MRI REPORT

Development of Particulate Emission Factors for Wet Cooling Towers

Final Report

For Office of Air Quality
Planning and Standards (MD-14)
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

Attn: Dennis Shipman

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MIDWEST RESEARCH INSTITUTE 425 Volker Boulevard, Kansas City, MO 64110-2299 • (816) 753-7600

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PREFACE

This report was prepared for the Office of Air Quality Planning and Standards (OAQPS), U.S. Environmental Protection Agency (EPA), under EPA Contract No. 68-DO-0137, Assignment No. 10, which is with the Field Studies Branch of the Office of Toxic Substances. Mr. Dennis Shipman was the requester of the work. The report was prepared by Mr. John S. Kinsey.

Approved for:

MIDWEST RESEARCH INSTITUTE

Paul C Constant

Paul C. Constant
Program Manager

November 11, 1991

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SECTION 1

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) Office of Air Quality Planning and Standards (OAQPS) has responsibility for developing and maintaining the document "Compilation of Air Pollutant Emission Factors" (AP-42). This document is a basic source of emission factors used in preparation of State Implementation Plans (SIPs), review of Prevention of Significant Deterioration (PSD) applications, new source review, and other federal, state, and local agency assessments of air pollution sources.

There is reason to believe that particulate emissions from commercial and industrial cooling towers may be a significant source of particulate matter emissions and in particular of PM-10.* The purpose of this work assignment was to develop candidate emission factors for PM-10 (and total particulate matter [PM], if appropriate) for possible inclusion in AP-42. The following sections describe the analyses performed in the work assignment, present candidate emission factors for wet cooling towers, and provide a draft AP-42 section for wet cooling towers.

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* PM-10 is defined as particles no greater than 10 μm in aerodynamic diameter (equivalent unit density spheres).

SECTION 2

PROCESS DESCRIPTIONS

2.1 INTRODUCTION AND PROCESS OVERVIEW

Cooling towers are heat exchangers that dissipate large heat loads to the atmosphere. They are an important component in many industrial and commercial processes that must dissipate heat.

Cooling towers are typically used for:

- Power generation cycles which require the condensation of a working fluid such as steam to complete the cycle and return the condensed fluid to the boiler. The cooling tower is used to dissipate the heat of condensation to the environment.
- Process cooling such as in the petrochemical and various materials production industries which must condense and/or cool the product to complete a process step or finish the operation.
- Air conditioning cycles which require not only the dissipation of the heat removed from the air-conditioned space but also the dissipation of the working energy required to operate the air conditioning equipment, such as a chiller.

Although high efficiency process designs and recycling of energy, when feasible, can help reduce the amount of heat that must be rejected to the atmosphere, ultimately all of these energy sources must dissipate their residual energy to the environment. Cooling towers have become an accepted method of accomplishing this heat rejection.

Cooling towers may range in size from less than $5(10)^6$ Btu/h [$5.3(10)^6$ kJ/h] for small air conditioning cooling towers to over $5{,}000(10)^6$ Btu/h [$5{,}275(10)^6$ kJ/h] for large power plant cooling towers. Although cooling towers can be classified several ways, the primary classifications are dry towers and wet towers. However, some hybrid wet-dry combinations exist. Subclassifications can include the type of draft and/or the location of the draft relative to the heat transfer medium, the type of heat transfer medium, the relative direction of air movement, and the type of distribution system.

Dry cooling towers rely on the sensible exchange of heat between the process and the air passing through the cooling tower. The heat transfer is measured by the decrease in the process temperature and a corresponding increase in the sensible or dry bulb temperature of the air passing through the cooling tower. Dry cooling towers typically have tubes (with or without fins) which contain the process fluid to be cooled, and the cooling air passes over the exterior tube surface to remove the heat.

When water is used as the heat transfer medium, wet or evaporative cooling towers may be used. Wet cooling towers rely on the latent heat of water evaporation to exchange heat between the process and the air passing through the cooling tower. The cooling water may be an integral part of the process or provide cooling via heat exchangers.

In wet cooling towers, the heat transfer is measured by the decrease in the process temperature and a corresponding increase in the moisture content and wet bulb temperature of the air passing through the cooling tower. (There may also be a change in the sensible or dry bulb temperature; however, its contribution to the heat transfer process is very small and is typically ignored when designing wet cooling towers.) Wet cooling towers typically have a wetted media called "fill" to promote evaporation by providing a large surface area and/or by creating many water drops with a large cumulative surface area.

Because wet cooling towers have direct contact between the cooling water and the air passing through the tower, some of the water may be entrained in the air stream and carried out of the tower as "drift" droplets. These droplets eventually evaporate, leaving fine particles formed by crystallization of the dissolved solids in the cooling water. Therefore, the constituents of the drift droplets may be classified an environmental emission source (i.e., particulate matter). Since the characterization of the drift emissions from wet cooling towers is a primary objective of this study, the following sections deal mainly with wet cooling towers.

2.2 CLASSIFICATION OF COOLING TOWERS

Cooling towers can be categorized by: the type of heat transfer; the type of draft and location of the draft relative to the heat transfer medium; the type of heat transfer medium; the relative direction of air and water contact; and the type of water distribution system. These variations are briefly described in the following sections. Since evaporative cooling towers are the predominate type and also the subject of this study, the majority of the discussion is directed to this type of tower. Diagrams of the various tower configurations are shown in Figures 2-1 to 2-5.

2.2.1 Heat Transfer Type

Cooling towers can reduce the temperature of the water by two heat transfer mechanisms. The first is sensible heat transfer between the air and the water. This is dependent on the difference between the water temperature and the dry bulb temperature of the air. In "dry" cooling towers, such as finned tube heat exchangers, all of the heat transfer is due to the sensible temperature difference.

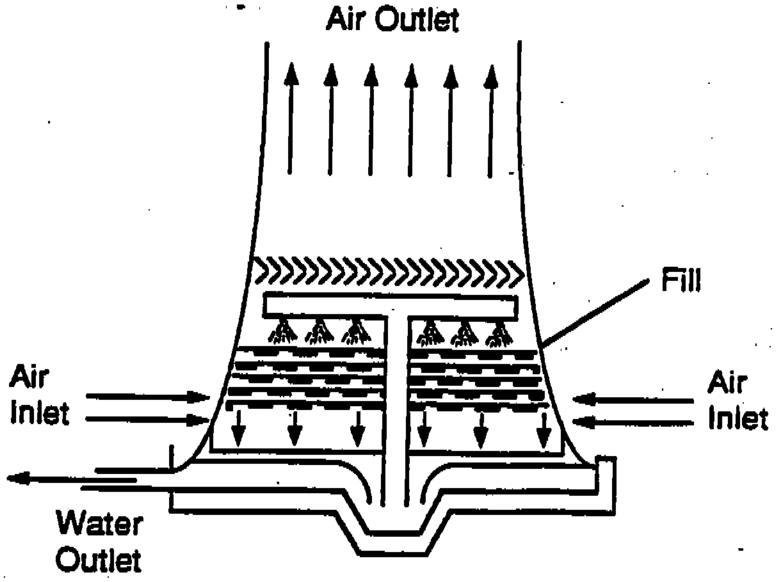
The second form of cooling is latent heat transfer, which occurs when a portion of the water to be cooled evaporates. This is dependent on the difference between the water temperature and the wet bulb temperature of the air. Because the wet bulb temperature is always less than or equal to the dry bulb temperature, a "wet" tower can provide lower temperatures, which may improve the overall system performance. Although wet cooling towers may also have some sensible cooling, the majority of the heat transfer is due to the latent cooling.

A few hybrid "wet-dry" cooling towers have been built in which a wet tower and a dry tower section are operated in series or parallel to shift a higher portion of the cooling to sensible heat transfer and conserve the amount of water evaporated. Wet-dry towers also tend to eliminate the visible plume of water droplets normally associated with wet cooling towers.

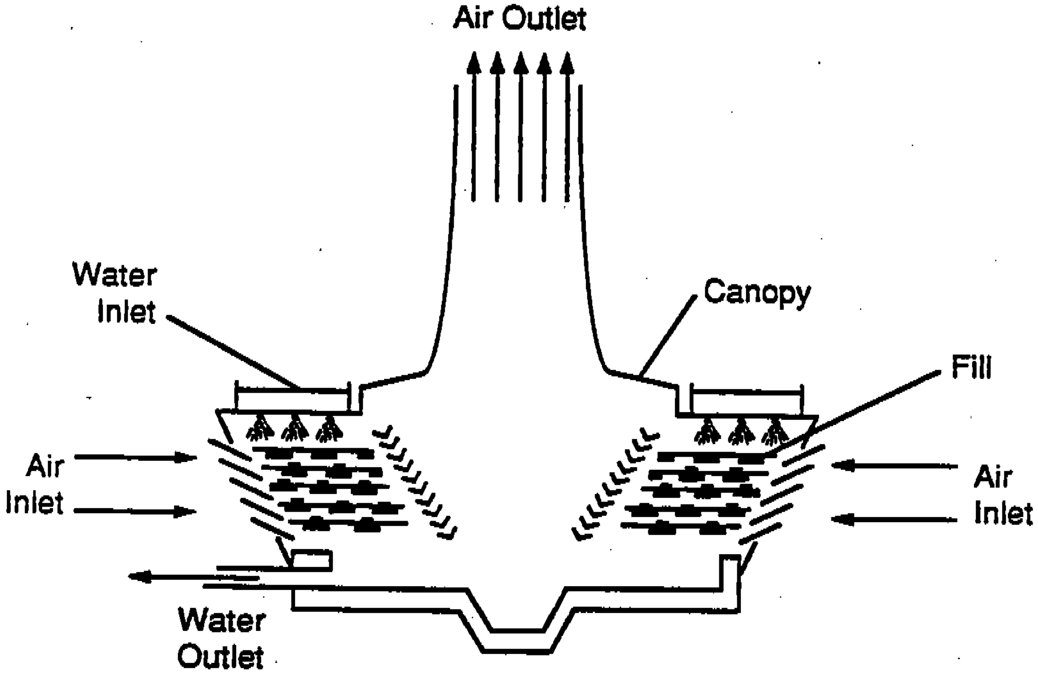
2.2.2 Draft Type

Cooling tower draft refers to the method in which airflow is created to move through the cooling tower and allow heat transfer to occur. Draft can be created naturally or mechanically.

In "natural draft" cooling towers (Figure 2-1), the air movement is dependent on the difference in density between the air surrounding the tower and the internal air. As the heat is transferred to the air passing through the tower, its density is reduced and it tends to rise and draw in additional cooling air at the base of the tower. The height and shape of the structure aid in the initiation and maintenance of the draft.



Counterflow Natural Draft Tower



Crossflow Natural Draft Tower

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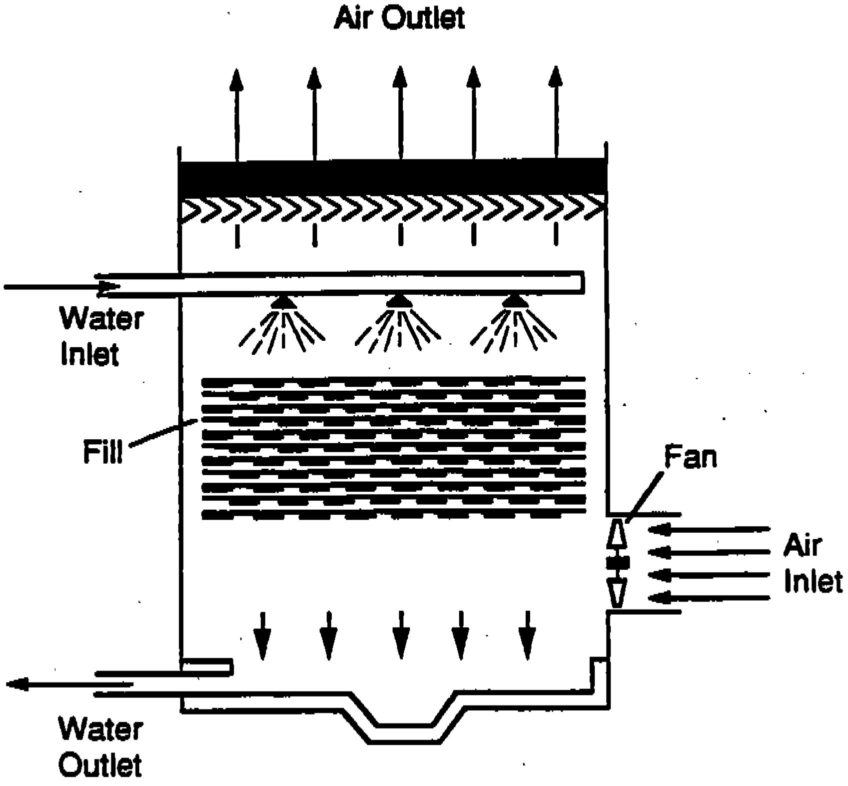
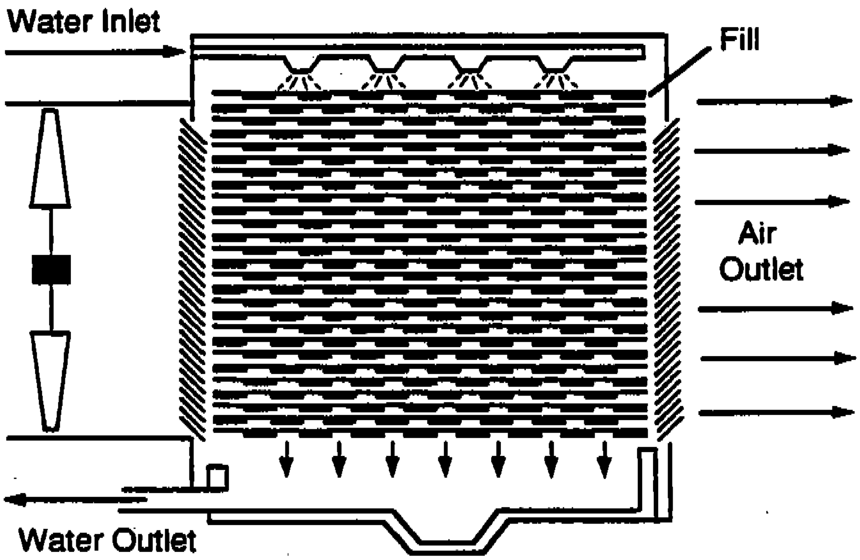
Figure 2-1. Natural draft wet cooling towers.



Forced Draft Counterflow Tower



Forced Draft Cross Flow Tower

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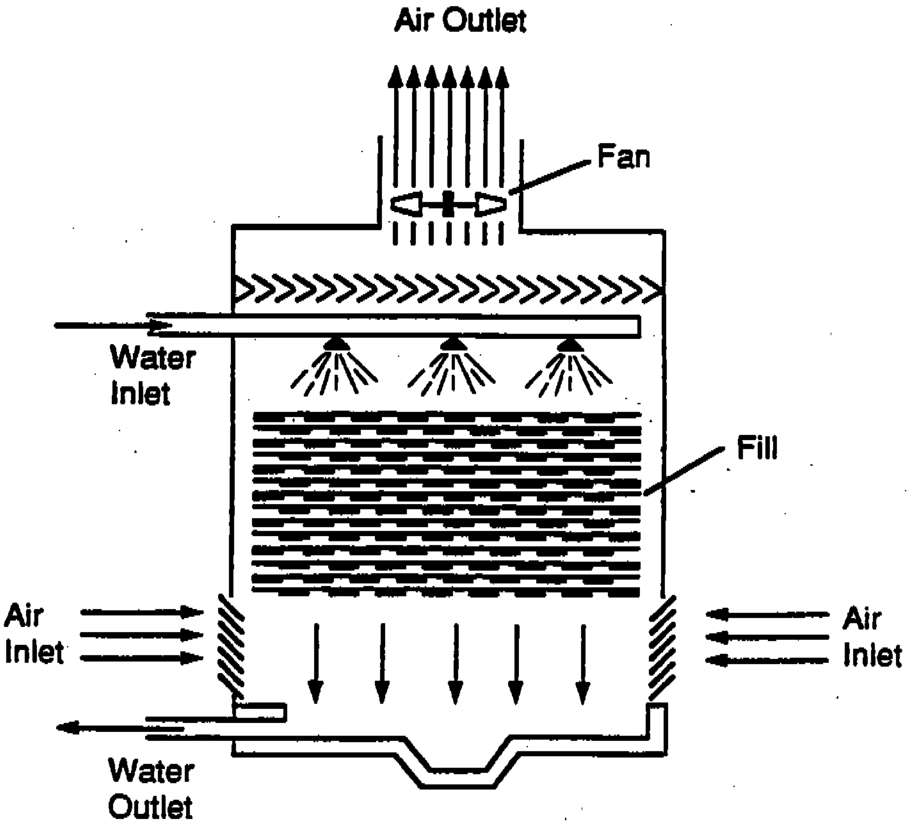
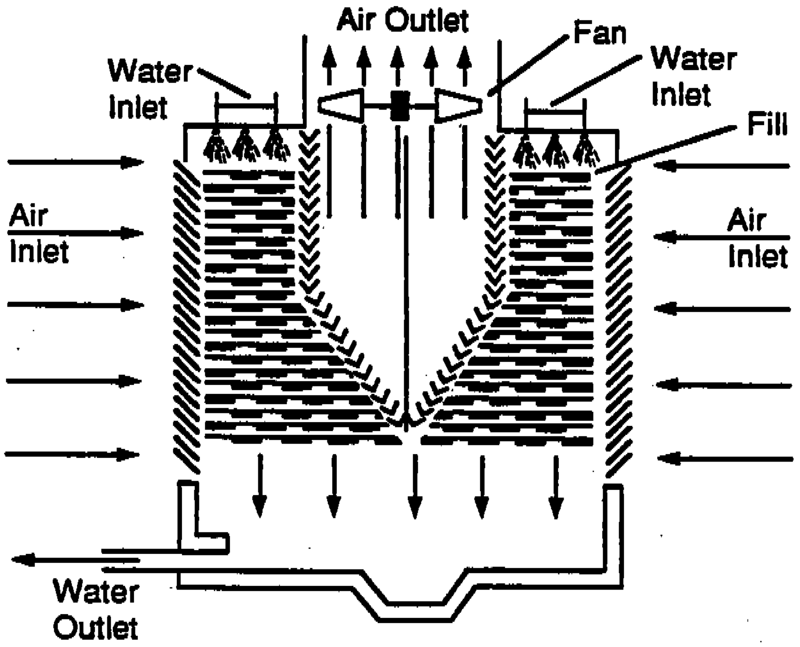
Figure 2-2. Forced draft wet cooling towers.



Induced Draft Counterflow Tower



Induced Draft Crossflow Tower

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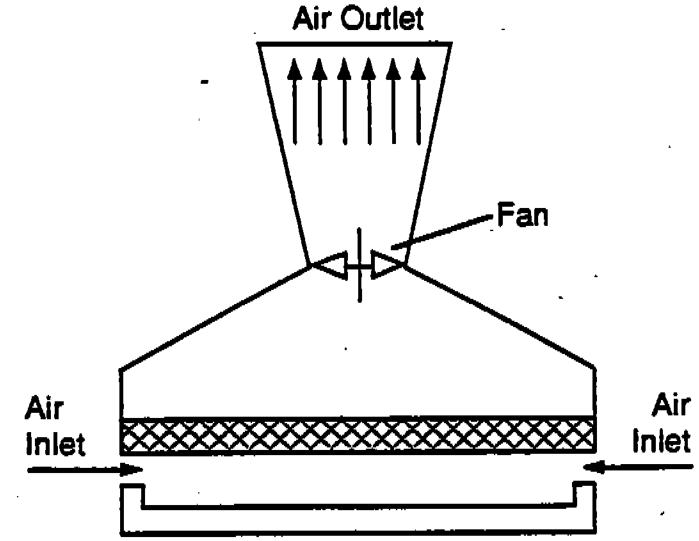
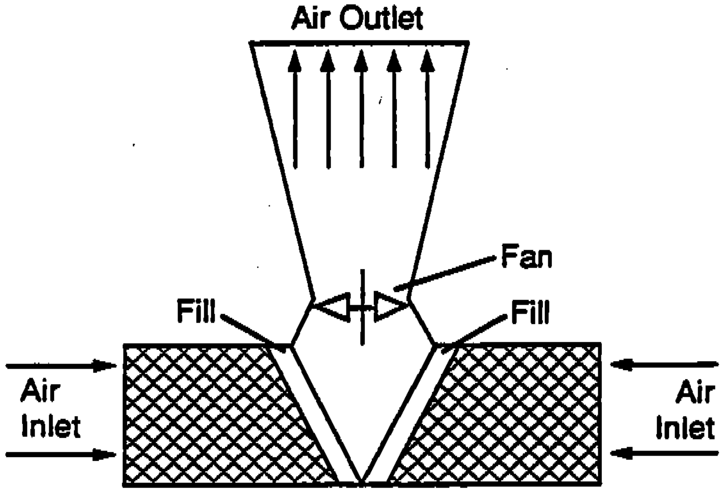
Figure 2-3. Induced draft wet cooling towers.



Fan Assist Counterflow
Induced Draft



Fan Assist Crossflow
Induced Draft

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Figure 2-4. Fan assist natural draft cooling towers.

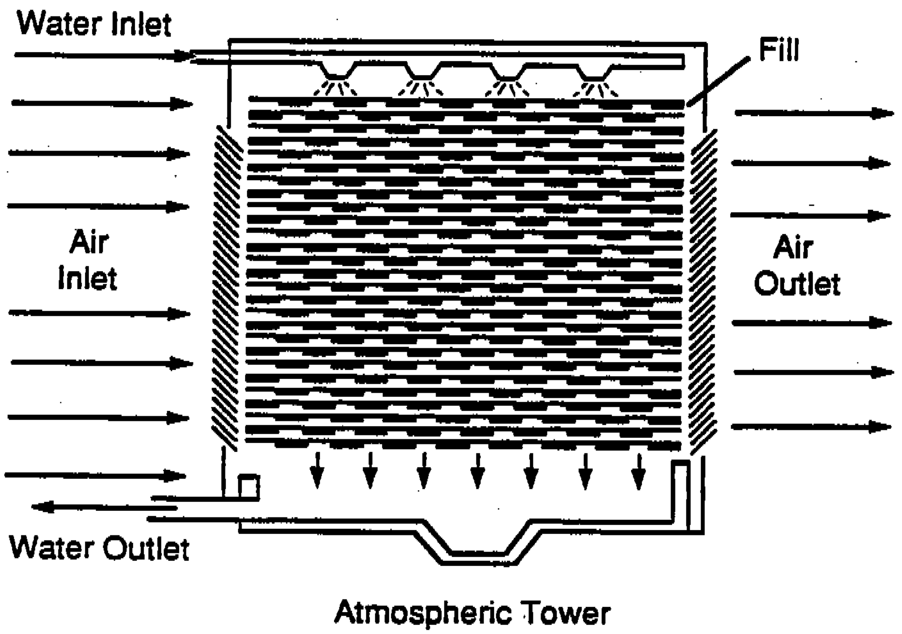

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Figure 2-5. Atmospheric wet cooling tower.

In "mechanical draft" cooling towers, the air movement is created by one or more fans. The tower may be "forced draft" (Figure 2-2) in which the fans are located at the tower inlet or "induced draft" (Figure 2-3) in which the fans are located at the tower exhaust.

Several special cases also exist. Fan-assisted natural draft towers (Figure 2-4) have one or more fans to assist with the tower draft. Atmospheric towers (Figure 2-5) have no fans and rely on atmospheric conditions such as wind in addition to air density to move the cooling air. Spray ponds and canals rely on fountain-like nozzles to inject water into air for atmospheric cooling.

2.2.3 Heat Transfer Medium Type

The cooling tower heat transfer medium is called "fill." Cooling tower fill is usually divided into two categories—"film fill" and "splash fill."

Film fill relies on the installation of a cooling medium with a large surface area for air-water heat transfer to occur. Film fills may include various materials such as ceramic, fiber reinforced cement, fiberglass, metal, plastic, and wood formed in closely spaced vertical sheets, honeycomb assemblies, or tiles. The materials may have other features, such as corrugations or holes, to further enhance the heat transfer area.

Splash fill relies on the formation of many small drops of water to obtain the air-water heat transfer surface. Like film fill, splash fill can be made of various materials and configured with different spacings and densities of packing to enhance the heat transfer area. Some towers may not have any splash fill for the internal heat transfer medium and rely only the initial water distribution spray system to create small droplets with a large cumulative surface area for heat transfer.

2.2.4 Direction of Air-Water Contact

Cooling towers usually are classed as having "counter-flow" or "cross-flow" heat transfer. Counter-flow cooling towers have the air moving vertically up while the water is moving vertically down. Cross-flow cooling towers have the air moving horizontally while the water is moving downward. These are the relative directions of the air and water in the heat transfer medium portion of the tower. Due to construction details, the relative airflow direction may be different in the tower inlet or exit, therefore, the heat transfer may not be 100% counter-flow or cross-flow in specific towers.

2.2.5 Water Distribution Type

Water distribution systems can be divided into two basic types--gravity and pressure. Gravity distribution systems rely on free flow through holes or orifices in troughs or boxes to initially inject the water into the cooling tower. Frequently the orifices contain distribution plates to assist with the breakup of the water jet into small droplets.

Pressure distribution systems use a network of closed pipes with periodically spaced nozzles to spray the water into the cooling tower under moderate pressure. The nozzle design and spray pressure cause the water to be broken up into numerous drops as it is discharged into the tower.

2.3 ENVIRONMENTAL EMISSIONS

Wet cooling towers have several environmental side effects in addition to the heat and moisture transferred to the environment. Because the wet cooling tower typically evaporates a portion of the water passing through it during the cooling process, the remaining water becomes more concentrated with dissolved/suspended minerals and/or chemicals in the water. Consequently a portion of the cooling tower water must be removed as "blow down" to keep the material concentrations within acceptable limits. To avoid waterborne environmental problems, it may be necessary to provide for the treatment of the effluent before disposal.

Cooling tower "drift" is water lost from the tower as liquid droplets (not recondensed water vapor) entrained in the exhaust air. Drift generally contains dissolved solids and is independent of the water lost by evaporation. Evaporation rates are typically 1% to 2% of the circulating water flow rate with drift rates ranging from as high as 0.01% to < 0.0001%.

The magnitude of the drift loss is influenced by the number and size of droplets produced within the cooling tower, which in turn is determined by the fill design, the air and water patterns, and other interrelated factors. Tower maintenance and operation can also influence the formation of drift droplets. For example, excessive water flow, excessive airflow, and water bypassing the tower drift eliminators can promote and/or increase drift emissions. Figure 2-6 shows an example curve of liquid drift emissions vs. droplet size for a typical mechanical draft cooling tower.[1]

Because the drift droplets generally have the same water chemistry as the water circulating through the tower, they can be the source of airborne emissions. Large drift droplets settle out of the tower exhaust air stream and deposit near the tower (Figure 2-7 for the same tower as above). This can lead

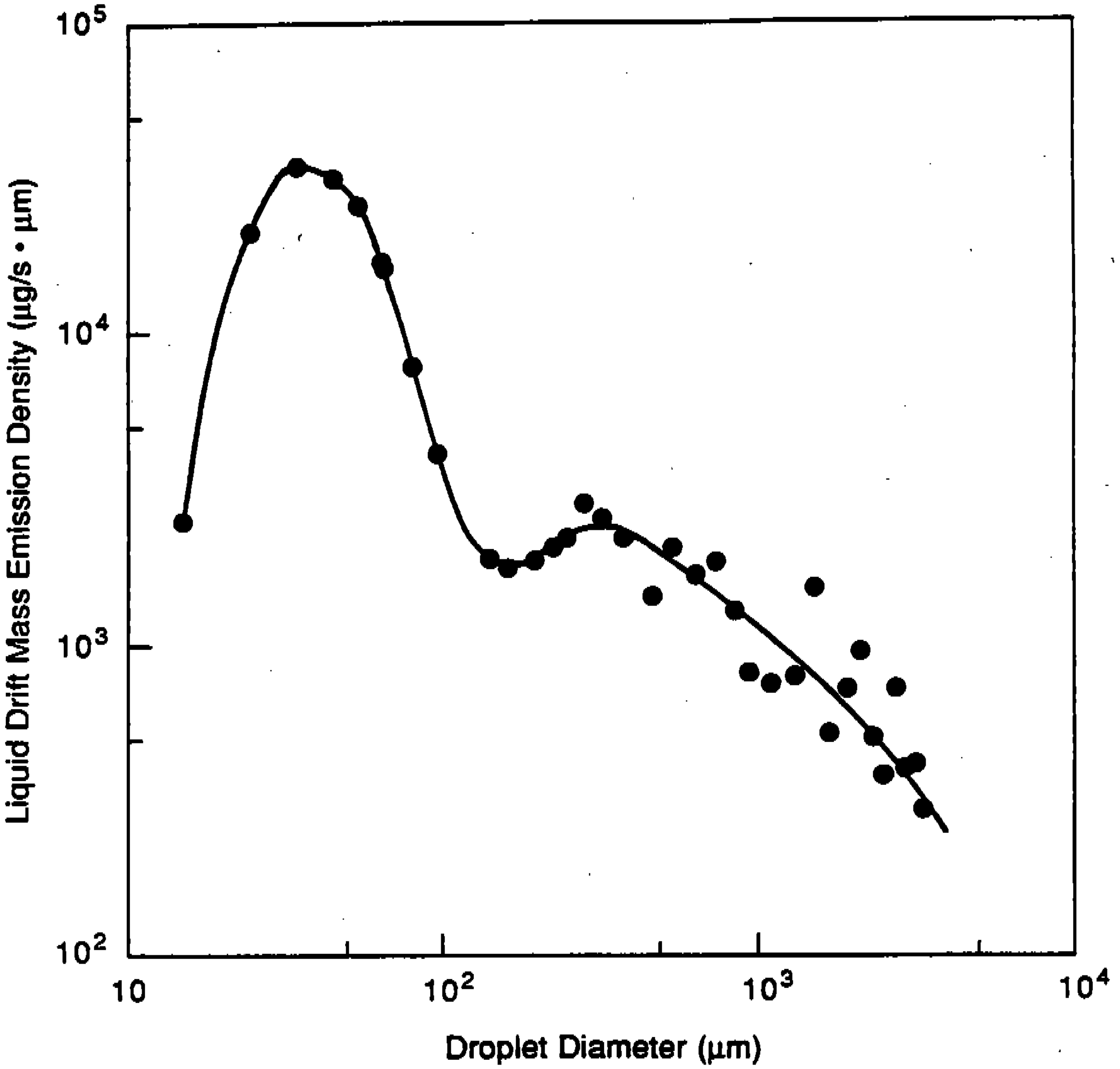

Figure 2-6. **Drift mass emission spectrum for the PG&E Pittsburg, California, cooling towers.**[1]

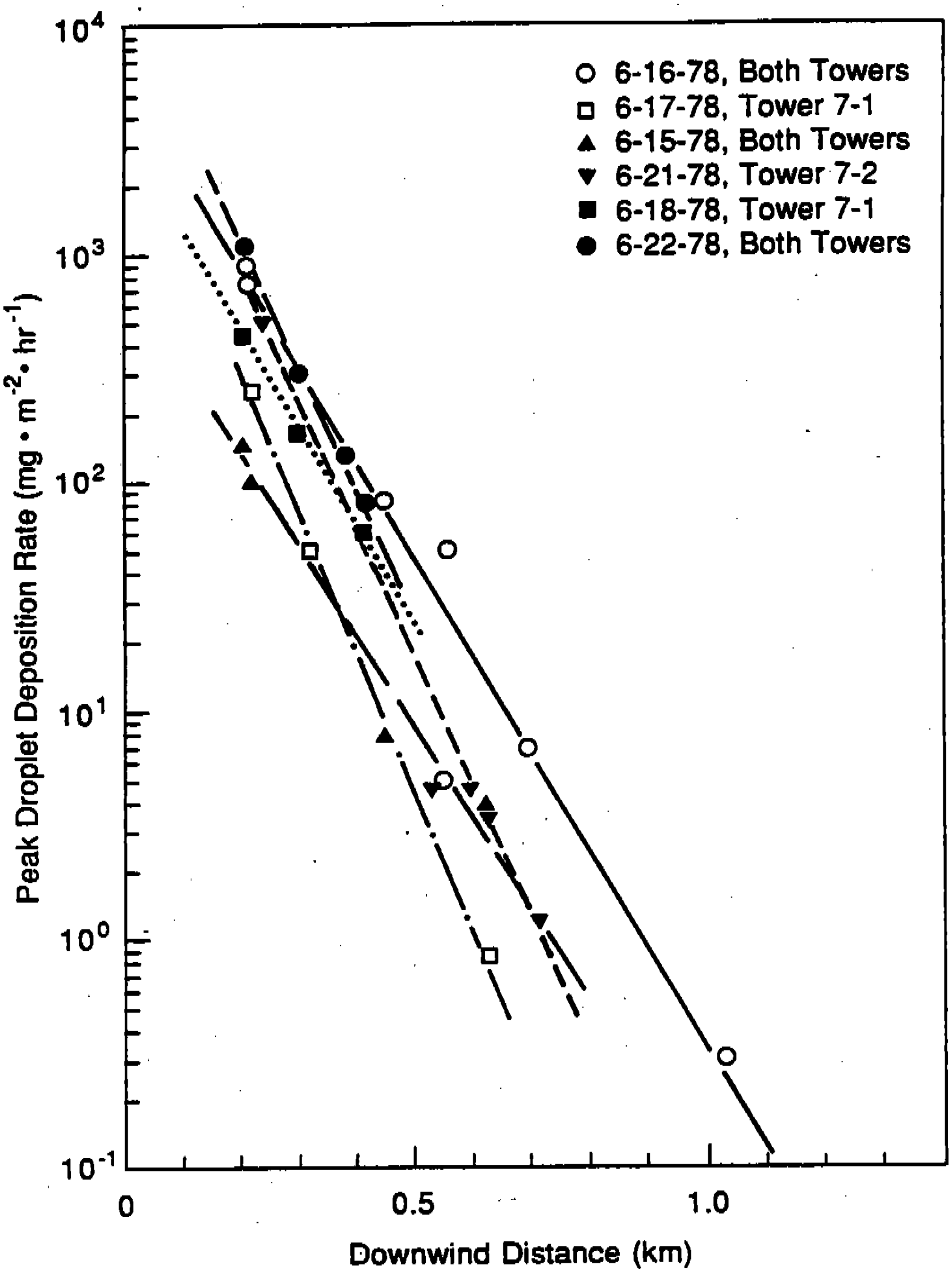

Figure 2-7. **Peak drift droplet deposition rate as a function of downwind distance for PG&E Pittsburg, California, cooling towers.**[1]

to wetting, icing, salt deposition, and related problems such as damage to equipment or vegetation. Because other drift droplets may evaporate before being deposited in the area surrounding the tower, they can also result in particulate emissions in the form of solid residue. Theoretically, drift droplets approximately less than 100 μm in diameter can result in PM-10 emissions ~ 3 s after injection into air at 80% to 90% relative humidity and 26.7°C (80°F).[2]

In order to reduce the drift from cooling towers, drift eliminators are usually incorporated into the cooling tower design to remove as many droplets as practical from the air stream before it exits the tower. The drift eliminators used in cooling towers rely on inertial separation caused by directional changes of the airflow while passing through the eliminators.

Like cooling tower fill materials, drift eliminators may include various materials such as ceramic, fiber reinforced cement, fiberglass, metal, plastic and wood installed or formed into closely spaced slats, sheets, honeycomb assemblies, or tiles. The materials may have other features such as corrugations and water removal channels to further enhance the drift removal.

The efficiency of a drift eliminator is a function of its design. Figure 2-8 presents schematics of the three major drift eliminator designs: herringbone (blade-type), waveform, and cellular (or honeycomb).[2] In general (with a few exceptions), herringbone units are the least efficient, cellular units are the most efficient, and waveform units achieve an intermediate efficiency. Drift eliminators installed in towers built in recent years are more likely to be higher efficiency waveform or cellular units, but a large number of older towers still have lower efficiency herringbone and waveform eliminators. Important design considerations for drift eliminators include the air velocity and pressure drop through the eliminators, as well as provisions for reducing or eliminating droplet reentrainment and air leakage (i.e., short-circuiting).

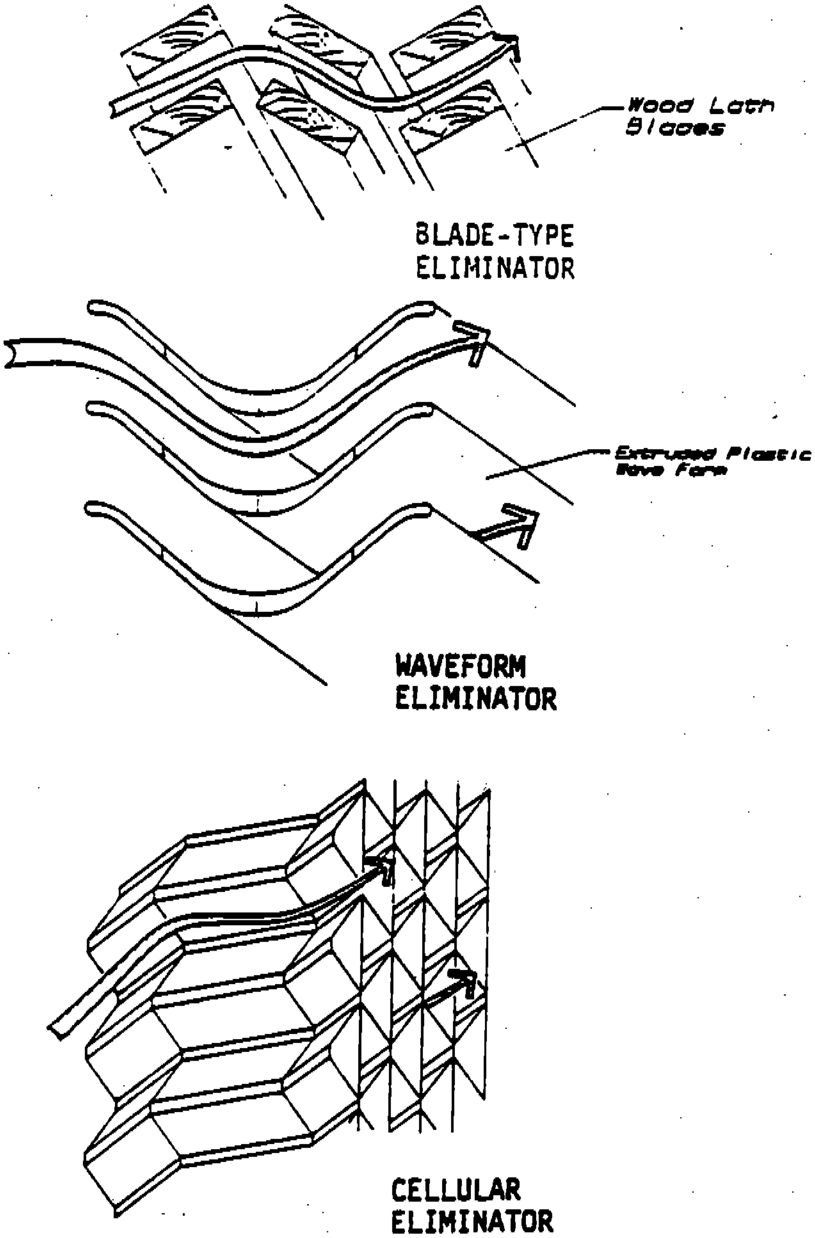

Figure 2-8. Major drift eliminator designs.[2]

REFERENCES FOR SECTION 2

1. Laulainen, N. S., et al. (1979). *Comprehensive Study of Drift from Mechanical Draft Cooling Towers*. PNL-3083, Pacific Northwest Laboratory, Richland, Washington, September.

2. Midwest Research Institute (1988). Background Information Document, Chapters 3 Through 8 for Chromium Emissions from Industrial Process Cooling Towers. Draft Report, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, August 13.

SECTION 3

GENERAL DATA ANALYSIS AND TESTING PROCEDURES

3.1 LITERATURE SEARCH AND SCREENING

The first step of this investigation involved an extensive search of the available literature relating to particulate emissions associated with wet cooling towers. This search included: data contained in the open literature (e.g., National Technical Information Service); source test reports and background documents located in the files of the EPA's Office of Air Quality Planning and Standards (OAQPS); and MRI's own files (Kansas City and North Carolina). The search was thorough but not exhaustive. Additional information may exist; however, funding limitations preclude further searching.

To reduce the large amount of literature collected to a final group of pertinent references, the following general criteria were used:

1. Source testing must be part of the reference study. Some reports reiterate information from previous studies and thus were not considered.

2. The document must constitute the original source of test data. For example, a technical paper was not included if the original study was already contained in a previous document. If the exact source of the data could not be determined or the raw data were not included, the document was eliminated.

A final set of reference materials was compiled after a thorough review of the pertinent reports, documents, and information according to these criteria. This set of documents was further analyzed to derive candidate emission factors for total drift and PM-10.

3.2 DATA QUALITY RATING SYSTEM

As part of MRI's analysis, the final set of reference documents was evaluated for quantity and quality of the data. The following data were always excluded from consideration.[1]

1. Test series averages reported in units that cannot be converted to the selected reporting units.

2. Test series representing incompatible test methods (e.g., comparison of EPA Method 5 front-half with EPA Method 5 front- and back-half).

3. Test series in which the cooling tower is not clearly identified and described.

If there was no reason to exclude a particular data set, each was assigned a rating as to its quality. The rating system used was that specified by the OAQPS for the preparation of AP-42 Sections.[1] The data were rated as follows:

A - Multiple tests performed on the same source using sound methodology and reported in enough detail for adequate validation. These tests do not necessarily have to conform to the methodology specified by EPA reference test methods, although such reference methods were certainly used as a guide.

