASE I - SURVEY OF AVAILABLE FIELD METHODS AND SELECTION OF BEST AVAILABLE FIELD METHOD(S) FOR VALIDATION

This first phase, involved the collection of any information relevant to the measurement of chromium emissions from cooling towers. Numerous articles, publications, studies, and test reports were collected and reviewed. Discussions were held with industrial personnel responsible for assessing and controlling cooling tower operations and with key emission measurement groups that are currently performing cooling tower drift measurements and other cooling tower evaluations.

Because chromium emissions require laboratory analysis, a remote sensing device cannot be used in their measurement. With manual methods, chromium emissions had, in the past for many source categories, been satisfactorily collected using either a dry collection or wet collection technique. The dry technique generally includes (1) a precollector (of the heated glass beads or cyclone type) to collect the majority of the drift, followed by (2) a filter to ensure near complete collection. The wet technique typically involves collection of the drift in a liquid (in impingers), which may or may not be followed by a filter.

The use of the analytical techniques described in the attached EPA draft test method for hexavalent chromium and the use of Neutron Activation Analysis (NAA) should give sufficient accuracy within the working range for use in an EPA Reference Method. Collection efficiency of the sampling train used to collect the drift and an accurate analytical technique to measure the amount of chromium collected were acceptable for other source categories but would have to be verified again for this source category.

The single technical aspect of the method that needed to be resolved was how to collect a representative sample from the cooling tower in the presence of cyclonic flow.

2.2 PHASE II - FIELD EVALUATION

The initial method development and evaluation test was performed on a mechanical cooling tower. Therefore, the following dicussions regarding the field evaluation tests of the methods assume their use on mechanical cooling towers with cyclonic flow.

As previously mentioned, both dry and wet collection techniques have been previously used for drift measurement. Also, EPA has successfully used both dry and wet collection techniques for studies of chromium emissions from other industrial categories.

For these methods evaluation tests, EPA had initially selected a dry collection technique using a cyclone prior to the filter. This approach has been selected to reduce the overall weight and size of the sample collection train which would be suspended above the fan. The wet technique would require sample concentration prior to analysis to obtain a quantifiable chromium concentration.

2.2.1 Approach

There are two methods of calculating the mass emission rate of measured pollutants collected isokinetically: one is on a concentration basis and the other on a ratio of areas basis. For its Reference Methods, the EPA currently uses the concentration basis. To determine the mass emission rate, the concentration of pollutant measured by the sampling train is multiplied by the flow rate measured by the pitot tube. This approach is more accurate for isokinetic testing involving emissions composed of small particles. The second approach (using the ratio of areas) calculates the mass emissions collected by

the sampling train divided by the time for collection and then multiplies this by the ratio of the area of the stack divided by the area of the nozzle. This approach is more accurate for a isokinetic sampling of large particles.

2.2.2 Cyclonic Flow Bias

Mechanical cooling towers have vane axial fans. These fans create cyclonic flow in the discharge stack. This cyclonic flow creates significant problems with respect to both measurement of the flow rate and sample collection. A pitot tube, when oriented parallel to the tower wall, will give measured values higher than true values. The type "S" pitot tube can be rotated to compensate for flow misalignment in the yaw direction. However, it cannot compensate for flow misalignment in the pitch angle.

An accurate flow determination can be made under cyclonic flow conditions using a 3-dimensional pitot tube. These pitot tubes determines the flow misalignment in both the yaw and the pitch angle directions. Because of the overall weight of the 3-dimensional probe, the time required in making the measurements, the complexity of its use, and the small sensor holes that are prone to plugging, the 3-dimensional pitot tube would not be practical for making flow measurements on cooling towers.

Based on discussions with Environmental Systems Corporation (ESC), which has done much of the developmental work on cooling tower drift testing, the most practical and most accurate instrument to measure flow rate in cooling towers is the propeller anemometer. When the propeller anemometer is positioned parallel to the axis of the fan, it very nearly gives the true value for the gas velocity in the vertical direction.

2.2.3 Orientation of Sampling Train Nozzle

Since cooling towers are characterized by having emissions composed of very large particles (as explained later), it should be possible to conduct accurate testing using the ratio of areas for calculation. For this technique, the probe nozzle would be oriented in the normal manner (parallel to the fan axis). EPA intended to show that, in contrast to the use of the alignment method,[2] there is no need to align the nozzle in the actual direction of flow at each sampling point.

Because the nozzle would also be oriented parallel to the axis of the fan, there was some concern that the drift could impact on the sides of the nozzle

and bias the results. Therefore, standard nozzles were to be checked to determine if impacting drift would present a problem. In addition, nozzles were redesigned to minimize the impact area and brought to the field in the event that the standard nozzles showed either an apparent bias from the impacting drift or a high degree of imprecision.

2.2.4 Field Experiment

The method development test was conducted at a pilot scale crossflow tower at the Munters Corporation in Fort Myers, Florida. The field experiment was designed to provide analytical data within 24 hours of sampling to ensure that the majority of the tentative results of the study would be available to EPA prior to leaving the field.

The field validation was designed with five experiments as follows:

1) Smaller particles with an average angle of flow misalignment - standard nozzle

   - 50% Isokinetic (2 trains) vs. 100% Isokinetic (2 trains) vs. 150% Isokinetic (2 trains)

2) Large particles with a greater than average flow misalignment - standard nozzle

   - 50% Isokinetic (2 trains) vs. 100% Isokinetic (2 trains) vs. 150% Isokinetic (2 trains)

3) Large particles with greater than average flow misalignment - redesiged nozzle

   - 50% Isokinetic (2 trains) vs. 100% Isokinetic (2 trains) vs. 150% Isokinetic (2 trains)

4) Large particles with an average flow misalignment - Impinger train vs. heated cyclone and filter

5) Analysis of pollutant concentration with respect to particle size distribution

Each experiment was conducted at a single point within the tower. Six sampling trains were used to provide the necessary data for statistical evaluation. Each of the 6 nozzles were located within approximately 4 inches of each other. Two velocity measurement devices were used, the propeller anemometer and the 3-dimensional pitot tube. The isokinetic sampling rates for all six trains were set based on the readings of the propeller anemometer. The 3-dimensional pitot tube readings were only used as reference values to evaluate the propeller anemometer.

Each of the comparisons were to be run 3 or 4 times depending on the average sampling time required. This resulted in 3 or 4 pairs of results for use in the statisical evaluation. If the first two experiments produced the desired response, then the third experiment with the redesigned nozzle would not be conducted as explained below.

2.2.5 Preliminary Evaluation

A preliminary evaluation of the propeller anemometer and characterization of the cooling tower flow discharge was made. This included establishing the proper equal area sampling point locations and then conducting two complete traverses, each using the propeller anemometer and the 3-dimensional pitot tube.

The cooling tower water was spiked with lithium bromide. The spiking of the water was conducted to provide two measurable elements in the water that do not typically exist in the ambient air. The use of a spike or surrogate compound may be necessary to provide accurate data on other drift measurements for chromium when the chromium concentration in the water is extremely low (less than 4 ppm).

After the water was spiked, the concentration of the bromine was measured on-site with a specific ion electrode to verify that the proper concentration had been reached. The specific ion electrode was to be used to measure the concentration of both the cooling tower water and samples. This approach was designed to ensure that all samples were within the proper quantifiable limits.

It had been EPA's intent to spike the cooling water at the Munters facility with chromate (in addition to lithium bromide) and to measure the emissions of chromium, too. In pursuit of this, EPA requested that the State of Florida allow a one-time chromate spiking of the cooling water and was denied the request. The absence of chromium in the cooling water diminished the evaluation of the test to some degree. However, since the analytical techniques for chromium have already been thoroughly documented as both accurate and precise, the evaluation using bromine and lithium would still be suitable for demonstrating viability of the sampling method. The use of the bromine as a surrogate for low chromium sources will have to be evaluated at other sources during the standard setting program.

2.2.6 Experiment #1

The first experiment was designed to show that cyclonic flow involving small particles can be sampled with the nozzle in the normal orientation when using the ratio of areas calculation.

Initially, the particle size distribution was set at the lower end (preponderance of small particles) which is more characteristic of high efficiency drift eliminators. The mass median particle size was believed to be about 100 um. An in-situ hot wire particle size measurement device was used to estimate the particle size distribution.[3]

A point within the duct was selected that had a typical misalignment flow angle (30^{o} to 60^{o}). This experiment was conducted first to minimize any possible bias of the drift impacting on the sides of the nozzle.

Three runs were to be conducted; one pair of trains were to be set to sample at 50% of isokinetic (I), one pair of trains were to be set to sample at 100% of isokinetic, and one pair of trains were to be set to sample at 150% of isokinetic.

