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Chromium Emissions from Industrial Process Cooling Towers - Background Information for Proposed Standards

NESHAP

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Clean Air
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CHROMIUM EMISSIONS FROM INDUSTRIAL PROCESS COOLING TOWERS--
BACKGROUND INFORMATION FOR PROPOSED STANDARDS

August 1993

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1.0 SUMMARY

National emission standards for hazardous air pollutants (NESHAP) are established under Section 112 of the Clean Air Act (CAA) (P.L. 101-459), as amended in 1990. Section 112(b) of the CAA contains a list of hazardous air pollutants (HAP's), which are the specific air toxics to be regulated by NESHAP. Emission standards established under Section 112 apply to both new and existing sources and are to achieve the maximum degree of reduction in HAP emissions achievable, taking into consideration the cost of achieving such emission reductions, any non-air quality health and environmental impacts, and energy requirements. These standards have been termed the maximum achievable control technology (MACT) standards.

Chromium compounds are included on the list of HAP's established in Section 112(b) of the CAA. Section 112(c) requires the Administrator to use this pollutant list to develop and publish a list of source categories for which NESHAP are to be developed. The source category list was published on July 16, 1992. Industrial process cooling towers (IPCT's), which emit chromium compounds, are included on the source category list. This background information document (BID) supports proposed standards for chromium emissions from IPCT's.

1.1 CONTROL OPTIONS

Table 1-1 is a summary of the control options for chromium emissions from IPCT's. Three control options have been identified. Option I is the "no action," or baseline, option; Option II involves the use of high-efficiency drift eliminators (HEDE's) on IPCT's; and Option III involves the use of nonchromate-based water treatment programs and represents MACT

TABLE 1-1. SUMMARY OF CONTROL OPTIONS

Control option	Control technique
Option I (no action)	Existing (baseline) level of control -nonchromate-based water treatment programs used in 90 percent of IPCT's -high-efficiency drift eliminators used on 5 percent of IPCT's -IPCT's on chromate use 13 parts per million chromate in cooling water
Option II	High-efficiency drift eliminators that reduce uncontrolled emissions by 67 percent
Option III	Nonchromate-based water treatment programs that eliminate all chromium emissions

for both new and existing IPCT's. These options form the basis of the proposed regulatory alternatives for controlling chromium emissions from IPCT's.

1.2 ENVIRONMENTAL IMPACT

Table 1-2 summarizes the environmental and economic impacts associated with the control options for IPCT's. Control Option I represents no change to existing conditions. Control Option II (HEDE retrofits) would reduce nationwide chromium emissions from the baseline level of 22.9 megagrams per year (Mg/yr) (25.3 tons per year [tons/yr]) to 7.8 Mg/yr (8.6 tons/yr). Control Option III (nonchromates) would completely eliminate chromium emissions from IPCT's.

As shown in Table 1-2, the reduction in nationwide chromium emissions associated with either of the control options would result in minimal adverse environmental impacts. Control Option III would have a negligible negative water impact; chromium discharges would decrease, but phosphate discharges would increase under this control option. Control Option III also would have a negligible positive impact on solid waste resulting from the elimination of chromium from the waste stream. A negligible positive energy impact would be attributable to Control Option II due to the lower energy demands to operate cooling towers equipped with HEDE's. Under Control Option III, energy demands would increase slightly, resulting in a negligible negative energy impact.

1.3 ECONOMIC IMPACT

An overview of the economic impacts of the options for controlling chromium emissions from IPCT's is presented in Table 1-2. Table 1-3 summarizes the nationwide capital and annualized costs associated with each of the control options. Analyses of the costs and economic impacts are presented in Chapters 8 and 9.

TABLE 1-2. ASSESSMENT OF ENVIRONMENTAL AND ECONOMIC IMPACTS FOR CONTROL OPTIONS

Administrative action	Air impact	Water impact	Solid waste impact	Energy impact	Noise impact	Economic impact
Control Option I Baseline	0	0	0	0	0	0
Control Option II High-efficiency drift eliminators	+3**	0	0	+1	0	-1**
Control Option III Nonchromate-based water treatment programs	+4**	-1**	+1**	-1	0	-1**
Delayed standards or no standards	0	0	0	0	0	0

KEY: + = beneficial impact
- = adverse impact
0 = no impact
1 = negligible impact
2 = small impact
3 = moderate impact
4 = large impact
* = short-term impact
** = long-term impact
*** = irreversible impact

TABLE 1-3. NATIONWIDE CAPITAL AND ANNUALIZED COSTS OF CONTROL OPTIONS FOR INDUSTRIAL PROCESS COOLING TOWERS[a]

Control option	Capital costs, $ million	Net annualized costs, $ million/yr
Control Option I Baseline	0	0
Control Option II High-efficiency drift eliminators	39.3	11.3
Control Option III Nonchromate-based water treatment programs	6.3	14.0

[a]Costs above baseline in 1991 dollars.

2. INTRODUCTION

2.1 BACKGROUND AND AUTHORITY FOR STANDARDS

According to industry estimates, more than 2.4 billion pounds of toxic pollutants were emitted to the atmosphere in 1988 (Implementation Strategy for the Clean Air Act Amendments of 1990, EPA Office of Air and Radiation, January 15, 1991). These emissions may result in a variety of adverse health effects, including cancer, reproductive effects, birth defects, and respiratory illnesses. Title III of the Clean Air Act Amendments of 1990 provides the tools for controlling emissions of these pollutants. Emissions from both large and small facilities that contribute to air toxics problems in urban and other areas will be regulated. The primary consideration in establishing national industry standards must be demonstrated technology. Before national emission standards for hazardous air pollutants (NESHAP) are proposed as Federal regulations, air pollution prevention and control methods are examined in detail with respect to their feasibility, environmental impacts, and costs. Various control options based on different technologies and degrees of efficiency are examined, and a determination is made regarding whether the various control options apply to each emissions source or if dissimilarities exist between the sources. In most cases, regulatory alternatives are subsequently developed that are then studied by EPA as a prospective basis for a standard. The alternatives are investigated in terms of their impacts on the environment, the economics and well-being of the industry, the national economy, and energy and other impacts. This document summarizes the information obtained through these studies so that

interested persons will be able to evaluate the information considered by EPA in developing the proposed standards.

National emission standards for hazardous air pollutants for new and existing sources are established under Section 112 of the Clean Air Act as amended in 1990 [42 U.S.C. 7401 et seq., as amended by PL 101-549, November 15, 1990], hereafter referred to as the Act. Section 112 directs the EPA Administrator to promulgate standards that "require the maximum degree of reduction in emissions of the hazardous air pollutants subject to this section (including a prohibition of such emissions, where achievable) that the Administrator, taking into consideration the cost of achieving such emission reductions, and any non-air quality health and environmental impacts and energy requirements, determines is achievable ... ." The Act allows the Administrator to set standards that "distinguish among classes, types, and sizes of sources within a category or subcategory."

The Act differentiates between major sources and area sources. A major source is defined as "any stationary source or group of stationary sources located within a contiguous area and under common control that emits or has the potential to emit considering controls, in the aggregate, 10 tons per year or more of any hazardous air pollutant or 25 tons per year or more of any combination of hazardous air pollutants." The Administrator, however, may establish a lesser quantity cutoff to distinguish between major and area sources. The level of the cutoff is based on the potency, persistence, or other characteristics or factors of the air pollutant. An area source is defined as "any stationary source of hazardous air pollutants that is not a major source." For new sources, the amendments state that the "maximum degree of reduction in emissions that is deemed achievable for new sources in a category or subcategory shall not be less stringent than the emission control that is achieved in practice by the best controlled similar source, as determined by the Administrator." Emission standards for existing sources:

may be less stringent than the standards for new sources in the same category or subcategory but shall not be less stringent, and may be more stringent than--

> (A) the average emission limitation achieved by the best performing 12 percent of the existing sources (for which the Administrator has emissions information), excluding those sources that have, within 18 months before the emission standard is proposed or within 30 months before such standard is promulgated, whichever is later, first achieved a level of emission rate or emission reduction which complies, or would comply if the source is not subject to such standard, with the lowest achievable emission rate (as defined by Section 171) applicable to the source category and prevailing at the time, in the category or subcategory for categories and subcategories with 30 or more sources, or
>
> (B) the average emission limitation achieved by the best performing five sources (for which the Administrator has or could reasonably obtain emissions information) in the category or subcategory for categories or subcategories with fewer than 30 sources.

The Federal standards are also known as "MACT" standards and are based on the maximum achievable control technology previously discussed. The MACT standards apply to both major and area sources, although the existing source standards may be less stringent than the new source standards, within the constraints presented above. The MACT is considered to be the basis for the standard, but the Administrator may promulgate more stringent standards than the MACT floor, which have several advantages. First, they may help achieve long-term cost savings by avoiding the need for more expensive retrofitting to meet possible future residual risk standards, which may be more stringent (discussed in Section 2.7). Second, Congress was clearly interested in providing incentives for improving technology. Finally, in the Clean Air Act Amendments of 1990, Congress gave EPA a clear mandate to reduce the health and environmental risk of air toxics emissions as quickly as possible.

For area sources, the Administrator may "elect to promulgate standards or requirements applicable to sources in such categories or subcategories which provide for the use of generally available control technologies or management practices by such sources to reduce emissions of hazardous air pollutants." These area source standards are also known as "GACT" (generally available control technology) standards, although MACT may be applied at the Administrator's discretion, as discussed previously.

The standards for hazardous air pollutants (HAP's), like the new source performance standards (NSPS) for criteria pollutants required by Section 111 of the Act (42 U.S.C. 7411), differ from other regulatory programs required by the Act (such as the new source review program and the prevention of significant deterioration program) in that NESHAP and NSPS are national in scope (versus site-specific). Congress intended for the NESHAP and NSPS programs to provide a degree of uniformity to State regulations to avoid situations where some States may attract industries by relaxing standards relative to other States. States are free under Section 116 of the Act to establish standards more stringent than Section 111 or 112 standards.

Although NESHAP are normally structured in terms of numerical emissions limits, alternative approaches are sometimes necessary. In some cases, physically measuring emissions from a source may be impossible or at least impracticable due to technological and economic limitations. Section 112(h) of the Act allows the Administrator to promulgate a design, equipment, work practice, or operational standard, or combination thereof, in those cases where it is not feasible to prescribe or enforce an emissions standard. For example, emissions of volatile organic compounds (many of which may be HAP's, such as benzene) from storage vessels for volatile organic liquids are greatest during tank filling. The nature of the emissions (i.e., high concentrations for short periods during filling and low concentrations for longer periods during storage) and the configuration of storage tanks make direct emission measurement

impractical. Therefore, the MACT or GACT standards may be based on equipment specifications.

Under Section 112(h)(3), the Act also allows the use of alternative equivalent technological systems: "If, after notice and opportunity for comment, the owner or operator of any source establishes to the satisfaction of the Administrator that an alternative means of emission limitation" will reduce emissions of any air pollutant at least as much as would be achieved under the design, equipment, work practice, or operational standard, the Administrator shall permit the use of the alternative means.

Efforts to achieve early environmental benefits are encouraged in Title III. For example, source owners and operators are encouraged to use the Section 112(i)(5) provisions, which allow a 6-year compliance extension of the MACT standard in exchange for the implementation of an early emission reduction program. The owner or operator of an existing source must demonstrate a 90 percent emission reduction of HAP's (or 95 percent if the HAP's are particulates) and meet an alternative emission limitation, established by permit, in lieu of the otherwise applicable MACT standard. This alternative limitation must reflect the 90 (95) percent reduction and is in effect for a period of 6 years from the compliance date for the otherwise applicable standard. The 90 (95) percent early emission reduction must be achieved before the otherwise applicable standard is first proposed, although the reduction may be achieved after the standard's proposal (but before January 1, 1994) if the source owner or operator makes an enforceable commitment before the proposal of the standard to achieve the reduction. The source must meet several criteria to qualify for the early reduction standard, and Section 112(i)(5)(A) provides that the State may require additional reductions.

2.2 SELECTION OF POLLUTANTS AND SOURCE CATEGORIES

As amended in 1990, the Act includes a list of 190 HAP's. Petitions to add or delete pollutants from this list may be submitted to EPA. Using this list of pollutants, EPA will publish a list of source categories (major and area sources) for

which emission standards will be developed. Within 2 years of enactment (November 1992), EPA will publish a schedule establishing dates for promulgating these standards. Petitions may also be submitted to EPA to remove source categories from the list. The schedule for standards for source categories will be determined according to the following criteria:

(A) The known or anticipated adverse effects of such pollutants on public health and the environment;

(B) The quantity and location of emissions or reasonably anticipated emissions of HAP's that each category or subcategory will emit; and

(C) The efficiency of grouping categories or subcategories according to the pollutants emitted or the processes or technologies used.

After the source category has been chosen, the types of facilities within the source category to which the standard will apply must be determined. A source category may have several facilities that cause air pollution, and emissions from these facilities may vary in magnitude and control cost. Economic studies of the source category and applicable control technology may show that air pollution control is better served by applying standards to the more severe pollution sources. For this reason, and because there is no adequately demonstrated system for controlling emissions from certain facilities, standards often do not apply to all facilities at a source. For the same reasons, the standards may not apply to all air pollutants emitted. Thus, although a source category may be selected to be covered by standards, the standards may not cover all pollutants or facilities within that source category.

2.3 PROCEDURE FOR DEVELOPMENT OF NESHAP

Standards for major and area sources must (1) realistically reflect MACT or GACT; (2) adequately consider the cost, the non-air quality health and environmental impacts, and the energy requirements of such control; (3) apply to new and existing sources; and (4) meet these conditions for all variations of industry operating conditions anywhere in the country.

The objective of the NESHAP program is to develop standards to protect the public health by requiring facilities to control emissions to the level achievable according to the MACT or GACT guidelines. The standard-setting process involves three principal phases of activity: (1) gathering information, (2) analyzing the information, and (3) developing the standards.

During the information-gathering phase, industries are questioned through telephone surveys, letters of inquiry, and plant visits by EPA representatives. Information is also gathered from other sources, such as a literature search. Based on the information acquired about the industry, EPA selects certain plants at which emissions tests are conducted to provide reliable data that characterize the HAP's emissions from well-controlled existing facilities.

In the second phase of a project, the information about the industry, the pollutants emitted, and the control options are used in analytical studies. Hypothetical "model plants" are defined to provide a common basis for analysis. The model plant definitions, national pollutant emissions data, and existing State regulations governing emissions from the source category are then used to establish regulatory alternatives. These regulatory alternatives may be different levels of emissions control or different degrees of applicability or both.

The EPA conducts studies to determine the cost, economic, environmental, and energy impacts of each regulatory alternative. From several alternatives, EPA selects the single most plausible regulatory alternative as the basis for the NESHAP for the source category under study.

In the third phase of a project, the selected regulatory alternative is translated into standards, which, in turn, are written in the form of a Federal regulation. The Federal regulation limits emissions to the levels indicated in the selected regulatory alternative.

As early as is practical in each standard-setting project, EPA representatives discuss the possibilities of a standard and the form it might take with members of the National Air Pollution

Control Techniques Advisory Committee, which is composed of representatives from industry, environmental groups, and State and local air pollution control agencies. Other interested parties also participate in these meetings.

The information acquired in the project is summarized in the background information document (BID). The BID, the proposed standards, and a preamble explaining the standards are widely circulated to the industry being considered for control, environmental groups, other government agencies, and offices within EPA. Through this extensive review process, the points of view of expert reviewers are taken into consideration as changes are made to the documentation.

A "proposal package" is assembled and sent through the offices of EPA Assistant Administrators for concurrence before the proposed standards are officially endorsed by the EPA Administrator. After being approved by the EPA Administrator, the preamble and the proposed regulation are published in the Federal Register.

The public is invited to participate in the standard-setting process as part of the Federal Register announcement of the proposed regulation. The EPA invites written comments on the proposal and also holds a public hearing to discuss the proposed standards with interested parties. All public comments are summarized and incorporated into a second volume of the BID. All information reviewed and generated in studies in support of the standards is available to the public in a "docket" on file in Washington, D.C. Comments from the public are evaluated, and the standards may be altered in response to the comments.

The significant comments and EPA's position on the issues raised are included in the preamble of a promulgation package, which also contains the draft of the final regulation. The regulation is then subjected to another round of internal EPA review and refinement until it is approved by the EPA Administrator. After the Administrator signs the regulation, it is published as a "final rule" in the Federal Register.

2.4 CONSIDERATION OF COSTS

The requirements and guidelines for the economic analysis of proposed NESHAP are prescribed by Presidential Executive Order 12291 (EO 12291) and the Regulatory Flexibility Act (RFA). The EO 12291 requires preparation of a Regulatory Impact Analysis (RIA) for all "major" economic impacts. An economic impact is considered to be major if it satisfies any of the following criteria:

1. An annual effect on the economy of $100 million or more;
2. A major increase in costs or prices for consumers; individual industries; Federal, State, or local government agencies; or geographic regions; or
3. Significant adverse effects on competition, employment, investment, productivity, innovation, or on the ability of United States-based enterprises to compete with foreign-based enterprises in domestic or export markets.

An RIA describes the potential benefits and costs of the proposed regulation and explores alternative regulatory and nonregulatory approaches to achieving the desired objectives. If the analysis identifies less costly alternatives, the RIA includes an explanation of the legal reasons why the less costly alternatives could not be adopted. In addition to requiring an analysis of the potential costs and benefits, EO 12291 specifies that EPA, to the extent allowed by the CAA and court orders, demonstrate that the benefits of the proposed standards outweigh the costs and that the net benefits are maximized.

The RFA requires Federal agencies to give special consideration to the impact of regulations on small businesses, small organizations, and small governmental units. If the proposed regulation is expected to have a significant impact on a substantial number of small entities, a regulatory flexibility analysis must be prepared. In preparing this analysis, EPA takes into consideration such factors as the availability of capital for small entities, possible closures among small entities, the increase in production costs due to compliance, and a comparison

of the relative compliance costs as a percent of sales for small versus large entities.

The prime objective of the cost analysis is to identify the incremental economic impacts associated with compliance with the standards based on each regulatory alternative compared to baseline. Other environmental regulatory costs may be factored into the analysis wherever appropriate. Air pollutant emissions may cause water pollution problems, and captured potential air pollutants may pose a solid waste disposal problem. The total environmental impact of an emission source must, therefore, be analyzed and the costs determined whenever possible.

A thorough study of the profitability and price-setting mechanisms of the industry is essential to the analysis so that an accurate estimate of potential adverse economic impacts can be made for proposed standards. It is also essential to know the capital requirements for pollution control systems already placed on plants so that the additional capital requirements necessitated by these Federal standards can be placed in proper perspective. Finally, it is necessary to assess the availability of capital to provide the additional control equipment needed to meet the standards.

2.5 CONSIDERATION OF ENVIRONMENTAL IMPACTS

Section 102(2)(C) of the National Environmental Policy Act (NEPA) of 1969 requires Federal agencies to prepare detailed environmental impact statements on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment. The objective of NEPA is to build into the decision-making process of Federal agencies a careful consideration of all environmental aspects of proposed actions.

In a number of legal challenges to standards for various industries, the United States Court of Appeals for the District of Columbia Circuit has held that environmental impact statements need not be prepared by EPA for proposed actions under the Clean Air Act. Essentially, the Court of Appeals has determined that the best system of emissions reduction requires the Administrator to take into account counterproductive environmental effects of

proposed standards as well as economic costs to the industry. On this basis, therefore, the Courts established a narrow exemption from NEPA for EPA determinations.

In addition to these judicial determinations, the Energy Supply and Environmental Coordination Act of 1974 (PL-93-319) specifically exempted proposed actions under the Clean Air Act from NEPA requirements. According to Section 7(c)(1), "No action taken under the Clean Air Act shall be deemed a major Federal action significantly affecting the quality of the human environment within the meaning of the National Environmental Policy Act of 1969" (15 U.S.C. 793(c)(1)).

Nevertheless, EPA has concluded that preparing environmental impact statements could have beneficial effects on certain regulatory actions. Consequently, although not legally required to do so by Section 102(2)(C) of NEPA, EPA has adopted a policy requiring that environmental impact statements be prepared for various regulatory actions, including NESHAP developed under Section 112 of the Act. This voluntary preparation of environmental impact statements, however, in no way legally subjects the EPA to NEPA requirements.

To implement this policy, a separate section is included in this document that is devoted solely to an analysis of the potential environmental impacts associated with the proposed standards. Both adverse and beneficial impacts in such areas as air and water pollution, increased solid waste disposal, and increased energy consumption are discussed.

2.6 RESIDUAL RISK STANDARDS

Section 112 of the Act provides that 8 years after MACT standards are established (except for those standards established 2 years after enactment, which have 9 years), standards to protect against the residual health and environmental risks remaining must be promulgated, if necessary. The standards would be triggered if more than one source in a category or subcategory exceeds a maximum individual risk of cancer of 1 in 1 million. These residual risk regulations would be based on the concept of providing an "ample margin of safety to protect public health."

The Administrator may also consider whether a more stringent standard is necessary to prevent--considering costs, energy, safety, and other relevant factors--an adverse environmental effect. In the case of area sources controlled under GACT standards, the Administrator is not required to conduct a residual risk review.

3.0 INDUSTRIAL PROCESS COOLING TOWERS

3.1 GENERAL

This section provides a description of the source category and the major users of industrial process cooling towers (IPCT's), the cooling tower system, the heat exchangers served by cooling towers, cooling water chemical treatment programs, the mechanism by which hexavalent chromium (Cr^{+6}) is emitted, and the emission control techniques.

3.2 DEFINITION OF SOURCE CATEGORY

All cooling towers that are used to remove heat from an industrial process or chemical reaction are included in the IPCT source category. Towers that are used to cool both industrial processes and heating, ventilating, and air conditioning (HVAC) and refrigeration systems also are included in the source category. Only towers devoted exclusively to cooling HVAC and refrigeration systems are excluded from the source category.

Major users of IPCT's that also use chromium-based water treatment chemicals are chemical manufacturing plants, petroleum refineries, primary metals facilities, and several miscellaneous manufacturing industries (textiles, tobacco products, tire and rubber products, and glass products). Other major users of IPCT's, which do not use chromium-based water treatment chemicals, include the electrical utility, food processing, and pulp and paper industries. The number of plants in each industry, the total number of IPCT's in each industry, and the number of IPCT's that are using chromates were estimated by procedures presented in Chapter 5. From the information presented in detail in Chapter 5, it is estimated that IPCT's are used at approximately 189 petroleum refineries, 1,824 chemical

manufacturing plants, 210 primary metals plants, and 599 plants in the miscellaneous industries.[1-3] In addition, the percentage of cooling towers using chromium-based water treatment chemicals in each industry is estimated as 20 percent at petroleum refineries, 10 percent at chemical manufacturing plants, 10 percent at primary metals facilities, 7.5 percent at plants in the tire and rubber industry, and 2.5 percent at plants in the other miscellaneous industries.[4-7] These estimates result in a total of about 790 IPCT's using chromium-based water treatment chemicals: 136 at petroleum refineries, 510 at chemical plants, 97 at primary metals plants, and 47 at miscellaneous plants.[8-15] The nationwide baseline Cr^{+6} emissions from these towers are estimated to be 22.9 megagrams per year (Mg/yr) (25.3 tons per year [tons/yr]).

3.3 INDUSTRIAL COOLING SYSTEM COMPONENTS

3.3.1 Cooling Tower

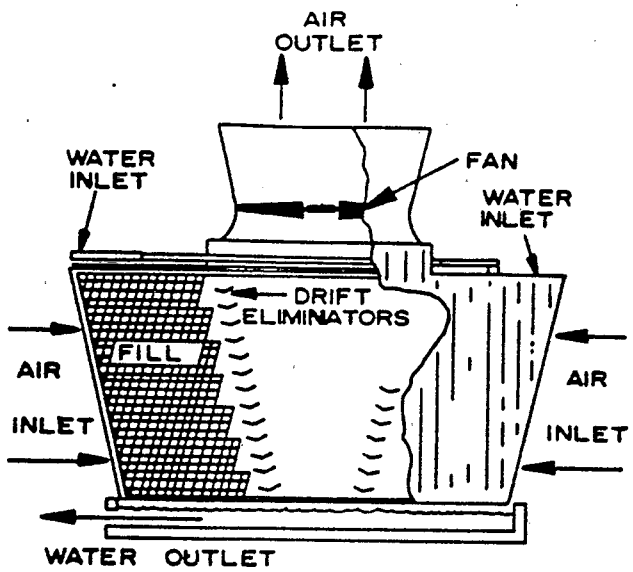
Cooling towers are devices that cool warm water by contacting it with ambient air that is drawn or forced through the tower. Typically, about 80 percent of the cooling occurs from evaporation of water as the air flowing through the tower contacts water cascading from the top to the bottom of the tower. The remaining 20 percent of the cooling is the result of sensible heat transfer that raises the air temperature.[16] Most tower systems are designed with recirculating water systems to conserve water resources or reduce costs of purchasing water. The major cooling tower components include the fan(s), fill material, water distribution deck, or header, drift eliminator, structural frame, and cold water basin. Other components that affect tower operation include the pumps and pipes necessary to circulate the cooling water through the cooling tower and heat exchanger loops.

Most IPCT's are designed with induced-draft airflow, but many have forced-draft airflow, and some (especially in the utilities industry) have natural-draft airflow. Induced draft is provided by a propeller-type axial fan located in the stack at the top of the tower. Forced-draft towers are usually smaller than induced-draft towers and have either centrifugal fans

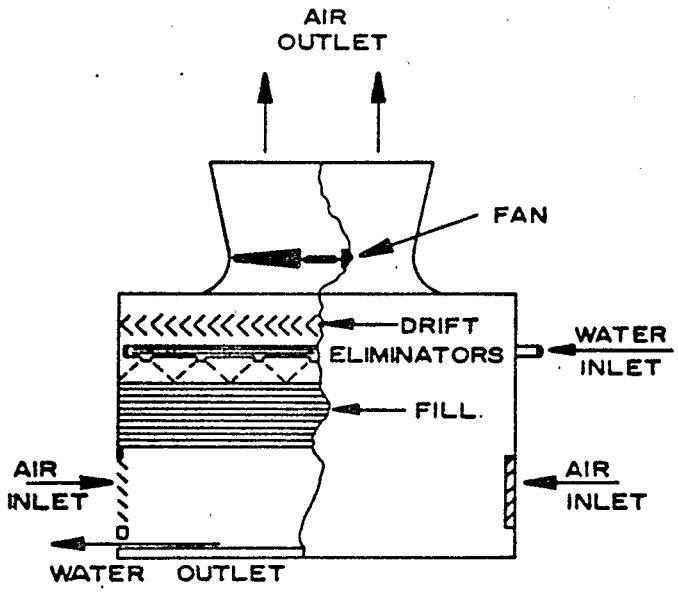
located at the base of the tower, which is constructed as a plenum to provide positive-pressure airflow through the fill material, or axial fans located on the side of the tower. Natural-draft airflow relies on air currents created by temperature differences between the air in the tower and the atmosphere. When the cooling demands are minimal and the air temperature is low enough, water can be circulated through the tower and cooled sufficiently without using the fans. In these instances, a natural draft is created in the cooling tower. In addition, the direction of the airflow through a mechanical draft tower is either crossflow or counterflow. Crossflow refers to horizontal airflow through the fill, and counterflow refers to upward vertical airflow. Schematics of counterflow and crossflow cooling towers are presented in Figure 3-1.

Fill material is used to maintain an even distribution of water across the horizontal plane of the tower and to create as much water surface as practical to enhance evaporation and sensible heat transfer. The fill material improves the water-to-air interface by creating either a large number of water droplets or many thin vertical sheets (or tubes) of water. Splash fill is constructed as successive layers of staggered impact surfaces in the form of bars. Small droplets are formed as warm water falls through the fill and splashes off each layer. Splash fill typically is constructed of wood, polyvinyl chloride (PVC), polystyrene, polypropylene, or asbestos cement board. Film fill is constructed of sheets of material in a "honeycomb" configuration. The fill is oriented such that water enters the open end of the honeycomb and flows vertically in sheets along the surface of the fill material. Typically, film fill materials are PVC, polystyrene, or polypropylene. Schematics of both splash and film fill are presented in Figure 3-2.

The mechanism by which the warm water is distributed over the fill material depends on the type of tower. In crossflow towers, there is a water distribution deck above the fill material at the top of the tower. The floor of this deck contains gravity flow nozzles, and the water level in the deck



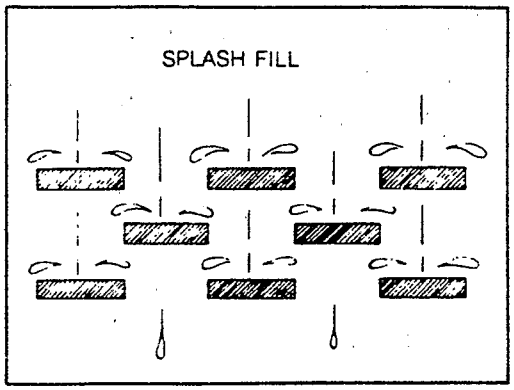
MECHANICAL DRAFT
CROSS-FLOW TOWER



MECHANICAL DRAFT
COUNTER-FLOW TOWER

Figure 3-1. Internals of crossflow and counterflow cooling towers.

(Reprinted from Drift Technology for Cooling Towers, The Marley Company, 1973.)



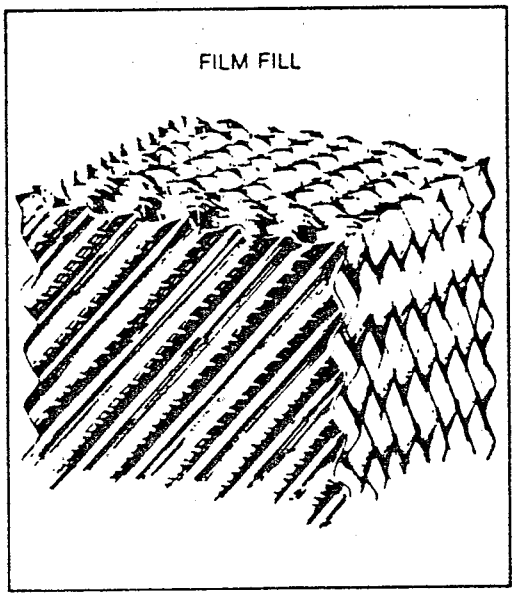


Figure 3-2. Details of splash fill and film fill.
(Reprinted from Custodis-Cottrell product brochure.)

controls the rate of water flow onto the fill. In counterflow towers, the water distribution system is constructed of a series of header pipes connected to pressure flow nozzles placed above the fill material. In both systems, the nozzles are arranged to provide even water distribution over the fill material.

Water droplets entrained in the air and the dissolved and suspended solids contained in the droplets that are emitted from cooling towers are referred to as drift. (Drift is discussed in Section 3.6.) Drift eliminators can be installed at the exit of the fill sections to reduce the amount of drift in the exiting airflow. The efficiency of a drift eliminator is a function of its design. Figure 3-3 presents schematics of the three major drift eliminator designs: herringbone (blade-type), waveform, and cellular (or honeycomb). 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 are constructed of wood, PVC, metal, asbestos-cement, polystyrene, or cellulose. The material most often specified is PVC. Drift eliminators installed in towers built in recent years are more likely to be high-efficiency waveform or cellular units, but a large number of older towers still have low-efficiency eliminators.

The structural frame of cooling towers can be wood, concrete, masonry, steel, and combinations of these materials. The cold water basins (reservoirs) typically are located directly below the fill material at the base of the cooling tower. Basin size is affected by the size of the tower and by the necessity to accommodate any short-term fluctuations in the water volume of the system.

3.3.2 Heat Exchangers and Cooling Water Cycle

In a typical IPCT system, cooling water is pumped from the cooling tower basin to the heat exchanger(s) served by the tower, and the heated water flows back to the cooling tower water distribution deck. The cooling water loop may include numerous separate heat exchangers of various designs. Heat exchangers are designed to transfer heat from one fluid to another. The

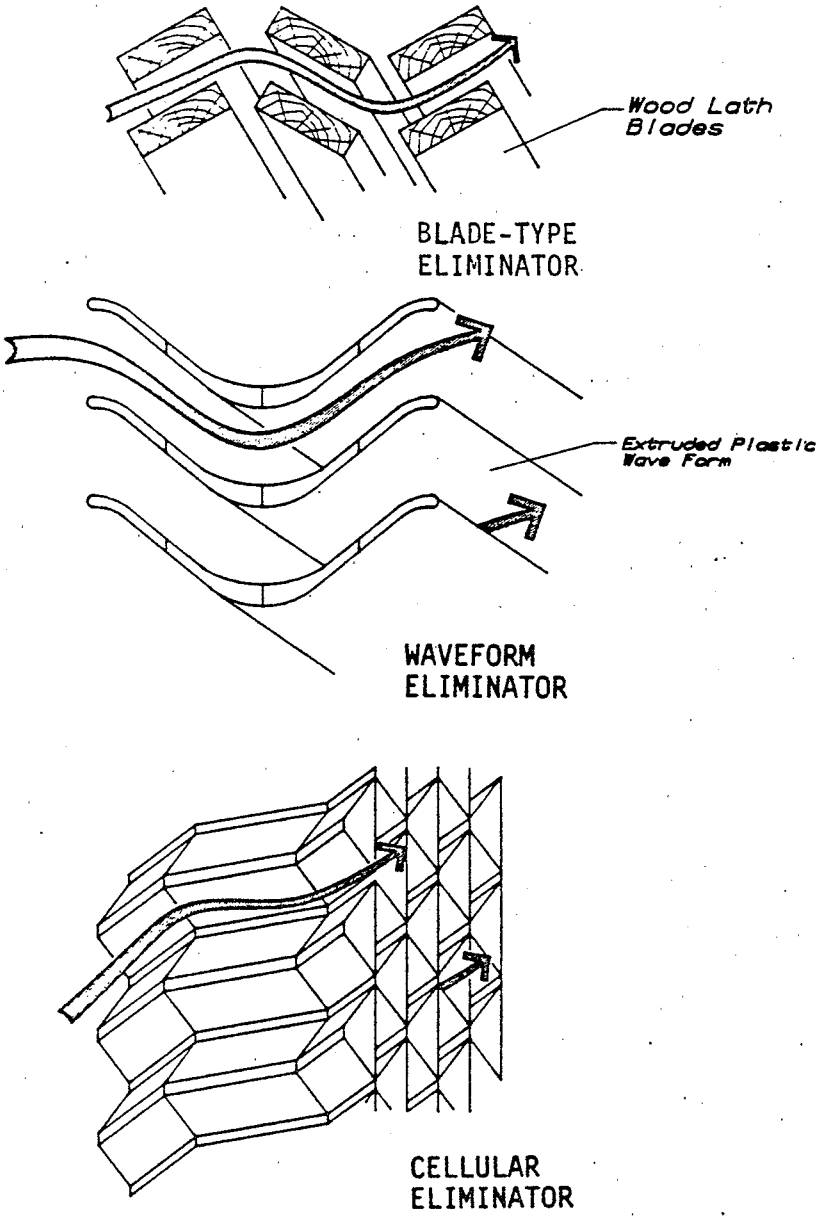


Figure 3-3. Operating principles of various drift eliminators.

(Reprinted from Reference No. 17.)

transfer can occur directly by mixing the hot and cold materials or indirectly through a device separating the hot and cold materials. Indirect heat exchanger types include shell-and-tube, flat plate, and spiral designs. In most industries, heat transfer is accomplished with shell-and-tube heat exchangers that typically are constructed from carbon steel.[16] However, metals such as stainless steel, copper, and admiralty brass are also used. Graphite blocks, titanium, Hastelloy, and other very corrosion-resistant metals are used in severe environments.

Although maximum process fluid temperatures may exceed 1000°C (1832°F), the bulk fluid process temperatures at the inlets to the heat exchangers are much less than the process fluid temperatures due to heat losses between the process reactor and heat exchangers. In addition, because the volume of cooling water is much greater than the volume of process fluid that is cooled per unit time, and because of other losses in heat, the temperature of the cooling water within the heat exchanger (bulk water temperature) rarely exceeds 70°C (160°F) in most IPCT systems. The temperature of the heat exchanger material (skin temperature) on both the process side and the water side of the exchanger is less than the process fluid temperature and greater than the bulk water temperature.

The side of the heat exchanger providing the cooling is referred to as the water side, and the side with the process fluid is referred to as the process side. The water side of the heat exchanger is of primary interest for the cooling tower source category because of the effects of cooling water treatment programs on operating and maintaining the heat exchangers. Water velocities in heat exchangers vary but normally range between 0.9 to 2.4 meters per second (m/s) (3 to 8 feet per second [ft/s]).[18]

3.4 CHEMICAL TREATMENT PROGRAMS

3.4.1 Purpose

Chemicals are added to the recirculating cooling water to inhibit the corrosive effects of the water, to control the rate of scaling and fouling, and to control the growth of microorganisms in both the cooling tower and the heat exchangers.

As evaporation occurs during cooling, the chemical constituents of the water become concentrated. A percentage of the recirculating water is intentionally discharged (blowdown) to limit the concentrations of suspended and dissolved solids to acceptable levels. Also, as water cascades through the tower, some is entrained and emitted from the stack as drift. Fresh water (makeup) is added to make up for the losses resulting from evaporation, blowdown, and drift.

Typical water treatment program chemicals include (1) a corrosion inhibitor, (2) an antiscalant, (3) an antifoulant, (4) a dispersant, (5) a surfactant, (6) a biocide, and (7) an acid and/or caustic soda for pH control. Chromium-based chemicals are corrosion inhibitors. The quality of the cooling tower water supply directly affects the type and quantity of chemicals required to maintain a satisfactory chemical treatment program. The three problems--corrosion, scaling and fouling, and microbiological growth--and the chemicals used to control them are discussed later in this section.

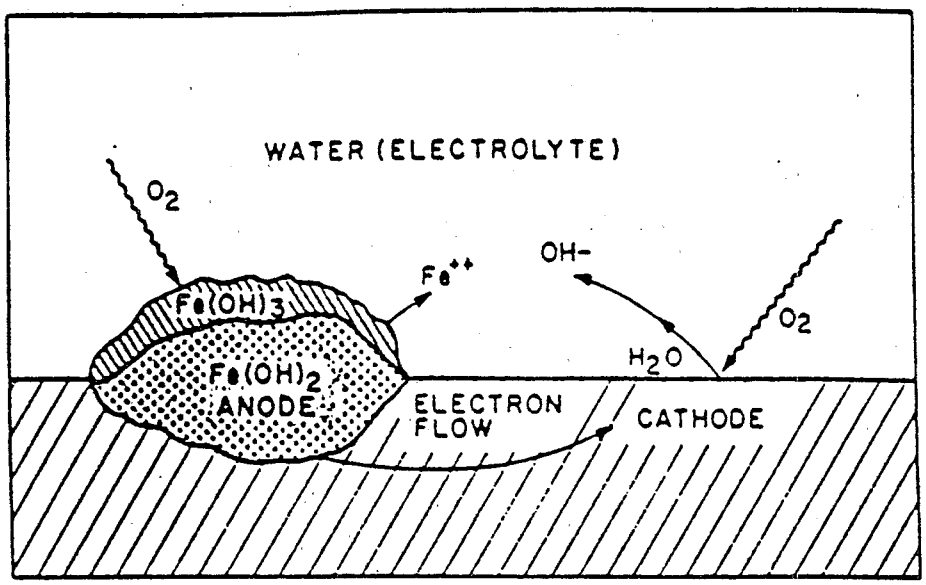
Physical parameters that affect the selection of chemical treatment programs include heat exchanger material, bulk water and water-side skin termperatures, water velocity, and holding time index.[19,20] The holding time index is usually defined as the half-life of the recirculating water, or the time required for half of the recirculating water to be replaced.