B - Tests performed by a generally sound methodology but lacking enough detail for adequate validation.

C - Tests based on an untested or new methodology or lacking a significant amount of background data.

D - Tests based on a generally unacceptable method but which may provide an order-of-magnitude value for the source.

The following criteria were used to evaluate source test reports for sound methodology and adequate detail:

1. <u>Source operation</u>. The manner in which the source was operated is well documented in the report. The source was operating within typical parameters during the test.

2. <u>Sampling procedures</u>. The sampling procedures conformed to a generally accepted methodology. If actual procedures deviated from accepted methods, the deviations are well documented. When deviations occurred, an evaluation was made of how such alternative procedures could influence the test results.

3. <u>Sampling and process data</u>. Adequate sampling and process data are documented in the report. Many variations can occur without warning during testing and sometimes without being noticed. Such

variations can induce wide deviations in sampling results. If a large spread between test results cannot be explained by information contained in the test report, the data are suspect and were given a lower rating.

4. Analysis and calculations. The test reports contain original raw data sheets. The nomenclature and equations used were compared to those specified by EPA (if any) to establish equivalency. The depth of review of the calculations was dictated by the reviewer's confidence in the ability and conscientiousness of the tester, which in turn was based on factors such as consistency of results and completeness of other areas of the test report.

Finally, no attempt was made to recover missing data or obtain additional information either from contractors or tower operators for each test series reviewed. This activity was considered to be beyond the scope of the present study. Only the information provided in each test report was considered.

3.3 DRIFT TESTING METHODS

Drift measuring instruments fall into two general categories: those which measure droplet size distribution and those which measure total drift mineral mass flux.[2] Both techniques exhibit certain inherent problems.

Given the droplet size distribution and plume velocity at the tower exit, the drift mass flux across the exit plane can be derived. Any instrument that measures droplet size distribution in a unit volume also provides total drift mass flux. However, the calculation of total drift from the droplet size distribution can be highly sensitive to small errors in drop size. Also, it is very difficult to size and count all of the smaller droplets, which results in an incomplete droplet size distribution. The relative effect of this deficiency in sampling the small end of the size distribution becomes more pronounced as the drift elimination system becomes more efficient, because the mass fraction of the small drops characteristically becomes greater. Also, if total drift mass is calculated from the droplet spectrum, the technique must be able to distinguish small drift droplets from recondensed moisture in the airstream.

From the total drift mineral mass flux, the total drift mass flux can be calculated if the bulk mineral concentration in the drift is known. Because it is usually unknown, the bulk mineral concentration in the drift is generally assumed to be equal to the mineral concentration in the circulating water, and an apparent drift mass flux is determined accordingly. Also, it is assumed that all of the mineral matter is collected in the sampling train, which may or may not actually be the case.

In determining drift mineral mass flux from a given tower there are two major problem areas: (a) obtaining a representative sample; and (b) obtaining enough sample to quantify. Obtaining a representative sample can be achieved by selecting a large number of sampling points over the cross-sectional area of the stack so that variations in the velocity profile are accounted for adequately. The second problem is minimized by the selection of a sensitive analytical method which requires only minute quantities of sample.

Drift instruments themselves can be grouped under four general headings: chemical balance; collection; optical; and thermodynamic/condensation. Some collection instruments and all optical techniques are "isokinetic," meaning that the airflows into the sampling device with the same speed and direction as the air that flows past the instrument. This ensures that certain particle sizes are not selectively eliminated because of differences in inertial characteristics in the presence of curved streamlines. In other words, a basic concern in drift measurement (especially with respect to particle size) is that the particle flow is not disturbed by the sampling device during the sampling process. Descriptions of methods and instruments used to determine total drift are described in Sections 3.3.1 through 3.3.5.

3.3.1 Chemical Balance Methods

Chemical balance methods involve monitoring a tracer in the circulating water and noting the change in tracer concentration due to drift loss with the blowdown closed. An alternative method does not require any extraneous tracer material, but instead monitors the concentration of naturally occurring dissolved minerals in the makeup water and circulating water with no blowdown. Any loss in the amount of mineral in the system, after taking into account that added by makeup and that lost due to leakage, will be due to drift. Chemical balance methods are of questionable usefulness with today's small drift losses.

3.3.2 Droplet Collection Methods

The largest category of drift measuring instruments contains collection techniques whereby an imprint of the drop is taken, the droplets are preserved intact, or the liquid droplets are extracted from the air, evaporated, and the mineral residue analyzed. Each is described below.

3.3.2.1 Imprinting Techniques

Droplets can be impacted on glass slides coated with oil, on photographic film coated with liquid plastic, or in gelatin-like materials. Magnesium oxide and carbon black are also used as slide coating media. The craters left by the impinging droplets are then related to drop size.

Another imprinting technique is the paper stain method. Droplets are absorbed by the paper, causing a chemical reaction which leaves behind an insoluble blue stain, the diameter of which is related to droplet diameter. Figure 3-1 shows the classification of stain shapes produced by water droplets on sensitive paper.[3]

3.3.2.2 Cyclone Separators

Cyclone separators use inertial forces to extract liquid water droplets from the air samples. The mineral concentration of the water sample is then determined by chemical analysis. If the cyclone samples isokinetically (which is difficult since it must be operated at constant flow), it measures the apparent drift mass flux by assuming the same bulk mineral concentration in the drift as in the circulating water. If the fog-portion of the water sample were known, the bulk mineral concentration of the drift could be determined directly. However, since the mass of fog water per unit volume of air is a highly fluctuating quantity in a cooling tower, the amount of fog water in the sample is usually not known and assumed to be negligible. Figure 3-2 shows a diagram of an Ecodyne Cyclone Separator used for drift determination.[4]

3.3.2.3 Collection of Drift Residue

The final, and most important, collection method involves the collection of drift residue. In this technique, drift impinges on glass beads, glass wool, or filter paper and is evaporated, leaving behind the mineral residue, the mass of which is determined either by gravimetric or chemical analysis. (Note that gravimetric methods of analysis are usually limited to towers with high drift rates and/or mineral concentrations in the circulating water.) Wet impingers have also been used either before or after droplet impingement/evaporation to provide additional collection in the sampling train. If the sampling is isokinetic, the apparent drift mass flux can be derived from the analytical data.

The two most widely employed drift collection techniques are the heated bead method and the wet impinger method. These two methods were described in most of the test reports reviewed during the present study.

As the title would suggest, the heated bead method utilizes an aspirated glass tube containing glass beads. The tube is equipped with an electrical heating element designed to evaporate the incoming water droplets. In some cases, a water trap and/or backup filter are also used downstream of the heated

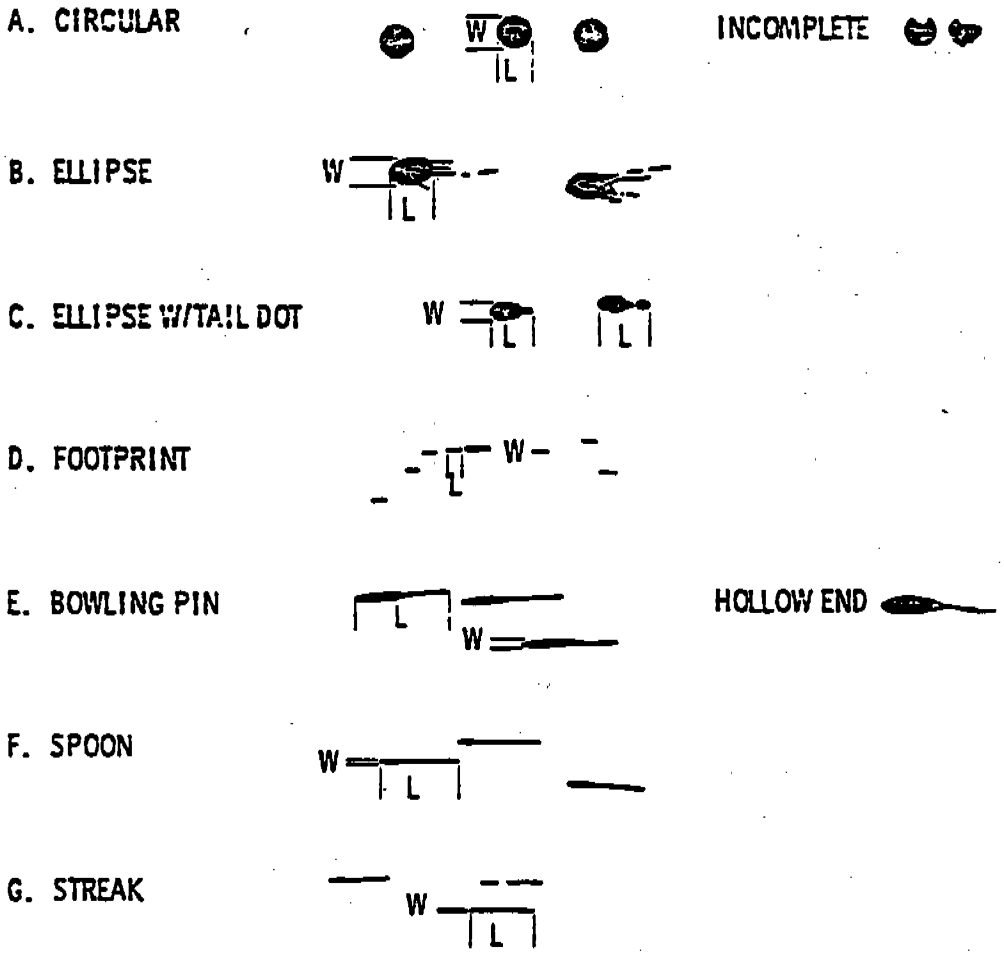

Figure 3-1. Stain shape classification for sensitive paper.[3]

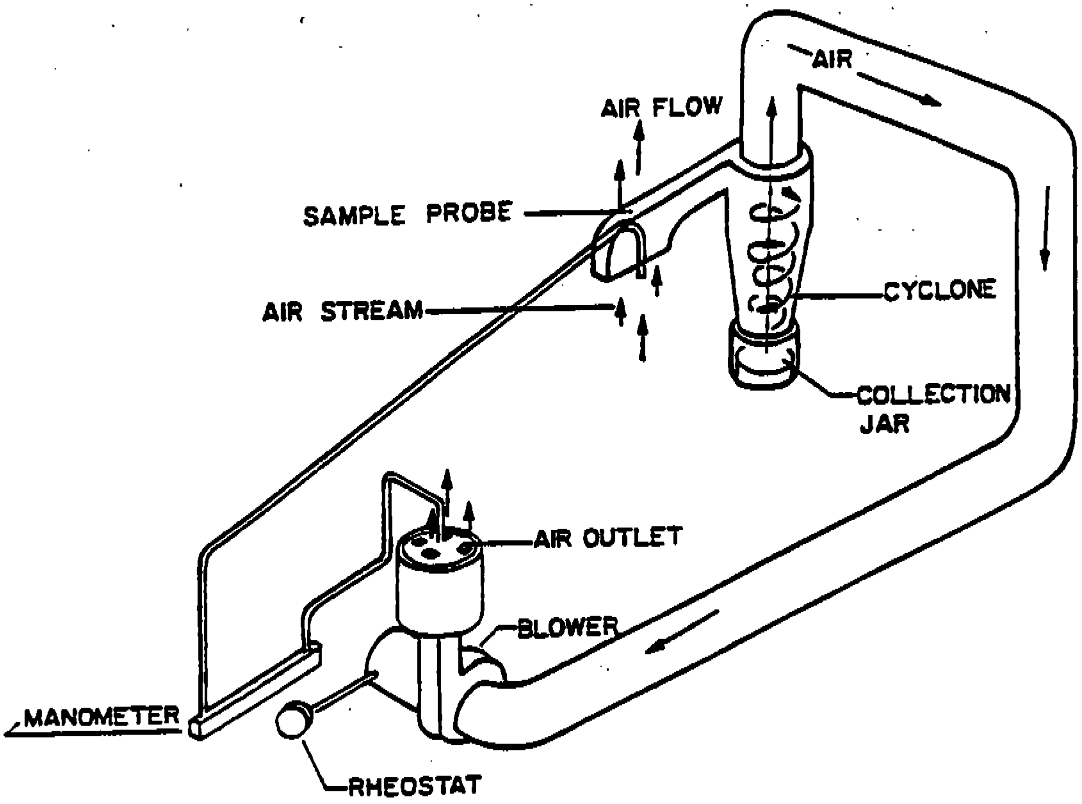

Figure 3-2. Diagram of Ecodyne cyclone separator.[4]

tube to collect additional dissolved mineral matter. Air velocity of the gas exiting the tower usually is determined by a propeller anenometer that is reported to be self-compensating for cyclonic flow (i.e., pitch and yaw).[5] A diagram of a typical heated bead sampling train is shown in Figure 3-3.

For sample recovery, the glass beads are washed with a dilute acid solution and analyzed by atomic absorption (AA) spectroscopy (or other suitable technique). The apparent drift mass flux is then computed from the mineral residues retained in the glass tube assuming the same composition as the circulating water flow.

Several inherent problems can be expected with the heated bead method. First, it is assumed that all droplets impact onto the heated beads and evaporate, leaving all dissolved minerals on the bead surfaces. As far as can be determined, this assumption has never been verified experimentally. (Note that a water trap and/or backup filter were added in later tests.) In fact, testing conducted for the EPA has shown that substantial quantities of mineral matter can penetrate the front portion of a standard Method 5 sampling train and is collected in the wet impingers (Table 3-1).[5] These data would suggest that heated beads (which are less efficient at collecting small particles) may not collect all of the mineral matter in the drift droplets, thus creating a negative bias to the resulting data.

Another potential problem with the heated bead method involves anisokinetic sampling errors. Normally, the glass tube is oriented parallel to the overall direction of airflow (e.g., fan hub). A protractor and a telltale (small plastic strip) attached to the propeller anenometer are used to determine the flow rate and direction at each sampling point. After testing, the air velocity measured by the anemometer is mathematically corrected for cyclonic flow using the pitch and yaw indicated by the telltale and the sampling volume adjusted accordingly. Because the tube is not actually oriented into the local flow direction, this approach may or may not actually achieve isokinetic sampling conditions.

According to testing performed for the EPA, drift sampling at or below isokinetic conditions should present no substantial problems.[5] However, the same study showed that sampling above isokinetic conditions (i.e., 150%) can cause a positive bias in the resulting data on the order of 40%.5 Thus, the above approach may exhibit errors of the same magnitude as shown in the EPA study.

Several variations of the <u>wet impinger method</u> have been developed for the measurement of apparent drift mass flux. These include modifications to EPA Methods 5 and 13A as well as other similar sampling trains.

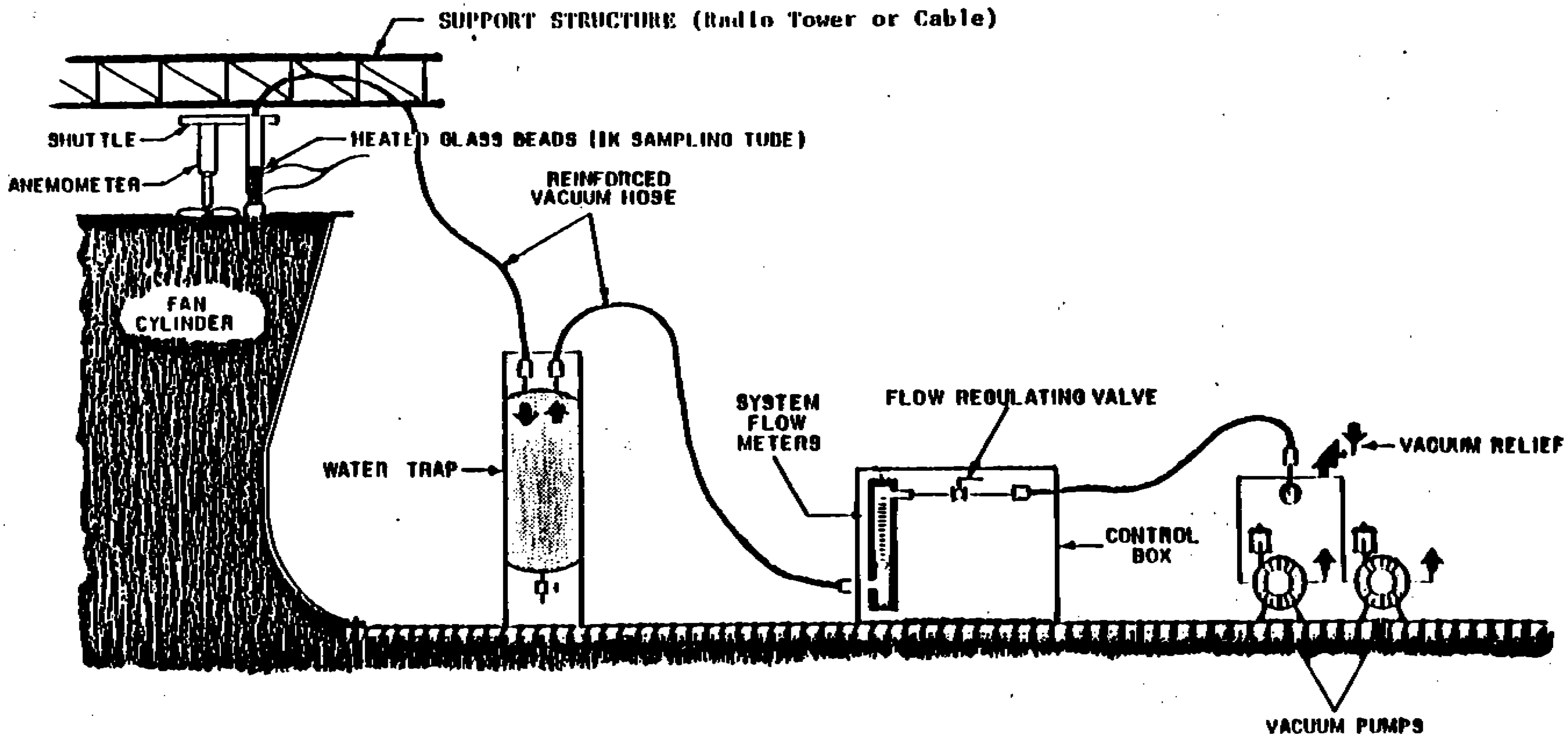

Figure 3-3. Typical heated bead sampling train.

Table 3-1. PERCENT SAMPLE RECOVERY BY TRAIN COMPONENT IN EPA STUDY[5]

Series of run number	Train type	Compound	Percent recovery (of total catch) in particular train component
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[a]	75% in first two impingers, 8.7% in third impinger, 16.3% on Teflon filter
3-A+F-3	Impinger train	Br[a]	98.9% in first two impingers, 0.7% in third impinger, 0.4% on Teflon filter

[a] 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.

Wet impinger sampling trains used for drift determination generally consist of a series (i.e., two or more) of wet impingers followed by an appropriate backup filter and desiccant trap. Distilled water is usually placed in the first two impingers and the third impinger left dry. The backup filter is commonly located behind the dry impinger. Type S pitot tubes are often used for velocity determination using the "alignment approach," which accounts for cyclonic flow in the yaw direction.[6] A diagram of the Method 13A sampling train is shown in Figure 3-4.

Sample recovery is performed using a distilled water wash of the entire sampling train (including the backup filter) with the elemental composition of the sample determined by digestion and either AA or inductively coupled argon plasma (ICAP) spectroscopy. Total drift mass flux is then calculated from the analytical results based on the concentration of one or more elements contained in the circulating water flow.

As with the heated bead method, the overall collection efficiency of the wet impinger method has not been determined experimentally. However, a recent EPA study revealed that the majority of the drift residue was collected in the impingers with only about 20% caught on the backup filter.[5] This is illustrated by the data shown in Table 3-2 for a tracer compound (lithium bromide) added to the basin water of the test tower.[5] Based on these limited data, it would be expected that the wet impinger method could have a higher collection efficiency than the use of heated beads for drift determination. However, a collaborative study would be required to verify such a conclusion.

Table 3-2. PERCENT RECOVERY OF LITHIUM BY SAMPLE TRAIN COMPONENT[5]

	Percent of total sample collected by sampling train component		
Run No.	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

Another concern with the wet impinger method is the determination of velocity in cyclonic flow and thus anisokinetic sampling. Since the "alignment approach" (the pitot tube is rotated until no flow is measured [i.e., null point] and then the probe assembly is rotated 90 degrees) only compensates for cyclonic flow in the yaw direction, there may be some experimental error associated with flow in the pitch direction. (Note that a 6% error in flow measurement was found to be associated with pitch angle alone in a study sponsored by EPA.[5]) Since errors in velocity measurement using the alignment approach have not been quantified specifically for cooling tower stacks, potential experimental errors might be expected due to sampling above isokinetic conditions.[5]

3.3.3 Optical Methods

Optical techniques are most useful where information on droplet size distribution is desired.. The most straightforward of these is <u>microphotography</u>. Microphotography is limited by the large number of photographs necessary to give a representative sample volume. Holography has also been used extensively for measuring naturally occurring fog droplet size distributions, and has been applied to cooling towers. However, it suffers from the same problems of small sample size per holograph, and greatly increased complexity.

<u>Laser light scattering</u> uses a photodetector to measure the amount of light scattered by a particle in a laser beam. The intensity of the light scattered is

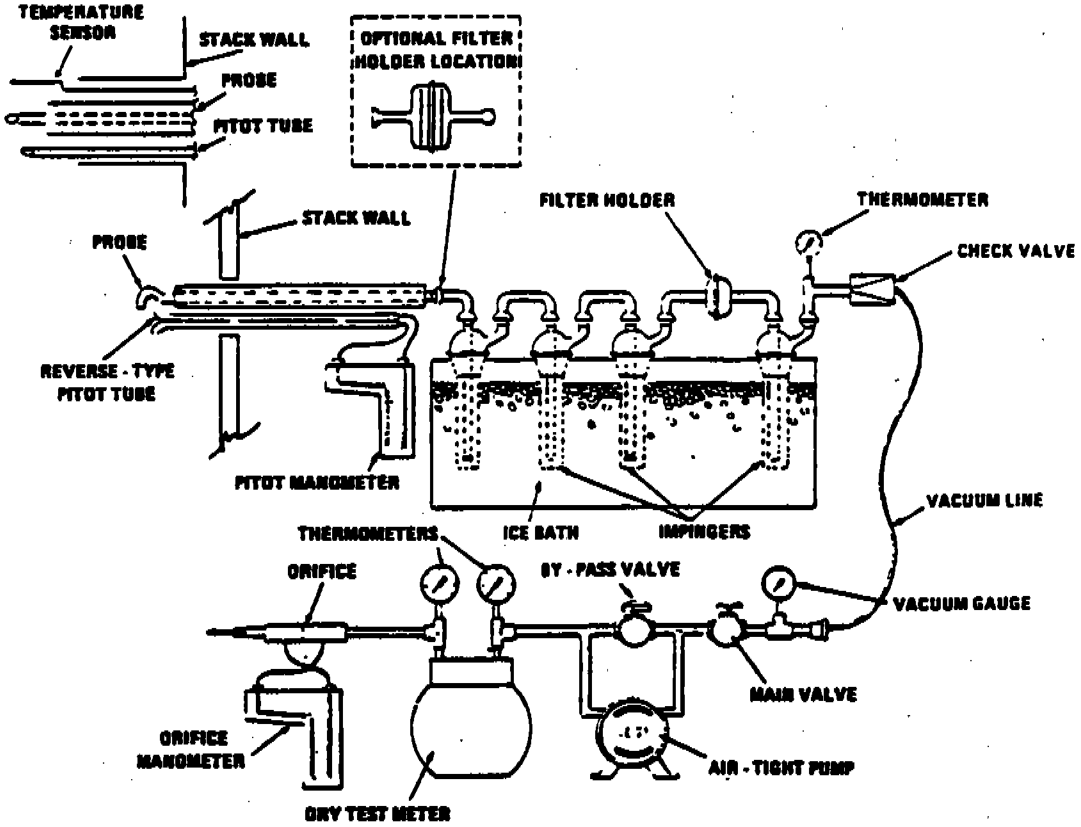

Figure 3-4. Method 13A sampling train.

proportional to the drop diameter. This method is capable of operating on-line, providing immediate results without tedious analysis, and measuring a large sample volume. However, it is relatively expensive and limited in accuracy and measuring capability in some respects.

Another device that uses a laser source measures particle diameter by light imaging, using a linear optical array to measure particle diameter. It is similar in cost to the laser light scattering system but does not suffer some of the errors inherent in that system. Its primary disadvantage at present is that it does not have the depth of development and experience in cooling tower application that laser light scattering possesses.

The primary advantages of optical techniques are that they measure particles in situ, thus ensuring an undisturbed sample, and they can have on-line capability for drop size information. The main disadvantages are cost, complexity, and inability to distinguish drift from recondensate.

3.3.4 Thermodynamic and Condensation Methods

Various thermodynamic and condensation instruments have been developed in Europe for the measurement of cooling tower drift. These have not been widely used in the United States but are worthy of note. The instruments developed include: the heating psychrometer, the double calorimeter, and the condensing apparatus.[4] Each is described below.

The heating psychrometer is a thermodynamic device designed to measure the total droplet content of the plume. If both drift as well as recondensate are present in the plume, this instrument cannot be used to determine the drift mass flux alone. Furthermore, in order to function properly, the plume sample must be in nonsuperheated thermodynamic equilibrium.

The heating psychrometer consists of two major components, an evaporator and a psychrometer.[4] The system draws a plume sample isokinetically. The sample is then heated so that all droplets evaporate and an unsaturated state is reached. The droplet content of the plume (in units of grams of water per kilogram of dry air) is then determined to be equal to the difference between the humidity measured with the psychrometer and the saturation humidity of the plume.

As is the heating psychrometer, the double calorimeter is a thermodynamic device designed to yield the instantaneous droplet content of a nonsuperheated plume sample in thermal equilibrium.[4] It consists of two consecutive heating stages made of aluminum which are connected by polyamide tubes. Platinum resistance thermometers are installed in the inlet section of the system, in the tube between the first and the second heating chamber, and downstream of the second heating chamber. In the first heating chamber, all droplets are evaporated. The heating power for the two heating chambers is known. This information together with a knowledge of the temperature rise across the two heating stages can be used to determine both the droplet and total moisture contents of the plume sample.

While measurement methods based upon thermodynamic principles alone cannot be used to measure drift flux (if both drift and recondensate are entrained in the plume), the condensing apparatus can be used regardless of whether or not recondensate is present.[4] However, the assumption is made that the dissolved solids contained in the plume are exclusively dissolved in the drift droplets and that the concentration in the drift is the same as that in the circulating cooling water. In this case, either a conductivity measurement or a chemical analysis of the collected water sample will yield the drift fraction of the total collected water mass.

During operation of the condensing apparatus, a small portion of the flow is withdrawn isokinetically and cooled inside a helix. In the cooling helix, the condensing moisture produces a film in which the entrained drift droplets as well as its dried residue are trapped. The liquid flowing down the cooling helix is then collected in a container, and the electrical conductivity of the sample measured. Using this measurement, the drift fraction of the condensate can be determined based on a similar measurement performed on a water sample from the tower basin.

3.3.5 Methods Comparison

Based on a review of available methods, it was determined that no one technique is entirely suitable for the measurement of cooling tower drift. Each exhibits certain inherent problems which limit the collection of representative drift data. Collaborative testing of the various methods at a well characterized and instrumented tower would be required to identify the individual technique or combination of techniques which best represent the total drift emissions from wet cooling towers.

The only attempt to conduct a comparison of various drift testing methods was performed by the Massachusetts Institute of Technology (MIT) in the early 1980s.[4] Nine different techniques (i.e., 1 coated-slide, 2 sensitive paper, 2 cyclone separators, 1 double calorimeter, 1 heating psychrometer, and 2 condensers) were evaluated by MIT in a small wind tunnel equipped with a laser light scattering instrument for drift measurement. The laser instrument had a range of droplet size between ~ 100 to 1,400 μm in diameter. Droplets were generated by a spray nozzle located downstream of the flow straightener. Of the methods evaluated, all were found to be acceptable under certain conditions and not acceptable in others.[4] Thus, no firm conclusions could be drawn from the MIT study.

Finally, when reviewing the various references described in Section 4, the measurement method used by the testing firm was considered in the quality rating for the data set (see Section 3.2). Since there is no "generally accepted methodology" for drift testing at present, it was decided that EPA Method 13A would be considered as the "reference" method for data evaluation. Although Method 13A may or may not be better than the other techniques discussed above, it is a formally established protocol and has been evaluated by EPA for other source categories. As such, this method will be used in this report as the "reference" method to rate the experimental data contained in each of the various documents.

3.4 PM-10 MEASUREMENT METHODS

PM-10 is generated by wet cooling towers when the drift droplets evaporate leaving fine particulate matter formed by crystallization of dissolved solids in the cooling water. Because these particles are normally formed some distance downwind of the cooling tower, a direct measurement of PM-10 emissions cannot be made. Instead, an indirect technique must be used whereby the droplets are first evaporated, with the resulting solid particles being size classified using some form of inertial separator.

At present there are no "recognized" methods for the measurement of PM-10 from cooling towers, and thus very little actual data are available. The techniques which have been employed consist of drift sampling using either an unheated or heated cascade impactor. The material collected on the various stages is then either chemically or gravimetrically analyzed. PM-10 emissions are calculated based on the concentration of one or more elements found on each stage or on the total mass collected on each stage.

Because little data are available on the PM-10 emissions from wet cooling towers, the development of applicable emission factors is difficult. However, available data indicate that all solid, dry particulate matter generated from droplet evaporation is very fine and definitely in the PM-10 size range.[9,10] Therefore, if it is assumed that: (1) the dissolved solids content of the drift droplets is the same as that of the circulating water; and (2) all dissolved solids create PM-10 size particles, the "apparent" PM-10 emission rate can be calculated from total drift measurements (if the total dissolved solids content of the circulating water is known). This approach was used in the development of the PM-10 emission factors shown in Section 4.3.2 of this report. The quality of the data and resulting emission factors were rated accordingly.

3.5 EMISSION FACTOR QUALITY RATING SYSTEM

The quality of the emission factors developed from analysis of the test data was rated utilizing the following general criteria:[1]

- A - Excellent: Developed only from A-rated test data taken from many randomly chosen facilities in the industry population. The source category* is specific enough to minimize variability within the source category population.

- B - Above average: Developed only from A-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industries. As in the A-rating, the source category is specific enough to minimize variability within the source category population.

- C - Average: Developed only from A- and B-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. As in the A-rating, the source category is specific enough to minimize variability within the source category population.

- D - Below average: The emission factor was developed only from A- and B-rated test data from a small number of facilities, and there is reason to suspect that these facilities do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of the emission factor are footnoted in the emission factor table.

- E - Poor: The emission factor was developed from C- and D-rated test data, and there is reason to suspect that the facilities tested do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of these factors are always footnoted.

The use of the above criteria is somewhat subjective, depending to a large extent on the individual reviewer. Details of how each candidate emission factor was rated are provided in Section 4.3.

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* Source category: A category in the emission factor table for which an emission factor has been calculated (generally a single type of cooling tower).

REFERENCES FOR SECTION 3

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SECTION 4

PARTICULATE EMISSION FACTOR DEVELOPMENT

The following section outlines the data and methodology used to develop particulate emission factors for cooling towers.

4.1 DOCUMENT REVIEW

Some 72 reference documents were collected and reviewed during the literature search conducted for this study. These documents are listed in Table 4-1 along with an indication as to whether the document contains PM-10 data.

The original group of 72 documents was reduced to a final set of 16 primary references utilizing the criteria outlined in Section 3.1. For those reference documents not used, Table 4-2 summarizes the reason(s) for their rejection.

4.2 EVALUATION OF SPECIFIC DATA SETS

The following is a discussion of the data contained in each of the primary references used in the development of candidate emission factors, according to reference number and date of publication.

4.2.1 Reference 1a (1990)

Reference 1a is a set of three reports for tests performed on three cooling towers California refinery. All towers tested were induced draft, counter-flow units supplying cooling water to process heat exchangers. One tower (Fluor) had 4 cells; the second (Fluor/Ecodyne), 5 cells; and the last tower (boric acid), 2 cells.

Table 4-1. REFERENCE DOCUMENTS OBTAINED DURING LITERATURE SEARCH

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* Indicates documents containing PM-10 data.

Table 4-2. DOCUMENTS REVIEWED BUT NOT INCLUDED IN EMISSION FACTOR DEVELOPMENT

Reference No.	Cause(s) for rejection
2	Not original source of test data
3	Not original source of test data
4	Not original source of test data
7	Not original source of test data
9	Not original source of test data
10	Does not contain raw data sheets
11	Did not give a % drift to calculate emission factor
12	Does not contain raw data sheets
13	Did not give a % drift to calculate emission factor
14	Does not contain raw data sheets
16	Not original source of test data
19	EPA recommendation; problems with analytical method
20	EPA recommendation; problems with analytical method
21	EPA recommendation; problems with analytical method
22	Does not contain raw data sheets
23	Not original source of test data
24	Comparison of emission measurement methods; no test data
25	Not original source of test data
26	Not original source of test data
27	Not original source of test data
30	Not original source of test data
31	Study of cooling tower water treatment; no test data
32	Organic emission data summarized; no drift data
33	Wind tunnel comparison of emission measurement methods; no field test data
35	Not original source of test data
36	Not original source of test data; missing pages
37	Not original source of test data

(continued)

Table 4-2 (Continued)

Reference No.	Cause(s) for rejection
38	Not original source of test data
39	Not original source of test data
40	Not original source of test data
41	Not original source of test data
42	Methods study only; no test data
43	Not original source of test data
44	Not original source of test data
45	Not original source of test data
46	Not original source of test data
47	Lack of process data to calculate emission factors
48	Not original source of test data
49	Not original source of test data
50	Not original source of test data
51	Not original source of test data
53	No test data: Efficiency of eliminators
55	No test data: Drift eliminator performance
56	Not original source of test data
57	No drift data: Cooling towers for air conditioning systems
58	Not original source of test data
59	Not original source of test data
60	No test data: Drift elimination
61	Not original source of test data
63	Proceedings: Not original test reports
65	Not original source of test data
66	Not original source of test data
67	No test data: Computer model description
68	No test data: Design information
69	No test data: Models only

Testing for total drift was performed using a Modified Method 13A impinger train with elemental composition of drift residue determined by ICAP. For PM-10, a sampling train was used consisting of: a metal sampling nozzle; a heated inlet section (for droplet evaporation); a heated Andersen Mark III cascade impactor with backup filter (for size classification of solid particles); and a Modified Method 13A impinger train. One cell of each tower was tested for both total drift and PM-10.

The calculated drift rates and PM-10 fraction for the three tower cells tested are provided below. Appropriate excerpts from the test report have been included in Appendix A.

Tower designation	Total drift from MM13A train (% circ. flow)[a]	Total drift from PM-10 train (% circ. flow)[b]	Percent PM-10 fraction[c]
Fluor Tower (4-cell)	0.00550	0.00418	92.2
Fluor-Ecodyne Tower (5-cell)	0.00607	0.00422	97.4
Ecodyne (2-cell)	0.00943	0.00372	95.1

[a] Average drift for three tracer elements as determined from Modified EPA Method 13A impinger train. Percent of circulating water flow.

[b] Average drift for three tracer elements as determined from total catch in the PM-10 sampling train. Percent of circulating water flow.

[c] Percent of material collected in the impactor/impinger sampling train ≤ 10 μm in aerodynamic diameter (i.e., PM-10) without the material collected in the nozzle and heated inlet. However, the nozzle and inlet catch are also suspected to be in the PM-10 size range.

Upon review of the reports included in Reference 1a, it was determined that the sampling procedures used and test results obtained were reasonably well documented. However, quality assurance procedures were lacking in the documentation provided. In addition, the method used for determination of PM-10 is unproven, and thus the data are automatically suspect. For these reasons, a rating of B was assigned to the total drift data and a rating of D to the PM-10 data contained in Reference 1a.

4.2.2 Reference 1 (1990)

Reference 1 is the report of a research and development drift test on one cell of a 4-cell, mechanical-draft, counter-flow cooling tower located at a typical industrial facility. This test was performed using Modified EPA Method 13A as the test procedure to isokinetically sample stack exhaust emissions.

The calculated drift rates for the cooling tower cell sampled were 0.00204% of circulating water flow (Mg tracer) and 0.00278% of circulating water flow (Na tracer), respectively. The average drift rate was 0.00241% for the cell sampled. Appropriate excerpts from the test report have been included in Appendix B.

Upon review of Reference 1, it was determined that the sample procedure used and the test results obtained were reasonably well documented. However, quality assurance procedures were not provided in the report. Therefore, the test data were assigned a rating of B.

4.2.3 Reference 2a (1989)

Reference 2a is another test of two towers (Sulfate No. 2 and No. 4) located at the same facility tested in References 10a and 18. The Sulfate No. 2 tower is an induced draft, counter-flow unit having two cells. A coil heat exchanger is used in the Sulfate No. 2 tower. The Sulfate No. 4 unit is an induced draft, cross-flow tower with two cells and 1-in (nominal) redwood fill. Both towers are equipped with pressurized water distribution systems.

Tests were conducted on both towers for total drift and PM-10. Total drift was determined using a heated bead sampling train equipped with water trap and backup filter. PM-10 was determined by an unheated Andersen Mark III cascade impactor. Total drift emissions were calculated from chemical analyses of sodium and sulfate (as sulfur) collected in the heated bead train. PM-10 was determined from gravimetric analysis of the collection substrates. The test data are summarized as follows:

	Sulfate No. 2	Sulfate No. 4
Total drift emissions (% of circulating water flow)	0.0004	0.0003
PM-10 emission rate (lb/h)	0.243	0.291

Excerpts from the document are included in Appendix C.

From a review of the subject report, it was determined that the test methods and resulting data were reasonably well documented. Calculations were also presented for the total drift values presented above. However, a number of potential problems were noted with the test data.

First, as discussed in Section 3.3, the heated bead method has certain inherent problems which are believed to substantially affect data quality. Also, the small amount of material collected on the impactor substrates and backup filter (i.e., 1,200 μg for the entire train) made accurate gravimetric analysis difficult. In addition, as far as could be determined, the impactor was not heated to eliminate moisture from the drift droplets and thus allow solid material to be collected on the various stages. This would tend to affect overall sample collection and thus data quality. For these reasons, a rating of C was assigned to the total drift data and a rating of D to the PM-10 data contained in Reference 2a.

4.2.4 Reference 5 (1989)

Reference 5 is the report of a drift test on two cells of a 7-cell, induced-draft, counter-flow cooling tower located at a power plant. The test was performed using Modified EPA Method 13A.

The calculated drift rates for Cell E lie between 0.0507% and 0.0918% of circulating water flow, depending on which of three tracers was used. The calculated drift rates for Cell F lie between 0.0394% and 0.0700% of water flow, again depending on which of the three tracers was used. The average drift rate from both cells was 0.0581%. Pertinent sections of the test report are provided in Appendix D.

After reviewing Reference 5, it was determined that the sampling procedure used and test results obtained were reasonably well described. However, quality assurance procedures were not provided. Therefore, the test data received a rating of B.

4.2.5 Reference 6 (1988)

Reference 6 is the report of a drift test on two cells of a 7-cell, induced-draft, counter-flow cooling tower located at a refinery. The test was performed using Modified EPA Method 13A.

The calculated drift rates for fan stack No. 1 lie between 0.0077% and 0.0348% of circulating water flow, depending on which one of four tracers was used. The calculated drift rates for fan stack No. 5 lie between 0.0063% and 0.0146% of water flow, again depending on the tracers used. The average drift rate from both fan stacks was 0.0168%. Pertinent sections of the test report are provided in Appendix E.

After reviewing Reference 6, it was determined that the sampling procedure used and test results obtained were fairly well documented. However, quality assurance procedures were not provided in the report. Therefore, a rating of B was assigned to the test data.

4.2.6 Reference 8 (1988)

Reference 8 is the report for a drift test performed on one fan stack of a 4-cell, induced-draft, cross-flow cooling tower located at a power plant. The test was conducted using Modified EPA Method 13A isokinetic sampling techniques.

The calculated drift rates (in % of circulating water flow) for the cooling tower cell tested are: 0.0540% (Na tracer); 0.0543% (Mg tracer); and 0.0522% of water flow (Ca tracer). The average drift rate was 0.0535%. Appropriate excerpts from the test report are included in Appendix F.

After reviewing Reference 8, it was determined that the sampling procedure used and test results obtained were reasonably well documented. However, quality assurance procedures were not provided in the report. Therefore, a rating of B was assigned to the test data.

4.2.7 Reference 10a (1987)

Reference 10a is a retest of two towers (Argus and Sulfate No. 2) located at the same facility described in Reference 18. The Argus tower is an induced-draft, cross-flow unit consisting of four cells with a wood lath mist eliminator. Sulfate No. 2 is an induced-draft, counter-flow tower with two cells and single-pass Thermatec mist eliminators. Both towers are equipped with a pressurized water distribution system.

One cell of each tower was tested using both a heated bead sampling train (with water trap) and water-sensitive paper. Six traverses were performed on the Argus tower and four traverses on the Sulfate No. 2 tower. Appropriate pages from the test report have been included in Appendix G. The test results are as follows:

Traverse	Tower	Drift fraction based on sodium concentration (% of circ. water flow)	Drift fraction based on Na mass flux (% of circ. water flow)
1	Argus	0.0273	0.0219
1a	Argus	0.0109	0.0111
1	Argus	0.0104	0.0147
2	Argus	0.0101	0.0146
3	Argus	0.0127	0.0169
4	Argus	0.0087	0.0124
1	Sulfate No. 2	0.0021	0.0032
2	Sulfate No. 2	0.0011	0.0021
3 & 4	Sulfate No. 2	0.0015	0.0022

Upon review of the subject document, it was determined that documentation with respect to the calculation scheme used to derive the above values was not presented. Similar (but not identical) values to those reported were obtained using the equations provided in Reference 18. Also, as mentioned previously, the heated bead method has several inherent problems which could effect data quality. For these reasons, the test data received a rating of C.