Initially, all samples collected were air freighted back to Research Triangle Park, NC and analyzed the next morning by RTI (Entropy's subcontractor under the EMB contract). RTI used the inductively-coupled argon plasmography (ICAP) technique for sample analysis. This analytical technique can provide analytical results for calcium, magnesium, manganese, sodium, and lithium. The results were then relayed by telephone to enable emission calculations to be completed within 24 hours of testing. In addition, all samples were analyzed on-site for bromine concentration prior to shipment.

The mass emission rate for each test run was calculated using both the ratio of areas technique and the concentration technique as shown below:

Pollutant Mass Rate (PMR_a) - Ratio of Areas

$$PMR_a = \frac{m_n}{\theta} \frac{A_s}{A_n} \frac{1}{1000} = mg/hr$$

where

m_n = mass of pollutant, ug
θ = sampling time, hr
A_s = area of stack, ft^2
A_n = area of nozzle, ft^2

Pollutant Mass Rate (PMR_c) - Concentration Basis

$$PMR_c = \frac{m_n \, v_{s_{std}} \, A_s}{V_{m_{std}} \, 1000} = mg/hr$$

where

m_n = mass of pollutant, ug

$V_{m_{std}}$ = sample volume metered, dscf

$v_{s_{std}}$ = velocity of stack, dsfh

A_s = area of stack, ft^2

Theoretically, the results of this experiment should have demonstrated that PMR_a is the same at 50% vs. 100% I and at 100% vs. 150% I. In addition, for each of the evaluations, PMR_a should have equaled PMR_c at 100% isokinetic.

2.2.7 Experiment #2

The second experiment was to assess any possible bias caused by the drift impacting on the sides (outside and inside) of the nozzle. The particle size distribution of the particles was changed to larger particles which are more characteristic of medium efficiency drift eliminators. The mass median diameter of the particles should have been approximately 300 to 400 um. The point in the tower selected for sampling was to have a greater than typical misalignment flow angle (60^o to 80^o).

Experiment #2 involved the same runs and comparisons as Experiment #1. If the comparisons again showed no bias, then there would be no need to run Experiment #3. If, however, it was apparent that the impact of the drift on the standard nozzle was creating either a high or low bias, then Experiment #3 was to be run using the redesigned nozzle.

2.2.8 Experiment #3

Experiment #3 was only to be conducted if Experiment #2 indicated that the impacting drift on the nozzle created a bias. Experiment #3 would be conducted in the same manner as Experiment #2 using the redesigned nozzle which would have a shorter nozzle tip. The shorter tip would minimize the area on which the drift could impact. Experiment #3 was not conducted since no bias was apparent in Experiment #2.

2.2.9 Experiment #4

Experiment #4 was to be conducted using an impinger train with a particle size distribution towards the larger particles (a condition expected to generate the most testing problems) and the flow at a typical misalignment angle (30^{o} to 60^{o}). The purpose of this experiment was to aid in designing a system that can be used at cooling towers in refineries and chemical plants where explosive atmospheres may exist. If an unheated train could be used, it would eliminate the need for electrical components on the portion of sampling train in contact with the cooling tower discharge.

Experiment #4 was to involve the same runs and comparisons as Experiment #1. If the experiment demonstrated that there were no problems, then the unheated system could be utilized at plants with potentially explosive emissions.

2.2.10 Experiment #5

Experiment #5 was conducted to determine if the pollutant concentration measured in the drift droplets varied with the particle size distribution of the effluent. The current literature does not document changes in the pollutant concentration with respect to particle size distribution in cooling towers. If chemical analyses of specific compounds or elements in the drift are to be an accurate indicator of the actual amount of drift, then the concentration of compounds or elements measured in the drift would have to be the same as the concentration in the cooling water over the entire range of particle size distributions of the drift.

To determine the actual concentration of the drift, the bromine concentration was to be measured. This was to be accomplished using two cyclones. The first cyclone would collect all particles greater than approximately 20 um. The second cyclone would collect particles from approximately 20 um down to approximately 5 um. The concentration of bromine was to be analyzed in the drift collected in each cyclone. The concentration of bromine measured in the drift collected from the different particle size ranges would be compared with the concentration of bromine in the cooling water.

2.2.11 Other Familiarization Tasks

Several other instruments which will not be part of the EPA Reference Method were used to make measurements at this test. This was done to

investigate instrument operations and calibrations and to provide sampling personnel a chance to become familiar with the instrument operation.

2.3 REFERENCES

1. Cox, X. B., R. L. Linton, and F. E. Butler, "Determination of Chromium Specialization in Environmental Particles; Multitechnique Study of Ferrochrome Smelter Dust," ES&T, Vol. 19, No. 4, April 1985.

2. Peeler, J. W., F. J. Phoenix, and D. J. Grove, "Characterization of Cylonic Flow and Analysis of Particulate Sampling Approaches at Asphalt Plants," Entropy Environmentalists, Inc.

3. "Development of Droplet Sizing for the Evaluation of Scrubbing Systems," United States Environmental Protection Agency, Research Triangle Park, North Carolina, EPA-600/7-79-166.

3.0 SUMMARY AND DISCUSSION OF RESULTS

The experiments described in Section 2.0 were to be conducted at the crossflow cooling tower at the Munters Corporation, however, later tests were modified in response to results of earlier runs. Only the outlet location of the Munters Corporation cooling tower was tested. A flow diagram for the tower is shown in Section 5.0 (Figure 5.1). No sample ports were installed on the tower; samples were collected at the exit of the fan stack. In keeping with this, all standards setting tests in the future will be conducted at the exit of the cooling tower stack(s). A complete description and diagram of the stack exit can be found in Section 5.0. The results for and any modifications in each experiment in the methods development test are presented and discussed below.

3.1 PROPELLER ANEMOMETER TESTING

The initial experiment was designed to confirm the propeller anemometer as the flow measurement method of choice. Several pretest calibrations were performed in a wind tunnel and then, during the cooling tower test program, the propeller anemometer was evaluated by comparing its measured value at each test point to the results obtained with a three dimensional pitot tube.

3.1.1 Anemometer Sensor Tests

The anemometer produces a voltage that is directly proportional to the rotational speed of the propeller. Five propeller anemometers were tested to determine a conversion factor for each of the sensors. The consistency of the results indicated that a conversion factor of 3.60 rpm/mV should be used for all of the sensors.

Initial Bearing Torque tests were conducted prior to the field test to ensure that the performance of the bearings in each sensor was within the limits established by the manufacturer. After the field testing was completed, a final Bearing Torque test was conducted for the one sensor used in the test program. No deterioriation in the bearings of this sensor was indicated.

The procedures and results for the anemometer sensor tests are presented in Appendix E.

3.1.2 Propeller Calibration/Angle Tests

The calibration of each of six propellers was evaluated using a wind tunnel at air velocities of 8.1 and 4.8 m/s. The propellers tested included two constructed of polypropylene (18 cm dia.), two constructed of polystyrene (23 cm dia.), and one constructed of polystyrene (19 cm dia.).

For one polystyrene and one polypropylene propeller, the angle of the propeller was varied 180° in increments of 10° in order to generate curves showing wind angle versus percent response.

The resulting calibration and wind angle curves were found to agree with those supplied by the manufacturer of the propellers. Since the test results provided by the manufacturer were found to be within 2% of the results for the wind tunnel tests, it was determined that the manufacturer's calibration results should be used in the test program. Detailed descriptions of the propeller calibrations are presented in Appendix E.

3.1.3 Preliminary Cooling Tower Tests

A preliminary evaluation of the propeller anemometer was conducted at the cooling tower discharge. The purpose of the testing was to characterize the flow profile at the cooling tower discharge and to compare the velocity results obtained from the propeller anemometer to those obtained from a 3-dimensional pitot tube. The traverse point locations were determined using Reference Method 5D. This method required that 24 points (12 points on each of two diameters) be sampled at the cooling tower discharge. The four traverse points closest to the sides of the exhaust duct could not be used in the anemometer test because the center of the propeller anemometer could not be moved close enough to the duct wall.

The results for the two runs on the cooling tower are summarized in Table 3.1. The mean velocities for Run 1 were 27.4 ft/s for the propeller anemometer and 24.6 ft/s for the 3-dimensional pitot. For Run 2, the mean velocity for the propeller anemometer was 27.1 ft/s and the mean velocity for the 3-dimensional pitot was 24.2 ft/s. The mean differences for the two runs were 11% and 12%. Since the two methods were within 2% in the wind tunnel testing, these differences were assumed to be measurement error and no corrections were made to the propeller anemometer readings during testing.