Major water chemistry parameters that affect the selection of chemical treatment programs include pH, calcium hardness (calcium ion concentration), alkalinity (bicarbonate, carbonate, and hydroxide ions), chloride, sulfate, silica, iron, dissolved solids (conductivity), and suspended solids.[19,20] Water quality also directly affects the number of cycles of concentration that can be maintained. The number of cycles of concentration is defined as the ratio of either the conductivity or calcium hardness of the recirculating water to that of the makeup water. The maximum allowable conductivity or calcium hardness is established based on the chemical treatment program and the acceptable rates of corrosion and scaling. In general, limits

are set so as not to exceed the mineral solubility and cause scale formation. Generally, the higher the water hardness or recirculating water pH, the fewer the cycles of concentration allowable. Recently developed calcium dispersants allow more cycles of concentration or higher pH in IPCT operations.

3.4.2 Corrosion

3.4.2.1 Description. Corrosion is the oxidation of a metal by some oxidizing agent in the environment. The area over which metal is oxidized (corroded) is called the anode; the area over which the oxidizing agent is reduced is called the cathode. In water, an electrochemical cell is formed in which cations migrate toward the cathode, anions move toward the anode, and electrons flow through the metal from anode to cathode. Water is the conducting fluid or electrolyte, and the metal surface develops anodic and cathodic areas as the result of differences in electrochemical potential, temperature, and the concentration of dissolved oxygen or solids. In equipment made from a single type of metal, differences in electrochemical potential occur as the result of impurities in the metal, localized stresses, grain size or composition differences, and discontinuities on the surface.[21] An electrochemical potential difference also is created when two different metals are in contact both with each other and the same solution. This electrochemical potential difference causes galvanic corrosion in the active (or least noble) metal that serves as the anode.[21,22] For both single and multiple metal systems, local differences in dissolved oxygen and solids concentrations and in temperature also cause anodic and cathodic areas in the metal to form. Anodic surfaces will exist in regions of low oxygen concentration, low temperature, and high salt concentrations.[16,23] As the anode corrodes and releases cations to solution, electrons are released that flow through the metal to the cathode. The flow of electrons through the metal is the corrosion current, which is limited by the rate at which electrons are accepted by the oxidizing agent at the cathode. Figure 3-4 illustrates the mechanisms for corrosion in a single metal and presents the reactions at the anode and cathode.



ANODIC REACTIONS

$$Fe \rightarrow Fe^{++}+2e^-$$

$$Fe^{++}+2OH^- \rightarrow Fe(OH)_2 \text{ (soluble form)}$$

$$Fe(OH)_2+H_2O+\tfrac{1}{2}O_2 \rightarrow 2Fe(OH)_3 \text{ (insoluble red-brown deposit)}$$

CATHODIC REACTIONS

$$\tfrac{1}{2}O_2+H_2O+2e^- \rightarrow 2OH^- \text{ (at pH >4)}$$

$$2e^-+2H^+ \rightarrow H_{2gas} \text{ (at pH <4)}$$

$$1\tfrac{1}{2}H_2+O_{2gas} \rightarrow H_2O+OH^-$$

Figure 3-4. Corrosion mechanism on carbon steel surface. (Reprinted from Reference 21.)

Two primary types of corrosion occur in cooling water systems depending on the equipment design and the system operation: general and localized corrosion.[16,18,21,22] In general corrosion (the less harmful type of corrosion), the metal dissolves uniformly. General corrosion occurs when the local concentration or temperature difference along the metal surface causes differences in electrochemical potential and creates corrosion cells. The movement of these cells from place to place on the metal surface as concentrations and temperatures fluctuate cause uniform corrosion along the surface of the metal.[21] However, the corrosion rate is enhanced by high concentrations and temperature. Fouling from corrosion products is likely to be the major problem when general corrosion occurs.[21,22]

Localized corrosion, typically in the form of pitting, occurs when the anodic sites remain stationary and corrosion proceeds rapidly at localized points. Corrosion of this type is a more serious problem than general corrosion in industrial systems because it can cause metal to perforate in a very short time.[21,22] Pitting corrosion is the formation of cavities or holes in the metal and can occur in crevices within a metal, at joints between metal sections, and under deposits of suspended solids and precipitating chemical species. Conditions that promote these deposits are low-velocity water flow, high concentrations of dissolved solids, and high pH.[21] Pitting can also occur when a dissolved cathodic (less active) metal plates out in spots on an anodic (active) surface. This most serious form of galvanic corrosion typically occurs in systems containing both copper and steel components. The copper can plate out on steel surfaces, causing galvanic corrosion of the steel. Once the plating occurs, it is very difficult to inhibit the resulting corrosion.[21] Severe localized galvanic corrosion also can result if the anodic area is small relative to the cathode; when the electron flow is from a small anodic area to a large cathode (which serves as an electron sink), the anode corrodes rapidly and a pit develops. However, when the anodic surface area is substantially larger than the cathodic surface, the corrosion is

general in nature because only a thin layer of metal will be removed over time. Pitting corrosion can also occur when small anodic areas are left unprotected by inhibitors, as discussed below.

3.4.2.2 Corrosion Inhibitors. Inhibitors are added primarly to protect the heat transfer surfaces from corrosion. These surfaces are the most critical metal components in the system. Corrosion can be retarded, but not totally prevented, and the rate of corrosion that is acceptable varies among systems. The terms and corrosion rates presented in Table 3-1 are generally used to describe the severity of carbon steel and copper corrosion.

Corrosion inhibitors used in a recirculating system limit the rate of reaction at the anode, the cathode, or both. The mechanisms by which these inhibitors protect the metal are passivation, precipitation, and adsorption. Anodic and cathodic inhibitors produce a barrier film, or deposit, on the anodic and cathodic metal surfaces, respectively. The barrier created by passivation is an oxide that forms on the metal surface, and the barrier created by precipitation is an insoluble precipitate that coats the metal surface. Typically, anodic inhibitors are passivators, and cathodic inhibitors are precipitators. Table 3-2 lists various anodic and cathodic inhibitors. Molecules that have polar properties provide a barrier by adsorbing on the entire metal surface. Adsorption inhibitors are usually organic compounds.[18,21,22]

The rate of corrosion at the anode is controlled by the rate of the cathodic reaction (i.e., the same mass of the anode corrodes for a given cathodic reaction rate). Thus, pitting may occur if only small spots of the anodic surface remain unprotected and the cathodic reaction is not controlled by cathodic inhibitors and/or organic adsorption inhibitors. Although chromate is an excellent anodic inhibitor, the likelihood that small spots will remain unprotected increases as the concentration of chromate maintained in the recirculating water decreases.[18,21,22]

TABLE 3-1. QUALITATIVE CLASSIFICATION OF CORROSION RATES[18]

Description	Corrosion rates, μm/yr (mils/yr)[a]	
	Carbon steel	Copper alloy
Negligible	<25.4-50.8 (<1-2)	<2.54 (<0.1)
Mild	50.8-127.0 (2-5)	3.81-5.08 (0.15-0.2)
Moderate	127.0-254.0 (5-10)	5.08-8.89 (0.2-0.35)
Severe	>254.0 (>10)	12.7-25.4 (0.5-1)

TABLE 3-2. ANODIC AND CATHODIC CORROSION INHIBITORS

Anodic	Cathodic
Chromate	Polyphosphate
Molybdate	Zinc
Orthophosphate	Polysilicate
Nitrite	
Orthosilicate	

3.4.2.2.1 Chromium-based inhibitors. Chromates historically have provided the best protection against corrosion for the money and effort. Less stringent monitoring and control of chemical concentration and pH are required with chromates than with alternative treatments. Even if the inhibitor feed is temporarily interrupted, the existing barrier film will continue to provide protection for several days.

Chromate concentration typically must be maintained above 200 parts per million (ppm) if the chromates are used alone in the recirculating water. However, chromates (which are anodic inhibitors) typically are used in combination with cathodic inhibitors. In these combinations, smaller concentrations of chromate provide the same corrosion protection that is provided by high concentrations of chromate alone. Vendors provide many chromium-based formulations for use in IPCT's. The chromium concentrations in these formulations generally range from 3 to 30 ppm as chromate. However, very few plants use chromate in concentrations of less than 10 ppm, and the results obtained with these "low" chromate water treatment programs have been mixed. Programs that contain less than 10 ppm of chromate require tighter chemical control and more expensive chemical additives than are required for formulations that use higher chromium concentrations. Plants that use chromates prefer to use higher chromate concentrations (i.e., 10 ppm or more) to avoid the additional costs for additives and tighter control requirements.

The inhibitor chemicals most commonly added to chromate-based formulations are zinc and phosphate; but organic compounds, polysilicates, and molybdates also are used. Some of the effects that these compounds have on the treatment program are discussed below, but because the same chemicals are used in nonchromate treatment programs, they are discussed in greater detail in Section 4.1.1. Table 3-3 provides concentrations and typical operating conditions of some of the corrosion inhibitor formulations discussed in various publications.[18,21,22]

Molybdates are anodic inhibitors that protect all metals but are most effective on steel. Zinc is an effective cathodic

TABLE 3-3. CHROMATE-BASED CORROSION INHIBITORS[18,21,22,24,25]

Chromate/zinc	5-20/2.5-10	pH 6.5-7.0
Chromate/orthophosphate	20-25/3-3.5	pH 7.0-7.5
	5-10/10	pH 6.2-6.8
Chromate/orthophosphate/zinc	15-25/2-5/2-5	pH 6.2-6.8
Chromate/polyphosphate/zinc	15-25/2-5/2-5	pH 6.0-7.0
	10-30/3-5/3-5	pH 6.5-7.0 CaH 100-600 ppm[c]
	20-25/5-10/2.5-3.0	pH 6.0-6.5 CaH <400
Chromate/zinc/phosphonate	15-25/2-4/3-5	pH 6.5-7.5
	2-3/2-3/5-10	pH 6.5-7.0
	20-25/2-4/3-5	pH 6.5-7.0
Chromate/phosphonate/specified	5-10/3-5	Not specified
Chromate/phosphonate/dispersant	5-15/2-6/2-6	pH 7.5-8.5
Chromate/dispersant	3-5/30	pH 7.5-8.0
	5-10/3-6	pH 7.5-8.0
Chromate/polysilicate	5-10/5-10	pH >7.5
		Si <10 ppm
Chromate/zinc/dispersant	10-20/1-2/1.5-10	pH 7.0-9.0
	10-15/1-2/5-10	pH 7.5-9.0
Chromate/molybdate	10-30/1-5	pH >7.5

[a]In all combinations except chromate/polysilicate, the organic triazole corrosion inhibitors should be included at 1 to 10 ppm when the system contains copper.
[b]The components of some combinations can be formulated differently for different applications.
[c]CaH is calcium hardness.

inhibitor for steel when the pH is below about 8.0; with increasing pH, the solubility of zinc decreases, and fouling may result. Polyphosphates also are effective cathodic inhibitors for steel, but they may react with copper or aluminum. Consequently, organic azoles are added to formulations containing phosphate that are used in systems containing components made with copper alloys. In addition, because of the nutrient value of polyphosphate, it is especially important to monitor microbiological activity and maintain the recommended types and concentrations of microbiocides in the recirculating water when polyphosphate is used. Orthophosphates are effective anodic inhibitors, but they typically must be used in small quantities or in conjunction with phosphate-specific dispersants to reduce the likelihood of fouling.

3.4.3 Scaling and Fouling

3.4.3.1 Description. Scale formation occurs when dissolved solids and gases in cooling water reach their limit of solubility and precipitate onto piping and heat transfer surfaces. Fouling occurs when deposits of dirt, leaves, and/or flocculations of insoluble salts or hydrous oxides produced by corrosion agglomerate in the heat exchanger tubes. Scaling and fouling reduce the flow rate and heat transfer in any heat exchanger. These conditions also contribute to pitting-type corrosion by creating corrosion cells and preventing the corrosion inhibitor from contacting the surface of the metal. Calcium carbonate is the most common scale found in cooling water systems, but calcium sulfate and calcium phosphate also can be formed in many systems. All three types of scale become less soluble and, therefore, more likely to form at high temperatures. Calcium sulfate is more likely to form at low pH, and the other two scales are more likely to form at high pH.

3.4.3.2 Antiscalants and Antifoulants. Control of scaling and fouling is achieved by controlling deposition onto surfaces. Deposition can be affected by changing the solubility of scale-forming salts, reducing the crystalline growth capacity of scale-

forming salts, and dispersing constituents that form fouling-related flocculations.

Chemical compounds that are commonly used and are the most effective in controlling the rate of scaling include polyphosphates, phosphonates, and polymeric and copolymeric dispersants. These compounds reduce the crystalline growth capacity of calcium salts. Certain phosphonate compounds affect the solubility of the calcium salts and reduce the formation of scale. Polymeric dispersants reduce the potential for fouling.[18,21,22]

Phosphonates typically are added to chromate-zinc formulations as an alternative to phosphate because phosphonates control scaling better than phosphate does. Also, the amount of chromate can be reduced when phosphonate is used because the phosphonate system can be operated at a slightly higher pH. A disadvantage of using phosphonate is that the powerful oxidizing potential of chlorine can promote corrosion of copper if phosphonates are present in the system. Adding benzotriazole (or other azoles) and dispersants can effectively control this problem. Phosphonates are also subject to biological oxidation, which results in the release of orthophosphonate ions that can cause fouling as well as reduce the recommended concentration of phosphonate. However, fouling is much less of a problem in systems treated with phosphonate than in systems treated with polyphosphates.[18]

3.4.4 Microbiological Control

Three types of microorganisms are found in cooling tower water systems: bacteria, fungi, and algae. Bacteria are dispersed in the water, fungi invade wood components, and algae attach to surfaces in the tower. Slime produced by bacteria can coat heat exchanger surfaces and aggregate debris on those surfaces, thereby reducing the efficiency of heat transfer. Biological deposits on metal surfaces also can accelerate pitting corrosion. Fungi can decay wood either by surface attack (soft rot) or internal attack of the cellulose (white rot) and, thus, are a threat to the structural integrity of wooden towers. Algal

growth can coat the fill material and reduce the effectiveness of the water droplet formation and, thus, the effectiveness of heat transfer in the tower.

Microbiocides can be classified as oxidizing agents, enzyme poisons, organic chemical compounds, and miscellaneous compounds. The oxidizing agents include chlorine, bromine, and iodine. Chlorine is the most widely used and the least costly microbiocide. Enzyme poisons include methylene bisthiocyanate, acrolein, and heavy metals (e.g., copper sulfate, copper citrate, tin, phenylmercuric acetate, and methyl mercury). Acrolein and the heavy metals are considered to be outdated technology and are not known to be currently used in IPCT systems. Organic compounds include dodecylquamidine hydrochloride and quaternary ammonium salts and normally require high dosage rates. Most microbiocides used for treating cooling water are included in the categories above, but dithiocarbamates are a class of miscellaneous compounds that also are effective microbiocides. However, they reduce chromate and, thus, cannot be used in chromate-treated systems.[18,21]

Organic chemical compounds that either hydrolyze to relatively nontoxic forms or that can be detoxified are also used as microbiocides. Hydrolyzable materials include 2,3-dibromo-3-nitrilopropionamide, chlorinated cyanurates, and halogenated hydantoins. Chemicals that are both hydrolyzable and detoxifiable are methylene bis-thiocyanate and bromonitro-styrene. Isothiazolin is a widely used biocide that can be detoxified.[23]

3.4.5 Cooling System Control

A cooling system chemical feed and monitoring control system maintains the proper operating conditions of the cooling system to minimize corrosion and fouling. Addition of treatment chemicals is regulated to prevent overfeeding and underfeeding and thereby optimize performance and operating costs. Cooling system control is achieved by monitoring water quality conditions and feeding appropriate concentrations of the required treatment chemicals described previously. Control system components may

include pH and conductivity monitors, a blowdown control valve, corrosion inhibitor feed, acid feed, microbiological control chemical (biocide) feed, and a makeup water pump. The components of the control system may be completely automated via an integrated computer system, automated yet function independently of one another, controlled by a combination of automated and manual controls, or operated manually.

A minimum control system consists of pH and conductivity monitors and some sort of chemical feed system. This type of control system, whether manual or automated, maintains the proper pH for effective corrosion inhibition based on the type of corrosion inhibitor used. This basic control system also controls the blowdown through conductivity measurements to limit conditions that favor scaling or fouling. Computer-based control systems are available that automate water quality monitors and chemical feed pumps. The control system program operates the chemical feed pumps based on measurements of specific water quality parameters. Even tighter control of chemical addition is achieved through computer feedback loops in which the computer compares the actual water quality to planned water quality conditions and adjusts chemical feed pumps to achieve the desired water quality conditions.

The level of control automation required by a cooling system depends on whether manual control at the plant is adequate to maintain acceptable pH and conductivity. A system operated by experienced personnel may not require as much automated control as a plant with inexperienced personnel or a plant that lacks the employee time to adequately monitor the cooling systems. However, using automated equipment may offer savings in chemical costs to some cooling systems through quality control and tighter monitoring conditions, which are possible with computer-run systems. Although an automated control system may prove cost effective, nonchromate- and chromate-based treatment programs both can be operated successfully without such a system.[19,20]

3.5 MAINTENANCE REQUIREMENTS

The maintenance requirements for cooling towers and associated heat exchangers are a function of the effectiveness of the chemical treatment programs. The effectiveness of the corrosion inhibitor is important to the life expectancy of metal surfaces exposed to the recirculating water in both the tower and heat exchanger. Metal structural components of the tower such as steel columns and beams, connector plates and bolts, piping and pumps, valves, and controller equipment corrode from exposure to the cooling tower water. However, the most critical corrosion occurs in the heat exchangers. Excessive corrosion, followed by fouling in heat exchangers, will result in both the need for excessive tube bundle cleaning to maintain heat transfer and tube bundle replacements because of pitting corrosion.

Corroded tubes may be discovered during routine inspections of the heat exchanger, but, in many instances, contamination of the recirculating water with process fluid (or vice versa) is the first indication of failed tubes. Typically, the leaking tubes are identified and plugged. Some loss of efficiency or cooling capacity because of plugged tubes can usually be tolerated because cooling systems are often designed with an excess of heat exchange capacity. However, in some processes, this margin may not exist because production levels are such that a "capacity bottleneck" is present at the heat exchanger. A new tube bundle generally is required when about 10 to 15 percent of the tubes are plugged.

Scaling and fouling can occur in both the cooling tower and the heat exchangers. In the cooling tower, scaling and fouling can reduce tower heat rejection capacity by interfering with splash or film fill water distribution and the formation of water droplets. Airflow characteristics also can be altered when airflow passages in the fill and drift eliminator become blocked; this blockage increases the pressure drop across the system and reduces cooling efficiency. The tower fill and drift eliminator surfaces are inspected periodically and cleaned if necessary. Usually, this work is performed during a process shutdown.

However, cleaning may be required more frequently if the scaling rate increases because of poor control of the cycles of concentration, contamination problems, or lack of attention to the chemical treatment program.

Scaling and fouling in heat exchanger tubes reduce the heat transfer capacity because of the low thermal conductivity of the crystalline film created on the tube surfaces and flow restrictions that result. The level of scaling and fouling in heat exchangers and, thus, the level of maintenance required, can vary with changes or variations in the water treatment program. The scale and foulants can be removed physically by a process called rodding, by water blasting, or by flushing with acids. These physical cleaning methods require that the heat exchanger be taken out of service until the maintenance is completed. Alternatively, side stream filters can be used to continuously remove silt and other foulants while the system is in service. In industrial plants that operate nearly continuously, the heat exchangers may not be inspected and cleaned for 3 years or more unless a problem occurs. Chemical cleaning also can take place while the system is in service, but the effectiveness of this procedure depends upon the level of scaling or fouling. If strong acids are to be used, the heat exchanger will be taken out of service to protect ancillary cooling water system components.

3.6 COMPOSITION AND FORMATION OF DRIFT

Water droplets entrained in the air and the dissolved and suspended solids contained in the droplets that are emitted from the stack are referred to as drift. These droplets contain the chemical constituents, additives, and contaminants present in the recirculating water. The droplets are formed both from water's splashing down through the fill material and from the shearing action of the airflow along the water surfaces within the tower. In the past, drift was usually associated only with the loss of water from the tower stack, but the minerals, metals, and other constituents of the recirculating water are also emitted in the drift droplets. The rate at which drift is emitted from the tower (i.e., the drift rate) is primarily a function of the air

velocity through the fill material, the recirculation rate, and the type of fill material and drift eliminator used. Although air velocity has a greater impact on the drift rate, drift rate is usually expressed as a percent of the water recirculation rates for two reasons: most IPCT's are designed so that air velocities through the fill are comparable, and it is much easier to measure the water recirculation rate than the air velocity through the fill. The rate of water flow through the fill material is referred to as "water loading," and the range of water loading in IPCT's is typically 81.5 to 410 liters per minute per square meter of a horizontal cross section of the fill ($L/min/m^2$) (2 to 10 gallons per minute per square foot [$gal/min/ft^2$]).[26,27] The velocity of the airflow in the fill typically is from 91 to 213 meters per minute (m/min) (300 to 700 feet per minute [ft/min]). At 91 m/min (300 ft/min), the airflow will entrain all water droplets smaller than 370 micrometers (μm) in diameter (14.6 thousandths-of-an-inch [mils]). At 213 m/min (700 ft/min), water droplets smaller than 800 μm (31.5 mils) in diameter will become entrained in the airflow. A drift eliminator manufacturer indicated that drift rates are highest when the air velocity is at either end of the range. Within the overall range, minimum drift rates are obtained over a much broader range for high-efficiency drift eliminators than for low-efficiency drift eliminators.

Velocities in the stack are usually between 460 and 550 m/min (1,500 and 1,800 ft/min) and, thus, are capable of carrying droplets larger than 800 μm (31.5 mils) in diameter.[28] If droplets this large are created in or near the stack, possibly by collision between droplets in the turbulent air stream or by impingement and condensation of smaller droplets on structural members near the fan, they may also become entrained.

Splash fill towers tend to have higher drift rates than film fill towers, because splash fill is designed to create water droplets. As mentioned previously, herringbone design drift eliminators are the least efficient, and cellular drift

eliminators are generally the most efficient type of drift eliminator.

The recirculating water contains the corrosion inhibitors; other additives; naturally occurring silica and calcium- and magnesium-containing compounds; and other dissolved solids. The concentration of these dissolved solids increases in evaporating drift droplets. According to the theoretical calculations of evaporation rates used to generate Table 3-4, droplets that are created at 30 μm (1.2 mils) and below get much smaller as they evaporate, and the concentration of the solids in those droplets increases as evaporation occurs. Tests sponsored by EPA show that, in many cases, over 90 percent of the Cr^{+6} emissions are contained in droplets less than 30 μm (1.2 mils) in diameter.[29-31] Thus, the tower emissions may include water droplets containing various concentrations of dissolved solids, and the smallest of these droplets (<30 μm [1.2 mils] in diameter) may contain a significantly higher concentration of dissolved solids, including chromate.

3.7 DRIFT EMISSION RATE

As mentioned previously, drift is often expressed as the percentage of the recirculating water flow rate that is emitted. Based on test results, a drift eliminator manufacturer claims that the achievable drift rates range from 0.001 to 0.02 percent of the recirculating water. The approximate dividing line between drift rates for high- and low-efficiency drift eliminators is 0.04 to 0.02 percent. Those achieving a lower percentage are "high efficiency," and those that cannot achieve 0.02 percent are "lower efficiency."[32,33] However, it is important to note that drift rate results are highly dependent on the measurement method; therefore, achievable drift rate claims may not be comparable if they are based on different measurement methods. According to a cooling tower manufacturer, differences in drift rate measurement arise when drift is expressed in terms of a percentage of the water flow rate because drift is more a function of airflow rate than water flow rate. Therefore, drift should be expressed as a concentration of tower exhaust air

rather than as a percentage of the recirculating water flow rate. However, because water flow rate is more easily measured than exhaust airflow rate, industry prefers to express drift in terms of percentage of water flow rate.[32]

One drift measurement method employs a type of paper sensitive to the impingement of drift droplets. An impinging droplet leaves a mark on the paper that, after microscopic examination, can be correlated to the droplet size; thus, the total mass of drift water may be calculated. However, this method aerodynamically excludes droplets smaller than about 30 μm (1.2 mils) in diameter.[29,30] Traditionally, the main focus of drift control has been to minimize the deposition of droplets and salts in the vicinity of the tower; drift deposition on plant or personal property in the immediate area around the tower can be a nuisance. Droplets less than 30 μm (1.2 mils) do not deposit but evaporate further and remain airborne.[34] Thus, the sensitive paper method measures only the portion of the drift most likely to cause deposition problems in the immediate area around the tower.

Other measurement techniques collect drift droplets isokinetically. A mineral or a tracer in the collected drift droplets is recovered in a sample train for chemical analysis. The chemical analysis performed determines the mass of the mineral or added tracer recovered in the sample. Then, if it is assumed that the concentration of the salt or tracer in the drift is the same as that in the cooling water itself, the drift rate can be calculated. Minerals and tracers that have been used for analysis include, but are not limited to, sodium, calcium, magnesium, strontium, and chromium. The collection and recovery efficiencies for this type of method are greater than those of the sensitive paper method. Over time, several different sampling train configurations have been developed. For a given tower, different collection and recovery efficiencies may be obtained with each of these configurations. Therefore, drift rates measured with different configurations may not be comparable.

When these isokinetic methods are used to measure drift rates it is assumed that the mineral or tracer concentration in the drift is equivalent to that in the cooling water. If, because of droplet evaporation, the salt concentration is significantly higher in the drift than in the cooling water, this method may overestimate the drift water loss rate. However, regardless of this uncertainty in the drift rate, the emission rate of the salt is accurately measured with the isokinetic method. This study is primarily concerned with the chromium emission rate, not the actual drift rate of water and salt combined. Therefore, the EPA emission tests performed in this study report only the Cr^{+6} emission rate. For each test, the emission rate is expressed as a percentage of the Cr^{+6} recirculating rate. (Further discussion on the EPA test program is included in Section 4.1.4.) This percentage can equal the drift rate only if the equivalent concentration assumption is made.

3.8 REFERENCES FOR CHAPTER 3

1. United States Refining Capacity. June 9, 1986. National Petroleum Refiners Association. Washington, D.C. pp. 5-17.

2. 1987 Census of Manufactures. U.S. Department of Commerce. Washington, D.C.

3. Steel, USA: Into the '80's, Techno-Economic Report. Institute for Iron and Steel Studies. Green Brook, NJ. January 1980.

4. Letter and attachments. Roti, J., Drew Industrial Division, Ashland Chemical, to Crowder, J., EPA:ISB. July 16, 1991. Response to questionnaire on cooling water treatment programs and control equipment.

5. Letter and attachments. James, E., Betz Industrial, to Crowder, J., EPA:ISB. July 17, 1991. Response to questionnaire on cooling water treatment programs and control equipment.

6. Questionnaire. Eastin, P., Nalco Chemical Company, to Myers, R., EPA:ISB. August 5, 1991. Response to questionnaire on cooling water treatment programs and control equipment.

7. Questionnaire. Lutey, R., Buckman Laboratories, to Myers, R., EPA:ISB. August 6, 1991. Response to questionnaire on cooling water treatment programs and control equipment.

8. Responses to Section 114 information requests Nos. 1 through 94 listed on Table 5-14.

9. Telecon. Upchurch, M., MRI, with Dean, J., Brown and Williamson Tobacco Company. October 31, 1986. Number of cooling towers.

10. Telecon. Upchurch, M., MRI, with Gallo, T., Corning Glass Works, Inc. October 31, 1986. Number of cooling towers.

11. Telecon. Upchurch, M., MRI, with Mabry, R., Mount Vernon Mills. October 31, 1986. Number of cooling towers.

12. Telecon. Upchurch, M., MRI, with Durvin, T., PPG Industries, Inc. October 30, 1986. Number of cooling towers.

13. Telecon. Upchurch, M., MRI, with Jordan, S., PPG Industries, Inc.--Glass Division. October 30, 1986. Number of cooling towers.

14. Telecon. Upchurch, M., MRI, with Howard, W., Jr., R. J. Reynolds Tobacco Company. December 2, 1986. Number of cooling towers.

15. Telecon. Upchurch, M., MRI, with Ryan, S., Reynolds Aluminum. October 23, 1986. Number of cooling towers.

16. Chemical Engineers Handbook. 5th Edition. J. Perry and Chilton, eds. New York, NY. McGraw Hill. 1973.

17. Kelly, G. M. A System-Efficient Approach to Cooling Tower Energy Modifications. Cooling Tower Institute Technical Paper No. TP-85-18. New Orleans, Louisiana. January 1985.

18. McCoy, J. W. The Chemical Treament of Cooling Water. Chemical Publishing Company, Inc. New York, NY. 1983. pp. 8-12, 21-44, 124-187.

19. Memorandum. Marinshaw, R., MRI, to Myers, R., EPA:ISB. April 3, 1991. Trip report: Nalco Chemical Company, Naperville, Illinois, on February 22, 1991.

20. Memorandum. Marron, J., MRI, to Myers, R., EPA:ISB. April 3, 1991. Trip report: Betz Industrial, Trevose, Pennsylvania, on February 26, 1991.

21. Betz Handbook of Industrial Water Conditioning. 8th Edition. Betz Laboratories. Trevose, PA. 1980. pp. 167-190, 202-215.

22. Strauss, S. and P. Puckorius. Cooling-Water Treatment for Control of Scaling, Fouling, Corrosion. Power Magazine. June 1984. pp. S-1 through S-24.

23. The Nalco Water Handbook. Nalco Chemical Company. F. Kemmer, ed. McGraw-Hill Book Company. New York, NY. 1988. pp. 20.1-22.22, 38.3-38.30.

24. Letter. Macht, W., Betz Entec, Inc., to Randall, D., MRI. April 10, 1987. Biocides and chromate-based water treatment programs.

25. Letter and attachments. James, E., Betz Laboratories, Inc., to Crowder, J., EPA:ESED. March 27, 1987. Comments on draft background information document Chapters 3-6, 8.

26. Baker, D. Cooling Tower Performance. Chemical Publishing Company. New York, NY. 1984. pp. 120-129.

27. Telecon. Randall, D., MRI, with Depalma, T., Custodis-Cottrell. June 4, 1987. Effect of water loading on drift rate.

28. Telecon. Nicholson, B., MRI, with Kuharic, I., Marley Cooling Tower Company. October 15, 1986. Cooling tower parameters.

29. Emission Test Report: Exxon Company U.S.A., Baytown, Texas. EMB Report 85-CCT-3. November 1986.

30. Emission Test Report: National Bureau of Standards Steam and Water Chill Plant, Gaithersburg, Maryland. EMB Report 85-CCT-4. November 1986.

31. Emission Test Report: Southeastern Manufacturing Facility. Draft. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. September 1987.

32. Telecon: Bellin, P., MRI, with Holmberg, J., Marley Cooling Tower Company. April 2, 1985. Drift eliminator efficiency.

33. Telecon: Bellin, P., MRI, with Holmberg, J., Marley Cooling Tower Company. July 19, 1985. Drift eliminator efficiency.

34. Memorandum from Marinshaw, R., MRI, to Industrial Process Cooling Towers Project Files. September 9, 1991. Draft. Relationships between evaporation and droplet size.

4.0 EMISSION CONTROL TECHNIQUES

4.1 CONTROL TECHNIQUES

This chapter describes techniques that are available to reduce hexavalent chromium (Cr^{+6}) emissions from industrial process cooling towers (IPCT's). The control techniques discussed include substituting nonchromate-based chemicals for chromate-based water treatment programs and retrofitting towers with high-efficiency drift eliminators (HEDE's).

4.1.1 Nonchromate Treatment Programs

In recent years, research efforts in cooling water treatment technology have focused almost exclusively on alternatives to chromate for corrosion protection. The result has been the development of improved polymers that overcome the earlier scaling and fouling problems with nonchromates and that have made nonchromate water treatment programs more competitive to chromate-based programs in cost and effectiveness.[1] Nonchromate treatment programs typically consist of combinations of cathodic inhibitors, anodic inhibitors, antiscalants, and dispersants. Many of the compounds used in nonchromate programs are essentially the same as those used as additives in the chromate programs described in Section 3.4.2.2. With all nonchromate inhibitors, monitoring and control are critical. It is necessary to control carefully the recommended pH and inhibitor concentrations. Vendors typically recommend some level of automated control (i.e., automated control of chemical feed, blowdown, pH, or some combination of these).[2-5] However, most systems do not require total feed and control automation. Good control of nonchromate programs can be achieved manually. In addition, when chlorine is used as a biocide, microbiological control is more

critical for many of the nonchromate programs that require alkaline conditions because chlorine is less effective at higher pH levels than at the lower levels characteristic of chromate programs.[4]

Suitable operating conditions for common nonchromate treatment programs are shown in Table 4-1. Typical nonchromate formulations are based on phosphates, molybdates, zinc, and organics. These and less common programs are discussed below.

4.1.1.1 Treatment Formulations and Operating Conditions.

4.1.1.1.1 Phosphates. Phosphate-based programs are widely used in IPCT's. The constituents of phosphate-based treatment programs include orthophosphates and/or polyphosphates and dispersants. The "dispersants" used with phosphate programs are actually stabilizers that maintain the solubility of phosphate under conditions in which they would otherwise be insoluble. Concentrations of phosphates in water treatment programs generally range from 4 to 18 parts per million (ppm). If the system contains copper or copper alloys, azoles are included in the treatment program to prevent phosphate from reacting with the metal. With these combinations, effective corrosion control can be achieved and deposition of calcium carbonate and calcium phosphate scale can be minimized.

Phosphate inhibitor programs may be modified to treat water with water quality limitations. Increased use of additives or other program modifications may be required to operate a phosphate program successfully under high iron concentrations, high calcium hardness (>800 to 1,000 ppm $CaCO_3$), high water side skin temperatures (60° to 82.2°C [140° to 180°F]), and high chloride concentrations (up to 15,000 ppm chloride).[5] An advantage of phosphates over chromates is that they do not react with reducing agents (contaminants such as H_2S and organic compounds) in the recirculating water and, thus, do not lose their effectiveness in contaminated water.[3,6]

4.1.1.1.2 Molybdates. Until recently, molybdate treatments were rarely used in situations where the cooling water was contaminated because the cost of molybdate treatments, under even

TABLE 4-1. RANGES OF WATER QUALITY PARAMETERS FOR REPRESENTATIVE NONCHROMATE COOLING WATER TREATMENT PROGRAMS

Component and water quality parameters	Water treatment programs					
	1	2	3	4	5	6
Ortho-PO_4, ppm PO_4	15-18	--	4-8	10-14	5-15	5-15
Zn, ppm	--	<2	0.5-1.5	--	--	2-4
Organic-PO_4, ppm PO_4	--	<6	--	--	--	--
Other additives	--	--	Dispersant	Dispersant	Dispersant	Dispersant
Water quality parameters						
m-alkalinity, ppm as $CaCO_3$	0-200	>150	35-1,500	0-400	50-300	50-200
pH	6.8-7.8	8-9	7.3-9.2	6.8-9.0	6.5-8.0	<8
Iron, ppm	0-5	0-5	<=4	<=2	<2	<2
Total hardness, ppm as $CaCO_3$	0-2,000	0-1,200	15-1,000[a]	50-1,500	50-300	<500
Silica (SiO_2), ppm	0-200	0-200	<=150	<=180	0-100	0-100
Chloride, ppm	0-4,000	0-3,000	<1,500	1,500	No limit	No limit
Sulfate, ppm	0-6,000	0-3,000	<2,500	<2,500	0-1,000	0-1,000
Conductivity, μmhos	<20,000	<10,000	<6,000	<4,000	<3,000	<3,000
Bulk water temperature, °C (°F)	<65.6 (<150)	<65.6 (<150)	<71.1 (<160)	<60 (<140)	<65.6 (<150)	<65.6 (<150)
Water side skin temperature, °C, (°F)	<82.2 (<180)	<82.2 (<180)	<71.1 (<160)	<60 (<140)	82.2 (<180)	82.2 (<180)
Holding time index, d	3	3	5	<2	<7	<7

[a]Calcium hardness.

the best of conditions, was substantially higher than the cost of phosphate-based and other nonchromate treatment programs. When used alone, molybdate, like chromate, is required in very high concentrations to achieve satisfactory results (typically several hundred ppm or even higher for some conditions). However, molybdate formulations incorporating other inhibitors (azoles, zinc, phosphate), phosphonates, dispersants, and surfactants have been developed. With these new formulations, the molybdate concentration in the recirculating water can be as low as 2 to 6 ppm. As part of a zinc-based program, molybdate can reduce mild steel corrosion rates and may function as an inhibitor for pitting corrosion. For best results, it has been recommended that a passivating pretreatment be conducted for up to 1 week with molybdate at five times the maintenance dosage; but for many systems, pretreatment at two to three times the maintenance dosage for 24 to 48 hours is sufficient.[2,3,6,7]

Molybdate-based treatment programs are used successfully with a system pH in the range of 6.5 to 9.0. However, the metal oxide film can be easily destroyed if the system pH drops below the lower end of this range (i.e., when the environment is highly corrosive), and deposition from scaling and fouling can interfere with film formation when the system pH is at the upper end of the range. These potential problems are controlled by adding polymeric dispersants and phosphonates to the formulation. Although the quickest and best recovery from a pH excursion is accomplished with chromate treatments, recovery from short-term pH excursions reportedly is good with molybdate treatments. Molybdates are compatible with all oxidizing and nonoxidizing microbiocides. Automatic control of pH, blowdown, and inhibitor feed rate is recommended. Low water velocity should be avoided because it can cause fouling and deposition, which damage the film.[2,3,6,7]

4.1.1.1.3 <u>Organics</u>. A number of all-organic formulations can be used to control corrosion. Modified lignins and tannins, polyamines, phosphonides, phosphonium compounds, and heterocyclic nitrogen compounds have been used, separately or in combination

with each other, as primary corrosion inhibitors in all-organic formulations. Typically, the target concentration reported is that of the total product (inhibitor, antiscalant, dispersant, surfactant, etc.) rather than that of the primary corrosion inhibitor or other individual components. For most programs, the target concentration is 50 to 150 ppm of product. The cost of an all-organic program is greater than that of chromate and most other nonchromate programs because the chemicals are more costly and because larger amounts of the chemicals are required.