4.2.8 Reference 15 (1987)

Reference 15 is the report for a drift test performed on two cells of an 18-cell, induced-draft, counter-flow cooling tower located at a fuel plant. This test was performed using Modified EPA Method 13A.

The calculated drift rates (in % of circulating water flow) for the "T" cell are: 0.020% (SiO_2 tracer); 0.018% (Cl^- tracer); 0.012% (SO_4 tracer); and 0.013% (Na tracer) of water flow. Drift rates for the "R" cell are: 0.042% (SiO_2 tracer); 0.025% (Cl^- tracer); 0.019% (SO_4 tracer); and 0.021% (Na tracer) of circulating water flow. The average drift rate for both cells is 0.021% of water flow. Appropriate excerpts from the test report are included in Appendix H.

Upon review of Reference 15, it was determined that the sampling procedure used and the test results obtained were reasonably well documented. However, quality assurance procedures were not provided. Therefore, a rating of B was assigned to the test data.

4.2.9 Reference 17 (1987)

Reference 17 is the report of a drift test on one cell of a 4-cell, induced-draft, counter-flow cooling tower located at a chiller station. The test was performed using Modified Method 13A.

The calculated drift rate for the cooling tower cell sampled was 0.007% of circulating water flow. Appropriate excerpts from the test report have been included in Appendix I.

Upon review of Reference 17, it was determined that the sample procedure used and the test results obtained were reasonably well documented. However, quality assurance procedures were not provided in the report. Therefore, a rating of B was assigned to the test data.

4.2.10 Reference 18 (1986)

Reference 18 is the report of drift tests on six cooling towers at a chemical plant in California. All six were induced-draft cooling towers with either a cross-flow or counter-flow heat transfer configuration.* Testing was performed using a heated bead sampling train.

The calculated drift fractions were: 0.0057% of water flow (Borax cooling tower); 0.0092% (Sulfate No. 1 cooling tower); 0.0035% (Sulfate No. 2 cooling tower); 0.0457% (Sulfate No. 3 cooling tower); 0.0030% (Sulfate No. 4 cooling tower); 0.0011% (Lime cooling tower); 0.0011% (No. 11 cooling tower); 0.0024% (No. 14 cooling tower); 0.0113% (Argus cooling tower). Appropriate excerpts from the test report have been included in Appendix J.

The data in the test report were given a rating of D because the report lacked sufficient quality assurance procedures. Also, there was a notation indicating that some of the data had been changed without an explanation.

4.2.11 Reference 28 (1984)

Reference 28 is the report of a drift test on one cell of a 4-cell, induced-draft, cross-flow cooling tower located at a refinery. The test was performed using isokinetic sampling of stack exhaust emissions using an EPA Method 13A-type impinger train and neutron activation analysis of the drift residue. Sodium bromide was used as a tracer in the basin water.

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* Sulfate No. 2 and Argus cooling towers were retested in Reference 10a. Sulfate No. 2 and Sulfate No. 4 cooling towers were retested in Reference 2a.

The calculated drift rate for the cooling tower cell sampled was 0.0104% of circulating water flow. Appropriate excerpts from the test report have been included in Appendix K.

The test method and results were well documented, and the test data were rated A.

4.2.12 Reference 29 (1984)

Reference 29 is the report of a drift test on one cell of a 2-cell, induced-draft, cross-flow cooling tower at a refinery. The test was conducted using a Method 13A-type impinger train and neutron activation analysis of the drift residue. The basin water was also spiked with sodium bromide to provide a tracer.

The calculated drift rate for the cooling tower cell sampled was 0.034% of circulating water flow. Appropriate excerpts from the test report have been included in Appendix L.

The test method was well described, but certain test data were not well documented or were inconsistent. Consequently, the test data were rated C.

4.2.13 Reference 34 (1983?)

Reference 34 is the report of a drift test performed on a single-cell, induced-draft, cross-flow cooling tower equipped with a poorly maintained wood slat mist eliminator. A physical inspection of the tower showed it to be in poor condition. The test was performed using a Method 13A-type impinger train. The recirculating water was also spiked with NaBr. The calculated drift rate for the cooling tower was 0.0305% of the circulating water flow.

The sampling procedures were adequately documented. Some original test data were only summarily reported, and other data were not reported. Quality assurance procedures were also not documented. Consequently, the test data in this report was assigned a D rating. Appropriate portions of the test report are included in Appendix M.

4.2.14 References 52 and 54 (1977)

References 52 and 54 complete a 2-volume report on emissions from a recirculating, natural-draft cooling tower at a power plant in Maryland. The tests were performed using a rhodamine dye tracer, a laser light scattering instrument (PILLS II), and sensitive paper.

The calculated drift fraction (droplet flux) for the cooling tower cell sampled was 0.00088% of circulating water flow. Appropriate excerpts from the test report can be found in Appendix N.

Review of both documents gave adequate coverage of quality assurance and test data, but limited information was given regarding characteristics of the cooling tower. The results obtained were not readily traceable, and vital information was missing for application to a current model. Also, the test methods used have not been adequately verified. Therefore, a rating of D was assigned to the test data contained in both references.

4.2.15 Reference 62 (1975)

Reference 62 is a report of drift emissions from a single-cell, induced-draft, cross-flow cooling tower located at a power plant in Florida. The tower was equipped with a long-cell honeycomb mist eliminator. Tests were performed using a laser light scattering instrument (PILLS II-A), sensitive paper, and a heated bead sampling system.

The calculated drift fraction (flux) for the cell was 0.00027% of circulating water flow. Appropriate excerpts from the test report can be found in Appendix O.

Although the reference lacked detail regarding the calibration of instruments, the review has shown a well documented test procedure. The test procedure used also may have problems affecting data quality as discussed above. Therefore, a rating of C has been assigned to the test data.

4.3 DEVELOPMENT OF CANDIDATE EMISSION FACTORS

4.3.1 Total Drift Emissions

Based on available test data, total drift emission factors were developed for both induced draft and natural draft wet cooling towers. To develop the candidate emission factors (Table 4-3), average values were calculated from the test results contained in the various reference documents in terms of percent of circulating water flow (i.e., 10^{-2} gal drift/gal water flow) as well as mass per unit circulating water volume (i.e., lb liquid drift/gal circulating water flow). These calculations, along with applicable supporting data, are provided in Appendices A to O for each of the 16 reference documents.

As can be observed from the emission factors shown in Table 4-3, the calculated values span several orders of magnitude. Also, in most cases, the type of mist eliminator used for drift control was not specified in the test report. For those data sets where the mist eliminator was specified, no logical trend was discerned in the drift data with respect to control efficiency vs. emissions (e.g., lower drift for high efficiency eliminators). For these reasons, it was decided to combine all A- and B-rated data sets in each source category to develop an overall candidate emission factor, regardless of mist eliminator type.

Therefore, to derive candidate emission factors for each source category, the arithmetic mean of the individual A- and B-rated emission factors was calculated in terms of percent liquid drift, lb liquid drift/gal circulating water flow, and g liquid drift/dkL (10^1 L) circulating water flow. Also calculated was the standard deviation of the data set used to derive each candidate factor.

Due to the generally low quality and high variability of the test data, a rating of D was assigned to the emission factors for induced draft cooling towers. Also, because only one data set was available for natural draft towers, a rating of E was assigned to the candidate emission factor for this source category.

4.3.2 PM-10 Emissions

As discussed above, fine particles in the PM-10 size range are produced when drift droplets evaporate downstream of wet cooling towers. These particles are derived from the dissolved solids contained in the droplets emitted from the tower. Large drift droplets (e.g., > - 100 μm) will settle from the plume close to the tower with the smaller droplets being carried for considerable distances downwind. As stated previously, PM-10 emissions must be determined from indirect stack measurements using a sampling train which first evaporates the liquid droplets.

Very few measured PM-10 data were found in the reference documents reviewed during the program. In fact, only two documents were identified as containing information pertaining to the PM-10 emissions from cooling towers. Of these two documents, only one (Reference 2a) actually reported PM-10 emissions from the tower. The other document (Reference 1a) reported only the percent of the material collected in the sampling train that was less than or equal to 10 μm in aerodynamic diameter. Both reports did, however, indicate that 92% to 100% of the total dissolved solids contained in the droplets were converted to PM-10 upon evaporation (see calculations in Appendices A and C).

Table 4-3. CANDIDATE TOTAL (LIQUID) DRIFT EMISSION FACTORS FOR WET COOLING TOWERS[a]

Type of tower	Heat transfer configuration	Reference No.	Type of mist eliminator	Average measured emission factor[b]			Data quality rating	Candidate total drift emission factor[c]			Emission factor rating
				% Drift	$\text{lb}/10^3$ gal	g/dkL		% Drift	$\text{lb}/10^3$ gal	g/dkL	
Induced draft	Counter-flow	1a	NA	0.0055	0.46[e]	0.55	B	0.020	1.7[d]	2.0	D
			NA	0.0061	0.50[e]	0.60	B				
			NA	0.0094	0.78[e]	0.94	B				
		1	NA	0.0024	0.20	0.24	B				
		2a	2-pass	0.00040	0.030[e]	0.04	C				
		5	NA	0.058	4.8	4.8	B				
		6	NA	0.017	1.4	1.7	B				
		10a	Single-pass	0.0021	0.17[e]	0.20	C				
		15	NA	0.021	1.8	2.1	B				
		17	NA	0.0070	0.58	0.70	B				
		18	NA	0.0057	0.47[e]	0.57	D				
			NA	0.0092	0.76[e]	0.92	D				
			NA	0.0035	0.29[e]	0.35	D				
			NA	0.046	3.8[e]	4.6	D				
			NA	0.0011	0.091[e]	0.11	D				
	Cross-flow	2a	Redwood	0.00030	0.020[e]	0.02	C				
		8	NA	0.054	4.5	5.4	B				
		10a	Wood herringbone	0.014	1.2[e]	1.4	C				
		18	NA	0.0030	0.25[e]	0.30	D				
			NA	0.0011	0.091[e]	0.11	D				
			NA	0.0024	0.20[e]	0.24	D				
			NA	0.011	0.94[e]	1.1	D				
		28	NA	0.010	0.86	1.0	A				
		29	NA	0.034	2.8	3.4	B				
		34	Wood slat[f]	0.031	2.5[e]	3.0	D				
		62	Long cell honeycomb	0.0027	0.023	0.028	C				
Natural draft		52, 54	NA	0.00088	0.073	0.088	D	0.00088	0.073	0.088	E

[a] Rounded to two significant figures. NA = not available.
[b] Expressed as a function of circulating water flow. 0.1 $\text{lb}/10^3$ gal = 0.12 g/dkL. 1 dkL = 10^1 L.
[c] Average of all A- and B-rated data sets (except natural draft tower) regardless of mist eliminator type or heat transfer configuration.
[d] Standard deviation = $1.6 (10)^{-3}$.
[e] See Table 4-4 for the "apparent" PM-10 emission factor.
[f] In poor condition.

Based on the review, it was determined that candidate emission factors for cooling towers could not be developed from the existing PM-10 data alone. However, it was also determined that data for total dissolved solids (TDS) were available for an additional 12 cooling towers in other reports. Therefore, it was decided to derive "apparent" PM-10 emission factors for induced draft cooling towers using the total drift emission factors shown in Table 4-3 and the associated TDS concentration in the circulating water flow.

In the emission factor calculations, it was conservatively assumed that 100% of the TDS in the drift droplets (assumed to be equal to that in the circulating water) is converted to PM-10 size particles and thus emitted from the stack. Also, no attempt was made to account for gravitational settling of the larger drift droplets near the tower. The PM-10 emission factors developed using this approach are shown in Table 4-4. As can be seen, a rating of E was assigned to the factors since they are, at this point, only engineering estimates. A validated test method and substantial additional data would be required to develop an improved PM-10 emission factor for induced draft cooling towers.

Table 4-4. CANDIDATE PM-10 EMISSION FACTORS FOR INDUCED DRAFT WET COOLING TOWERS

Heat transfer configuration	Reference No.	Mist eliminator type[a]	Apparent PM-10 emission factor[b]		Data quality rating	Candidate PM-10 emission factor[c]		Emission factor rating
			lb/10³ gal	g/dkL		lb/10³ gal	g/dkL	
Counter-flow	1a	NA	0.0018[d]	0.0022	D	0.019[e]	0.023	E
		NA	0.0018[d]	0.0022	D			
		NA	0.0066[d]	0.0079	D			
	2a	NA	0.002[f]	0.002	D			
	10a	Single-pass	0.016	0.019	C			
	18	NA	0.012	0.014	D			
		NA	0.026	0.031	D			
		NA	0.012	0.014	D			
		NA	0.16	0.19	D			
		NA	0.0012	0.0014	D			
Cross-flow	2a	Redwood	0.001[g]	0.001	D			
	10a	Wood Herringbone	0.039	0.047	C			
	18	NA	0.0080	0.0096	D			
		NA	0.0055	0.0066	D			
		NA	0.011	0.013	D			
		NA	0.021	0.025	D			
	34	Wood slat[h]	0.00096	0.0012	D			

[a] NA = not available.

[b] Calculated from total drift emission factor (TDEF) and total dissolved solids (TDS) in the circulating water flow assuming 100% conversion of TDS to PM-10 size particles. 0.1 lb/10^3 gal = 0.12 g/dkL; 1 dkL = 10^1 L.

[c] Average of all data sets regardless of quality rating or heat transfer configuration.

[d] Calculated from TDEF, TDS, and percent of material in PM-10 size range from measurements made with heated impactor/impinger sampling train.

[e] Standard deviation = 0.38 $(10)^{-4}$.

[f] Calculated value. Measured PM-10 emission factor = 1.88$(10)^{-3}$ lb/10^3 gal.

[g] Calculated value. Measured PM-10 emission factor = 1.39$(10)^{-3}$ lb/10^3 gal.

[h] In poor condition.

SECTION 5

PROPOSED AP-42 SECTION FOR WET COOLING TOWERS

A proposed new AP-42 section for wet cooling towers is presented on the following pages as it would appear in the document.

11.4 WET COOLING TOWERS

11.4.1 Process Overview[1]

Cooling towers are heat exchangers which are used to dissipate large heat loads to the atmosphere. They are used as an important component in many industrial and commercial processes which need to dissipate heat. Cooling towers may range in size from less than $5(10)^6$ Btu/h ($5.3(10)^6$ kJ) for small air conditioning cooling towers to over $5{,}000(10)^6$ Btu/h ($5{,}275(10)^6$ kJ/h) for large power plant cooling towers.

Although cooling towers can be classified several ways, the primary classification is into dry towers or wet towers. However, some hybrid wet-dry combinations exist. Subclassifications can include the type of draft and/or the location of the draft relative to the heat transfer medium, the type of heat transfer medium, the relative direction of air movement, and the type of distribution system.

When water is used as the heat transfer medium, wet or evaporative cooling towers may be used. Wet cooling towers rely on the latent heat of evaporation of water to exchange heat between the process and the air passing through the cooling tower. The cooling water may be an integral part of the process or provide cooling via heat exchangers.

In wet cooling towers, the heat transfer is measured by the decrease in the process temperature and a corresponding increase in the moisture content and wet bulb temperature of the air passing through the cooling tower. (There may also be a change in the sensible or dry bulb temperature; however, its contribution to the heat transfer process is very small and is typically ignored when designing wet cooling towers.) Wet cooling towers typically have a wetted media called "fill" to promote evaporation by providing a large surface area and/or by creating many water drops with a large cumulative surface area.

Cooling towers can be categorized by: the type of heat transfer; the type of draft and location of the draft relative to the heat transfer medium; the type of heat transfer medium; the relative direction of air and water contact; and the type of water distribution system. Since evaporative cooling towers are the predominant type and also generate air pollutants, this section is devoted to this type of tower. Diagrams of the various tower configurations are shown in Figures 11.4-1 and 11.4-2.

11.4.2 Emissions and Controls[1]

Because wet cooling towers have direct contact between the cooling water and the air passing through the tower, some of the liquid water may be entrained in the air stream and carried out of the tower as "drift" droplets. Therefore, the constituents of the drift droplets may be classified an environmental emission source (i.e., particulate matter).

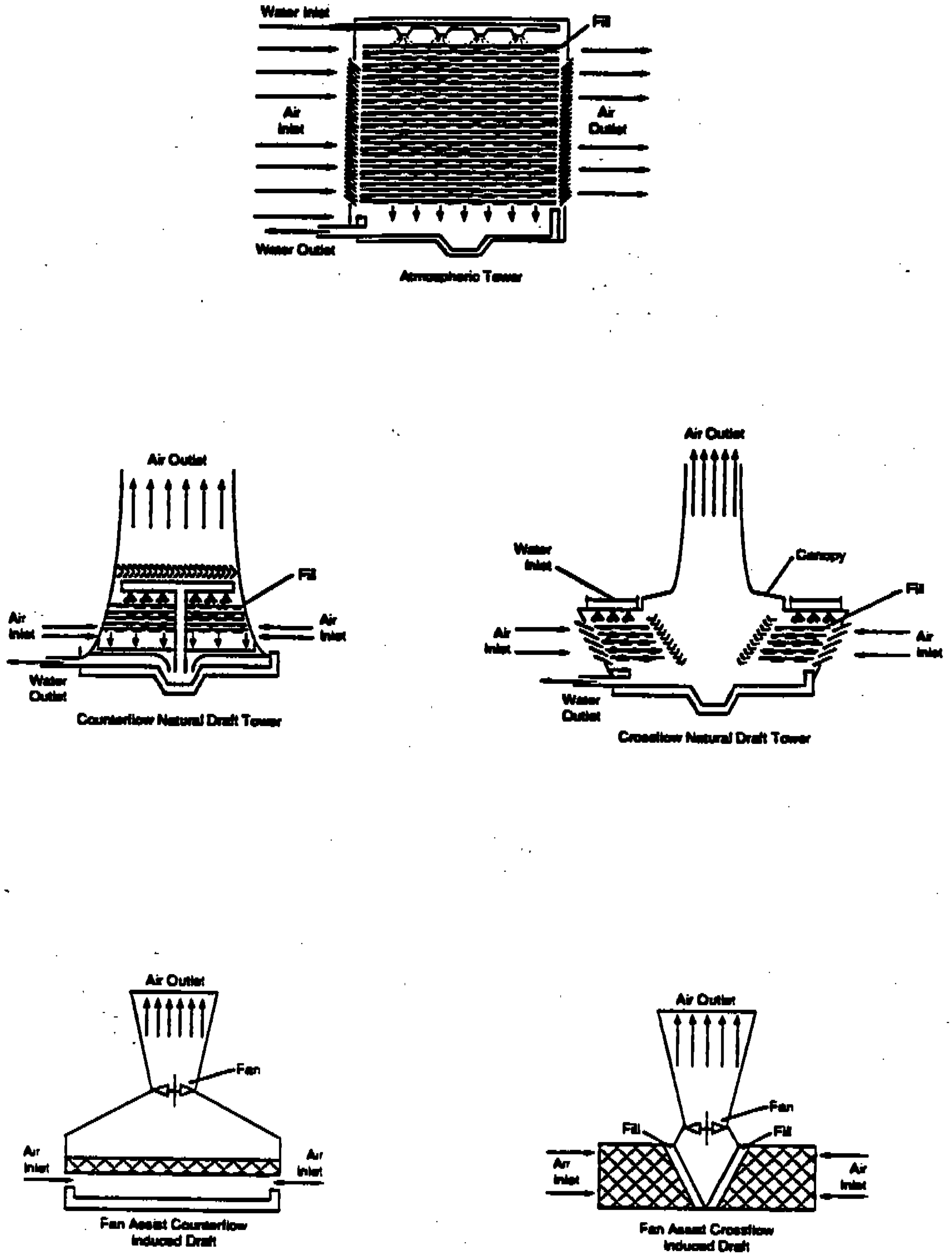
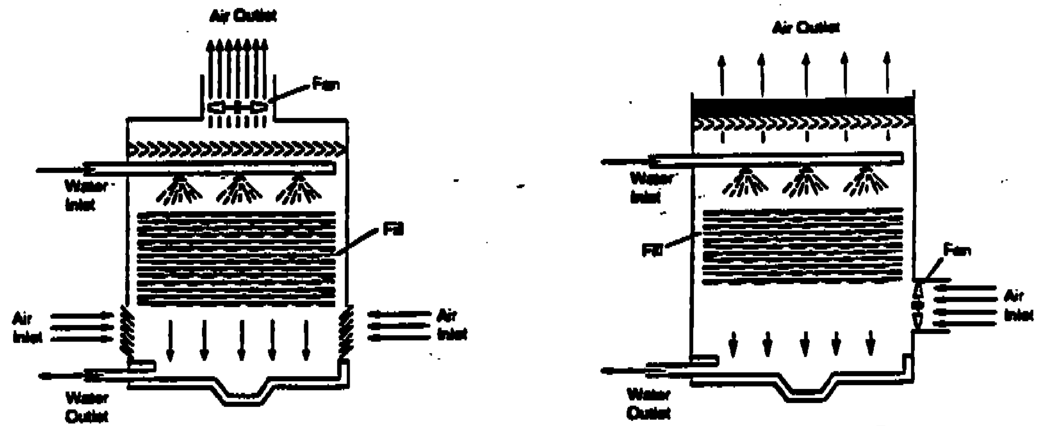
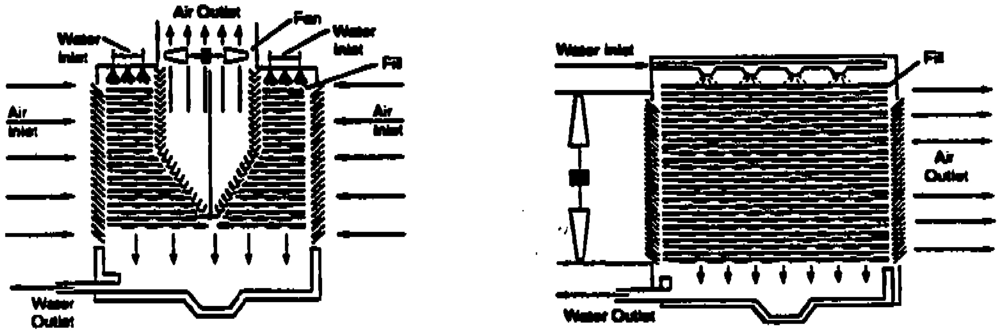


Figure 11.4-1. Atmospheric and natural draft cooling towers.



Induced Draft Counterflow Tower

Forced Draft Counterflow Tower



Induced Draft Crossflow Tower

Forced Draft Cross Flow Tower

Figure 11.4-2. Mechanical draft cooling towers.

The magnitude of drift loss is influenced by the number and size of droplets produced within the cooling tower, which in turn is determined by the fill design, the air and water patterns, and other interrelated factors. Tower maintenance and operation can also influence the formation of drift droplets. For example, excessive water flow, excessive air flow, and water bypassing the tower drift eliminators can promote and/or increase drift emissions.

Since the drift droplets generally have the same water chemistry as the water circulating through the tower, they may pose airborne emissions. Large drift droplets settle out of the tower exhaust air stream and deposit near the tower. This can lead to wetting, icing, salt deposition, and related problems such as damage to equipment or vegetation. Since other drift droplets may evaporate before being deposited in the area surrounding the tower, they can also result in PM-10 emissions. PM-10 is generated when the drift droplets evaporate leaving fine particulate matter formed by crystallization of dissolved solids. Dissolved solids found in cooling tower drift can consist of mineral matter, chemicals for corrosion inhibition, etc.

In order to reduce the drift from cooling towers, drift eliminators are usually incorporated into the cooling tower design to remove as many droplets as practical from the air stream before exiting the tower. The drift eliminators used in cooling towers rely on inertial separation caused by directional changes while passing through the eliminators. Drift eliminator configurations include herringbone (blade-type), waveform, and cellular (or honeycomb) designs with the cellular units generally being most efficient.

Like cooling tower fill materials, drift eliminators may include various materials such as ceramic, fiber reinforced cement, fiberglass, metal, plastic, and wood installed or formed into closely spaced slats, sheets, honeycomb assemblies, or tiles. The materials may have other features such as corrugations and water removal channels to further enhance the drift removal.

Table 11.4-1 provides available particulate emission factors for wet cooling towers. Separate emission factors are given for induced draft and natural draft cooling towers. Also note that the factors shown in Table 11.4-1 most closely represent older towers with less efficient mist elimination.

TABLE 11.4-1. PARTICULATE EMISSIONS FACTORS FOR WET COOLING TOWERS[a]

Type of cooling tower[b]	Total liquid drift emission factor[c]				Apparent PM-10 emission factor[d]		
	Percent of circulating water flow	lb/10^3 gal	g/dkL	Emission factor rating	lb/10^3 gal[e]	g/dkL[e]	Emission factor rating
Induced draft	0.020	1.7	2.0	D	0.019	0.023	E
Natural draft	0.00088	0.073	0.088	E	NA	NA	-

[a] References 1-17. Two significant figures. NA = not available.

[b] See Figures 11.4-1 and 11.4-2.

[c] Total liquid drift refers to water droplets entrained in the air stream exiting a cooling tower. Factors are expressed as: % of circulating water flow (10^{-2} gal drift/gal water flow or 10^{-2} L drift/L water flow); lb drift/10^3 gal circulating water flow; and g drift/dkL circulating water flow. 0.1 lb/10^3 gal = 0.12 g/dkL; 1 dkL = 10^1 L. References 2, 5, 6, 7, 9, 10, 12, 13, 15, and 16.

[d] Available data not sufficient to develop a true emission factor for wet cooling towers. Apparent emission factor calculated for each source using total drift emission factor and total dissolved solids (TDS) in circulating water assuming: TDS in circulating water = TDS in drift; and 100% conversion of TDS to PM-10 size particles in the atmosphere based on available test data. Does not account for near-source deposition of large droplets. Includes only solid PM-10 particles. References 2, 4, 8, 11, and 14.

[e] Emission factors expressed in terms of lb PM-10/10^3 gal circulating water flow and g PM-10/dkL circulating water flow.

References for Section 11.4

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4. Mass Emission Measurements Performed on Kerr McGee Chemical Corporations Westend Facility, Kerr McGee Chemical Corporation, Trona, California, Environmental Systems Corporation, Knoxville, Tennessee, December 8, 1989.

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13. Cooling Tower Drift Test Report for Unnamed Client of the Cooling Tower Institute, Houston, Texas, Midwest Research Institute, Kansas City, Missouri, August 1984.

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15. J. E. Meyer, and William Stanbro, Chalk Point Cooling Tower Project, Volume 1 and 2, JHU PPSP-CPCTP-16, John Hopkins University, Laurel, Maryland, August 1977.

16. J. K. Chan, and M. W. Golay, Comparative Evaluation of Cooling Tower Drift Eliminator Performance, MIT-EL 77-004, Massachusetts Institute of Technology, Energy Laboratory and Department of Nuclear Engineering, June 1977.

17. G. O. Schrecker, et al., Drift Data Acquired on Mechanical Salt Water Cooling Devices, EPA-650/2-75-060, U.S. Environmental Protection Agency, Washington, D.C., July 1975.

APPENDIX A

EMISSION FACTOR CALCULATIONS AND REPORT EXCERPTS FOR REFERENCE NO. 1A

(see Section 4.2.1 of text)

Fluor Tower (4 cells)

JS 4/16/96

CALCULATION SHEET

MRI Project 8987-35

Reference No. 1a   Type of Facility: Refinery
(e.g., power plant)

Location of Facility: Boron, CA   Test Date 11/89

Type of Cooling Tower (circle one): [✓ Wet Tower;] Dry Tower; Wet-Dry; Not Specified

Type of Draft (circle one): [✓ Mechanical Draft;] Natural Draft; Fan-Assist Natural Draft; Atmospheric; Not Specified

Fan Configuration (circle one as applicable): Forced Draft; [✓ Induced Draft;] Not Specified

Heat Transfer Configuration (circle one as applicable): [✓ Counterflow;] Crossflow; Spray; Not Specified

Type of Heat Transfer Media (circle one as applicable): Splash; Film; [✓ Not Specified]

Type of Fill (specify): Not Specific

Type of Hot Water Distribution System (circle one as applicable): [✓ Pressure System;] Gravity System; Not Specified

Water Flow Configuration (circle one as applicable): [✓ Recirculating;] Once-Through; Not Specified

Type of Mist Eliminator (specify): Not Specified

EMISSION RATE CALCULATIONS:

Measurement Method Used: Mod. Method 13A = Total Drift (Rating = E
Heated Anderson Impactor = TM-10 (Rating = D)

90-5 SEV binary wright 031490

From p. A-2 of the test report: Total Drift

EQUIVALENT SAMPLING TIME (MINUTES)=	240
NOZZLE DIAMETER (SQUARE FEET)=	0.00077
NET FREE STACK AREA (SQUARE FEET)=	214.41
WATERFLOW RATE PER CELL (GPM)=	2,129.0
AIRFLOW RATE (POUNDS DRY AIR/MIN)=	23,778

-------------------- DRIFT TEST RESULTS --------------------

TRACER ANALYZED	BASIN CONC. (mcg/g)	TRACER NET WT. (mcg)	DRIFT RATE ml/min	DRIFT % OF GPM	DRIFT % OF DRY AIR
B	403.0	178.85	513	0.00636	0.00475
LI	3.1	1.29	474	0.00589	0.00440
NA	1060.0	314.21	342	0.00425	0.00317
AVERAGE DRIFT ALL OF TRACERS			443	0.00550	0.00411

*Check calculations for Na:

% Drift = 100 * (NFA/NZA) * NWT/(WFR * EQT * BTC)

NFA = Net fan area (square feet)
NZA = Nozzle area (square feet)
NWT = Net weight of tracer in sampling train (mcg)
WFR = Water flow rate (grams per minute)
EQT = Equivalent sample time (240 minutes)
BTC = Basin tracer concentration (mcg/g)

$$\% \text{ Drift} = \frac{100(214.41\ \cancel{ft^2})(314.21\ \cancel{mcg})}{(0.00077\ \cancel{ft^2})(2129 \times 3785\ \cancel{g/min})(240\ \cancel{min})(1060\ \cancel{mcg/g})}$$

$$= 0.00427\ \% \text{ of circulating } H_2O \text{ flow}$$

OK!

(Note: total drift based on PM-10 sampling train for Na = 0.00371% per p. D-4 of test report)

*Total Drift Emissions (assuming average for all tracers & H_2O @ 25°C):

$$EF_{TD} = \frac{0.00550}{100} \frac{\text{gal. drift}}{\text{gal. } H_2O \text{ flow}} \times \underset{A-3}{8.312} \frac{\text{lbs drift}}{\text{gal. drift}} = 4.57(10)^{-4} \frac{\text{lbs drift}}{\text{gal } H_2O \text{ flow}}$$

Data Rating (Total Drift): B (Insufficient QA Documentation)

* PM-10 Emission Rate:

No value presented in report for PM-10 per se - only size distribution (p. 18)

Assuming: Total drift emissions (as above)
Total Dissolved Solids = 4200 ppm (from p. 17)
92.2% of TDS → PM-10 (from p. 18)

$$\therefore PM_{10} = 4.57(10)^{-4} \frac{\text{lbs drift}}{\text{gal. } H_2O \text{ flow}} \times 4200 \frac{\text{lbs. solids}}{10^6 \text{ lbs drift}} \times 0.922 \frac{\text{lbs } PM_{10}}{\text{lb. solid}}$$

$$= 1.77(10)^{-6} \frac{\text{lbs } PM_{10}}{\text{gal. } H_2O \text{ flow}}$$

Data Rating (PM-10): D (Unproven Method + Calc. Emission Factor)

MRI REPORT

Cooling Tower Test Report

Drift and PM_{10} Tests T89-50

At the U.S. Borax Plant
Refinery Cooling Tower
in Boron, California,
on a Fluor, 4-Cell,
Mechanical-Draft, Counter-Flow
Cooling Tower

For Westinghouse Electric Corporation
Power Generation Business Unit
The Quadrangle
4400 Alafaya Trail
Orlando, Florida 32826-2399

MRI Project No. 9150-86

February 1, 1990

MIDWEST RESEARCH INSTITUTE 425 Volker Boulevard, Kansas City, MO 64110-2299 • (816) 753-7600

SECTION 7

RESULTS AND CONCLUSIONS

The following equation is used by the MRI drift computer program to calculate the drift results:

$$\% \text{ Drift} = 100 * (NFA/NZA) * NWT/(WFR * EQT * BTC)$$

NFA = Net fan area (square feet)
NZA = Nozzle area (square feet)
NWT = Net weight of tracer in sampling train (mcg)
WFR = Water flow rate (grams per minute)
EQT = Equivalent sample time (240 minutes)
BTC = Basin tracer concentration (mcg/g)

The table below summarizes the results of the laboratory analysis and drift calculations.

Tracer analyzed	Tracer net wt. (mcg)	Basin conc. (mcg/g)	% Drift
B	139.70	837.0	0.00636
Li	1.61	6.7	0.00589
Na	316.70	1850.0	0.00425

The results of the drift test conducted for Westinghouse Electric Corporation, Power Generation Business Unit indicate ~~that cell No.~~ 1 of the refinery cooling tower had an average drift rate of 0.00550% of the circulating water rate. The average drift rate for ~~the cell~~ sampled should be representative of the drift rate of the tower since the tower cell geometry and operating parameters ~~were simi~~lar. The test flow of 2129 gpm and test water quality of 4200 ppm yields a mineral mass emission rate of 0.246 lb/hr for the ~~cell tested~~. If the other three cells of the tower perform the same, the mineral mass emission rate would be 0.984 lb/hr for all four cells.

The particle size distribution for the individual cascade impactor stages was as follows:

Stage	Particle size cutoff (Diameter µm)	Captured on stage: Weight (mcg)	Captured on stage: Percent (Stage)	Captured on stage: Percent (Cumulative)
Probe	> 10.30	430.0	43.76	43.76
No. 0	> 10.30	42.9	4.37	48.12
No. 1	10.30	10.5	1.07	49.19
No. 4	6.69	6.0	0.61	49.80
Impactor filter	1.66	57.9	5.89	55.69
Impingers	< 1.66	398.9	40.59	96.29
Impinger filter	< 1.66	36.5	3.71	100.00
Total		982.8		100.00

These data indicate that 51.88% of all of the material recovered in the complete cascade impactor system was PM_{10}. If the material which collected on the inside of the nozzle and heated tube wall without reaching the size classification plates is omitted from the calculations, the results indicate that 92.2% of the material recovered from the size classification plates was PM_{10}.

```
FILE NAME     : F86-09.DFT                                01-18-1990
RUN #         : 9                                       PROGRAM VER.
LOCATION      : US BORAX - CELL #1 PM10                04/26/89 V3.3
DATE          : 11-17-89
PROJECT #     : 9150-86


EQUIVALENT SAMPLING TIME (MINUTES)=                              360

NOZZLE DIAMETER (SQUARE FEET)=                               0.00034

NET FREE STACK AREA (SQUARE FEET)=                            214.41

WATERFLOW RATE PER CELL ( GPM )=                             2,129.0

AIRFLOW RATE ( POUNDS DRY AIR/MIN)=                           32,310


-------------------- DRIFT TEST RESULTS --------------------


 TRACER       BASIN       TRACER      DRIFT        DRIFT       DRIFT
ANALYZED      CONC.      NET WT.      RATE         % OF        % OF
             (mcg/g)      (mcg)      ml/min        GPM        DRY AIR

   B          837.0      139.70        292       0.00362     0.00199
   LI           6.7        1.61        419       0.00520     0.00286
   NA        1850.0      316.70        299       0.00371     0.00204


AVERAGE DRIFT ALL OF TRACERS             337       0.00418     0.00230
```

Fluor/Ecodyne Tower — 5 cells (#5 tested)

CALCULATION SHEET
MRI Project 8987-35

Reference No. 1a Type of Facility: Refinery
(e.g., power plant)

Location of Facility: Boron, CA Test Date 11/39

Type of Cooling Tower (circle one): [✓ Wet Tower;] Dry Tower; Wet-Dry; Not Specified

Type of Draft (circle one): [✓ Mechanical Draft;] Natural Draft; Fan-Assist Natural Draft; Atmospheric; Not Specified

Fan Configuration (circle one as applicable): Forced Draft; [✓ Induced Draft;] Not Specified

Heat Transfer Configuration (circle one as applicable): [✓ Counterflow;] Crossflow; Spray; Not Specified Cell tested

Type of Heat Transfer Media (circle one as applicable): Splash; Film; [✓ Not Specified]

Type of Fill (specify): Not Specified

Type of Hot Water Distribution System (circle one as applicable): [✓ Pressure System;] Gravity System; Not Specified

Water Flow Configuration (circle one as applicable): [✓ Recirculating;] Once-Through; Not Specified

Type of Mist Eliminator (specify): Not Specified

EMISSION RATE CALCULATIONS:

Measurement Method Used: Mod. Method 13A = Total Drift (Rating = B)
Heated Andersen Impactor = PM-10 (Rating = D)

90-5 SEV [illegible] 031490

From p. A-2 of test report: Total Drift

EQUIVALENT SAMPLING TIME (MINUTES)=	240
NOZZLE DIAMETER (SQUARE FEET)=	0.00137
NET FREE STACK AREA (SQUARE FEET)=	534.75
WATERFLOW RATE PER CELL (GPM)=	4,459.0
AIRFLOW RATE (POUNDS DRY AIR/MIN)=	29,804

---------------------- DRIFT TEST RESULTS ----------------------

TRACER ANALYZED	BASIN CONC. (mcg/g)	TRACER NET WT. (mcg)	DRIFT RATE ml/min	DRIFT % OF GPM	DRIFT % OF DRY AIR
B	335.0	270.94	1,313	0.00778	0.00971
LI	2.2	1.51	1,109	0.00657	0.00821
NA	990.0	397.55	652	0.00386	0.00482
AVERAGE DRIFT ALL OF TRACERS			1,025	0.00607	0.00758

* Check calculations for Na:

% Drift = 100 * (NFA/NZA) * NWT/(WFR * EQT * BTC)

NFA = Net fan area (square feet)
NZA = Nozzle area (square feet)
NWT = Net weight of tracer in sampling train (mcg)
WFR = Water flow rate (grams per minute)
EQT = Equivalent sample time (240 minutes)
BTC = Basin tracer concentration (mcg/g)

$$\% \text{ Drift} = \frac{100\,(534.75\ \cancel{ft^2})(397.55\ \cancel{mcg})}{(0.00137\ \cancel{ft^2})(4459 \times 3785\ \cancel{gal/min})(240\ \cancel{min})(990\ \cancel{mcg/g})}$$

$$= 0.00387\% \text{ of circulating water flow}$$

OK!

(Note: total drift based on PM-10 sampling train for Na = 0.00422% per p. D-4 of report)

* Total Drift Emissions (assuming average for all tracers & water @ 25°C):

$$EF_{TD} = \frac{0.00607}{100}\ \frac{\text{gal. drift}}{\text{gal. } H_2O \text{ flow}} \times 8.312\ \frac{\text{lbs drift}}{\text{gal. drift}} = 5.04(10)^{-4}\ \frac{\text{lbs drift}}{\text{gal. } H_2O \text{ flow}}$$

③

Data Rating (Total Drift): B (Insufficient QA Documentation)

* PM-10 Emission Rate:

No value presented in report for PM-10 per se: only size distribution (p. 18)

Assuming: Total Drift Emissions (as above)
Total Dissolved Solids = 3700 ppm (from p. 17)
97.4% of TDS → PM-10 (from p. 18)

$$\therefore PM_{10} = 5.04(10)^{-4} \frac{\text{lbs drift}}{\text{gal. } H_2O \text{ flow}} \times 3700 \frac{\text{lbs. solids}}{10^6 \text{ lbs drift}} \times 0.974 \frac{\text{lbs } PM_{10}}{\text{lb. solids}}$$

$$= 1.82(10)^{-6} \frac{\text{lbs } PM_{10}}{\text{gal. } H_2O \text{ flow}}$$

Data Rating (PM-10): D (Unproven Method + Calc. Emission Factor)

Cooling Tower Test Report

Drift and PM_{10} Tests T89-51

At the U.S. Borax Plant
Refinery Cooling Tower, Cell No. 5
in Boron, California,
on a Fluor/Ecodyne, 1-Cell Addition,
Mechanical-Draft, Counter-Flow
Cooling Tower

For Westinghouse Electric Corporation
Power Generation Business Unit
The Quadrangle
4400 Alafaya Trail
Orlando, Florida 32826-2399

MRI Project No. 9150-86

February 1, 1990

MIDWEST RESEARCH INSTITUTE 425 Volker Boulevard, Kansas City, MO 64110-2299 • (816) 753-7600

SECTION 7

RESULTS AND CONCLUSIONS

The following equation is used by the MRI drift computer program to calculate the drift results:

$$\% \text{ Drift} = 100 * (\text{NFA}/\text{NZA}) * \text{NWT}/(\text{WFR} * \text{EQT} * \text{BTC})$$

NFA = Net fan area (square feet)
NZA = Nozzle area (square feet)
NWT = Net weight of tracer in sampling train (mcg)
WFR = Water flow rate (grams per minute)
EQT = Equivalent sample time (240 minutes)
BTC = Basin tracer concentration (mcg/g)

The table below summarizes the results of the laboratory analysis and drift calculations.