The absolute angle of the flow in the cooling tower discharge was also determined from the 3-dimensional pitot traverse. The results for the cooling tower runs (presented in Table 3.2) show measured angles of 34° for Run 1 and 37° for Run 2. The angle of the flow was expected to cause a low bias

TABLE 3.1. COMPARISON OF PROPELLER ANEMOMETER AND 3-DIMENSIONAL PITOT RESULTS

Traverse Point	------RUN 1------ Propeller Anemometer (ft/s)	3-D Pitot (ft/s)	------RUN 2------ Propeller Anemometer (ft/s)	3-D Pitot (ft/s)
A-2	38	33	38	32
3	38	33	38	33
4	32	30	32	30
5	21	20	21	20
6	12	9	11	7
7	11	9	9	7
8	25	28	24	25
9	33	32	34	31
10	37	34	38	33
11	35	31	36	32
B-2	34	30	36	30
3	36	33	35	31
4	32	29	34	30
5	28	18	24	22
6	10	6	10	8
7	8	2	16	16
8	17	17	16	16
9	28	30	28	28
10	35	33	35	32
11	38	34	36	33
Mean Values:	27.4	24.6	27.1	24.2

TABLE 3.2. POINT-BY-POINT COMPARISONS OF FLOW ANGLE DIFFERENCES

(Angles in units of degrees)

Traverse Port	Traverse Point	Yaw Angle Run 1	Yaw Angle Run 2	Pitch Angle Run 1	Pitch Angle Run 2	Absolute Angle Run 1	Absolute Angle Run 2
A	1	-17	-19	8	18	19	27
	2	-11	-13	11	18	16	23
	3	-12	-14	17	19	21	24
	4	-19	-17	18	23	27	29
	5	-35	-32	24	31	42	44
	6	-64	-65	23	29	67	69
	7	60	62	-39	-44	67	70
	8	24	33	-27	-30	35	43
	9	22	20	-19	-23	28	30
	10	17	20	-14	-18	21	26
	11	20	20	-10	-13	22	23
	12	24	22	- 7	-14	24	25
B	1	-26	-24	15	17	30	30
	2	-19	-21	17	18	26	28
	3	-18	-17	19	19	26	26
	4	-20	-16	20	23	29	28
	5	-29	-15	35	33	45	36
	6	-65	-60	37	39	71	68
	7	83	76	-29	-36	83	78
	8	47	49	-26	-29	52	54
	9	24	27	-17	-22	28	34
	10	15	16	-11	-17	18	23
	11	13	14	- 7	-15	14	20
	12	14	14	- 4	-12	14	18
Avg. Abs.		29	29	19	23	34	37

in the propeller anemometer results, since the response of the propeller anemometer is approximately proportional to the cosine of the flow angle. Instead, the velocity measurements from the propeller anemometer were found to be on the average, 12% higher than the 3-dimensional probe results. This effect is believed to be caused by the pulsing effect of the exhaust and the inertia associated with the anemometer propeller.

The data from the cooling tower discharge traverses are included in Appendices A and C.

3.1.4 Use of the Propeller Anemometer During Sampling

During the sampling at the cooling tower discharge, the propeller anemometer was used to determine the effluent velocity at the sampling point. Since the sampling nozzles had to be located just upstream of the anemometer, there was concern that the sampling nozzles would hinder the flow, causing a bias in the anemometer results. It was found that the placement of six nozzles in front of the anemometer caused a low bias of approximately 9% in the velocity results. In order to account for this bias, the velocity was checked before and after each run, without the sampling nozzles in place. The response was also checked throughout the run to ensure that the velocity remained constant. The 9% difference was added to the value obtained for each run to account for the bias.

Since future implementation of this sampling method would require only one nozzle, the propeller anemometer response was observed while one nozzle was placed in its path. The addition of the nozzle produced no apparent change in the anemometer response.

3.1.5 Conclusions for Propeller Anemometer

The propeller anemometer was cited by cooling tower testing experts as the best method of determining the velocity and flow rate in cylonic flow. Both the wind tunnel and field evaluations demonstrated the fact that the propeller anemometer should be the flow measurement method of choice. As a result, it has been chosen for use in cooling tower testing and is incorporated into the recommended test methods presented in Appendix B.

3.2 METHODS DEVELOPMENT TEST EXPERIMENTS

3.2.1 Experiments 1 through 4

Experiment No. 1 was conducted using the EPA Method 5 (dry collection technique) sampling train to collect the drift. It was designed to evaluate PMR_a vs. PMR_c at different isokinetic rates using different nozzle diameters under small drift particle size conditions (respresenting use of high efficiency

drift eliminators). As shown in Table 3.3 for Run 1 of Experiment No. 1 (with the particle size distribution towards the smaller particles), six sample trains were operated simultaneously, two at 50% of the isokinetic rate, two at 100% of the isokinetic rate, and two at 150% of the isokinetic rate. The attached nozzles had diameters of 0.25 inches, 0.3 inches and 0.375 inches respectively. All were EPA Method 5-type trains which meant that they had front-half filters. The filters were of the glass fiber type which is typically used in EPA Method 5 testing. The only compound of interest in the cooling water was lithium bromide.

Runs 2 and 3 duplicated Run 1 in Experiment No. 1. The initial results of the front-half analysis indicated a problem with sample collection or the analytical technique. The impinger contents (back-half) were then analyzed. This analysis demonstrated that a significant amount of the compound was going through the filter into the impingers as shown in Table 3.4. Although the bromine analysis was not considered accurate enough for comparision of results (as shown later in the discussion of Experiment Nos. 3 and 4), it did indicate that more than half of the bromine was passing through the filter.

A Lithium Corporation representative was contacted and said that lithium could react with the glass fiber filter and form an insoluble lithium silicate. As a result of this possible reaction, the glass fiber filter was replaced with a Teflon filter or no filter starting with Run 5 of Experiment No. 1 and for all later runs.

Since the analytical results were not available until the afternoon following the previous day's sampling, Run 4 was conducted in the morning using a technique that proved unacceptable when the results of the previous day's sampling were received. Run 4 was conducted using glass fiber filters with all Trains at 100% isokinetic in an effort to determine the precision of sampling and analytical technique.

After it was discovered that the lithium reacted with the glass fiber filters, Run 1 of Experiment No. 4 (see Table 3.5) and Run 5 of Experiment No. 1 (see Table 3.5) were conducted using Teflon filters. It was not clear whether the bromine was being caught in the impingers because of poor sample train collection efficiency or because of the reaction of the lithium with the glass fiber filter, therefore, Run 5 of Experiment No. 1 was conducted using only front half Teflon filters and Run 4 of Experiment No. 1 was conducted using three Method 5 trains and three impinger trains. The results from both sample runs (see Table 3.4) clearly demonstrated that about half of many of the ions present (Li, Br, Ca and Mg) was actually passing through the filter and being

TABLE 3.3. TESTING SCHEDULE AT MUNTERS CORPORATION COOLING TOWER

Exper. No.	Run No.	Date (1986)	Particle Size		No. of Trains at Isokinetic			No. of Trains at Nozzle Size			Filter Location			Compounds in Water					Filter Type	
			Small	Large	50%	100%	150%	0.25	0.3	0.375	Front	Back	None	Li	Br	Na	Cl	Mo	Glass	Teflon
1	1	3/3	x		2	2	2	2	2	2	6			x	x				x	
1	2	3/3	x		2	2	2	2	2	2	6			x	x				x	
1	3	3/4	x		2	2	2	2	2	2	6			x	x				x	
1	4	3/4	x			6		2	2	2	6			x	x				x	
4	1	3/5		x		6			6		3	3		x	x					x
1	5	3/5		x	2	2	2	2	2	2	6			x	x	x	x			x
1	6	3/6		x	2	2	2	2	2	2		3	3	x	x	x	x			x
1	7	3/6		x	2	2	2	2	2	2		3	3	x	x	x	x			x
1	8	3/6		x	2	2	2	2	2	2		3	3	x	x	x	x			x
3	1	3/6	x		2	2	2	2	2	2		3	3	x	x	x	x	x		x
3	2	3/6	x		2	2	2	2	2	2		3	3	x	x	x	x	x		x
3	3	3/7	x		2	2	2	2	2	2		3	3	x	x	x	x	x		x
3	4	3/7	x		2	2	2	2	2	2		3	3	x	x	x	x	x		x
4	2	3/8	x			6		2	2	2		3	3	x	x	x	x	x		x
4	3	3/8	x			6		2	2	2		3	3	x	x	x	x	x		x

TABLE 3.4. PERCENT SAMPLE RECOVERY BY TRAIN COMPONENT

Series of Run Numbers	Train Type	Compound	Percent Recovery (of Total Catch) in Particular Train Compartment
1-A+F-3	Method 5	Li	91.5% in front-half, but reaction with glass fiber filter
1-A+F-4	Method 5	Li	87.1% in front-half, but reaction with glass fiber filter
1-A+F-5	Method 5	Ca	69.9% in front-half
1-A+F-5	Method 5	Mg	63.5% in front-half
4-A,C,F-1	Method 5	Li	49.3 in front-half, Teflon filter used
3-A+F-2,3+4	Impinger Train	Li*	75% in first two impingers, 8.7% in third impinger, 16.3% on Teflon filter
3-A+F-3	Impinger Train	Br*	98.9% in first two impingers, 0.7% in third impinger, 0.4% on Teflon filter

*Efficiency results are not shown for collection of Ca and Mg in the impinger train since the plant's distilled water that was used in the impinger reagent contained high levels of Ca, Mg, and Na.