The most common heterocyclic nitrogen compounds are the azoles, which are excellent copper corrosion inhibitors. Azoles protect copper by repairing defects (penetration and areas of erosion) that occur in the naturally formed protective film of cupric oxide. They also act synergistically with the natural film of calcium carbonate precipitate. Tolytriazole is one of the most effective organic compounds, but it is the most difficult to formulate. The compound 2-mercaptobenzothiazole also is effective but is oxidized to the inactive disulfide form if chlorine is present. When the formulation contains azoles, another inhibitor also must be included to protect carbon steel components of the cooling system.

The introduction of organo-phosphorus compounds has led to a new treatment procedure known as the alkaline approach. This type of program relies on the natural alkalinity and the reduced corrosivity of the water at high pH to inhibit corrosion. The system pH is raised to 7.5 to 9.0, and the organo-phosphorus compound controls the precipitation of calcium carbonate and other scale-forming species. However, in some systems, especially those operating at high temperature or with low flow velocities, the program may also need to be supplemented with other inhibitors. An advantage of organo-phosphorus compounds is that, unlike polyphosphates, they do not revert to orthophosphate except under severe microbiological attack. Thus, the likelihood of fouling with organo-phosphorus programs is lower than with polyphosphate-based treatment programs.

The protective films produced by all-organic treatments are more easily damaged than those produced by chromate, and closer control of operating parameters is required with all-organic programs than with chromate. Microbiological growth and deposition must be strictly controlled to avoid interference with film formation, alkaline conditions must be maintained, and the inhibitor concentration (or total product) must not be allowed to fall below recommended levels. Typically, pH is maintained in the range of 7.5 to 8.5, although in some programs it can be higher (8.8 to 9). Because alkaline conditions decrease the toxicity of some biocides (e.g., chlorine and methylene bisthiocyanate), the consumption of biocides is greater with all-organic programs than with chromate programs. Alkaline conditions are a major advantage of all-organic programs because acid feed is not required.[8] Alkaline conditions also promote scale formation, especially if the water is very hard. Successful all-organic programs depend on the presence of some scale; organic phosphates such as the phosphonates are often included in the formulation to control the amount. The best results are achieved when the pH, blowdown, and inhibitor concentration are controlled automatically.[2,3,6,7,9]

4.1.1.1.4 Zinc. Zinc-based treatment programs typically include other inhibitors (e.g., phosphates and azoles) and organo-phosphorus and polymeric dispersants. The other inhibitors are added for synergistic effects to ensure adequate corrosion inhibition. A combination of azoles and zinc are necessary when the cooling system contains copper components because zinc (and phosphate) only protects ferrous components. Zinc in combination with polyphosphate (alone or with orthophosphate) can be effective when the calcium hardness of the water is too low for phosphates alone to maintain effective corrosion inhibition.

Dispersants are added because zinc may otherwise be precipitated from the recirculating water under typical operating conditions. Excessive levels of orthophosphate and contamination with hydrogen sulfide both may cause precipitation of zinc and

loss of inhibitor. In addition, zinc hydroxides may precipitate at high pH (greater than about 8) because zinc solubility decreases with increasing pH. However, various organic phosphorus compounds and polymeric dispersants can control the amount of deposition and increase the zinc solubility pH. Alkaline zinc programs (pH 7.5 to 9) have the highest temperature limitations of nonchromate programs.[8]

4.1.1.1.5 No corrosion inhibitor. A treatment program without a corrosion inhibitor is uncommon and is used only in systems that are easily controlled, that are constructed of very corrosion-resistant heat exchanger materials, or that are not subject to high temperatures or contamination. Only scale and fouling control agents are added, and a high pH is maintained. Calcium carbonate scale prevents corrosion, but the scale must be controlled; insufficient scale will not provide adequate protection, and excessive scale will hamper heat transfer. Therefore, makeup water must have calcium hardness, and the amount in the recirculating water must be monitored closely. Automatic controllers help prevent problems. If antiscalants and dispersants are not added, the number of cycles of concentration must be decreased to prevent deposition, and blowdown must be increased. However, excessive scaling is still likely to occur in systems with no corrosion inhibitor, and, thus, the maintenance effort is higher for such systems than for systems using a treatment program that includes a corrosion inhibitor.

4.1.1.1.6 Others. Nitrites and orthosilicates are two anodic inhibitors that are often used in closed systems but are rarely used in open systems. Nitrites are required in very high concentrations, are attacked by oxidizing agents and certain bacteria, are toxic to animal life, and are only about two-thirds as effective as chromate. Orthosilicates also must be used in high dosages, are slow to take effect, and are not as effective as the other nonchromate inhibitors.[3] Use of ozone as a corrosion inhibitor has been reported in a small number of cooling towers but has not been given wide acceptance by industry. No other chemicals are added with ozone to the

recirculating water; scale, corrosion, and microbiological growth are said to be controlled by ozone alone. However, rigorous monitoring and maintenance are required when ozone is used.[10]

4.1.1.2 Effectiveness of Nonchromate Treatment Programs. Due to the limitations of the early nonchromate-based water treatment programs, nonchromates were rejected by many in industry, particularly for IPCT systems that operated under high temperatures, which generally are found in petroleum refineries and chemical manufacturing plants. According to water treatment chemical vendors, the problems with the initial nonchromate-based programs have largely been overcome and nonchromate-based water treatment programs can be designed to achieve results comparable to chromates in most, if not all, IPCT systems.[4,5]

Some responses to information requests received in 1985 and 1986 from petroleum refineries and steel plants indicated that treatment cost, process debits, fouling, and corrosion rates increased when chromate programs were switched to nonchromate programs.[11-27] A few respondents indicated that the problems, especially fouling, became too severe to continue with nonchromates. However, other respondents indicated that nonchromates worked well. Information gathered more recently from four petroleum refineries and 18 high-temperature process chemical manufacturing plants more accurately demonstrates the performance capabilities of the nonchromate-based programs currently in use.

During site visits to four petroleum refineries, information was collected on 21 IPCT systems. Three of the four refineries used relatively poor quality makeup water and reported data on heat exchangers with carbon steel tubes that were subjected to severe process environments. Recirculation rates for the IPCT's ranged from 12,100 liters per minute (L/min) to 340,700 L/min (3,200 gallons per minute [gal/min] to 90,000 gal/min). The majority of the 21 IPCT systems have been operated on nonchromates for at least 6 years. In most of these IPCT systems, the nonchromate-based treatment programs have performed well and have achieved results comparable to previous chromate-

based programs. Although quantitative data on the changes in performance of the water treatment programs following conversion to nonchromates are limited, plant personnel were generally pleased with the overall performance of the nonchromates. Several operators pointed out that the more serious problems originate on the process side of the heat exchangers, rather than on the water side, and, thus, are not related to the type of water treatment program. Others also noted that serious problems with the water treatment program occurred only in heat exchangers that were operated outside the design ranges for temperature and flow and that the same problems occurred in these heat exchangers when chromate was used.

Three of the four refineries reported no apparent change in general corrosion rates (based on corrosion coupon data) following conversion to nonchromates. Estimated carbon steel corrosion rates for these three facilities were reported to be less than 1 mil per year (mil/yr). The fourth refinery, which had mostly welded carbon steel heat exchanger tubes, reported an increase in corrosion along the welded seams of the tubes following conversion to nonchromates. However, actual corrosion rates were not available. In addition, several of the plant's heat exchangers were reported to be operating above design temperatures.

Information on heat exchanger pitting was reported for three of the four refineries. Operators at one plant suspected that although the incidence of pitting had not changed, the pitting rate had increased following conversion. However, they had not yet gathered enough data to quantify the increase. Pitting in one IPCT system at another refinery was reported to have decreased following conversion. For the majority of the IPCT systems, however, there had been no apparent change in heat exchanger pitting.

Fouling generally was reported to be the same with both chromate-based and nonchromate-based programs. Two of the refineries reported serious fouling problems, but the problems occurred with both chromate-based and nonchromate-based programs.

Of the 21 IPCT systems on which information was collected, an increase in fouling was reported for only one system.[28]

To further investigate the performance of nonchromate-based water treatment programs in IPCT systems that served severe process environments, information was gathered from manufacturers of chemicals that are produced under high process temperaturers. As a first step, several industry representatives were asked to identify chemicals that are produced under very high temperatures. Additional high-process-temperature chemicals were identified from Kirk-Othmer's Concise Encyclopedia of Chemical Technology. Process temperatures for these chemicals ranged from 300°C (572°F) to 1,100°C (2,012°F). (The lower limit of this range was arbitrarily selected to ensure a reasonably large population of manufacturers from which information could be collected). A list of these chemicals and their corresponding process temperatures is provided in Table 4-2.

In response to an information request on the performance of nonchromates in IPCT systems that are operated under "severe" service conditions (i.e., systems with heat exchanger process-side skin temperatures in excess of (71°C [160°F]), 18 chemical manufacturing plants provided information on 41 IPCT systems. The IPCT systems targeted for this information request serve chemical manufacturing processes that require high process temperatures. Data were reported on a total of 524 heat exchangers in severe process environments. Recirculation rates for the 41 IPCT's ranged from 1,960 L/min to 624,600 L/min (520 gal/min to 165,000 gal/min), and averaged 132,500 L/min (35,000 gal/min). The IPCT systems have been operated with nonchromate-based programs for an average of 6.1 years and range up to 15 years. In addition to the high, and in some cases extremely high, heat exchanger operating temperatures, these systems are operated with wide ranges of makeup water conditions, heat exchanger materials, and various levels of control automation. Because chromate program data were unavailable for many of the systems, a comprehensive comparison of performance between chromate-based and nonchromate-based programs is not

TABLE 4-2. HIGH PROCESS TEMPERATURE CHEMICALS

	Compound	Temp., °C
1.	2- and 4-methylpyridine	350-550
2.	Acetaldehyde	480
3.	Adiponitrile (ADN)	--
4.	Allyl chloride	300
5.	Ammonia	--
6.	Anthraquinone	350-450
7.	Carbon monoxide	--
8.	Carbon tetrachloride	300-650
9.	Chloroform	650-775
10.	Epoxy resin (EPR)	--
11.	Ethylene	750-900
12.	Hydrogen cyanide (HCN)	1,100
13.	Methanol	--
14.	Propylene	600-800
15.	Tetrachloroethylene (PERC)	425
16.	Trichloroethylene (TCE)	280-450
17.	Vinyl chloride (VC)	450-550

[a]Based on Kirk-Othmer's Concise Encyclopedia of Chemical Technology.

possible. However, based on the information provided, the overall performance of the nonchromate-based programs appears to be good, and, in many cases, exceptional.

Based on the corrosion rate classification provided in Table 3-1, 37 of the 41 IPCT systems had either mild or negligible corrosion and 3 systems experienced moderate corrosion. The remaining system reported a range of 1 (negligible) to 14 (severe) mils/yr for the general corrosion rate. However, it should be noted that the two plants with the highest reported corrosion rates also reported problems with low pH excursions that could have accelerated corrosion in the systems.

Only 8 of the 41 systems were characterized as having greater than 5 percent "problem" heat exchangers (i.e., those experiencing severe corrosion, pitting, scaling, or fouling). Of these eight IPCT systems, one is reported to have had an increase in the number of problem heat exchangers following conversion to nonchromates, and three are reported to have had no change in the number of problem heat exchangers following conversion; chromate program data were not available for the other four systems. Only 7 of the 41 IPCT systems were reported to need carbon steel tube bundles replaced more often than an average of once every 10 years, and none of the plants reported a decrease in tube bundle life expectancy following conversion to nonchromates. In only one of the IPCT systems were process upsets reported to have a greater adverse effect on water treatment program performance following conversion from chromates to nonchromates.

The severity of the process environment was defined in terms of heat exchanger operating temperatures. The process environment was classified as severe if heat exchanger process side skin temperature exceeded 71°C (160°F). For the 524 heat exchangers reported to operate in severe process environments, process-side skin temperatures averaged 85°C (185°F) and ranged up to 307°C (585°F); inlet bulk fluid process temperatures averaged 101°C (214°F) and ranged up to 316°C (600°F); outlet bulk fluid process temperatures averaged 54°C (129°F) and ranged

up to 149°C (300°F); outlet bulk water temperatures averaged 38°C (100°F) and ranged up to 104°C (220°F).

Among the IPCT's reported to be operating in the most severe process environments were two IPCT's at the PPG Industries, Inc., plant in Lake Charles, Louisiana. These IPCT's serve vinyl chloride (TE-II tower) and tetrachloroethylene/trichloroethylene (Per Tri tower) processes. The TE-II IPCT system has been operated under a nonchromate-based program for 12 years and currently uses a molybdate/zinc corrosion inhibitor formulation. The Per Tri system has used a phosphate-based inhibitor for 15 years. Process-side skin temperatures for the two systems averaged 107°C (224°F) and 177°C (350°F), respectively. Other heat exchanger operating temperatures were also above the average for all of the systems on which data were reported. Both IPCT systems are operated at seven cycles of concentration, and pH, conductivity (blowdown), and chemical feed are manually monitored and controlled. In addition, in the TE-II system, three of the five severe process environment heat exchangers are operated below design flow--a condition under which more fouling and underdeposit corrosion would be expected than if the system operated at design flow. However, despite these conditions, a carbon steel corrosion rate of only 0.7 mils/yr (negligible) was reported for these two systems. No problem heat exchangers are reported for either system. In addition, neither system is reported to have problems with scaling, scheduled heat exchanger cleanings are required no more than once per year, and no unscheduled cleanings have been required.

Other IPCT systems that had heat exchanger operating temperatures among the highest reported include tower CT-301 EII, which serves an epoxy resin process at the Dow Chemical Company plant in Freeport, Texas, and the OHC tower, which serves tetrachloroethylene and dichloroethane processes at the Occidental Chemical Corporation plant in Deer Park, Texas. The CT-301 EII system was converted to a phosphate-based inhibitor in May 1990. At the same time, an integrated control system was installed. Carbon steel corrosion rates are reported to be less

than 2 mils/yr, which is comparable to the corrosion rate reported under the previous chromate-based program. Although other information on the performance of the nonchromate program for this system is limited, no problems are reported.

The OHC system has operated under a phosphate-based corrosion inhibitor for 2 years, and chemical control is fully automated. Carbon steel corrosion rates for both the current nonchromate and previous chromate programs are reported to be less than 1 mil/yr. Since the conversion to nonchromates, the scheduled cleaning frequency (once per year) has not changed and no unscheduled process shutdowns have occurred.

The only IPCT system for which high heat exchanger temperatures coincided with serious problems was the hydrogen cyanide/ammonia recovery IPCT system at the E. I. du Pont de Nemours & Company, Inc., plant in Victoria, Texas. In this system, process-side skin and inlet bulk fluid process temperatures were below or near average for the group, and outlet bulk fluid temperature was slightly above average, but outlet bulk water temperature (66°C [150°F]) was the highest reported. This system has experienced severe fouling since the conversion from chromate to a phosphonate corrosion inhibitor. However, water treatment program performance is expected to improve when the facility switches to a phosphate/zinc formulation in April 1991.

In order to analyze the data collected during these investigations, makeup water quality was defined in terms of pH and the concentrations of chloride, total hardness, and total dissolved solids. Typical freshwater ranges for these parameters are pH 6 to pH 8; 10 to 100 ppm chloride; 50 to 400 ppm total hardness as calcium carbonate; and 25 to 5,000 ppm total dissolved solids. Makeup water quality is considered poor if the water is characterized by levels of any of these parameters outside these typical ranges. In addition, total dissolved solids concentrations at the upper end of this range generally require pretreatment before use as makeup water. Makeup water quality for the 41 IPCT systems covered by the information

request varied considerably. Total dissolved solids ranged from 2 to 800 ppm, pH ranged from 6.0 to 10.5, and hardness ranged from 25 to 276 ppm as $CaCO_3$. Chloride concentrations ranged from 4 to 200 ppm during average rainfall conditions and in some systems up to 1,000 ppm during drought. Among the systems using the poorest quality makeup water, very few nonchromate program performance problems were reported. One facility with poor quality makeup water reported an increase in carbon steel corrosion rate and in the number of problem heat exchangers following the conversion from chromates to nonchromates. However, problems reported for other systems with poor quality makeup water were generally negligible.

Although tight control of water quality parameters and chemical feed is more critical for nonchromate-based than for chromate-based water treatment programs, the information request responses demonstrated that sophisticated control systems are not a requirement for successful nonchromate program operation. Generally, the performance of cooling systems under manual control is without notable problems. For example, the largest IPCT system for which information was obtained (recirculation rate of (624,600 L/min [165,000 gal/min]) was controlled manually and reported no problems with the water treatment program. Although more manually controlled systems than completely automated systems (i.e., systems with automated pH, blowdown, and chemical feed control) were identified as having some minor problems, manually controlled and semiautomated systems were reported to have roughly the same occurrence of only minor to negligible problems. The data indicate that completely automated systems produce slightly better results, but other factors must also contribute to the overall effectiveness of water treatment programs. The majority of IPCT's experienced only negligible performance problems regardless of the level of control automation.[29]

4.1.2 Reduction of Drift

Historically, the purpose of drift reduction has been to alleviate the nuisance deposition of water drift and its

dissolved solids on nearby buildings or on personal property such as automobiles. More recently, the concern has focused on the environmental impact caused by the compounds contained in the drift and, thus, the deposition of these compounds. Installation of HEDE's is the most common way to reduce drift.

Drift eliminators are designed with pressure drops lower than those of other air pollution control equipment and rely primarily upon the impaction of water droplets on drift eliminator surfaces to reduce the amount drift exiting the cooling tower. The drift eliminator blades are configured to force directional changes in the airflow such that the momentum of the water droplets causes them to impinge onto the blade surfaces. The number of directional airflow changes, the spacing between the blade surfaces, the angle of directional change, and the capability to return the collected water to a quiescent area of the plenum are the major design differences in drift eliminators that affect efficiency.

Figure 3-3 shows sketches of various types of drift eliminators. Low-efficiency drift eliminators include herringbone, some waveform (sinusoidal), and some cellular designs. Herringbone designs are constructed to create two or three major directional changes in the airflow. The blades are sloped in opposing directions in a manner that provides drainage of the accumulated drift into the fill area. The blades typically are constructed of wood, but other materials (e.g., metal and asbestos cement board) also are used. Waveform drift eliminators are configured in a sinusoidal wave pattern such that two major directional changes in the airflow are created. The sinusoidal blades are constructed of asbestos cement board or polyvinyl chloride (PVC) material. Cellular drift eliminators are configured with thinner blades in a honeycomb pattern. The airflow passages in the cellular drift eliminators, which are narrower than those of other designs, reduce the distance a droplet must travel across the stream to impact on the surface. Drainage of the collected water to prevent reentrainment is not a design criteria of low-efficiency drift eliminators (LEDE's).

High-efficiency drift eliminators include a few of both cellular and sinusoidal designs. The cellular HEDE's that achieve the higher efficiencies are designed with complex configurations that contain numerous, closely constructed airflow passages. Thin materials of construction are used to reduce the area of blockage to the airflow and minimize the pressure drop that is created by the eliminator. For sinusoidal drift eliminators, the blades are placed closer together in high-efficiency designs than in low-efficiency designs, and the exit is configured with a tip for draining captured water that normally is partially reentrained in the airflow. Typically, drainage of water into a quiescent area of the tower is a major design consideration of HEDE's.

The performance of a drift eliminator is affected primarily by the droplet or particle size and the airflow velocities through the drift eliminator. Small droplets are created both from evaporation of larger droplets and the physical breakdown of larger droplets into small droplets. Parameters that affect the rate of evaporation and the size of droplets created include the water distribution system, the type of fill, the type of tower, the meteorological conditions, and the temperature of the recirculating water.

A drift eliminator manufacturer indicates that HEDE's can remove 80 percent or more of the drift discharged from low-efficiency herringbone drift eliminators.[30] These drift eliminator efficiencies, however, are based on data collected with a test method that has not been submitted to EPA for approval. Five series of emission tests that included both sensitive paper measurements and isokinetic tests were conducted by EPA on towers equipped with LEDE's and HEDE's. Table 4-2 presents the results of the EPA-sponsored isokinetic tests at Exxon's Baytown, Texas, refinery; the National Institute of Standards and Technology (NIST), formerly the National Bureau of Standards in Gaithersburg, Maryland, a southeastern manufacturing facility (SMF); and Allied Fibers, Moncure, North Carolina.[31-35] Table 4-2 also presents the results of an emission test conducted

by Mobil Oil Corporation.[36] For each test, an emission factor was developed that expresses the Cr^{+6} emissions as a percentage of the Cr^{+6} recirculating in the tower. The Cr^{+6} emission factor calculated from the test results for towers equipped with LEDE's was set at 0.03 percent of the Cr^{+6} recirculating. The emission reduction achievable by using HEDE's instead of LEDE's was determined to be 67 percent in simultaneous tests of towers of similar construction and operation (except for the drift eliminator) at the SMF. Therefore, the Cr^{+6} emission factor for HEDE's was set at 0.01 percent of the Cr^{+6} recirculating. The Exxon and NIST data show that this level should be achievable by other towers equipped with HEDE's. The NIST and Exxon HEDE Cr^{+6} emissions are much lower than 0.01 percent of the Cr^{+6} recirculating, and the emission reduction for HEDE's over LEDE's at Exxon was about 88 percent. Although the Exxon towers were of different designs, they were operated in a similar manner during the tests. With the exception of the Allied test, the average emission factors presented in Table 4-3 are largely consistent with each other and industry estimates and are therefore believed to be adequate for estimating nationwide Cr^{+6} emissions. Additional discussion of the data and development of the emission factors is presented in Section 5.2.

For the EPA tests, in addition to isokinetic emission tests that were performed to determine Cr^{+6} emissions from five cooling towers, tests on three towers by the sensitive paper technique were conducted to determine the mass emissions and size spectra of the water drops greater than about 30 microns (μm) in diameter. Tests by the absorbent paper technique were conducted to determine the emissions of Cr^{+6} in droplets greater than about 30 μm in diameter. The results of these tests consistently indicated that greater than 90 percent of the Cr^{+6} emissions in the drift were smaller than 30 μm in diameter.[31,32]

Emission tests sponsored by EPA indicate that HEDE performance depends upon installation and maintenance practices. Inspections should be conducted periodically to ensure that the drift eliminators fit tightly around structural members so that

TABLE 4-3. SUMMARY OF EPA-SPONSORED AND EPA-APPROVED EMISSION TESTS[30-35]

	Cr^{+6} emission factor[b]	
	LEDE	HEDE
EPA-sponsored tests		
Exxon	0.0318[a]	0.0037[a]
NIST (1st test)	--	0.0038
SMF	0.0267	0.0087
NIST (2nd test)	--	0.0051
Allied --		0.337 to 1.471[c]
Industry test		
Mobil	0.033	--

[a]As discussed in Section 5.2, extreme outlying data were not included in these averages.
[b]Cr^{+6} emission rate expressed as a percentage of the Cr^{+6} recirculating rate.
[c]Based on test results for four surrogate elements.

cooling water cannot bypass them. In addition, towers should be inspected for leaks from the distribution deck planking to ensure there are no leaks bypassing the drift eliminators into the tower plenum. This leakage, which is often entrained in the high-velocity air in the stack, can cause high drift rates.

4.2 REFERENCES FOR CHAPTER 4

1. Memorandum. Marinshaw, R., MRI, to Myers, R., EPA:ISB. January 19, 1990. Meeting with George Brannon, Nalco Chemical Company, on December 6, 1989.

2. Betz Handbook of Industrial Water Conditioning. 8th Edition. Betz Laboratories, Trevose, Pennsylvania. 1980. pp. 167 to 190, 205 to 215.

3. Strauss, S., and P. Puckorius. Cooling-Water Treatment for Control of Scaling, Fouling, Corrosion. Power Magazine. June 1984. pp. S-1 through S-24.

4. Memorandum. Marinshaw, R., MRI, to Myers, R., EPA:ISB. April 3, 1991. Trip report: Nalco Chemical Company, Naperville, Illinois, on February 22, 1991.

5. Memorandum. Marron, J., MRI, to Myers, R., EPA:ISB. April 3, 1991. Trip report: Betz Industrial, Trevose, Pennsylvania, on February 26, 1991.

6. Simon, D. State-of-the-Art Survey of Nonchromate Cooling Water Corrosion Inhibitors. MTI Manual No. 4. Materials Technology Institute of the Chemical Process Industries, Inc. July 1980. pp. 1 to 24.

7. Letter and attachments. Metz, B., Wright Chemical Corp., to Crowder, J., EPA:ESD. April 9, 1987. Comments on draft background information document.

8. The Changing Chemistries of Cooling Water Treatment. M. Kaufman. Industrial Water Treatment. October 1990. pp. 13 to 16.

9. McCoy, J. W. The Chemical Treatment of Cooling Water. New York, New York. Chemical Publishing Company, Inc. 1983. pp. 8 to 12, 21 to 44, 124 to 187.

10. Historical Perspective of Cooling Tower Ozonation. A. Pryor and M. Bukay, ed's. Industrial Water Treatment. October 1990. pp. 26 to 32.

11. Letter and attachments. Evans, R., AMOCO Oil Company, to Myers, R., EPA:ISB. June 14, 1985. Response to Section 114 information request.

12. Letter and attachments. Simmons, R., ARCO Petroleum Products Company, to Farmer, J., EPA:ESD. June 3, 1985. Response to Section 114 information request.

13. Letter and attachments. Parker, F., Chevron U.S.A., to Farmer, J., EPA:ESD. May 16 and 31, 1985. Response to Section 114 information request.

14. Letter and attachments. Johnson, J., Exxon Company, U.S.A., to Farmer, J., EPA:ESD. May 20, 1985. Response to Section 114 information request.

15. Letter and attachments. Dunn, W., Gulf Oil Products Company, to Farmer, J., EPA:ESD. May 21, 1985. Response to Section 114 information request.

16. Letter and attachments. Johnson, R., Phillips Petroleum Company, to Farmer, J., EPA:ESD. June 5, 1986. Response to Section 114 information request.

17. Letter and attachments. Kienle, R., Shell Oil Company, to Farmer, J., EPA:ESD. May 22, 1985. Response to Section 114 information request.

18. Letter and attachments. Hawes, R., Mobil Oil Corp., to Farmer, J., EPA:ESD. May 20, 1985. Response to Section 114 information request.

19. Letter and attachments. Cox, R., Texaco U.S.A., to Farmer, J., EPA:ESD. May 24, 1985. Response to Section 114 information request.

20. Letter and attachments. Mullins, J., Shell Oil Company, to Farmer, J., EPA:ESD. August 7, 1986. Response to Section 114 information request.

21. Letter and attachments. Felderman, A., Union Oil Company of California, to Farmer, J., EPA:ESD. July 11, 1986. Response to Section 114 information request.

22. Letter and attachments. Kopeck, J., Union Oil Company of California, to Farmer, J., EPA:ESD. July 11, 1986. Response to Section 114 information request.

23. Letter and attachments. Campbell, R., Union Oil Company of California, to Farmer, J., EPA:ESD. July 11, 1986. Response to Section 114 information request.

24. Letter and attachments. Holmes, M., Chevron U.S.A., Inc., to Farmer, J., EPA:ESD. July 18, 1986. Response to Section 114 information request.

25. Letter and attachments. Boyer, D., Chevron U.S.A., Inc., to Farmer, J., EPA:ESD. July 18, 1986. Response to Section 114 information request.

26. Letter and attachments. Hannon, M., Chevron U.S.A., Inc., to Farmer, J. EPA:ESD. August 5, 1986. Response to Section 114 information request.

27. Letter and attachments. Lenz, G., Chevron U.S.A., Inc., to Farmer, J., EPA:ESD. August 5, 1986. Response to Section 114 information request.

28. Memorandum. Marinshaw, R., MRI, to Myers, R., EPA:ISB. May 15, 1991. Summary of information gathered from California petroleum refineries.

29. Memorandum. Marinshaw, R., and J. Marron, MRI, to Myers, R., EPA:ISB. June 7, 1991. Preliminary analysis of Section 114 information requests on nonchromate-based cooling water treatment programs.

30. Telecon. Bellin, P., to Holmberg, J., Marley Cooling Tower Company. July 19, 1985. Drift eliminator efficiency.

31. Emission Test Report: National Bureau of Standards, Gaithersburg, Maryland. EMB Report 85-CCT-4. October 1986.

32. Emission Test Report: Exxon Company Petroleum Refinery, Baytown, Texas. EMB Report 85-CCT-3. November 1986.

33. Emission Test Report: Southeastern Manufacturing Facility. EMB Report 87-CCT-5. Draft. September 1987.

34. Emission Test Report: National Institute of Standards and Technology, Gaithersburg, Maryland. U. S. EPA Contract No. 68D90055, ESD/TSD Project No. 85/02. Draft. October 1990.

35. Memorandum and attachments. McClintock, S., Entropy, to Bivins, D., EPA/EMB. June 5, 1991. Cooling tower data analysis of the Allied Fibers emission test.

36. Letter and attachments. Hawes, R., Mobil Oil Corp., to Randall, D., MRI. August 24, 1987. Emission test results.

5.0 MODEL COOLING TOWERS

This chapter defines design and operating parameters for seven model industrial process cooling tower (IPCT) systems. The models represent the nationwide population of IPCT systems in seven industries that currently use chromium-based chemicals in the recirculating cooling water. The seven industries are grouped into four industry categories: petroleum refineries, chemical manufacturing plants, primary metals industry, and miscellaneous industries. The miscellaneous industries category includes tobacco products, tire and rubber products, textile finishing mills, and glass products. This chapter also presents emission factors that relate the hexavalent chromium (Cr^{+6}) emission rate to the Cr^{+6} recirculation rate for EPA-sponsored emission tests and one industry test that used a sampling procedure similiar to that used in the initial series of EPA tests. Finally, this chapter presents the nationwide estimated baseline Cr^{+6} emissions for each industry and for the total of all industries.

5.1 MODEL IPCT SYSTEMS

Six model cooling towers were developed to characterize the existing size range of cooling towers in all industries, and each industry is characterized by a distribution of up to four of these model towers. The baseline and controlled Cr^{+6} emission rates are a function of the recirculation rate and the Cr^{+6} concentration in the recirculating water. The Cr^{+6} emission rates for the model towers were based on emission factors developed from emission test data.

The model towers were developed based on information obtained from site visits, telephone contacts, and information

requests. It was necessary to rely upon engineering judgment in those cases where the information obtained from cooling tower users, chemical treatment vendors, industry sources, and source tests was inconsistent and/or incomplete.

5.1.1 Model Cooling Towers

Parameters used to define the model cooling towers include the water recirculation rate, liquid-to-gas (L/G) ratio, cooling range, cycles of concentration, and air velocity through the fill. These parameters were used to determine other parameters such as the heat load, tower dimensions, evaporation rate, blowdown rate, airflow rate, and number of cells. The heat load that can be dissipated by the IPCT is a function of the recirculation rate and the cooling range. Although the average cooling range may vary among industries, the average range of 11.1°C (20°F) for petroleum refineries (the highest and most representative average, according to information request responses) was applied to all industries.[1] This action maximizes the blowdown rate, which, as is shown in Chapter 8, results in the highest (or worst case) water treatment chemical costs. Average values also were assumed for the cycles of concentration, L/G ratio, stack air temperature, and the efficiency of heat dissipation in the fill, which minimized the number of model tower types needed to characterize the industries. Six model IPCT's were developed, and the parameters for each are presented in Table 5-1 and are discussed in greater detail in the following sections.

5.1.1.1 Recirculation Rate. Recirculation rate is the main parameter used to define a model tower; all other parameters are a function of recirculation rate or are constant. Model tower recirculation rates were based on responses to information requests from plants in each of the industries.[2] An attempt was made to group the recirculation rates that are characteristic of each industry into ranges comparable to those of the other industries. This resulted in a total of six model tower sizes in various combinations to represent the seven industries. The miscellaneous industries were represented by only one or two

TABLE 5-1. MODEL TOWER PARAMETERS

Assumptions

Cooling range, °C (°F):	11.1 (20)
Cycles of concentration:	4
L/G:	0.8
Air velocity, m/min (ft/min):	518 (1700)
Sat. air density, kg/m^3 (lb/ft^3):	1.15 (0.072)
Latent/total heat:	0.8
Stack air temperature, °C (°F):	32.2 (90)

Model tower	Recirculation rate, L/min (gal/min)	Evaporation rate, L/min (gal/min)	Blowdown rate, L/min (gal/min)	Airflow rate, m^3/min (ft^3/min)	Initial total stack area, m^2 (ft^2)	Riser cells	Fan cells	Initial stack area per fan cell m^2 (ft^2)	Stack diameter, m (ft)	
									Calculated	Rounded
A	3,785 (1,000)	64 (17)	21 (6)	4,100 (145,000)	8 (85)	1	1	8 (85)	3.2 (10.4)	3.1 (10)
B	7,570 (2,000)	129 (34)	43 (11)	8,200 (290,000)	16 (171)	1	1	16 (171)	4.5 (14.7)	4.6 (15)
C	18,925 (5,000)	322 (85)	107 (28)	20,500 (724,000)	40 (426)	2	2	20 (213)	5 (16.4)	5.2 (17)
D	58,668 (15,500)	997 (264)	332 (88)	63,600 (2,246,000)	123 (1,321)	4	4	31 (330)	6.3 (20.5)	6.4 (21)
E	158,970 (42,000)	2,702 (714)	901 (238)	172,300 (6,085,000)	334 (3,579)	8	8	42 (447)	7.3 (23.8)	7.3 (24)
F	397,425 (105,000)	6,756 (1,785)	2,252 (595)	430,800 (15,212,000)	835 (8,948)	8	16	52 (559)	8.1 (26.6)	8.2 (27)

TABLE 5-1. (continued)

Model tower	Air velocity per stack, m/min (ft/min)	Final stack area per cell, m^2 (ft^2)	Final stack area per tower, m^2 (ft^2)	Recirculation rate, L/min (gal/min)		Tower dimensions, m (ft)		
				Per riser cell	Per fan cell	Height	Length	Width
A	563 (1,847)	7 (79)	7 (79)	3,785 (1,000)	3,785 (1,000)	4.9 (16)	4.3 (14)	8.5 (28)
B	501 (1,642)	16 (177)	16 (177)	7,570 (2,000)	7,570 (2,000)	6.4 (21)	4.9 (16)	10.1 (33)
C	487 (1,596)	42 (227)	42 (454)	9,463 (2,500)	9,463 (2,500)	9.1 (30)	9.8 (32)	10.7 (35)
D	495 (1,622)	128 (346)	129 (1,384)	14,667 (3,875)	14,667 (3,875)	12.2 (40)	30.5 (100)	11.9 (39)
E	513 (1,682)	336 (452)	336 (3,616)	19,871 (5,250)	19,871 (5,250)	15.2 (50)	68.3 (224)	12.8 (42)
F	506 (1,661)	851 (572)	851 (9,152)	49,678 (13,125)	24,839 (6,563)	19.8 (65)	75.6 (248)	23.2 (76)

model tower types, and the petroleum refining, chemical manufacturing, and primary metals industries were represented by four model tower types each. This arrangement was selected because the overall range of recirculation rates obtained from the information requests was much smaller for the miscellaneous industries than for the other industries. The ranges and averages from the information requests and the resulting model recirculation rates for each industry are presented in Table 5-2.

5.1.1.2 Evaporation Rate. The evaporation rate is a function of the recirculation rate, the cooling range, and the atmospheric temperature and humidity. The evaporation rate can be estimated with Equation 1, which was used to calculate evaporation rates for the model towers:[3]

$$E = (0.00153)(R)(\Delta T) \qquad (1)$$

where:

E = evaporation rate, liters per minute (L/min);

R = recirculation rate of cooling water, L/min; and

ΔT = cooling range of water, °C.

Atmospheric conditions also affect the ratio of latent-to-sensible heat transfer, which typically is about 4 to 1.[3] Also, as discussed above, the average cooling range of 11.1°C (20°F) obtained from the information request responses from petroleum refineries was applied to all of the industries.

5.1.1.3 Blowdown Rate. Equations 2 and 3 present the approximate relationships among the blowdown, evaporation, drift, and makeup rates and the cycles of concentration.[3,4,5]

$$M = B + E + D \qquad (2)$$

$$C = \frac{B + E + D}{B+D} \qquad (3)$$

where:

M = makeup rate, L/min;

B = blowdown rate, L/min;

D = drift rate, L/min;

C = cycles of concentration; and

E = evaporation rate, L/min.

TABLE 5-2. RECIRCULATION RATES FOR MODEL TOWERS AS DEVELOPED FROM INFORMATION REQUESTS

Industry	Data from information request responses				Models developed	
	Recirculation rate range, L/min x 10^3 (gal/min x 10^3)	No. of towers	Fraction in each size range	Average recirculation rate per tower, L/min (gal/min)	Designated model tower	Model tower recirculation rate, L/min (gal/min)
Petroleum refining	<36.8 (<9.7)	58	0.389	19,796 (5,230)	C	18,927 (5,000)
	36.8-92 (9.7-24.3)	43	0.289	58,213 (15,380)	D	58,674 (15,500)
	92-210 (24.3-55.6)	43	0.289	164,388 (43,430)	E	158,987 (42,000)
	>210 (>55.6)	5	0.034	396,706 (104,810)	F	397,468 (105,000)
		149				
Chemical manufacturing	<10.5 (<2.8)	54	0.500	4,012 (1,060)	A	3,785 (1,000)
	10.5-26.3 (2.8-6.9)	26	0.241	17,979 (4,750)	C	18,927 (5,000)
	26.3-131 (6.9-34.7)	17	0.157	57,835 (15,280)	D	58,674 (15,500)
	>131 (>34.7)	11	0.102	156,245 (41,280)	E	158,987 (42,000)
		108				
Primary metals	<21 (<5.6)	20	0.328	3,747 (990)	A	3,785 (1,000)
	21-52.6 (5.6-13.9)	18	0.295	20,780 (5,490)	C	18,927 (5,000)
	52.6-210 (13.9-55.6)	19	0.311	59,387 (15,690)	D	58,674 (15,500)
	>210 (>55.6)	4	0.066	399,810 (105,630)	F	397,468 (105,000)
		61				
Tobacco	<26.3 (<6.9)	10	0.625	7,229 (1,910)	B	7,571 (2,000)
	>26.3 (>6.9)	6	0.375	55,412 (14,640)	D	58,674 (15,500)
		16				
Tire and rubber	<78.9 (<20.8)	21	1.000	8,403 (2,220)	B	7,571 (2,000)
Textiles finishing	<15.6 (<4.2)	13	1.000	4,769 (1,260)	A	3,785 (1,000)
Glass manufacturing	<15.8 (<4.2)	3	1.000	8,441 (2,230)	B	7,571 (2,000)

Typically, the drift rate is either neglected or approximated as up to 0.02 percent of the recirculation rate, and the cycles of concentration are predetermined based on the makeup water quality and the water treatment program. Equation 4, produced by rearranging Equation 3 and neglecting the drift rate, shows that blowdown can be expressed as a function of cycles of concentration and the evaporation rate:

$$B = E/(C-1) \quad (4)$$

The information request respondents indicated that most towers operate with two to eight cycles of concentration and that the average is four.[6] Thus, four cycles of concentration and the evaporation rate determined from Equation 1 were used in Equation 4 to calculate the blowdown rate for each model tower.