Tracer analyzed	Tracer net wt. (mcg)	Basin conc. (mcg/g)	% Drift
B	270.94	335.0	0.00778
Li	1.51	2.2	0.00657
Na	397.55	990.0	0.00386

The results of the drift test conducted for Westinghouse Electric Corporation, Power Generation Business Unit, indicate that cell No. 5 had an average drift rate of 0.00607% of the circulating water rate. The test flow of 4459 gpm and test water quality of 3700 ppm would yield a mineral mass emission rate of 0.50 lb/hr for the cell tested.

The particle size distribution for the individual cascade impactor stages was as follows:

Stage	Particle size cutoff Diameter (µm)	Captured on stage		
		Weight (mcg)	Percent (Stage)	Percent (Cumulative)
Probe	> 10.10	647.3	3.21	33.21
No. 0	> 10.10	33.5	1.72	34.93
No. 1	10.10	24.6	1.26	36.19
No. 4	6.55	17.8	0.91	37.11
Impactor Filter	1.63	103.4	5.31	42.41
Impingers	< 1.63	1083.0	55.57	97.98
Impinger Filter	< 1.63	39.3	2.02	100.00
Total		1948.9		100.00

These data indicate that 65.07% of all of the material recovered in the complete cascade impactor system was PM_{10}. If the material which collected on the inside of the nozzle and heated tube wall without reaching the size classification plates is omitted from the calculations, the results indicate that 97.4% of the material recovered from the size classification plates was PM_{10}.

```
FILE NAME    : F86-11.DFT                                    01-19-1990
RUN #        : 11                                           PROGRAM VER.
LOCATION     : US BORAX - CELL #5                          04/26/89 V3.3
DATE         : 11-18-89
PROJECT #    : 9150-86


EQUIVALENT SAMPLING TIME (MINUTES)=                                  470

NOZZLE DIAMETER (SQUARE FEET)=                                   0.00034

NET FREE STACK AREA (SQUARE FEET)=                                534.75

WATERFLOW RATE PER CELL ( GPM )=                                 4,439.0

AIRFLOW RATE ( POUNDS DRY AIR/MIN)=                               41,196



--------------------- DRIFT TEST RESULTS --------------------


 TRACER      BASIN      TRACER      DRIFT       DRIFT       DRIFT
ANALYZED     CONC.      NET WT.     RATE        % OF        % OF
            (mcg/g)     (mcg)      ml/min       GPM       DRY AIR

   B         964.0      245.60       850      0.00504     0.00455
   LI          6.8        0.90       442      0.00262     0.00237
   NA       1970.0      497.80       843      0.00500     0.00451


AVERAGE DRIFT ALL OF TRACERS           712      0.00422     0.00381
```

Ecodyne - 2 cell (1 tested)

CALCULATION SHEET
MRI Project 8987-35

Reference No. 1a Type of Facility: Refinery
(e.g., power plant)

Location of Facility: Boron, CA Test Date 11/89

Type of Cooling Tower (circle one): [✓ Wet Tower;] Dry Tower; Wet-Dry; Not Specified

Type of Draft (circle one): [✓ Mechanical Draft;] Natural Draft; Fan-Assist Natural Draft; Atmospheric; Not Specified

Fan Configuration (circle one as applicable): Forced Draft; [✓ Induced Draft;] Not Specified

Heat Transfer Configuration (circle one as applicable): [✓ Counterflow;] Crossflow; Spray; Not Specified

Type of Heat Transfer Media (circle one as applicable): Splash; Film; [✓ Not Specified]

Type of Fill (specify): Not Specified

Type of Hot Water Distribution System (circle one as applicable): [✓ Pressure System;] Gravity System; Not Specified

Water Flow Configuration (circle one as applicable): [✓ Recirculating;] Once-Through; Not Specified

Type of Mist Eliminator (specify): Not Specified

EMISSION RATE CALCULATIONS:

Measurement Method Used: Mod. Method 13A = Total Drift (Rating: B)
Heated Andersen Impactor = PM-10 (Rating: D)

From p. A-2 of test report: Total Drift

EQUIVALENT SAMPLING TIME (MINUTES)=	240
NOZZLE DIAMETER (SQUARE FEET)=	0.00106
NET FREE STACK AREA (SQUARE FEET)=	520.02
WATERFLOW RATE PER CELL (GPM)=	5,090.0
AIRFLOW RATE (POUNDS DRY AIR/MIN)=	59,658

-------------------- DRIFT TEST RESULTS --------------------

TRACER ANALYZED	BASIN CONC. (mcg/g)	TRACER NET WT. (mcg)	DRIFT RATE ml/min	DRIFT % OF GPM	DRIFT % OF DRY AIR
B	378.0	361.64	1,952	0.01013	0.00721
LI	2.8	2.84	2,054	0.01066	0.00759
NA	2380.0	1685.19	1,444	0.00750	0.00534
AVERAGE DRIFT ALL OF TRACERS			1,817	0.00943	0.00671

* Check calculations for Na:

$$\% \text{ Drift} = 100 * (NFA/NZA) * NWT/(WFR * EQT * BTC)$$

NFA = Net fan area (square feet)
NZA = Nozzle area (square feet)
NWT = Net weight of tracer in sampling train (mcg)
WFR = Water flow rate (grams per minute)
EQT = Equivalent sample time (240 minutes)
BTC = Basin tracer concentration (mcg/g)

$$\% \text{ Drift} = \frac{100\,(520.02\ \cancel{\text{ft}^2})(1685.19\ \cancel{\text{mcg}})}{(0.00106\ \cancel{\text{ft}^2})(5090 \times 3785\ \underset{g}{\cancel{\text{gal/min}}})(240\ \cancel{\text{min}})(2380\ \underset{g}{\cancel{\text{mcg/g}}})}$$

$$= 0.00751\ \% \text{ of circulating flow}$$

OK!

(Note: total drift based on PM-10 sampling train for Na = 0.0036%;
per p. D-4 of test report)

* Total Drift Emissions (assuming average of all tracers & H_2O @ 25°C)

$$EF_{TD} = \frac{0.00943}{100}\ \frac{\text{gal. drift}}{\text{gal. } H_2O \text{ flow}} \times 8.312\ \frac{\text{lbs drift}}{\text{gal. drift}} = 7.84(10)^{-4}\ \frac{\text{lbs drift}}{\text{gal. } H_2O \text{ flow}}$$

(3)

Data Rating (Total Drift): B (Insufficient QA Documentation)

- PM-10 Emission Rate:

No value presented in report for PM-10 per se: only size distribution (p. 18)

Assuming: Total Drift Emissions (as above)
Total Dissolved Solids = 8900 ppm (from p. 17)
95.1 % of TDS → PM-10 (from p. 18)

$$\therefore \; PM_{10} = 7.84 (10)^{-4} \frac{\text{lbs drift}}{\text{gal. } H_2O \text{ flow}} \times 8900 \frac{\text{lbs. solids}}{10^6 \text{ lbs drift}} \times 0.951 \frac{\text{lbs } PM_{10}}{\text{lb. solids}}$$

$$= 6.63 (10)^{-6} \frac{\text{lbs } PM_{10}}{\text{gal. } H_2O \text{ flow}}$$

Data Rating (PM-10): D (Unproven Method + Calc. Emission Factor)

MRI REPORT

Cooling Tower Test Report

Drift and PM_{10} Tests T89-52

At the U.S. Borax Plant
Boric Acid Plant Cooling Tower
in Boron, California,
on a Ecodyne, 2-Cell,
Mechanical-Draft, Counter-Flow
Cooling Tower

For Westinghouse Electric Corporation
Power Generation Business Unit
The Quadrangle
4400 Alafaya Trail
Orlando, Florida 32826-2399

MRI Project No. 9150-86

February 1, 1990

MIDWEST RESEARCH INSTITUTE 425 Volker Boulevard, Kansas City, MO 64110-2299 • (816) 753-7600

SECTION 7

RESULTS AND CONCLUSIONS

The following equation is used by the MRI drift computer program to calculate the drift results:

$$\% \text{ Drift} = 100 * (\text{NFA}/\text{NZA}) * \text{NWT}/(\text{WFR} * \text{EQT} * \text{BTC})$$

NFA = Net fan area (square feet)
NZA = Nozzle area (square feet)
NWT = Net weight of tracer in sampling train (mcg)
WFR = Water flow rate (grams per minute)
EQT = Equivalent sample time (240 minutes)
BTC = Basin tracer concentration (mcg/g)

The table below summarizes the results of the laboratory analysis and drift calculations.

Tracer analyzed	Tracer net wt. (mcg)	Basin conc. (mcg/g)	% Drift
B	361.64	378.0	0.01013
Li	2.84	2.8	0.01066
Na	1685.19	2380.0	0.00750

The results of the drift test conducted for Westinghouse Electric Corporation, Power Generation Business Unit, indicate that the tested cell on the boric acid cooling tower had an average drift rate of 0.00943% of the circulating water rate. The average drift rate for the cell sampled should be representative of the drift rate of the tower since the tower cell geometry and operating parameters were similar. The test flow of 5090 gpm and test water quality of 8900 ppm yields a mineral mass emission rate of 2.14 lb/hr for the cell tested. If the other cell of the tower performs the same, the mineral mass emission rate would be 4.28 lb/hr for both cells.

The particle size distribution for the individual cascade impactor stages was as follows:

Stage	Particle size cutoff Diameter (µm)	Captured on stage Weight (mcg)	Percent (Stage)	Percent (Cumulative)
Probe	> 10.15	1077.0	49.60	49.60
No. 0	> 10.15	54.0	2.49	52.09
No. 1	10.15	13.6	0.63	52.71
No. 4	6.58	7.2	0.33	53.04
Impactor filter	1.64	170.5	7.85	60.90
Impingers	< 1.64	807.1	37.17	98.07
Impinger filter	< 1.64	42.0	1.93	100.00
Total		2171.4		100.00

These data indicate that 47.91% of all of the material recovered in the complete cascade impactor system was PM_{10}. If the material which collected on the inside of the nozzle and heated tube wall without reaching the size classification plates is omitted from the calculations, the results indicate that 95.1% of the material recovered from the size classification plates was PM_{10}.

```
FILE NAME   : F86-08.DFT                                 01-18-1990
RUN #       : 8                                          PROGRAM VER.
LOCATION    : US BORAX - BORIC ACID PM10                04/26/89 V3.3
DATE        : 11-16-89
PROJECT #   : 9150-86


EQUIVALENT SAMPLING TIME (MINUTES)=                             390

NOZZLE DIAMETER (SQUARE FEET)=                              0.00034

NET FREE STACK AREA (SQUARE FEET)=                           520.02

WATERFLOW RATE PER CELL ( GPM )=                            5,090.0

AIRFLOW RATE ( POUNDS DRY AIR/MIN)=                          66.131



-------------------- DRIFT TEST RESULTS ------------------


 TRACER     BASIN     TRACER     DRIFT       DRIFT       DRIFT
ANALYZED    CONC.    NET WT.     RATE        % OF        % OF
           (mcg/g)    (mcg)     ml/min       GPM        DRY AIR

   B        801.0    224.70      1,097     0.00569     0.00366
   LI         7.0      0.64        359     0.00186     0.00120
   NA      4840.0    860.10        695     0.00361     0.00232


AVERAGE DRIFT ALL OF TRACERS           717     0.00372     0.00239
```

APPENDIX B

EMISSION FACTOR CALCULATIONS AND REPORT EXCERPTS FOR REFERENCE NO. 1

(see Section 4.2.2 of text)

ISK

CALCULATION SHEET
MRI Project 8987-35

Reference No. 1 Type of Facility: Not Specified
(e.g., power plant)

Location of Facility: Not Specified Test Date Not Specified

Type of Cooling Tower (circle one): [✓ Wet Tower]; Dry Tower; Wet-Dry; Not Specified

Type of Draft (circle one): [✓ Mechanical Draft]; Natural Draft; Fan-Assist Natural Draft; Atmospheric; Not Specified

Fan Configuration (circle one as applicable): Forced Draft; [✓ Induced Draft]; Not Specified

Heat Transfer Configuration (circle one as applicable): [✓ Counterflow]; Crossflow; Spray; Not Specified

Type of Heat Transfer Media (circle one as applicable): Splash; Film; [✓ Not Specified]

Type of Fill (specify): Not Specified

Type of Hot Water Distribution System (circle one as applicable): Pressure System; Gravity System; [✓ Not Specified]

Water Flow Configuration (circle one as applicable): [✓ Recirculating]; Once-Through; Not Specified

4 in-line cells w/common cold H_2O basin - 1 cell tested

Type of Mist Eliminator (specify): Not Specified

EMISSION RATE CALCULATIONS:

Measurement Method Used: EPA Method 13A - Pitot Alignment Method for Cyclonic flow

From Appendix A, p. A-2 of Report:

EQUIVALENT SAMPLING TIME (MINUTES)= 240

NOZZLE DIAMETER (SQUARE FEET)= 0.00106

NET FREE STACK AREA (SQUARE FEET)= 522.29

WATERFLOW RATE PER CELL (GPM)= 9,818.0

AIRFLOW RATE (POUNDS DRY AIR/MIN)= 48,299

------------------- DRIFT TEST RESULTS -------------------

TRACER ANALYZED	BASIN CONC. (mcg/g)	TRACER NET WT. (mcg)	DRIFT RATE l/min	DRIFT % OF GPM	DRIFT % OF DRY AIR
Mg	146.0	54.11	0.8	0.00204	0.00347
Na	585.0	294.70	1.0	0.00278	0.00471
AVERAGE DRIFT ALL OF TRACERS			0.9	0.00241	0.00409

To Check Calculations Using Mg as Tracer:

% Drift = 100 * (NFA * NWT) / (NZA * WFR * EQT * BTC)

NFA = Net Fan Area (square feet)
NWT = Net Weight of Tracer (mcg)
NZA = Nozzle Area (square feet)
WFR = Waterflow Rate (grams per minute)
EQT = Equivalent Sample Time (minutes)
BTC = Basin Tracer Concentration (mcg/g)

$$\therefore \%\ \text{Drift} = 100 \times \frac{522.29\ \cancel{ft^2} \times 54.11\ \cancel{mcg}}{0.00106\ \cancel{ft^2} \times 9818\ gal/\cancel{min} \times 240\ \cancel{min} \times 146\ \cancel{mcg}/g}$$

$$= 100 \times 0.0775\ \frac{gm}{gal} \times \frac{1\ gal}{3785\ gm} = 0.00205\ \%$$

Calc. OK!

Using Average % Drift for Both Tracers; Total Drift Emissions Would Be: Assume H_2O @ 25°C

$$EF = \frac{0.00241}{100} \frac{\cancel{\text{gal drift}}}{\text{gal. } H_2O \text{ flow}} \times 8.312 \frac{\text{lbs. drift}}{\cancel{\text{gal. drift}}} = 2.00(10)^{-4} \frac{\text{lbs}}{\text{gal.}} \text{ to atmos.}$$

Data Rating: B (Insufficient QA on Sampling Equipment & Laboratory Data)

Cooling Tower Test Report
Typical Drift Test

On a 4-Cell, Mechanical-Draft,
Counter-Flow Cooling Tower

For the MRI Cooling Tower Test Group
Internal Drift Research and Development Program

MRI Project No. 9150

January 12, 1990

```
FILE NAME   :                                           11-26-1989
RUN #       :                                          PROGRAM VER.
LOCATION    :                                         04/26/89 V3.3
DATE        :
PROJECT #   :


EQUIVALENT SAMPLING TIME (MINUTES)=                              240

NOZZLE DIAMETER (SQUARE FEET)=                               0.00106

NET FREE STACK AREA (SQUARE FEET)=                            522.29

WATERFLOW RATE PER CELL ( GPM )=                             9,818.0

AIRFLOW RATE ( POUNDS DRY AIR/MIN)=                           48,299



-------------------- DRIFT TEST RESULTS --------------------


 TRACER      BASIN     TRACER     DRIFT        DRIFT       DRIFT
ANALYZED     CONC.     NET WT.    RATE         % OF        % OF
            (mcg/g)    (mcg)      1/min        GPM        DRY AIR

   Mg        146.0      54.11      0.8       0.00204     0.00347
   Na        585.0     294.70      1.0       0.00278     0.00471


AVERAGE DRIFT ALL OF TRACERS          0.9       0.00241     0.00409
```

APPENDIX C

EMISSION FACTOR CALCULATIONS AND REPORT EXCERPTS FOR REFERENCE NO. 2a

(see Section 4.2.3 of text)

CALCULATION SHEET
MRI Project 8987-35

Reference No. 2a Type of Facility: Sulfate Production – #2 Tower
(e.g., power plant)

Location of Facility: Trona, CA Test Date 9/89

Type of Cooling Tower (circle one): [✓ Wet Tower;] Dry Tower; Wet-Dry; Not Specified

Type of Draft (circle one): [✓ Mechanical Draft;] Natural Draft; Fan-Assist Natural Draft; Atmospheric; Not Specified

Fan Configuration (circle one as applicable): Forced Draft; [✓ Induced Draft;] Not Specified

Heat Transfer Configuration (circle one as applicable): [✓ Counterflow;] Crossflow; Spray; Not Specified

Type of Heat Transfer Media (circle one as applicable): Splash; Film; [✓ Not Specified]

Type of Fill (specify): Coil heat exchanger

Type of Hot Water Distribution System (circle one as applicable): [✓ Pressure System;] Gravity System; Not Specified

Water Flow Configuration (circle one as applicable): Recirculating; Once-Through; Not Specified

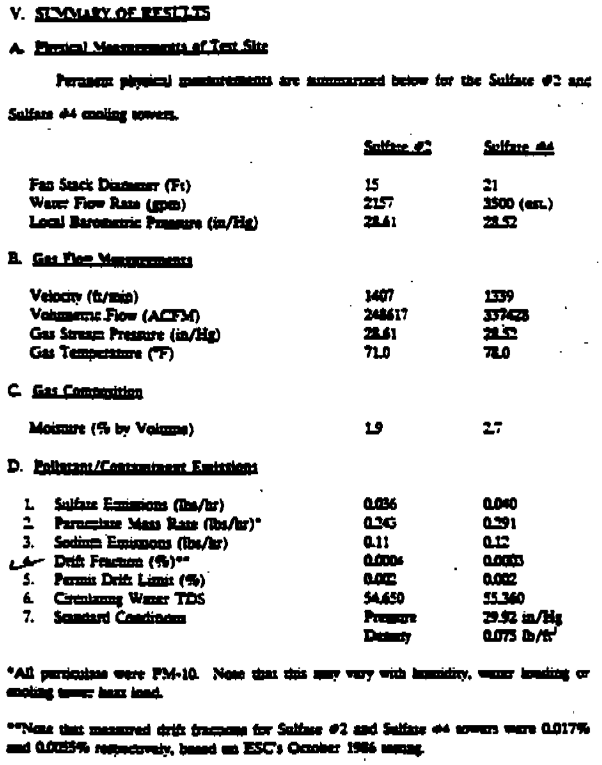
Type of Mist Eliminator (specify): 2-pass

EMISSION RATE CALCULATIONS:

Measurement Method Used: Total Drift = Heated Beads
PM-10 = Andersen Impactor (Mark III)
(not heated)

Data Ratings: Total Drift = C
PM-10 = D$^{\text{C-2}}$

From p. 11 of report:



V. SUMMARY OF RESULTS

A. Physical Measurements of Test Site

Pertinent physical measurements are summarized below for the Sulfate #2 and Sulfate #4 cooling towers.

	Sulfate #2	Sulfate #4
Fan Stack Diameter (Ft)	15	21
Water Flow Rate (gpm)	2157	3500 (est.)
Local Barometric Pressure (in/Hg)	28.61	28.52
B. Gas Flow Measurements		
Velocity (ft/min)	1407	1339
Volumetric Flow (ACFM)	248617	337428
Gas Stream Pressure (in/Hg)	28.61	28.52
Gas Temperature (°F)	71.0	78.0
C. Gas Composition		
Moisture (% by Volume)	1.9	2.7
D. Pollutant/Contaminant Emissions		
1. Sulfate Emissions (lbs/hr)	0.036	0.040
2. Particulate Mass Rate (lbs/hr)*	0.243	0.291
3. Sodium Emissions (lbs/hr)	0.11	0.12
4. Drift Fraction (%)**	0.0004	0.0003
5. Permit Drift Limit (%)	0.002	0.002
6. Circulating Water TDS	54,650	55,360
7. Standard Conditions	Pressure	29.92 in/Hg
	Density	0.075 lb/ft³

*All particulate were PM-10. Note that this may vary with humidity, water loading or cooling tower heat load.

**Note that measured drift fractions for Sulfate #2 and Sulfate #4 towers were 0.017% and 0.0035% respectively, based on ESC's October 1986 testing.

Calc. in Table 4.1b check OK!

For Sulfate #2 Tower:

- Total Drift from Tower –

$$EF = \frac{0.0004}{100} \frac{\cancel{\text{gal. drift}}}{\text{gal. H}_2\text{O flow}} \times 8.312 \frac{\text{lbs. drift}}{\cancel{\text{gal. drift}}} = 3(10)^{-5} \frac{\text{lbs}}{\text{gal}}$$

to atmos.

- PM-10 Emissions from Tower –

— $$PM_{10} = 0.243 \frac{\text{lbs}}{\text{hr.}} \times \frac{1\ \cancel{\text{min.}}}{2157\ \text{gal. H}_2\text{O flow}} \times \frac{1\ \text{hr.}}{60\ \cancel{\text{min.}}} = 1.88(10)^{-6} \frac{\text{lbs PM-10}}{\text{gal.}}$$

to atmos.

— PM-10 based on TDS in circulating H_2O (assuming: TDS in drift = TDS in basin H_2O; TDS = PM-10):

$$3(10)^{-5} \frac{\text{lbs drift}}{\text{gal flow}} \times 54{,}650 \frac{\text{lbs. solids}}{10^6\ \text{lbs. drift}} = 2(10)^{-6} \frac{\text{lbs PM-10}}{\text{gal. flow}}$$

CALCULATION SHEET
MRI Project 8987-35

Reference No. 2a Type of Facility: Sulfate Production - #4 Tower
(e.g., power plant)

Location of Facility: Trona, CA Test Date 9/89

Type of Cooling Tower (circle one): [✓ Wet Tower;] Dry Tower; Wet-Dry; Not Specified

Type of Draft (circle one): [✓ Mechanical Draft;] Natural Draft; Fan-Assist Natural Draft; Atmospheric; Not Specified

Fan Configuration (circle one as applicable): Forced Draft; [✓ Induced Draft;] Not Specified

Heat Transfer Configuration (circle one as applicable): Counterflow; [✓ Crossflow;] Spray; Not Specified

Type of Heat Transfer Media (circle one as applicable): Splash; [✓ Film;] Not Specified

Type of Fill (specify): 1" Nominal Redwood

Type of Hot Water Distribution System (circle one as applicable): [✓ Pressure System;] Gravity System; Not Specified

Water Flow Configuration (circle one as applicable): Recirculating; Once-Through; [✓ Not Specified]

Type of Mist Eliminator (specify): Redwood

EMISSION RATE CALCULATIONS:

Measurement Method Used: Total Drift = Heated Beads
PM-10 = Andersen Impactor (Mark III)
(not heated)

T

From p. 11 of report:

V. SUMMARY OF RESULTS

A. Physical Measurements of Test Site

Pertinent physical measurements are summarized below for the Sulfate #2 and Sulfate #4 cooling towers.

	Sulfate #2	Sulfate #4
Fan Stack Diameter (Ft)	15	21
Water Flow Rate (gpm)	2157	3500 (est.)
Local Barometric Pressure (in/Hg)	28.61	28.52

B. Gas Flow Measurements

Velocity (ft/min)	1407	1339
Volumetric Flow (ACFM)	248617	337428
Gas Stream Pressure (in/Hg)	28.61	28.52
Gas Temperature (°F)	71.0	78.0

C. Gas Composition

Moisture (% by Volume)	1.9	2.7

D. Pollutant/Contaminant Emissions

1. Sulfate Emissions (lbs/hr)	0.036	0.040
2. Particulate Mass Rate (lbs/hr)*	0.243	0.291
3. Sodium Emissions (lbs/hr)	0.11	0.12
4. Drift Fraction (%)**	0.0004	0.0003
5. Permit Drift Limit (%)	0.002	0.002
6. Circulating Water TDS	54,650	55,360
7. Standard Conditions	Pressure	29.92 in/Hg
	Density	0.075 lb/ft^3

Calc. in Table 4.26 check OK!

*All particulate were PM-10. Note that this may vary with humidity, water loading or cooling tower heat load.

**Note that measured drift fractions for Sulfate #2 and Sulfate #4 towers were 0.017% and 0.0055% respectively, based on ESC's October 1986 testing.

For Sulfate #4 Tower:

* Total Drift From Tower –

$$EF = \frac{0.0003}{100} \frac{\cancel{\text{gal. drift}}}{\text{gal. H}_2\text{O flow}} \times 8.312 \frac{\text{lbs. drift}}{\cancel{\text{gal. drift}}} = 2(10)^{-5} \frac{\text{lbs. drift}}{\text{gal. H}_2\text{O flow}}$$

to atmos.

* PM-10 Emissions from Tower –

– $$0.291 \frac{\text{lbs.}}{\cancel{\text{hr.}}} \times \frac{1 \cancel{\text{min}}}{3500 \text{ gal. H}_2\text{O flow}} \times \frac{1 \cancel{\text{hr.}}}{60 \cancel{\text{min}}} = 1.39(10)^{-6} \frac{\text{lbs PM-10}}{\text{gal. H}_2\text{O flow}}$$

to atmos.

– PM-10 based on TDS in circulating H_2O (assuming: TDS in drift = TDS in basin H_2O; TDS = PM-10):

$$2(10)^{-5} \frac{\cancel{\text{lbs. drift}}}{\text{gal. H}_2\text{O}} \times 55{,}360 \frac{\text{lbs. solids}}{10^6 \cancel{\text{lbs. drift}}} = 1(10)^{-6} \frac{\text{lbs. PM-10}}{\text{gal. H}_2\text{O flow}}$$

[redacted]

2a

TIN NO. 89-1183
Issue Date: 10/31/89
Revision 1
Rev. Date: 12/8/89

I. MASS EMISSION MEASUREMENTS PERFORMED ON KERR McGEE CHEMICAL CORPORATIONS WESTEND FACILITY
COOLING TOWER SULFATE 2 (Permit No. B 001923)
COOLING TOWER SULFATE 4 (Permit No. B 001925)
SEPTEMBER 12-14, 1989

Prepared For:

Kerr McGee Chemical Corporation
13200 Main Street
P.O. Box 367
Trona, CA 93562

Prepared By:

Environmental Systems Corporation
200 Tech Center Drive
Knoxville, Tennessee 37912

Reviewed By: Harry W. Smith /kvw Date: 12/8/89

Approved By: Date: 12/8/89

V. SUMMARY OF RESULTS

A. Physical Measurements of Test Site

Pertinent physical measurements are summarized below for the Sulfate #2 and Sulfate #4 cooling towers.

	Sulfate #2	Sulfate #4
Fan Stack Diameter (Ft)	15	21
Water Flow Rate (gpm)	2157	3500 (est.)
Local Barometric Pressure (in/Hg)	28.61	28.52

B. Gas Flow Measurements

Velocity (ft/min)	1407	1339
Volumetric Flow (ACFM)	248617	337428
Gas Stream Pressure (in/Hg)	28.61	28.52
Gas Temperature (°F)	71.0	78.0

C. Gas Composition

Moisture (% by Volume)	1.9	2.7

D. Pollutant/Contaminant Emissions

1.	Sulfate Emissions (lbs/hr)	0.036	0.040
2.	Particulate Mass Rate (lbs/hr)*	0.243	0.291
3.	Sodium Emissions (lbs/hr)	0.11	0.12
4.	Drift Fraction (%)**	0.0004	0.0003
5.	Permit Drift Limit (%)	0.002	0.002
6.	Circulating Water TDS	54,650	55,360
7.	Standard Conditions	Pressure	29.92 in/Hg
		Density	0.075 lb/ft^3

*All particulate were PM-10. Note that this may vary with humidity, water loading or cooling tower heat load.

**Note that measured drift fractions for Sulfate #2 and Sulfate #4 towers were 0.017% and 0.0055% respectively, based on ESC's October 1986 testing.

APPENDIX D

EMISSION FACTOR CALCULATIONS AND REPORT EXCERPTS
FOR REFERENCE NO. 5

(see Section 4.2.4 of text)

DH

CALCULATION SHEET
MRI Project 8987-35

Reference No. 5 Type of Facility: Power Plant
(e.g., power plant)

Location of Facility: Not Specified Test Date Not Specified

Type of Cooling Tower (circle one): [✓ Wet Tower]; Dry Tower; Wet-Dry; Not Specified

Type of Draft (circle one): [✓ Mechanical Draft]; Natural Draft; Fan-Assist Natural Draft; Atmospheric; Not Specified

Fan Configuration (circle one as applicable): Forced Draft; [✓ Induced Draft]; Not Specified

Heat Transfer Configuration (circle one as applicable): [✓ Counterflow]; Crossflow; Spray; Not Specified

Type of Heat Transfer Media (circle one as applicable): Splash; Film; [✓ Not Specified]

Type of Fill (specify): Not Specified

Type of Hot Water Distribution System (circle one as applicable): Pressure System; Gravity System; [✓ Not Specified]

Water Flow Configuration (circle one as applicable): [✓ Recirculating]; Once-Through; Not Specified

7-in line cells w/common cold H_2O basin - 2 cells tested

Type of Mist Eliminator (specify): Not Specified

EMISSION RATE CALCULATIONS:

Measurement Method Used: Modified EPA Method 12?

90-5 SEV kinseywksht 031490

From Appendix A, p. A-6 of Report
For Fan F:

EQUIVALENT SAMPLING TIME (MINUTES)= 200.0

NOZZLE DIAMETER (SQUARE FEET)= 0.00137

NET FREE STACK AREA (SQUARE FEET)= 1166.14

WATERFLOW RATE PER CELL (GPM)= 18,214

AIRFLOW RATE (POUNDS DRY AIR/MIN)= 60,596

--------------------- DRIFT TEST RESULTS --------------------

TRACER ANALYZED	BASIN CONC. (mcg/g)	TRACER NET WT. (mcg)	DRIFT RATE l/min	DRIFT % OF GPM	DRIFT % OF DRY AIR
Ca	66.20	752.1	48.3	0.0700	0.1756
Mg	20.60	140.7	29.0	0.0421	0.1056
Na	1790.00	11441.5	27.2	0.0394	0.0988
AVERAGE DRIFT ALL OF TRACERS			34.8	0.0505	0.1267

To check calculations using Ca as Tracer:

% Drift = 100 * (NFA * NWT) / (NZA * WFR * EQT * BTC)

NFA = Net Fan Area (ft²)
NWT = Net Weight of Tracer (mcg)
NZA = Nozzle Area (ft²)
WFR = Waterflow Rate (g/min)
EQT = Equivalent Sample Time (200 min)
BTC = Basin Tracer Concentration (mcg/g)

$$\therefore \ \% \text{ Drift} = 100 \times \frac{1166.14 \ \cancel{ft^2} \times 752.1 \ \cancel{mcg}}{0.00137 \ \cancel{ft^2} \times 18214 \ gal/\cancel{min} \times 200 \ \cancel{min} \times 66.2 \ \cancel{mcg}/g}$$

$$= 100 \times 2.65 \ \frac{\cancel{g}}{\cancel{gal}} \times \frac{1 \ \cancel{gal}}{3785 \ \cancel{g}} = 0.0700\%$$

Calc. OK!

From Appendix B, p. B-6 of Report
For Fan E:

```
EQUIVALENT SAMPLING TIME (MINUTES)=                              200.0

NOZZLE DIAMETER (SQUARE FEET)=                                   0.00137

NET FREE STACK AREA (SQUARE FEET)=                               1166.14

WATERFLOW RATE PER CELL ( GPM )=                                  18,214

AIRFLOW RATE ( POUNDS DRY AIR/MIN)=                               73,390



-------------------- DRIFT TEST RESULTS -------------------


TRACER      BASIN      TRACER       DRIFT        DRIFT       DRIFT
ANALYZED    CONC.      NET WT.      RATE         % OF        % OF
           (mcg/g)     (mcg)        l/min        GPM        DRY AIR

  Ca        63.60       947.3       63.3        0.0918      0.1901
  Mg        20.30       180.3       37.7        0.0547      0.1134
  Na      1730.00     14222.6       34.9        0.0507      0.1049


AVERAGE DRIFT ALL OF TRACERS        45.3        0.0657      0.1361
```

To check calculations using Ca as Tracer:

% Drift = 100 * (NFA * NWT) / (NZA * WFR * EQT * BTC)

NFA = Net Fan Area (ft²)
NWT = Net Weight of Tracer (mcg)
NZA = Nozzle Area (ft²)
WFR = Waterflow Rate (g/min)
EQT = Equivalent Sample Time (200 min)
BTC = Basin Tracer Concentration (mcg/g)

$$\therefore \quad \% \text{ Drift} = 100 \times \frac{1166.14\,\text{ft}^2 \times 947.3\,\text{mcg}}{0.00137\,\text{ft}^2 \times 18214\,\text{gal/min} \times 200\,\text{min} \times 63.6\,\text{mcg/g}}$$

$$= 100 \times 3.48\,\text{g/gal} \times 1\,\text{gal}/3785\,\text{g} = 0.0918\,\%$$

Calc OK!

Using Avgerage % Drift for Both Fans and the 6 Tracers:

$$Avg = \frac{0.0505 + 0.0657}{2} = 0.0581\%$$

Total Drift Emissions Would Be: Assume H_2O @ 25°C

$$EF = \frac{0.0581}{100} \frac{\text{gal drift}}{\text{gal } H_2O \text{ flow}} \times 8.312 \frac{\text{lb drift}}{\text{gal drift}} = 4.83 \times 10^{-3} \frac{\text{lb}}{\text{gal}}$$

Data Rating: B (Insuffient QA on Sampling Equipment & Laboratory Data)

5

MRI REPORT

Cooling Tower Test Report

[redacted]

[redacted]

[redacted] 7-cell
Mechanical-Draft, Counter-Flow
Cooling Tower

[redacted]

MRI Project No.[redacted]

March 20, 1989

```
FILE NAME      : [redacted]                          [redacted]
RUN #          : 1                                      PROGRAM VER.
LOCATION       : [redacted]                          10/01/88 V2.1
DATE           : [redacted]
PROJECT #      : [redacted]


EQUIVALENT SAMPLING TIME (MINUTES)=                            200.0

NOZZLE DIAMETER (SQUARE FEET)=                               0.00137

NET FREE STACK AREA (SQUARE FEET)=                           1166.14

WATERFLOW RATE PER CELL ( GPM )=                              18,214

AIRFLOW RATE ( POUNDS DRY AIR/MIN)=                           60,596



--------------------- DRIFT TEST RESULTS --------------------


 TRACER      BASIN       TRACER       DRIFT       DRIFT       DRIFT
ANALYZED     CONC.       NET WT.      RATE        % OF        % OF
            (mcg/g)      (mcg)        l/min       GPM        DRY AIR

   Ca         66.20       752.1       48.3       0.0700      0.1756
   Mg         20.60       140.7       29.0       0.0421      0.1056
   Na       1790.00     11441.5       27.2       0.0394      0.0988


AVERAGE DRIFT ALL OF TRACERS          34.8       0.0505      0.1267
```

```
FILE NAME    : [redacted]                          [redacted]
RUN #        : 2                                   PROGRAM VER.
LOCATION     : [redacted]                          [redacted]
DATE         :
PROJECT #    :


EQUIVALENT SAMPLING TIME (MINUTES)=                         200.0

NOZZLE DIAMETER (SQUARE FEET)=                            0.00137

NET FREE STACK AREA (SQUARE FEET)=                        1156.14

WATERFLOW RATE PER CELL ( GPM )=                           18,214

AIRFLOW RATE ( POUNDS DRY AIR/MIN)=                        73,390



--------------------- DRIFT TEST RESULTS ---------------------


 TRACER      BASIN      TRACER     DRIFT     DRIFT      DRIFT
ANALYZED     CONC.      NET WT.    RATE      % OF       % OF
            (mcg/g)     (mcg)      l/min     GPM       DRY AIR

   Ca         63.60      947.3     63.3     0.0918     0.1901
   Mg         20.30      180.3     37.7     0.0547     0.1134
   Na       1730.00    14222.6     34.9     0.0507     0.1049


AVERAGE DRIFT ALL OF TRACERS       45.3     0.0657     0.1361
```

APPENDIX E

EMISSION FACTOR CALCULATIONS AND REPORT EXCERPTS FOR REFERENCE NO. 6

(see Section 4.2.5 of text)

CALCULATION SHEET
MRI Project 8987-35

Reference No. 6 Type of Facility: Refinery
(e.g., power plant)

Location of Facility: N/S Test Date 1988

Type of Cooling Tower (circle one): [✓ Wet Tower]; Dry Tower; Wet-Dry; Not Specified

Type of Draft (circle one): [✓ Mechanical Draft]; Natural Draft; Fan-Assist Natural Draft; Atmospheric; Not Specified

Fan Configuration (circle one as applicable): Forced Draft; [✓ Induced Draft]; Not Specified

Heat Transfer Configuration (circle one as applicable): [✓ Counterflow]; Crossflow; Spray; Not Specified

Type of Heat Transfer Media (circle one as applicable): Splash; Film; [✓ Not Specified]

Type of Fill (specify): N/S

Type of Hot Water Distribution System (circle one as applicable): Pressure System; Gravity System; [✓ Not Specified]

Water Flow Configuration (circle one as applicable): [✓ Recirculating]; Once-Through; Not Specified

7 in-line cells w/common cold H_2O basin - 2 cells tested

Type of Mist Eliminator (specify): N/S

EMISSION RATE CALCULATIONS:

Measurement Method Used: EPA MM13A

From Appendix A, p. A-2 of Report:

Equivalent Sampling Time (min) = 240

Nozzle Diameter = 0.5021 in

Nozzle Area (ft²) = $\pi r^2 = \pi (0.2511 \text{ in})^2 = 0.1980 \text{ in}^2 \times \frac{1^2 \text{ ft}^2}{12^2 \text{ in}^2} =$ 0.00138

Net Free Stack Area (ft²) = 577.27

Water Flowrate per cell (gal/min)
(pg B-6 of Report) 77814 $\frac{\text{gal}}{\text{min}}$ (all cells) × $\frac{1}{7 \text{ cells}}$ = 11,116.3

For Fan Stack 1:

------------------- DRIFT ANALYSIS -------------------

TRACER ANALYZED	SAMPLE WEIGHT (mcg)	WATER BLANK (mcg/g)	BASIN CONC. (mcg/g)	% DRIFT
Ca	1354.9	0.0000	170.50	0.0348
Cr	14.7	0.0034	8.32	0.0077
Mg	331.6	0.0000	77.10	0.0188
Na	1836.8	0.0000	288.50	0.0279

Avg Drift all Tracers 0.0223

To Check calculations Using Ca as Tracer:

% Drift = 100 • (NFA • NWT)/(NZA • WFR • EQT • BTC)

where: NFA = Net Fan Area (square feet)
NWT = Net Weight of Tracer (micrograms)
NZA = Nozzle Area (square feet)
WFR = Water Flow Rate (grams per minute)
EQT = Equivalent Sample Time (240 minutes)
BTC = Basin Tracer Concentration (micrograms per grams)

$$\therefore \% \text{ Drift} = 100 \times \frac{577.27\ ft^2 \times 1354.9\ mcg}{0.00138\ ft^2 \times 11{,}116.3\ gal/min \times 240\ min \times 170.5\ mcg/g}$$

$$= 100 \times 1.2460\ \frac{g}{gal} \times \frac{1\ gal}{3785\ g} = 0.0329\ \%$$

Calc. OK!

For Fan Stack 5 (Appendix A, pg A-6 of Report):

-------------------- DRIFT ANALYSIS --------------------

TRACER ANALYZED	SAMPLE WEIGHT (mcg)	WATER BLANK (mcg/g)	BASIN CONC. (mcg/g)	% DRIFT
Ca	631.1	0.0000	177.50	0.0146
Cr	13.3	0.0034	8.70	0.0063
Mg	207.4	0.0000	80.20	0.0107
Na	956.6	0.0000	295.50	0.0133
Avg Drift all Tracers				0.0112

To Check Calculations -- Input values same as Stack Fan 1 except for sample weight and Basin Conc. Ca as Tracer

$$\% \text{ Drift} = 100 \times \frac{577.27\ ft^2 \times 631.1\ mcg}{0.00138\ ft^2 \times 11{,}116.3\ gal/min \times 240\ min \times 177.5\ mcg/g}$$

$$= 100 \times 0.5575\ \frac{g}{gal} \times \frac{1\ gal}{3785\ g} = 0.0147$$

Calc. OK!

Using Average % Drift for Both Stacks and 8 tracers; Total Drift Emissions Would Be:

Assume H_2O @ 25°C

$$\text{Avg} = \frac{0.0112 + 0.0223}{2} = 0.0168\%$$

$$EF = \frac{0.0168}{100}\ \frac{gal\ drift}{gal\ H_2O\ flow} \times 8.312\ \frac{lbs\ drift}{gal\ drift} = 0.00139\ \frac{lbs}{gal}\ \text{to atmos}$$

Data Rating: B (Insufficient QA on Sampling Equipment & Laboratory Data)

COOLING TOWER TEST REPORT

DRIFT TEST
ON THE

7-CELL, MECHANICAL-DRAFT, COUNTER-FLOW COOLING TOWER

I. INTRODUCTION

The testing services of Midwest Research Institute (MRI) were retained by the Watson Cogeneration Company to conduct drift tests using EPA Modified Method 5 isokinetic sampling techniques on a mechanical-draft, counter-flow cooling tower. The cooling tower is located at The work was performed by Nicholas M. Stich and Steve Cummins of MRI.