TABLE 3.5. SUMMARY OF PMR_a and PMR_c RESULTS FOR LITHIUM ANALYZED BY GFAA

Series of Run Numbers	Sample Train	Probe Length (ft)	Avg. Δ H	Nozzle dia (in.)	Isokinetic Rate (%)	Pollutant Mass Rate* PMR_a	Pollutant Mass Rate* PMR_c
Method 5 type train with Teflon filters at different isokinetic rates and nozzle sizes							
1-A+F-5	A+B	2	1.6	0.37	50	105	210
	C+D	4	3.3	0.31	100	100*	105
	E+F	6	2.8	0.25	150	182	123
Impinger type train at 100% isokinetic rate with same nozzle size							
4-A+F-1	A+B	2	2.8	0.31	100	82	78
	C+D	4	3.2	0.31	100	100*	103
	E+F	6	2.9	0.30	100	99	103
Impinger type train at 100% isokinetic rate with different nozzle sizes							
4-A+F-2	A+B	2	5.8	0.37	100	87	89
4-A+F-3	C+D	4	3.0	0.30	100	100*	103
	E+F	6	1.2	0.25	100	378	375
Impinger type train at different isokinetic rates and nozzle sizes							
1-A+F-6	A+B	2	1.6	0.37	50	101	204
1-A+F-7	C+D	4	3.4	0.31	100	100*	100
1-A+F-8	E+F	6	2.9	0.25	150	136	91
3-A+F-1							
Impinger type train at different isokinetic rates and nozzle sizes							
3-A+F-2	A+B	6	1.6	0.37	50	107	212
3-A+F-3	C+D	4	3.1	0.30	100	100*	102
3-A+F-4	E+F	2	2.8	0.25	150	193	130

*Pollutant mass rate averages presented have been normalized to the average PMR_a's for the runs conducted at 100% isokinetic, which have been set equal to 100. The high and low values for all groups with more than one run have been dropped in calculating the averages.

collected in the impingers. These results clearly demonstrated that the front filter was not acceptable for quantitively removing the compounds of interest.

3.2.2 PMR_a vs. PMR_c for Large Particles

To increase the emissions in an effort to reduce the sampling time and to evaluate PMR_a vs. PMR_c for the larger particles, the particle size distribution was shifted toward the larger particles. This was accomplished by partially removing one of the mist eliminator panels.

Runs 6, 7 and 8 of Experiment No. 1 were then conducted using impinger trains (see Table 3.6). The results for these runs again showed that the PMR_a for the run conducted at 150% isokinetic was biased 36% high, having a normalized value of 136.

3.2.3 PMR_a vs PMR_c for Small Particles

After the test program, Munters Corporation had planned to add sodium molybdate to the cooling water to assist in their corrosion problems. To provide an additional element for analysis, molybdenum, the sodium molybdate was added prior to the last day of testing. The final series of experiments, Runs 2, 3, and 4 of Experiment No. 3 and all of Experiment No. 4, was conducted with a smaller particle size distribution. Since it was observed that the runs showing a high bias (all conducted at 150% isokinetic) had all used the longer probes and quarter-inch nozzles, the probes were switched for Runs 2, 3 and 4 of Experiment No. 3 to determine if the bias was a result of the longer probe. Runs 2 and 3 of Experiment No. 4 used the probes in the orginal order to, if possible, quantify the bias. The results shown in Table 3.7 indicate that the trains run at 150% isokinetic with the shorter probes and quarter-inch nozzles showed a high bias again. The results for Runs 2 and 3 of Experiment No. 4 (Table 3.8) showed a similar bias for trains run at 100% isokinetic with the longer probes and quarter-inch nozzles. The resulting implication was that the nozzles (illogically) were causing the bias. The results of the analysis for molybdenum are not shown since the results indicated that a large portion of the molybdenum was lost during the analysis.

3.2.4 Further Analysis of Sample by NAA

Since the bias of the results from runs conducted at 150% isokinetic could not be explained, further analysis for bromine of three sets of samples were conducted using Neutron Activation Analysis (NAA). This was done to determine if the bias was due to the lithium concentration being so close to the detection

TABLE 3.6. IMPINGER TYPE-TRAIN AT DIFFERENT ISOKINETIC RATES AND NOZZLE SIZES

Run Number	Date (1986)	Filter Type	Filter Location	Probe Length (ft)	Avg. ΔH	Nozzle Dia (in.)	Isokinetic Rate (%)	Pollutant Mass Rate of Lithium			
								PMR_a lb/hr x 10^{-6}	PMR_c lb/hr x 10^{-6}	PMR_a* normal.	PMR_c* normal.
1-A-6	3/6	None	N/A	2	1.59	0.374	50.5	161.0	318.2	95	188
1-B-6	3/6	Teflon	Back	2	1.58	0.374	50.5	220.6	436.3	130	258
1-C-6	3/6	None	N/A	4	3.40	0.305	102.9	238.4	231.3	141	137
1-D-6	3/6	Teflon	Back	4	3.42	0.310	97.1	99.9	102.7	59	61
1-E-6	3/6	None	N/A	6	2.86	0.244	150.4	224.6	149.2	133	88
1-F-6	3/6	Teflon	Back	6	2.86	0.245	153.3	160.0	104.2	95	62
1-A-7	3/6	None	N/A	2	1.57	0.374	50.5	246.0	486.7	211	417
1-B-7	3/6	Teflon	Back	2	1.55	0.374	50.2	131.6	261.9	113	224
1-C-7	3/6	None	N/A	4	3.34	0.305	102.6	83.6	81.4	72	70
1-D-7	3/6	Teflon	Back	4	3.33	0.310	96.8	149.9	154.6	128	132
1-E-7	3/6	None	N/A	6	2.82	0.244	149.8	430.1	286.8	368	230
1-F-7	3/6	Teflon	Back	6	2.85	0.245	149.9	95.2	63.4	82	54
1-A-8	3/6	None	N/A	2	1.61	0.374	50.7	138.9	273.8	83	167
1-B-8	3/6	Teflon	Back	2	1.59	0.374	50.0	115.2	230.1	69	138
1-C-8	3/6	None	N/A	4	3.41	0.305	102.8	200.3	194.7	120	117
1-D-8	3/6	Teflon	Back	4	3.39	0.310	97.1	133.2	137.0	80	82
1-E-8	3/6	None	N/A	6	2.87	0.244	149.3	291.8	195.2	175	117
1-F-8	3/6	Teflon	Back	6	2.88	0.245	148.2	270.4	182.2	162	109

*Pollutant mass rate averages presented here have been normalized to the average of the PMR_a's for the C and D trains for each run, which was set equal to 100.

TABLE 3.7. IMPINGER-TYPE TRAIN AT DIFFERENT ISOKINETIC RATES AND NOZZLE SIZES

Run Number	Date (1986)	Filter Type	Filter Location	Probe Length (ft)	Avg. Δ H	Nozzle Dia (in.)	Isokinetic Rate (%)	Pollutant Mass Rate of Lithium			
								PMR_a lb/hr x 10^{-6}	PMR_c lb/hr x 10^{-6}	PMR_a* normal.	PMR_c* normal.
3-A-2	3/7	None	N/A	6	1.53	0.374	50.5	34.3	67.9	116	229
3-B-2	3/7	Teflon	Back	6	1.51	0.374	49.8	43.3	86.9	146	294
3-C-2	3/7	None	N/A	4	3.01	0.305	98.4	24.6	24.9	83	84
3-D-2	3/7	Teflon	Back	4	3.02	0.304	95.8	34.6	36.1	117	122
3-E-2	3/7	None	N/A	2	2.74	0.244	149.6	69.1	46.1	233	156
3-F-2	3/7	Teflon	Back	2	2.75	0.245	147.5	80.0	54.1	270	183
3-A-3	3/7	None	N/A	6	1.57	0.374	50.6	23.7	46.8	75	149
3-B-3	3/7	Teflon	Back	6	1.54	0.374	49.7	27.8	55.8	88	177
3-C-3	3/7	None	N/A	4	3.07	0.305	98.7	23.3	23.6	74	75
3-D-3	3/7	Teflon	Back	4	3.06	0.304	96.2	39.6	41.1	126	131
3-E-3	3/7	Teflon	Back	2	2.77	0.244	148.5	55.7	37.4	177	119
3-F-3	3/7	None	N/A	2	2.79	0.245	147.1	41.9	28.5	133	91
3-A-4	3/7	None	N/A	6	1.61	0.374	50.8	37.6	74.0	113	222
3-B-4	3/7	Teflon	Back	6	1.58	0.374	50.5	36.8	72.7	111	218
3-C-4	3/7	None	N/A	4	3.17	0.305	99.3	36.9	37.1	111	111
3-D-4	3/7	Teflon	Back	4	3.16	0.304	97.5	29.7	30.4	89	91
3-E-4	3/7	None	N/A	2	2.78	0.244	150.9	40.3	26.7	121	80
3-F-4	3/7	Teflon	Back	2	2.77	0.245	149.1	76.2	51.0	229	153

*Pollutant mass rate averages presented here have been normalized to the average of the PMR_a's for the C and D trains for each run, which was set equal to 100.