5.1.1.4 Tower Dimensions. Model tower stack diameters were determined from estimates of the airflow rate and velocity. A cooling tower manufacturer indicated that the L/G ratio varies among towers from about 0.5 to 2.5 and that the stack and fans are designed for air velocities in the range of 6.1 to 11.2 meters per second (m/s) (1,200 to 2,200 feet per minute [ft/min]).[7] The responses to the information requests indicate that 0.8 is a typical L/G ratio.[7] This ratio and the specific volume of saturated air at the estimated average temperature in the tower (32°C [90°F]) were used to calculate the airflow rate. The total stack area was then calculated using an air velocity of 8.6 m/s (1,700 ft/min). The number of fan cells per tower was estimated by trial and error. The stack area per cell was determined by dividing the total stack area by the number of cells selected, and the cell stack diameter was calculated from the cell stack area. The calculation procedure was repeated until a series of cell diameters was obtained that increased slightly as the recirculation rate increased. This relationship of diameter to recirculation rate was indicated in the responses to information requests and in manufacturers' product literature.[7,8] The resulting diameter was then rounded to the nearest whole number and the individual cell stack area, total stack area, and the stack air velocity were recalculated. The

revised air velocities differ from the target by less than 6 percent (except for the smallest tower) and are well within the design range. Table 5-1 presents the results.

The height of the tower depends on the type of fill and the efficiency of the fill at creating a large water-to-air interface. Responses to the information requests indicate that a wide range of tower heights exists for a specific tower or cell recirculation rate. Because the model towers have been selected with similar recirculation rates per cell, selecting the tower heights based on this parameter would result in nearly uniform tower heights. However, the responses to the information requests indicate that the tower height typically increases as the recirculation rate increases.[8,9] Therefore, the data from the information requests have been used to estimate the heights of the model towers, and the results are shown in Table 5-1.

The lengths of the model towers were determined by assuming a distance of 1.2 m (4 ft) between the fans and 0.6 m (2 ft) from the end fans to the edge of the tower. These values are averages of distances observed during EPA-sponsored emission tests and obtained from tower manufacturer product literature. All but one of the six model towers were arranged with an equal number of fan cells and riser cells; the largest tower was arranged with two fan cells per riser cell. These configurations and the resulting lengths, presented in Table 5-1, are within the range of those in the information request responses.[8,9]

The widths of the model towers were determined by adding 2.7 m (9 ft) to each side of the fan and 1.2 m (4 ft) between fans. The results are provided in Table 5-1 and, again, are similar to the widths reported in the responses to the information requests.[8,9]

5.2 HEXAVALENT CHROMIUM EMISSION FACTOR

In order to estimate baseline and controlled emissions of Cr^{+6}, emission factors were developed that relate the Cr^{+6} emission rate to the Cr^{+6} recirculation rate. The emission factors express the emission rate as a percent of the recirculation rate. The percentage is equivalent to units (in

this case, milligrams [mg]) of Cr^{+6} emitted per unit of Cr^{+6} recirculating in the tower (mg Cr^{+6} emitted/mg Cr^{+6} recirculating). Data from seven EPA-sponsored emission tests and one industry-sponsored emission test were considered in developing nationwide emission factors. The EPA-sponsored tests were conducted at the Department of Energy Gaseous Diffusion Plant in Paducah, Kentucky (DOE-Paducah); the Exxon refinery in Baytown, Texas (Exxon-Baytown); the National Institute of Standards and Technology facility, formerly the National Bureau of Standards, in Gaithersburg, Maryland (NIST-Gaithersburg); a southeastern manufacturing facility (SMF); and the Allied Fibers facility in Moncure, North Carolina (Allied-Moncure). The industry-sponsored emission test was conducted on two towers at the Mobil Oil Corporation refinery in Torrance, California (Mobil-Torrance). Emission factors were developed for towers equipped with low-efficiency drift eliminators (LEDE's) at Exxon-Baytown, SMF, and Mobil-Torrance, and for towers equipped with high-efficiency drift eliminators (HEDE's) at Exxon-Baytown, NIST-Gaithersburg, SMF, and Allied-Moncure. Emission factors were not developed for the test at DOE-Paducah because an unknown quantity of chromium in the sample was lost during laboratory analysis. The average baseline (LEDE) and controlled (HEDE) emission factors for each test site are presented in Table 5-3.[10-15]

Three procedures were used to calculate emission factors. The Cr^{+6} emission factors for the Exxon and first series of NIST tests were determined by dividing theoretical Cr^{+6} emission rates by actual Cr^{+6} recirculating rates (Procedure 1). It was necessary to calculate theoretical Cr^{+6} emission rates because the Cr^{+6} concentrations in the recirculating water were not high enough to collect sufficient quantities of Cr^{+6} in the sampling equipment to allow direct analysis for Cr^{+6}. The emission samples were, however, analyzed for total chromium, and the recirculating water samples were analyzed for both Cr^{+6} and total chromium. It was then assumed that the Cr^{+6}-to-total chromium ratio in the emission samples was equal to that in the

TABLE 5-3. EMISSION FACTORS FROM EPA- AND INDUSTRY-SPONSORED TESTS[10-15]

Test site	Sampling method[d]	Baseline emission factor (standard-efficiency drift eliminators)[a]							
		Procedure 1[b]						Procedure 2[c]	
		Minimum	Maximum	Average	Standard deviation	Minimum	Maximum	Average	Standard deviation
Exxon-Baytown, TX[e]	A	0.0039	0.068	0.032	0.026				
SMF	A	0.0098	0.075	0.027	0.017	0.0020	0.0074	0.0034	0.0016
SMF	B	0.0072	0.055	0.027	0.017	0.0020	0.0036	0.0021	0.00062
Mobil-Torrance, CA	C			~0.033					~0.013

Test site	Sampling method[d]	Controlled emission factor (high-efficiency drift eliminators)[a]											
		Procedure 1[b]				Procedure 2[c]				Procedure 3[g]			
		Minimum	Maximum	Average	Standard deviation	Minimum	Maximum	Average	Standard deviation	Minimum	Maximum	Average	Standard deviation
Exxon-Baytown, TX[e]	A	0.0019	0.0068	0.0037	0.0018								
NIST-Gaithersburg, MD (1st test)	A	0.0010	0.013	0.0038	0.0041								
SMF	A	0.0032	0.019	0.0087	0.0037	0.00039	0.0014	0.00075	0.0003				
SMF	B	0.0012	0.011	0.0044	0.0030	0.00019	0.0019	0.00096	0.0006				
NIST-Gaithersburg, MD (2nd test)	B									0.0031	0.0083	0.0051	0.0019
Allied-Moncure, NC	B									0.337	1.471	0.770	0.342

[a] Cr^{+6} emission rate expressed as a percentage of the Cr^{+6} recirculating rate.
[b] Procedure 1 assumes that the ratio of Cr^{+6} to total chromium in the emission samples is the same as the ratio in the recirculating water.
[c] Procedure 2 involves a direct analysis of the emission sample for Cr^{+6}.
[d] A: EPA modified Method 13 isokinetic train (EPA-sponsored test).
B: Cooling Tower Institute isokinetic train (EPA-sponsored test).
C: California Air Resources Board Method 5 isokinetic train (Mobil Oil Corporation test).
[e] Some of the results from this test were suspect because of their extreme variability and, thus, were not used to determine the emission factor.
[f] In the EPA-sponsored tests, the Cr^{+6} in the recirculating water accounted for more than 99 percent of the total chromium content. This percentage was assumed in calculating the Procedure 1 emission factor for Mobil-Torrance (no cooling water measurements were reported).
[g] Procedure 3 involves the use of surrogate elements native to the recirculating water. The emission rate is based on the average of selected surrogate elements.

recirculating water, and the theoretical Cr^{+6} emission rate was calculated by equating the Cr^{+6}-to-total chromium ratios.

At the SMF, the Cr^{+6} emission factor was calculated by the same procedure described above. In addition, because recirculating Cr^{+6} levels at the SMF were 10 to 20 times higher than at any tower tested previously, emission samples were obtained that could also be analyzed for Cr^{+6}. In this case, the Cr^{+6} emission factors were determined by dividing the actual Cr^{+6} emission rates by the actual Cr^{+6} recirculation rates (Procedure 2). It was assumed that Cr^{+6} emission factors developed using this procedure would yield results that were more representative of actual Cr^{+6} emissions than would emission factors developed using Procedure 1. However, as shown in Table 5-3, these emission factors are approximately 9 times lower than the factors obtained by Procedure 1. Further testing of Procedure 2 by EPA indicated that the test method was responsible for much of the conversion of Cr^{+6} to trivalent chromium (Cr^{+3}).

Data from the Mobil-Torrance test indicate that emission samples contain a higher proportion of Cr^{+3} than does the recirculating water. For the Mobil towers, on average, half of the chromium in the emission samples was in the trivalent form.[13] These test data were recorded using a slightly different sampling train than was used for the EPA-sponsored tests and were not subject to EPA quality assurance/quality control. However, the data from both Mobil-Torrance and the SMF indicate that a portion of the Cr^{+6} was reduced to Cr^{+3} prior to sample analysis. The additional testing by EPA to determine the cause of the conversion of Cr^{+6} to Cr^{+3} at the SMF test provides reason to suspect that the same interference due to sampling methods occurred at the Mobil test.

Unlike the previous tests, in which Cr^{+6} emission rates were determined by directly measuring either total or hexavalent chromium in the recirculating water and drift samples, a different analytical procedure was used to determine emission factors for the second NIST-Gaithersburg and Allied-Moncure tests. This procedure (Procedure 3), which has been used

extensively by the Cooling Tower Institute, uses surrogate mineral concentrations to determine the drift rate. In the second NIST and Allied tests, the recirculating water and drift samples were analyzed for several native elements. After screening, emission data for four elements were selected as the basis for determining the drift rate for each tower. The overall emission factor for each tower was determined by averaging the individual emission factors for the four selected elements. This method of determining tower emission factor relies on the assumption that the emission rate for any element in the recirculating water is the product of a constant overall tower emission factor and the concentration of the element in the recirculating water. A serious shortcoming of this procedure is that there is little scientific basis for the method of screening out certain elements from the group of elements above detection limit in both the emission sample and recirculating water. Because of the wide range of emissions and concentrations of elements in the recirculating water, the magnitude of the average emission factor calculated using this procedure is highly dependent upon which elements are screened out.

As shown in Table 5-3, the range and standard deviation of emission factors developed from each set of test data indicate the difficulty in obtaining precise drift test results. In addition to the chromium conversion issue, which apparently biases emission factors developed using Procedure 2, and the validity of the screening method used in Procedure 3, other problems were also experienced with the test program, as described below. However, because the average emission factors developed from the majority of the tests are consistent with each other and with industry estimates, it is believed that the test results are adequate for the purposes of estimating nationwide Cr^{+6} emissions.

5.2.1 Baseline Emission Factor

The nationwide baseline emission factor was set at 0.03 percent of the Cr^{+6} recirculation rate. This value is based on the average of LEDE emission factors using Procedure 1 for the

EPA-sponsored tests at the SMF and Exxon and for the test conducted by Mobil. Two of the seven runs for the Exxon test were not included in the average because they were considered suspect. The emissions for these two runs were substantially higher than those for the other runs. In fact, results from these two runs indicated that the theoretical mass emission rate of Cr^{+6} was comparable to or even greater than the mass discharge rate of Cr^{+6} in the blowdown.[a] This result contradicts engineering judgment and is inconsistent with the makeup feed rates of Cr^{+6} for these towers. For these reasons, the two outlying runs were declared invalid, and the Exxon LEDE emission factor of 0.0318 percent of the Cr^{+6} recirculating rate is based on the remaining five runs. Because of the chromium conversion problem, emission factors developed using Procedure 2 were not considered in determining the nationwide baseline emission factor. Further, because neither the NIST nor the Allied towers were equipped with LEDE's, Procedure 3 emission factors did not apply to baseline emissions.

5.2.2 Controlled Emission Factor

The nationwide controlled emission factor is dependent on the emission reduction potential of HEDE's. The tests at the SMF were specifically designed to determine the effectiveness of HEDE's and LEDE's operating under similar conditions. Controlled and uncontrolled towers of similar design and operation were tested simultaneously under essentially identical meteorological conditions. Because of this specific test design and the good test precision achieved at the SMF, the nationwide controlled emission factor was calculated by applying the emission reduction

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[a]For example, the blowdown rate for Cooling Tower 68 was approximately 70 gallons per minute (gal/min). At an average Cr^{+6} concentration of 7.6 mg/L, the Cr^{+6} discharge rate is approximately 120,000 mg Cr^{+6}/hr. For one run on Fan Stack 1 of Cell 1 (recirculation rate = 2,100 gal/min), the measured emission rate was 25,060 mg/hr. If this emission rate were projected for the entire tower (recirculation rate = 22,500 gal/min), the tower emission rate would be approximately 270,000 mg/hr (225 percent of the Cr^{+6} discharge in the blowdown).

observed in the tests at the SMF (using Procedure 1) to the baseline emission factor. Comparing the controlled and uncontrolled towers using data from the EPA modified Method 13 test runs, the HEDE achieved a 67 percent emission reduction over the LEDE. Therefore, the emission factor for HEDE's is 0.01 percent of the Cr^{+6} recirculating rate.

Although there was considerable scatter in the data from run to run, controlled emission factors developed from the Exxon-Baytown and both NIST tests averaged 0.0037, 0.0038 (first test--Procedure 1), and 0.0051 percent (second test--Procedure 3), respectively. Thus, the nationwide controlled emission factor developed from the SMF data is a conservative value that provides a margin above the highest value observed for an HEDE in available emission tests. This value ensures that the emission reduction potential of HEDE's is not overestimated. The NIST and Exxon controlled emission factors are significantly below this level, and the emission reduction for HEDE's over LEDE's was higher at Exxon than at the SMF (88 percent versus 67 percent). As with the baseline runs, however, outlying data were not included in the average controlled emission factor for the Exxon test.

Data for the Allied-Moncure test indicate an emission factor of 0.337 to 1.471 percent, which is between one and two orders of magnitude higher than the average emission factor for all of the previous tests. Unlike the Exxon-Baytown test in which two of the seven runs resulted in extremely high values, the Allied results are consistently higher for all runs. The reasons for the very high results are not understood. However, several factors about the Allied test differ from the previous tests. Because the Allied tower serves a direct contact spray heat exchanger, the cooling water contains a high concentration of ethylene glycol (9.5 percent). In addition, the cooling water treatment program includes an antifoaming agent and a dispersant. According to a water treatment chemical vendor, the type of dispersant used (ethoxylated octylphenol) acts as a surfactant to reduce the surface tension of the cooling water. This may result

in the production of water droplets that are smaller than otherwise would be formed in the tower and may increase the number of droplets that exit the tower as drift.[16] The interaction of the ethylene glycol and cooling water additives may also have an effect on the emission rate. According to a cooling tower vendor, ambient conditions also may have contributed to the elevated emission rate at Allied. In cool weather, cooling towers produce much more fog and condensation. Condensate may redissolve solids encrusted on the tower structural members and sampling equipment. The resulting highly concentrated liquid can then enter the sampling nozzle and contaminate the sample.[17] Because the Allied results are so much higher than those of previous tests, the emission factor developed from the Allied data was not taken into consideration in developing a nationwide controlled emission factor.

5.2.3 Modeled Hexavalent Chromium Emissions

The baseline Cr^{+6} emission rate for each model tower was calculated by multiplying the nationwide baseline emission factor by the model recirculation rate and the Cr^{+6} concentration in the recirculating water as shown in Equation 5:

$$E_{Cr^{+6}} = (K)(C_{Cr^{+6}})(R) \qquad (5)$$

where:

$E_{Cr^{+6}}$ = Cr^{+6} emission rate, mg Cr^{+6}/min

K = Cr^{+6} emission factor, 0.03 percent of recirculating Cr^{+6} (mg Cr^{+6} emitted/mg Cr^{+6} recirculating/100);

$C_{Cr^{+6}}$ = concentration of Cr^{+6} in cooling water, mg Cr^{+6} recirculating/L of water (for the model towers, this equals 5.83 parts per million [ppm]); and

R = recirculation rate of cooling water, L/min.

Analysis of information request responses showed that the chromate concentration maintained in petroleum refinery cooling towers using chromate-based treatment is about 13 ppm.[18] Further analysis of the limited data for other industries showed various average chromate concentrations for individual industries, but the average for the combination of all nonpetroleum industries also was about 13 ppm.[19] In addition, a survey conducted by the

Chemical Manufacturers Association (CMA) indicated that cooling tower water at chemical manufacturing plants contains an average of about 13 ppm chromate.[20] Thus, 13 ppm chromate (5.83 ppm Cr^{+6}) was used in Equation 5.

5.3 DISTRIBUTION OF MODEL TOWERS AND BASELINE EMISSIONS BY INDUSTRY

Two major considerations within each industry category are the number of model cooling towers each industry category contains and the distribution of those model cooling towers among the six model types. The number and types of cooling towers within a particular industry category are related to the typical cooling demands for the processes involved. As discussed in Section 5.1.1.1, the model cooling tower size is determined by the recirculation rate, and, as shown in Table 5-1, each industry was characterized by one, two, or four model cooling tower types based on the recirculation rate ranges obtained from information request responses. The total number of cooling towers in each industry was estimated using the procedures discussed in Sections 5.3.1 through 5.3.4. These tower estimates were used with the percentages of towers in each of the selected recirculation rate ranges in Table 5-1 to determine the distribution of each model type for each industry. Hexavalent chromium emissions for each industry were estimated from the percentage of towers in the industry using chromate-based water treatment, the Cr^{+6} concentration in the recirculating water, the emission factor, and the average fan utilization rate for the industry. The source of industry-specific data and the baseline emissions for each industry are also discussed in Sections 5.3.1 through 5.3.4. Table 5-4 lists the Standard Industrial Classification (SIC) codes for each of the industries for which Cr^{+6} emissions were estimated.

5.3.1 Petroleum Refineries

In January 1986, there were 189 operating petroleum refineries in the United States with a total crude operating capacity of 14.64 million barrels per calendar day.[21] The refineries that responded to the information requests have a

TABLE 5-4. SOURCE CATEGORY STANDARD INDUSTRY CLASSIFICATION (SIC)

Source category	SIC code
Petroleum refining	2911
Chemical manufacturing	
Industrial organic	2812; 2813; 2816; 2819
Industrial inorganic	2861
Agricultural	2873; 2874; 2875; 2879
Miscellaneous	2891; 2892; 2893; 2895; 2899
Primary metals	
Blast furnaces and steel mills	3312
Primary copper	3331
Primary nonferrous metals, N.E.C.	3339
Glass products	
Flat glass	3211
Glass containers	3221
Tobacco products	
Cigarettes	2111
Cigars	2121
Chewing and smoking tobacco	2131
Rubber products	
Tires and inner tubes	3011
Dyeing and finishing textiles, except wood fabrics and knit goods	
Finishing plants, cotton	2261
Finishing plants, manmade	2262
Finishing plants, N.E.C.	2269

total crude capacity of 4.41 million barrels per calendar day and 206 cooling towers.[18,21] The same ratio of towers-to-crude capacity was applied to all 189 refineries to obtain the estimate of 680 towers in the industry. Data from the information request responses indicate that the mean concentration of chromate in the recirculating water is about 13 ppm, and that the fans run an average of 87.3 percent of the time.[18] Current estimates by water treatment vendors indicate that approximately 20 percent of the towers in the petroleum refining industry are using chromate-based water treatments.[22-24] Table 5-5 presents the tower and operating parameters and baseline Cr^{+6} emissions from cooling towers in the petroleum refining industry.

5.3.2 Chemical Manufacturing Plants

Two similar estimates of the number of chemical manufacturing facilities in the United States have been obtained. The CMA estimates that there are from 1,500 to 2,000 bulk chemical manufacturing plants.[20] The 1987 Census of Manufactures from the U.S. Department of Commerce indicated that there were 5,341 chemical manufacturing establishments and that 1,824 of these establishments had more than 20 employees.[25] It has been assumed that the processes operated at most plants with fewer than 20 employees do not require cooling towers. Therefore, emission calculations have been based on the estimate that 1,824 plants have cooling towers. Because the towers in the chemical manufacturing industry were much smaller than those in the petroleum refining industry, according to the information request responses, the model tower types for the chemical manufacturing industry are also smaller. The responses to information requests also indicated that there are about 2.8 towers per plant and that the fans run an average of 72.2 percent of the time.[26] The results of a CMA survey indicate that the average chromate concentration in IPCT's at chemical manufacturing plants is about 13 ppm.[20] Current estimates by water treatment vendors indicate that approximately 10 percent of chemical manufacturers currently use chromium to control corrosion.[22-24] The tower and operating parameters and the

TABLE 5-5. CHROMIUM EMISSION ESTIMATES FOR PETROLEUM REFINERIES

Assumptions	
No. of plants:	189
No. of towers per plant:	3.6
No. of towers nationwide:	680
Percentage of towers using CrO_4:	20
CrO_4 concentration, ppm:	13
Molecular weight [MW] Cr/(MW CrO_4):	0.448
Cycles of concentration:	4
Latent heat/total heat:	0.8
Utilization rate, percent:	87.3
Chromium emission factor:	0.03 percent of recirculating Cr^{+6}

Model tower type	Fraction in each size range	Average recirculation rate		No. of towers nationwide	No. of towers using CrO_4	Hexavalent chromium emissions per tower				Nationwide Cr^{+6} emissions	
		L/min	gal/min			mg/min	lb/min x 10^4	kg/yr	lb/yr	kg/yr	lb/yr
C	0.389	18,925	5,000	265	53	28.9	0.64	15.2	33.4	778	1,714
D	0.289	58,668	15,500	196	39	89.5	1.97	47.0	103.7	1,774	3,911
E	0.289	158,970	42,000	196	39	242.5	5.35	127.4	281.0	4,806	10,596
F	0.034	397,425	105,000	23	5	606.2	13.36	318.6	702.4	1,541	3,396
Total				680	136					8,898	13,617

baseline Cr^{+6} emissions from cooling towers in the chemical manufacturing industry are presented in Table 5-6.

5.3.3 Primary Metals Industry

The primary metals industry includes steel manufacturing plants and nonferrous primary metals plants. The number of primary and specialty steel-making plants was based on the 1980 Techno-Economic Report from the Institute for Iron and Steel Studies.[25] After adjustment to account for the number of plants known to be shut down, it was estimated that there are 149 plants in the industry. The 1987 Census of Manufactures indicated that 61 primary nonferrous metal plants have more than 20 employees.[25] As with the chemical manufacturing industry, it was assumed that only plants with more than 20 employees would have processes that need cooling towers. Responses from steel manufacturers to the information requests indicate that each site has an average of 4.6 cooling towers, the average chromate concentration in the recirculating water is 13 ppm, and the average daily fan utilization rate is about 78.8 percent.[28] Recent estimates by water treatment vendors indicate that approximately 10 percent of primary metals plants use chromate-based water treatment programs.[22-24] Table 5-7 presents the tower and operating parameters and the combined baseline Cr^{+6} emissions from cooling towers at steel-making and primary nonferrous metal manufacturing plants.

5.3.4 Miscellaneous Industries

This category comprises other industries that use chromium-based corrosion inhibitors and includes tobacco products manufacturing, tire and rubber products manufacturing, textile finishing mills, and glass products manufacturing. The number of plants in each industry has been estimated from the 1987 Census of Manufactures by the same procedure used to determine the number of chemical manufacturing plants.[25] Based on the small amount of data available from information request responses, there does not appear to be large-scale use of chromium-based corrosion inhibitors. In fact, none of the responses to the 1987 information request from tobacco, textiles, and glass plants

TABLE 5-6. CHROMIUM EMISSION ESTIMATES FOR CHEMICAL MANUFACTURING

Assumptions	
No. of plants:	1,824
No. of towers per plant:	2.8
No. of towers nationwide:	5,107
Percentage of towers using CrO_4:	10
CrO_4 concentration, ppm:	13
(MW Cr)/(MW CrO_4):	0.448
Cycles of concentration:	4
Latent heat/total heat:	0.8
Utilization rate, percent:	72.2
Chromium emission factor:	0.03 percent of recirculating Cr^{+6}

Model tower type	Fraction in each size range	Average recirculation rate		No. of towers nationwide	No. of towers using CrO_4	Hexavalent chromium emissions per tower				Nationwide Cr^{+6} emissions	
		L/min	gal/min			mg/min	lb/min x 10^4	kg/yr	lb/yr	kg/yr	lb/yr
A	0.500	3,785	1,000	2,554	255	4.8	0.1	2.5	5.5	619	1,364
C	0.241	18,925	5,000	1,230	123	23.9	0.53	12.5	27.7	1,493	3,290
D	0.157	58,668	15,500	804	80	74.0	1.63	38.9	85.8	3,009	6,634
E	0.102	158,970	42,000	520	52	200.5	4.42	105.4	232.4	5,300	11,685
Total				5,107	510					10,421	22,973

TABLE 5-7. CHROMIUM EMISSION ESTIMATES FOR PRIMARY METALS INDUSTRY

Assumptions	
No. of plants:	210
No. of towers per plant:	4.6
No. of towers nationwide:	966
Percentage of towers using CrO_4:	10
CrO_4 concentration, ppm:	13
(MW Cr)/(MW CrO_4):	0.448
Cycles of concentration:	4
Latent heat/total heat:	0.8
Utilization rate, percent:	78.8
Chromium emission factor:	0.03 percent of recirculating Cr^{+6}

Model tower type	Fraction in each size range	Average recirculation rate		No. of towers nationwide	No. of towers using CrO_4	Hexavalent chromium emissions per tower				Nationwide Cr^{+6} emissions	
		L/min	gal/min			mg/min	lb/min x 10^4	kg/yr	lb/yr	kg/yr	lb/yr
A	0.328	3,785	1,000	317	32	5.2	0.11	2.7	6.0	85	187
C	0.295	18,925	5,000	285	29	26.1	0.57	13.7	30.2	384	847
D	0.311	58,668	15,500	301	30	80.8	1.78	42.5	93.6	1,232	2,715
F	0.066	397,425	105,000	63	6	547.2	12.06	287.6	634.0	1,669	3,679
Total				966	97					3,369	7,427

indicated that chromate-based corrosion inhibitors are used. Recent estimates by water treatment vendors indicate that the percentage of miscellaneous industry plants that use chromium ranges from less than 1 to 5 percent.[22-24] Thus, it was assumed that 2.5 percent of the towers in these industries are using chromate-based water treatment. It also was assumed that the average chromate concentration in towers for all of the miscellaneous industries was 13 ppm, to be consistent with the information for the other industries.

5.3.4.1 Tobacco Products. The tobacco products industry contains 49 plants with greater than 20 employees, and each plant has an average of about 5.5 cooling towers.[25,29,30] Because the towers are used primarily as part of climate control systems, the heat load is moderate. Thus, more than half of the industry has been represented by the next-to-smallest model tower type. Information request responses indicated that the fans operate about 59 percent of the time.[30] Table 5-8 presents the tower and operating parameters and the baseline Cr^{+6} emissions from cooling towers at tobacco products manufacturing plants.

5.3.4.2 Tire and Rubber Products. The tire and rubber products manufacturing industry contains 97 plants with greater than 20 employees, each with an average of about 2.7 cooling towers.[25,31,32] Information request responses received in 1987 indicated that the industry can be represented by the next-to-smallest model tower, that about 15 percent of the towers used chromate-based water treatment, and that the fans operated about 65.5 percent of the time.[31] According to a water treatment vendor, the number of plants using chromium in most industries has decreased by at least 50 percent in the last 5 years, and, as mentioned previously, responses from other vendors indicate that the percentage of miscellaneous industries plants that use chromate is generally less than 5 percent.[22,24] Therefore, it is assumed that a maximum of 7.5 percent of tire and rubber plants currently use chromium. Table 5-9 presents the tower and operating parameters and the baseline Cr^{+6} emissions from cooling towers at tire and rubber manufacturing plants.

TABLE 5-8. CHROMIUM EMISSION ESTIMATES FOR TOBACCO INDUSTRY

Assumptions	
No. of plants:	49
No. of towers per plant:	5.5
No. of towers nationwide:	270
Percentage of towers using CrO_4:	2.5
CrO_4) concentration, ppm:	13
(MW Cr)/(MW CrO_4):	0.448
Cycles of concentration:	4
Latent heat/total heat:	0.8
Utilization rate, percent:	59
Chromium emission factor:	0.03 percent of recirculating Cr^{+6}

Model tower type	Fraction in each size range	Average recirculation rate		No. of towers nationwide	No. of towers using CrO_4	Hexavalent chromium emissions per tower				Nationwide Cr^{+6} emissions	
		L/min	gal/min			mg/min	lb/min x 10^4	kg/yr	lb/yr	kg/yr	lb/yr
B	0.625	7,570	2,000	168	4	7.8	0.17	4.1	9.0	16	35
D	0.375	58,668	15,500	101	3	60.5	1.33	31.8	70.1	92	203
Total				270	7					108	238

TABLE 5-9. CHROMIUM EMISSION ESTIMATES FOR TIRE AND RUBBER INDUSTRY

Assumptions	
No. of plants:	97
No. of towers per plant:	2.7
No. of towers nationwide:	262
Percentage of towers using CrO_4:	7.5
CrO_4) concentration, ppm:	13
(MW Cr)/(MW CrO_4):	0.448
Cycles of concentration:	4
Latent heat/total heat:	0.8
Utilization rate, percent:	65.5
Chromium emission factor:	0.03 percent of recirculating Cr^{+6}

Model tower type	Fraction in each size range	Average recirculation rate		No. of towers nationwide	No. of towers using CrO_4	Hexavalent chromium emissions per tower				Nationwide Cr^{+6} emissions	
		L/min	gal/min			mg/min	lb/min x 10^4	kg/yr	lb/yr	kg/yr	lb/yr
B	1.000	7,570	2,000	262	20	8.7	0.19	4.6	10.0	88	194
Total				262	20					88	194

5.3.4.3 Textile Finishing Mills. The finishing step is assumed to require the vast majority of the cooling in the production of textile products. Therefore, the plants chosen for this category were restricted to those within the SIC codes for the finishing of various textiles. The available data indicate that there are 322 finishing plants with greater than 20 employees and each plant has an average of about 2.4 cooling towers.[25,33,34] Because air washing systems and cooling of air compressors comprise the majority of the cooling requirement, the heat load is moderate. The information request responses indicated that the industry could be represented by the smallest model tower. The information request responses also indicated that the average fan utilization rate is about 47 percent.[34] Table 5-10 presents the tower and operating parameters and the baseline Cr^{+6} emissions from cooling towers at textile finishing mills.

5.3.4.4 Glass Products. This industry includes flat glass and glass container manufacturing plants, which contain 38 and 93 plants with greater than 20 employees, respectively.[25] From the limited information request data available, it is estimated that an average plant can be represented with 0.4 of the next-to-smallest model tower type.[35,38] This corresponds well with the model types used to represent the other miscellaneous industries. Table 5-11 presents the tower and operating parameters and the baseline Cr^{+6} emissions from cooling towers at glass products manufacturing plants.

5.4 NATIONWIDE EMISSIONS SUMMARY

Table 5-12 summarizes the estimated Cr^{+6} emissions for each industry category and presents the estimated number of cooling towers and total nationwide emissions for all four industry categories. Chromium emissions from the industrial cooling tower source category are estimated to be 23 megagrams per year (25 tons per year).

TABLE 5-10. CHROMIUM EMISSION ESTIMATES FOR TEXTILES FINISHING INDUSTRY

Assumptions	
No. of plants:	322
No. of towers per plant:	2.4
No. of towers nationwide:	773
Percentage of towers using CrO_4:	2.5
CrO_4) concentration, ppm:	13
(MW Cr)/(MW CrO_4):	0.448
Cycles of concentration:	4
Latent heat/total heat:	0.8
Utilization rate, percent:	47
Chromium emission factor:	0.03 percent of recirculating Cr^{+6}

Model tower type	Fraction in each size range	Average recirculation rate,		No. of towers nationwide	No. of towers using CrO_4	Hexavalent chromium emissions per tower				Nationwide Cr^{+6} emissions	
		L/min	gal/min			mg/min	lb/min x 10^4	kg/yr	lb/yr	kg/yr	lb/yr
A	1.000	3,785	1,000	773	19	3.1	0.07	1.6	3.6	30	66
Total				773	19					30	66

TABLE 5-11. CHROMIUM EMISSION ESTIMATES FOR GLASS PRODUCTS INDUSTRY

Assumptions	
No. of plants:	131
No. of towers per plant:	0.4
No. of towers nationwide:	52
Percentage of towers using CrO_4:	2.5
CrO_4 concentration, ppm:	13
(MW Cr)/(MW CrO_4):	0.448
Cycles of concentration:	4
Latent heat/total heat:	0.8
Utilization rate, percent:	58
Chromium emission factor:	0.03 percent of recirculating Cr^{+6}

Model tower type	Fraction in each size range	Average recirculation rate		No. of towers nationwide	No. of towers using CrO_4	Hexavalent chromium emissions per tower				Nationwide Cr^{+6} emissions	
		L/min	gal/min			mg/min	lb/min x 10^4	kg/yr	lb/yr	kg/yr	lb/yr
B	1.000	7,570	2,000	52	1	7.7	0.17	4.0	8.9	3.9	8.6
Total				52	1					3.9	8.6

TABLE 5-12. NATIONWIDE HEXAVALENT CHROMIUM EMISSIONS SUMMARY

Industry	No. of cooling towers using chromate	Cr^{+6}	
		Mg/yr	Tons/yr
Petroleum refining	136	8.90	9.81
Chemical manufacturing	510	10.42	11.49
Primary metals	97	3.37	3.71
Tobacco products	7	0.108	0.12
Tire and rubber	20	0.088	0.097
Textiles finishing	19	0.030	0.033
Glass manufacturing	1	0.0039	0.0043
TOTAL	790	22.9	25.3

TABLE 5-13. REFERENCES FOR RESPONSES TO SECTION 114 INFORMATION REQUESTS

Ref. No.	Company name	Plant location(s)
	RECEIVED MAY THROUGH AUGUST 1985	
1	ARMCO, Inc.	Middletown, Ohio; Ashland, Ky.
2	Bethlehem Steel Corp.	Burns Harbor, Ind.; Johnstown, Pa.
3	Inland Steel Corp.	East Chicago, Ind.
4	Lone Star Steel Company	Lone Star, Tex.
5	LTV Steel Corp.	Warren and Cleveland, Ohio; Aliquippa, Pa.; Gadsden, Ala.
6	McLouth Steel Products Corp.	Trenton, Mich.
7	U.S. Steel Corp.	Fairless, Pa.; Gary, Ind.; Lorain, Ohio; Orem, Utah
8	Wheeling-Pittsburgh Steel Corp.	Monessen, Pa.; Steubenville, Ohio
9	Amoco Oil Company	Texas City, Tex.; Whiting, Ind., Salt Lake City, Utah; Savannah, Ga.
10	ARCO Petroleum Products Company	Ferndale, Wash.; Houston, Tex.; Philadelphia, Pa.; Prudhoe Bay, Alaska
11	Chevron U.S.A., Inc.	Pascagoula, Miss.; Bakersville and El Segundo, Calif.; El Paso, Tex.
12	Exxon Company U.S.A.	Baton Rouge, La.; Baytown, Tex.; Billings, Mont.; Bernicia, Calif.
13	Gulf Oil Products Company	Port Arthur, Tex.
14	Mobil Oil Corp.	Ferndale, Wash.; Beaumont, Tex.; Paulsboro, N.J.; Joliet, Ill.
15	Phillips Petroleum Company	Sweeny and Borger, Tex.; Woods Cross, Utah
16	Shell Oil Company	Deer Park, Tex.; Norco, La.; Wilmington, Calif.
17	Texaco USA	Port Arthur, Tex.; Convent, La.; Wilmington, Calif.
	RECEIVED JUNE THROUGH SEPTEMBER 1986	
18	BASF Corp.	Anaheim, Calif.; Detroit, Mich.; Greenville, Ohio
19	Occidental Chemical Corp.	Niagara Falls, N.Y.; Columbia, Tenn.; Jeffersonville, Ind.; Pottstown, Pa.
20	Pfizer, Inc.	Canaan, Groton, and Wallington, Conn.; Southport, N.C.
21	Acme Steel Company	South Chicago, Ill.
22	Kaiser Aluminum & Chemical Corp.	Spokane and Mead, Wash.
23	Chevron U.S.A., Inc.	El Paso, Tex.; Barber's Point, Hawaii; Pascagoula, Miss.; El Segundo, Calif.
24	Shell Oil Company	Deer Park, Tex.; Martinez and Wilmington, Calif.; Norco, La.
25	UNOCAL Corp.	Lemont, Ill.; Rodeo and Wilmington, Calif.
	RECEIVED MAY THROUGH AUGUST 1987	
26	Abbott Laboratories	Abbott Park, Ill.
27	Air Products & Chemicals, Inc.	Allentown, Pa.
28	American Cyanamid Hannibal Plant	Hannibal, Mo.
29	Armour Pharmaceutical (Rorer Group, Inc.)	Kankakee, Ill.
30	Bemis Specialty Films	Minneapolis, Minn.
31	Borden Chemical	Diboll, Tex.
32	Camac Corp.	Bristol, Va.
33	Carus Chemical Company	Lasalle, Ill.
34	Chevron Chemical–Ortho Division	Richmond, Calif. (two plants)
35	Dial Corp. (Greyhound Corp.)	Montgomery, Ill.
36	E. I. du Pont de Nemours & Company	Charleston, S.C.
37	Ferro Corp.	Culver City, Calif.
38	General Latex and Chemical Corp.-Ohio	Ashland, Ohio
39	Goodyear Tire and Rubber Company	Beaumont, Tex.
40	Harshaw/Filtrol Partnership	Cleveland, Ohio
41	J. R. Simplot Company–Helm Plant	Helm, Calif.
42	Lonza, Inc. (Glycol Division)	Painesville, Ohio
43	Lubrizol Corp.	Deer Park, Tex.
44	McCloskey Corp. (California)	Los Angeles, Calif.
45	Milliken and Company	LaGrange, Ga.
46	Monsanto Agricultural Products	Luling, La.
47	Company	Greenville, S.C.
48	Morton Thiokol, Inc.	Harriman, N.Y.
49	Nepera, Inc.	Pryor, Okla.
50	N-ReN Corp., Cherokee Nitrogen Division, Olin Chemicals	Charleston, Tenn.