II. TEST SITE DESCRIPTION

The plant is located in The cooling tower provides cooling water to process heat exchangers and steam condensers. The cooling tower is located at

The cooling tower consists of seven mechanical-draft, counter-flow cells in a continuous straight line with a common cold water basin beneath the tower. Each cell is equipped with a 28-ft diameter, six-bladed fan driven by a 100-hp motor. The hub seal was 84 in. in diameter. The fan stack was 336 in. in diameter at the sample plane location and constructed of fiberglass.

One underground ground steel conduit returns hot water from the plant to the cooling tower. The main line then tees off to feed seven individual 18-in-diameter cell risers. Pitot taps for water flow and hot water measurement were located in the 18-in lines.

The cold water from the cooling tower basin is collected in the pump forebay adjacent to the tower where four of the five pumps are used to return cold water to the plant. Taps with temporary standpipes were used for the measurement of cold water temperatures on each of the four pump discharge lines.

```
FILE NAME     :                                          PROGRAM VER.
RUN #         : 1                                        10/01/88 V2.1
LOCATION      :
DATE          :
PROJECT #     :

INITIAL METER VOLUME (CUBIC FEET)=                            190.000
FINAL METER VOLUME (CUBIC FEET)=                              632.390
METER FACTOR=                                                  0.9857
FINAL LEAK RATE (CU FT/MIN)=                                    0.000

NET METER VOLUME (CUBIC FEET)=                                436.064
GAS VOLUME (DRY STANDARD CUBIC FEET)=                         429.883

BAROMETRIC PRESSURE (IN. HG)=                                   29.95
STATIC PRESSURE (INCHES H20)=                                   -0.15

PERCENT OXYGEN=                                                  21.0
PERCENT CARBON DIOXIDE=                                           0.0
MOISTURE COLLECTED (ML)=                                          0.0
PERCENT WATER=                                                    5.3

DRY MOLECULAR WEIGHT=                                           28.84
WET MOLECULAR WEIGHT=                                           28.26

AVERAGE METER TEMPERATURE (F.)=                                  78.8
AVERAGE DELTA H (IN. H20)=                                       2.19
AVG.SUM of SQR DELTA P (for % ISOKINETIC)=                     0.4433

% ISOKINETIC=                                                   101.0

AVERAGE STACK TEMPERATURE (F.)=                                  93.7
AVG. SUM of SQR DELTA P * COS of ANGLE (IN. H20)=              0.4125
PITOT COEFFICIENT=                                               0.84
SAMPLING TIME (MINUTES)=                                        221.8
NOZZLE DIAMETER (INCHES)=                                      0.5021

STACK AXIS (INCHES)=                                            336.0
HUB AXIS (INCHES)=                                               84.0
NET FREE STACK AREA (SQUARE FEET)=                             577.27

STACK VELOCITY  (ACTUAL, FEET/MIN)=                             1,438
FLOW RATE (ACTUAL, CUBIC FT/MIN)=                             829,828
FLOW RATE (STANDARD, WET, CUBIC FT/MIN)=                      791,849
FLOW RATE (STANDARD, DRY, CUBIC FT/MIN)=                      749,685


   ------------------ DRIFT ANALYSIS ---------------------

   TRACER        SAMPLE      WATER      BASIN        % DRIFT
  ANALYZED       WEIGHT      BLANK      CONC.
                 (mcg)      (mcg/g)    (mcg/g)

     Ca          1354.9     0.0000     170.50        0.0348
     Cr            14.7     0.0034       8.32        0.0077
     Mg           331.6     0.0000      77.10        0.0188
     Na          1836.8     0.0000     288.50        0.0279
```

```
FILE NAME     :
RUN #         : 2
LOCATION      :                                          PROGRAM VER.
DATE          :                                          10/01/88 V2.1
PROJECT #     :

INITIAL METER VOLUME (CUBIC FEET)=                            635.000
FINAL METER VOLUME (CUBIC FEET)=                             1086.130
METER FACTOR=                                                  0.9857
FINAL LEAK RATE (CU FT/MIN)=                                   0.000

NET METER VOLUME (CUBIC FEET)=                                444.679
GAS VOLUME (DRY STANDARD CUBIC FEET)=                         437.389

BAROMETRIC PRESSURE (IN. HG)=                                   29.85
STATIC PRESSURE (INCHES H20)=                                   -0.15

PERCENT OXYGEN=                                                  21.0
PERCENT CARBON DIOXIDE=                                           0.0
MOISTURE COLLECTED (ML)=                                          0.0
PERCENT WATER=                                                    4.8

DRY MOLECULAR WEIGHT=                                           28.84
WET MOLECULAR WEIGHT=                                           28.32

AVERAGE METER TEMPERATURE (F.)=                                  78.1
AVERAGE DELTA H (IN. H20)=                                       2.11
AVG.SUM of SQR DELTA P (for % ISOKINETIC)=                     0.4316

% ISOKINETIC=                                                   101.3

AVERAGE STACK TEMPERATURE (F.)=                                  90.1
AVG. SUM of SQR DELTA P * COS of ANGLE (IN. H20)=              0.4158
PITOT COEFFICIENT=                                               0.84
SAMPLING TIME (MINUTES)=                                        229.6
NOZZLE DIAMETER (INCHES)=                                      0.5021

STACK AXIS (INCHES)=                                            336.0
HUB AXIS (INCHES)=                                               84.0
NET FREE STACK AREA (SQUARE FEET)=                             577.27

STACK VELOCITY  (ACTUAL, FEET/MIN)=                             1,445
FLOW RATE (ACTUAL, CUBIC FT/MIN)=                             834,219
FLOW RATE (STANDARD, WET, CUBIC FT/MIN)=                      798,609
FLOW RATE (STANDARD, DRY, CUBIC FT/MIN)=                      760,493

   ------------------ DRIFT ANALYSIS ------------------

   TRACER        SAMPLE      WATER       BASIN       % DRIFT
   ANALYZED      WEIGHT      BLANK       CONC.
                 (mcg)       (mcg/g)     (mcg/g)

     Ca          631.1       0.0000      177.50      0.0146
     Cr           13.3       0.0034        8.70      0.0063
     Mg          207.4       0.0000       80.20      0.0107
     Na          956.6       0.0000      295.50      0.0133
```

MIDWEST RESEARCH INSTITUTE

DATA SHEET "E"
WATER FLOW MEASUREMENT
PITOT TUBE

FILE NO.: ____________

TEST DATE. ____________

PITOT TUBE MAKE, MODEL MRI - Simplex	SERIAL NO. MRI - 8842	PIPE SIZE, INCHES NOM = 18 I.D =
DATE CALIBR. APR - 1988	TUBE COEFFICIENT c = .7948	AREA = .00545 ID², SQ FT A =

PIPE I.D	IN			LOCATION DECIMAL INCHES		STA. DESC Riser # 7 TIME				STA. DESC Bypass TIME			
RDG NO.	DIA. x	RDG NO.	DIA. x	CALCULATED	CORRECTED*	d. m.	√d	d. m	√d	d. in	√d	d. m	√d
1	.013												
2	.039												
3	.067												
4	.097			17 1/8		North TAP		South TAP		HORZ			
5	.129					17¼"		17 1/8					
6	.165	1	.026	7/16		68		50		Bypass Shut Off			
7	.204	2	.082	1 3/8		82		61		For Thermal Test			
8	.250	3	.146	2 1/2		88		64					
9	.306	4	.226	3 7/8		84		65					
10	.388	5	.342	5 7/8		79		68					
11	.612	6	.658	11 1/4		69		82					
12	.694	7	.774	13 1/4		72		82					
13	.750	8	.854	14 5/8		68		81					
14	.796	9	.918	15 3/4		63		66					
15	.835	10	.974	16 11/16		43		51					
16	.871												
17	.903												
18	.933												
19	.961												
20	.987												

(18 IN DIAM AND OVER; UNDER 18 IN DIAM)

TOTAL	84.26	TOTAL	81.56	TOTAL		TOTAL	
AVG	8.426	AVG	8.156	AVG		AVG	
TRAVERSE AVG √d				TRAVERSE AVG √d			

North TAP = 11140
South TAP = 10783
US GPM Riser #7 avg = 10961

US GPM ____________

RDG NO	TIME	d
A		
B		
C		

Q, gpm = √d (1040 x C x A) = √d (________)

BASIS AIR/WATER MANOMETER

Riser #1 - 10565
#2 - 11161
#3 - 11050
#4 - 11496
#5 - 11232
#6 - 11349
#7 - 10961

* CALCULATED VALUE DECREASED BY DISTANCE FROM END OF PITOT TUBE TO CENTER LINE OF IMPACT HOLE.

Total Tower Flow = $\boxed{77814 \text{ gpm}}$

APPENDIX F

EMISSION FACTOR CALCULATIONS AND REPORT EXCERPTS FOR REFERENCE NO. 8

(see Section 4.2.6 of text)

CH

CALCULATION SHEET
MRI Project 8987-35

Reference No. 8 Type of Facility: Power Plant
(e.g., power plant)

Location of Facility: N/S Test Date 1988

Type of Cooling Tower (circle one): [✓ Wet Tower]; Dry Tower; Wet-Dry; Not Specified

Type of Draft (circle one): [✓ Mechanical Draft]; Natural Draft; Fan-Assist Natural Draft; Atmospheric; Not Specified

Fan Configuration (circle one as applicable): Forced Draft; [✓ Induced Draft]; Not Specified

Heat Transfer Configuration (circle one as applicable): Counterflow; [✓ Crossflow]; Spray; Not Specified

Type of Heat Transfer Media (circle one as applicable): Splash; Film; [✓ Not Specified]

Type of Fill (specify): N/S

Type of Hot Water Distribution System (circle one as applicable): Pressure System; Gravity System; [✓ Not Specified]

Water Flow Configuration (circle one as applicable): [✓ Recirculating]; Once-Through; Not Specified

4 in-line cells w/a common cold H_2O basin - 1 cell tested

Type of Mist Eliminator (specify): N/S

EMISSION RATE CALCULATIONS:

Measurement Method Used: Modified EPA Method 13A. Alignment approach was performed using the air flow/drift probe assembly.

90-5 SEV binary whole 031490

From Appendix A, pg A-2 of Report:

Equivalent Sampling Time (min) = 240

Nozzle Diameter = 0.4413 in

Nozzle Area (ft²) = $\frac{1}{4}\pi d^2 = \frac{1}{4}\pi(.4413)^2 = 0.1530\,\text{in}^2 \times \frac{1\,\text{ft}^2}{12^2\,\text{in}^2} =$ 0.00106

Net Free Stack Area (ft²) = 522.29

Water Flow Rate per Cell (gal/min) = 9974.3

(pg B-7 of Report) $39897\,\frac{\text{gal}}{\text{min}} \times \frac{1}{4\,\text{cell}} =$

------------------- DRIFT ANALYSIS -------------------

TRACER ANALYZED	SAMPLE WEIGHT (mcg)	WATER BLANK (mcg/g)	BASIN CONC. (mcg/g)	% DRIFT
NA	7350	0	740	0.0540
MG	1040	0	104	0.0543
CA	5040	0	524	0.0522

AVERAGE PERCENT DRIFT OF ALL TRACERS ANALYZED 0.0535

To Check Calculations using Na as Tracer:

% Drift = 100 * (NFA * NWT) / (NZA * WFR * EQT * BTC)

NFA = Net Fan Area (square feet)
NWT = Net Weight of Tracer (µg)
NZA = Nozzle Area (square feet)
WFR = Water flow Rate (grams per minute)
EQT = Equivalent Sample Time (240 minutes)
BTC = Basin Tracer Concentration (µg/g)

$$\therefore \ \%\,\text{Drift} = 100 \times \frac{522.29\,\text{ft}^2 \times 7350\,\text{mcg}}{0.00106\,\text{ft}^2 \times 9974.3\,\text{gal/min} \times 240\,\text{min} \times 740\,\text{mcg/g}}$$

$$= 100 \times 2.044\,\frac{\text{g}}{\text{gal}} \times \frac{1\,\text{gal}}{3785\,\text{g}} = 0.0540$$

Calc OK!

Using Avgerage % Drift for the Three Tracers;
Total Drift Emissions would be:

Assume H_2O @ 25°C

$$EF = \frac{0.0535}{100} \frac{\text{gal drift}}{\text{gal } H_2O \text{ flow}} \times 8.312 \frac{\text{lbs drift}}{\text{gal drift}} = 4.45 \times 10^{-3} \frac{\text{lbs}}{\text{gal}}$$

to atmosphere

Data Rating: B (Insufficient QA on Sampling Equipment & Laboratory Data)

COOLING TOWER TEST REPORT

DRIFT TEST
ON THE

4-CELL, MECHANICAL-DRAFT, CROSS-FLOW
COOLING TOWER

I. INTRODUCTION

The testing services of Midwest Research Institute (MRI) were retained by to conduct a drift test using modified EPA Method 5 isokinetic sampling techniques on mechanical-draft, cross-flow cooling tower. The cooling tower is located at The work was performed by Mr. Nicholas M. Stich and Mr. George Cobb of MRI. The tower manufacturer was represented by was represented by Mr.

The thermal and drift tests were originally scheduled for the week of

II. TEST SITE DESCRIPTION

is located at in cooling tower provides cooling water to steam condensers. The cooling tower is located in an unobstructed area on the north side of the plant.

The cooling tower consists of four mechanical-draft, cross-flow cells in a continuous straight line with a common cold water basin beneath the tower. Each cell is equipped with a 28-ft diameter fan driven by a 100-hp motor. The hub seal is 96 in. in diameter. The fan stack is 324 in. in diameter at the sample plane location and constructed of fiberglass.

An underground steel conduit returns hot water from the plant to the cooling tower. The main line then tees off to feed two individual 30-in diameter cell risers. Pitot taps for water flow measurement were locate in the 30-in lines.

```
FILE NAME    :                                          PROGRAM
RUN #        : FAN #2                                           V2.1
LOCATION     :
DATE         :
PROJECT #    :

INITIAL METER VOLUME (CUBIC FEET)=                              735.000
FINAL METER VOLUME (CUBIC FEET)=                               1075.820
METER FACTOR=                                                    0.9857
FINAL LEAK RATE (CU FT/MIN)=                                      0.000

NET METER VOLUME (CUBIC FEET)=                                  335.946
GAS VOLUME (DRY STANDARD CUBIC FEET)=                           302.708

BAROMETRIC PRESSURE (IN. HG)=                                     28.05
STATIC PRESSURE (INCHES H20)=                                     -0.17

PERCENT OXYGEN=                                                    21.0
PERCENT CARBON DIOXIDE=                                             0.0
MOISTURE COLLECTED (ML)=                                            0.0
PERCENT WATER=                                                      3.6
  **SATURATED STACK**

DRY MOLECULAR WEIGHT=                                             28.84
WET MOLECULAR WEIGHT=                                             28.45

AVERAGE METER TEMPERATURE (F.)=                                    91.6
AVERAGE DELTA H (IN. H20)=                                         1.69
AVG.SUM of SQR DELTA P (for % ISOKINETIC)=                       0.5034

% ISOKINETIC=                                                     102.7

AVERAGE STACK TEMPERATURE (F.)=                                    79.5
AVG. SUM of SQR DELTA P * COS of ANGLE (IN. H20)=                0.3816
PITOT COEFFICIENT=                                                 0.84
SAMPLING TIME (MINUTES)=                                          176.1
NOZZLE DIAMETER (INCHES)=                                        0.4413

STACK AXIS (INCHES)=                                              324.0
HUB AXIS (INCHES)=                                                 96.0
NET FREE STACK AREA (SQUARE FEET)=                               522.29

STACK VELOCITY  (ACTUAL, FEET/MIN)=                               1,352
FLOW RATE (ACTUAL, CUBIC FT/MIN)=                               706,171
FLOW RATE (STANDARD, WET, CUBIC FT/MIN)=                        647,664
FLOW RATE (STANDARD, DRY, CUBIC FT/MIN)=                        624,225

  ------------------ DRIFT ANALYSIS ------------------

   TRACER       SAMPLE      WATER      BASIN      % DRIFT
  ANALYZED      WEIGHT      BLANK      CONC.
                (mcg)      (mcg/g)    (mcg/g)

     NA          7350         0         740       0.0540
     MG          1040         0         104       0.0543
     CA          5040         0         524       0.0522

  AVERAGE PERCENT DRIFT OF ALL TRACERS ANALYZED           0.0535
```

MIDWEST RESEARCH INSTITUTE

FILE NO.: ____________

DATA SHEET "E"
WATER FLOW MEASUREMENT
PITOT TUBE

TEST DATE: ____________

PITOT TUBE MAKE, MODEL MRI - Simplex	SERIAL NO. MRI - 6842	PIPE SIZE, INCHES NOM = 30 I.D. = 29½ 29¼
DATE CALIBR.	TUBE COEFFICIENT c = .7948	AREA = .00545 ID². SQ FT 29¼ = 4.6664 A = 29½ = 4.7445

~~South~~ East 29¼ 29½

PIPE I.D.			IN.	LOCATION		STA. DESC. ~~South~~ South Pr... ~~...~~		TIME Riser ~~East~~ East		STA. DESC. South ~~East~~ ...		~~...~~ West TIME ~~...~~ East	
				DECIMAL INCHES									
RDG NO.	DIA. x	RDG NO.	DIA. x	29½ CALCULATED	29¼ CORRECTED*	d. in.	√d	d. in.	√d	d. in.	√d	d. in.	√d
1	.013			3/8	3/8	23¾		26¼		24¼		21¾	
2	.039			1⅛	1⅛	26¾		28½		27–		22¾	
18 IN. DIAM AND OVER 3	.067			2–	1 15/16	28½		32–		26½		24½	
4	.097			2⅞	2 13/16	29¼		32¼		27½		23½	
5	.129			3 13/16	3¾	29½		32–		24¾		24½	
6	.165	UNDER 18 IN. DIAM 1	.026	4⅞	4 13/16	31½		32–		25½		24½	
7	.204	2	.082	6–	5 15/16	30–		32½		25¾		25–	
8	.250	3	.146	7⅜	7 5/16	31½		32½		26–		28½	
9	.306	4	.226	9 1/16	8 15/16	31¼		31¾		27¼		26–	
10	.388	5	.342	11 7/16	11⅜	31½		31½		27½		28¼	
11	.612	6	.658	18 1/16	17⅞	30¼		29½		28½		29¼	
12	.694	7	.774	20 7/16	20 5/16	30–		29½		27½		30¼	
13	.750	8	.854	22⅛	21 15/16	30–		28¾		28½		30–	
14	.796	9	.918	23½	23 5/16	28½		28–		27½		29¾	
15	.835	10	.974	24⅝	24 7/16	28–		26½		27–		29½	
16	.871			25 11/16	25½	26–		25¼		24¾		27½	
17	.903			26⅝	26 7/16	23¾		23½		23½		27¼	
18	.933			27½	27 7/16	23½		22½		24–		25½	
19	.961			28⅜	28¼	20¼		19½		20–		24¾	
20	.987			29⅛	28⅞	21½		17–		10¾		23½	

TOTAL	105.16	TOTAL	105.81	TOTAL	100.08	TOTAL	
AVG	5.258	AVG	5.280	AVG	5.000	AVG	4.974
TRAVERSE AVG √d				TRAVERSE AVG √d			

West Trav. = 20629
South Trav = 20364
US GPM East Riser = 20497

South = 19284
West = 19515
US GPM West Riser = 19400

RDG NO	TIME	d
A		
B		
C		

Q, gpm = √d (1040 x C x A) = √d (________)

BASIS AIR/WATER MANOMETER

Total Tower Flow = 39897

* CALCULATED VALUE DECREASED BY DISTANCE FROM END OF PITOT TUBE TO CENTER LINE OF IMPACT HOLE.

APPENDIX G

EMISSION FACTOR CALCULATIONS AND REPORT EXCERPTS FOR REFERENCE NO. 10a

(see Section 4.2.7 of text)

CALCULATION SHEET
MRI Project 8987-35

Argus CT

Reference No. 10a

Type of Facility: Kerr McGee Chemical Corp
(e.g., power plant)

Location of Facility: Argus Co / Searless Lake

Test Date 1/76

Type of Cooling Tower (circle one): [✓ Wet Tower]; Dry Tower; Wet-Dry; Not Specified

Type of Draft (circle one): [✓ Mechanical Draft]; Natural Draft; Fan-Assist Natural Draft; Atmospheric; Not Specified

Fan Configuration (circle one as applicable): Forced Draft; [✓ Induced Draft]; Not Specified

Heat Transfer Configuration (circle one as applicable): Counterflow; [✓ Crossflow]; Spray; Not Specified

Type of Heat Transfer Media (circle one as applicable): Splash; Film; Not Specified

Type of Fill (specify): 4 x 4 wood lath

Type of Hot Water Distribution System (circle one as applicable): Pressure System; Gravity System; Not Specified Hot H2O distribution basin

Water Flow Configuration (circle one as applicable): [✓ Recirculating]; Once-Through; Not Specified

Type of Mist Eliminator (specify): Wood lath herringbone

4-cell Marley 2 pass w/ conventional Basin & nozzles

EMISSION RATE CALCULATIONS:

Measurement Method Used: Total Drift = Heated Beads
Total Drift = Sensitive Paper (not used in calc.)

90-5 SEV history.wks 031490

Data Rating = C

From p. 2 of test report:

Table 1.1
Comparison Between Drift Fractions
From November/December and January 1987

Traverse	Date	Tower	Drift Fraction Based on Exhaust Air Sodium Concentration (% of Circ. Waterflow)	Drift Fraction Based on Na Mass Flux (% of Circ. Waterflow)	Drift Fraction Based on Sensitive Papers (% of Circ. Waterflow)
1 & 2	11/1/86	Sulfate #2	0.0035	0.0035	—
1 & 2	11/[illegible]/86	Argus	0.0045	0.0045	—
1	1/9/87	Argus	0.0273	0.0219	—
1a	1/9/87	Argus	0.0109	0.0111	—
1	1/16/87	Argus	0.0104	0.0147	0.0108
2	1/16/87	Argus	0.0101	0.0146	0.0100
3	1/17/87	Argus	0.0127	0.0169	0.0108
4	1/17/87	Argus	0.0087	0.0124	0.00039
1	1/18/87	Sulfate #2	0.0021	0.0032	0.00039
2	1/18/87	Sulfate #2	0.0011	0.0021	0.00039
3 & 4	1/19/87	Sulfate #2	0.0015	0.0022	0.00039

Not used in calculations!

* For Argus Tower: Total Drift EF

$$\text{Avg. Drift (Na Conc)} = \frac{0.0273 + 0.0109 + 0.0104 + 0.0101 + 0.0127 + 0.0087}{6}\ \%$$

$$= 0.0134\ \%$$

$$\text{Avg. Drift (Na Flux)} = \frac{0.0219 + 0.0111 + 0.0147 + 0.0146 + 0.0169 + 0.0124}{6}\ \%$$

$$= 0.0153\ \%$$

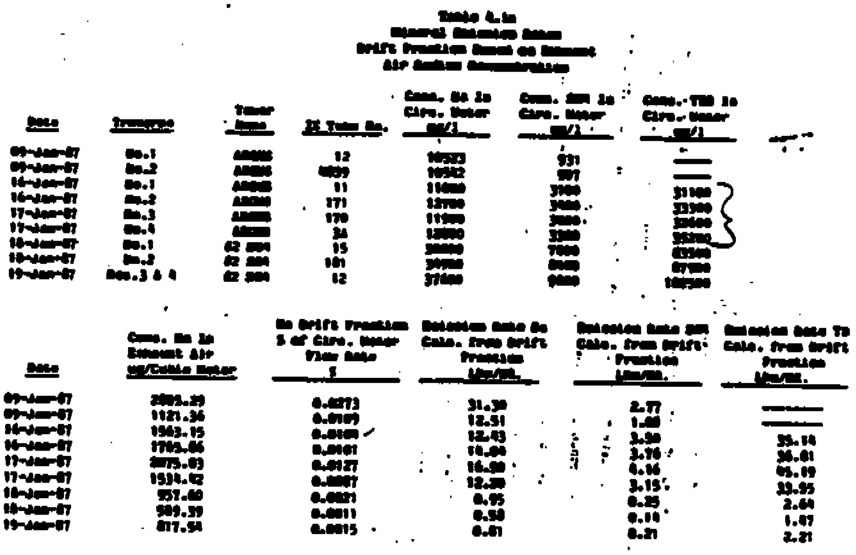
$$\text{Avg. Drift (Both Methods)} = \frac{0.0134 + 0.0153}{2}\ \%$$

$$= 0.0144\ \%$$

$$\text{Total Drift from Tower} = \frac{0.0144}{100}\ \frac{\text{gal. drift}}{\text{gal. } H_2O \text{ circ.}} \times 8.312\ \frac{\text{lbs}}{\text{gal.}} = 1.2(10)^{-3}\ \frac{\text{lbs. drift}}{\text{gal. } H_2O \text{ circ. to atmos.}}$$

* For Argus Tower: PM-10 (by TDS calc.)

From Table 4.1a, p. 20 of report:



$$\text{Avg. TDS} = \frac{31{,}100 + 33{,}300 + 35{,}200}{3}\ \frac{\text{mg}}{\text{L}} = 32{,}300\ \text{mg/L}\ (\text{ppm})$$

Assuming: TDS in drift = TDS in circulating H_2O

$$PM_{10} = 1.2(10)^{-3}\ \frac{\text{lbs. drift}}{\text{gal. } H_2O \text{ flow}} \times 32{,}300\ \frac{\text{lbs. solids}}{10^6 \text{ lbs. drift}} = 3.9(10)^{-5}\ \frac{\text{lbs. } PM_{10}}{\text{gal. } H_2O}$$

to atmos.

CALCULATION SHEET
MRI Project 8987-35

Sulfate #2 CT

Reference No. 10-a Type of Facility: Kerr McGee Chemical Corp
(e.g., power plant)

Location of Facility: Western Facility / Searles Lake Ca Test Date 1/86

Type of Cooling Tower (circle one): [✓ Wet Tower]; Dry Tower; Wet-Dry; Not Specified

Type of Draft (circle one): [✓ Mechanical Draft]; Natural Draft; Fan-Assist Natural Draft; Atmospheric; Not Specified

Fan Configuration (circle one as applicable): Forced Draft; [✓ Induced Draft]; Not Specified

Heat Transfer Configuration (circle one as applicable): [✓ Counterflow]; Crossflow; Spray; Not Specified

Type of Heat Transfer Media (circle one as applicable): Splash; Film; [✓ Not Specified]

Type of Fill (specify): Coil Heat Exchanger

Type of Hot Water Distribution System (circle one as applicable): [✓ Pressure System]; Gravity System; Not Specified (Upspray)

Water Flow Configuration (circle one as applicable): Recirculating; Once-Through; Not Specified

Type of Mist Eliminator (specify): Single Pass PVC Thermatec

2-cell Coil Shed w/manifolded upspray water distribution

EMISSION RATE CALCULATIONS:

Measurement Method Used: Total Drift = Heated Beads

Total Drift = Sensitive Paper (not used in calc.)

Data Rating = C

From Table 1.1, p. 2 of Test Report:

Table 1.1
Comparison Between Drift Fractions
From October/November and January 1987

Traverse	Date	Tower	Drift Fraction Based on Exhaust Air Sodium Concentration (% of Circ. Waterflow)	Drift Fraction Based on Na Mass Flux (% of Circ. Waterflow)	Drift Fraction Based on Sensitive Papers (% of Circ. Waterflow)
1 & 2	11/7/86	Sulfate #2	0.0025	.0025	—
1 & 2	11/9/86	Argon	0.0115	.0115	—
1	1/9/87	Argon	0.0273	0.0219	—
1A	1/9/87	Argon	0.0109	0.0111	—
1	1/16/87	Argon	0.0108	0.0147	0.0100
2	1/16/87	Argon	0.0101	0.0146	0.0100
3	1/17/87	Argon	0.0127	0.0169	0.0100
4	1/17/87	Argon	0.0087	0.0179	0.00039
1	1/18/87	Sulfate #2	0.0021	0.0032	0.00039
2	1/18/87	Sulfate #2	0.0011	0.0021	0.00039
3 & 4	1/19/87	Sulfate #2	0.0015	0.0022	0.00039

For Sulfate #2 Tower: Total Drift EF

$$\text{Avg. Drift (Na Conc.)} = \frac{0.0021 + 0.0011 + 0.0015}{3}\ \% = 0.0016\%$$

$$\text{Avg. Drift (Na Flux)} = \frac{0.0032 + 0.0021 + 0.0022}{3}\ \% = 0.0025\%$$

$$\text{Avg. (Both Methods)} = \frac{0.0016 + 0.0025}{2}\ \% = 0.0021\%$$

$$\text{Total Drift from Tower} = \frac{0.0021}{100}\ \frac{\text{gal. drift}}{\text{gal. } H_2O \text{ flow}} \times 8.312\ \frac{\text{lbs}}{\text{gal}} = 1.7(10)^{-4}\ \frac{\text{lbs. drift}}{\text{gal. } H_2O \text{ flow}}$$

For Sulfate #2 Tower: PM-10 (by TDS calc.)

From Table 4.1a, p. 20 of test report:

Table 4.1a
Mineral Extension Data
Drift Fraction Based on Exhaust
Air Sodium Concentration

Date	Traverse	Tower Name	IK Tube No.	Conc. Na in Circ. Water mg/l	Conc. SO4 in Circ. Water mg/l	Conc. TDS in Circ. Water mg/l
09-Jan-87	No.1	ARGON	12	10523	931	—
09-Jan-87	No.2	ARGON	1059	10542	987	—
16-Jan-87	No.1	ARGON	11	11000	3100	31100
16-Jan-87	No.2	ARGON	171	12700	3400	33300
17-Jan-87	No.3	ARGON	170	11900	3000	30600
17-Jan-87	No.4	ARGON	34	12000	3300	32500
18-Jan-87	No.1	#2 SO4	15	30000	7800	83500
18-Jan-87	No.2	#2 SO4	101	39500	8400	87900
19-Jan-87	Nos.3 & 4	#2 SO4	12	37000	9800	102500

$$\text{Avg. TDS} = \frac{83{,}500 + 87{,}900 + 102{,}500}{3}\ \frac{\text{mg}}{\text{L}} = 91{,}300\ \underset{(\text{ppm})}{\text{mg/L}}$$

Assuming: TDS in drift = TDS in circulating H_2O

$$PM_{10} = 1.7(10)^{-4}\ \frac{\text{lbs. drift}}{\text{gal. } H_2O \text{ flow}} \times 91{,}300\ \frac{\text{lbs. solids}}{10^6 \text{ lbs. drift}} = 1.6(10)^{-5}\ \frac{\text{lbs } PM_{10}}{\text{gal. } H_2O \text{ fl.}}$$

to atmos.

TIN 87-1016

Report of Cooling Tower
Drift Emission Sampling
at
Argus and Sulfate #2
Cooling Towers

Prepared For:

Kerr McGee Chemical Corporation
13200 Main Street
P.O. Box 367
Trona, CA 93562

Prepared By:

Environmental Systems Corporation
200 Tech Center Drive
Knoxville, TN 37912

February 1987

Table 4.1a
Mineral Emission Rates
Drift Fraction Based on Exhaust Air Sodium Concentration

Date	Traverse	Tower Name	IK Tube No.	Conc. Na In Circ. Water mg/1	Conc. SO4 In Circ. Water mg/1	Conc. TDS In Circ. Water mg/1
09-Jan-87	No.1	ARGUS	12	10523	931	--------
09-Jan-87	No.2	ARGUS	4059	10542	907	--------
16-Jan-87	No.1	ARGUS	11	11000	3100	31100
16-Jan-87	No.2	ARGUS	171	12700	3400	33300
17-Jan-87	No.3	ARGUS	170	11900	3000	32600
17-Jan-87	No.4	ARGUS	3A	12800	3300	35200
18-Jan-87	No.1	#2 804	15	30000	7800	83500
18-Jan-87	No.2	#2 804	181	34900	8400	87900
19-Jan-87	Nos.3 & 4	#2 804	12	37600	9800	102900

Date	Conc. Na In Exhaust Air ug/Cubic Meter	Na Drift Fraction % of Circ. Water Flow Rate %	Emission Rate Na Calc. from Drift Fraction LBm/HR.	Emission Rate SO4 Calc. from Drift Fraction LBm/HR.	Emission Rate TDS Calc. from Drift Fraction LBm/HR.
09-Jan-87	2805.29	0.0273	31.30	2.77	--------
09-Jan-87	1121.36	0.0109	12.51	1.08	--------
16-Jan-87	1563.15	0.0104 ✓	12.43	3.50	35.14
16-Jan-87	1765.86	0.0101	14.04	3.76	36.81
17-Jan-87	2075.03	0.0127	16.50	4.16	45.19
17-Jan-87	1534.42	0.0087	12.20	3.15	33.55
18-Jan-87	957.60	0.0021	0.95	0.25	2.64
18-Jan-87	589.39	0.0011	0.58	0.14	1.47
19-Jan-87	817.54	0.0015	0.81	0.21	2.21

Table 1.1
Comparison Between Drift Fractions From October/November and January 1987

Traverse	Date	Tower	Drift Fraction Based on Exhaust Air Sodium Concentration (% of Circ.Waterflow)	Drift Fraction Based on Na Mass Flux (% of Circ. Waterflow)	Drift Fraction Based On Sensitive Papers (% of Circ.Waterflow)
1 & 2	11/1/86	Sulfate #2	0.0035	0.0035	------
1 & 2	11/4/86	Argus	0.0115	0.0113	------
1	1/9/87	Argus	0.0273	0.0219	------
1a	1/9/87	Argus	0.0109	0.0111	------
1	1/16/87	Argus	0.0104	0.0147	0.0108
2	1/16/87	Argus	0.0101	0.0146	0.0108
3	1/17/87	Argus	0.0127	0.0169	0.0108
4	1/17/87	Argus	0.0087	0.0124	0.00039
1	1/18/87	Sulfate #2	0.0021	0.0032	0.00039
2	1/18/87	Sulfate #2	0.0011	0.0021	0.00039
3 & 4	1/19/87	Sulfate #2	0.0015	0.0022	0.00039

APPENDIX H

EMISSION FACTOR CALCULATIONS AND REPORT EXCERPTS FOR REFERENCE NO. 15
(see Section 4.2.8 of text)

[illegible]

CALCULATION SHEET
MRI Project 8987-35

Reference No. 15 Type of Facility: Fuel Plant
(e.g., power plant)

Location of Facility: N/S Test Date [illegible]

Type of Cooling Tower (circle one): [✓ Wet Tower]; Dry Tower;
Wet-Dry; Not Specified

Type of Draft (circle one): [✓ Mechanical Draft]; Natural Draft;
Fan-Assist Natural Draft; Atmospheric; Not Specified

Fan Configuration (circle one as applicable): Forced Draft;
[✓ Induced Draft]; Not Specified

Heat Transfer Configuration (circle one as applicable): [✓ Counterflow];
Crossflow; Spray; Not Specified

Type of Heat Transfer Media (circle one as applicable): Splash; [✓ Film];
Not Specified

Type of Fill (specify): Plastic

Type of Hot Water Distribution System (circle one as applicable):
Pressure System; Gravity System; [✓ Not Specified]

Water Flow Configuration (circle one as applicable): [✓ Recirculating];
Once-Through; Not Specified

18 in-line cells w/common cold H2O basin - 2 cells tested

Type of Mist Eliminator (specify): N/S

EMISSION RATE CALCULATIONS:

Measurement Method Used: Flanner's Approach (MM13A)

90-5 SEV kinary wksht 031490

From Appendix A, pg A-5 of Report:

For The "T" Cell Test

Net Fan Area = 728.95 ft^2
Nozzle Area = 1.0502×10^{-3} ft^2
Equivalent Sample Collection Time = 240 minutes
Water Flow Rate = 140609 gpm / 18 cells = 7811.6 GPM (per cell)

SUMMARY OF DRIFT TEST RESULTS[a]

Tracer Analyzed	"R" Stack Test Results	"T" Stack Test Rrsults
SiO_2	0.042%	0.020%
Cl^-	0.025%	0.018%
SO_4^{-2}	0.019%	0.012%
Na	0.021%	0.013%

---

[a] Percentage of total water flow emitted as drift.

Tracer	Basin Conc. (mcg/g)	Tracer Net Wt (mcg)
SiO_2	54	110.5
Cl^-	86	156.0
SO_4^{-2}	540	650.0
Na	250	338.0

To Check Calculations Using SiO_2 as Tracer:

% Drift = 100 * (NFA * NWT) / (NZA * WFR * EQT * BTC)

NFA = Net Fan Area (square feet)
NWT = Net Weight of Tracer (mcg)
NZA = Nozzle Area (square feet)
WFR = Waterflow Rate (grams per minute)
EQT = Equivalent Sample Time (minutes)
BTC = Basin Tracer Concentration (mcg/g)

$$\therefore \%\text{ Drift} = 100 \times \frac{728.95\,\cancel{ft^2} \times 110.5\,mcg}{1.0502\times10^{-3}\,\cancel{ft^2} \times 7811.6\,gal/min \times 240\,min \times 54\,mcg/g}$$

$$= 100 \times 0.758\,\frac{g}{gal} \times \frac{1\,gal}{3785\,gm} = 0.020\%$$

Calc OK!

From Appendix E, pg E-E of Report:

For The "R" Cell Test

Net Fan Area = 728.95 ft^2
Nozzle Area = 1.0502×10^{-3} ft^2
Equivalent Sample Collection Time = 240
Water Flow Rate = 140609 gpm / 18 cells = 7811.6

Tracer	Basin Conc (mcg/g)	Tracer Net Wt (mcg)
SiO	55	252.0
Cl^-	90	246.4
SO_4^{-2}	660	1344.0
Na	270	616.0

To Check Calculations Using SiO:

$$\therefore \%\text{ Drift} = 100 \times \frac{728.95\,\cancel{ft^2} \times 252.0\,mcg}{1.0502\times10^{-3}\,\cancel{ft^2} \times 7811.6\,gal/min \times 55\,mcg/g \times 240\,min}$$

$$= 100 \times 1.696\,\frac{g}{gal} \times \frac{1\,gal}{3785\,gm} = 0.045\%$$

Calc OK!

Using Average % Drift for Both Cells and & Tracers;
Total Drift Emissions Would Be: Assume H_2O @ 25°C

$$EF = \frac{0.021}{100}\,\frac{gal\,drift}{gal\,H_2O\,flow} \times 8.312\,\frac{lbs\,drift}{gal\,\cancel{drift}} = 1.77\times10^{-3}\,\frac{lbs}{gal} \text{ to atmospl}$$

Data Rating: B (Insufficient QA on Sampling Equipment & Laboratory Data)

COOLING TOWER INSTITUTE TEST REPORT

DRIFT TEST
ON
18-CELL, MECHANICAL-DRAFT, COUNTER-FLOW COOLING TOWER

I. INTRODUCTION

The testing services of the Cooling Tower Institute (CTI) were retained by the ., under Purchase Order No. to conduct a drift test on a ., 18-cell, mechanical-draft, counter-flow cooling tower in accordance with the CTI Acceptance Test Code ATC-105. The cooling tower is located at the plant near The work was performed by Midwest Research Institute (MRI) under contract with the CTI as the official CTI test representatives. The CTI test representatives for this test were Mr. Kenneth W. Hennon and Mr. Thomas E. Weast. The tower manufacturer was represented by The plant was represented by and by Local representatives of the , also witnessed portions of the test.

II. TEST SITE DESCRIPTION

The is located on the The cooling tower provides cooling water to various process heat exchangers used by the plant in the The cooling tower is located in an unobstructed area adjacent to the side of the plant.

The cooling tower consists of 18 wood-framed, mechanical-draft, counter-flow cells in a continuous straight line with a common cold water basin beneath the tower. The cells use a plastic film-type fill for the heat transfer surface. Each cell is equipped with a 28-ft diameter fan driven by a 240-kw motor. (The tower was originally equipped with 100-kw motors.)

IV. ANALYSIS OF SAMPLES AND RESULTS

The samples of the cooling tower circulating water, recovered drift samples with rinses and impinger solutions, and blank rinse samples were analyzed by the laboratory using atomic adsorption spectroscopy. The analysis was performed for four trace constituents: SiO_2; Cl^-; SO_4^{-2}; and Na.

The test results are summarized in the following table. Details are presented in the attached appendices.

SUMMARY OF DRIFT TEST RESULTS[a]

Tracer Analyzed	"R" Stack Test Results	"T" Stack Test Results
SiO_2	0.042%	0.020%
Cl^-	0.025%	0.018%
SO_4^{-2}	0.019%	0.012%
Na	0.021%	0.013%

---

[a] Percentage of total water flow emitted as drift.