TABLE 3.8. IMPINGER-TYPE TRAIN AT 100% ISOKINETIC RATE AND DIFFERENT NOZZLE SIZES

Run Number	Date (1986)	Filter Type	Filter Location	Probe Length (ft)	Avg. ΔH	Nozzle Dia (in.)	Isokinetic Rate (%)	Pollutant Mass Rate of Lithium			
								PMR_a lb/hr $\times 10^{-6}$	PMR_c lb/hr $\times 10^{-6}$	PMR_a* normal.	PMR_c* normal.
4-A-2	3/8	None	N/A	2	5.73	0.374	100.7	19.6	19.5	82	82
4-B-2	3/8	Teflon	Back	2	6.15	0.374	98.0	18.0	18.3	75	76
4-C-2	3/8	None	N/A	4	3.05	0.305	102.8	40.5	39.4	169	165
4-D-2	3/8	Teflon	Back	4	3.05	0.304	96.1	7.4	7.7	31	32
4-E-2	3/8	None	N/A	6	1.19	0.244	103.6	128.6	124.0	537	518
4-F-2	3/8	Teflon	Back	6	1.19	0.245	97.9	70.5	71.9	294	300
4-A-3	3/8	None	N/A	2	5.67	0.374	99.9	19.6	19.6	96	96
4-B-3	3/8	Teflon	Back	2	5.78	0.374	96.2	18.8	19.5	92	96
4-C-3	3/8	Teflon	Back	4	3.02	0.305	98.9	17.2	17.4	85	86
4-D-3	3/8	None	N/A	4	3.05	0.304	96.6	23.5	24.3	115	119
4-E-3	3/8	None	N/A	6	1.23	0.244	102.7	94.1	91.5	462	450
4-F-3	3/8	Teflon	Back	6	1.23	0.245	99.2	45.7	46.0	225	226

*Pollutant mass rate averages presented here have been normalized to the average of the PMR_a's for the C and D trains for each run, which was set equal to 100.

limit of the analytical method. The complete results for the bromine analysis by NAA are shown in Table 3.9. A summary of these results is presented in Table 3.10. The bromine results indicate that the bias was not due to any analytical error as they agreed very well with the lithium results.

3.2.5 Precision of Method

The results expressed as PMR_a for runs conducted at 50% isokinetic and runs at 100% isokinetic were very similar. Since it could not be determined why the results (PMR_a) at 150% isokinetic were biased high, the decision was made to determine the precision of the data and to determine if the calculated precision was acceptable. Table 3.11 presents the percent differences for the paired trains (Trains A and B, Trains C and D, and Trains E and F). The average emission rates and precisions at a 95% confidence level were calculated for the four trains (A, B, C and D) and for the six trains (A, B, C, D, E and F). These results show that for the purpose of a compliance test which consists of three runs conducted within 10 percent of the isokinetic rate (100 % isokinetic), the average of the three runs should be within about 35% of the actual value (determined by this reference method over numerous runs) with a 95% confidence level. This precision of the sampling and analytical method does not account for process variation. It has been demonstrated that the chromium test method when applied to sources having greater chromium concentrations (i.e., hard chrome plating operations) has the precision of EPA Method 5 ($\pm$10% with a 95% confidence level).

3.2.6 Collection Efficiency of Sampling Train

For test series 3-2, 3-3, 3-4, 4-2, and 4-3, the impinger train collection efficiency was checked. Analyses of the impinger samples were conducted for several compounds; however, except in the case of lithium, the blank values were too high to obtain reliable results. A summary of the analytical results for the efficiency check is shown in Table 3.12. These results indicate that some lithium was not collected by the sample train. The collection efficiency of hexavalent chromium has been measured for the impinger train at other industries, and close to 100% collection efficiency was always observed. Based on these results and the results of other studies conducted by EPA, the impinger train should quanitatively remove all the chromium from the emissions sampled and should be sufficient for collecting bromide (the recommended surrogate) which is more soluble than lithium. Further checks will be made on future tests.

TABLE 3.9. IMPINGER-TYPE TRAIN AT DIFFERENT ISOKINETIC RATES AND NOZZLE SIZES
ANALYSIS CONDUCTED BY NAA

Run Number	Date (1986)	Filter Type	Filter Location	Probe Length (ft)	Avg. ΔH	Nozzle Dia (in.)	Isokinetic Rate (%)	Pollutant Mass Rate of Bromide			
								PMR_a lb/hr x 10^{-6}	PMR_c lb/hr x 10^{-6}	PMR_a* normal.	PMR_c* normal.
3-A-1	3/6	None	N/A	2	1.51	0.374	50.3	780	1547	108	214
3-B-1	3/6	None	N/A	2	1.49	0.374	50.3	973	1945	134	268
3-C-1	3/6	None	N/A	4	3.20	0.305	102.1	584	571	81	79
3-D-1	3/6	None	N/A	4	3.20	0.310	95.5	865	905	119	125
3-E-1	3/6	None	N/A	6	2.70	0.244	148.5	1624	1092	224	151
3-F-1	3/6	None	N/A	6	2.69	0.245	147.0	1194	811	165	112
3-A-3	3/7	None	N/A	6	1.57	0.374	50.6	203	402	---	---
3-B-3	3/7	Teflon	Back	6	1.54	0.374	49.7	519	1043	123	248
3-C-3	3/7	None	N/A	4	3.07	0.305	98.7	388	393	92	93
3-D-3	3/7	None	Back	4	3.06	0.304	96.2	453	470	108	112
3-E-3	3/7	Teflon	Back	2	2.77	0.244	148.5	1202	808	286	192
3-F-3	3/7	None	N/A	2	2.79	0.245	147.1	1082	735	257	175
4-A-3	3/8	None	N/A	2	5.67	0.374	99.9	436	435	72	72
4-B-3	3/8	Teflon	Back	2	5.78	0.374	96.2	452	469	75	78
4-C-3	3/8	Teflon	Back	4	3.02	0.305	98.9	554	560	92	93
4-D-3	3/8	None	N/A	4	3.05	0.304	96.6	653	675	108	112
4-E-3	3/8	None	N/A	6	1.23	0.244	102.7	1234	1200	204	199
4-F-3	3/8	Teflon	Back	6	1.23	0.245	99.2	965	972	160	161

*Pollutant mass rate averages presented here have been normalized to the average of the PMR_a's for the C and D trains for each run, which was set equal to 100.

TABLE 3.10. SUMMARY OF PMR_a and PMR_c RESULTS FOR BROMIDE ANALYZED BY NAA

Series of Run Numbers	Sample Train	Probe Length (ft)	Avg. ΔH	Nozzle dia (in.)	Isokinetic Rate (%)	Pollutant Mass Rate* PMR_a	Pollutant Mass Rate* PMR_c
	Impinger type train at different isokinetic rates and nozzle sizes						
3-A+F-1	A+B	2	1.5	0.37	50	121	241
	C+D	4	3.2	0.31	100	100*	102
	E+F	6	2.7	0.25	150	195	132
	Impinger type train at 100% isokinetic rate and different nozzle sizes						
3-A+F-3	A+B	6	1.5	0.37	50	123	248
	C+D	4	3.1	0.30	100	100*	103
	E+F	2	2.8	0.25	150	272	184
	Impinger type train at 100% isokinetic rate with different nozzle sizes						
4-A+F-3	A+B	2	5.7	0.37	100	73	75
	C+D	4	3.0	0.30	100	100*	103
	E+F	6	1.2	0.25	100	182	180

*Pollutant mass rate averages presented have been normalized to the average PMR_a's for the runs conducted at 100% isokinetic, which have been set equal to 100. The high and low values for all groups with more than one run have been dropped in calculating the averages.