TABLE 5-13. (continued)

Ref. No.	Company name	Plant location(s)
51	Procter and Gamble	Cincinnati, Ohio
52	Reichhold Chemicals, Inc.	White Plains, N.Y.
53	Rubicon, Inc.	Geismar, La.
54	Ruetgers-Nease Chemical Company, Inc.	Gracewood, Ga.
55	SmithKline Chemicals	Conshohocken, Pa.
56	Standard Chlorine of Delaware	Delaware City, Del.
57	Stepan Company	Winder, Ga.
58	Union Carbide Corp.	Danbury, Conn.
59	Uniroyal Chemical Company, Inc.	Geismar, La.
60	USI Chemicals Company	Morris, Ill.
61	Vista Chemical Comany	Westlake, La.
62	General Foods Manufacturing Corp.	White Plains, N.Y.
63	Holland Dairies, Inc.	Holland, Ind.
64	Mallet and Company, Inc.	Carnegie, Pa.
65	AFG Industries	Kingsport, Tenn. and Bridgeport, W. Va.
66	Corning Glass Works	Wilmington, N.C.
67	Appleton Papers, Inc.	Appleton, Wis.
68	International Paper Company	Moss Point, Mass.
69	Arco Petroleum Products Company	Ferndale, Wash.
70	Calumet Refining Company	Chicago, Ill.
71	Fina Oil and Chemical Company	Port Arthur, Tex.
72	Murphy Oil Company	El Dorado, Ark.
73	Union Pacific Resources Company	Wilmington, Calif.
74	Aurora Industries, Inc.	Montgomery, Ill.
75	Revere Copper Products, Inc.	New Bedford, Mass.
76	Chaparral Steel Company	Midlothian, Tex.
77	Georgetown Steel Corp.	Georgetown, S.C.
78	Nucor Steel Division/Nucor Corp.	Darlington, S.C.
79	American Fuel Cell and Coated Fabrics	Magnolia, Ark.
80	Burlington Industries	Caroleen, N.C.
81	Graniteville Company	Graniteville, S.C.
82	Hitco	Gardena, Calif.
83	Winston Mills, Inc.	Swannanoa, N.C.
84	Copper Tire and Rubber Company	Findley, Ohio
85	Cupples Company	St. Louis, Mo.
86	Dunlop Tire Corp.	Buffalo, N.Y.
87	Gates Molded Products	Denver, Colo.
88	General Tire, Inc.	Akron, Ohio
89	Oliver Rubber Company, Oakland Plant	Oakland, Calif.
90	American Tobacco Company	Reidsville, N.C.
91	Brown & Williamson Tobacco Company	Louisville, Ky.
92	Liggett and Myers Tobacco Company	Durham, N.C.
93	Lorillard, Inc.	Greensboro, N.C.
94	R. J. Reynolds Tobacco Company	Winston-Salem, N.C.

5.5 REFERENCES FOR CHAPTER 5

1. Responses to Section 114 information requests Nos. 9-17 listed on Table 5-13.

2. Responses to Section 114 information requests Nos. 1-94 listed on Table 5-13.

3. Chemical Engineers Handbook. 5th Edition. Perry and Chilton, eds. McGraw Hill, New York. 1973.

4. Cooling Tower Fundamentals. J. Hensley, ed. Marley Cooling Tower Company, Mission, Kansas. 1983.

5. Betz Handbook of Industrial Water Conditioning, Eighth Edition. Betz Laboratories, Trevose, Pennsylvania. 1980. pp. 167-190, 202-215.

6. Responses to Section 114 information requests Nos. 1, 5-61, 69-66, 69-73, 76-94 listed on Table 5-13.

7. Telecon. Nicholson, B., MRI, with Kuharic, I., Marley Cooling Tower Company. October 15, 1986. Liquid-to-gas ratios and stack velocities.

8. Responses to Section 114 information requests Nos. 26, 30, 43, 50, 53, 59, 69, 77, 84 listed on Table 5-13.

9. Responses to Section 114 information requests Nos. 9-17, 23-25 listed on Table 5-13.

10. Emission Test Report: Exxon Company Petroleum Refinery, Baytown, Texas. EMB Report 85-CCT-3. November 1986.

11. Emission Test Report: Southeastern Manufacturing Facility. Draft. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. September 1987.

12. Emission Test Report: National Bureau of Standards Steam and Water Chill Plant, Gaithersburg, Maryland. EMB Report 85-CCT-4. November 1986.

13. Letter and attachments. Hawes, R., Mobil Oil Corp., to Randall, D., MRI. August 24, 1987. Response to request for emission test report on Mobil Oil, Torrance, California, refinery.

14. Emission Test Report: National Institute of Standards and Technology, Gaithersburg, Maryland. U. S. EPA Contract No. 68D90055, ESD/TSD Project No. 85/02. Draft. October 1990.

15. Memorandum and attachments. McClintock, S., Entropy, to Bivins, D., EPA/EMB. June 5, 1991. Cooling tower data analysis of the Allied Fibers emission test.

16. Telecon. Marinshaw, R., MRI, to Trulear, M., Nalco Chemical Company. July 29, 1991. Effect of cooling water additives on drift rate.

17. Telecon. Marinshaw, R., MRI, to Lindahl, P., Marley Cooling Tower Company. July 23, 1991. Factors that affect drift rate.

18. Responses to Section 114 information requests Nos. 9-17, 23-25, 69 listed on Table 5-13.

19. Responses to Section 114 information requests Nos. 1, 5-8, 18, 22, 26, 30, 43, 50, 53, 59, 77, 84 listed on Table 5-13.

20. Letter and attachments. Mayer, A., Chemical Manufacturers Association, to Cuffe, S., EPA:ISB. September 27, 1986. Summary of CMA member survey on corrosion inhibitors used in process cooling towers including average ppm in circulating water.

21. United States Refining Capacity. June 9, 1986. National Petroleum Refiners Association. pp. 5-17.

22. Letter and attachment. James, E., Betz Industrial, to Crowder, J., EPA:ISB. July 17, 1991. Response to questionnaire on cooling water treatment programs.

23. Letter and attachment. Roti, J., Drew Industrial, to Crowder, J., EPA:ISB. July 16, 1991. Response to questionnaire on cooling water treatment programs.

24. Telecon. Marron, J., MRI, to Lutey, R., Buckman Laboratories. August 2, 1991. Information on cooling water treatment programs.

25. 1987 Census of Manufactures. U.S. Department of Commerce, Washington, DC.

26. Responses to Section 114 information requests Nos. 18-20, 26-61, listed on Table 5-13.

27. Steel, USA: Into the 80's, Techno-Economic Report. Institute for Iron and Steel Studies. Green Brook, NJ. January. 1980. 16 pp.

28. Responses to Section 114 information requests Nos. 1-8, 21-22, 76-78 listed on Table 5-13.

29. Telecon. Upchurch, M., MRI, with Dean, J., Brown & Williamson Tobacco Company. October 31, 1986. Number of cooling towers.

30. Responses to Section 114 information requests Nos. 90-94 listed on Table 5-13.

31. Responses to Section 114 information requests Nos. 84-89 listed on Table 5-13.

32. Letter and attachments. Carpenter, E., Uniroyal Goodrich Tire Company, to Randall, D., MRI. October 21, 1986. Cooling tower and chemical treatment data.

33. Telecon. Upchurch, M., MRI, with Mabry, R., Mount Vernon Mills. October 31, 1986. Number of cooling towers.

34. Responses to Section 114 information requests Nos. 79-83 listed on Table 5-13.

35. Telecon. Upchurch, M., MRI, with Jordan, S., PPG Industries--Glass Division. October 30, 1986. Number of cooling towers.

36. Telecon. Upchurch, M., MRI, with Gallo, T., Corning Glass Works, Inc. October 31, 1986. Number of cooling towers.

37. Telecon. Upchurch, M., MRI, with Durvin, T., PPG Industries. October 30, 1986. Number of cooling towers.

38. Responses to Section 114 information requests Nos. 65-66 listed on Table 5-13.

6.0 REGULATORY ALTERNATIVES

6.1 DEVELOPMENT OF REGULATORY ALTERNATIVES

Based on an analysis of possible emission control techniques, three regulatory alternatives have been developed to assess the emission reduction and cost impacts of the various control options on the model plants. These alternatives are listed below.

1. Regulatory Alternative I (Baseline)--No regulatory action. This alternative involves no further regulatory action to control hexavalent chromium emissions from industrial process cooling towers (IPCT's).

2. Regulatory Alternative II--Drift eliminator retrofit. This alternative would require that cooling towers that use chromate-based chemical treatment programs be retrofitted with high-efficiency drift eliminators (HEDE's).

3. Regulatory Alternative III--Nonchromate programs. This alternative would require that only nonchromium-based water treatment chemicals be used in cooling towers.

6.2 APPLICATION OF ALTERNATIVES TO MODEL TOWERS

Baseline hexavalent chromium (Cr^{+6}) emission estimates were calculated for each category of model tower. Similarly, the incremental cost associated with each regulatory alternative was determined for all models in all categories. A reduction from baseline emissions was then determined for each alternative, and the cost effectiveness was calculated (see Chapter 8). Hexavalent chromium emissions estimates for all regulatory alternatives are presented in Table 6-1. The cost and emission impact of each of the regulatory alternatives beyond baseline are summarized below.

TABLE 6-1. EMISSION ESTIMATES FOR ALL REGULATORY ALTERNATIVES

	Cr^{+6} emissions under regulatory alternatives, Mg/yr		
	I (Baseline)	II[a]	III[b]
Petroleum manufacturing	8.90	3.04	0
Chemical manufacturing	10.42	3.56	0
Primary metals	3.37	1.15	0
Textile finishing	0.108	0.037	0
Tobacco products	0.088	0.030	0
Tire and rubber	0.030	0.010	0
Glass manufacturing	0.0039	0.0013	0
All industries	22.9	7.8	0

[a]Based on the current best estimate of an achievable emissions reduction of 64 percent as supported by EPA tests.
[b]Based on 100 percent emission reduction through prohibiting use of chromate.

Regulatory Alternative II. As explained previously in Section 4.1.3, the best estimate of the emission reduction achievable by an HEDE is 67 percent. Assuming that 5 percent of IPCT's already are equipped with HEDE's, the emission reduction achievable with this alternative is 64 percent. The cost of this alternative would be from the purchase, installation, and testing of the drift eliminators in all towers using chromate. The enforcement burden for this alternative is high and involves emission testing after every retrofit to ensure compliance and annual inspections of all IPCT's using chromate to ensure that the HEDE's are in good condition and are properly sealed.

Regulatory Alternative III. A ban on all chromate use in cooling towers would result in elimination of all public health risk attributable to Cr^{+6} emissions from IPCT's. The cost of this option is attributable to increased chemical cost of nonchromate treatment programs and the installation of chemical feed and control equipment. The enforcement burden for this option is very low, involving prohibiting the sale of chromate by chemical treatment vendors.

6.3 MACT FOR THE IPCT SOURCE CATEGORY

To develop a NESHAP under the CAA as amended November 1990 requires that a distinction be made between major and area sources. A major source is defined as "any stationary source or group of stationary sources within a contiguous area and under common control that emits more than 10 tons per year (tons/yr) of any one HAP or more than 25 tons/yr of any combination of HAP's." No known IPCT's emit more than 10 tons/yr of chromium compounds. However, the majority of chromium-using IPCT's are located at facilities (including most refineries and chemical plants and many primary metals plants) that emit in excess of 25 tons/yr of HAP's. Because these three industries represent 80 percent of the chromium-using plants and 94 percent of chromium-using IPCT's, it can be assumed that most IPCT's will be considered major sources.

The CAA as amended gives the Administrator discretion with regard to the appropriate control level to be required for area sources (i.e., those that emit less than the major source cutoff). Such sources may be regulated using generally available control technology (GACT) as opposed to maximum available control technology (MACT). Just as with standards developed for major sources, the Administrator may, for area sources, develop different standards for new and existing sources.

The MACT for new major sources is defined to be no less stringent than the level of emission control achieved in practice by the best controlled similar source. For existing major sources, MACT must be no less stringent than the average emission level achieved by the best performing 12 percent of existing sources or the best performing 5 sources in categories with less than 30 sources. These minimum required levels of control are called the "MACT floors." The Administrator may also set standards that "distinguish among classes, types and sizes of sources within a category or subcategory." In determining MACT for a source category or subcategory, costs and economic impacts must be considered. Eight years after MACT is established an analysis of residual risk is required in order to determine if additional controls are necessary.

There is no need to define a "floor" for GACT, but a qualitative assessment must be made that demonstrates that the area sources cause an adverse threat to health or the environment. In addition to costs and economic impacts, the technical capabilities of plant owners or operators who operate and maintain the emission control system must also be considered. However, a residual risk analysis is not required for GACT standards.

As shown in Table 6-2, nonchromates are used in approximately 90 percent of the IPCT's in the industries affected nationwide. It is estimated that HEDE's are used in only 5 percent of the IPCT's nationwide. Thus, not only is

TABLE 6-2. DISTRIBUTION OF REGULATORY ALTERNATIVES AMONG EXISTING IPCT's

Industry	Total number of cooling towers	Number of cooling towers using chromate	Cooling towers using HEDE's (RA II), percent	Cooling towers using nonchromates (RA III) percent
Petroleum refining	680	136	5	80
Chemical manufacturing	5,107	510	5	90
Primary metals	966	97	5	90
Tobacco products	270	7	5	97.5
Tire and rubber	262	20	5	92.5
Textiles finishing	773	19	5	97.5
Glass manufacturing	52	1	5	97.5
Nationwide	8,110	790	5	90

the use of nonchromates the more effective hexavalent chromium emission control method, nonchromates are more widely used than HEDE's. Thus, in the absence of subcategorization of the IPCT source category, the MACT floor for existing major sources, and MACT for new major sources would be the use of nonchromates. Because nonchromates are so widely used, GACT for the IPCT source category is likely to be use of nonchromates.

As Table 6-2 also shows, nonchromates are used in at least 80 percent of the IPCT's in each of the industry categories of concern. Thus, an industry-based subcategorization of the IPCT source category would not result in any subcategory with a less stringent MACT. In addition, the available information indicates that nonchromates are currently used in the majority of IPCT systems of all sizes. Nonchromates are in much more widespread use than chromate in industries that use large IPCT's, such as petroleum refining and chemical manufacturing, and in industries that use small IPCT's, such as textile finishing and glass manufacturing. Also, in most plants, IPCT's generally are either all on chromate or all on nonchromates and, as stated above, a large majority of plants use nonchromates. Thus, a size-based subcategorization also would not change MACT for the IPCT source category. High process temperatures and poor quality makeup water have been identified as two of the most critical parameters for determining the success of a cooling water treatment program. Results of a recent telephone survey and information request among manufacturers of chemicals that require high process temperatures indicate that nonchromates are used in more than 80 percent of the IPCT's that serve these processes and that the nonchromate-based water treatment programs currently available are achieving results comparable to or better than chromate-based water treatment programs. Further, the quality of the makeup water used by the plants responding to the information request varied considerably. Results

achieved at plants with the poorest quality makeup water did not indicate a higher occurrence of problems related to the water treatment program than were indicated for the plants that used good quality water. Thus, it does not appear that subcategorization of the IPCT source category according to process temperatures or water quality is warranted.

7.0 ENVIRONMENTAL AND ENERGY IMPACTS

An analysis of the environmental and energy impacts of the regulatory alternatives specified in Chapter 6 for controlling Cr^{+6} emissions from industrial process cooling towers is presented in this chapter. The incremental increase or decrease in air pollution, water pollution, solid waste disposal, and energy consumption for Regulatory Alternatives (RA's) II (high-efficiency drift eliminator [HEDE] retrofit) and III (nonchromate programs) as compared to RA I (baseline) are discussed. The baseline control level represents the existing Cr^{+6} emission level. All impacts are based on the current population of towers in each industry category presented in Chapter 5 and on the industry growth projections that are presented in Chapter 9.

7.1 AIR POLLUTION IMPACT

7.1.1 Existing Sources

The model towers established in Chapter 5 were used to estimate the emissions of Cr^{+6}, phosphate, and particulate matter (PM) from existing sources. Table 7-1 presents the model towers and the baseline emission rates of each pollutant.

7.1.1.1 Primary Emissions. The annual Cr^{+6} emissions for the model towers in each industry are presented in Table 7-2 for each RA. The average number of cooling towers per plant, their average size, and their utilization rates were used to calculate the emissions. The total baseline Cr^{+6} emissions from all IPCT's are 22.9 megagrams per year (Mg/yr) (25.2 tons per year [tons/yr]). The chemical manufacturing, petroleum refining, and primary metals industries account for 99 percent of the total Cr^{+6} emissions.

TABLE 7-1. BASELINE EMISSION RATE ESTIMATES FOR MODEL TOWERS

Model tower	Recirculation rate, ℓ/min (gal/min)	Blowdown rate, ℓ/min (gal/min)	Baseline emissions per model tower, g/hr (lb/hr)[a]			
			Baseline chromate-using tower, Cr^{+6} emissions	Baseline chromate-using tower, phosphate emissions	Tower on nonchromate program, phosphate emissions	Particulate matter emissions from any model tower
A	3,785 (1,000)	19 (5)	0.4 (0.001)	0.18 (0.0004)	0.92 (0.002)	68 (0.15)
B	7,570 (2,000)	38 (10)	0.8 (0.002)	0.43 (0.00095)	2.15 (0.0047)	136 (0.30)
C	18,925 (5,000)	95 (25)	2.0 (0.004)	1.04 (0.0023)	5.21 (0.012)	341 (0.75)
D	58,675 (15,500)	299 (79)	6.1 (0.014)	3.19 (0.007)	15.9 (0.035)	1,056 (2.3)
E	158,990 (42,000)	806 (213)	16.7 (0.04)	8.58 (0.019)	42.9 (0.095)	2,861 (6.3)
F	397,470 (105,000)	2,017 (533)	41.6 (0.09)	21.5 (0.047)	0.238	7,154 (16)

[a]Emissions calculated from: $E = (k)(C_x)(R)$

E = emissions (g/hr)

k = emission factor (0.0003)

R = recirculation rate (L/min)

when x = Cr^{+6}, C_x = 5.82 ppm Cr^{+6} (13 ppm CrO_4)

when x = P, C_x = (3 ppm PO_4) (for baseline/RA II)

when x = P, C_x = (15 ppm PO_4) (for RA III)

when x = total dissolved solids, C_x = 1,000 ppm TDS

TABLE 7-2. HEXAVALENT CHROMIUM, PHOSPHATE, AND PARTICULATE MATTER (PM) EMISSION ESTIMATES (1991) FOR EACH REGULATORY ALTERNATIVE

Industry	RA I baseline emissions Mg/yr			RA II emissions, Mg/yr			RA III emissions, Mg/yr		
	Cr^{+6}	Phosphate	PM	Cr^{+6}	Phosphate	PM	Cr^{+6}	Phosphate	PM
Petroleum refining	8.9	38.9	3,800	3.0	35.9	2,800	0.0	57.3	3,800
Chemical manufacturing	10.4	16.9	2,600	3.5	13.2	1,400	0.0	38.3	2,600
Primary metals	3.4	36.8	2,900	1.1	35.6	2,500	0.0	43.8	2,900
Textile finishing	0.11	5.5	400	0.04	5.5	400	0.0	5.8	400
Tobacco products	0.09	4.6	300	0.03	4.3	300	0.0	4.6	300
Tire and rubber	0.03	0.31	0	0.01	0.43	0	0.0	0.61	0
Glass products	0.004	0.31	10	0.00	0.18	10	0.0	0.21	10
All industries	22.9	103.3	10,010	8	95.1	7,410	0	150.6	10,010

7.1.1.2 Secondary Emissions. Nonchromate treatment programs typically require higher levels of phosphates and polymeric dispersants than chromate treatment programs. Nonchromate treatment programs may also contain molybdates. Thus, secondary emissions of these compounds would increase under RA III. There are currently no Federal standards for air emissions of any of these compounds.

7.1.1.2.1 Phosphate emissions. Phosphate compounds are the most commonly used nonchromate water treatment. To arrive at a maximum estimate of phosphate emissions from cooling towers, it was assumed that all towers not using chromates as corrosion inhibitors use phosphates and that all towers using chromates are using them in combination with a phosphate compound. The typical concentration of phosphates in towers not using chromates is 14 to 18 parts per million (ppm) and in towers using baseline chromate programs is 2 to 5 ppm (see Table 7-3).[1] For purposes of this analysis, a 15 ppm phosphate concentration was assumed for towers using nonchromate programs, and a 3 ppm phosphate concentration was assumed for towers using baseline chromate programs. It was assumed that the emission factors developed for estimating Cr^{+6} emissions from IPCT's also apply to phosphate.

Phosphate emission estimates for each RA and each industry are presented in Table 7-2. Total baseline phosphate emissions for all IPCT's are estimated to be 103.3 Mg/yr (114 tons/yr). Phosphate emissions under RA III are estimated to be 151 Mg/yr (166 tons/yr), a 45 percent increase over baseline. Regulatory Alternative II would reduce phosphate emissions 64 percent from towers using chromate. This would result in an overall phosphate emissions estimate of 95.1 Mg/yr (105 tons/yr), an 8 percent reduction below baseline.

7.1.1.2.2 Zinc emissions. Zinc is a common corrosion inhibition agent present in many IPCT treatment programs. Almost all current chromate programs contain zinc because the two metals act synergistically to inhibit corrosion; therefore, less of each is required. Nonchromate treatments may also contain zinc at levels similar to those in the chromate/zinc treatment they

TABLE 7-3. CHROMATE-BASED CORROSION INHIBITORS

Combination[a]	Concentration, ppm[b]	Operating conditions
Chromate/orthophosphate	20-25/3-3.5 5-10/10	pH 7.0-7.5 pH 6-2-6.8
Chromate/orthophosphate/zinc	15-25/2-5/2-5	pH 6.2-6.8
Chromate/polyphosphate/zinc	15-25/2-5/2-5 10-20/3-5/3-5 20-25/5-10/2.5-3.0 5/10/unknown	pH 6.0-7.0 pH 6.5-7.0 CaH 100-600 ppm[c] pH 6.0-6.5 CaH <400-600 ppm pH 6.5/7.2
Chromate/zinc/phosphonate	15-25/2-4/3-5 2-3/2-3/5-10 20-25/2-4/3-5	pH 6.5-7.5 pH 6.5-7.0 pH 6.5-7.0
Chromate/phosphonate	5-10/3-5 5-10/not specified	Not specified pH 7.5-8.5
Chromate/phosphonate/dispersant	5-15/2-6/2-6	pH 7.5-8.5

[a]In all combinations the organic triazole corrosion inhibitors should be included at 1 to 10 ppm when the system contains copper.
[b]Different formulations are required depending on the pH range of operation.
[c]CaH is calcium hardness.

replace. As chromate/zinc treatments are replaced by nonchromate treatments, zinc emissions are not expected to change significantly.[2,3] Therefore, no zinc emissions estimates were calculated.

7.1.1.2.3 Molybdate emissions. Molybdate treatments currently have a very small share of the water treatment market. Although good performance can be achieved with these treatments, the chemical cost is much higher than that of other treatment programs. Although the market for molybdate programs is expected to grow under RA III, predicting the amount of increased usage is not possible without extensive market research. Also, the toxicity of molybdate is lower than that of Cr^{+6}, and molybdate is not currently considered to be environmentally hazardous.[4] Therefore, molybdate emissions were not estimated.

7.1.1.2.4 Particulate matter. Particulate matter emissions were calculated by assuming a total dissolved solids content of 1,000 ppm in the recirculating water and applying a PM emission factor of 0.03 percent. It was assumed that the emission factors developed for estimating Cr^{+6} emissions from IPCT's also apply to PM. Thus, PM emissions are estimated to be 172 times higher than Cr^{+6} emissions from a baseline tower (1,000 ppm PM/5.82 ppm Cr^{+6}). Regulatory Alternative II would reduce PM emissions by 64 percent in towers that are retrofit with HEDE's. Table 7-2 presents the estimated emissions of PM for all industry categories under each RA.

7.1.2 New Sources

The projected Cr^{+6} emissions in the fifth year of the standard were estimated by multiplying the current Cr^{+6} emissions in each industry by the projected annual production rate change of that industry compounded over 7 years. The baseline year for the regulation is 1991; therefore, the emission estimates were projected 7 years from 1991 in order to include emission estimates for 1998, which will be the fifth year of the standard. In some cases, the available information was extrapolated because projections were provided for less than 7 years or for only

segments of a particular industry. The estimated Cr^{+6} emissions in 1998 for each industry and each RA are presented in Table 7-4.

The chemical manufacturing industry is expected to increase production by an annual rate of 2 percent from 1991 to 1995.[5] No information was available regarding growth rates past 1995; therefore, it was assumed that the chemical manufacturing industry would continue to increase production at the same annual rate through 1998. The petroleum refining industry is expected to increase production capacity by less than 2 percent from 1991 to 1996.[6] Therefore, the annual growth rate for that time period is approximately 0.4 percent; this growth rate was assumed to continue at the same rate from 1996 to 1998. The production of tires and nontire rubber products is expected to increase 1 to 2 percent in 1990.[7] An annual growth rate of 1.5 percent was applied from 1990 through 1998.

Primary iron and steel production is expected to decrease by greater than 10 percent in 1991 and then return to 1990 levels in 1992. After 1992, shipments are expected to remain relatively the same over the long term.[8] An average annual growth rate of 0.2 percent per year was applied to nonferrous metals production. Because the nonferrous metals make up approximately 38.5 percent of the primary metals industry (as discussed in Chapter 5), an average annual growth rate of 0.1 percent was used for the primary metals industry. An average annual growth rate of 1 percent was applied to glass production from 1991 to 1998.[9] The output of tobacco products is expected to decline by as much as 5 percent per year for the next 4 years.[10] This decline was applied through 1998. Production of textile mill products increased 1 percent per year from 1988 to 1990.[9] This growth rate was applied through 1998.

The total phosphate and PM emissions for each industry in 1998 are also presented in Table 7-4. The total baseline Cr^{+6} emissions from all industrial process cooling towers (IPCT's) are estimated to be 25 Mg/yr (28 tons/yr) in 1998. This represents an increase in emissions of 9 percent between 1991 and 1998.

TABLE 7-4. EMISSION ESTIMATES FOR 1998 (FIFTH YEAR OF STANDARD)

Industry	Annual growth rate projection, percent	RA I emissions, Mg/yr			RA II emissions, Mg/yr			RA III emissions, Mg/yr		
		Cr^{+6}	Phosphate	PM	Cr^{+6}	Phosphate	PM	Cr^{+6}	Phosphate	PM
Petroleum refining	0.4	9.2	39.8	3,908	3.0	37.1	2,879	0.0	59.2	3,908
Chemical manufacturing	2.0	11.9	18.4	2,987	4.0	15.3	1,608	0.0	44.1	2,987
Primary metals	0.1	3.4	36.8	2,920	1.14	35.9	2,518	0.0	44.1	2,920
Textile finishing	1.0	0.12	5.85	429	0.04	5.79	429	0.0	6.10	429
Tobacco products	-5.0	0.06	3.13	210	0.02	3.10	210	0.0	3.25	210
Tire and rubber	1.5	0.03	0.49	0	0.01	0.49	0	0.0	0.58	0
Glass products	1.0	0.004	0.21	11	0.00	0.021	11	0.0	0.21	11
All industries		25	105	10,464	8	97.7	7,654	0	158	10,464

7.2 WATER POLLUTION IMPACT

Regulatory Alternative III affects the chemistry of the cooling water and would affect the chemistry of the blowdown, which may result in water pollution impacts. As users switch from chromate-based treatment programs to nonchromate-based treatment programs, substitutes for chromate must be added to the cooling water. Among the possible substitutes are phosphates, phosphonates, zinc, and molybdates. The relative increase or decrease in discharges of Cr^{+6} and phosphate under the various RA's was estimated using the model towers developed in Chapter 5 and presented in Table 7-5 and Table 7-6. Blowdown rates for each tower were multiplied by the average concentration of each chemical in the cooling water before and after implementation of each RA to calculate the discharge.

7.2.1 Chromium Discharges

Table 7-5 presents the estimated discharges of Cr^{+6} via blowdown for each industry category under each RA. The baseline discharge was calculated using the model chromate level of 13 ppm (5.82 ppm Cr^{+6}) and the blowdown rate for each model tower. Current Cr^{+6} discharges are estimated to be 400 Mg/yr (440 tons/yr). These untreated discharge estimates represent Cr^{+6} contained in IPCT blowdown prior to treatment. Current water regulations require that most of these discharges be treated for Cr^{+6} removal either on the plant site or at publicly owned treatment works (POTW's).

Regulatory Alternative II (requiring HEDE retrofits) would not change the quality of the water effluent from IPCT's, and pollutant discharges would remain essentially the same as those under RA I. Regulatory Alternative III would eliminate all water discharges of Cr^{+6}.

7.2.2 Phosphate Discharges

Phosphorus is an essential nutrient for plants and animals. Excessive discharges of phosphorus, however, to lakes and streams can promote the growth of algae, which can produce toxins and raise the biochemical oxygen demand. The net result is a lower dissolved oxygen level, which can have disastrous consequences

TABLE 7-5. ESTIMATED WATER DISCHARGES (1991) OF HEXAVALENT CHROMIUM FOR ALL REGULATORY ALTERNATIVES

Industry	No. of Cr-using towers	Annual nationwide Cr^{+6} discharge, Mg	
		Baseline and RA II	RA II
Petroleum refining	136	155	0
Chemical manufacturing	510	182	0
Primary metals	97	59	0
Textiles finishing	19	0.5	0
Tobacco products	7	1.9	0
Tire and rubber manufacturing	20	1.5	0
Glass manufacturing	1	0.1	0
All industries	790	400	0

TABLE 7-6. ESTIMATED PHOSPHATE (PO_4) DISCHARGES (1991) FOR EACH REGULATORY ALTERNATIVE[a]

Industry	No. of cooling towers	No. of Cr-using towers	No. of nonchromate towers	Baseline RA I and RA II annual nationwide PO_4 discharges, Mg	Increase in PO_4 discharges under RA III, Mg/yr	Total PO_4 discharges under RA III, Mg/yr
Petroleum refining	680	136	544	1,664	322	1,986
Chemical manufacturing	5,108	510	4,598	4,325	374	4,699
Primary metals	966	97	869	1,435	123	1,554
Textiles finishing	773	19	754	52	0.12	55
Tobacco products	269	7	262	166	4.0	169
Tire and rubber industry	262	20	242	49	3.1	52
Glass manufacturing	52	1	51	9.2	0.15	9.2
All industries	8,110	790	7,320	7,700	826	8,524

[a]Discharges under Regulatory Alternative II are the same as baseline discharges.

for aquatic life. Nonchromate treatment programs often contain phosphorus in the form of phosphates or phosphonates. To estimate the maximum increase in phosphorus levels under RA III it was assumed that: (1) all towers currently using chromates would switch to a phosphate-containing treatment program, (2) current chromate treatments would contain 3 ppm phosphate, and (3) nonchromate treatments would contain 15 ppm phosphate.

Table 7-6 shows the baseline phosphate discharges and the discharges under RA III to the receiving water for each industry category. The current discharge rate (7,700 Mg/yr [8,470 tons/yr]) is expected to increase by 826 Mg/yr (909 tons/yr) (approximately 11 percent) to 8,524 Mg/yr (9,376 tons/yr) under RA III. Table 7-7 compares this estimated discharge increase from cooling towers to discharges from selected phosphorus sources.

Phosphorus export coefficients estimate the mass loading of phosphorus to a surface water body per year per unit of source (e.g., hectare [HA]).[11] These coefficients are used to model the loading from similar sources. However, numerous factors affect the coefficients' magnitude. Export coefficients are calculated from watersheds with known soil types, precipitation, land uses, and other site-specific characteristics that alter runoff. An export coefficient is selected to model the mass loadings of a watershed by matching the characteristics of the two watersheds as closely as possible. Thus, the nationwide phosphorus loadings from particular sources listed in Table 7-7 are presented in ranges that represent variability in loadings due to varying characteristics incorporated in export coefficients that may be applied to that source type. The total discharge of phosphorus from IPCT's under RA III is relatively small compared to the other selected sources listed in Table 7-7. However, the impact of increased phosphorus discharges on a site-specific basis could affect the nutrient condition of local receiving waters.

TABLE 7-7. SELECTED PHOSPHORUS DISCHARGE SOURCES[11,12]

Discharge source	Land area, 10^6 HA	Range of phosphorus coefficients, kg/HA-y	Estimated range of phosphorus discharge, Mg/yr
Increase from IPCT's for RA III for 1991			2,781
Cropland runoff	195.3	0.1-18.6	19,530-3,632,580
Mixed agriculture	195.3	0.08-3.25	15,624-634,725
Pastureland and rangeland	211.1	0.14-4.90	29,554-1,034,390
Forestland	246.1	0.019-0.830	4,676-204,263
Animal feedlot and manure storage	0.0836	21.28-795.20	1,779-66,479
Urban runoff	6.1	0.19-6.23	1,159-38,003
Petroleum refining[a]			3.43
Chemical manufacturing[a]			0.84
Primary metals[a]			2.4
Textile finishing[a]			0.06
Tobacco products[a]			1.14
Tire and rubber[a]			0.18
Glass manufacturing[a]			0.02

[a]Average phosphorus discharge per plant.

7.2.3 Zinc Discharges

As stated in Section 7.1.1.2.2, nonchromate treatments contain levels of zinc similar to those in baseline chromate programs. Therefore, zinc discharges are not expected to increase under any of the RA's.

7.2.4 Molybdate Discharges

As stated in Section 7.1.1.2.3, there are not presently enough data to estimate the amount of increased use of this chromium substitute.

7.2.5 New Sources

Growth factors presented in Section 7.1.2 were used to estimate the trends in Cr^{+6} and phosphate discharges over the 7-year period from 1991 to 1998. Tables 7-8 and 7-9 present the growth factors for each industry and the projected (1998) discharges of Cr^{+6} and phosphate (respectively) for each regulatory alternative.

The total baseline discharges of Cr^{+6} in 1998 are estimated to be 426.8 Mg (469.5 tons/yr). This represents an increase in Cr^{+6} discharges of 6.5 percent between 1991 and 1998. Baseline discharges of phosphate in 1998 are estimated to be 8,168 Mg (8,985 tons/yr). This represents an increase in phosphate discharges of 7.2 percent between 1991 and 1998.

7.3 SOLID WASTE DISPOSAL

Blowdown from cooling towers may be treated to reduce the concentrations of corrosion inhibitors (e.g., chromium, zinc, phosphorus, and molybdenum). The resulting sludge is likely to be more concentrated in these elements than the blowdown was before treatment.

Chromium-containing solid waste (i.e., the treatment sludge) is sometimes identified as a hazardous waste, EPA hazardous waste No. D007, under Resource Conservation and Recovery Act (RCRA) Part 261 Subpart C--Characteristics of Hazardous Waste; it is considered a hazardous waste if its leachate by the Toxicity Characteristic Leaching Procedure contains greater than 5 milligrams per liter (mg/L) total chromium. Chromium-containing waste is also subject to the Land Disposal

TABLE 7-8. ESTIMATED WATER DISCHARGES OF HEXAVALENT CHROMIUM FOR ALL REGULATORY ALTERNATIVES IN 1998 (5th Year of Standard)

Industry	Annual growth rate projection, percent	Annual nationwide Cr^{+6} discharge, Mg	
		Baseline and RA II	RA III
Petroleum refining	0.4	159	0
Chemical manufacturing	2	205	0
Primary metals	0.1	59	0
Textiles finishing	1	0.6	0
Tobacco products	-5	1.4	0
Tire and rubber manufacturing	1.5	1.7	0
Glass manufacturing	1	0.1	0
All industries		426.8	0

TABLE 7-9. ESTIMATED PHOSPHATE DISCHARGES FOR EACH REGULATORY ALTERNATIVE IN 1998[a]
(5th Year of the Standard)

Industry	Annual growth rate projection, percent	Baseline annual nationwide P discharges, Mg	Total P discharges under RA III, Mg
Petroleum refining	0.4	1,704	2,035
Chemical manufacturing	2	4,781	5,291
Primary metals	0.1	1,444	1,566
Textiles finishing	1	55	58
Tobacco products	-5	123	126
Tire and rubber industry	1.5	52	55
Glass manufacturing	1	9.2	9.2
All industries		8,168	9,140

Restrictions in RCRA Part 268, which allows land disposal only if the hazardous waste is treated in accordance with Subpart D--Treatment Standards. A concentration in the waste of 5 mg/L total chromium may not be exceeded to allow land disposal. Hazardous wastes also must be handled and stored according to specific RCRA procedures. Baseline blowdown discharges of Cr^{+6} are estimated at 400 Mg/yr (440 tons/yr). Therefore, solid waste disposal of a maximum of 400 Mg/yr (440 tons/yr) of Cr^{+6} may be expected in the sludge from blowdown treatment processes.

Zinc-, molybdenum-, and phosphorus-containing wastes are not identified as hazardous wastes and therefore do not have the same solid waste disposal requirements as chromium-containing wastes. Under RA II, the blowdown Cr^{+6} concentrations would be the same as baseline Cr^{+6} blowdown concentrations, resulting in the same Cr^{+6} solid waste disposal (400 Mg/yr [440 tons/yr] maximum). Regulatory Alternative III would eliminate the use of Cr^{+6} and, thus, eliminate solid waste disposal of Cr^{+6} from IPCT's.

7.4 ENERGY IMPACT

Energy impacts over baseline (RA I) would result from using HEDE's (RA II) and the chemical feed and control equipment required for nonchromate-based water treatment programs (RA III). For both alternatives, the energy impacts would be relatively minor.

Although HEDE's are designed for greater impaction of water droplets on eliminator surfaces than are low-efficiency drift eliminators (LEDE's), the pressure drop through an HEDE is generally less than the pressure drop through an LEDE. Thus, a net energy savings results when LEDE's are replaced with HEDE's. The difference in pressure drop between an LEDE and an HEDE is mainly a function of eliminator design, type of tower (crossflow vs. counterflow), and air velocity. For crossflow towers designed with eliminator airflow velocities in the typical range of 91.5 to 213 meters per minute (m/min) (300 to 700 feet per minute [ft/min]), the difference in pressure drop between an HEDE and an LEDE is negligible. However, for counterflow towers, the reduction in pressure loss, and thus, the reduction in energy

consumption, is more significant.[13] Based on information provided by vendors, the difference in pressure loss between a counterflow tower with an HEDE and a counterflow tower equipped with an LEDE can be estimated to be 0.076 grams per square centimeter (0.03 inches of water).[13-15] Based on the assumption that 25 percent of the IPCT's in the industries of concern are counterflow design, the nationwide energy savings due to this RA would be 5,294 megawatt hours per year (MWhr/yr). Table 7-10 summarizes the nationwide energy savings for each of the seven industries.

As discussed in Chapter 3, nonchromate-based water treatment programs generally require tighter control of chemical feed and recirculating water quality parameters. As discussed in Chapter 8, the components required for a basic chemical feed and monitoring system include a pH controller, conductivity controller, and metering chemical feed pumps. Information provided by vendors indicates that this type of system typically requires 0.5 kW to operate, and at least 50 percent of the IPCT's in the industries of concern have at least one of these control components in place.[16-18] Based on these assumptions, the resulting nationwide increase in energy consumption due to this RA would be 2,587 MWhr/yr. Table 7-11 summarizes the nationwide increases in energy consumption for each of the seven industries.