V. DISCUSSION AND CONCLUSIONS

The definition of drift as used in this report is, "The percentage of the water flowing through the tower which is discharged through the fan in the form of water droplets or aerosols." Under the conditions of these tests, the calculated drift rates were between 0.019% and 0.042% for the "R" cell and between 0.012% and 0.018% for the "T" cell depending on which tracer is used. If one of the tracers (SiO_2) is discarded because of erratic (i.e., compared to the other materials) behavior, the variation in the test data decreases. The drift rates are then between 0.019% and 0.025% for the "R" cell and between 0.012% and 0.018% for the "T" cell. If the results are averaged, a drift rate of 0.018% is obtained which should be reasonably representative of the tower.

$$\%\,Drift = \frac{\frac{\text{Net Fan Area}}{\text{Nozzle Area}} \times \frac{\text{Total Weight of Drift Sample with Rince}}{\text{Equivalent Sample Collection Time}} \times \text{Concentration of Tracer in Drift Sample}}{\text{Water Flow Rate} \times \text{Concentration of Tracer in Water Flow}} \times 100$$

For The "T" Cell Test

Net Fan Area = $\boxed{728.95\ ft^2}$

Nozzle Area = $\boxed{1.0502 \times 10^{-3}\ ft^2}$

Total Weight of Drift Sample with Rince = $\boxed{650}$

Equivalent Sample Collection Time = $\boxed{240 \text{ minutes}}$ (40 points @ 6 min/point)

Water Flow Rate = $\boxed{140609 \text{ gpm} / 18 \text{ cells}}$ × 8.34 lb/gal × 454 g/lb = 29,577,572 g/min

$$\%\,Drift = \frac{\frac{728.95}{1.0502 \times 10^{-3}} \times \frac{650}{240} \times \text{Concentration of Tracer in Drift Sample}}{29{,}577{,}572 \times \text{Concentration of Tracer in Water Flow}} \times 100$$

$$= 0.06354 \times \frac{\text{Concentration of Tracer in Drift Sample}}{\text{Concentration of Tracer In Water Flow}} \times 100$$

$$= 0.06354 \times \frac{C_1}{C_2} \times 100$$

For $RSiO_2$ Tracer	$C_1 = 0.17$	$C_2 = 54$	% Drift =	0.020 %
" Cl^- "	$C_1 = 0.24$	$C_2 = 86$	% Drift =	0.018 %
" SO_4 "	$C_1 = 1.0$	$C_2 = 540$	% Drift =	0.012 %
" Na "	$C_1 = 0.52$	$C_2 = 250$	% Drift =	0.013 %

$$\%\,\text{Drift} = \frac{\dfrac{\text{Net Fan Area}}{\text{Nozzle Area}} \times \dfrac{\text{Total Weight of Drift Sample with Rince}}{\text{Equivalent Sample Collection Time}} \times \text{Concentration of Tracer in Drift Sample}}{\text{Water Flow Rate} \times \text{Concentration of Tracer in Water Flow}} \times 100$$

For The "R" Cell Test

Net Fan Area = $\boxed{728.95\ ft^2}$

Nozzle Area = $\boxed{1.0502 \times 10^{-3}\ ft^2}$

Total Weight of Drift Sample with Rince = $\boxed{560}$

Equivalent Sample Collection Time = $\boxed{240\ \text{minutes}}$ (40 points @ 6 min/point)

Water Flow Rate = $\boxed{140609\ gpm / 18\ cells \times 8.34\ lb/gal}$ $\times 454\ g/lb = 29{,}577{,}572\ g/min$

$$\%\,\text{Drift} = \frac{\dfrac{728.95}{1.0502 \times 10^{-3}} \times \dfrac{560}{240} \times \text{Concentration of Tracer in Drift Sample}}{29{,}577{,}572 \times \dfrac{15}{17} \times \text{Concentration of Tracer in Water Flow}} \times 100$$

$$= 0.05171 \times \frac{\text{Concentration of Tracer in Drift Sample}}{\text{Concentration of Tracer In Water Flow}} \times 100$$

$$= 0.05171 \times \frac{C_1}{C_2} \times 100$$

For $RSiO_2$ Tracer $C_1 = 0.45$ $C_2 = 55$ % Drift = 0.042%

" Cl^- " $C_1 = 0.44$ $C_2 = 90$ % Drift = 0.025%

" SO_4 " $C_1 = 2.4$ $C_2 = 660$ % Drift = 0.019%

" Na " $C_1 = 1.1$ $C_2 = 270$ % Drift = 0.021%

rev 2/1/

APPENDIX I

EMISSION FACTOR CALCULATIONS AND REPORT EXCERPTS FOR REFERENCE NO. 17

(see Section 4.2.9 of text)

CALCULATION SHEET
MRI Project 8987-35

Reference No. 17 Type of Facility: Chiller Station
(e.g., power plant)

Location of Facility: N/S Test Date 1/87

Type of Cooling Tower (circle one): [✓ Wet Tower]; Dry Tower; Wet-Dry; Not Specified

Type of Draft (circle one): [✓ Mechanical Draft]; Natural Draft; Fan-Assist Natural Draft; Armospheric; Not Specified

Fan Configuration (circle one as applicable): Forced Draft; [✓ Induced Draft]; Not Specified

Heat Transfer Configuration (circle one as applicable): [✓ Counterflow]; Crossflow; Spray; Not Specified

Type of Heat Transfer Media (circle one as applicable): Splash; Film; [✓ Not Specified]

Type of Fill (specify): N/S

Type of Hot Water Distribution System (circle one as applicable): Pressure System; Gravity System; [✓ Not Specified]

Water Flow Configuration (circle one as applicable): [✓ Recirculating]; Once-Through; Not Specified

4 in-line cells w/a common cold H_2O basin - 1 cell tested

Type of Mist Eliminator (specify): N/S

EMISSION RATE CALCULATIONS:

Measurement Method Used: Industry accepted isokinetic sampling techniques - M.M 13a

90-S SEV kinneywksht 031490

From Appendix B, pg B-2+3 of Report:

The total weight of Br in the sample train (Br_T) is the sum of the Br found in the impinger content and the water rinse (Br_I), and on the filter (Br_F).

$$Br_T = Br_I + Br_F$$

$$= 102.00 + 0.24 = 102.24 \ \mu g \ Br$$

Corrections (B_T) for the water blank (W_B) must be applied to the weight of bromine collected in the sample train. In this test, 425 mL of water were used in the impingers and water rinse. A blank filter (F_B) was also analyzed.

$$(B_T) = (W_B) + (F_B)$$

$$= 2.55 + 0.07 = 2.62 \ \mu g \ Br$$

The net corrected weight of bromine in the sample train due to drift (Br_C) is:

$$(Br_C) = (Br_T) - (B_T)$$

$$= 102.24 - 2.62 = 96.62 \ \mu g \ Br$$

After obtaining the corrected Br weight (Br_C) for the sample train, the concentration of Br (in μg/dscf) in the stack air is calculated from the sample volume, V_S:

$$\text{Conc. Br in stack} = \frac{Br_C}{V_S} = \frac{99.62 \ \mu g \ Br}{551.1 \ dscf}$$

$$= 0.18 \ \mu g \ Br/dscf$$

Since the total stack flow rate was measured as 666,444 dscfm, the total Br emissions from the stack (Br_S) is calculated by:

$$\text{Total Br from stack} = 666{,}444 \ dscfm \times \frac{0.18 \ \mu g \ Br}{dscfm}$$

$$= 119{,}960 \ \mu g \ Br/min$$

The volume of basin water, W_V, required to deliver 119,960 µg of Br is calculated by:

$$W_V = \frac{\text{Total Br from stack}}{\text{Conc. Br in basin}}$$

$$= \frac{119{,}960\ \mu\text{g Br/min}}{55.2\ \mu\text{g Br/mL}} = 2{,}173\ \text{mL/min}$$

Converting to gallons per minute gives:

$$\text{gpm} = \frac{2{,}173\ \text{mL/min}}{3{,}784\ \text{mL/gal.}} = 0.57\ \text{gpm}$$

or 192 gal/hr.

The percent drift, % D, can now be calculated according to the equation:

$$\%\ D = \frac{\text{Vol. basin water from stack } (W_V)}{\text{Total water vol. through basin}} \times 100$$

$$= \frac{0.57\ \text{gpm}}{7{,}386\ \text{gpm}} \times 100 = 0.007\%$$

Calc OK!

Using % Drift, Total Drift Emissions Would Be: Assume H_2O @ 25°C

$$EF = \frac{0.007}{100}\ \frac{\text{gal}\cancel{\text{drift}}}{\text{gal } H_2O \text{ flow}} \times 8.312\ \frac{\text{lbs drift}}{\text{gal}\cancel{\text{drift}}} = 5.82 \times 10^{-4}\ \frac{\text{lb}}{\text{gal}}$$

to atmos

Data Rating: B (Insufficient QA on Sampling Equipment & Laboratory Data)

COOLING TOWER INSTITUTE TEST REPORT

DRIFT ACCEPTANCE TEST
ON A

6-CELL, MECHANICAL-DRAFT, COUNTER-FLOW
COOLING TOWER

I. INTRODUCTION

The testing services of the Cooling Tower Institute (CTI) were retained by the struction (OFPC) Project No. , to conduct a drift acceptance test on a 6-cell, mechanical-draft, counter-flow cooling tower in accordance with the CTI Acceptance Test Code ATC-105. The cooling tower is located at campus. The work was performed by Midwest Research Institute (MRI) under contract with the CTI as the official CTI test representative. The CTI test representatives for this test were Mr. Thomas E. Weast, Mr. Kenneth W. Hennon, and Mr. George R. Cobb. The tower manufacturer was not represented. The plant was represented by

Cooling tower drift is defined as the percent of water flow through the tower which exits through the fan in the form of water droplets or aerosols. The amount of drift from the tower was determined by isokinetically sampling a representative fraction of the tower airflow and measuring the amount of aerosol leaving the stack. Sodium bromide (NaBr) was spiked into the basin as a tracer for the analysis. Neutron activation analysis (NAA), an extremely sensitive detection technique, was then used to measure the amount of bromine in the basin water and that exiting from the stack. From measurement of the total bromine collected in the sampler and the concentration of bromine in the basin water, the drift rate was calculated.

II. TEST SITE DESCRIPTION

is located on the north side of the The cooling tower provides cooling water to air conditioning equipment. The cooling tower is located on the roof of the building.

The cooling tower consists of six mechanical-draft, counter-flow cells of which four cells are presently complete and two are for future expansion. The cells are in a continuous straight line with a common cold water basin beneath the tower. Each cell is equipped with a 22-ft diameter fan driven by a 75-hp motor.

TABLE 1

SAMPLE ANALYSIS

Sample No.	Description	Sample Volume (mL)	Sample Concentration (µg/mL)	Total Br (µg)
102	Basin water	-	55.2	-
104	Impinger contents	425	0.24	102.00
106	Water blank	425	0.006	2.55
107	Filter	-	-	0.24
108	Filter blank	-	-	0.07

All samples, except the filters, are run in triplicate. The average of the three values is recorded in Table 1 and was used in the calculation.

V. CALCULATION PROCEDURE AND RESULTS

The calculation of correction factors needed to determine drift are relatively complex. The calculation procedure, without indicating the corrections, is presented in this section. The purpose is to provide a clear picture of the principles underlying the calculation of the drift rate. The actual calculations with all the correction factors have been provided in Appendix B. The sampling data used in the calculations are shown in Table 2.

TABLE 2

SAMPLING DATA

Description	
Corrected total Br in sample	99.62 µg[a]
Sample volume	551.1 dscf
Stack airflow rate	666,444 dscfm
Basin water Br concentration	55.2 µg/mL
Water flow rate through the cell	7,386 gpm

---

[a] See calculations in Appendix B.

COMPLETE CALCULATIONS

This appendix provides the calculations for this test, complete with all correction factors applied. All numbers have been rounded to three significant figures. The data used were taken from Tables 1 and 2 in the report.

The total weight of Br in the sample train (Br_T) is the sum of the Br found in the impinger content and the water rinse (Br_I), and on the filter (Br_F).

$$Br_T = Br_I + Br_F$$

$$= 102.00 + 0.24 = 102.24 \ \mu g \ Br$$

Corrections (B_T) for the water blank (W_B) must be applied to the weight of bromine collected in the sample train. In this test, 425 mL of water were used in the impingers and water rinse. A blank filter (F_B) was also analyzed.

$$(B_T) = (W_B) + (F_B)$$

$$= 2.55 + 0.07 = 2.62 \ \mu g \ Br$$

The net corrected weight of bromine in the sample train due to drift (Br_C) is:

$$(Br_C) = (Br_T) - (B_T)$$

$$= 102.24 - 2.62 = 96.62 \ \mu g \ Br$$

After obtaining the corrected Br weight (Br_C) for the sample train, the concentration of Br (in µg/dscf) in the stack air is calculated from the sample volume, V_S:

$$\text{Conc. Br in stack} = \frac{Br_C}{V_S} = \frac{99.62 \ \mu g \ Br}{551.1 \ dscf}$$

$$= 0.18 \ \mu g \ Br/dscf$$

Since the total stack flow rate was measured as 666,444 dscfm, the total Br emissions from the stack (Br_S) is calculated by:

$$\text{Total Br from stack} = 666{,}444 \ dscfm \times \frac{0.18 \ \mu g \ Br}{dscfm}$$

$$= 119{,}960 \ \mu g \ Br/min$$

The volume of basin water, W_V, required to deliver 119,960 μg of Br is calculated by:

$$W_V = \frac{\text{Total Br from stack}}{\text{Conc. Br in basin}}$$

$$= \frac{119{,}960\ \mu g\ Br/min}{55.2\ \mu g\ Br/mL} = 2{,}173\ mL/min$$

Converting to gallons per minute gives:

$$gpm = \frac{2{,}173\ mL/min}{3{,}784\ mL/gal.} = 0.57\ gpm$$

or 192 gal/hr.

The percent drift, % D, can now be calculated according to the equation:

$$\% D = \frac{\text{Vol. basin water from stack } (W_V)}{\text{Total water vol. through basin}} \times 100$$

$$= \frac{0.57\ gpm}{7{,}386\ gpm} \times 100 = \boxed{0.007\%}$$

APPENDIX J

EMISSION FACTOR CALCULATIONS AND REPORT EXCERPTS FOR REFERENCE NO. 18

(see Section 4.2.10 of text)

CALCULATION SHEET
MRI Project 8987-35

Borax CT

Reference No. 18 Type of Facility: Kerr McGee Chemical Corp
(e.g., power plant)

Location of Facility: Westend Facility / San Bernardino Co. Test Date 11/85

Type of Cooling Tower (circle one): [✓ Wet Tower]; Dry Tower; Wet-Dry; Not Specified

Type of Draft (circle one): [✓ Mechanical Draft]; Natural Draft; Fan-Assist Natural Draft; Atmospheric; Not Specified

Fan Configuration (circle one as applicable): Forced Draft; [✓ Induced Draft]; Not Specified

Heat Transfer Configuration (circle one as applicable): [✓ Counterflow]; Crossflow; Spray; Not Specified

Type of Heat Transfer Media (circle one as applicable): Splash; Film; [✓ Not Specified]

Type of Fill (specify): N/S

Type of Hot Water Distribution System (circle one as applicable): Pressure System; Gravity System; [✓ Not Specified]

Water Flow Configuration (circle one as applicable): Recirculating; Once-Through; [✓ Not Specified]

[illegible]

Type of Mist Eliminator (specify): N/S

EMISSION RATE CALCULATIONS:

Measurement Method Used: Isokinetic Drift Sampling
Heated Beads

CALCULATION SHEET
MRI Project 8987-35

1, 2, 3 CT

Reference No. 18 Type of Facility: Kerr McGee Chemical Corp
(e.g., power plant)

Location of Facility: Westend Facility Test Date '86
Searles Valley

Type of Cooling Tower (circle one): [✓ Wet Tower]; Dry Tower; Wet-Dry; Not Specified

Type of Draft (circle one): [✓ Mechanical Draft]; Natural Draft; Fan-Assist Natural Draft; Atmospheric; Not Specified

Fan Configuration (circle one as applicable): Forced Draft; [✓ Induced Draft]; Not Specified

Heat Transfer Configuration (circle one as applicable): [✓ Counterflow]; Crossflow; Spray; Not Specified

Type of Heat Transfer Media (circle one as applicable): Splash; Film; [✓ Not Specified]

Type of Fill (specify): N/S

Type of Hot Water Distribution System (circle one as applicable): Pressure System; Gravity System; [✓ Not Specified]

Water Flow Configuration (circle one as applicable): Recirculating; Once-Through; [✓ Not Specified]

Type of Mist Eliminator (specify): N/S

Each one 2-cell

EMISSION RATE CALCULATIONS:

Measurement Method Used: Isokinetic Drift Sampling

90-5 SEV [illegible] 031490

③

CALCULATION SHEET
MRI Project 8987-35

#4 Sulfate CT

Reference No. 18 Type of Facility: Kerr McGee Chemical Corp
(e.g., power plant)

Location of Facility: Westend Facility / Searles Lake, Ca Test Date 11/86

Type of Cooling Tower (circle one): [✓ Wet Tower]; Dry Tower; Wet-Dry; Not Specified

Type of Draft (circle one): [✓ Mechanical Draft]; Natural Draft; Fan-Assist Natural Draft; Atmospheric; Not Specified

Fan Configuration (circle one as applicable): Forced Draft; [✓ Induced Draft]; Not Specified

Heat Transfer Configuration (circle one as applicable): Counterflow; [✓ Crossflow]; Spray; Not Specified

Type of Heat Transfer Media (circle one as applicable): Splash; Film; [✓ Not Specified]

Type of Fill (specify): N/S

Type of Hot Water Distribution System (circle one as applicable): Pressure System; Gravity System; [✓ Not Specified]

Water Flow Configuration (circle one as applicable): Recirculating; Once-Through; [✓ Not Specified]

Type of Mist Eliminator (specify): N/S

2-cells

NOTE: Air velocity through fill + drift eliminator was significantly below normal because 1 cell was out of service.

EMISSION RATE CALCULATIONS:

Measurement Method Used: Isokinetic Drift Sampling

90-5 SEV kinsey wkshi 031490

CALCULATION SHEET
MRI Project 8987-35

Lime CT

Reference No. 18 Type of Facility: Kerr McGee Chemical Corp
(e.g., power plant)

Location of Facility: Westend Facility / Searles Lake, Ca Test Date [illegible]

Type of Cooling Tower (circle one): [✓ Wet Tower]; Dry Tower; Wet-Dry; Not Specified

Type of Draft (circle one): [✓ Mechanical Draft]; Natural Draft; Fan-Assist Natural Draft; Atmospheric; Not Specified

Fan Configuration (circle one as applicable): Forced Draft; [✓ Induced Draft]; Not Specified

Heat Transfer Configuration (circle one as applicable): [✓ Counterflow]; Crossflow; Spray; Not Specified

Type of Heat Transfer Media (circle one as applicable): Splash; Film; [✓ Not Specified]

Type of Fill (specify): N/S

Type of Hot Water Distribution System (circle one as applicable): Pressure System; Gravity System; [✓ Not Specified]

Water Flow Configuration (circle one as applicable): Recirculating; Once-Through; [✓ Not Specified]

Type of Mist Eliminator (specify): N/S

EMISSION RATE CALCULATIONS:

Measurement Method Used: Isokinetic Drift Sampling

CALCULATION SHEET
MRI Project 8987-35

Nos 11 + Nos 14

Reference No. 18 Type of Facility: Kerr McGee Chemical Corp
(e.g., power plant)

Location of Facility: Trona Ca / Searles Lake Test Date 11/86

Type of Cooling Tower (circle one): [✓ Wet Tower]; Dry Tower; Wet-Dry; Not Specified

Type of Draft (circle one): [✓ Mechanical Draft]; Natural Draft; Fan-Assist Natural Draft; Atmospheric; Not Specified

Fan Configuration (circle one as applicable): Forced Draft; [✓ Induced Draft]; Not Specified

Heat Transfer Configuration (circle one as applicable): Counterflow; [✓ Crossflow]; Spray; Not Specified

Type of Heat Transfer Media (circle one as applicable): Splash; Film; [✓ Not Specified]

Type of Fill (specify): N/S

Type of Hot Water Distribution System (circle one as applicable): Pressure System; Gravity System; [✓ Not Specified]

Water Flow Configuration (circle one as applicable): Recirculating; Once-Through; [✓ Not Specified]

Type of Mist Eliminator (specify): N/S

#11 - 3 cell, #14 - 4 cell

EMISSION RATE CALCULATIONS:

Measurement Method Used: Isokinetic Drift Sampling

CALCULATION SHEET

MRI Project 8987-35

Argus II

Reference No. 18 Type of Facility: Kerr McGee Chemical Corp
(e.g., power plant)

Location of Facility: Argus Cal/Searles Lake Test Date 11/86

Type of Cooling Tower (circle one): [✓ Wet Tower]; Dry Tower; Wet-Dry; Not Specified

Type of Draft (circle one): [✓ Mechanical Draft]; Natural Draft; Fan-Assist Natural Draft; Atmospheric; Not Specified

Fan Configuration (circle one as applicable): Forced Draft; [✓ Induced Draft]; Not Specified

Heat Transfer Configuration (circle one as applicable): Counterflow; [✓ Crossflow]; Spray; Not Specified

Type of Heat Transfer Media (circle one as applicable): Splash; Film; [✓ Not Specified]

Type of Fill (specify): N/S

Type of Hot Water Distribution System (circle one as applicable): Pressure System; Gravity System; [✓ Not Specified]

Water Flow Configuration (circle one as applicable): Recirculating; Once-Through; [✓ Not Specified]

Type of Mist Eliminator (specify): N/S

4 cells

EMISSION RATE CALCULATIONS:

Measurement Method Used: Iso-Kinetic Drift Sampling

From Test Report:

7

Drift Fraction and Emissions

for Boron and Sulfate

Tower	Recirculating Flow Rate (GPM)	Concentration in mg/L Boron	Concentration in mg/L Sulfate	Drift ⚠ Fraction (%)	Mass Emission ⚠ lbs/hr Boron	Mass Emission ⚠ lbs/hr Sulfate
Borax Cooling Tower (Center Cell)	3000	59	2700	0.0057	0.0053	0.231
#1 Sulfate Cooling Tower (South Cell)	3500	80	3400	0.0092	0.0129	0.548
#2 Sulfate Cooling Tower (North Cell)	3500	90	4400	0.0035	0.0055	0.270
#3 Sulfate Cooling Tower (South Cell)	3500	91	4700	0.0457	0.0789	3.765
#4 Sulfate Cooling Tower (South Cell)	9360	73	3300	0.0030	0.0103	0.464
Lime Cooling Tower	2950	33	1500	0.0011	0.00054	0.024
#11 Cooling Tower (North Cell East)	15000	1200	10000	0.0011	0.0992	0.826
#14 Cooling Tower (Center Cell)	24000	270	11000	0.0024	0.0779	3.173
Argus Cooling Tower (#2)	30000	53	2100	0.0113	0.0900	3.565

– The report says that ⚠ indicates changed data, however it does not explain what it means (how or why they changed the data).

– To Check Calculations:

$$DF = \frac{\text{liters/minute emitted}}{\text{liters/minute circulated}} = \frac{F_{kj} \cdot A_{fs} \cdot S_t \cdot 1585}{R \cdot C}$$

where:

DF = Drift fraction (% of R)

F_{kj} = Mineral mass emission rate of sodium $\left(\frac{\text{mgm}}{\text{m}^2 \cdot \text{s}}\right)$

A_{fs} = Area of the fan stack (m^2)

S_t = Number of stacks per tower

R = Recirculating water flow rate (GPM)

C = Concentration of sodium in the cooling water (mgm/L)

②

For Borax CT, Na for a Tracer:

$$\therefore \text{Drift \%} = \frac{2.403\,\frac{\text{mgm}}{\text{m}^2\cdot\text{s}} \times 14.69\,\text{m}^2 \times 3 \times 60\,\frac{\text{s}}{\text{min}} \times \frac{264.17\,\text{gal}}{1000\,\text{L}}}{3000\,\text{gal/min} \times 9960\,\text{mg Na/L}} \times 100$$

$= 0.0057$

Calc OK!

Using % Drift and Total Dissolved Solids a PM₁₀ Emission Factor would be:

Assume all particles emitted are PM₁₀

Borax: $0.000057 \times 25000\,\frac{\text{mg}}{\text{L}} \times \underbrace{\frac{\text{g}}{1000\,\text{mg}} \times \frac{1\,\text{lb}}{453.592\,\text{g}} \Big/ \frac{1\,\text{L}}{.26417\,\text{g}}}_{8.345\times10^{-6}}$

$= 1.2 \times 10^{-5}$ lb/gal

#1 CT: $0.000092 \times 34000\,\frac{\text{mg}}{\text{L}} \times 8.345\times10^{-6}\,\frac{\text{lb}\cdot\text{L}}{\text{mg}\cdot\text{gal}}$

$= 2.6 \times 10^{-5}$ lb/gal

#2 CT: $0.000035 \times 42{,}000\,\frac{\text{mg}}{\text{L}} \times 8.345\times10^{-6}\,\frac{\text{lb}\cdot\text{L}}{\text{mg}\cdot\text{gal}}$

$= 1.2 \times 10^{-5}$ lb/gal

#3 CT: $0.000457 \times 42000\,\frac{\text{mg}}{\text{L}} \times 8.345\times10^{-6}\,\frac{\text{lb}\cdot\text{L}}{\text{mg}\cdot\text{gal}}$

$= 1.6 \times 10^{-4}$ lb/gal

#4 CT: $0.000030 \times 32000\,\frac{\text{mg}}{\text{L}} \times 8.345\times10^{-6}\,\frac{\text{lb}\cdot\text{L}}{\text{mg}\cdot\text{gal}}$

$= 8.0 \times 10^{-6}$ lb/gal

Lime CT: $0.000011 \times 13000\,\text{mg/L} \times 8.345\times10^{-6}\,\frac{\text{lb}\cdot\text{L}}{\text{mg}\cdot\text{gal}}$

$= 1.2 \times 10^{-6}$ lb/gal

#11 CT : $0.000011 \times 60{,}000\ \mathrm{mg/L} \times 8.345 \times 10^{-6}\ \frac{\mathrm{lb \cdot L}}{\mathrm{mg \cdot gal}}$

$= 5.5 \times 10^{-6}\ \mathrm{lb/gal}$

#14 CT : $0.000024 \times 57{,}000\ \mathrm{mg/L} \times 8.345 \times 10^{-6}\ \frac{\mathrm{lb \cdot L}}{\mathrm{mg \cdot gal}}$

$= 1.1 \times 10^{-5}\ \mathrm{lb/gal}$

Argus : $0.000113 \times 22{,}000\ \mathrm{mg/L} \times 8.345 \times 10^{-6}\ \frac{\mathrm{lb \cdot L}}{\mathrm{mg \cdot gal}}$

$= 2.1 \times 10^{-5}\ \mathrm{lb/gal}$

Data Rating: D (Lacks QA on Sampling
Equipment & Laboratory Data.
Cannot Determine what they
mean by change of drum.)

Emission Factor : Assume H_2O @ 25°C

#1 CT = .000092 × 8.312 = 0.00076
#2 CT = .000035 × 8.312 = 0.00029
#3 CT = .000457 × 8.312 = 0.0038
#4 CT = .000030 × 8.312 = 0.00025
Lime = .000011 × 8.312 = 0.000091
#11 CT = .000011 × 8.312 = 0.000091
#14 CT = .000024 × 8.312 = 0.00020
Argus = .000113 × 8.312 = 0.00094

18

TIN 86-1143

Isokinetic Droplet Emission Measurements of Selected Induced Draft Cooling Towers
(Revised 12/18/86)

Prepared For:

Kerr McGee Chemical Corporation
P.O. Box 367
Trona, CA 93562

Prepared By:

Environmental Systems Corporation
200 Tech Center Drive
Knoxville, TN 37912

November, 1986

described by equation 4.3 can be used in quantifying individual emission rates for all ions of interest.

Table 4.2

Drift Fraction and Emissions for Boron and Sulfate

Tower	Recirculating Flow Rate (GPM)	Concentration in mg/L		Drift ⚠ Fraction (%)	Mass Emission ⚠ lbs/hr	
		Boron	Sulfate		Boron	Sulfate
Borax Cooling Tower (Center Cell)	3000	59	2700	0.0057	0.0053	0.231
#1 Sulfate Cooling Tower (South Cell)	3500	80	3400	0.0092	0.0129	0.548
#2 Sulfate Cooling Tower (North Cell)	3500	90	4400	0.0035	0.0055	0.270
#3 Sulfate Cooling Tower (South Cell)	3500	91	4700	0.0457	0.0789	3.765
#4 Sulfate Cooling Tower (South Cell)	9360	73	3300	0.0030	0.0103	0.464
Lime Cooling Tower	2950	33	1500	0.0011	0.00054	0.024
#11 Cooling Tower (North East Cell)	15000	1200	10000	0.0011	0.0992	0.826
#14 Cooling Tower (Center Cell)	24000	270	11000	0.0024	0.0779	3.173
Argus Cooling Tower (# 2)	30000	53	2100	0.0113	0.0900	3.565

4.2 Discussion of Results

The drift fraction calculations performed using equation 4.2 and the concentration of sodium in the cooling water samples revealed drift fractions between 0.0011 and 0.0457 percent of recirculating water flow rate.

The 0.0457 percent drift fraction for the #3 Sulfate Cooling Tower represents an unusually high rate of drift loss. This could have been caused by a physical gap between drift eliminator panels; however, no such gaps were visible to the test crew working at the exit plane of the fan stack. Another

Table 4.1a

IK Tube Number: 1K6 (Log #11-079-5)
Cooling Water Sample Number: W6 (Log #11-079-15)
Cooling Tower Name: Borax Cooling Tower (Westend Facility)

Date of Sampling: October 31, 1986
Duration: 5 minutes per point
Number of Points Sampled: 16

Chemical Analysis

Chemical Constituent	Recirculating Cooling Water (mg/L)	Redissolved IK Tube Residue (micrograms) (sample)	Pretest Blank* IK Tube (micrograms) (sample)	Procedural Blank (micrograms) (sample)	Mass Mineral Flux $\frac{\text{mgs}}{\text{m}^2 \cdot \text{s}}$
Metals					
Aluminum	<0.03	35		15	
Antimony	<0.4	<200		<200	
Arsenic	0.60	<1.5	0.5	<1.5	
Barium	0.07	5		80	
Beryllium	<0.006	<3		<3	
Boron	59	33		4.5	0.0125
Cadmium	0.02	<10		<10	
Calcium	29	380	35.8	155	0.151
Chromium Total	5.3	<15	<2.5	<15	
Chromium (Hex)	<0.02	<10		<10	
Cobalt	<0.04	<15		<15	
Copper	<0.03	<20		950	
Iron	0.04	240		140	0.0439
Lead	<0.03	<1.5 ⚠		2 ⚠	
Lithium	.71	<10		10	
Magnesium	3.1	30		20	0.0044
Manganese	0.007	1.5		2	
Mercury	<0.002	ND	<0.5	ND	
Molybdenum	<0.2	<100		<100	
Nickel	<0.06	<30		<30	
Potassium	76	<500		<500	
Selenium	1	<500		<500	
Silicon	56	200		100	
Silver	<0.01	<5		<5	
Sodium	9900	5500 ⚠	22	200 ⚠	2.403 ⚠
Strontium	2.6	3		1.5	
Thallium	<0.4	<250		<200	
Tin	<0.6	<300		<300	
Titanium	<0.006	14		22	
Vanadium	<0.22	<15		<15	
Zinc	<0.08	<40		<40	
Anions					
Chloride	13,000				
Fluoride	3.6	5		<5	
Sulfate	2,700	2,450 ⚠	<995	<500 ⚠	0.855 ⚠
Solids					
Total Dissolved Solids	$\boxed{25,000}$	20,000 ⚠		20,000 ⚠	

* Average of five (5) samples of second pre-test rinse. (IK Tube Nos.)

⚠ Indication of changed data

Table 4.1b

IK Tube Number: IK11 (Log #11-079-9)
Cooling Water Sample Number: W11 (Log #11-079-19)
Cooling Tower Name: #1 Sulfate Cooling Tower (Westend Facility)

Date of Sampling: October 31, 1986
Duration: 5 minutes per point
Number of Points Sampled: 16

Chemical Analysis

Chemical Constituent	Recirculating Cooling Water (mg/L)	Redissolved IK Tube Residue (micrograms) (sample)	Pretest Blank* IK Tube Second (micrograms) (sample)	Procedural Blank (micrograms) (sample)	Mass Mineral Flux $\frac{mg}{m^2 \cdot s}$
Metals					
Aluminum	<0.03	50		15	
Antimony	<0.4	<200		<200	
Arsenic	0.74	<1.5	0.5	<1.5	
Barium	0.07	5		80	
Beryllium	<0.006	<3		<3	
Boron	80	95		4.5	0.0397
Cadmium	0.02	<10		<10	
Calcium	16	1900	35.8	155	0.818
Chromium Total	8.5	<15	<2.5	<15	
Chromium (Hex)	<0.02	<10		<10	
Cobalt	<0.03	<15		<15	
Copper	0.16	35		950	
Iron	<0.03	2,050		140	0.838
Lead	<0.03	<1.5 ⚠		2 ⚠	
Lithium	0.93	15		10	
Magnesium	2.5	55		20	0.0154
Manganese	<0.003	9		2	
Mercury	<0.002	ND	<0.5	ND	
Molybdenum	<0.2	<100		<100	
Nickel	<0.06	<30		<30	
Potassium	120	<500		<500	
Selenium	<1	<500		<500	
Silicon	64	100		100	
Silver	<0.01	<5		<5	
Sodium	13,000	18,000 ⚠	22	200 ⚠	7.885 ⚠
Strontium	3.2	6		1.5	
Thallium	<0.4	<200		<200	
Tin	<0.6	<300		<300	
Titanium	<0.006	44.5		22	
Vanadium	0.27	<15		<15	
Zinc	<0.08	900		<40	0.377
Anions					
Chloride	19,000				
Fluoride	4.8	10		<5	
Sulfate	3,400	4,650 ⚠	<995	< 500 ⚠	1.820 ⚠
Solids					
Total Dissolved Solids	$\boxed{34,000}$	60,000 ⚠		20,000 ⚠	

* Average of five (5) samples of second pre-test rinse. (IK Tube Nos.)

⚠ Indication of changed data

Table 4.1c

IK Tube Number: IK2 (Log #11-079-2)
Cooling Water Sample Number: W2 (Log #11-079-12)
Cooling Tower Name: #2 Sulfate Cooling Tower (Westend Facility)

Date of Sampling: November 1, 1986
Duration: 5 minutes per point
Number of Points Sampled: 16

Chemical Analysis

Chemical Constituent	Recirculating Cooling Water (mg/L)	Redissolved IK Tube Residue (micrograms) (sample)	Pretest Blank* IK Tube Second (micrograms) (sample)	Procedural Blank (micrograms) (sample)	Mass Mineral Flux $\frac{mg}{m^2 \cdot s}$
Metals					
Aluminum	<0.03	45		15	
Antimony	<0.4	<200		<200	
Arsenic	1.0	<1.5	0.5	<1.5	
Barium	0.13	10		80	
Beryllium	<0.006	<3		<3	
Boron	90	49		4.5	0.0195
Cadmium	0.03	<10		<10	
Calcium	51	240	35.8	155	0.090
Chromium Total	12	<15	<2.5	<15	
Chromium (Hex)	<0.02	<10		<10	
Cobalt	<0.03	<15		<15	
Copper	<0.04	<20		950	
Iron	<0.03	900		140	0.333
Lead	<0.03	1.5 △		2 △	
Lithium	.98	335		10	
Magnesium	4.3	20		20	
Manganese	4.0	4.5		2	
Mercury	<0.002	ND	<0.5	ND	
Molybdenum	<0.2	<100		<100	
Nickel	<0.06	<30		<30	
Potassium	140	<500		<500	
Selenium	<1	<500		<500	
Silicon	50	100		100	
Silver	<0.01	<5		<5	
Sodium	16,000	8,500 △	22	200 △	3.718 △
Strontium	4.4	3		1.5	
Thallium	<0.4	<200		<200	
Tin	<0.6	<300		<300	
Titanium	<0.006006	11		22	
Vanadium	0.34	<15		<15	
Zinc	<0.08	45		<40	0.0022
Anions					
Chloride	27,000				
Fluoride	5.2	105		<5	
Sulfate	4,400	3,750 △	<995	<500 △	1.425 △
Solids					
Total Dissolved Solids	$\boxed{42,000}$	90,000 △		20,000 △	

* Average of five (5) samples of second pretest rinse. (IK Tube Nos.)

△ Indication of changed data

Table 4.1d

IK Tube Number: IK1 (Log #11-079-1)
Cooling Water Sample Number: W1 (Log #11-079-11)
Cooling Tower Name: #3 Sulfate Cooling Tower (Westend Facility)

Date of Sampling: November 1, 1986
Duration: 5 minutes per point
Number of Points Sampled: 16

Chemical Analysis

Chemical Constituent	Recirculating Cooling Water (mg/L)	Redissolved IK Tube Residue (micrograms) (sample)	Pretest Blank* IK Tube Second (micrograms) (sample)	Procedural Blank (micrograms) (sample)	Mass Mineral Flux $\frac{mg}{m^2 \cdot s}$
Metals					
Aluminum	<0.03	40		15	
Antimony	<0.4	<200		<200	
Arsenic	0.95	3.0	0.5	<1.5	
Barium	0.13	5		80	
Beryllium	<0.006	<3		<3	
Boron	91	800		4.5	0.345
Cadmium	0.03	<10		<10	
Calcium	56	480	35.8	155	0.195
Chromium Total	14	105	<2.5	<15	
Chromium (Hex)	<0.02	<10		<10	
Cobalt	<0.03	<15		<15	
Copper	<0.04	35		950	
Iron	<0.03	300		140	0.0702
Lead	<0.03	9 ⚠		2 ⚠	
Lithium	0.97	425		10	
Magnesium	6.3	60		20	0.0175
Manganese	0.014	0.35		2	
Mercury	<0.002	ND	<0.5	ND	
Molybdenum	<0.2	<100		<100	
Nickel	<0.06	<30		<30	
Potassium	130	500		<500	
Selenium	——	<500		<500	
Silicon	51	250		100	
Silver	<0.01	<5		<5	
Sodium	16,000	110,000 ⚠	22	200 ⚠	48.24 ⚠
Strontium	4.4	11.5		1.5	
Thallium	<0.4	<200		<200	
Tin	<0.6	<300		<300	
Titanium	<0.006	28		22	
Vanadium	0.35	<15		<15	
Zinc	<0.08	<40		<40	
Anions					
Chloride	25,000				
Fluoride	5.4	45		5	
Sulfate	4,700	43,000 ⚠	<955	<500 ⚠	18.64 ⚠
Solids					
Total Dissolved Solids	$\boxed{42,000}$	325,000 ⚠		20,000 ⚠	

* Average of five (5) samples of second pretest rinse. (IK Tube Nos.).

⚠ indicates change of data

Table 4.1f

IK Tube Number: 1K9 (Log #11-079-8)
Cooling Water Sample Number: W9 (Log #11-079-18)
Cooling Tower Name: #4 Sulfate Cooling Tower (Westend Facility)

Date of Sampling: November 2, 1986
Duration: 5 minutes per point
Number of Points Sampled: 15

Chemical Analysis

Chemical Constituent	Recirculating Cooling Water (mg/L)	Redissolved IK Tube Residue (micrograms) (sample)	Pretest Blank* IK Tube Second (micrograms) (sample)	Procedural Blank (micrograms) (sample)	Mass Mineral Flux gms / m² · s	lbs / hr
Metals						
Aluminum	<0.03	15		15		
Antimony	<0.4	<200		<200		
Arsenic	0.65	<1.5	0.5	<1.5		
Barium	0.09	5		80		
Beryllium	<0.006	<3		<3		
Boron	73	<2.5		<4.5		
Cadmium	<0.02	<10		<10		
Calcium	76	180	35.8	155	0.0674	
Chromium Total	32	<15	<2.5	<15		
Chromium (Hex)	41	<10		<10		
Cobalt	<0.03	15		<15		
Copper	<0.04	25		950		
Iron	<0.03	115		140		
Lead	<0.03	<1.5 ⚠		2 ⚠		
Lithium	0.8	<10		10		
Magnesium	2.5	<30		20	0.0047	
Manganese	<0.003	1.5		2		
Mercury	<0.002	ND	<0.5	ND		
Molybdenum	<0.2	<100		<100		
Nickel	<0.06	<30		<30		
Potassium	100	<500		<500		
Selenium	<1	<500		<500		
Silicon	60	100		100		
Silver	<0.01	<5		<5		
Sodium	12,000	2,600 ⚠	22	200 ⚠	1.206 ⚠	
Strontium	3.0	1.5		1.5		
Thallium	<0.4	<200		<200		
Tin	0.6	<300		<300		
Titanium	<0.006	11.5		22		
Vanadium	0.26	<15		<15		
Zinc	<0.08	<40		<40		
Anions						
Chloride	15,000					
Fluoride	4.1	<5		<5		
Sulfate	3,300	<500 ⚠	<995	<500 ⚠	0.0 ⚠	
Solids						
Total Dissolved Solids	$\boxed{32,000}$	15,000 ⚠		20,000 ⚠		

* Average of five (5) samples of second pretest rinse. (IK Tube Nos.)

⚠ Indicates change of data

Table 4.1e

IK Tube Number: JK5 (Log #11-079-4)
Cooling Water Sample Number: W5 (Log #11-079-14)
Cooling Tower Name: Lime Cooling Tower (Westend Facility)

Date of Sampling: November 2, 1986
Duration: 10 minutes per point
Number of Points Sampled: 18

Chemical Analysis

Chemical Constituent	Recirculating Cooling Water (mg/L)	Redissolved IK Tube Residue (micrograms) (sample)	Pretest Blank* IK Tube Seconds (micrograms) (sample)	Procedural Blank (micrograms) (sample)	Mass Mineral Flux $\frac{mg}{m^2 \cdot s}$
Metals					
Aluminum	<0.03	25		15	
Antimony	<0.4	<200		<200	
Arsenic	0.58	1.5	0.5	<1.5	
Barium	0.04	5		80	
Beryllium	<0.006	<3		<3	
Boron	33	<2.5		4.5	
Cadmium	<0.02	<10		<10	
Calcium	39	600	35.8	155	0.117
Chromium Total	<0.03	<0.3	<2.5	<15	
Chromium (Hex)	<0.02	<10		<10	
Cobalt	<0.03	<0.3		<15	
Copper	<0.04	<0.4		950	
Iron	<0.03	6.9		140	
Lead	<0.03	2 △		2 △	
Lithium	0.49	25		10	
Magnesium	1.5	200		20	0.0373
Manganese	<0.003	<2		2	
Mercury	<0.002	ND	<0.5	ND	
Molybdenum	<0.2	<100		<100	
Nickel	<0.06	<30		<30	
Potassium	56	<500		<500	
Selenium	<1	<500		<500	
Silicon	33	200		100	
Silver	<0.01	<5		<5	
Sodium	4,400	3,300 △	22	200 △	1.438 △
Strontium	1.1	1.5		1.5	
Thallium	<0.4	<200		<200	
Tin	<0.6	<300		<300	
Titanium	<0.006	22.5		22	
Vanadium	2.8	<15		<15	
Zinc	<0.08	<40		<40	
Anions					
Chloride	6,100				
Fluoride	2.0	5.0		<5	
Sulfate	1,500	700 △	<995	<500 △	0.041 △
Solids					
Total Dissolved Solids	$\boxed{13,000}$	375,000 △		20,000 △	

* Average of five (5) samples of second pretest rinse. (IK Tube Nos.)