TABLE 3.11. CALCULATED PRECISION OF IMPINGER TRAIN RESULTS

Run Number and Description	Relative Percent Difference		Mean Values +/- Percent Range at the 95% Confidence Level	
1-A+F-5	A/B	21.1%	(A+B+C+D)	74.3 +/- 19.96%
Different Isokinetic	C/D	12.1%	(All six)	93.4 +/- 30.91%
Rates and Nozzle Sizes	E/F	20.4%		
1-A+F-6	A/B	15.6%	(A+B+C+D)	180.0 +/- 34.20%
Different Isokinetic	C/D	40.9%	(All six)	184.1 +/- 23.10%
Rates and Nozzle Sizes	E/F	16.8%		
1-A+F-7	A/B	30.3%	(A+B+C+D)	152.8 +/- 43.72%
Different Isokinetic	C/D	28.4%	(All six)	189.4 +/- 55.44%
Rates and Nozzle Sizes	E/F	63.8%		
1-A+F-8	A/B	9.3%	(A+B+C+D)	146.9 +/- 24.69%
Different Isokinetic	C/D	20.1%	(All six)	191.6 +/- 31.44%
Rates and Nozzle Sizes	E/F	3.8%		
3-A+F-1	A/B	23.2%	(A+B+C+D)	63.6 +/- 22.32%
Different Isokinetic	C/D	15.5%	(All six)	68.2 +/- 19.06%
Rates and Nozzles Sizes	E/F	19.0%		
3-A+F-2	A/B	11.6%	(A+B+C+D)	34.2 +/- 21.89%
Different Isokinetic	C/D	16.9%	(All six)	47.7 +/- 36.83%
Rates and Nozzles Sizes	E/F	7.3%		
3-A+F-3	A/B	8.0%	(A+B+C+D)	28.6 +/- 26.08%
All 100% Isokinetic	C/D	25.9%	(All six)	35.3 +/- 28.88%
Different Nozzle Sizes	E/F	14.1%		
3-A+F-4	A/B	1.1%	(A+B+C+D)	35.3 +/- 10.33%
All 100% Isokinetic	C/D	10.8%	(All six)	42.9 +/- 31.10%
Different Nozzle Sizes	E/F	30.8%		
4-A+F-1	A/C/E	23.5%	(A+C+E)	62.2 +/- 32.56%
All 100% Isokinetic	B/D/F	9.0%	(B+D+F)	171.1 +/- 12.44%
Different Nozzle Sizes				
4-A+F-2	A/B	3.4%	(A+B+C+D)	21.5 +/- 63.18%
Different Isokinetic	C/D	69.1%	(All six)	47.5 +/- 76.83%
Rates and Nozzle Sizes	E/F	29.2%		
4-A+F-3	A/B	2.1%	(A+B+C+D)	19.8 +/- 13.26%
Different Isokinetic	C/D	15.5%	(All six)	36.5 +/- 66.11%
Rates and Nozzle Sizes	E/F	34.6%		

TABLE 3.12. PERCENT RECOVERY OF LITHIUM BY SAMPLE TRAIN COMPONENT

Run No.	Percent of Total Sample Collected by Sampling Train Component		
	Probe and first two impingers	Third impinger	Backup filter
3-2	79%	8%	13%
3-3	78%	5%	17%
3-4	77%	4%	19%
4-2	72%	16%	12%
4-3	63%	12%	25%

3.2.7 Surrogates for Drift Testing

Several compounds and elements were analyzed in this testing program. Only one was found to be acceptable to meet the criteria necessary for surrogate analytes for cooling towers; this element was bromine. Based on a previous EPA screening study, total chromium also appeared to be acceptable. Both should be analyzed using Neutron Activation Analysis (NAA). NAA can detect chromium at levels as low as 0.05 ug with an accuracy of $\pm$15% and bromide at levels of 0.0005 ug with an accuraccy of $\pm$10%. All other elements and analytical techniques evaluated require a detection limit of approximately 1 ug of the specific analyte in the sample and/or the element exists in sufficient quantities in the ambient air to create a high background or blank level (which would have to be subtracted from the emission rate). Table 3.13 presents the elements and analytical methods evaluated during this sampling program and recommendations for the use of each. When an element was not recommended as a surrogate, the recommendation was based only on the results of this study. If the tester has a more accurate analytical technique or is in an area that is free of background contamination, an element may be acceptable.

3.2.8 Conclusions

The results obtained at Munters Corporation support the information supplied by CTI and other experts in the field of cooling tower testing, that a propeller anemometer should be used for measuring fan cell gas velocities and that bromide would be a suitable surrogate for cooling tower drift emission measurements. Based on a previous EPA screenig study, total chromium also appeared to be suitable.

A recommended test method for measuring chromium emissions from cooling towers (see Appendix B) has been developed based on testing the low level

TABLE 3.13. ANALYTICAL TECHNIQUES AND ANALYTES EVALUATED

Element	Analytical Technique	Quantifiable Detection Limit	Present in Ambient Air	Remarks	Recommendation
Li	Graphite Furnace/Atomic Absorption	0.1 ug	Unlikely	Lithium can react with glass to form an insoluble compound	Not recommended due to possible reactions
Li	Neutron Activation Analysis	0.1 ug	Unlikely	Sodium in cooling water makes NAA of Li not acceptable	Unacceptable at low levels
Br	Ion Chromatographic	1 ug	Unlikely	Other elements make low level analysis difficult and detection limit requires long sampling times	Unacceptable at low levels
Br	Neutron Activation Analysis	0.005 ug	Unlikely	Bromine is one of elements better analyzed by NAA	Acceptable
Na	Inductively-Coupled Argon Plasmography	1 ug	Likely	Both potential background levels and high detection limit make sodium a poor choice at low levels	Unacceptable at low levels
Ca	Inductively-Coupled Argon Plasmography	0.5 ug	Likely	Both potential background levels and high detection limit make calcium a poor choice at low levels	Unacceptable at low levels
Mo	Inductively-Coupled Argon Plasmography	0.05 ug	Unlikely	Molybdenum was lost in sampling train or in sample containers; poor recovery	Unacceptable

(continued)

TABLE 3.13. (Continued)

Element	Analytical Technique	Quantifiable Detection Limit	Present in Ambient Air	Remarks	Recommendation
Mo	Neutron Activation Analysis	0.05 ug	Unlikely	Molybdenum was lost in the sample train or in the sample containers; poor recovery	Unacceptable at low levels
Cr^{+6}	Colorimetric	1 ug	Unlikely	Detection limit requires a sample collection time which is too long	Unacceptable at low levels
Cr	Neutron Activation Analysis	0.05 ug	Unlikely	Chromium is one of the elements better analyzed NAA	Acceptable

drift emissions at the Munters Corporation and on numerous tests conducted at other industries having chromium emissions. The draft method presented in Appendix B utilizes a sampling train similar to that currently used by the Cooling Tower Institute (CTI) for drift measurement.

The recommended method does not account for recirculation of the drift back into the same tower or cross contamination by drift from surrounding towers. Also, the background (ambient) contribution of chromium is not taken into account since chromium should not be present in the ambient air. It would not be practical to account for these cases, and each facility tested should use its best judgement to minimize the same tower and cross-tower contamination.

3.2.9 Other Measurements

Ambient Measurements - A meteorological station equipped with a wind vane and a cup anemometer was used to determine the wind direction and speed at the cooling tower discharge. The relative humidity and ambient temperature were determined from wet- and dry-bulb thermometers. A globe thermometer was used to measure the mean radiant temperature. The barometric pressure was measured by personnel at Page Field, an airport adjacent to the Munters facility.

DC-2 Droplet Counter - The DC-2 Hot Wire Droplet Counter is a prototype instrument developed by KLD Associates, Inc. for the measurement of concentration and size distribution of liquid droplets in a gas stream. This instrument was used to collect data on the particulate size distribution in the cooling tower discharge at the sampling location. The averages of all the runs indicated that 85% by weight of droplets were >450 microns and 97% by weight of droplets were >281 microns in size. Problems were encountered with the instrument during testing, and upon further discussion with KLD Associates it was revealed that they did not consider the prototype reliable.

4.0 PROCESS OPERATIONS

The Munters Corporation evaluates the performance of components such as fill and drift eliminators in simulated cooling tower configurations on a contract basis and for product development in their crossflow and counterflow cooling towers. A wide range of design specifications can be selected to simulate operating conditions that exist in actual cooling tower installations. The airflow and waterflow rates can be varied to achieve a wide range of liquid-to-gas ratios, air velocities, and drift rates. Various types and combinations of fill materials and drift eliminators can be installed to mock various cooling tower configurations.

Testing was conducted on Munters' cross-flow tower with high-efficiency drift eliminators (D-15). The tower has only a single cell as shown in Figure 5.1 (see Section 5.0). No blowdown was conducted during testing to conserve the surrogate analytes. Makeup water was added between runs, as needed, to keep the water at the proper level.