7.5 STATE REGULATIONS

7.5.1 Air Emissions

The California Air Resources Board (CARB) is the first State agency to regulate Cr^{+6} emissions from cooling towers. The CARB identified Cr^{+6} as a toxic air contaminant (TAC) in January 1986. California State law requires that once a substance has been identified as a TAC, a report must be prepared by CARB to determine the appropriate degree of control needed for the substance.[19] The CARB estimated that in 1985 Cr^{+6} emissions from cooling towers (all types, including industrial) accounted for 68 percent of all Cr^{+6} emissions in the State of California.[19] The airborne toxic control measure (ATCM) adopted by the CARB in March 1989 banned Cr^{+6}-containing compounds from use in all

TABLE 7-10. ESTIMATED ANNUAL REDUCTIONS IN ENERGY CONSUMPTION FOR REGULATORY ALTERNATIVE II (HEDE RETROFIT)

Industry category	Annual energy savings, MWhr/yr
Petroleum refinishing	2,450
Chemical manufacturing	2,380
Primary metals	420
Textile finishing	4.5
Tobacco products	20.2
Tire and rubber products	18.4
Glass products	0.5
Nationwide	5,294

TABLE 7-11. ESTIMATED ANNUAL INCREASE IN ENERGY CONSUMPTION FOR REGULATORY ALTERNATIVE III (NONCHROMATE)

Industry category	Increased annual energy consumption, MWhr/yr
Petroleum refinishing	520
Chemical manufacturing	1,610
Primary metals	338
Textile finishing	41
Tobacco products	18
Tire and rubber products	57
Glass products	2.5
Nationwide	2,587

cooling towers. The ATCM requires owners or operators of cooling towers to:

1. Register existing cooling towers with the local air pollution control district (APCD) or air quality management district (AQMD);

2. Discontinue using Cr^{+6};

3. Keep the concentration of Cr^{+6} in the recirculating water below 0.15 mg/L;

4. Monitor the recirculating water for chromium by an approved method every 6 months;

5. Maintain records of the test results for 2 years; and

6. Provide information to the local APCD on all new towers installed after the ATCM is adopted.

Operators of wooden towers may receive an exemption that will allow greater than 0.15 mg/L Cr^{+6} in recirculating water for a period of 6 months after the ATCM compliance date. Violation of the ATCM may result in a civil penalty not to exceed $10,000 per day for each day of violation. The local APCD's must adopt a control measure at least as stringent as the ATCM adopted by CARB. Districts were required to propose measures by July 1990 and to adopt measures by September 1990.[20] The ATCM was codified March 12, 1990.[21]

The CARB is currently working with local APCD's to adopt local control measures for chromium. Although most of the APCD's are adopting the ATCM verbatim or with only minor changes, some APCD's have not adhered to the schedule for ATCM proposal and adoption. As of March 1991, 15 out of a total of 41 APCD's have adopted chromium control measures approved by CARB.[19] No other States are known to be considering proposals to limit Cr^{+6} emissions from cooling towers.

7.5.2 Water Discharges

Representative State water quality criteria for Cr^{+6}, zinc, and phosphorus are presented in Table 7-8. The most recent Federal water quality criteria for chromium and zinc were published in the Federal Register in July 1985 and March 1987, respectively. Most States have now adopted EPA water quality

criteria for chromium and zinc.[22] The water quality criteria for Cr^{+6} has reduced the allowable concentration of Cr^{+6} for discharge to surface waters in the United States.

Phosphorus may be addressed in water quality criteria or narrative standards. Sixteen States have numeric phosphorus criteria ranging from 7.4 to 1,000 micrograms per liter ($\mu g/L$) for various types of receiving waters. Lakes and reservoirs generally have the most restrictive phosphorus criteria. Almost all States have regulations containing narrative statements prohibiting discharge of any substances at levels that are injurious to fish and wildlife or that render water unsuitable for drinking.[22] Molybdenum is typically addressed under a heavy metals category for which standards are set relative to the toxicity of each substance.

Most zinc water quality standards are calculated from an equation that considers the hardness of the receiving water. Zinc toxicity changes with water hardness. The majority of values presented in Table 7-12 were calculated for a hardness of 100 mg/L as calcium carbonate, which is a hardness value often used for comparison purposes.

Permit values applied to the discharges from a facility are likely to differ from the values in Table 7-12. Permit values are determined from a number of site-specific factors including waste-load allocations and consideration of the designated uses of the receiving water.

7.6 POLLUTION PREVENTION

The Pollution Prevention Act of 1990 (PPA) (passed by Congress on October 27, 1990) establishes pollution prevention as national policy to prevent pollution or reduce it at the source whenever feasible; recycle in an environmentally safe manner, whenever feasible, pollutants that cannot be prevented; treat in an environmentally safe manner, whenever feasible, pollutants that cannot be prevented or recycled; and dispose of or release pollutants in an environmentally safe manner only as a last resort.

TABLE 7-12. REPRESENTATIVE STATE WATER QUALITY CRITERIA[a,17]

Pollutant	Fresh water acute value	Fresh water chronic value	Marine acute value	Marine chronic value	Drinking water value	Range of lake values
Hexavalent chromium	16	11	1,100	50	50	
Zinc	117[b]	106[b]	95	86	5,000	
Phosphorus				0.1		7.4 to 1,000

[a]All values are μg/L.
[b]Hardness dependent values, 100 mg/L as $CaCO_3$ used as an example.

Pollution prevention is not defined in the Act, but it is intended to include source reduction and to exclude most forms of recycling.[23] Pollution prevention policy applies to any hazardous substance, pollutant, or contaminant.

Source reduction is defined as any practice that reduces the amount of any hazardous substance, pollutant, or contaminant entering any waste stream or otherwise released into the environment (including fugitive emissions) prior to recycling, treatment, or disposal and reduces the hazards to public health and the environment associated with the release of such substances, pollutants, or contaminants.[23] Regulatory Alternative II cannot be considered a source reduction technique. High-efficiency drift eliminators would reduce the amount of drift and, thereby, reduce the amount of chromium emitted, but this would not reduce the amount of chromium entering the waste stream (i.e., the concentration of chromium in the drift and blowdown). However, RA III is considered a pollution prevention alternative under the PPA. Converting to nonchromate-based water treatment programs would reduce the emissions of chromium to zero and eliminate pollution at the source through a cost-effective change in materials used. In addition to eliminating chromium emissions, using nonchromates has several other benefits. Besides eliminating onsite spills, transportation, storage, and water discharges of a hazardous substance, using nonchromates also eliminates worker exposure to a hazardous substance during formulation and use. The nonchromate alternative eliminates the use of chromium at the source and thereby constitutes a pollution prevention measure.

Under RA III phosphate emissions and discharges would increase. This would likely affect the local growth of aquatic plants and deplete dissolved oxygen in the receiving water. However, a large percentage of the phosphate concentration may be removed from discharges by standard wastewater treatment methods.

7.7 REFERENCES FOR CHAPTER 7

1. Betz Handbook of Industrial Water Conditioning. Betz Laboratories, Inc. Trevose, Pennsylvania. 8th Edition. 1980. pp. 207-208.

2. Telecon. Nicholson, B., MRI, with Soule, C., Dearborn Division, W. R. Grace & Company. March 26, 1986. Effects of regulatory alternatives on water discharges.

3. Telecon. Nicholson, B., MRI, with Dowdle, B., Mogul. March 30, 1987. Effects of regulatory alternatives on water discharges.

4. Robitaille, D. R. Molybdate Inhibitors for Problem Cooling Waters. Chemical Engineering. October 4, 1982. pp. 132 to 142.

5. Chemical and Engineering News. 69(25):30. June 24, 1991.

6. U.S. Industrial Outlook 1991--Petroleum Refining. pp. 4-2.

7. U.S. Industrial Outlook 1991--Plastics and Rubber. pp. 14-5.

8. Telecon. Marron, J., MRI, with Bell, C., U.S. Department of Commerce. July 22, 1991. Iron and Steel production growth projections.

9. Predicast Forecasts. Issue No. 120. Fourth Quarter. August 3, 1990.

10. U.S. Industrial Outlook 1990--Food, Beverages and Tobacco. pp. 34-33.

11. Modeling Phosphorus Loading and Lake Response Under Uncertainty: A Manual and Compilation of Export Coefficients. U. S. Environmental Protection Agency. Publication No. EPA-440/5-80-011. June 1980.

12. Analysis of Phosphorus Sources in the Environment. U. S. Environmental Protection Agency. Publication No. EPA-560/2-79-002. March 1979.

13. Telecon. Marinshaw, R., MRI, to Lindahl, P., Marley Cooling Tower Company. August 12, 1991. Pressure drop through drift eliminators.

14. Fax transmittal. Skold, J., Munters Corporation, to Marinshaw, R., MRI. August 13, 1991. Pressure drop through Munters D-15 drift eliminators.

15. Fax transmittal. Whittemore, M., Brentwood Industries, Inc., to Marinshaw, R., MRI. August 13, 1991. Pressure drop through Brentwood CDX drift eliminators

16. Telecon. Marinshaw, R., MRI, to James, E., Betz Industrial. August 2, 1991. Cooling water treatment programs and control equipment.

17. Telecon. Marinshaw, R., MRI, to Domino, E., Betz Industrial. August 15, 1991. Chemical feed and control equipment costs, operation, and maintenance.

18. Telecon. Marinshaw, R., MRI, to Eastin, P., Nalco Chemical Company. August 19, 1991. Water treatment chemical and control equipment costs and requirements.

19. Staff Report. State of California Air Resources Board. Proposed Hexavalent Chromium Control Plan. January 1988. 40 p.

20. Proposed Hexavalent Chromium Control Measure for Cooling Towers. State of California Air Resources Board. January 20, 1989. 23 p.

21. Telecon. Marron, J., MRI, with Popejoy, C., California Air Resources Board. February 20, March 7, and March 15, 1991. Status of the California hexavalent chromium control measure for cooling towers.

22. Memorandum. Marron, J., MRI, to Chromium Emissions From Industrial Process Cooling Towers NESHAP Project File. State Water Quality Criteria. August 5, 1991.

23. Memorandum. Laskowski, S., EPA, to Pollution Prevention Advisory Committee. Pollution Prevention Act of 1990. November 27, 1990.

8.0 COST ANALYSIS OF CONTROL OPTIONS

8.1 INTRODUCTION

This chapter presents estimates of the nationwide costs that would be incurred by the petroleum refining, chemical manufacturing, primary metals, and miscellaneous industries to reduce hexavalent chromium (Cr^{+6}) emissions from industrial process cooling towers (IPCT's). Regulatory Alternatives II (high-efficiency drift eliminator [HEDE] retrofits) and III (use of nonchromates) were evaluated with respect to Regulatory Alternative I (baseline) to determine the increase in costs for each of the two control technologies represented by the regulatory alternatives. Cost factors for each of the model towers presented in Chapter 5 were first determined and then applied to the number and sizes of model towers that best represent the industries of concern. The costs are based on information obtained from vendors, manufacturers, and responses to information requests. In some cases, it was also necessary to rely on engineering judgement and information on general industry practices and trends to develop cost factors.

8.2 ANNUALIZED COST OF CONTROL TECHNIQUES

8.2.1 High-Efficiency Drift Eliminator Retrofits

Regulatory Alternative II is based on retrofitting HEDE's on all IPCT's in which chromium is used to control corrosion. The components of the cost estimate for this alternative include capital costs, the cost of a compliance test, and the cost of annual inspections. Maintenance and labor costs are not included because it is assumed that the maintenance and labor requirements for HEDE's are no different than those for standard, low-efficiency drift eliminators (LEDE's). Energy costs also are not

included in the cost estimate for this alternative. The pressure drop through a typical HEDE in a crossflow tower is comparable to the pressure drop through an LEDE, and, thus, the difference in energy requirements between a tower equipped with HEDE's and a comparable tower with LEDE's is negligible.[1] The difference in pressure drop through a counterflow HEDE and a counterflow LEDE is more significant, but because it is estimated that a maximum of 25 percent of IPCT's in the industries of concern are of counterflow design, it is assumed that any difference in energy requirements for counterflow IPCT's is also negligible.[1,2]

It is estimated that 5 percent of existing towers are already equipped with HEDE's.[3]

8.2.1.1 Capital Costs. Capital costs include the purchased equipment costs, taxes and freight, direct installation costs, and indirect installation costs. According to a cooling tower manufacturer, typical unit material costs (including taxes) for HEDE's are \$5.50 per square foot (\$/ft^2) for crossflow towers and \$3.60/ft^2 for counterflow towers. Unit freight and direct installation costs for crossflow towers are estimated to be \$0.70/ft^2 and \$2.75/ft^2, respectively. For counterflow towers, unit freight and direct installation costs are typically \$0.50/ft^2 and \$1.85/ft^2, respectively. Also, contingencies for HEDE retrofits are estimated to be 20 percent.[2]

In order to estimate the entire purchased equipment costs for a drift eliminator retrofit, it is necessary to estimate the area of drift eliminator required. For a crossflow IPCT, the required drift eliminator area is estimated from the tower height, tower length, and angle of the eliminator to vertical using the following equation:[1]

$$A = (H)(L)(1/\cos\theta)(2) \qquad (1)$$

where:

A = drift eliminator area;

H = height of tower;

L = length of tower; and

$\cos\theta$ = cosine of angle of eliminator to vertical, typically 9 degrees.

The factor of two takes into account the two banks of drift eliminators in a crossflow tower. Because the drift eliminator area required for a crossflow IPCT is comparable to that required for a counterflow IPCT with equivalent recirculation rate and splash fill, Equation 1 can be used to estimate the HEDE areas required for all model towers without the need to account for the percentage of crossflow and counterflow towers.[2]

The values above were used to estimate capital costs for retrofitting HEDE's on all model towers.

8.2.1.2 Compliance Test Costs. It is assumed that compliance tests would be required on all IPCT's equipped with HEDE's to ensure that the tower achieves a drift rate of no more than 0.01 percent of the recirculating water flow. Therefore, the cost of a compliance test is included in the overall cost estimate for Regulatory Alternative II. As discussed in Appendix C, results from EPA-sponsored emissions tests indicate that a minimum of 18 test runs are required to distinguish between the emission rate for a tower equipped with HEDE's and for a comparable tower equipped with LEDE's. According to a testing firm, the cost of an IPCT emissions test using the Cooling Tower Institute sampling train with surrogate mineral analysis can be estimated to be $57,000.[4] This cost includes the cost of 18 test runs, sample analysis using inductively coupled argon plasma spectroscopy, and preparation of an emissions test report. Thus, the cost of a compliance test is assumed to be $57,000 for all model towers.

8.2.1.3 Annual Inspection Costs. Under this regulatory alternative, all IPCT's equipped with HEDE's would be required to be inspected annually. The purpose of the inspection is to ensure that the HEDE's are in good condition and are properly sealed. The cost of the annual inspection was assumed to increase with tower size, starting at $600 for model towers with recirculation rates up to 18,900 liters per minute (L/min) (5,000 gallons per minute [gal/min]) and increasing to $1,200 for the largest model tower size. These figures are consistent with

standard rates that a major drift eliminator manufacturer charges for inspecting a cooling tower.[5]

8.2.1.4 Annualized HEDE Retrofit Costs. The annualized cost to retrofit HEDE's on each of the model IPCT's is summarized in Table 8-1. These costs are based on an annual interest rate of 10 percent and an HEDE lifetime of 15 years. In addition, to account for the distribution of IPCT designs (75 percent crossflow and 25 percent counterflow) in the industries of concern, a composite unit cost for HEDE's was used in estimating the cost to retrofit HEDE's on the model towers. As shown in Table 8-1, the annualized costs of this regulatory alternative range from $8,700 for the smallest model tower to $51,000 for the largest tower.

8.2.2 Nonchromate Water Treatment Programs

Regulatory Alternative III is based on banning the use of chromate-based water treatment programs in IPCT's. The components of the nonchromate program costs that were applied to the model towers include the increased cost of nonchromate chemicals over the cost of chromate chemicals and the cost to install and operate automated chemical feed and control equipment. Information recently obtained from petroleum refineries, chemical manufacturing plants that produce high-process-temperature chemicals, and water treatment chemical vendors indicates that, with few exceptions, nonchromates perform comparably to chromates in controlling corrosion in IPCT systems, provided that the water treatment programs are properly controlled.[6,7] Therefore, in estimating the increased costs for nonchromate programs over chromate programs, it was assumed that corrosion rates, heat exchanger lifetime, cleaning requirements, and other maintenance requirements are comparable for both types of water treatment programs. Thus, it was assumed that there are no increases in maintenance costs associated with the performance of water treatment programs following conversion to nonchromates. Based on information provided by water treatment chemical vendors, it is not necessary to shut down an IPCT system when converting from chromates to nonchromates and there are no costs

associated with the conversion process other than the costs associated with installing automated chemical feed and control equipment.[8-10] For systems that are severely scaled or fouled, conversion should be scheduled to coincide with scheduled shutdowns to allow cleaning of the system. (In such cases, cleaning would also be required if the system were to continue to operate on a chromate-based water treatment program.) Finally, because manpower requirements are comparable for both chromates and nonchromates, it is assumed that labor costs do not change following conversion to nonchromates.

8.2.2.1 Water Treatment Chemical Costs. Information obtained from four water treatment chemical vendors indicates that the costs of chromate-based water treatment programs range from $30 to $130 per million pounds of blowdown, and the costs of nonchromate-based water treatment programs range from $60 to $250 per million pounds of blowdown.[11-14] To estimate representative chemical costs for both types of programs, a weighted average of the costs submitted by all four vendors was determined. The weighing factors taken into consideration included the average costs of each type of chromate and nonchromate program, the percentage of sales of each type of program by the vendors, and estimates of each vendor's market share of petroleum refineries, chemical plants, primary metals plants, and other industries. This resulted in an average chromate program cost of $72 per million pounds of blowdown and an average nonchromate program cost of $126 per million pounds of blowdown.

8.2.2.2 Chemical Feed and Control Equipment Costs. Based on information obtained from water treatment vendors, the minimum equipment requirements to achieve adequate control of nonchromate-based water treatment programs include a pH controller, conductivity/blowdown controller, and some (typically two) metering chemical feed pumps.[11-14] The components of the cost estimate for a typical installation of these three types of control equipment include capital costs and annual costs. These are discussed below.

8.2.2.2.1 Capital costs. Capital costs include the purchased equipment costs, direct installation costs, indirect installation costs, freight, and taxes. Vendors have indicated that the costs of a basic pH controller, conductivity controller, and metering pump are $2,000, $2,000 and $600, respectively, and direct installation costs are typically 25 percent of the capital costs.[12,13,15] It is assumed that indirect installation costs, taxes, and freight can be estimated as 20 percent, 3 percent, and 5 percent, respectively, of the capital costs. These figures were used to estimate the costs to install a complete control system in a model cooling tower.

8.2.2.2.2 Annual costs. Annual costs include maintenance costs and the cost of energy to operate the equipment. Maintenance costs include the costs to replace probes and rebuild pumps. Based on information provided by vendors, pH probes typically cost $175 and must be replaced annually, conductivity probes typically cost $150 and must be replaced every 3 years, and pump maintenance costs are typically $75 per year. The entire control system typically requires 0.5 kilowatts to operate.[15] The unit cost of electricity for industry was assumed to be $0.047 per kilowatt-hour.[16] These figures were used to estimate the annual costs of chemical feed and control systems on the model towers.

8.2.2.3 Annualized Costs for Nonchromate-Based Programs. The annualized costs to convert and operate the model IPCT's on nonchromate-based water treatment programs are summarized in Table 8-2. The chemical cost component represents the difference in annual chemical costs between chromate-based and nonchromate-based programs. In determining the annualized capital costs for the chemical feed and control equipment, a 5-year equipment life and 10 percent interest rate were assumed.[15] In addition, approximately 50 percent of the plants in the industries of concern already have at least one of these three types of control equipment in place, and many plants have all three types of equipment. For the purpose of estimating the equipment costs, it was assumed that 50 percent of the IPCT's nationwide would

require all three types of control equipment and 50 percent of the IPCT's nationwide would require two of the three types of control equipment.[17] The annualized costs of this regulatory alternative range from $4,300 for the smallest model tower to $144,000 for the largest model tower.

8.2.3 Summary of Costs and Cost Effectiveness of Regulatory Alternatives

The annualized costs and cost effectiveness of the regulatory alternatives for each of the seven industries by model IPCT size are presented in Tables 8-3 to 8-9. Table 8-10 summarizes the nationwide costs and cost effectiveness values for the regulatory alternatives. Regulatory Alternative II, which is based on retrofitting HEDE's on all chromate-using IPCT's, achieves a 64 percent emission reduction, based on the assumptions that each HEDE reduces emissions by 67 percent and 5 percent of all IPCT's already are equipped with HEDE's. The overall annualized cost of this alternative is $11.3 million, and the cost effectiveness is $750,000 per megagram ($/Mg). Regulatory Alternative III, which is based on converting all chromate-using IPCT's to nonchromate-based water treatment programs, achieves a 100 percent emission reduction. The overall annualized cost of this alternative is $14 million, and the cost effectiveness is $610,000/Mg.

TABLE 8-1. HEDE RETROFIT COSTS FOR MODEL COOLING TOWERS

Model plant	Recirculation rate		HEDE net area		HEDE capital cost, $	Annualized HEDE capital cost, $	Annualized compliance test cost, $	Annual inspection cost, $	Total annual costs, $
	L/min	gal/min	m^2	ft^2					
A	3,790	1,000	42	454	4,463	587	7,494	600	8,680
B	7,570	2,000	63	680	6,695	880	7,494	600	8,970
C	18,900	5,000	181	1,940	19,129	2,515	7,494	600	10,600
D	58,700	15,500	753	8,100	79,704	10,479	7,494	800	18,800
E	159,000	42,000	2,110	22,700	223,171	29,341	7,494	1,000	37,800
F	397,000	105,000	3,030	32,600	321,207	42,230	7,494	1,200	50,900

TABLE 8-2. NONCHROMATE COSTS FOR MODEL COOLING TOWERS

Model plant	Recirculation rate		Blowdown rate		Annual chemical cost, $		Increase in annual chemical cost for nonchromate, $	Annualized equipment cost, $	Total annual cost, $
	L/min	gal/min	kg/yr/10^6	lb/yr/10^6	Chromate	Nonchromate			
A	3,790	1,000	11	24	1,752	3,067	1,314	2,954	4,270
B	7,570	2,000	23	50	3,588	6,279	2,691	2,954	5,650
C	18,900	5,000	56	124	8,929	15,625	6,696	2,954	9,650
D	58,700	15,500	174	385	27,703	48,481	20,778	2,954	23,700
E	159,000	42,000	474	1,040	75,183	131,571	56,387	2,954	59,300
F	397,000	105,000	1,180	2,610	187,916	328,854	140,937	2,954	144,000

TABLE 8-3. CONTROL COST ESTIMATE FOR PETROLEUM REFINERIES

Model tower	Average recirculation rate		No. of towers nationwide	No. of towers using CrO_4	HEDE retrofits		Nonchromate	
Type	L/min	gal/min			Annualized cost, $	Cost effectiveness, $/Mg	Annualized cost, $	Cost effectiveness, $/Mg
C	18,900	5,000	265	53	534,000	1,040,000	511,000	657,000
D	58,700	15,500	196	39	696,000	595,000	926,000	521,000
E	159,000	42,000	196	39	1,400,000	443,000	2,310,000	481,000
F	397,000	105,000	23	5	242,000	239,000	720,000	467,000
Total for industry			680	136	2,870,000	490,000	4,470,000	502,000

TABLE 8-4. CONTROL COST ESTIMATE FOR CHEMICAL MANUFACTURING

Model tower	Average recirculation rate		No. of towers nationwide	No. of towers using CrO_4	HEDE retrofits		Nonchromate	
Type	L/min	gal/min			Annualized cost, $	Cost effectiveness, $/Mg	Annualized cost, $	Cost effectiveness, $/Mg
A	3,790	1,000	2,554	255	2,100,000	5,170,000	1,090,000	1,760,000
C	18,900	5,000	1,230	123	1,240,000	1,260,000	1,190,000	796,000
D	58,700	15,500	804	80	1,430,000	721,000	1,900,000	631,000
E	159,000	42,000	520	52	1,870,000	536,000	3,090,000	582,000
Total for industry			5,107	510	6,640,000	970,000	7,260,000	697,000

TABLE 8-5. CONTROL COST ESTIMATE FOR PRIMARY METALS INDUSTRY

Model tower	Average recirculation rate,		No. of towers nationwide	No. of towers using CrO_4	HEDE retrofits		Nonchromate	
Type	L/min	gal/min			Annualized cost, $	Cost effectiveness, $/Mg	Annualized cost, $	Cost effectiveness, $/Mg
A	3,790	1,000	317	32	264,000	4,720,000	137,000	1,610,000
C	18,900	5,000	285	29	292,000	1,160,000	280,000	729,000
D	58,700	15,500	301	30	535,000	660,000	712,000	578,000
F	397,000	105,000	63	6	290,000	264,000	863,000	517,000
Total for industry			966	97	1,380,000	622,000	1,990,000	591,000

TABLE 8-6. CONTROL COST ESTIMATE FOR TOBACCO INDUSTRY

Model tower	Average recirculation rate		No. of towers nationwide	No. of towers using CrO_4	HEDE retrofits		Nonchromate	
Type	L/min	gal/min			Annualized cost, $	Cost effectiveness, $/Mg	Annualized cost, $	Cost effectiveness, $/Mg
B	7,570	2,000	168	4	34,100	3,240,000	22,600	1,410,000
D	58,700	15,500	101	3	53,500	884,000	71,200	774,000
Total for industry			270	7	87,700	1,240,000	93,700	868,000

TABLE 8-7. CONTROL COST ESTIMATE FOR TIRE AND RUBBER INDUSTRY

Model tower	Average recirculation rate				HEDE retrofits		Nonchromate	
Type	L/min	gal/min	No. of towers nationwide	No. of towers using CrO_4	Annualized cost, $	Cost effectiveness, $/Mg	Annualized cost, $	Cost effectiveness, $/Mg
B	7,570	2,000	262	20	170,000	2,930,000	113,000	1,280,000
Total for industry			262	20	170,000	2,930,000	113,000	1,280,000

TABLE 8-8. CONTROL COST ESTIMATE FOR TEXTILES FINISHING INDUSTRY

Model tower	Average recirculation rate		No. of towers nationwide	No. of towers using CrO_4	HEDE retrofits		Nonchromate	
Type	L/min	gal/min			Annualized cost, $	Cost effectiveness, $/Mg	Annualized cost, $	Cost effectiveness, $/Mg
A	3,790	1,000	773	19	157,000	7,850,000	81,100	2,700,000
Total for industry			773	19	157,000	7,850,000	81,100	2,700,000

TABLE 8-9. CONTROL COST ESTIMATE FOR GLASS PRODUCTS INDUSTRY

Model tower	Average recirculation rate		No. of towers		HEDE retrofits		Nonchromate	
Type	L/min	gal/min	Nationwide	Using CrO_4	Annualized cost, $	Cost effectiveness, $/Mg	Annualized cost, $	Cost effectiveness, $/Mg
B	7,570	2,000	52	1	8,520	3,280,000	5,650	1,450,000
Total for industry			52	1	8,520	3,280,000	5,650	1,450,000

TABLE 8-10. SUMMARY OF COSTS AND COST EFFECTIVENESS OF CONTROL MEASURES

Industry category	Baseline Cr^{+6} emissions, Mg/yr	HEDE retrofits			Nonchromates		
		Cr^{+6} emissions reduction, Mg/yr	Control cost, $	Cost effectiveness, $/Mg	Cr^{+6} emissions reduction, Mg/yr	Control cost, $	Cost effectiveness, $/Mg
Petroleum refining	8.90	5.86	2,870,000	490,000	8.90	4,470,000	502,000
Chemical manufacturing	10.42	6.84	6,640,000	970,000	10.42	7,260,000	697,000
Primary metals	3.37	2.22	1,380,000	622,000	3.37	1,990,000	591,000
Tobacco products	0.108	0.071	87,700	1,240,000	0.108	93,700	868,000
Tire and rubber	0.088	0.058	170,000	2,930,000	0.088	113,000	1,280,000
Textile finishing	0.030	0.020	157,000	7,850,000	0.030	81,100	2,700,000
Glass manufacturing	0.0039	0.0026	8,520	3,280,000	0.0039	5,650	1,450,000
NATIONWIDE	22.9	15.1	11,300,000	750,000	22.9	14,000,000	611,000

8.3 REFERENCES FOR CHAPTER 8

1. Telecon. Marinshaw, R., MRI, with Lindahl, P., Marley Cooling Tower Company. August 12, 1991. Pressure drop through high efficiency drift eliminators.

2. Telecon. Marinshaw, R., MRI, with Beyer, A., Marley Cooling Tower Company. August 13 and 16, 1991. Costs associated with retrofitting high efficiency drift eliminators.

3. Telecon. Marron, J., MRI, with DePalma, T., Tower Performance, Inc. August 20, 1991. Use of high efficiency drift eliminators by industry.

4. Telecon. Marinshaw, R., MRI, to Watson, P., Entropy Environmentalists. August 19 ,1991. Estimated cost of cooling tower compliance test.

5. Telecon. Marron, J., MRI, to Beyer, A., Marley Cooling Tower Company. August 20, 1991. Cooling tower inspection costs.

6. Memorandum. Marinshaw, R., MRI, to Myers, R., EPA:ISB. May 15, 1991. Summary of Information Gathered From California Petroleum Refineries.

7. Memorandum. Marinshaw, R. and Marron, J., MRI, to Myers, R., EPA:ISB. June 7, 1991. Preliminary Analysis of Section 114 Questionnaires on Nonchromate-Based Cooling Water Treatment Programs.

8. Telecon. Marinshaw, R., MRI to Eastin, P., Nalco Chemical Chemical Company. October 22, 1991. Converting cooling towers from chromates to nonchromates.

9. Memorandum. Marron, J., MRI, to Myers, R., EPA:ISB. April 3, 1991. Trip report: Betz Industrial, Trevose, Pennsylvania, on February 26, 1991.

10. Telecon. Marron, J., MRI, to Clavin, S., Betz Industrial. October 15, 1991. Cleaning and pretreatment cost requirements associated with conversion to nonchromates.

11. Letter and attachments. Roti, J., Drew Industrial Division, Ashland Chemical, to Crowder, J., EPA:ISB. July 16, 1991. Response to questionnaire on cooling water treatment programs and control equipment.

12. Letter and attachments. James, E., Betz Industrial, to Crowder, J., EPA:ISB. July 17, 1991. Response to questionnaire on cooling water treatment programs and control equipment.

13. Questionnaire. Eastin, P., Nalco Chemical Company, to Myers, R., EPA:ISB. August 5, 1991. Response to questionnaire on cooling water treatment programs and control equipment.

14. Questionnaire. Lutey, R., Buckman Laboratories, to Myers, R., EPA:ISB. August 6, 1991. Response to questionnaire on cooling water treatment programs and control equipment.

15. Telecon. Marinshaw, R., MRI, with Domino, E., Betz Industrial. August 15, 1991. Cost and lifetime of chemical feed and control equipment.

16. Monthly Energy Review, Energy Information Administration. Retail prices of electricity. March 1991. p.109.

17. Telecon. Marinshaw, R., MRI, with James, E., Betz Industrial. August 2, 1991. Cooling water treatment programs and control equipment.

9.0 ECONOMIC IMPACTS

The purpose of this chapter is to determine the economic impacts likely to occur as a result of the regulation of hexavalent chromium emissions from IPCT's (Industrial Process Cooling Towers). By limiting these emissions, the proposed regulatory alternatives hold the potential for cost increases for all firms that currently use chromate corrosion inhibitors. Furthermore, to the extent that the regulation could affect the use of chromates in IPCT's, the suppliers of such products could face the reduction or elimination of the market for their products.

In Section 9.1, industry profiles are developed for the suppliers of chromate corrosion inhibitors and for the major end users of these corrosion inhibitors for cooling tower operation. Section 9.1.1 provides information on the market and suppliers of corrosion inhibitor products. In Sections 9.1.2 through 9.1.4, profiles are presented for those industries which are major users of chromates, namely, chemical manufacturing, petroleum refining, and the primary metals industry. Profiles of the textile finishing, tobacco products, tire and rubber products, and glass products industries are presented in Sections 9.1.5 through 9.1.8. These industries are relatively minor users of chromate corrosion inhibitors. For all the user industries, data are presented regarding the value of shipments, industry structure, domestic production, domestic consumption, foreign trade, and employment. These data are reported in order to provide the statistical basis for the economic impact analysis.

Section 9.2 examines the economic impacts of the different regulatory alternatives. The impacts are expressed in terms of price increases and reductions in quantity demanded for each of the user industries.

The economic impacts in Section 9.2 are calculated using aggregate industry data rather than product data because IPCT's are not specific to the manufacture of individual products but instead are used in the production of many products at a manufacturing site. In this sense, cooling towers represent a utility to the plant. For example, in the petroleum refining industry, IPCT's are not used solely for the production of distillate fuel but also for the manufacture of many other petroleum products.

Regulating hexavalent chromium emissions from IPCT's may have a significant impact on a substantial number of small businesses. If this is the case, then, according to the Regulatory Flexibility Act, the proposing agency must prepare a Regulatory Flexibility Analysis (RFA). In order to determine whether a RFA is necessary, the magnitude of the regulation's impact on small businesses is examined in Section 9.3.

9.1 INDUSTRY PROFILES

9.1.1 The Supply and Demand of Chromate Corrosion Inhibitors

The corrosion inhibitors market covers the use of a large number of chemicals that function as corrosion inhibitors in a variety of industrial applications. The market is often described in terms of corrosion inhibitors that function to reduce or eliminate corrosion on either the "process side" or the "water side" of industrial operations. The process side refers to chemicals added to process streams at petroleum refineries, oil fields, and pipelines in order to limit the corrosive effects of the materials being processed. Corrosion inhibitors used on the water side include those intended to reduce corrosion in either boiler water or in cooling tower water. Those used in cooling water applications are the focus of concern in this discussion.[1]

Chromates have historically been the easiest and most effective to use of all corrosion inhibitors because they required less monitoring and control than nonchromate corrosion inhibitors. This contributed to the lower cost of chromate programs versus substitute programs. However, regulations restricting the allowable effluent emissions of hexavalent chromium have caused many IPCT operators to use substitutes in order to avoid increased productions costs. The improvement in the performance of nonchromate formulations has also influenced the decision of many firms to substitute for chromate formulations. Although early nonchromate programs had their difficulties, those currently sold are as easy to control and as effective or more effective than chromates.[2,3]

Corrosion inhibitors are sold by firms who supply these chemical formulations for use in water treatment or process applications. The market was worth over $700 million in 1988. With respect to water treatment applications, the primary suppliers include Betz Laboratories, Calgon, Dearborn, Drew Chemicals, Mogul, and Nalco Chemical.

The corrosion inhibitor formulation is only part of the product sold by these companies. The identification of the optimal formulation for a specific facility requires the specialized expertise of the technical staffs of the suppliers. In most cases the formulations are changed in response to changes in plant process parameters or changes in intake water quality. In essence, the product being sold is a corrosion inhibitor service rather than a specific group of chemicals.

It is important to note that the industries using corrosion inhibitors place greater emphasis on the technical services.[1] While these industries prefer to purchase the formulations at the least possible cost, they cannot afford the high costs associated with corrosion. The costs include

those resulting from inefficient heat exchange and the need to replace corroded heat exchangers and other process equipment. Consequently, industries using chromate corrosion inhibitors may be relatively price-insensitive if chromates have been identified as the most effective corrosion inhibitor. However, this is less likely now than in the past because nonchromates are now as effective as chromates. Also, the costs of using chromates will increase due to regulation, thus making them more comparable to nonchromate costs.

9.1.2 Chemical Manufacturing

The chemical industry (SIC 28) is extremely diverse in terms of the range of products manufactured. To simplify the discussion of the industry, it is helpful to consider the industry as being composed of five major subgroups -- basic chemicals, organic chemicals, synthetic materials, agricultural chemicals, and finished chemical products. It should be noted that there is considerable overlap among these five subgroups.

Basic chemicals are used as building blocks, processing aids, or catalysts in chemical and non-chemical manufacturing. This group includes commercially important inorganics (such as sulfuric acid and phosphates), inorganic pigments, chlor-alkalies, and industrial gases. Basic chemicals are usually recovered from mineral ores or as coproducts in manufacturing processes such as metals production or petroleum refining. For the most part, basic chemicals are generic products in that they are usually sold as commodities and there is little product differentiation.

Industrial organic chemicals are substances containing elemental carbon; they are usually derived from petroleum and natural gas. These chemicals can be categorized into three groups: basic organics, intermediates, and finished goods. Basic organic chemicals are derived directly from raw materials such as aliphatics and aromatics.

Intermediate organics are more refined basic organics which are used to produce finished organic products. The distinction between basic, intermediate, and finished organics is blurred; in many instances basic and intermediate organics are sold as end products. Organic chemicals are used in the manufacture of many chemical products including plastics, synthetic rubber, pharmaceuticals, and adhesives.

Synthetic materials include plastics, man-made fibers, and synthetic rubber. Plastics are polymers which are combined with curatives, fillers, and other agents and then shaped or molded under pressure to a solid state. Key plastic materials include acrylonitrile-butadiene-styrene (ABS) resins, polyethylene, polyvinyl chloride, and phenolic. Man-made fibers include materials developed from cellulose (known as cellulosics) and fibers derived from hydrocarbons (non-cellulosics). Rayon and acetate are major cellulosics; nylon, polyester, and polypropylene are major non-cellulosics. Synthetic rubbers, often referred to as elastomers because of their elasticity, are polymeric materials which resemble natural rubber. Most often used in tire production, major synthetic rubbers include styrene-butadiene rubber (SBR), polybutadiene, and nitrile rubber.

Agricultural chemicals are chemicals used by the farm industry, most notably fertilizers and pesticides. Fertilizers include nitrogen, phosphate, and potash formulations; they are used to provide nutrients to crops. Pesticides and herbicides are used to destroy insects, weeds, and fungus; usually they are proprietary formulations.

Chemical products are upgraded basic and intermediate chemicals manufactured for specific end uses. They are not sold as commodities, but are sold with brand names and compete on performance as well as price. Coatings and

allied products, soap and toiletries, and drugs are major chemical product groups.

Chemical manufacturing processes often operate at extremely high temperatures, particularly in the production of petrochemicals. Many sectors of the industry use large amounts of water to cool their production process and often employ cooling towers. Fourteen four-digit chemical manufacturing industries which are part of SIC 28 have been identified as chromate users. These industries are SICs 2812, 2813, 2816, 2819 (industrial inorganic chemicals), 2861 (gum and wood chemicals, an industrial organic industry), 2873, 2874, 2875, 2879 (agricultural chemicals), and 2891, 2892, 2893, 2895, 2899 (miscellaneous chemical products). Survey results indicate that of those processes using cooling towers, 10 percent use chromate corrosion inhibitors.[a] The producers most likely to use IPCT's are large facilities producing several products at high temperatures.

While in certain instances the data presented are specific to the 14 industries under consideration, the majority of data are aggregate information concerning the entire chemical industry.