△ indicates change of data

Table 4.1g

IK Tube Number: IK8 (Log #11-079-7)
Cooling Water Sample Number: W8 (Log #11-079-17)
Cooling Tower Name: #11 Cooling Tower (Trona Facility)

Date of Sampling: November 3, 1986
Duration: 5 minutes per point
Number of Points Sampled: 16

Chemical Analysis

Chemical Constituent	Recirculating Cooling Water (mg/L)	Redissolved IK Tube Residue (micrograms) (sample)	Pretest Blank* IK Tube Second (micrograms) (sample)	Procedural Blank (micrograms) (sample)	Mass Mineral Flux $\frac{\text{gms}}{m^2 \cdot s}$
Metals					
Aluminum	<0.03	30		15	
Antimony	<0.4	<200		<200	—
Arsenic	18	5	0.5	<1.5	
Barium	0.04	5		80	
Beryllium	<0.006	3		<3	
Boron	1200	460		4.5	0.200
Cadmium	0.45	<10		<10	
Calcium	7.6	145	35.8	155	0.048
Chromium Total	<0.03	<15	<2.5	<15	
Chromium (Hex)	<0.02	<10		<10	
Cobalt	<0.03	<15		<15	
Copper	<0.04	<20		950	
Iron	0.27	335		140	0.0855
Lead	<0.03	2 ⚠		2 ⚠	
Lithium	3.2	10		10	
Magnesium	5.2	45		20	0.0110
Manganese	0.0016	3		2	
Mercury	<0.002	ND	<0.5	ND	
Molybdenum	<0.2	<100		<100	
Nickel	<0.06	<30		<30	
Potassium	2100	3000		<500	
Selenium	<1	<500		<500	
Silicon	8.6	150		100	
Silver	<0.01	<5		<5	
Sodium	11,000	4500 ⚠	22	200 ⚠	1.964 ⚠
Strontium	2.2	3		1.5	
Thallium	<0.4	<200		<200	
Tin	<0.6	<300		<300	
Titanium	<0.006	26		22	
Vanadium	<0.03	<15		<15	
Zinc	<0.08	<40		<40	
Anions					
Chloride	21,000				
Fluoride	4.6	<5		<5	
Sulfate	10,000	5000 ⚠	<995	<500 ⚠	1.974 ⚠
Solids					
Total Dissolved Solids	$\boxed{60,000}$	44,000 ⚠		20,000 ⚠	

* Average of five (5) samples of second pretest Rinse. (IK Tube Nos.)

⚠ indicates change of data

Table 4.1h

IK Tube Number: IK7 (Log #11-079-6)
Cooling Water Sample Number: W7 (Log #11-079-16)
Cooling Tower Name: #14 Cooling Tower (Trona Facility)

Date of Sampling: November 3, 1986
Duration: 5 minutes per point
Number of Points Sampled: 18

Chemical Analysis

Chemical Constituent	Recirculating Cooling Water (mg/L)	Redissolved IK Tube Residue (micrograms) (sample)	Pretest Blank* IK Tube Second (micrograms) (sample)	Procedural Blank (micrograms) (sample)	Mass Mineral Flux $\frac{\text{[illegible]}}{m^2 \cdot s}$
Metals					
Aluminum	<0.03	75		15	
Antimony	<0.4	<200		<200	
Arsenic	11	4	0.5	<1.5	
Barium	0.02	20		80	
Beryllium	<0.006	<3		<3	
Boron	270	140		4.5	0.0528
Cadmium	0.29	<10		<10	
Calcium	3.2	135	35.8	155	0.039
Chromium Total	<0.04	<15	<2.5	<15	
Chromium (Hex)	<0.02	<10		<10	
Cobalt	<0.03	<15		<15	
Copper	<0.04	<20		950	
Iron	0.22	2,250		140	0.823
Lead	<0.03	2 ⚠		2 ⚠	
Lithium	4.0	15		10	
Magnesium	7.7	30		20	0.0039
Manganese	0.016	10.5		2	
Mercury	<0.002	ND	<0.5	ND	
Molybdenum	<0.2	<100		<100	
Nickel	<0.06	<30		<30	
Potassium	570	<500		<500	
Selenium	<1	<500		<500	
Silicon	9.1	100		100	
Silver	<0.01	<5		<5	
Sodium	19,000	9,000 ⚠	22	200 ⚠	3.500 ⚠
Strontium	2.4	3		1.5	
Thallium	<0.4	<200		<200	
Tin	<0.6	<300		<300	
Titanium	<0.006	17		22	
Vanadium	<0.03	<15		<15	
Zinc	<0.08	<40		<40	
Anions					
Chloride	26,000				
Fluoride	6.5	5		<5	
Sulfate	11,000	5,000 ⚠	<995	<500 ⚠	1.754 ⚠
Solids					
Total Dissolved Solids	$\boxed{57,000}$	38,000 ⚠		20,000 ⚠	

* Average of five (5) samples of second pretest Rinse. (IK Tube Nos.)

⚠ indicates change of data

Table 4.11

IK Tube Number: IK4 (Log #11-079-3)
Cooling Water Sample Number: W4 (Log #11-079-13)
Cooling Tower Name: Argus Cooling Tower (Argus Facility)

Date of Sampling: November 4, 1986
Duration: 5 minutes per point
Number of Points Sampled: 16

Chemical Analysis

Chemical Constituent	Recirculating Cooling Water (mg/L)	Redissolved IK Tube Residue (micrograms) (sample)	Pretest Blank* IK Tube Second (micrograms) (sample)	Procedural Blank (micrograms) (sample)	Mass Mineral Flux $\frac{ppm -}{m^2 \cdot s}$
Metals					
Aluminum	<0.03	30		15	
Antimony	<0.4	<200		<200	
Arsenic	0.56	1.5	0.5	<1.5	
Barium	0.08	5		80	
Beryllium	<0.006	<3		<3	
Boron	53	210		4.5	0.090
Cadmium	<0.02	<10		<10	
Calcium	14	205	35.8	155	0.074
Chromium Total	11	25	<2.5	<15	
Chromium (Hex)	14	<10		<10	
Cobalt	<0.03	<15		<15	
Copper	<0.04	120		950	
Iron	<0.03	295		140	0.0680
Lead	<0.03	6 ⚠		2 ⚠	
Lithium	1.0	<10		10	
Magnesium	2.2	100		20	0.0351
Manganese	<0.003	2.5		2	
Mercury	<0.002	ND	<0.5	ND	
Molybdenum	<0.2	<100		<100	
Nickel	<0.06	<30		<30	
Potassium	65	<500		<500	
Selenium	<1	<500		<500	
Silicon	60	200		100	
Silver	<0.01	<5		<5	
Sodium	8,200	24,500 ⚠	22	200 ⚠	10.736 ⚠
Strontium	2.7	7.5		1.5	
Thallium	<0.4	<200		<200	
Tin	<0.6	<300		<300	
Titanium	<0.006	17		22	
Vanadium	0.20	<15		<15	
Zinc	<0.08	<40		<40	
Anions					
Chloride	12,000				
Fluoride	3.3	15		<5	
Sulfate	2,100	7,000 ⚠	<995	<500 ⚠	2.851 ⚠
Solids					
Total Dissolved Solids	$\boxed{22,000}$	90,000 ⚠		20,000 ⚠	

* Average of five (5) samples of second pretest Rinse. (IK Tube Nos.)

⚠ indicates change of data

ESC

PROJECT Kerr McGee Chemical Corp.
SUBJECT Calculation of Mass [illegible]
Flux
BY BRC DATE 11/25/95 PAGE 2 OF 10

IK Tube #6 (Borax Cooling Tower)
use Procedural Blank (except for Na, Ca, SO4 use Average Pretest Blank)
Fan Stack Area = 158.1 ft² = 14.69 m²
Sampling time 16 pts × 5 min/pt = 80 minutes.
Sample tube Area = 4.750x10⁻⁴ m²

$$\frac{X_{IK} - X_{BK}}{4.750\times10^{-4}\,m^2 \cdot 4800\,sec} \cdot \frac{1\,mgm}{1000\,\mu gms} = \frac{X_{IK} - X_{BK}}{2280} = \frac{mgms}{m^2 \cdot sec}$$

⚠ Sodium $\frac{5500 - 22}{2280} = \boxed{\frac{2.403\,mgm}{m^2 \cdot S}} \times \frac{.7376}{1000} \times \frac{158.1\,ft^2}{stack} \times 3\,stacks = \boxed{0.841\,\frac{lbs}{hr}}$ Na

Calcium $\frac{380 - 35.8}{2280} = \boxed{\frac{0.151\,mgm}{m^2 \cdot S}} \times \frac{.7376 \times 158.1 \times 3}{1000} = \boxed{0.053\,\frac{lbs}{hr}}$ Ca

⚠ Sulfate $\frac{2450 - 500}{2280} = \boxed{\frac{0.855\,mgm}{m^2 \cdot S}} \times \frac{.7376 \times 158.1 \times 3}{1000} = \boxed{0.299\,\frac{lbs}{hr}}$ SO4

Magnesium $\frac{30 - 20}{2280} = \boxed{\frac{.0044\,mgm}{m^2 \cdot S}} \times \frac{.7376 \times 158.1 \times 3}{1000} = \boxed{0.0015\,\frac{lbs}{hr}}$ Mg

Potassium — — —

Iron $\frac{240 - 140}{2280} = \boxed{\frac{.0439\,mgm}{m^2 \cdot S}} \times \frac{.7376 \times 158.1 \times 3}{1000} = \boxed{0.015\,\frac{lbs}{hr}}$ Fe

Boron $\frac{33 - 4.5}{2280} = \boxed{\frac{.0125\,mgm}{m^2 \cdot S}} \times \frac{.7376 \times 158.1 \times 3}{1000} = \boxed{0.004\,\frac{lbs}{hr}}$ B

ESC

PROJECT Kerr McGee Chemical Corporation
SUBJECT Determination of Drift Fraction
Based on Sodium
BY BRC DATE 11/26/86 PAGE 2 OF 2

I K Tube	Tower	F GPM	△1 W mg Na / $m^2 \cdot s$	X m^2 / Stack	Y Stacks / Tower	Z mg Na / Liter	△1 % Drift
6	Borax	3000	2.403	14.69	3	9900	0.0057
11	#1 Sulfate	3500	7.885	16.70	2	13000	0.0092
2	#2 Sulfate	3500	3.718	16.75	2	16000	0.0035
1	#3 Sulfate	3500	48.24	16.75	2	16000	0.0457
5	Lime	2950	1.438	16.98	1	4400	0.0030
9	#4 Sulfate	9360	1.206	32.70	2	12000	0.0011
8	#11 Tower	15000	1.964	20.28	3	11000	0.0011
7	#14 Tower	24000	3.500	48.40	4	19000	0.0024
4	Argus	30000	10.736	40.88	4	8200	0.0113

APPENDIX K

EMISSION FACTOR CALCULATIONS AND REPORT EXCERPTS FOR REFERENCE NO. 28

(see Section 4.2.11 of text)

CALCULATION SHEET
MRI Project 8987-35

Reference No. 28 Type of Facility: Refinery
(e.g., power plant)

Location of Facility: Not specified Test Date 12/84

Type of Cooling Tower (circle one): [✓ Wet Tower;] Dry Tower; Wet-Dry; Not Specified

Type of Draft (circle one): [✓ Mechanical Draft;] Natural Draft; Fan-Assist Natural Draft; Atmospheric; Not Specified

Fan Configuration (circle one as applicable): Forced Draft; [✓ Induced Draft;] Not Specified

Heat Transfer Configuration (circle one as applicable): Counterflow; [✓ Crossflow;] Spray; Not Specified

Type of Heat Transfer Media (circle one as applicable): [✓ Splash;] Film; Not Specified

Type of Fill (specify): Doron V-bar filled

Type of Hot Water Distribution System (circle one as applicable): Pressure System; Gravity System; [✓ Not Specified]

Water Flow Configuration (circle one as applicable): [✓ Recirculating;] Once-Through; Not Specified

Type of Mist Eliminator (specify): Not specified

EMISSION RATE CALCULATIONS:

Measurement Method Used:
- Spike of basin water with NaBr tracer
- Isokinetic flow sampling of stack exhaust with impinger train
- Neutron Activation Analysis

3/8/90 ③
MAG

From Appendix A, pA-4 of Report ㉘

```
Init. Vol= 499.523
Fin. Vol= 654.727
M Factor= 1.018
Leak Check= .003
Baro. P= 29.79
Static P= .22
% O2= 20.9
% CO2= 0
% H20= 2
Cp= .84
Time= 219.433
Nozzle D= .25
Net Vol= 155.204
Dry St V= 155.423
Std Vol(M^3)= 4.40095
H2O>Sat
% H2O(Est.)= 1.94921
Stack P= 29.8062
Ave M T= 76.4125
Ave sqr Dp= .582512
Ave Dp= .339322
Ave Dh= 1.6765
Ave St T= 63.05
Stack Vel= 1964.93
[redacted]
Dry MW= 28.836
Excess Air=-118743
Wet MW= 28.6248
GR/DSF Factor=
 9.90847E-02
Factor(7%O2)= 13.8718
AXIS 1= 336.58
AXIS 2= 336.58
CIRCULAR STACK
ACFM= 1.21409E+06
WSCFM= 1.22092E+06
DSCFM= 1.19712E+06
```

```
Init. Vol= 499.523
Fin. Vol= 654.727
M Factor= 1.018
Leak Check= .003
Baro. P= 29.79
Static P= .22
% O2= 20.9
% CO2= 0
% H20= 2
Cp= .84
Time= 219.433
Nozzle D= .25
Net Vol= 155.204
Dry St V= 155.423
Std Vol(M^3)= 4.40095
H2O>Sat
% H2O(Est.)= 1.94921
Stack P= 29.8062
Ave M T= 76.4125
Ave sqr Dp= .629541
Ave Dp= .396222
Ave Dh= 1.6765
Ave St T= 63.05
[redacted]
% Iso= 99.2353
Dry MW= 28.836
Excess Air=-118743
Wet MW= 28.6248
GR/DSF Factor=
 9.90847E-02
Factor(7%O2)= 13.8718
AXIS 1= 336.58
AXIS 2= 336.58
CIRCULAR STACK
[redacted]
```

As shown above:

Actual sampling time (min) = 219.4
Nozzle diameter (in) = 0.25
Sample volume (dscf) = 155.4
Total cell air flow rate (dscfm) = 1,197,120
Four cells x 4
Total stack flow rate (dscfm) = 4,788,480

Equivalent sampling time (min) = 40 periods x 6 min = 240

3/8/90 ④
M.Fes

From Appendix A, p A-5 of Report ㉘

19	961			5-		5½	
20	987			2¾		3-	

RDG NO	TIME	σ
A		
B		
C		

Q gpm = $\sqrt{\sigma}$ (1040 × C × A) = $\sqrt{\sigma}$ (______)

BASIS AIR-WATER MANOMETER

TOTAL	61.287	TOTAL	57.901	TOTAL		TOTAL
AVG	3.0643	AVG	2.8951	AVG		AVG
TRAVERSE AVG $\sqrt{\sigma}$			2.9797	TRAVERSE AVG $\sqrt{\sigma}$		

US GPM 7492

US GPM ______

15100 Both Risers

* CALCULATED VALUE DECREASED BY DISTANCE FROM END OF PITOT TUBE TO CENTER LINE OF IMPACT HOLE

A-5

CTI FORM ATC-106 E

Waterflow rate for 2 cells (GPM) = 15,100
× 2
Tower waterflow rate (GPM) = 30,200

From Appendix A, p. A-6 of Report ㉘

Drift sample analysis

Triplicate analysis

Requestor ID	Description	Conc. Br	Avg (ppm)
100 A	Basin H_2O Before	29.4 ppm	
100 B		29.8	29.9
100 C		30.6	
101 A	Basin H_2O After	19.6 ppm	
101 B		26.2	23.0
101 C		23.2	

3/8/90
MAB

From p. A-6 of Report (28) Drift Sample Analysis (cont)

Requestor ID	Description	Conc. Br	Avg
102 A	Impinger Contents	0.037 ppm	
102 B		0.038	0,0357
102 C		0.032	
103	Filter	0.042 µg Br	
104 A	H_2O Rinse	0.029 ppm	
104 B		0.033	0.0307
104 C		0.030	
105 A	Acid Rinse	0.011 ppm	
105 B		0.007	0,0087
105 C		0.008	
106 A	H_2O Blank	0.008 ppm	
106 B		0.006	0.0080
106 C		0.010	
107 A	Acid Blank	0.008 ppm	
107 B		0.012	0.011
107 C		0.013	
108 A	Filter Blank	0.008 µg Br	0.009
108 B		0.010	

From p. 6 of Report (28) SAMPLE ANALYSIS RESULTS

Sample No.	Description	Sample Vol. (mL)	Sample Concentration (µg/mL)	Total Br (µg)
100	Basin water before test	-	29.933	-
101	Basin water after test	-	23.000	-
102	Impinger cont.	182	0.036	6.552
103	Filter	-	-	0.042
104	Water rinse	205	0.031	6.355
105	Acid rinse	107	0.009	0.963
106	Water blank	-	0.006	- 2.32
107	Acid blank	-	0.011	- 1.18
108	Filter blank	-	-	0.009

All samples, except the filters, are run in triplicate. The average of the three values is recorded in Table 1 and was used in the calculation.

From p. B-2 of Report ㉘

⑥

COMPLETE CALCULATIONS

This appendix provides the calculations for this test, complete with all correction factors applied. All numbers have been rounded to three significant figures. The data used was taken from Tables 1 and 2 in the report.

The total weight of Br in the sample train (Br_T) is the sum of the Br found in the impinger content (Br_I), the water rinse (Br_W), the acid rinse (Br_A), and on the filter (Br_F).

$$Br_T = Br_I + Br_W + Br_A + Br_F$$

$$= 6.55 + 6.36 + 0.96 + 0.04 = 13.91 \ \mu g \ Br$$

Corrections (B_T) for the acid blank (A_B) and the water blank (W_B) must be applied to the weight of bromine collected in the sample train. In this test, 182 mL and 205 mL of water were used in the impingers and water rinse, respectively. For the acid rinse 107 mL was used. A blank filter (F_B) was also analyzed.

$$(B_T) = (A_B) + (W_B) + (F_B)$$

$$= 1.18 + 2.32 + 0.01 = 3.51 \ \mu g \ Br$$

The net corrected weight of bromine in the sample train due to drift (Br_C) is:

$$(Br_C) = (Br_T) - (B_T)$$

$$= 13.91 - 3.51 = 10.4 \ \mu g \ Br$$

After obtaining the corrected Br weight (Br_C) for the sample train, the concentration of Br (in μg/dscf) in the stack air is calculated from the sample volume, V_S:

$$\text{Conc. Br in stack} = \frac{Br_C}{V_S} = \frac{10.4 \ \mu g \ Br}{155.4 \ dscf}$$

$$= 0.067 \ \mu g \ Br/dscf$$

Since the total stack flow rate was measured as 4,788,480 dscfm, the total Br emissions from the stack (Br_S) is calculated by:

$$\text{Total Br from stack} = 4{,}788{,}480 \ dscfm \times \frac{0.067 \ \mu g \ Br}{dscfm}$$

$$= 320{,}828 \ \mu g \ Br/min$$

From p. B-3 of Report ㉘

⑦

The volume of basin water, W_V, required to deliver 320,828 µg of Br is calculated by:

$$W_V = \frac{\text{Total Br from stack}}{\text{Conc. Br in basin}}$$

$$= \frac{320{,}828\ \mu g\ Br/min}{26.5\ \mu g\ Br/mL} = 12{,}107\ mL/min$$

Converting to gallons per minute gives:

$$gpm = \frac{12{,}107\ mL/min}{3{,}784\ mL/gal.} = 3.2\ gpm$$

or 192 gal/hr.

The percent drift, % D, can now be calculated according to the equation:

$$\%\ D = \frac{\text{Vol. basin water from stack } (W_V)}{\text{Total water vol. through basin}} \times 100$$

$$= \frac{3.2\ gpm}{30{,}200\ gpm} \times 100 = 0.01\%$$

NFA - Net fan area (ft²)

Fan stack diameter = 350 in
Fan hub diameter = 96 in

$$\pi\left(\frac{350\,in \times \frac{ft}{12\,in}}{2}\right)^2 - \pi\left(\frac{96\,in \times \frac{ft}{12\,in}}{2}\right)^2$$

$$= 617.9\ ft^2$$

NWT - Net weight of tracer (μg)

10.4 μg Br

NZA - Nozzle area (ft²)

$$\pi\left(\frac{0.25\,in \times \frac{ft}{12\,in}}{2}\right)^2 = 0.000341\ ft^2$$

WFR - Waterflow rate (g/min)

$$7550\ gal/min \times \frac{3785g}{gal} = 28{,}576{,}750\ g/min$$

EQT - Equivalent sample time (min)

240 min

BTC - Basin Tracer Concentration (mcg/g)

26.5 μg Br/ml = 26.5 mcg/g

To check calculations:

% Drift = 100 * (NFA * NWT) / (NZA * WFR * EQT * BTC)

NFA = Net Fan Area (square feet)
NWT = Net Weight of Tracer (mcg)
NZA = Nozzle Area (square feet)
WFR = Waterflow Rate (grams per minute)
EQT = Equivalent Sample Time (minutes)
BTC = Basin Tracer Concentration (mcg/g)

$$\% \text{ Drift} = 100 \times \frac{617.9 * 10.4}{0.000341 \times 28{,}576{,}750 \times .240 \times 26.47}$$

$$= 0.0104$$

Or @ STP

$$\text{E.F.} = \frac{0.0104}{100} \cdot \frac{\text{gal drift}}{\text{gal } H_2O \text{ flow}} \times \frac{8.312 \text{ lbs. drift}}{\text{gal drift}}$$

$$= 8.64 \times 10^{-4} \frac{\text{lbs drift}}{\text{gal } H_2O \text{ flow}}$$

Data Rating: A

COOLING TOWER INSTITUTE TEST REPORT

DRIFT TEST

4-CELL
MECHANICAL-DRAFT CROSS-FLOW COOLING TOWER

I. INTRODUCTION

The testing services of the CTI were retained by Inc., under Contract to conduct a drift test on a 4-cell mechanical-draft, cross-flow cooling tower located at the Refinery. The work was performed by MRI under contract with CTI as the official CTI test representative. The CTI test representatives were Mr. Thomas E. Weast and Mr. George R. Cobb. The which was contracted to repair and upgrade the tower, was represented by The plant was represented by

Cooling tower drift is defined as the percent of water flow through the tower which exits through the fan in the form of water droplets or aerosols. The amount of drift from the tower was determined by isokinetically sampling a representative fraction of the tower airflow and measuring the amount of aerosol leaving the stack. Sodium bromide (NaBr) was spiked into the basin as a tracer for the analysis. Neutron activation analysis (NAA), an extremely sensitive detection technique, was then used to measure the amount of bromine exiting from the stack. From measurement of the total bromine collected in the sampler and the concentration of bromine in the basin water, the drift rate can be calculated.

II. TEST SITE DESCRIPTION

The is located in Cooling tower serves several refinery processes. The 4-cell evaporative cooling tower was a conventional splash bar filled, cross-flow design built approximately 10 years ago. During the rebuilding, it was equipped with Doron V-bar fill and new fan drives.

Water was supplied to the tower by two 24-in. nominal diameter risers. Pitot taps were installed in the vertical section of the riser at approximately 40 ft above grade. The cold water from the tower normally passes through several pumps to the plant processes; however, on the day of the test only one pump was in operation due to the low heat load available. Two cells of the tower were used at the beginning of the test, but an increase in heat load during the test required the use of a third cell. Even though total flow to the tower was increased, flow to each cell was kept constant.

TABLE 1

SAMPLE ANALYSIS RESULTS

Sample No.	Description	Sample Vol. (mL)	Sample Concentration (μg/mL)	Total Br (μg)
100	Basin water before test	-	29.933	-
101	Basin water after test	-	23.000	-
102	Impinger cont.	182	0.036	6.552
103	Filter	-	-	0.042
104	Water rinse	205	0.031	6.355
105	Acid rinse	107	0.009	0.963
106	Water blank	-	0.006	-
107	Acid blank	-	0.011	-
108	Filter blank	-	-	0.009

All samples, except the filters, are run in triplicate. The average of the three values is recorded in Table 1 and was used in the calculation.

V. CALCULATION PROCEDURE AND RESULTS

Since the calculation of correction factors needed to determine the drift rate are relatively complex, the calculation procedure without indicating the corrections is presented in this section. The purpose is to provide a clear picture to the principles underlying the calculation of the drift rate. The actual calculations with all the correction factors have been provided in Appendix B. The sampling data used in the calculations are shown in Table 2.

TABLE 2

SAMPLING DATA

Description	
Corrected total Br in sample	10.4 μg[a]
Sample volume	155.4 dscf
Stack air flow rate	4,788,480 dscfm[b]
Basin water Br concentration	26.5 μg/mL
Water flow rate through the tower	30,200 gpm[c]

---

[a] See calculations in Appendix B.

[b] Includes all fans.

[c] Based on 7,550 gpm per cell.

```
Init. Vol= 499.523
Fin. Vol= 654.727
M Factor= 1.018
Leak Check= .003
Baro. P= 29.79
Static P= .22
% O2= 20.9
% CO2= 0
% H20= 3
Cp= .84
Time= 219.433
Nozzle D= .25
Net Vol= 155.204
Dry St V= 155.423
Std Vol(M^3)= 4.40095
H2O>Sat
% H2O(Est.)= 1.94981
Stack P= 29.8062
Ave M T= 76.4125
Ave sqr Dp= .582512
Ave Dp= .33932
Ave Dh= 1.6765
Ave St T= 63.05
Stack Vel= 1964.93
[redacted]
Dry MW= 28.836
Excess Air=-118743
Wet MW= 28.6248
GR/DSF Factor=
 9.90847E-02
Factor(7%O2)= 13.8718
AXIS 1= 336.58
AXIS 2= 336.58
CIRCULAR STACK
ACFM= 1.21409E+06
WSCFM= 1.22092E+06
DSCFM= 1.19712E+06
```

```
Init. Vol= 499.523
Fin. Vol= 654.727
M Factor= 1.018
Leak Check= .003
Baro. P= 29.79
Static P= .22
% O2= 20.9
% CO2= 0
% H20= 3
Cp= .84
Time= 219.433
Nozzle D= .25
Net Vol= 155.204
Dry St V= 155.423
Std Vol(M^3)= 4.40095
H2O>Sat
% H2O(Est.)= 1.94981
Stack P= 29.8062
Ave M T= 76.4125
Ave sqr Dp= .629541
Ave Dp= .396322
Ave Dh= 1.6765
Ave St T= 63.05
[redacted]
% Iso= 99.2353
Dry MW= 28.836
Excess Air=-118743
Wet MW= 28.6248
GR/DSF Factor=
 9.90847E-02
Factor(7%O2)= 13.8718
AXIS 1= 336.58
AXIS 2= 336.58
CIRCULAR STACK
[redacted]
```

USE WITH CTI
EST CODE ATC-105

COOLING TOWER INSTITUTE
ACCEPTANCE TEST PROCEDURE
DATA SHEET "E"
WATER FLOW MEASUREMENT
PITOT TUBE

FILE NO ____________

TEST DATE ____________

PITOT TUBE MAKE, MODEL	SERIAL NO	PIPE SIZE, INCHES NOM = ID =
DATE CALIBR	TUBE COEFFICIENT C =	AREA = .00545 ID², SQ FT A =

West

PIPE ID			IN	LOCATION		STA DESC N 23½		TIME W 23½		STA DESC		TIME	
RDG NO	DIA X	RDG NO	DIA X	DECIMAL INCHES CALCULATED	CORRECTED*	d, in	√d	d, in	√d	d, in	√d	d, in	√d
18 IN. DIAM AND OVER		UNDER 18 IN DIAM											
1	013					7 7/8		6 7/8					
2	039					9 1/8		7 3/8					
3	067					10 3/8		7 7/8					
4	097					10 3/4		8 3/4					
5	129					11 5/8		8 7/8					
6	165	1	026			13-		9 3/8					
7	204	2	082			13 1/2		10 1/4					
8	250	3	146			13 3/8		10 5/8					
9	306	4	226			12 3/4		11-					
10	388	5	342			12-		11-					
11	612	6	658			12-		10 3/4					
12	694	7	774			11-		10 3/4					
13	750	8	854			10 1/4		10-					
14	796	9	918			9 5/8		9 5/8					
15	835	10	974			8 1/2		8 1/2					
16	871					7 1/2		7 1/2					
17	903					6 5/8		7 1/8					
18	933					5 5/8		6-					
19	961					5-		5 1/2					
20	987					2 3/4		3-					

TOTAL √d	61.287	TOTAL	57.901	TOTAL		TOTAL	
AVG	3.0643	AVG	2.8951	AVG		AVG	
TRAVERSE AVG √d			2.9797	TRAVERSE AVG √d			
US GPM 7492				US GPM			

15100 Both Risers

RDG NO	TIME	d
A		
B		
C		

$Q\ \text{gpm} = \sqrt{d}\,(1040 \times C \times A) = \sqrt{d}\,(\_\_\_\_\_\_)$

BASIS AIR/WATER MANOMETER

* CALCULATED VALUE DECREASED BY DISTANCE FROM END OF PITOT TUBE TO CENTER LINE OF IMPACT HOLE

CTI FORM ATC-105 **E** ________

UNIVERSITY OF MISSOURI

Research Reactor Facility

Research Park
Columbia, Missouri 65211
Telephone (314) 882-4211

January 11, 1985

Dr. Dick Cobb
Midwest Research Institute
425 Volker Boulevard
Kansas City, MO 64110

Dear Dr. Cobb:

Enclosed, please find the results from the analysis of your samples submitted on 20-Dec-84.

Requestor ID	Description	Conc. Br
100 A	Basin H_2O Before	29.4 ppm
100 B		29.8
100 C		30.6
101 A	Basin H_2O After	19.6 ppm
101 B		26.2
101 C		23.2
102 A	Impinger Contents	0.037 ppm
102 B		0.038
102 C		0.032
103	Filter	0.042 µg Br
104 A	H_2O Rinse	0.029 ppm
104 B		0.033
104 C		0.030
105 A	Acid Rinse	0.011 ppm
105 B		0.007
105 C		0.008
106 A	H_2O Blank	0.008 ppm
106 B		0.006
106 C		0.010
107 A	Acid Blank	0.008 ppm
107 B		0.012
107 C		0.013
108 A	Filter Blank	0.008 µg Br
108 B		0.010

COMPLETE CALCULATIONS

This appendix provides the calculations for this test, complete with all correction factors applied. All numbers have been rounded to three significant figures. The data used was taken from Tables 1 and 2 in the report.

The total weight of Br in the sample train (Br_T) is the sum of the Br found in the impinger content (Br_I), the water rinse (Br_W), the acid rinse (Br_A), and on the filter (Br_F).

$$Br_T = Br_I + Br_W + Br_A + Br_F$$

$$= 6.55 + 6.36 + 0.96 + 0.04 = 13.91 \ \mu g \ Br$$

Corrections (B_T) for the acid blank (A_B) and the water blank (W_B) must be applied to the weight of bromine collected in the sample train. In this test, 182 mL and 205 mL of water were used in the impingers and water rinse, respectively. For the acid rinse 107 mL was used. A blank filter (F_B) was also analyzed.

$$(B_T) = (A_B) + (W_B) + (F_B)$$

$$= 1.18 + 2.32 + 0.01 = 3.51 \ \mu g \ Br$$

The net corrected weight of bromine in the sample train due to drift (Br_C) is:

$$(Br_C) = (Br_T) - (B_T)$$

$$= 13.91 - 3.51 = 10.4 \ \mu g \ Br$$

After obtaining the corrected Br weight (Br_C) for the sample train, the concentration of Br (in µg/dscf) in the stack air is calculated from the sample volume, V_S:

$$\text{Conc. Br in stack} = \frac{Br_C}{V_S} = \frac{10.4 \ \mu g \ Br}{155.4 \ dscf}$$

$$= 0.067 \ \mu g \ Br/dscf$$

Since the total stack flow rate was measured as 4,788,480 dscfm, the total Br emissions from the stack (Br_S) is calculated by:

$$\text{Total Br from stack} = 4{,}788{,}480 \ dscfm \times \frac{0.067 \ \mu g \ Br}{dscfm}$$

$$= 320{,}828 \ \mu g \ Br/min$$

The volume of basin water, W_V, required to deliver 320,828 μg of Br is calculated by:

$$\dot{W}_V = \frac{\text{Total Br from stack}}{\text{Conc. Br in basin}}$$

$$= \frac{320{,}828\ \mu\text{g Br/min}}{26.5\ \mu\text{g Br/mL}} = 12{,}107\ \text{mL/min}$$

Converting to gallons per minute gives:

$$\text{gpm} = \frac{12{,}107\ \text{mL/min}}{3{,}784\ \text{mL/gal.}} = 3.2\ \text{gpm}$$

or 192 gal/hr.

The percent drift, % D, can now be calculated according to the equation:

$$\%\ D = \frac{\text{Vol. basin water from stack } (W_V)}{\text{Total water vol. through basin}} \times 100$$

$$= \frac{3.2\ \text{gpm}}{30{,}200\ \text{gpm}} \times 100 = 0.01\%$$

APPENDIX L

EMISSION FACTOR CALCULATIONS AND REPORT EXCERPTS FOR REFERENCE NO. 29

(see Section 4.2.12 of text)

CALCULATION SHEET
MRI Project 8987-35

Reference No. 29 Type of Facility: Refinery
(e.g., power plant)

Location of Facility: Not specified Test Date 8/84

Type of Cooling Tower (circle one): [✓ Wet Tower;] Dry Tower; Wet-Dry; Not Specified

Type of Draft (circle one): [✓ Mechanical Draft;] Natural Draft; Fan-Assist Natural Draft; Atmospheric; Not Specified

Fan Configuration (circle one as applicable): Forced Draft; [✓ Induced Draft;] Not Specified

Heat Transfer Configuration (circle one as applicable): Counterflow; [✓ Crossflow;] Spray; Not Specified

Type of Heat Transfer Media (circle one as applicable): [✓ Splash;] Film; Not Specified

Type of Fill (specify): Not specified

Type of Hot Water Distribution System (circle one as applicable): Pressure System; Gravity System; [✓ Not Specified]

Water Flow Configuration (circle one as applicable): Recirculating; Once-Through; [✓ Not Specified]

Type of Mist Eliminator (specify): Not specified

EMISSION RATE CALCULATIONS:

Measurement Method Used:
- Spike of basin water with NaBr tracer
- Isokinetic flow sampling of stack exhaust with impinger train
- Neutron Activation Analysis

3/23/90
MAG

③

From Appendix A, p A-4 of Report (29)

```
Init. Vol= 152.9
Fin. Vol= 242.443
M Factor= 1.018
Leak Check= 0
Baro. P= 29.03
Static P= .2
% O2= 20.9
% CO2= 0
% H2O= 4
Cp= .84
Time= 139.1
Nozzle D= .252
Net Vol= 89.543
Dry St V= 86.1889
Std Vol(M^3)= 2.44053
H2O>Sat
% H2O(Sat.)= 3.4341
Stack P= 29.0447
Ave M T= 83.2375
Ave sqr Dp= .414112
Ave Dp= .171489
Ave Dh= 1.19325
Ave St T= 78.95
Stack Vel= 1440.48
% Iso= 100.035
Dry MW= 28.836
Excess Air=-118743
Wet MW= 28.4639
GR/DSF Factor= .178677
Factor(7%O2)= 25.0147
AXIS 1= 378
AXIS 2= 378
CIRCULAR STACK
ACFM= 1.12253E+06
WSCFM= 1.0676E+06
DSCFM= 1.03094E+06
```

As shown above:

Actual sampling time (min) = 139.1
Nozzle diameter (in) = 0.252
Sample volume (dscf) = 86.1889
Total cell airflow rate (dscfm) = 1,030,940
Two cells × 2
Total stack flow rate (dscfm) = 2,061,880

Equivalent sampling time = 40 periods × 7.5 min = 300

④

From Appendix A, p A-6 of Report ㉙

18	933	11 1/8	24 1/8	21 1/2	22 1/8	20 7/8
19	961	18 7/16	22 7/8	25 1/4	20 3/4	19 1/2
20	987	18 15/16	16 3/4	10 3/4	17 1/4	19 1/2

CP 28 3/4

RDG NO	TIME	d
A		
B		
C		

TOTAL	10237	TOTAL	10103	TOTAL	97730	TOTAL	97473
AVG	5.1196	AVG	5.054	AVG	4.8865	AVG	4.8736
TRAVERSE AVG $\sqrt{d}$			5.0855	TRAVERSE AVG $\sqrt{d}$			4.8801

C.P. 26

× 1653.6

× 1659.0

US GPM 8409

US GPM 8096

$\boxed{16505}$ (97.1% of Design

1659.0 west

$Q\ \text{gpm} = \sqrt{d}\,(1040 \times C \times A) = \sqrt{d}\,(\underline{1653.6})$ East

BASIS AIR/WATER MANOMETER

* CALCULATED VALUE DECREASED BY DISTANCE FROM END OF PITOT TUBE TO CENTER LINE OF IMPACT HOLE

A-6

Waterflow rate for Cell #1 (GPM) = 8409

" Cell #2 (GPM) = 8096

Tower water flow rate (GPM) 16,505

From Appendix A, p A-7 of Report ㉙

Duplicate Sample Analysis

Sample		Br Conc. (ppm)	Avg (ppm)
100	Acid Blank	0.025	0.028
100	Acid Blank	0.032	
102	Water Blank	0.056	0.194
102	Water Blank	0.333	
103	Acid Rinse	0.057	0.058
103	Acid Rinse	0.058	
104	Water Rinse	0.092	0.102
104	Water Rinse	0.111	
105	Impinger Contents	0.060	0.058
105	Impinger Contents	0.055	
108	Basin Water before NaBr	0.29	0.28
108	Basin Water before NaBr	0.26	
109	Basin Water before test	17.8	18.6
109	Basin Water before test	19.4	
110	Basin Water after test	18.5	18.2
110	Basin Water after test	18.0	
106	Filter	0.059	0.059
107	Filter Blank #1	0.046	0.050
107	Filter Blank #2	0.054	

⑤

From p. 8 of Report (29)

Sample No.	Description	Sample Vol. (mL)	Sample Concentration (µg/mL)	Total Br (µg)
100	Acid blank	-	0.0285	-
102	Water blank	-	0.0560	-
107	Filter blank	-	-	0.046
103	Acid rinse	194	0.0575	11.16
104	Water rinse	273	0.1015	27.71
105	Impinger cont.	191	0.0575	10.98
106	Filter	-	-	0.059
108	Basin water before NaBr	-	0.275	-
109	Basin water before test	-	18.6	-
110	Basin water after test	-	18.25	-

The sample train impinger and water rinse samples were run in duplicate. The average of the two values is recorded in Table 1 and was used in the calculation.

From p. 9 of Report (29)

SAMPLING DATA

Description	
Corrected total Br in sample	18.4 µg[a]
Sample volume	86.2 dscf
Stack air flow rate	1,959,966 dscfm[b] ⇐ Not consistent with data forms
Basin water Br concentration	18.4 µg/mL
Water flow rate through the tower	17,815 gpm

---

[a] See calculations in Appendix B.

[b] Includes both fans.

⑥

COMPLETE CALCULATIONS

This appendix provides the calculations for this test, complete with all correction factors applied. All numbers have been rounded to three significant figures. The data used was taken from Tables 1 and 2 in the report.