During the entire test series, the tower was operated at a recirculation waterflow rate of about 250 gallons per minute and at a liquid to gas ratio of approximately 0.66. The only process operating parameter that was not representative of an actual high-efficiency cooling tower was the percent of saturation. The Munters pilot unit is designed for heating the water and testing over shorter time intervals than were tested. As a result, the discharge from the tower could not be kept near saturation. The gases exiting the drift eliminator are computer monitored by the Munters Corporation and a summary of the monitoring results are presented in Table 4.1.

TABLE 4.1. COOLING WATER AND AIR TEMPERATURES IN ^{o}F

Run No.	Water Temperature Enter	Water Temperature Exit	Ambient Temperature Wet bulb	Ambient Temperature Dry bulb	Discharge Temperature Wet bulb	Discharge Temperature Dry bulb
1-1	61.5	58.5	56.9	67.0	58.0	63.3
1-2	57.5	56.5	56.3	64.5	57.0	62.2
1-3	82.2	70.0	55.2	63.2	65.2	66.2
1-4	79.2	69.6	60.3	69.5	67.2	69.8
4-1	88.4	74.5	56.2	67.3	69.3	70.5
1-5	77.5	68.7	60.3	70.5	66.9	70.5
1-6	88.9	73.6	58.2	65.5	69.3	70.2
1-7	77.5	68.3	59.7	68.7	66.5	68.4
1-8	71.4	66.4	60.9	68.5	65.1	68.3
3-1	92.4	75.8	60.1	67.7	72.2	72.6
3-2	82.5	71.6	61.6	74.2	68.9	73.0
3-3	----------NOT RECORDED----------					
4-2	----------NOT RECORDED----------					
4-3	----------NOT RECORDED----------					

5.0 SAMPLING LOCATIONS AND TEST METHODS

This section describes the sampling locations and test methods used to characterize emissions from the crossflow cooling tower at the Munters Corporation's test facility in Fort Myers, Florida. The cooling tower exhaust stack was used as the sampling location for the testing to measure the drift emissions using the surrogate analytes lithium and bromine (introduced into the cooling water as LiBr), the drift size distribution, and the exhaust velocity. In addition, cooling water samples were taken from the recirculation basin for background analysis of the bromine content. A meteorological station was located approximately twelve feet from the exhaust stack sampling location to monitor ambient temperatures, wind speed, and wind direction. The relative positions and the type of testing conducted at each location are shown in the simplified process flow diagram (see Figure 5.1) and accompanying Table 5.1. The subsections which follow further describe each sampling location and the applicable test methods.

5.1 COOLING TOWER EXHAUST STACK (Sampling Location A)

Sampling for lithium and bromine, as well as the drift sizing and velocity determination, was conducted at the crossflow cooling tower exhaust stack (Sampling Location A) shown in Figure 5.2. Sampling probes were introduced into the flow from the exit of the exhaust stack, and nozzles were located approximately two inches below the exhaust plane. Based on a preliminary three-dimensional pitot probe velocity traverse, a single point along the east-west diameter of the exhaust stack was determined to have a typical misaligned flow angle (30^{o}-60^{o}). All sampling probes were placed within one inch of this point (except the particle sizing probe; it was located on the same diameter roughly opposite this point). The axial component of flow was continuously monitored using a propeller anemometer located approximately three inches above the sampling point.

Method 5- and impinger-type trains were used for lithium and bromine sample collection. Sampling was conducted at a single point for approximately 120 minutes per run. A total of six sampling probes and trains were used during each run allowing different nozzle sizes, probe lengths, filtering techniques, and isokinetic flow percentages to be used within a single run in order to assess the relative merits of these sampling equipment variables.

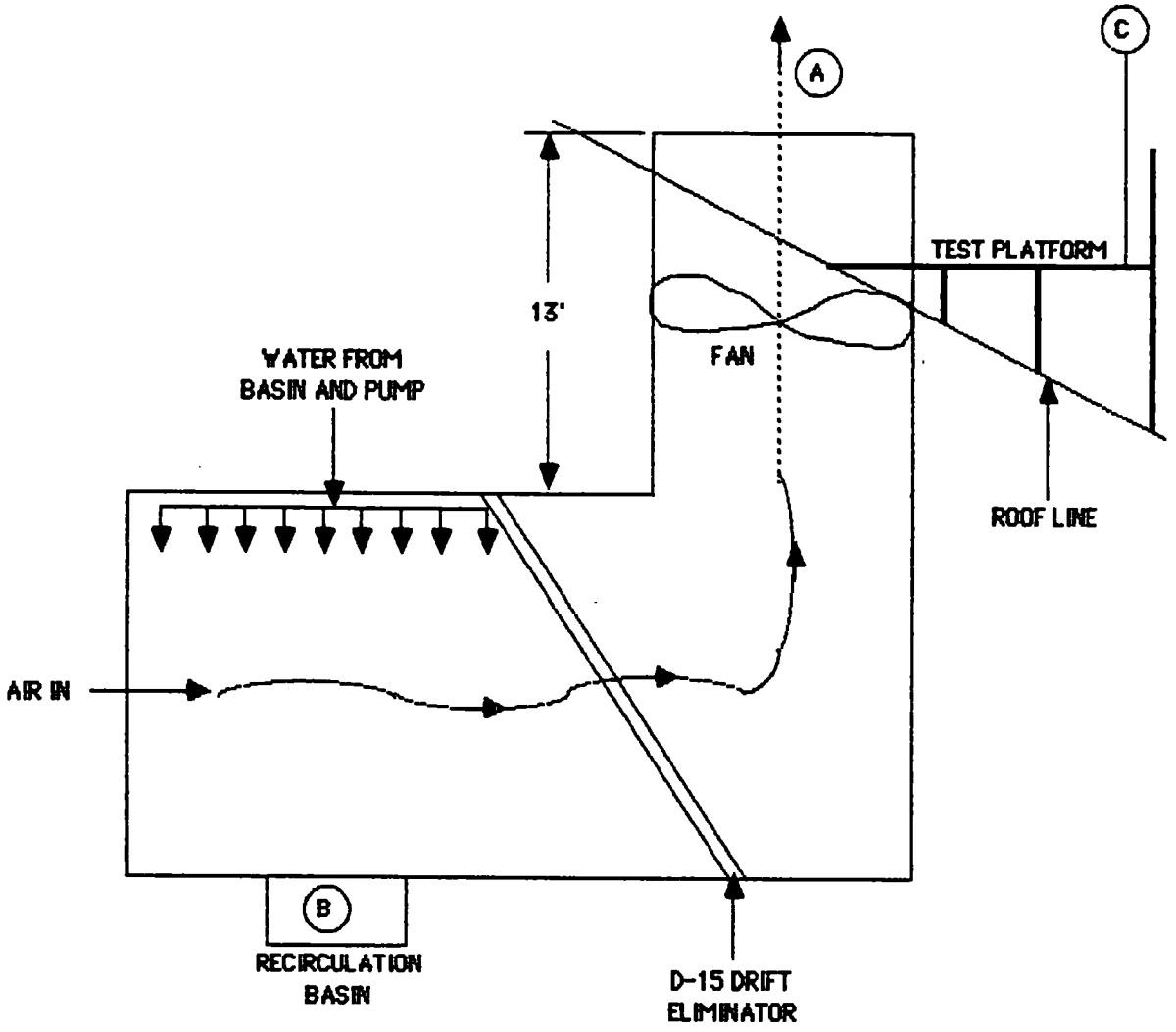

FIGURE 5.1 AIR FLOW DIAGRAM OF MUNTERS CORPORATION CROSSFLOW COOLING TOWER SHOWING SAMPLING LOCATIONS.