9.1.2.1 Industry Shipments. The aggregate historical values of shipments for the 14 industries are shown in Table 9-1. The data represent the value of all products and services sold by establishments in the chemical manufacturing industries using chromate corrosion inhibitors.

The peak occurred in 1981 when shipments were valued at $68,300 million. The value of shipments subsequently fell

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[a]Estimates of the percentage of plants using chromate corrosion inhibitors are based on an engineering survey of the major cooling water treatment chemical vendors.

TABLE 9-1. VALUE OF SHIPMENTS FOR CHEMICAL MANUFACTURING INDUSTRIES, 1980-1989[a,4,5]

	Value of Shipments (10^6 1991 Dollars)[b]
1989	65,152
1988	63,446
1987	59,363
1986	56,898
1985	61,420
1984	64,411
1983	58,865
1982	61,071
1981	68,300
1980	67,429

[a]The industries in question are SICs 2812, 2813, 2816, 2819, 2861, 2873, 2874, 2875, 2879, 2891, 2892, 2893, 2895, and 2899.
[b]The data are normalized using the implicit price deflator for GNP.

10.6 percent in 1982, due in large part to the recession. Through 1985 the value of shipments fluctuated due to a number of reasons. These difficulties included a strong U.S. dollar (which hurt the industry's balance of trade), high energy and raw material costs, overcapacity from plant expansions at the end of the previous decade, and the economic downturn of 1985. Also, from 1980 to 1985 the industry was restructuring. By trimming excess capacity and employment, manufacturers steadily increased the industry value of shipments from 1986 to 1989 when shipments were valued at $65,152 million. Also contributing to this growth were lower oil prices and a decline in the value of the dollar.

9.1.2.2 Industry Structure. According to the 1987 Census of Manufactures, in that year there were 5,343 establishments in the 14 industries. Of these, 1,824 (34%) employed 20 or more personnel. The establishments in the industry were controlled by 3,602 companies.

The chemical industry's capacity utilization rate had been over 80 percent since 1987.[6] However, capacity growth combined with decreased demand from the automotive and construction sectors helped push down the utilization rate from 89 percent in 1989 to 78 percent in 1990.[7]

The chemical industry is highly integrated as well as diversified. Many of the major chemical producers are integrated backward into chemical feedstocks such as petroleum; many are also integrated forward into finished chemical products. Almost all of the major chemical producers are diversified into other markets to some degree. Of the top 100 chemical producers (ranked by chemical sales), only 40 producers had 100 percent of their revenues in 1990 generated from chemical product sales.[8]

9.1.2.3 Domestic Production. There is no meaningful measure of aggregate unit output for the chemical industry

because of the diversity of products manufactured by the industry. Table 9-2 shows domestic production for several important chemical products from 1986 to 1989. This table gives an indication of the level of activity in the industry.

The majority of the chemicals listed enjoyed production growth from 1986 to 1988, as did the entire chemical industry. Growth fell in 1989 for many chemicals as the economy slowed in the latter part of the year.

Annually, the Federal Reserve Board compiles a production index for the chemical industry. The index eliminates differences in measuring units (pounds, gallons, cubic feet, etc.) and indicates the sum total of production in the industry. It allows for comparison of year to year production and identification of trends in the industry. Chemical production rose 5.4 percent in 1987 and 1988 (Table 9-3). Production rose in 1990 in all sectors except industrial organic chemicals and agricultural chemicals.

9.1.2.4 Domestic Consumption. Chemicals are used in a wide range of industries, most notably the automobile, construction, agricultural, and pharmaceutical industries. Many of the industries which are heavy consumers of chemicals are influenced by the general health of the economy. Therefore, the chemical industry tends to follow the general business cycle of the economy. The demand for chemicals declined beginning in the fourth quarter of 1989 in response to the slowdown in the economy. As the economy suffered, so did the automotive and construction industries, two major consumers of chemicals.

Since many chemical products are used to produce other chemical products, there are interdependencies among different sectors of the industry. For example, demand for basic chemicals such as nitrogen and phosphate is influenced

TABLE 9-2. U.S. PRODUCTION OF KEY CHEMICALS, 1986-1989[a]

	1986	1987	1988	1989
Basic Chemicals (10^6 kg)				
Nitric Acid	6,109	6,554	7,249	7,574
Chlorine	9,467	10,050	10,212	10,354
Sulfuric Acid	32,652	35,612	38,628	39,282
Industrial Organic Chemicals (10^6 kg)				
Ethylene	14,905	15,854	16,875	15,870
Propylene	7,494	8,627	9,627	9,331
1,3-Butadiene	1,155	1,329	1,437	1,416
Agricultural Chemicals (10^6 kg)				
Nitrogen Solutions	5,393	5,432	6,349	5,120
Phosphate Rock	32,865	35,680	38,301	43,251
Potassium Chloride	1,556	1,642	2,035	2,101
Chemical Products (10^6 gallons)				
Coatings and Allied Products	987	1,013	1,056	1,069[a]

[a]Preliminary

TABLE 9-3. PRODUCTION INDEXES FOR THE U.S. CHEMICAL INDUSTRY, 1980-1990[8]

(1987=100)	1990	1989	1988	1987	1986	1985	1984	1983	1982	1981	1980
Chemicals and Products	110.3	108.5	105.4	100.0	94.6	91.4	91.4	87.5	81.8	89.2	87.8
Basic Chemicals	108.6	106.6	98.3	100.0	95.1	96.1	96.9	92.1	86.5	96.9	96.5
Industrial Organic Chemicals	107.1	109.2	103.1	100.0	95.1	94.1	93.4	89.9	81.0	97.0	92.8
Synthetic Materials	106.5	103.1	104.4	100.0	91.6	86.9	88.9	84.3	71.8	79.5	71.2
Chemical Products	113.3	110.1	107.5	100.0	95.9	90.2	89.0	86.6	83.0	85.4	87.6
Agricul-tural Chemicals	105.1	108.2	107.2	100.0	88.5	96.1	102.0	87.5	88.8	102.3	97.2

by demand for agricultural chemicals which are manufactured with these chemicals.

The sensitivity of chemical sales to price changes, or the elasticity of demand, is generally regarded to be low. While to some extent individual chemicals may serve as substitutes for others, there are few substitutes for generic chemical products. Also, chemical products are generally regarded as necessities and very often represent a very small portion of the price of final products that they are used to produce. For these reasons, relatively small changes in chemical prices are not usually associated with significant changes in quantities demanded.

Published estimates of the elasticity of demand for chemicals in general are uncommon. Those estimates that have been located indicate that elasticities for specific chemicals vary widely, but are most often between -0.5 and zero. These estimates indicate that the demand for chemicals is generally relatively inelastic, as a one percent increase in price would cause a decrease in quantity demanded of less than one percent.

9.1.2.5 Foreign Trade. From 1980 to 1985, the trade balance for the U.S. chemical industry declined. The strength of the U.S. dollar hurt domestic exports. However, strong demand overseas in the latter part of the decade, due to growing foreign economies in combination with a weaker dollar, reversed this trend. The value of chemical exports in 1989 was $39,231 million (1991 dollars), while imports were valued at $22,314 million.[6] The trade balance of $16,917 in 1989 was almost double that of 1985.[6]

9.1.2.6 Employment. In 1989, there were 228,800 employees in the 14 industries under consideration.[5] This figure represents a 2.1 percent increase from 1988.[5] Of the 1989 employment total, 133,000 personnel were production workers.

9.1.2.7 Outlook. Industry growth will closely follow the growth of the domestic economy.[7] As previously stated, the demand for chemicals is dependent on some of the major economic sectors such as automotive and construction industries.

9.1.3 Petroleum Refining

The Standard Industrial Classification Code for petroleum refining is 2911; this industry includes all firms involved in the refining of crude oil into marketable products. Major petroleum products include motor gasoline, distillate fuel oil, residual oil, jet fuel, and liquified petroleum gases.

The refining of crude oil involves extremely high process temperatures. For this reason, cooling towers used in the refining of petroleum products often use chromate corrosion inhibitors. Survey results indicate that 20 percent of the cooling towers in petroleum refining use chromates.[a]

9.1.3.1 Industry Shipments. The petroleum refining industry's value of shipments is shown in Table 9-4. In 1987, certain product classes of SIC 2911 were reassigned to other 4-digit industries; this reassignment had the effect of redefining SIC 2911.[4] Thus, value of shipments data are only reported from 1987 onwards. Previous data are not comparable to what is reported in the table.

In 1988, the value of shipments declined 2.6 percent. There was a subsequent 6 percent increase in 1989 as crude oil prices rose.

9.1.3.2 Industry Structure. As of June, 1991, there were approximately 190 domestic refineries.[9] The number of

[a]Estimates of the percentage of plants using chromate corrosion inhibitors are based on an engineering survey of the major cooling water treatment chemical vendors.

TABLE 9-4. VALUE OF SHIPMENTS FOR THE PETROLEUM REFINING INDUSTRY, 1987-1989[4,5]

	Value of Shipments (10^6 1991 Dollars)[a]
1989	141,067
1988	133,366
1987	136,983

[a]The data are normalized using the implicit price deflator for GNP.

refineries has declined 41.4 percent since 1981 when there were 324 U.S. petroleum refineries.[10] The majority of the closures occurred in the earlier part of the decade among the smallest refineries. The trend toward larger refineries was encouraged by the high crude oil prices prevailing before 1985 (which favored more integrated facilities) and decreases in petroleum consumption.

In the last 15 years, no new refineries have been built in the United States. Future construction is unlikely due to the nature of the permitting process, current economic conditions, and environmental constraints. New capacity is added via construction of new processing units at existing refineries, modifications to existing units, and through taking parts from or reactivating mothballed refineries.

The industry utilization rate for operable capacity (operating capacity plus idle capacity) rose from 86.3 percent in 1989 to 87.1 percent in 1990.[10] Also rising was the utilization rate for operating capacity, from 90.2 percent in 1989 to 90.9 percent in 1990.[10] Most refineries are designed to be efficient at rates between 85 to 95 percent of capacity.

Many petroleum refining companies are integrated backward to crude oil production. Major petroleum refiners such as Exxon, Sunoco and Amoco are all active in the exploration and drilling of crude oil. From 1981 to 1989, the major integrated oil companies accounted for 65 to 75 percent of total U.S. refining capacity.[11] The major refiners are also involved in the marketing of their products to the consumer as well as producing petrochemical products. The volatile nature of the oil industry has caused this diversification into other markets. As a result, there has been more intense competition in marketing among oil producers, particularly in the gasoline market. Discounts for paying with cash and the emergence of

convenience stores are examples of new marketing approaches used by gasoline marketers.

9.1.3.3 Domestic Production. Production of several major petroleum products is shown in Table 9-5. In 1990, finished motor gasoline was the number one petroleum product, accounting for 46 percent of domestic refineries' net production of finished petroleum products.[10] After increasing steadily from 1985 to 1989, production fell slightly (less than 1%) in 1990. Production of residual fuel oil and liquified petroleum gases also fell in 1990. Distillate fuel oil, jet fuel, and other petroleum products experienced increased production in 1990.

9.1.3.4 Domestic Consumption. Table 9-6 details trends in the apparent consumption (production plus imports minus exports) of petroleum products from 1981 to 1990. The consumption of finished motor gasoline declined 1.3 percent in 1990 to 7.2 million barrels per day due to an increase in the average price of motor gasoline and a gain in fuel efficiency. Distillate fuel oil experienced a 4.3 percent decrease in consumption; this was the first decline since 1982. The decline was partly attributable to milder weather which lowered the demand for heating oil. Also contributing to the decline in overall consumption was a slowdown in the growth of industrial production, resulting in lower demand for diesel fuel. Milder weather also affected electric utility demand for residual fuel oil. Consumption of residual fuel oil fell 10.3 percent, resulting in 1.2 million barrels consumed per day in 1990. Jet fuel continued its decade-long rise in consumption. Demand rose 2.2 percent to push daily consumption to 1.5 million barrels in 1990. The impetus behind jet fuel consumption is an increase in business and recreational air travel. Liquified

TABLE 9-5. AVERAGE U.S. PRODUCTION OF PETROLEUM PRODUCTS, 1981-1990[10]

	Quantity (10^3 Barrels Per Day)					
	Finished Motor Gasoline	Distillate Fuel Oil	Residual Fuel Oil	Jet Fuel	Liquified Petroleum Gases	Other Petroleum Products
1990	6,959	2,925	950	1,488	1,749	2,842
1989	6,963	2,899	954	1,403	1,791	2,771
1988	6,956	2,859	926	1,370	1,817	2,773
1987	6,841	2,731	885	1,343	1,748	2,737
1986	6,752	2,798	889	1,293	1,695	2,704
1985	6,419	2,687	882	1,189	1,704	2,532
1984	6,453	2,681	891	1,132	1,697	2,500
1983	6,340	2,456	852	1,022	1,642	2,437
1982	6,338	2,606	1,070	978	1,528	2,475
1981	6,405	2,613	1,321	968	1,571	2,771

TABLE 9-6. AVERAGE APPARENT CONSUMPTION IN THE U.S. OF PETROLEUM PRODUCTS, 1981-1990[10]

	Quantity (10^3 Barrels Per Day)					
	Finished Motor Gasoline	Distillate Fuel Oil	Residual Fuel Oil	Jet Fuel	Liquified Petroleum Gases	Other Petroleum Products
1990	7,235	3,021	1,229	1,522	1,556	2,402
1989	7,328	3,157	1,370	1,489	1,668	2,285
1988	7,336	3,122	1,378	1,449	1,656	2,303
1987	7,206	2,976	1,264	1,385	1,612	2,187
1986	7,034	2,914	1,418	1,307	1,512	2,045
1985	6,831	2,868	1,202	1,218	1,599	1,947
1984	6,693	2,845	1,369	1,175	1,572	2,007
1983	6,622	2,690	1,421	1,046	1,509	1,877
1982	6,539	2,671	1,716	1,013	1,499	1,856
1981	6,588	2,829	2,088	1,007	1,466	2,081

petroleum gases experienced the second largest drop in demand, 6.7 percent in 1990. Consumption of other petroleum products rose 5 percent in 1990.

Four factors influence the demand for petroleum products: economic growth, prices, weather conditions, and conservation efforts.[10] Economic expansion increases consumption of petroleum products. Petroleum prices are inversely related to consumption levels; the lower the price, the greater the consumption. Weather directly influences the demand for heating fuels and residual fuel oils.

The demand for refined petroleum products, in the short-run, is widely held to be relatively price inelastic. Petroleum products are regarded as necessities for which there are no readily available substitutes. In the long-run, the demand becomes less inelastic as consumers have more time to switch to alternate fuel sources.

9.1.3.5 Foreign Trade. According to the 1991 U.S. Industrial Outlook, in 1989 exports for SIC 2911 were valued at $4,800 million (1991 dollars) while imports were valued at $12,726 million. This difference resulted in a negative balance of trade of $7,926 million.

9.1.3.6 Employment. In 1989, the petroleum refining industry employed 72,400 personnel. Of this total, 47,900 personnel were production workers.[5] Texas, California, Louisiana, and Pennsylvania accounted for 63 percent of the industry's employment in 1987.[4]

9.1.3.7 Outlook. For the long-run, domestic refinery output is not expected to expand significantly over its level at the end of the 1980s, given present and planned capacity.[11] It is unlikely that demand will increase significantly due to expectations for higher product prices.

The biggest issue facing the industry is the effect of environmental restrictions on the production of

transportation fuels. These fuels have been included in the Clean Air Act because of the pollution they cause in congested, urban areas. Changes in the formulations of these fuels will necessitate major changes in refinery processing. These changes may affect industry profits. For example, gasoline reformulation will probably necessitate a capital investment of $10 to $30 billion during the next decade.

9.1.4 Primary Metals

Three four-digit primary metals industries use chromate corrosion inhibitors in their IPCT's. These industries are SIC 3312, Blast Furnaces and Steel Mills, SIC 3331, Primary Copper, and SIC 3339 Primary Nonferrous Metals Not Elsewhere Classified. Survey results indicate that 10 percent of the IPCT's in these industries use chromate corrosion inhibitors.[a]

9.1.4.1 Industry Shipments. Table 9-7 details value of shipments data from 1980 to 1989. For all three industries the values of their shipments were the highest in either 1980 or 1981. Each industry experienced declines during the economic downturns of 1982 and 1985. SIC 3312 had a 3.7 percent decline in its value of shipments in 1989, when the value was $51,455 million. In the same year, SIC 3331 had a 3.9 percent increase to a value of $4,459 million. Also growing in 1989 was the value of shipments for SIC 3339, which was $5,001 million (a 3.9% increase over 1988).

9.1.4.2 Industry Structure. SIC 3312 is made up of establishments that manufacture hot metal, pig iron, and silvery pig iron from iron ore and iron and steel scrap.

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[a]Estimates of the percentage of plants using chromate corrosion inhibitors are based on an engineering survey of the major cooling water treatment chemical vendors.

TABLE 9-7. VALUE OF SHIPMENTS FOR THE PRIMARY METALS INDUSTRIES, 1980-1989[4,5]

	Value of Shipments (10^6 1991 Dollars)[a]			
	Blast Furnaces and Steel Mills SIC 3312	Primary Copper SIC 3331	Primary Nonferrous Metals, n.e.c. SIC 3339	Total
1989	51,455	4,459	5,001	60,915
1988	53,411	4,293	4,811	62,515
1987	44,801	2,963	3,831	51,595
1986	41,776	2,470	3,074	47,320
1985	46,724	2,747	3,755	53,226
1984	50,993	3,481	4,020	58,494
1983	47,772	4,544	4,542	56,858
1982	50,101	4,187	4,362	58,650
1981	83,174	7,766	4,743	95,683
1980	79,847	8,754	6,210	94,811

[a]The data are normalized using the implicit price deflator for GNP.

The establishments are also engaged in converting pig iron, scrap iron, and scrap steel into steel, as well as hot-rolling iron and steel into basic shapes such as plates, sheets, strips, rods, bars, and tubing.[4] Data for 1987 indicate that SIC 3312 was comprised of 342 establishments operated by 270 companies.[4] Sixty-five percent (222) of all establishments employed 20 or more personnel.

The domestic steel industry restructured during 1980s in response to a long, cyclical slide in demand which ended in 1986. This downturn was caused by increased foreign competition from substitute materials such as plastics, aluminum, glass, and ceramics. In order to restructure, the industry reduced capacity by 25 percent, halved its labor force, and modernized its remaining facilities. Also, the major integrated producers retreated from producing commodity steel products due to increased competition from minimills (smaller, less integrated producers who have significantly lower capital costs). Instead, they are now concentrating on higher-margin products such as coated and galvanized steel. The industry is becoming more internationalized as domestic producers enter joint ventures and projects with foreign producers.

SIC 3331 is part of the larger SIC 333, Primary Nonferrous Metals. Firms in SIC 3331 are primarily engaged in the smelting of copper from the ore and in the refining of copper by electrolytic or other processes.[4] According to the 1987 Census of Manufactures, there were 13 establishments in this industry, 12 of which employed 20 or more personnel. The 13 establishments were owned by eight companies.

The Census of Manufactures reported that there were 108 establishments in SIC 3339 in 1987; these were owned by 96 companies. Forty-nine establishments employed 20 or more personnel.

9.1.4.3 Domestic Production. Production data specific to the three industries under consideration are not available. Therefore, Table 9-8 details the information concerning the production of all primary metals by domestic mines. The value of primary metals production from mines rose less than one percent from 1989 to 1990 to a value of $12,953 million. Domestic steel consumption was weak in 1990, but this was almost offset by increased world consumption. At the same time the majority of nonferrous metals increased in production.

Information concerning capacity utilization rates for the three industries is not available for 1990. The most recent data indicates that in 1988 the capacity utilization rate was 82 percent for SIC 3312, 94 percent for SIC 3331, and 92 percent for SIC 3339.[13]

9.1.4.4 Domestic Consumption. The value of apparent consumption of both ferrous and nonferrous metals from 1986 to 1990 is listed in Table 9-9. These data are reported in lieu of specific information for SICs 3312, 3331, and 3339. The consumption of ferrous metals was $50,207 million in 1990, a 1.9 percent increase from 1989. Strong foreign demand for steel offset a decline in domestic demand. Nonferrous metals consumption decreased to $25,673 million due to a slight to moderate decrease in demand.

Approximately one-third of steel consumption is accounted for by consumer products.[14] Steel consumption is also dependent on the demand from the automobile and heavy machinery industries. Nonferrous metals such as copper and aluminum are used in electrical equipment and telecommunications equipment. Copper is also consumed for use in building construction, industrial machinery and equipment, transportation equipment, and consumer products.

TABLE 9-8. U.S. MINE PRODUCTION OF PRIMARY METALS, (FERROUS AND NONFERROUS) 1986-1990[12]

	Value of Production (10^6 1991 Dollars)[a]
1990	12,953 (est.)
1989	12,863
1988	11,494
1987	8,619
1986	6,967

[a]The data are normalized using the implicit price deflator for GNP.

est. - Estimate.

TABLE 9-9. U.S. APPARENT CONSUMPTION OF PRIMARY METALS, 1986-1990[12]

	Value of Apparent Consumption (10^6 1991 Dollars)[a]	
	Ferrous	Nonferrous
1990	50,207 (est.)	25,673 (est.)
1989	49,247	26,344
1988	50,617	26,263
1987	46,929	23,523
1986	46,172	22,967

[a]The data are normalized using the implicit price deflator for GNP.

est. - Estimate.

9.1.4.5 Foreign Trade. Exports of ferrous metals in 1990 were valued at approximately $4,244 million (1991 dollars), a 19.6 percent increase in current dollars over 1989. Imports totalled $15,527 million in value. Seven thousand five hundred fifty-seven million dollars of nonferrous metals were exported in 1990, while $9,006 million were imported.[12]

9.1.4.6 Employment. In 1989, total employment in SIC 3312 was 190,600 with 148,800 (78%) personnel employed in production. Seventy-nine percent (3,000) of the 3,800 personnel employed in the SIC 3331 were production workers; 7,700 production workers in SIC 3339 accounted for 73 percent of total industry employment of 10,500.[5]

9.1.4.7 Outlook. The long-term outlook for steel is that demand will be stable over the next five years, barring an economic downturn.[14] Overcapacity, which plagued the industry in the mid-1980s, will not be a problem in the 1990s due to the industry's restructuring. However, steel producers will have to replace some aging facilities, as well as having to install technology to control hazardous emissions regulated by the Clean Air Act. In order to do this, the producers will have to make large capital outlays; attracting the necessary funds will be difficult because investors are not drawn to an industry whose profit margins are not high. The major integrated producers may deintegrate to deal with this financial pressure.[15]

No long-term forecasts are available for the nonferrous metals industry. Increases in production were expected for 1991. Demand for the majority of nonferrous metals was expected to decline, resulting in price decreases.[14]

9.1.5 Tobacco Products Industry

The tobacco products industry is composed of four four-digit industries: cigarettes (SIC 2111), cigars (SIC 2121), chewing and smoking tobacco (SIC 2131), and tobacco stemming

and redrying (SIC 2141). Only the first three will be examined in this profile because SIC 2141 does not employ cooling towers in the manufacturing process.

Survey results indicate that cooling towers are used in the production of tobacco products, and that no more than 2.5 percent of these towers use chromate corrosion inhibitors.[a]

9.1.5.1 Industry Shipments. The value of shipments data from 1980 to 1989 for each of the three tobacco industries are listed in Table 9-10. The total value of shipments rose 60.4 percent from 1980 to 1989, with the decade-high of $25,098 million occurring in 1989. Cigarette shipments (SIC 2111) accounted for 93.5 percent of total 1989 tobacco product shipments. Like the total value of shipments, the value of cigarette shipments grew steadily throughout the ten-year period, growing 63.3 percent from 1980. The ten-year high occurred in 1989 as shipments grew 4.1 percent to $23,468 million. From 1980 to 1989, chewing and smoking tobacco shipments grew 63 percent in value. The value of shipments grew 5.9 percent in 1989 to achieve a decade-high value of $1,409 million. Only cigar shipments declined in value from 1980 to 1985, 45.6 percent.

Driving the growth in the value of shipments for SICs 2111 and 2131 were retail price hikes by tobacco product producers and strong exports to Europe and the Far East.[16] SIC 2121 suffered from import competition.[16]

9.1.5.2 Industry Structure. In 1987, there were 61 total establishments for these three industries, 49 with more than 20 employees. According to the 1987 Census of Manufactures, there were 12 establishments in SIC 2111, 20

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[a]Estimates of the percentage of plants using chromate corrosion inhibitors are based on an engineering survey of the major cooling water treatment chemical vendors.

TABLE 9-10. VALUE OF SHIPMENTS FOR TOBACCO PRODUCTS, 1980-1989[4,5]

	Value of Shipments (10^6 1991 dollars)[a]			
	Cigarettes SIC 2111	Cigars SIC 2121	Chewing and Smoking Tobacco SIC 2131	Total
1989	23,468	221	1,409	25,098
1988	22,535	226	1,330	24,091
1987	20,130	222	1,291	21,643
1986	18,779	302	1,271	20,352
1985	18,278	299	1,161	19,738
1984	17,621	314	1,018	18,953
1983	16,528	379	915	17,822
1982	16,499	345	905	17,749
1981	15,281	399	884	16,564
1980	14,374	406	864	15,644

[a]The data are normalized using the implicit price deflator for GNP.

in SIC 2121, and 29 in SIC 2131. The domestic cigar industry had 16 companies in 1987 and the chewing and smoking tobacco industry 23. In 1990, there were six domestic cigarette companies.

Currently, the cigarette industry is dominated by the two largest producers -- Philip Morris, Inc. and R.J. Reynolds Tobacco Co. -- which in 1990 accounted for 70.9 percent of the market. The remaining four companies held the rest of the market with individual shares ranging from 3.7 to 10.8 percent.[16]

Domestic decline in the consumption of cigarettes has forced producers to diversify in an attempt to become less dependent on cigarette sales. For example, Philip Morris has diversified into soft drinks, beer, and real estate. R.J. Reynolds formed RJR Nabisco with the Nabisco Corporation, and Brown and Williamson is a unit of B.A.T. Industries. Cigarettes remain the primary source of revenue for these companies, but as the cigarette market becomes more mature, cigarette producers will continue to diversify.

9.1.5.3 Domestic Production. Domestic production of tobacco products is shown in Table 9-11. Production of cigarettes in 1988 totalled 695 billion units, up less than one percent from the previous year.

Overall production of cigarettes fell 2.7 percent from 1980 to 1988. Cigar production fell 50 percent; chewing and smoking tobacco production fell 13.4 percent from 1980 to 1987.

In all cases, production peaks occurred at the beginning of the decade. Production fell as total consumption of tobacco decreased steadily throughout the decade.

TABLE 9-11. U.S. PRODUCTION OF TOBACCO PRODUCTS, 1980-1988[17]

	Quantity		
	Cigarettes (10^9 Units)	Cigars (10^9 Units)	Chewing and Smoking Tobacco (10^6 kg)
1988	695.0	2.0	N.A.
1987	689.0	2.1	64.0
1986	658.0	2.9	66.7
1985	665.0	3.1	71.7
1984	669.0	3.5	73.9
1983	667.0	3.6	73.5
1982	694.0	3.7	73.9
1981	737.0	4.0	73.9
1980	714.0	4.0	73.9

N.A. - Not Available.

9.1.5.4 Domestic Consumption. Domestic consumption for tobacco products declined steadily throughout the decade (Table 9-12). From 1981 to 1989, cigarette per-capita consumption declined 24 percent, cigar per-capita consumption 42 percent, and chewing and smoking tobacco per-capita consumption 35 percent. The declines in consumption are attributable to higher prices for tobacco products, health concerns, declining social acceptance, and restrictions on where people can smoke.

The demand for tobacco products is generally believed to be inelastic -- that is, smokers will pay higher prices to continue their habit. Smokers, however, may be more responsive to price than first believed. The introduction to the market of generic and discount brands shows that consumers are at least conscious of the price of tobacco products. While the demand for tobacco products is probably still relatively inelastic, consumers are at least responsive to price segmentation tactics by producers.

9.1.5.5 Foreign Trade. As domestic consumption of tobacco products declines, foreign markets become increasingly important to U.S. manufacturers. Exports of cigarettes totalled $6.7 billion (1991 dollars) in 1990, a 31 percent increase from 1989.[16] The leading markets for U.S. exports are Europe and the Far East. Information concerning imports is unavailable.

9.1.5.6 Employment. According to the 1989 Annual Survey of Manufactures, 29,600 personnel were employed in SIC 2111, 22,100 of whom were production workers. Employment in the cigarette industry is down 25 percent from the 39,300 personnel in 1980.[4] SIC 2121 experienced a 62 percent drop in employment; 2,300 personnel were employed by the industry in 1989 as opposed to 6,100 in 1980.[4] Of the

TABLE 9-12. U.S. PER-CAPITA CONSUMPTION OF TOBACCO PRODUCTS, 1981-1989[16]

	Quantity		
	Cigarettes (Units)	Cigars (Units)	Chewing and Smoking Tobacco (kg)
1989	2,926	28.3	0.47
1988	3,096	29.1	0.49
1987	3,197	31.7	0.53
1986	3,274	35.8	0.55
1985	3,370	37.9	0.60
1984	3,448	43.8	0.66
1982	3,739	45.2	0.68
1981	3,836	48.9	0.72

2,300 employees in 1989, 1,800 were production workers. There was a decrease of eight percent in the number of personnel in SIC 2131 in the same time period; 3,300 were employed in 1989 as opposed to 3,600 in 1980.[4] Two thousand three hundred personnel were production workers in 1989.

9.1.5.7 Outlook. According to the 1990 U.S. Industrial Outlook, the five-year forecast was that all tobacco products would experience five percent annual declines in output. The cigarette industry was expected to weather this decline due to strong foreign demand. However, it was expected that this foreign demand would level off after record years at the end of the 1980s.

9.1.6 Textile Finishing

Textile mill products are included in SIC group 22. The group includes establishments involved in the preparation of fiber and the manufacture of yarn, thread, twine, and cordage; the manufacture of broad woven fabric and carpeting; the dyeing and finishing of fiber, yarns, and knit apparel; the coating and treating of fabrics; and the manufacture of knitted apparel, felt goods, nonwoven fabrics, and miscellaneous textiles.

The types of textile mills most likely to use cooling towers include finishing plants for cotton (SIC 2261), finishing plants for manmade fibers (SIC 2262), and finishing plants not elsewhere classified (SIC 2269). The establishments in SIC 2261 are engaged in finishing purchased cotton broadwoven fabric as well as in the shrinking and sponging of cotton fabrics. They also chemically finish cotton fabrics for water repellency, fire resistance, and mildew proofing. In SIC 2262 manmade fiber and silk broadwoven fabric are finished. SIC Industry 2269 is made up of establishments which dye and finish textiles.

The use of chromates in cooling towers in textile manufacturing is less frequent than in major industries

because the temperature of the manufacturing process is less severe. Survey results indicate that, at most, 2.5 percent of the IPCT's used in textile production use chromium-based corrosion inhibitors.[a]

Due to the availability of data, the information presented pertains to the three industries only in certain instances. The information in the domestic production, domestic consumption, foreign trade, and outlook sections is for the textile industry as a whole.

9.1.6.1 Industry Shipments. The value of industry shipments from 1980 to 1989 is shown in Table 9-13. SIC 2662 had the highest value of shipments in 1989 ($4,110 million) among the three industries. However, this figure represented a 7.6 percent decline from 1988. Also experiencing a decline was SIC 2261; the value of shipments fell 3.2 percent to $1,513 million in 1989. Only SIC 2269 experienced growth between 1988 and 1989, growing 11.3 percent to a decade-high of $1,559 million.

9.1.6.2 Industry Structure. The textile industry is a complex production and marketing chain by which fiber is made into fabric or finished products for sale to consumers and industrial users. The steps performed at each part of this chain are complex and diverse. Therefore, the firms in textile manufacturing vary greatly according to size and specialization. Several major companies manufacture fabric and finished products, while smaller firms are more specialized. However, no one company dominates the industry. Since the start of the 1980s, intense foreign competition has forced the textile industry to undergo major

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[a]Estimates of the percentage of plants using chromate corrosion inhibitors are based on an engineering survey of the major cooling water treatment chemical vendors.

TABLE 9-13. VALUE OF SHIPMENTS FOR THE TEXTILE FINISHING INDUSTRIES, 1980-1989[4,5]

	Value of Shipments (10^6 1991 Dollars)[a]			
	SIC 2261	SIC 2262	SIC 2269	Total
1989	1,513	4,110	1,559	7,182
1988	1,563	4,447	1,401	7,411
1987	1,609	5,105	1,469	8,183
1986	1,045	4,943	1,086	7,074
1985	1,038	4,648	1,186	6,872
1984	1,076	4,832	1,389	7,297
1983	1,137	4,731	1,526	7,394
1982	1,026	4,335	1,404	6,765
1981	1,591	4,294	1,057	6,942
1980	1,946	3,910	1,066	6,922

[a]The data are normalized using the implicit price deflator for GNP.

restructuring. Foreign textile manufacturers have lower production costs, particularly lower labor costs. As a result, they have been able to take away market share from domestic producers. To become more competitive, U.S. producers have closed obsolete facilities, increased expenditures on more productive equipment, and reduced the labor force. Furthermore, several major mergers and acquisitions have taken place, solidifying the position of some of the larger firms.

According to the 1987 Census of Manufactures, there were 648 establishments in the three textile finishing industries, owned by 605 companies. Three hundred twenty-one of these establishments employed 20 or more personnel. SIC 2261 had 198 establishments owned by 184 companies. The largest total number of establishments was in SIC 2262 where there were 268 owned by 245 companies. The 182 establishments (176 companies) in SIC 2269 were the fewest of the three industries. There were 105 establishments employing 20 or more personnel in SIC 2261, 123 in SIC 2262, and 93 in SIC 2269.

9.1.6.3 Domestic Production. Output data for all textile mill products is unavailable. In lieu of actual output, Table 9-14 reports the Federal Reserve Board's textile mill production index. It is evident that production grew 21.2 percent from 1980 to 1989. Textile production is heavily affected by the level of inventories held by apparel manufacturers and clothing retailers. When large inventories of apparel are held, textile production must slow down until these inventories are lowered.

To become more competitive on the world market, U.S. producers have focused on increasing productivity by reducing labor inputs and increasing capital expenditures on

TABLE 9-14. TEXTILE MILL PRODUCTION INDEX, 1980-1989[18]

	Total Textile Mill Products (1980=100)
1988	121.2
1988	115.3
1987	115.0
1986	108.3
1985	101.4
1984	103.4
1983	100.1
1982	88.5
1981	97.3
1980	100.0

plant equipment. Investment in plant and equipment totalled $2.2 billion in 1989 and $2.1 billion in 1990.[19]

Data for 1988 indicate that the capacity utilization rate was 89 percent in SIC 2261, 90 percent in SIC 2262, and 68 percent in 2269.[13]

9.1.6.4 Domestic Consumption. Consumption of textile products can be viewed in terms of three markets: the home furnishing market, the apparel market, and the industrial and commercial market. Approximately 38 percent (2,332 million kilograms in 1988) of textile fiber shipments go to the home furnishing market. In 1989, consumers spent $17.4 billion on semi-durable home furnishings. Major home products include carpets, bedclothes, drapes, and towels. This market is highly cyclical and is determined by the level of disposable income. During the recession of the early 1980s, demand for home furnishings (and hence textile products) was down, particularly for carpets, which are high-price, replacement items. Approximately 60 percent of textile fibers used in home furnishings are used in the production of carpets and rugs.[18]

A key market in the textile industry is the apparel market, which uses approximately 37.4 percent (2,283 million kilograms in 1988) of all fiber processed. The market is important to textile manufacturers because of the large consumer outlays each year on apparel. An estimated $170 billion was spent on clothing in 1989.[18]

Industrial uses for textile fabrics account for roughly 21 percent (1,282 million kilograms in 1988) of all textile fibers and include medical uses, filtration products, automobile seat covers, and book bindings. Like the home furnishing and apparel markets, demand for textile fabrics in industrial applications is cyclical. Usage of industrial fibers declined in 1982 and again in 1985 in response to business cycle downturns.[18]

9.1.6.5 Foreign Trade. An important aspect of the textile industry is foreign trade, where rising levels of imports have caused major restructuring in the U.S. industry. Imports of textile products, particularly apparel products, have been rising since the early 1970s. The trade deficit in textile products increased dramatically at the start of the 1980s as the value of the U.S. dollar appreciated relative to other currencies.

In 1990, the foreign-trade deficit for textile mill products was reduced by $1.4 billion (1991 dollars), when imports declined and exports jumped sharply. The value of imports was down seven percent while the exports rose 30 percent. Exports accounted for six percent of the value of industry shipments. Export growth was fueled by a U.S. Government-backed development program and a weaker U.S. dollar.[19]

9.1.6.6 Employment. Data from the 1989 Annual Survey of Manufactures indicates that 14,900 personnel were employed in SIC 2261, 23,700 in SIC 2262, and 13,200 in SIC 2269. Eighty-one percent of the employees in SICs 2261 and 2262 were production workers. In SIC 2269, 86 percent were production workers. The leading states in terms of employment for all three industries were North Carolina and South Carolina. Employment has declined as facilities have been closed and advanced technology has been introduced.[18]

9.1.6.7 Outlook. No long-term forecasts are available. A survey of textile industry executives found the general consensus of opinion to be that the market situation was static and that they did not expect a climb out of the economic recession that began in late 1989 until the end of 1991.[20]

9.1.7 Tire and Rubber Products

The tire and rubber products industry covered in this profile is SIC 3011 (tires and inner tubes). The tire and

inner tube industry includes the manufacture of tires for autos, aircraft, farm vehicles, bicycles, and trucks. According to survey results, no more than 7.5 percent of the IPCT's employed in tire and inner tube manufacturing use chromate corrosion inhibitors.[a]

9.1.7.1 Industry Shipments. The value of shipments from 1980 to 1989 is listed in Table 9-15. The value of industry shipments fell during the 1982 recession and the 1985 economic downturn. There was growth of 6.4 percent from 1986 to 1988. The value subsequently dropped less than one percent in 1989, ending the decade at $12,559 million.

9.1.7.2 Industry Structure. The 1987 Census of Manufactures reports that 115 companies operated 163 facilities in the tire and inner tube industry. Ninety-seven facilities (59.5%) employed 20 or more personnel.

The tire industry has become global after a series of sales, mergers, acquisitions, and restructurings in the 1980s. A substantial amount of domestic capacity is now controlled by foreign firms. There remain only two public tire manufacturers, Goodyear Tire and Rubber and Cooper Tire and Rubber. The firm with the largest world market share is Michelin, with a 22 percent share. Goodyear controls 20 percent of the world market, Bridgestone/Firestone 17 percent, Continental General nine percent, and Pirelli/Armstrong six percent.[21]

Nearly all of the largest tire manufacturers are vertically integrated. These manufacturers produce the necessary raw material (carbon black, synthetic rubbers, etc.) and many often market their tires directly to

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[a]Estimates of the percentage of plants using chromate corrosion inhibitors are based on an engineering survey of the major cooling water treatment chemical vendors.