The total weight of Br in the sample train (Br_T) is the sum of the Br found in the impinger content (Br_I), the water rinse (Br_W), the acid rinse (Br_A), and on the filter (Br_F).

$$Br_T = Br_I + Br_W + Br_A + Br_F$$

$$= 11.0 + 27.7 + 11.2 + 0.059 = 50.0\ \mu g\ Br$$

Corrections (B_T) for the acid blank (A_B) and the water blank (W_B) must be applied to the weight of bromine collected in the sample train. In this test, 273 mL and 191 mL of water were used in the impingers and water rinse, respectively. For the acid rinse 194 mL was used. A blank filter (F_B) was also analyzed.

$$(B_T) = (A_B) + (W_B) + (F_B)$$

$$= 5.53 + 26.0 + 0.046 = 31.6\ \mu g\ Br$$

The net corrected weight of bromine in the sample train due to drift (Br_C) is:

$$(Br_C) = (Br_T) - (B_T)$$

$$= 50.0 - 31.6 = 18.4\ \mu g\ Br$$

After obtaining the corrected Br weight (Br_C) for the sample train, the concentration of Br (in µg/dscf) in the stack air is calculated from the sample volume, V_S:

$$\text{Conc. Br in stack} = \frac{Br_C}{V_S} = \frac{18.4\ \mu g\ Br}{86.2\ dscf}$$

$$= 0.213\ \mu g\ Br/dscf$$

Since the total stack flow rate was measured as 1,959,966 dscfm, the total Br emissions from the stack (Br_S) is calculated by:

$$\text{Total Br from stack} = 1{,}959{,}966\ dscfm \times \frac{0.213\ \mu g\ Br}{dscfm}$$

$$= 417{,}473\ \mu g\ Br/min$$

The volume of basin water, W_V, required to deliver 417,473 µg of Br is calculated by:

$$W_V = \frac{\text{Total Br from stack}}{\text{Conc. Br in basin}}$$

$$= \frac{417{,}473\ \mu g\ Br/min}{18.4\ \mu g\ Br/mL} = 22{,}689\ mL/min$$

Converting to gallons per minute gives:

$$gpm = \frac{22{,}689\ mL/min}{3{,}784\ mL/gal.} = 6.0\ gpm$$

or 360 gal/hr.

The percent drift, % D, can now be calculated according to the equation:

$$\%\ D = \frac{\text{Vol. basin water from stack } (W_V)}{\text{Total water vol. through basin}} \times 100$$

$$= \frac{6.0}{17{,}815} \times 100 = 0.034\%$$

Since net fan area was unable to be calculated because of lack of fan and hub diameters, the above result could not be checked.

To convert @ STP

$$E.F. = \frac{0.034\ \text{gal drift}}{100\ \text{gal } H_2O\ \text{flow}} \times \frac{8.312\ \text{lbs drift}}{\text{gal drift}}$$

$$= 0.00283\ \frac{\text{lbs/drift}}{\text{gal } H_2O\ \text{flow}}$$

Data Rating: B (insufficient data to check calculations)

COOLING TOWER INSTITUTE TEST REPORT

THERMAL ACCEPTANCE TEST
2-CELL
MECHANICAL-DRAFT CROSS-FLOW COOLING TOWER
AT

I. INTRODUCTION

The testing services of the CTI were retained by under Contract No. to conduct a drift acceptance test on 2-cell, mechanical-draft, cross-flow cooling tower located at the Refinery. The work was performed by MRI under contract with CTI as the official CTI test representative. The CTI test representatives were Mr. Thomas E. Weast and Mr. George R. Cobb. The tower manufacturer was represented by The plant was represented by tion.

Cooling tower drift is defined as the percent of water flow through the tower which exits through the fan in the form of water droplets or aerosols. The amount of drift from the tower was determined by isokinetically sampling a representative fraction of the tower airflow and measuring the amount of aerosol leaving the stack. Sodium bromide (NaBr) was spiked into the basin as a tracer for the analysis. Neutron activation analysis (NAA), an extremely sensitive detection technique, was then used to measure the amount of bromine exiting from the stack. From measurement of the total bromine collected in the sampler and the concentration of bromine in the basin water, the drift rate can be calculated.

II. TEST SITE DESCRIPTION

The Refinery, is located south of The evaporative cooling tower serving the new plant expansion was of a conventional splash bar filled, cross-flow design. Each cell was supplied by a single 20-in. nominal diameter pipe riser. Pitot taps were installed in the vertical section of each riser at approximately 18 ft above grade. Each cell had a single fan driven by a 150-hp motor. The cold water from the tower passes through two pumps to the plant process.

Due to the time required to collect adequate samples from the stack for analysis, only one cell of the two cell tower was tested for drift. Air and water flow measurements were taken from the other cell and used to calculate the towers total drift.

TABLE 1

SAMPLE ANALYSIS RESULTS

Sample No.	Description	Sample Vol. (mL)	Sample Concentration (μg/mL)	Total Br (μg)
100	Acid blank	-	0.0285	-
102	Water blank	-	0.0560	-
107	Filter blank	-	-	0.046
103	Acid rinse	194	0.0575	11.16
104	Water rinse	273	0.1015	27.71
105	Impinger cont.	191	0.0575	10.98
106	Filter	-	-	0.059
108	Basin water before NaBr	-	0.275	-
109	Basin water before test	-	18.6	-
110	Basin water after test	-	18.25	-

The sample train impinger and water rinse samples were run in duplicate. The average of the two values is recorded in Table 1 and was used in the calculation.

V. CALCULATION PROCEDURE AND RESULTS

Since the calculation of correction factors needed to determine the drift rate are relatively complex, the calculation procedure without indicating the corrections is presented in this section. The purpose is to provide a clear picture to the principles underlying the calculation of the drift rate. The actual calculations with all the correction factors have been provided in Appendix B. The sampling data used in the calculations are shown in Table 2.

The calculation of the drift rate requires several steps. First, the concentration of bromine in the air from the stack is calculated from the equation:

$$\text{Conc. Br in stack air } (\mu g/ft^3) = \frac{\text{Corrected total Br in sample } (\mu g)}{\text{Sample volume } (ft^3)}$$

Next, the total stack emission of Br is obtained by multiplying the stack concentration by the stack flow rate:

$$\text{Total Br emissions } (\mu g/min) = \text{Conc. Br in stack air } (\mu g/ft^3) \times \text{Stack airflow rate } (ft^3/min)$$

TABLE 2

SAMPLING DATA

Description	
Corrected total Br in sample	18.4 μg[a]
Sample volume	86.2 dscf
Stack air flow rate	1,959,966 dscfm[b]
Basin water Br concentration	18.4 μg/mL
Water flow rate through the tower	17,815 gpm

---

[a] See calculations in Appendix B.
[b] Includes both fans.

The bromine emissions are then related to the basin water lost by the equation:

$$\text{Vol. of basin water lost (mL/min)} = \frac{\text{Total Br emissions } (\mu g/\text{min})}{\text{Basin water conc. } (\mu g/\text{mL})}$$

The drift then is calculated as a percent of the total flow through the tower according to the equation:

$$\%\ \text{Drift} = \frac{\text{Vol. of basin water lost (mL/min)}}{\text{Water flow through tower (mL/min)}} \times 100$$

Blank corrections were applied for the water and acid solutions in the rinse. Complete calculations with the appropriate corrections have been provided in Appendix B.

When the calculations were completed, the drift for the tower was found to be 0.034%. For the measured water flow rate of 17,815 gpm, this amounts to 6.0 gal/min or 360 gal/hr of basin water discharged by the tower as drift.

VI. DISCUSSION AND CONCLUSIONS

The definition of drift as used in this report is, "the percentage of the water flowing through the tower which is discharged through the fan in the form of water droplets or aerosols." Under the conditions of this test, the drift rate was found to be 0.034% or 6 gal/min. The percent drift measured is below the 0.044% specified in the design parameters.

Appendix A contains a summary of the raw data collected during the testing of the stack (including airflow measurements) and the basin water flow.

```
Init. Vol= 152.9
Fin. Vol= 242.443
M Factor= 1.018
Leak Check= 0
Baro. P= 29.03
Static P= .2
% O2= 20.9
% CO2= 0
% H20= 4
Cp= .84
Time= 139.1
Nozzle D= .252
Net Vol= 89.543
Dry St V= 86.1889
Std Vol(M^3)= 2.44053
H2O>Sat
% H2O(Sat.)= 3.4341
Stack P= 29.0447
Ave M T= 83.2375
Ave sqr Dp= .414112
Ave Dp= .171489
Ave Dh= 1.19325
Ave St T= 78.95
Stack Vel= 1440.48
% Iso= 100.035
Dry MW= 28.836
Excess Air=-118743
Wet MW= 28.4639
GR/DSF Factor= .173677
Factor(7%O2)= 25.0147
AXIS 1= 378
AXIS 2= 378
CIRCULAR STACK
ACFM= 1.12253E+06
WSCFM= 1.06758E+06
DSCFM= 1.03094E+06
```

WITH CTI
ODE ATC 105

COOLING TOWER INSTITUTE
ACCEPTANCE TEST PROCEDURE
DATA SHEET "E"
WATER FLOW MEASUREMENT
PITOT TUBE

FILE NO

TEST DATE

PITOT TUBE MAKE MODEL	SERIAL NO	PIPE SIZE INCHES NOM = 19	ID 19.156
DATE CALIBR	TUBE COEFFICIENT C = .7944	AREA = .00545 ID² SQ FT A 2.0015	

EAST | WEST

PIPE I D RDG NO	DIA x	IN RDG NO	DIA x	LOCATION DECIMAL INCHES 19 3/16 CALCULATED	CORRECTED*	STA DESC 19 3/16 ϕ - SE d in	√d	TIME 19 1/16 ϕ - SW d in	√d	STA DESC 19 1/8 SE d in	√d	TIME 19 1/16 - SW d in	√d
1	013			1/4		21 3/4		22 1/4		21 1/2		21-	
2	039			3/4		23 1/4		25 1/2		21 5/8		23 1/4	
3	067			1 5/16		24 3/8		26 3/8		22 1/2		24-	
4	097			1 13/16		25 5/8		26 5/8		23 5/8		25-	
5	129			2 1/2		27 1/8		30 3/4		24 7/8		25 3/4	
6	165	1	026	3 3/16		27 1/4		28 1/4		25 5/8		26-	
7	204	2	082	3 15/16		27 3/4		26 5/8		25 3/4		26 5/8	
8	250	3	146	4 13/16		28 1/2		28 1/2		25 3/8		26 3/8	
9	306	4	226	5 7/8		29 1/2		28 1/2		25 1/2		26 1/2	
10	.388	5	342	7 7/16		29 5/8		28 5/8		26 1/8		26 5/8	
11	612	6	658	11 3/4		30-		28-		26 5/8		25 1/4	
12	694	7	774	13 5/16		30-		27 1/2		26 1/4		24 3/4	
13	750	8	854	14 3/8		30-		27 1/4		25 3/4		24 1/2	
14	796	9	918	15 1/4		28 1/2		26 1/4		25 1/4		24 1/2	
15	835	10	974	16-		27 3/4		26-		25-		23 3/8	
16	871			16 11/16		26 7/8		24 3/8		24 1/4		22 3/8	
17	903			17 5/16		25 1/2		23 3/4		23 1/4		21-	
18	933			17 7/8		24 1/8		21 1/2		22 1/8		20 3/8	
19	961			18 7/16		22 7/8		25 1/4		20 3/4		19 1/2	
20	987			18 15/16		16 1/4		10 3/4		17 1/4		19 1/2	

(18 IN DIAM AND OVER; UNDER 18 IN DIAM)

CP 28 3/4

TOTAL	102.39	TOTAL	101.03	TOTAL	97.730	TOTAL C.P.-26-	97.473
AVG	5.1196	AVG	5.0514	AVG	4.8865	AVG	4.8736
TRAVERSE AVG √d			5.0855	TRAVERSE AVG √d			4.8801
× 1653.6				× 1659.0			
US GPM 8409				US GPM 8096			

16505 (97.1% of Design)

RDG NO	TIME	d
A		
B		
C		

1659.0 west

Q gpm = $\sqrt{d}$ (1040 × C × A) = $\sqrt{d}$ (1653.6) East

BASIS AIR/WATER MANOMETER

* CALCULATED VALUE DECREASED BY DISTANCE FROM END OF PITOT TUBE TO CENTER LINE OF IMPACT HOLE

UNIVERSITY OF MISSOURI

Research Reactor Facility

Research Park
Columbia, Missouri 65211
Telephone (314) 882-4211

October 25, 1984

Dr. Ken Wilcox
Midwest Research Institute
425 Volker Boulevard
Kansas City, MO 64110

Dear Dr. Wilcox:

Enclosed, please find the results for the set of samples submitted for analysis on 10-Sept-84.

Sample		Br Conc. (ppm)
100	Acid Blank	0.025
100	Acid Blank	0.032
102	Water Blank	0.056
102	Water Blank	0.333
103	Acid Rinse	0.057
103	Acid Rinse	0.058
104	Water Rinse	0.092
104	Water Rinse	0.111
105	Impinger Contents	0.060
105	Impinger Contents	0.055
108	Basin Water before NaBr	0.29
108	Basin Water before NaBr	0.26
109	Basin Water before test	17.8
109	Basin Water before test	19.4
110	Basin Water after test	18.5
110	Basin Water after test	18.0
106	Filter	0.059
107	Filter Blank #1	0.046
107	Filter Blank #2	0.054

Except for the Filters, all samples were run in duplicate. All duplicates, except for sample 102, agree within counting statistical error. Should you have any questions about the results, or if we can be of any further service, please give me a call.

Sincerely,

James J Carni

James J. Carni, M.A.
Research Scientist

JJC:ls
Enclosure

COLUMBIA KANSAS CITY ROLLA ST. LOUIS

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APPENDIX M

EMISSION FACTOR CALCULATIONS AND REPORT EXCERPTS FOR REFERENCE NO. 34

(see Section 4.2.13 of text)

CALCULATION SHEET
MRI Project 8987-35

Reference No. 34 Type of Facility: Not specified
(e.g., power plant)

Location of Facility: Not specified Test Date 10/83

Type of Cooling Tower (circle one): [✓ Wet Tower;] Dry Tower; Wet-Dry; Not Specified

Type of Draft (circle one): Mechanical Draft; Natural Draft; Fan-Assist Natural Draft; Armospheric; [✓ Not Specified]

Fan Configuration (circle one as applicable): Forced Draft; Induced Draft; [✓ Not Specified]

Heat Transfer Configuration (circle one as applicable): Counterflow; [✓ Crossflow;] Spray; Not Specified

Type of Heat Transfer Media (circle one as applicable): [✓ Splash;] Film; Not Specified

Type of Fill (specify): Wood fill

Type of Hot Water Distribution System (circle one as applicable): Pressure System; Gravity System; [✓ Not Specified]

Water Flow Configuration (circle one as applicable): [✓ Recirculating;] Once-Through; Not Specified

Type of Mist Eliminator (specify): Wood slats (some were missing)

EMISSION RATE CALCULATIONS:

Measurement Method Used:
- Spike of basin water with NaBr tracer
- Isokinetic sampling of stack exit airstream using 4-impinger train and backup filter
- Neutron activation analysis
- Background sample

From p. 11 of Report (34)

TABLE 2

SAMPLING DATA

Description	
Corrected total Br in sample	8.3 μg[a]
Sample volume	28.5 dscf
Stack air flow rate	59,600 dscfm
Basin water Br concentration	23.9 μg/ml
Water flow rate through the tower	629 gpm

---

[a] See calculations in Appendix B.

[illegible]	[illegible]
19	981
20	982

RDG NO	TIME	d
A	11:13	17
B	[illegible]	17
C		

gpm = $\sqrt{d}$ (1040 × C × A) = $\sqrt{d}$ (177.06)

BASIS AIR WATER MANOMETER

TOTAL	35.136	TOTAL		TOTAL	44.057	TOTAL	
AVG	3.5136	AVG		AVG	4.4057	AVG	
TRAVERSE AVG $\sqrt{d}$			3.5136	TRAVERSE AVG $\sqrt{d}$			

ONE Pump	Two Pumps
US GPM 629.2	US GPM 757

* CALCULATED VALUE DECREASED BY DISTANCE FROM END OF PITOT TUBE TO CENTER LINE OF IMPACT HOLE

Note: only one pump was used - 629 gal/min

From p. 10 of Report (34)

TABLE 1

SAMPLE ANALYSIS RESULTS

Sample No.	Description	Sample Vol. (ml)	Sample Conc. (μg/ml)[a]	Total Br (μg)
100	Basin water before addition of NaBr	-	0.1350	-
101	Basin water after addition of NaBr but before test	-	24.3000	-
102	Basin water after addition of NaBr and after test	-	23.5000	-
107	Sample train impinger water and water rinse	170	0.0599 ± 0.0007	10.1800
108	Sample train acid rinse	74	0.0149	1.1000
109	Sample train backup filter	-	-	0.0104
103	Blank train impinger water and water rinse	130	0.0113 ± 0.0003	1.4600
104	Blank train acid rinse	42	0.0265	1.1100
105	Blank train backup filter	-	-	0.0081
106	Background filter	-	-	0.1210
110	Acid rinse blank	-	0.0081	-
111	Water rinse blank	-	0.0003	-
112	Background filter blank	-	-	0.0078
113	Sample train filter blank	-	-	< 0.0050

---

[a] The detection limit for Br is 0.0001 μg.

From p. 9 of Report '34

Total dissolved solids in the basin water was determined by evaporating 100 ml of the basin water to dryness and weighing the residue. The concentration of dissolved solids was found to be 0.00313 lb/gal., or 0.037% by weight.

(5)

From Appendix B p. B-2 of Report (34)

COMPLETE CALCULATIONS

The calculations for this test are provided, complete with all correction factors applied. An effort has been made to include adequate explanations for all of these numerous corrections. All numbers have been rounded to three significant figures. The data used was taken from Tables 1 and 2 in the report.

The total weight of Br in the sample train (Br_T) is the sum of Br found in the water rinse (Br_W), the acid rinse (Br_A), and on the filter (Br_F).

$$Br_T = Br_W + Br_A + Br_F$$

$$= 10.2 + 1.10 + 0.0104 = 11.3\ \mu g\ Br$$

The total weight of Br in the blank train (Br_B) is determined similarly:

$$Br_B = 1.46 + 1.11 + 0.0081 = 2.57\ \mu g\ Br$$

However, since the volumes of rinse used for the blank train are less than those used in the sample train, additional corrections (Br_R) for the acid blank (A_B) and water blanks (W_B) must be made before the blank correction can be applied to the sample train. In this test, 170 ml of water were used to rinse the sample train and 130 ml were used for the blank train. For the acid rinse, 74 and 42 ml were used, respectively.

$$Br_R = W_B + A_B$$

$$= [(170-130) \times 0.0081] + [(74-42) \times 0.00029]$$

$$= 0.32 + 0.0093 = 0.33\ \mu g\ Br$$

This value must be added to the blank train before subtracting from the sample train. The background contribution (Br_F) must also be considered. For this test, a total of 0.121 µg Br was collected from 39.0 acf of air. The concentration of Br in the ambient air is then:

$$\text{Air conc.} = \frac{0.121\ \mu g\ Br}{39\ acf} = 0.0031\ \mu g\ Br/acf$$

Since the sample volume was 28.5 ft³, the weight of Br in the sample train due to background (Br_{air}) is:

$$Br_{air} = 28.5\ ft^3 \times 0.0031\ \mu g/ft^3$$

$$= 0.088\ \mu g\ Br$$

From Appendix B, p B-3 of Report (34)

The net corrected bromine in the sample train due to drift (Br_C) is:

$$Br_C = Br_T - (Br_B + Br_R) - Br_{air}$$
$$= 11.3 - (2.57 + 0.33) - 0.088$$
$$= 8.3 \ \mu g \ Br$$

After obtaining the corrected Br weight (Br_C) for the sample train, the concentration of Br (in µg/dscf) in the stack air is calculated from the sample volume, V_S:

$$\text{Conc. Br in stack} = \frac{Br_C}{V_S} = \frac{8.3 \ \mu g \ Br}{28.5 \ dscf}$$
$$= 0.291 \ \mu g \ Br/dscf$$

Since the total stack flow rate was found to be 59,600 dscfm, the total Br emissions from the stack (Br_S) is calculated by:

$$\text{Total Br from stack} = 59{,}600 \ dscfm \times \frac{0.291 \ \mu g \ Br}{dscfm}$$
$$= 17{,}400 \ \mu g \ Br/min$$

The concentration of Br in the basin water was found to be 23.9 µg/ml so that the volume of basin water, W_V, required to deliver 17,400 µg of Br is calculated by:

$$W_V = \frac{\text{Total Br from stack}}{\text{Conc. Br in basin}}$$
$$= \frac{17{,}400 \ \mu g \ Br/min}{23.9 \ \mu g \ Br/ml} = 728 \ ml/min$$

Converting to gallons per minute give:

$$gpm = \frac{728 \ ml/min}{3{,}784 \ ml/gal.} = 0.192 \ gpm$$

or 11.5 gal/hr.

The percent drift, % D, can now be calculated according to the equation:

$$\% \ D = \frac{\text{Vol. basin water from stack } (W_V)}{\text{Total water vol. through basin}} \times 100$$
$$\doteq \frac{0.192}{629} \times 100 = 0.0305\%$$

$$EF = \frac{0.0305}{100} \ \frac{\text{gal drift}}{\text{gal. } H_2O \text{ flow}} \times 8.312 \ \frac{\text{lbs drift}}{\text{gal. drift}} = 25 (10)^{-4} \ \frac{\text{lbs drift}}{\text{gal } H_2O \text{ flow}}$$

Calculation of total dissolved solids (TDS) in drift

0.00313 lb TDS/gal × 11.5 gal/hr

= 0.636 lb TDS/hr

The above number is a factor of 5.28 smaller than that reported on p.12 of the report, which is 0.19 lb/hr. Author of report confirmed this error.

Emission Factor = 0.00313 lb TDS/gal drift × $\frac{0.000305 \text{ gal drift}}{\text{gal recirc } H_2O}$

= 9.55×10^{-7} lb TSD/gal recirculating H_2O

Data Rating: D (Raw and QA data were not adequate for checking calculations.)

I. INTRODUCTION

MRI conducted a test on October to determine the amount of drift from a cooling tower located at the in . Mr. George R. Cobb and Mr. Thomas E. Weast represented MRI, and

Cooling tower drift is defined as the percent of water flow through the tower which exits through the fan in the form of water droplets or aerosols. The amount of drift from the tower was determined by isokinetically sampling a representative fraction of the tower airflow and measuring the amount of aerosol leaving the stack. For purposes of this test, the basin was spiked with sodium bromide (NaBr) which functioned as a tracer for the analysis. Neutron activation analysis (NAA), an extremely sensitive detection technique, was then used to measure the amount of bromide exiting from the stack. From measurement of the total bromine collected in the sampler and the concentration of bromine in the basin water, the drift rate can be readily calculated.

Upon arriving at the test site, an inspection of the cooling tower indicated that the tower was a single-cell cross-flow tower apparently manufactured by the The original nameplate was missing, and the only identification was the fans and water distribution valves which are designs. A check with the indicated they had sold a Model cooling tower to

Physical inspection of the tower indicated that a number of the wood drift eliminator slats in the air plenum were missing. The splash type wood fill had a substantial coating of algae, and the wire guard on the fan stack discharge was coated with both heavy mineral deposits and algae. Because the cooling tower water flow was low, all of the distribution nozzles in the hot water basins were not equally flooded. Except for the above observations, the tower appeared to be in a typically normal operating mode.

The area surrounding the tower was wet apparently due to varying combinations of tower drift, splash out, and recent precipitation. The tower was continually discharging drift droplets whenever the fan was in operation. The area around the tower outlet had a green coating.

Another tower was located next to the tower being tested. It was not operated during our site preparations and tests.

III. ANALYSIS METHOD AND RESULTS

NAA was performed on the samples by the University of Missouri, Columbia. This process involves exposure of the samples to a neutron source where the following nuclear reaction occurs.

$$^{79}_{35}\mathrm{Br} + ^{1}_{0}\mathrm{n} \rightarrow ^{80}_{35}\mathrm{Br}$$

The $^{80}_{35}\mathrm{Br}$, which is radioactive, decays according to the reaction:

$$^{80}_{35}\mathrm{Br} \rightarrow ^{80}_{36}\mathrm{Kr} + \beta^{-} + \text{gamma radiation (616 Kev)}$$

The characteristics of the gamma radiation were then used to determine the amount of bromine in the sample. The optimum detection limit for the method is 0.0001 μg. This is well below the amount of bromine collected by the sampler. The analysis data are shown in Table 1.

The sample train and blank train impinger and water rinse samples were run in triplicate. The average of the three values is recorded in Table 1 and was used in the calculation. The average deviation is also listed for each.

Total dissolved solids in the basin water was determined by evaporating 100 ml of the basin water to dryness and weighing the residue. The concentration of dissolved solids was found to be 0.00313 lb/gal., or 0.037% by weight.

IV. CALCULATION PROCEDURE AND RESULTS

Since the calculation of correction factors needed for determining the drift rate are relatively complex, the calculation procedure without indicating the corrections is presented in this section. The purpose is to provide a clear picture to the principles underlying the calculation of the drift rate. The actual calculations with all the correction factors have been provided in Appendix B. The sampling data used in the calculations are shown in Table 2.

The calculation of the drift rate requires several steps. First, the concentration of bromine in the air from the stack is calculated from the equation:

$$\text{Conc. Br in stack air } (\mu g/ft^3) = \frac{\text{Corrected Br in sample } (\mu g)}{\text{Sample volume } (ft^3)}$$

Next, the total stack emission of Br is obtained by multiplying the stack concentration by the stack flow rate:

$$\text{Total Br emissions } (\mu g/hr) = \text{Conc. Br in stack air } (\mu g/ft^3) \times \text{Stack airflow rate } (ft^3/hr)$$

TABLE 1

SAMPLE ANALYSIS RESULTS

Sample No.	Description	Sample Vol. (ml)	Sample Conc. (μg/ml)[a]	Total Br (μg)
100	Basin water before addition of NaBr	-	0.1350	-
101	Basin water after addition of NaBr but before test	-	24.3000	-
102	Basin water after addition of NaBr and after test	-	23.5000	-
107	Sample train impinger water and water rinse	170	0.0599 ± 0.0007	10.1800
108	Sample train acid rinse	74	0.0149	1.1000
109	Sample train backup filter	-	-	0.0104
103	Blank train impinger water and water rinse	130	0.0113 ± 0.0003	1.4600
104	Blank train acid rinse	42	0.0265	1.1100
105	Blank train backup filter	-	-	0.0081
106	Background filter	-	-	0.1210
110	Acid rinse blank	-	0.0081	-
111	Water rinse blank	-	0.0003	-
112	Background filter blank	-	-	0.0078
113	Sample train filter blank	-	-	< 0.0050

---

[a] The detection limit for Br is 0.0001 μg.

TABLE 2

SAMPLING DATA

Description	
Corrected total Br in sample	8.3 μg[a]
Sample volume	28.5 dscf
Stack air flow rate	59,600 dscfm
Basin water Br concentration	23.9 μg/ml
Water flow rate through the tower	629 gpm

---

[a] See calculations in Appendix B.

ITH CTI
ODE ATC-105

COOLING TOWER INSTITUTE

ACCEPTANCE TEST PROCEDURE
DATA SHEET "E"
WATER FLOW MEASUREMENT
PITOT TUBI

FILE NO

TEST DATE

PITOT TUBE MAKE MODEL Simplex 36"	SERIAL NO CFA-1121	PIPE SIZE, INCHES NOM = 6 ID = 6.25
DATE CALIBR June 93	TUBE COEFFICIENT C = .8022	AREA = .00545 ID² SQ FT A = .21305

PIPE I D			IN	LOCATION DECIMAL INCHES		STA DESC one Pump	TIME 11:05			STA DESC Two Pumps		
RDG NO	DIA x	RDG NO	DIA x	CALCULATED	CORRECTED*	d in	√d	d in	√d	d in	√d	
1	.013											
2	.039											
3	.067											
4	.097											
5	.129											
6	.165	1	.026	.1604	5/32	13 1/8				19 3/8		
7	.204	2	.082	.5104	1/2	16 1/4				22 3/8		
8	.250	3	.146	.9153	29/32	17 3/8				23 5/8		
9	.306	4	.226	1.4154	1 13/32	17 5/8				24 1/4		
10	.388	5	.342	2.1364	2 1/8	17 3/4				24 1/4		
11	.612	6	.658	4.1132	4 1/8	16				21 7/8		
12	.694	7	.774	4.8366	4 27/32	14 3/8				20 3/4		
13	.750	8	.854	5.3347	5 11/32	14				19 5/8		
14	.796	9	.918	5.7356	5 3/4	11 5/8				16 5/8		
15	.835	10	.974	6.0896	6 [illegible]	4 1/4				6 1/8		
16	.871											
17	.903											
18	.933											
19	.961											
20	.987											

18 IN DIAM AND OVER

UNDER 18 IN DIAM

TOTAL	35.136	TOTAL		TOTAL	44.057
AVG	3.5136	AVG		AVG	4.4057
TRAVERSE AVG √d			3.5136	TRAVERSE AVG √d	
one Pump				Two Pumps	
US GPM 629.2				US GPM 757	

RDG NO	TIME	d
A	11:13	17
B	[illegible]	17
C		

Q gpm = √d (1040 × C × A) = √d (177.06)

BASIS AIR WATER MANOMETER

* CALCULATED VALUE DECREASED BY DISTANCE FROM END OF PITOT TUBE TO CENTER LINE OF IMPACT HOLE

CTI FORM ATC-105 E

APPENDIX N

EMISSION FACTOR CALCULATIONS AND REPORT EXCERPTS FOR REFERENCE NOS. 52 AND 54

(see Section 4.2.14 of text)

CALCULATION SHEET
MRI Project 8987-35

Reference No. 5254 Type of Facility: [illegible]
(e.g., power plant)

Location of Facility: [illegible] Test Date

Type of Cooling Tower (circle one): Wet Tower; Dry Tower; Wet-Dry; [✓ Not Specified]

Type of Draft (circle one): Mechanical Draft; [✓ Natural Draft;] Fan-Assist Natural Draft; Armospheric; Not Specified

Fan Configuration (circle one as applicable): Forced Draft; Induced Draft; [✓ Not Specified]

Heat Transfer Configuration (circle one as applicable): Counterflow; Crossflow; Spray; [✓ Not Specified]

Type of Heat Transfer Media (circle one as applicable): Splash; Film; [✓ Not Specified]

Type of Fill (specify): [illegible]

Type of Hot Water Distribution System (circle one as applicable): Pressure System; Gravity System; [✓ Not Specified]

Water Flow Configuration (circle one as applicable): [✓ Recirculating;] Once-Through; Not Specified

Type of Mist Eliminator (specify): [illegible]

EMISSION RATE CALCULATIONS:

Measurement Method Used: [illegible]
[illegible] Sensitive Paper

From Vol. 1 p. 2-5 of Report ②

DRIFT DROPLET MASS FRACTION DISTRIBUTION:

Diameter Range (UM)	Average Diameter (UM)	Mass Fraction (%) Summer (June 76)	Winter (Dec 75)	Composite**
10-110	60	59.6	60.2	59.9
110-210	160	24.1	20.1	22.1
210-300	255	7.00	6.30	6.64
300-400	350	2.34	3.45	2.90
400-500	450	1.50	2.70	2.10
500-600	550	1.22	2.10	1.66
600-700	650	1.06	1.75	1.41
700-900	800	1.60	2.20	1.90
900-1200	1050	1.18	1.20	1.19
1200-1500	1350	0.26	0.0	0.13
1500-2000	1750	0.14	0.0	0.07

Circulating Water Flow Rate: 984 M^3/min

Drift Rate: 0.00088%

Drift Emission Rate: 0.144 Kg/sec

Using % Drift Rate; Total Drift Emissions:

Assume Drift = H_2O @ 25°C

$$EF = \frac{0.00088 \text{ gal drift}}{100 \text{ gal } H_2O \text{ flow}} \times 8.312 \frac{\text{lbs } H_2O}{\text{gal } H_2O} = 7.31 \times 10^{-5} \text{ lbs/gal}$$

Data Rating D (lack of adequate documentation)

JHU
PPSP-CPCTP-16
AUGUST 1977

Chalk Point Cooling Tower Project

JHU/APL FY 1977 FINAL REPORT

(July 1, 1976-June 30, 1977)

Volume 1

SALT LOADING, MODELING AND AIRCRAFT HAZARD STUDIES

Prepared by

APPLIED PHYSICS LABORATORY

Approved by

M. L. Moon
M. L. Moon
Power Plant Site Evaluation Project Supervisor

A. G. Schulz
Assistant Director for Planning

The work described in this report was performed by the Applied Physics Laboratory of the Johns Hopkins University. This report is submitted in partial fulfillment of the requirements of State of Maryland Contract No. P-72-03(77) (Contract Modification No. 9 and No. 11) administered by the State of Maryland, Department of Natural Resources Energy and Costal Zone Administration Power Plant Siting Program.

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Johns Hopkins Road, Laurel, Maryland 20810

JHU
PPSP-CPCTP-16
AUGUST 1977

Chalk Point Cooling Tower Project

JHU/APL 1977 Final Report

(July 1, 1976-June 30, 1977)

Volume 2

COOLING TOWER DRIFT DYE TRACER EXPERIMENT JUNE 16 and 17, 1977

Prepared by
J. H. Meyer
Project Engineer
William D. Stanbro
Project Chemist

Approved by

M L Moon
M. L. Moon
Power Plant Site Evaluation Project Supervisor

A G Schulz
A. G. Schulz
Assistant Director for Planning

The work described in this report was performed by the Applied Physics Laboratory of the Johns Hopkins University. This report is submitted in partial fulfillment of the requirements of State of Maryland Contract No. P-72-02(77) (Contract Modification No. 9 and No. 11) administered by the State of Maryland, Department of Natural Resources Energy and Coastal Zone Administration Power Plant Siting Program.

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Johns Hopkins Road, Laurel, Maryland 20810

VOL 1

TABLE 2-1: DRIFT DROPLET CHARACTERIZATION PARAMETER ASSUMED* FOR PRELIMINARY CHALK POINT NATURAL DRAFT TOWER SALT DEPOSITIONS CALCULATIONS.

DRIFT DROPLET MASS FRACTION DISTRIBUTION:

Diameter Range (UM)	Average Diameter (UM)	Mass Fraction (%)		
		Summer (June 76)	Winter (Dec 75)	Composite**
10-110	60	59.6	60.2	59.9
110-210	160	24.1	20.1	22.1
210-300	255	7.00	6.30	6.64
300-400	350	2.34	3.45	2.90
400-500	450	1.50	2.70	2.10
500-600	550	1.22	2.10	1.66
600-700	650	1.06	1.75	1.41
700-900	800	1.60	2.20	1.90
900-1200	1050	1.18	1.20	1.19
1200-1500	1350	0.26	0.0	0.13
1500-2000	1750	0.14	0.0	0.07

Circulating Water Flow Rate:	984 M^3/min
Drift Rate:	0.00088%
Drift Emission Rate:	0.144 Kg/sec
Basin Salinity	
Summer (June 76):	13 PPT
Winter (Dec. 75):	6.2 PPT
Annual (Design):	14 PPT

*Parameters derived from data measured by ESC.
**Composite distribution is average of summer and winter distributions.

APPENDIX O

EMISSION FACTOR CALCULATIONS AND REPORT EXCERPTS FOR REFERENCE NO. 62

(see Section 4.2.15 of text)

CALCULATION SHEET
MRI Project 8987-35

Reference No. 62 Type of Facility: [illegible]
(e.g., power plant)

Location of Facility: [illegible] Test Date [illegible]

Type of Cooling Tower (circle one): Wet Tower; Dry Tower; Wet-Dry; [✓ Not Specified]

Type of Draft (circle one): [✓ Mechanical Draft;] Natural Draft; Fan-Assist Natural Draft; Atmospheric; Not Specified

Fan Configuration (circle one as applicable): Forced Draft; [✓ Induced Draft;] Not Specified

Heat Transfer Configuration (circle one as applicable): Counterflow; [✓ Crossflow;] Spray; Not Specified

Type of Heat Transfer Media (circle one as applicable): Splash; Film; [✓ Not Specified]

Type of Fill (specify): [illegible] ([illegible])

Type of Hot Water Distribution System (circle one as applicable): [✓ Pressure System;] Gravity System; Not Specified Spray [illegible]

Water Flow Configuration (circle one as applicable): [✓ Recirculating;] Once-Through; Not Specified

Receives FW from cooling canal
system & discharges [illegible]

Type of Mist Eliminator (specify): [illegible]

[illegible]

EMISSION RATE CALCULATIONS:

Measurement Method Used: [illegible]

From p.93 of report

②

d(center) (µm)	Δd (µm)	$\Delta X_i/\Delta d$ (µg/m³·µm)	Composite Drift Mass Emission Rate, ΔD_i (µg/s)
20	20	29.5	2.78E 05
40	20	44.1	4.14E 05
65	30	40.2	5.61E 05
95	30	31.9	4.40E 05
130	40	24.7	4.46E 05
175	50	17.3	3.82E 05
225	50	12.0	2.57E 05
275	50	7.6	1.58E 05
325	50	5.7	1.16E 05
375	50	4.8	9.41E 04
425	50	4.4	8.37E 04
475	50	3.7	6.89E 04
525	50	3.4	6.12E 04
575	50	3.4	5.83E 04

Note: 2.78E 05 means 2.78×10^5

TOTAL COMPOSITE DRIFT MASS EMISSION RATE, $\Sigma\Delta D_i$ = 3.42 gm/s

MASS MEDIAN DIAMETER of the composite drift mass density distribution, $\Delta X_i/\Delta d$ = 120 µm

COMPOSITE TOWER DRIFT FRACTION (based on the design flow rate of 1260 kg/s) = 0.00027%

FAN STACK EXIT AREA, A = 54.5 m²

TOTAL COMPOSITE DRIFT FLUX, $\Sigma\Delta D_i/A$ = 0.063 gm/m²·s

From [illegible]

$$\frac{3.42\,g}{sec} \cdot \frac{kg}{1000\,g} \cdot \frac{1}{1260\,kg/s} \cdot 100 = 0.00027\%$$

Using [illegible]

Figure [illegible]

[illegible]

Data Rating D (Lack of Documentation)
(test method)

62

PB-246 800

DRIFT DATA ACQUIRED ON MECHANICAL SALT WATER COOLING DEVICES

GUNTER O. SCHRECKER, ET AL

ENVIRONMENTAL SYSTEMS CORPORATION
KNOXVILLE, TENNESSEE

JULY 1975

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DRIFT DATA ACQUIRED ON MECHANICAL SALT WATER COOLING DEVICES

by

Gunter O. Schrecker
Ronald O. Webb
David A. Rutherford
Frederick M. Shofner

Environmental Systems Corporation
P.O. Box 2525
Knoxville, Tennessee 37901

Contract No. 68-02-1365
ROAP No. 21ARW-002
Program Element No. 1AB015

EPA Project Officers:

Kenneth Baker
Control Systems Laboratory
National Environmental Research Center
Research Triangle Park, North Carolina 27711

and

Frank H. Rainwater
National Thermal Pollution Research Center
National Environmental Research Center
Corvallis, Oregon 97330

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RESEARCH AND DEVELOPMENT
WASHINGTON, D.C. 20460

July 1975

in this manner are mainly useful for the purpose of illustration. Also shown in Table 4 and in Figure 14 are the averages of all five diameter traverses. Comparing the two curves in Figure 14, one can see that the effect of including the summer data in the average is small on only one radius, tending to decrease the sodium mass flux at each position approximately equally. On the other radius the effect is quite noticeable and erratic. The high value at position 26 was due to the one data point taken during the summer test since no IK measurements were taken at this position during the winter test.

The calculated values for the upper limit of the mineral mass emission fraction for each of the five diameters is shown below, as obtained from the IK data sheets:

Diameter Traverse	Upper Limit of the Mineral Mass Emission Fraction η_{max}, (%)
SW-NE 1	0.00072
SW-NE 2	0.00099
SW-NE 3	0.0012
NW-SE 1	0.00062
NW-SE 2	0.00063

The arithmetic average of these values is 0.00083%. It should be noted that the water flow rate during the winter test was 1260 kg/s (20,000 gpm) whereas it was only 970 kg (15,400 gpm) during the summer test when data along the diameter traverse SW-NE 3 were obtained.

Cooling Tower Composite Curve Calculation

The drift droplet size data obtained by PILLS/SP during the five diameter traverses of the cooling tower was used to calculate a cooling tower composite curve in the manner described in Section IV. The values calculated for composite drift mass emission, ΔD_i composite, and composite drift mass density distribution $\frac{\Delta X_i}{\Delta d}\Big|_{composite}$, are tabulated in Table 5. The composite mass emission data for each size range were summed yielding a total composite drift mass emission rate, $D_{composite}$, of 3.42 gm/s. The composite tower drift fraction at design flow of 1260 kg/s is, therefore, 0.00027%. The composite mass median diameter calculated from the drift mass density distribution equals 120 μm. The composite drift mass density distribution is plotted in Figure 15. It shows a peak in the droplet size range of 30 to 50 μm with a center diameter of 40 μm. The largest value of droplet diameter for which the mass density distribution is shown

Table 5

COOLING TOWER COMPOSITE DRIFT MASS EMISSION PARAMETERS

d(center) (μm)	Δd (μm)	$\Delta X_i/\Delta d$ (μg/m^3·μm)	Composite Drift Mass Emission Rate, ΔD_i (μg/s)
20	20	29.5	2.78E 05
40	20	44.1	4.14E 05
65	30	40.2	5.61E 05
95	30	31.9	4.40E 05
130	40	24.7	4.46E 05
175	50	17.3	3.82E 05
225	50	12.0	2.57E 05
275	50	7.6	1.58E 05
325	50	5.7	1.16E 05
375	50	4.8	9.41E 04
425	50	4.4	8.37E 04
475	50	3.7	6.89E 04
525	50	3.4	6.12E 04
575	50	3.4	5.83E 04

Note: 2.78E 05 means 2.78 x 10^5

TOTAL COMPOSITE DRIFT MASS EMISSION RATE, $\Sigma\Delta D_i$ = 3.42 gm/s

MASS MEDIAN DIAMETER of the composite drift mass density distribution, $\Delta X_i/\Delta d$ = 120 μm

COMPOSITE TOWER DRIFT FRACTION (based on the design flow rate of 1260 kg/s) = 0.00027%

FAN STACK EXIT AREA, A = 54.5 m^2

TOTAL COMPOSITE DRIFT FLUX, $\Sigma\Delta D_i/A$ = 0.063 gm/m^2·s