TABLE 5.1. SAMPLING PLAN FOR MUNTERS CORPORATION

Sample Type	Sampling Location	Number of Runs	Methods
Lithium	A	15	EPA Method 5- or Impinger-type train with ICAP Analysis Off-site
Bromine	A	15	EPA Method 5- of Impinger-type train with IC and NAA Analysis Off-site
Drift Size Distribution	A	3	Cyclone
Drift Size Distribution	A	15	Modified Hot-Wire Anemometer
Velocity Determination	A	Single Point Continuous	Propeller Anemometer
Cooling Water Samples	B	15 Pair Grab Samples	Specific Ion Electrode Bromine Analysis On-site and ICAP Off-site
Meteorological Data	C	Continuous	Cup Anemometer, Directional Anemometer, Globe Thermometer, Wet & Dry Bulb Thermometers

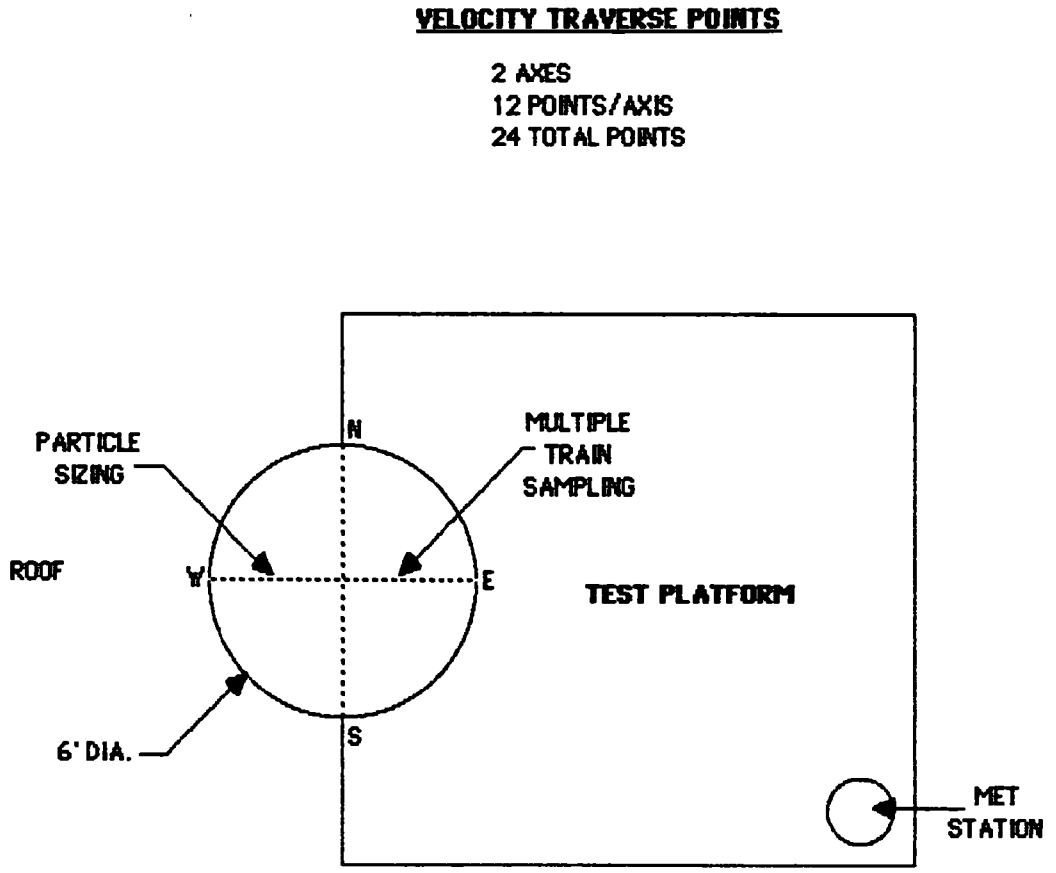

FIGURE 5.2 TOP VIEW OF CROSSFLOW COOLING TOWER EXHAUST STACK, MUNTERS CORPORATION (SAMPLING LOCATION A).

5.2 COOLING WATER BASIN (Sampling Location B)

At the start and completion of each emissions test run, two cooling water samples were taken from the recirculation water basin. These samples were taken by hand and stored in 500 ml glass jars. Analysis of each sample for bromine content was conducted on-site using a specific ion-electrode and off-site using inductively-coupled argon plasmography (ICAP).

5.3 AMBIENT METEOROLOGICAL STATION (Sampling Location C)

A meteorological station was assembled and operated continuously 12 feet from the exhaust stack in order to quantify ambient conditions at the time of sampling. Wind speed and direction were monitored using a cup anemometer and directional anemometer and recorded on a strip chart recorder. Ambient wet bulb/dry bulb temperatures were obtained using a psychrometer and the effects of radiant energy were quantified using a globe thermometer (black-body thermometer).

5.4 VELOCITY AND GAS TEMPERATURE

A three-dimensional pitot tube and a bank of magnehelic gauges were used to measure the gas velocity pressure (delta P) and both the yaw and pitch flow angles. Velocity pressures and angles were measured at 12 sampling points along each of the two traverse diameters (as per Method 5D) as shown in Figure 5.2, to determine an average flow velocity and angle at each point. The temperature at each sampling point was measured using a thermocouple and digital readout. In addition, a propeller anemometer was used to determine a total flow velocity in the axial direction at each of these points; the results were then compared to the results of the 3-D pitot probe traverse.

5.5 MOLECULAR WEIGHT

Flue gas composition was essentially that of the ambient air drawn into the cooling tower via the vane axial fan. Therefore, the dry molecular weight and composition of air was used.

5.6 LITHIUM AND BROMINE

Method 5 sampling procedures, as described in the Federal Register,* were used with the Method 5- and impinger-type trains to measure lithium and bromine

*40 CFR 60, Appendix A, Reference Methods 2, 3, and 5, July 1, 1980.

emissions at Sampling Location A. All tests were conducted at constant percentages of isokinetic (50, 100, and 150) by regulating the sample flow rate relative to the flue gas flow rate as measured by the propeller anemometer. Sampling trains consisted of a heated, glass-lined probe, and either (1) a 3-inch nominal diameter glass fiber or Teflon filter and a series of Greenburg-Smith impingers (two containing 100 ml of deionized-distilled water, one empty and one with silica gel), or (2) a series of Greenburg-Smith impingers (two containing 100 ml of deionized-distilled water, one empty and with with silica gel) with a 3-inch nominal Teflon filter located between the third and fourth impinger. A distilled water rinse of the nozzle, probe, appropriate filter holder portions, and impingers of the sample train was made at the end of each test. This rinse was added to the impinger and filter sample. The entire sample was typically concentrated to approximately 10 ml. The lithium content of the cooling tower exhaust samples was determined by RTI (Entropy's subcontractor under the EMB contract) using the inductively-coupled argon plasmography or the graphite frunace/atomic absorption technique for sample analysis. Bromine content was measured by RTI using ion chromatography. See Appendix B for the detailed draft test methods.

6.0 QUALITY ASSURANCE

Because the end product of testing is to produce representative emission results, quality assurance is one of the main facets of stack sampling. Quality assurance guidelines provide the detailed procedures and actions necessary for defining and producing acceptable data. Two such documents were used in this test program to ensure the collection of acceptable data and to provide a definition of unacceptable data. These documents are the EPA Quality Assurance Handbook Volume III, EPA-600/4-77-027 and Entropy's "Quality Assurance Program Plan," which has been approved by the U. S. EPA, EMB.

Relative to this test program, the following steps were taken to ensure that the testing and analytical procedures produce quality data.

- Calibration of field sampling equipment. (Appendix E describes calibration guidelines in more detail.)
- Checks of train configuration and calculations.
- On-site quality assurance checks of sampling train components.
- Use of designated analytical equipment and sampling reagents.

Pre- and post-test calibrations were performed for each of the meter boxes used for sampling. Calibrations were also performed for the temperature sensing equipment, nozzles, anemometer sensor, and the entire propeller anemometer apparatus. Appendix E includes the calibration data sheets for each dry gas meter used for testing and data sheets for the calibrations of the other sampling equipment mentioned.

Audit solutions were used to check the analytical procedures of the laboratories conducting the lithium, bromine, molybdenum, calcium, and magnesium analyses. Table 6.1 presents the results of these analytical audits. The audit tests show that the analytical techniques were good.

The sampling equipment, reagents, and analytical procedures for this test series were in compliance with all necessary guidelines set forth for accurate test results as described in Volume III of the Quality Assurance Handbook.

TABLE 6.1. AUDIT REPORT ANALYSIS

Plant: Munters Corporation Task No.: 3503

Date Samples Received: _____ Date Analyzed: April 1986

Samples Analyzed By: RTI and NCSU

Reviewed By: P. Grohse / J. Weaver Date of Review: _____

Sample Number	ug/mL Cr^{+6} or Cr	Source of Sample	Analytical Technique	Audit Value	Relative Error, %
QA-1-86	0.5 µg/ml Mg	Entropy	ICAP	0.46 µg/ml	-8.0
QA-1-86	1.0 µg/ml Ca	Entropy	ICAP	0.90 µg/ml	-10.0
QA-1-86	2.0 µg/ml Mo	Entropy	ICAP	2.05 µg/ml	+2.5
QA-2	25 µg/L Li	RTI internal	GF/AA	28 µg/L	+12.0
QA-3	50 µg/L Li	RTI internal	GF/AA	47 µg/L	-6.0
QA-4	100 µg/L Li	RTI internal	GF/AA	105 µg/L	+5.0
SRM 1566	55.0 µg Br	NBS	NAA	52.422 µg	-4.7
SRM 1527	8.2 µg Br	NBS	NAA	8.51 µg	+3.8
EPA Cert. Std.	50.0 µg/ml Br	EPA	NAA	50.123 µg/ml	+0.2
SRM 1084	97.0 µg Mo	NBS	NAA	95.902 µg	-1.1
SRM 1084	97.0 µg Mo	NBS	NAA	98.092 µg	+1.1