TABLE 9-15. VALUE OF SHIPMENTS FOR THE TIRE AND INNER TUBE INDUSTRY, 1980-1989[4,5]

	Value of Shipments (10^6 1991 Dollars)[a]
1989	12,559
1988	12,615
1987	12,083
1986	11,853
1985	12,802
1984	13,556
1983	13,323
1982	12,708
1981	14,285
1980	13,973

[a]The data are normalized using the implicit price deflator for GNP.

consumers through company-owned retail outlets. The large producers are also diversified into non-tire markets, most often into related chemical fields.

In addition to large multinational tire producers, there are a number of independent tire manufacturers. These companies all operate more or less domestically, are less integrated, and often market on a geographic or specialty product basis.

9.1.7.3 Domestic Production. Production of passenger car, truck, and bus tires is shown in Table 9-16. Domestic production of tires rose one percent in 1989 to 216.4 million units. Production of tires in the U.S. declined during 1982 and 1985. Production, however, is still below levels in the latter part of the 1970s. In 1977, the U.S. produced 232 million units, 6.7 percent more than 1989 production.

9.1.7.4 Domestic Consumption. The decline in tire demand in recent years is due in large part to the popularity of the radial tire. Radial tires have useful lives double that of the bias ply and have become the consumer's choice in the original equipment market (OEM) and the replacement market. Radial tires accounted for 94 percent of passenger car tires and 65 percent of highway truck tires sold in 1989. Despite an increase in the number of registered vehicles in the U.S., tire consumption has declined as consumers need tires less frequently. Imported cars (equipped with foreign tires) and imported tires have also contributed to the decline in U.S. tire consumption.[21]

The demand for tires is most likely relatively inelastic because tires are necessities for which no substitutes exist. Consumers, though, are to some degree conscious of price as seen in the increase in lower-priced imports. Except in the case of specialty, high performance

TABLE 9-16. U.S. PRODUCTION OF CAR, TRUCK, AND BUS TIRES, 1980-1989[21]

	Quantity (10^6 Units)
1989	216.4
1988	214.6
1987	206.0
1986	190.3
1985	196.9
1984	209.4
1983	186.9
1982	178.5
1981	181.8
1980	159.3

tires, however, consumers purchase tires out of necessity. While the decision to purchase tires certainly includes consideration of price, it is doubtful that consumers who need tires would postpone the purchase solely on the basis of price.

9.1.7.5 Foreign Trade. Between 1985 and 1990, imports grew steadily. Exports grew sharply between 1988 and 1989. In 1989, exports were valued at $918 million (1991 dollars) while imports were valued at $2,868 million.[22]

9.1.7.6 Employment. In 1989, there were 68,000 employees in SIC 3011 according to the Annual Survey of Manufactures. Fifty-four thousand, six hundred (80%) were production workers.

9.1.7.7 Outlook. Tire production is forecast to grow by only one percent annually for the next several years according to Standard and Poor's Corporation.[21] Further consolidation will force small private tire manufacturers to cooperate more closely with their customers. Speed of delivery and quality of service, not quality differences between tires, are increasing in importance.

9.1.8 Glass Products

The segments of the glass products industry most likely to use chromates are the producers of flat glass (SIC 3211) and glass containers (SIC 3221). Flat glass products include those used in building construction, car windows and windshields, mirrors, solar panels, and signs. Glass container products are used for commercial packaging, commercial bottling, and home canning.

Glass product manufacturers are relatively minor users of chromium-based corrosion inhibitors. Survey results indicate that no more than 2.5 percent of the cooling towers

used in flat glass and glass container production use chromate corrosion inhibitors.[a]

9.1.8.1 Industry Shipments. The constant dollar value of industry shipments for the glass products industry is shown in Table 9-17. The value of industry shipments of flat glass products fell 2.8 percent in 1989 to $2,664 million. Prices have declined in recent years as manufacturers engaged in price competition to boost volume. Shipments of glass containers also fell in value, declining 2.0 percent to 5,174 million.

9.1.8.2 Industry Structure. For the flat glass industry (SIC 3211) the 1987 Census of Manufactures reported that there were 84 establishments, 38 (45%) of which employed 20 or more personnel. In 1987, SIC 3221, the glass container industry, had 106 establishments, 88 percent (93) employing 20 or more personnel.

9.1.8.3 Domestic Production. Table 9-18 reports production data for flat glass and glass containers. The production of flat glass rose steadily from 1986 to 1989, then levelled out at 4.7 billion square feet. Production of glass containers peaked in 1989 when 285.5 million units were produced.

9.1.8.4 Domestic Consumption. Nearly 57 percent of flat glass shipments is consumed by the construction industry and 25 percent is used by the automotive industry.[23] The remaining quantity is used in "specialty products" such as signs, mirrors, and solar panels. Demand for flat glass

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[a]Estimates of the percentage of plants using chromate corrosion inhibitors are based on an engineering survey of the major cooling water treatment chemical vendors.

TABLE 9-17. VALUE OF SHIPMENTS FOR SIC 3211 AND SIC 3221[4,5]

	Value of Shipments (10^6 1991 Dollars)[a]		
	Flat Glass SIC 3211	Glass Containers SIC 3221	Total
1989	2,664	5,174	7,838
1988	2,741	5,280	8,021
1987	2,954	5,536	8,490
1986	2,868	5,535	8,403
1985	2,645	5,645	8,290
1984	2,583	5,662	8,245
1983	2,530	6,370	8,900
1982	2,266	7,098	9,364
1981	2,398	7,129	9,527
1980	2,455	7,132	9,587

[a]The data are normalized using the implicit price deflator for GNP.

TABLE 9-18. U.S. PRODUCTION OF FLAT GLASS AND GLASS CONTAINERS, 1986-1990[23,24]

	Quantity	
	Flat Glass (10^9 square feet)	Glass Containers (10^6 units)
1990	4.2 (est.)	285.1 (est.)
1989	4.7	285.5
1988	4.2	280.4
1987	4.1	281.6
1986	3.7	N.A.

est. - Estimate.

N.A. - Not Available.

in the automobile and construction industries has declined due to the recession beginning in 1989.

Glass containers are most frequently used to hold beer, food, and soft drinks. These markets accounted for 86 percent of glass container shipments in 1989. Demand for glass containers fell slightly in 1990 as metal cans gained market share.[24]

Estimates of the elasticity of demand for flat glass products and glass containers are unavailable. Flat glass products are necessary inputs in building construction and automobile manufacturing, although plastics can be used as substitutes. Also, the cost of flat glass products, in most cases, represents a small portion of the final cost of buildings and automobiles. These factors suggest that the demand for flat glass products is somewhat inelastic.

The demand for glass containers is most likely less inelastic than the demand for flat glass products because of the availability of close substitutes in aluminum cans and plastics. Glass container manufacturers may have some difficulty in passing on large price increases.

9.1.8.5 Foreign Trade. In 1989, exports of flat glass were valued at $534 million (1991 dollars) and imports at $460 million.[23] Exports of glass containers were valued at $51 million (1991 dollars) while imports were valued at $190 million.[24]

9.1.8.6 Employment. According to the Annual Survey of Manufactures, there were 15,000 personnel employed in SIC 3211 in 1989, 12,100 (81%) of whom were production workers. Thirty-nine thousand three hundred personnel were employed in SIC 3221, 34,500 (88%) of whom were production workers.

9.1.8.7 Outlook. Strong demand from the automotive and construction industries for flat glass is expected to boost output after the mid-1990s. New product development

will continue in order to generate new demand in these industries.[23]

The glass container industry is expected to grow one percent annually from 1991 to 1995. The majority of glass containers will be utilized by the food and beverage industries.[24]

9.2 ECONOMIC IMPACT ANALYSIS

This section examines the economic impacts resulting from the regulation of hexavalent chromium emissions from IPCT's. To determine the economic impacts, three regulatory alternatives (RA's) are considered. Regulatory alternative one (RA I) involves no further regulatory action, while regulatory alternatives two and three (RA II and RA III) require regulation of emissions. RA II requires IPCT's using chromates to be retrofitted with high-efficiency drift eliminators (HEDE's); RA III requires a total ban of chromate use in IPCT's. Both RA II and RA III will have economic impacts on firms using chromates in their IPCT's. These impacts are expressed in terms of price increases and the resultant reductions in quantity demanded.

9.2.1 Methodology

The implementation of emissions control techniques causes an increase in the costs of production. This increase in costs results in an upward and leftward shift of the regulated firm's supply curve (in other words, a decrease in supply). This decrease leads to a higher price and a lower quantity demanded. The shift of the regulated firm's supply curve also causes a corresponding shift in the market supply curve for an industry; the market supply curve is by definition the horizontal summation of the supply curves of all firms in the industry. A leftward shift, or decrease in supply, of the market supply curve will result in a higher equilibrium price and lower quantity demanded for the industry.

This analysis will calculate the maximum percentage change in price for two different scenarios. Both scenarios assume that the affected firms will be able to fully pass on their control costs. Scenario I also assumes that the marginal firms in the regulated industry are the ones still using chromates in their IPCT's. Therefore, only the marginal firms will experience an increase in costs due to the regulation of chromate use. In order to calculate the maximum percentage change in price, we divide the control costs associated with a regulatory alternative by the total revenue attributable to chromate users. This approach averages the price increase among the firms using chromates in their IPCT's. For the regulation of hexavalent chromium emissions, the control costs result from either the use of HEDE's or the substitution of nonchromate corrosion inhibitors. The first step in deriving the total revenue attributable to chromate users is to multiply the value of shipments for the regulated industry by the percentage of facilities using IPCT's. This product is then multiplied by the percentage of IPCT's using chromates in order to obtain the revenue base.

However, firms using chromates may not be the marginal firms in their respective industries. Thus, a second approach is used to calculate the percentage price increase. Scenario II estimates the expected price increase by averaging the increase in costs across an entire regulated industry. To calculate the average price increase, the control costs associated with either regulatory alternative are divided by the total value of shipments for the regulated industry. This average price increase represents a point estimate of the expected cost increase for the marginal firm. Since the estimate represents an average price increase, we should expect some of the more efficient firms in each industry to experience a lower cost increase. We should also expect that some of the less efficient firms

will experience a greater cost increase than the average estimate.

It is difficult to determine what the actual percentage price increase will be for a firm using chromate corrosion inhibitors. The distribution of IPCT's among firms in the regulated industries is unknown. It is also not known whether firms using chromates in their IPCT's have a great amount of pricing discretion. These firms will absorb some of the control costs associated with RA II and RA III if they cannot achieve the maximum percentage price increases.

An important determinant of the size of the percentage increase in the equilibrium price for a regulated industry is the market structure. Under perfect competition, firms will be able to fully recover costs through the price increase. However, as the market structure deviates from perfect competition, the price increase will be less than what is necessary to fully recover costs. Since the seven regulated industries under consideration are not fully competitive, the firms in the industry will increase their prices by less than what is necessary to fully recover control costs. Note, however, that the calculations in this analysis assume full-cost pass through; in other words, the calculations are based on the model of perfect competition.

An increase in price will result in a decrease in the quantity demanded or output. The percentage reduction in output can be calculated using the formula for the price elasticity of demand.

$$E = \frac{\%\Delta Q_D}{\%\Delta P}$$

where E = price elasticity of demand

$\%\Delta Q_D$ = percentage change in quantity demanded

$\%\Delta P$ = percentage change in price

Rearranging the formula:

$$\%\Delta Q_D = \%\Delta P \times E$$

Thus, the percentage change in quantity demanded can be determined using the previously calculated percentage changes in price for either scenario and an estimate of the price elasticity of demand.

The price elasticity of demand is a measure of the responsiveness of the quantity demanded to changes in price. If the price elasticity is between 0 and -1, then demand is characterized as being price inelastic. An increase in price will cause a less than proportional decrease in the quantity demanded. The more price inelastic demand is, the greater the ability of producers to increase prices without losing output. Since the percentage change in price is greater than the percentage change in quantity demanded, we expect the total revenue of producers to increase. When the price elasticity is equal to -1, demand is characterized as being unitary elastic, and the changes in price and quantity demanded are the same. Because the changes exactly offset each other, total revenue will remain the same. Finally, when the price elasticity is less than -1, then an increase in price will cause a more than proportional decrease in the quantity demanded. In this case demand is characterized as being elastic. Relatively elastic demand restricts the ability of producers to increase prices without losing output and therefore revenues. Since the percentage change in quantity demanded will be greater than the percentage change in price, we expect the total revenue of producers to decrease if they increase the price of their products.

In this analysis it can be assumed that the demand curve for each industry under consideration is most likely price inelastic. However, because published estimates of the various price elasticities are rare, the percentage reductions in the quantity demanded are calculated using an

inelastic estimate of price elasticity (-0.5), an unitary elastic estimate (-1.0), and an elastic estimate (-1.5). Another reason for using the three estimates is that the demand curves for the products associated with a particular industry will most likely vary from being relatively inelastic to being slightly inelastic. For example, while the demand for flat glass products is relatively inelastic, the demand for glass containers is only slightly inelastic due to the possible substitutes previously mentioned. Using the inelastic and unitary elastic estimates accounts for the variability of inelasticity in each industry. The elastic estimate is used as a worst-case estimate; if demand were elastic, then an increase in price would cause a larger percentage reduction in the quantity demanded than if demand were inelastic or unitary elastic.

9.2.2 Percentage Price Increases

As outlined in the methodology, the maximum percentage price increases are calculated for two different scenarios. In addition, control costs are calculated for two regulatory alternatives. The choice of scenario will not change total control costs for either regulatory alternative. These costs are listed in Table 9-19. For either regulatory alternative, the industry that will bear the highest control costs is the chemical industry. The industries that have the highest percentage of IPCT's using chromate corrosion inhibitors (chemical manufacturing, petroleum refining, and primary metals) bear higher control costs than the relatively minor users of chromates (tobacco products, textile finishing, tire and rubber products, and glass products).

The revenue figure used to calculate the percentage price increases depends on the assumptions we make. For Scenario I, where we assume that the marginal firms are

TABLE 9-19. ANNUAL CONTROL COSTS (1991 DOLLARS) FOR THE REGULATED INDUSTRIES[25]

Industry	Regulatory Alternative	
	II: HEDE Retrofits	III: Nonchromates
Chemical Manufacturing	6,640,000	7,260,000
Petroleum Refining	2,870,000	4,470,000
Primary Metals	1,380,000	1,990,000
Tobacco Products	87,700	93,700
Textile Finishing	157,000	81,100
Tire and Rubber Products	170,000	113,000
Glass Products	8,520	5,650

using chromates, the revenue figure used for each regulated industry is the value of shipments of the industry attributable to chromate users. As previously mentioned, control costs are averaged across the entire industry for Scenario II due to the lack of information for identifying firms using chromates. Thus, the total value of shipments of the industry is used as a revenue figure. The revenue figures used for both scenarios are listed in Table 9-20.

The data reported in Tables 9-19 and 9-20 allow us to calculate the maximum percentage price increases. Table 9-21 details the results for Scenario I. For all industries the percentage increases are very small. The largest increases will occur in chemical manufacturing; the marginal firm will have to increase prices by 0.299 percent if IPCT's are retrofitted with HEDE's, and 0.326 percent if the use of chromates in IPCT's is banned altogether.

If control costs are assigned to all firms in the industry (Scenario II), then the percentage price increases are even smaller (Table 9-22). Except for the chemical manufacturing industry, in no case will firms in an industry have to increase price by more than 0.010 percent. Firms in chemical manufacturing will have to increase price by 0.010 percent for RA II or 0.011 percent for RA III to fully recoup control costs.

9.2.3 Percentage Reductions in the Quantity Demanded

The percentage reductions in the quantity demanded in each industry are detailed in Tables 9-23 and 9-24. Using the derived percentage price increases, the reductions were calculated for inelastic, unitary elastic, and elastic demand scenarios.

As was the case with the percentage changes in price, all the percentage reductions are very small for both scenarios. In no case would an industry experience even a

TABLE 9-20. REVENUE FIGURES FOR PRICE INCREASE SCENARIOS I AND II

Industry	1989 Value of Shipments (1991 Dollars)	
	Scenario I: Marginal Firms Using Chromates	Scenario II: All Firms Using Chromates
Chemical Manufacturing	2,224,167,097	65,152,000,000
Petroleum Refining	28,213,400,000	141,067,000,000
Primary Metals	2,762,883,369	60,915,000,000
Tobacco Products	504,017,213	25,098,000,000
Textile Finishing	86,450,000	7,182,000,000
Tire and Rubber Products	560,532,055	12,559,000,000
Glass Products	135,102,368	7,838,000,000

TABLE 9-21. PERCENTAGE PRICE INCREASES FOR SCENARIO I

Industry	Regulatory Alternative	
	II: HEDE Retrofits	III: Nonchromates
Chemical Manufacturing	0.299%	0.326%
Petroleum Refining	0.010%	0.016%
Primary Metals	0.050%	0.072%
Tobacco Products	0.017%	0.019%
Textile Finishing	0.182%	0.094%
Tire and Rubber Products	0.030%	0.020%
Glass Products	0.006%	0.004%

TABLE 9-22. PERCENTAGE PRICE INCREASES FOR SCENARIO II

Industry	Regulatory Alternative	
	II: HEDE Retrofits	III: Nonchromates
Chemical Manufacturing	0.010%	0.011%
Petroleum Refining	0.002%	0.003%
Primary Metals	0.002%	0.003%
Tobacco Products[a]	-	-
Textile Finishing	0.002%	0.001%
Tire and Rubber Products	0.001%	0.001%
Glass Products[a]	-	-

[a]The percentage changes are less than 0.001%.

one percent reduction in the quantity demanded. Table 9-23 details the reductions in quantity demanded for Scenario I. These reductions in the quantity demanded will occur if chromate-using firms are the marginal firms in the industry and increased price to fully recoup control costs (Scenario I). The chromate-using firm in the chemical manufacturing industry would experience the largest output reductions. If demand were elastic, the quantity demanded would drop by 0.448 percent for RA II and a 0.490 percent for RA III. The chemical manufacturing industry will also have the largest reductions in quantity demanded if control costs are borne by the entire industry (Scenario II). These reductions are detailed in Table 9-24. Under RA II the reduction will be 0.015 percent, while under RA III it will be 0.017 percent.

9.2.4 Further Analysis of the Chemical Manufacturing Industry

Some of the chemicals produced by the chemical manufacturing industry have a low market price due to the low value added during production. Firms producing low value-added chemicals may experience greater economic impacts than firms producing high value-added chemicals because control costs as a percentage of price are higher.

However, an analysis of a low value-added chemical, ethylene, indicates that the impacts resulting from the regulation of hexavalent chromium emissions are less severe than those for the chemical industry overall. The results show that impacts are not only a function of price but a function of volume as well. A low value-added chemical would have to be produced at low volume in order for firms in the industry to experience significant impacts. Based on our knowledge of the chemical industry, we observe that most low value-added chemicals are in fact produced at high volumes. Thus, control costs are spread over a larger volume of output, resulting in a lower unit cost of compliance and less severe impacts.

TABLE 9-23. PERCENTAGE REDUCTIONS IN QUANTITY DEMANDED FOR SCENARIO I

	Regulatory Alternative					
	II: HEDE Retrofits			III: Nonchromates		
Industry / Elasticity:	-0.5	-1.0	-1.5	-0.5	-1.0	-1.5
Chemical Manufacturing	0.149%	0.299%	0.448%	0.163%	0.326%	0.490%
Petroleum Refining	0.005%	0.010%	0.015%	0.008%	0.016%	0.024%
Primary Metals	0.025%	0.050%	0.075%	0.036%	0.072%	0.108%
Tobacco Products	0.009%	0.017%	0.026%	0.009%	0.019%	0.028%
Textile Finishing	0.091%	0.182%	0.272%	0.047%	0.094%	0.141%
Tire and Rubber Products	0.015%	0.030%	0.045%	0.010%	0.020%	0.030%
Glass Products	0.003%	0.006%	0.009%	0.002%	0.004%	0.006%

TABLE 9-24. PERCENTAGE REDUCTIONS IN QUANTITY DEMANDED FOR SCENARIO II

	Regulatory Alternative					
	II: HEDE Retrofits			III: Nonchromates		
Industry	Elasticity: -0.5	-1.0	-1.5	-0.5	-1.0	-1.5
Chemical Manufacturing	0.005%	0.010%	0.015%	0.006%	0.011%	0.017%
Petroleum Refining	0.001%	0.002%	0.003%	0.002%	0.003%	0.005%
Primary Metals	0.001%	0.002%	0.003%	0.002%	0.003%	0.005%
Tobacco Products[a]	-	-	0.001%	-	-	0.001%
Textile Finishing[a]	0.001%	0.002%	0.003%	0.001%	0.001%	0.002%
Tire and Rubber Products	0.001%	0.001%	0.002%	-	0.001%	0.001%
Glass Products[a]	-	-	-	-	-	-

[a]The reductions in quantity demanded are less than 0.001% for certain elasticities.

9.3 SMALL BUSINESS IMPACTS

According to the Regulatory Flexibility Act, the proposing agency must determine whether the regulation will have a significant impact on a substantial number of small entities. If more than 20 percent of small entities are significantly impacted, then a Regulatory Flexibility Analysis (RFA) must be prepared. Using the criteria of the Act, it can be determined that there is not a significant impact on a substantial number of small entities due to the regulation of hexavalent chromium emissions from IPCT's.

A significant impact occurs if any of the following four criteria are satisfied. The first criterion is that annual compliance costs increase total costs of production by more than 5 percent. The second criterion is that compliance costs as a percent of sales are at least 10 percentage points higher for small entities. If the capital cost of compliance represent a significant portion of the capital available to small entities, then the impact is considered significant. Finally, the impact is also considered significant if the requirements are likely to result in closures of small entities.

It is highly unlikely that any criterion would be met for either regulatory alternative. Information is not available concerning the costs of production for firms in the regulated industries. However, because compliance costs as a percentage of value of shipments are very small, it is highly unlikely that the total costs of production would increase by more than five percent. In other words, the assumption is that the value of shipments can be used as an approximation of the costs of production. It is also doubtful that compliance costs as a percentage of sales would be significantly higher, as shown by the aforementioned percentage price increases. Capital availability should not be constrained because total control costs are relatively small and would not require extensive

capital financing. If capital availability is not a problem, then the likelihood of closures is small. Since there are no significant impacts on a substantial number of small entities, an RFA is not required.

REFERENCES

1. "The Corrosion Inhibitors Market, Report #A1048." Frost and Sullivan, Inc., New York, NY. 1982. pp. 4, 9, 117.

2. Memorandum. Marinshaw, R., MRI, to Myers, R., EPA:ISB. April 3, 1991. Trip report: Nalco Chemical Company, Naperville, Illinois, on February 22, 1991.

3. Memorandum. Marron, J., MRI, to Myers, R., EPA:ISB. April 3, 1991. Trip report: Betz Industrial, Trevose, Pennsylvania, on February 26, 1991.

4. 1987 Census of Manufactures. U.S. Department of Commerce, Washington, DC.

5. 1989 Annual Survey of Manufactures, U.S. Department of Commerce, Washington, DC.

6. Industry Surveys, "Chemicals -- Basic Analysis." Standard & Poor's Corp., New York, NY, November 8, 1990. pp. C42, C48.

7. U.S. Industrial Outlook 1991 -- Chemicals and Allied Products. pp. 12-1-12-13.

8. Chemical and Engineering News. 69(25):32-41. June 24, 1991.

9. Telecon. MRI, to Laffly, G., American Petroleum Institute. June 18, 1991. Information on petroleum refineries.

10. Petroleum Supply Annual 1990, Volume 1. U.S. Department of Energy, Washington, DC. pp. xi, 16-26, 49, 81.

11. U.S. Industrial Outlook 1991 -- Petroleum Refining. pp. 4-2; 4-4.

12. Mineral Commodities Summaries, 1991. U.S. Department of the Interior, Washington, DC. p. 5.

13. Current Industrial Reports - Manufacturers' Utilization of Plant Capacity. U.S. Department of Commerce, Washington, DC. April 1990.

14. U.S. Industrial Outlook 1991 -- Metals. pp. 15-1, 15-5.

15. Industry Surveys, "Steel and Heavy Machinery -- Basic Analysis." Standard & Poor's Corp., New York, NY, August 9, 1990, pp. 525-27.

16. Industry Surveys, "Food, Beverages, and Tobacco -- Basic Analysis." Standard & Poor's Corp., New York, NY, June 27, 1991, p. F34-F35.

17. Statistical Abstract of the United States 1990. U.S. Department of Commerce, Washington, DC. p. 752.

18. Industry Surveys, "Textiles, Apparel, and Home Furnishings -- Basic Analysis." Standard & Poor's Corp., New York, NY, June 14, 1990, p. T79-T83.

19. U.S. Industrial Outlook 1991 -- Textiles. p. 9-1.

20. Industry Surveys, "Textiles, Apparel, and Home Furnishings - Current Analysis." Standard & Poor's Corp., New York, NY, June 13, 1991, p. T52.

21. Industry Surveys, "Autos-Auto Parts -- Basic Analysis." Standard & Poor's Corp., New York, NY, December 13, 1991, p. A94-A96.

22. U.S. Industrial Outlook 1991 -- Plastics and Rubber. p. 14-2.

23. U.S. Industrial Outlook 1991 -- Construction Materials. pp. 7-3, 7-9.

24. U.S. Industrial Outlook 1991 -- Cans and Containers. pp. 11-2, 11-4.

25. Memo. Midwest Research Institute to Phil Mulrine, Environmental Protection Agency/ISB/SSS, September 20, 1991.

APPENDIX A.

EVOLUTION OF THE BACKGROUND INFORMATION DOCUMENT

APPENDIX A. EVOLUTION OF THE BACKGROUND INFORMATION DOCUMENT

The source category survey (Phase I) for chromium emissions from industrial process cooling towers (IPCT's) was begun in October 1984 by the U. S. Environmental Protection Agency (EPA). In April 1985, 18 Section 114 information requests were sent; 9 of these requests were sent to petroleum refineries, and 9 were sent to primary metals facilities. All but one of these facilities responded to the information request. The study to develop a national emissions standard for chromium emissions from IPCT's was initiated in September 1985. Table A-1 lists major events and accomplishments in the evolution of the background information document (BID) for the standard.

In October 1985, an effort was begun to obtain the information needed to develop the BID (Phase II). The information gathering effort included literature surveys; canvassing of State, regional, and local air pollution control agencies; plant visits; meetings with industry representatives; contacts with engineering consultants and equipment vendors; Section 114 information collection; and emission testing.

Twelve plants were visited to gather background information (including the types of water treatment programs and drift eliminators used) on IPCT's and to identify candidate test sites. As a result of the plant visits, four emission tests were conducted on a total of six cooling towers. Of these six cooling towers, three were equipped with high-efficiency drift

eliminators (HEDE's), two were equipped with low-efficiency drift eliminators (LEDE'S), and one was equipped with both.

Additional Section 114 information requests were sent to three petroleum refineries, five chemical manufacturing facilities, and one primary metals facility in June 1986. All of these facilities responded to the information request.

Chapters 3 through 6 and 8 of the draft BID, which describe the industry, emission control techniques, model plants, regulatory alternatives, and cost of emission controls, were completed in February 1987 and mailed to industry for review and comment.

In April 1987, Section 114 information requests were sent to 139 companies. Of these 139 companies, 61 reported that they had no cooling towers. The remaining 74 companies (76 facilities) that responded to the request comprised 38 chemical manufacturing plants, 8 tire and rubber plants, 5 petroleum refineries, 5 textile finishing plants, 5 tobacco processing plants, 3 food and kindred products plants, 3 primary metals plants, 3 steel plants, 2 pulp and paper plants, and 2 flat glass and container plants. The overall response rate for the information request was 97 percent.

In September 1987, evaluation of test data obtained at the Southeastern Manufacturing Facility (SMF) revealed the potential for conversion of hexavalent chromium to trivalent chromium in the cooling tower. The regular project schedule was delayed in December 1987 to permit additional source testing and laboratory studies to determine the extent of conversion and whether conversion was occurring in the cooling tower, drift eliminator, or sampling train. Despite additional testing by EPA using test methods that were designed specifically to prevent conversion in the sampling equipment, conversion from Cr^{+6} to Cr^{+3} could not be eliminated.

In October 1989, sites were conducted to four petroleum refineries that had recently converted IPCT's from chromate-based to nonchromate-based water treatment programs. The purpose of the visits was to determine the effectiveness of nonchromate-

based water treatment programs in comparison to the chromate-based programs that had been used previously at the refineries.

During the period of July to December 1989, six plants with IPCT's that were equipped with HEDE's were visited. The purpose of the visits was to evaluate the feasibility of additional emission testing using a different test method that quantified drift rates based on the emissions of surrogate elements. In July 1990 and January 1991, source tests were conducted at two facilities using the surrogate element test method.

From February to May 1991, surveys were sent to nine chemical manufacturing companies and nine water treatment chemical suppliers in order to determine the costs and effectiveness of nonchromate-based water treatment programs. The surveys focused on the performance of nonchromates in severe operating environments. The response rates for the chemical company and water treatment supplier surveys were 100 percent and 44 percent, respectively. Information on cooling tower and drift eliminator costs and designs was also gathered by telephone from several manufacturers.

In November 1991, the BID was revised to incorporate the new data that had been collected during the previous three years, and the status of the project was presented to the National Air Pollution Control Techniques Advisory Committee. Three work group meetings were held between April and August 1992 to discuss the status of the project, options selection, and the draft preamble and standard. The BID was again revised in September 1992 prior to Work Group Closure.

TABLE A-1. EVOLUTION OF THE BACKGROUND INFORMATION DOCUMENT

Date	Company, consultant, or agency/location	Nature of action
12/06/84	U. S. Environmental Protection Agency	Source test plan submitted
02/07/85	Mogul Division, Dexter Corp., Chagrin Falls, OH	Visit to water chemicals vendors
02/21/85	Marley Cooling Tower Company, Mission, KS	Visit to cooling tower manufacturer
02/28/85	U. S. Environmental Protection Agency, EMB	Recommendation memo on cooling tower modeling
04/15/85	Mobil Oil Corporation, Torrance, CA	Visit to petroleum refinery
04/16/85	Arco Petroleum Products Company, Carson, CA	Visit to petroleum refinery
04/17/85	Chevron U.S.A. Inc., Richmond, CA	Visit to petroleum refinery
04/18/85	Amoco Oil Company, Chicago, IL Atlantic Richfield Co., Los Angeles, CA Chevron U.S.A., Inc., San Francisco, CA Exxon Company, U.S.A., Houston, TX Gulf Oil Products Co., Houston, TX Mobil Oil Corp., Fairfax, VA Phillips Petroleum Co., Bartlesville, OK Shell Oil Co., Houston, TX Texaco, Inc., Houston, TX	Section 114 information request
04/23/85	Armco Inc., Middleton, OH Bethlehem Steel Co., Bethlehem, PA Inland Steel Corp., East Chicago, IL LTV Steel Company, Cleveland, OH Lone Star Steel Co., Lone Star, TX McLouth Steel Products Corp., Trenton, NJ National Steel Corp., Pittsburgh, PA U.S. Steel Corp., Pittsburgh, PA Wheeling-Pittsburgh Steel Corp., Wheeling, WV	Section 114 information request
05/08/85	Chemical Manufacturers' Association, Washington, D.C.	Request for information about cooling water and corrosion inhibitor use from member chemical manufacturing plants
08/08/85	U. S. Environmental Protection Agency, ISB	HEM inputs submitted
08/20/85	U. S. Environmental Protection Agency	Chromium chemicals concurrence meeting
09/01/85	U. S. Environmental Protection Agency	Technical Report—Cooling Towers
09/26/85	U. S. Environmental Protection Agency	Information memorandum submitted to ESD/OD
01/07/86	U. S. Department of Energy (DOE), Paducah, KY	Visit to gaseous diffusion plant
01/15/86	U. S. Environmental Protection Agency	Emission test request to conduct method evaluation tests at Munters Corp. was submitted
01/15/86	Association of Building Owners and Management (ABOM)	Requesting ABOM participation in cooling towers study
01/20/86	Munters Corporation, Fort Myers, FL	Visit to cooling tower manufacturer
01/30/86	Exxon Company, U.S.A., Baytown, TX	Visit to petroleum refinery
01/31/86	Amoco Oil Company, Texas City, TX	Visit to petroleum refinery
02/10/86	U. S. Environmental Protection Agency	Emission test request for Exxon-Baytown refinery
03/03/86-03/07/86	Munters Corporation, Fort Myers, FL	Visit to cooling tower manufacturer
03/27/86	U. S. Environmental Protection Agency	Five specific sites identified as candidates for additional testing
04/17/86	Philip Morris U.S.A., Richmond, VA	Visit to tobacco company
04/21/86	U. S. Environmental Protection Agency	Source test request for DOE gaseous diffusion plant, Paducah, KY
05/07/86	Chevron U.S.A., Inc., Pascagoula, MS	Visit to petroleum refinery

TABLE A-1. (continued)

Date	Company, consultant, or agency/location	Nature of action
05/08/86	NASA-Langley Research Center, Hampton, VA	Visit to research center
05/13/86	U. S. Environmental Protection Agency	Start Action Request for Development of an Accelerated NESHAP--Chromium Emissions from Cooling Towers
05/22/86	National Bureau of Standards (NBS), Gaithersburg, MD	Visit to NBS facility
05/27/86	U. S. Environmental Protection Agency	Source test request for NASA-Langley
06/04/86	Union Oil Co. Los Angeles,	Section 114 information request
06/12/86	Chevron U.S.A., San Francisco, CA Shell Oil Co., Houston, TX	Section 114 information request
06/16/86	Pfizer, Inc., New York, NY; Inmont Corporation, Clifton, NJ; Hooker Industrial and Specialty Chemicals, Niagara Falls, NY	Section 114 information request
06/23/86-06/27/86	DOE, Paducah, KY	Source test conducted
06/26/86	Interlake Inc., Oak Brook, IL Kaiser Aluminum & Chemical Corp., Oakland, CA LTV Corp., Cleveland, OH	Section 114 information request
08/18/86-08/22/86	NBS, Gaithersburg, MD	Source test conducted
08/21/86	U. S. Environmental Protection Agency	Questionnaire to 18 water treatment chemical suppliers
08/31/86-09/05/86	Exxon-Baytown Refinery, Baytown, TX	Source test conducted
09/15/86	U. S. Environmental Protection Agency	Responses to Section 114's received
11/26/86	U. S. Environmental Protection Agency	Preliminary cost estimates for regulatory alternatives
12/12/86	U. S. Environmental Protection Agency	Argonne modeling inputs submitted
12/19/86	U. S. Environmental Protection Agency	Model plant memo revised
12/19/86	U. S. Environmental Protection Agency	Cost memo revised
02/13/87	U. S. Environmental Protection Agency	BID chapters 3 through 6 and 8 mailed out to industry
03/10/87	U. S. Environmental Protection Agency	Draft test plan for additional tests submitted
04/07/87	U. S. Environmental Protection Agency	Draft BID chapters 7.1 & 7.2 submitted
04/21/87	U. S. Environmental Protection Agency	Section 114 information request to 139 companies
04/23/87	U. S. Environmental Protection Agency	Draft BID Appendix C submitted
04/30/87	Southern Manufacturing Facility (SMF)	Visit to SMF
04/30/87	U. S. Environmental Protection Agency	Additional test site selected
05/11/87	U. S. Environmental Protection Agency	Test request for SMF submitted
05/26/87	U. S. Environmental Protection Agency	Draft Working Group package submitted
06/25/87	U. S. Environmental Protection Agency	Draft Regulatory Impacts Analysis (RIA) submitted
06/29/87	U. S. Environmental Protection Agency	Risk Assessment inputs to HEM model
07/01/87	U. S. Environmental Protection Agency	Final Working Group Package submitted
07/09/87	U. S. Environmental Protection Agency	Final draft of RIA
07/13/87	U. S. Environmental Protection Agency	Information package sent to Working Group Members
07/13/87-07/17/87	SMF	Source test conducted
09/09/87	U. S. Environmental Protection Agency	Preliminary test data received from Entropy
12/15/87	U. S. Environmental Protection Agency	Project schedule delayed to allow testing and laboratory studies to investigate chromium speciation in cooling towers
05/04/88	U. S. Environmental Protection Agency	Revised draft HEM risk assessment inputs for modeling annual incidence and maximum individual risk submitted
05/09/88	U. S. Environmental Protection Agency	Results from laboratory studies received

TABLE A-1. (continued)

Date	Company, consultant, or agency/location	Nature of action
05/27/88	U. S. Environmental Protection Agency	Revised draft of Chapters 3 through 8 and Appendices C, D, and F submitted
08/08/88-08/11/88	SMF	Method development test
07/18/89	University of North Carolina, Chapel Hill, NC	Visit to university physical plant
08/23/89	Allied-Signal, Inc., Moncure, NC	Visit to synthetic fiber manufacturer
10/02/89-10/03/89	Chevron U.S.A., Inc., Richmond, California	Visit to petroleum refinery
10/04/89	TOSCO Corporation, Martinez, California	Visit to petroleum refinery
10/20/89-10/21/89	Chevron U.S.A., Inc., El Segundo, California	Visit to petroleum refinery
10/22/89-10/23/89	Shell Oil Company, Martinez, California	Visit to petroleum refinery
12/05/89	E. I. duPont de Nemours & Company, Inc., Wilmington, NC	Visit to chemical manufacturer
12/13/89	E. I. duPont de Nemours & Company, Inc., Camden, SC	Visit to chemical manufacturer
12/14/89	Amoco Chemical Company, Mount Pleasant, SC	Visit to chemical manufacturer
12/14/89	Georgetown Steel Corporation, Georgetown, SC	Visit to steel plant
07/13/90-07/19/90	National Institute of Standards and Technology, Gaithersburg, MD	Source test
01/14/91-01/22/91	Allied Fibers, Moncure, NC	Source test
02/15/91	Chevron Chemical Company, San Ramon, CA Monsanto Chemical Company, St. Louis, MO Dow Chemical U.S.A., Midland, MI E. I. du Pont de Nemours & Company, Inc., Beaumont, TX Eastman Chemical Products, Inc., Kingsport, TN Occidental Chemical Corp., Dallas, TX PPG Industries, Inc., Pittsburgh, PA Union Carbide Corp., Danbury, CT Vulcan Materials Company, Birmingham, AL	Section 114 information request to nine companies
02/22/91	Nalco Chemical Company, Naperville, IL	Visit to water treatment chemical supplier
02/26/91	Betz Industrial, Trevose, PA	Visit to water treatment chemical supplier
03/26/91	U. S. Environmental Protection Agency	Technical memorandum: Status of California chromate ban
05/24/91	Betz Industrial, Trevose, PA Nalco Chemical Company, Naperville, IL Dearborn Chemical Company, Lake Zurich, IL Calgon Corp., Pittsburgh, PA Dexter Corp., Chagin Falls, OH Chemtreat, Inc., Richmond, VA Chemlink, Inc., Houston, TX Buckman Laboratories, Memphis, TN Drew Industrial, Boonton, NJ	Questionnaire to nine water treatment chemical suppliers
06/07/91	U. S. Environmental Protection Agency	Technical memorandum: Preliminary analysis of Section 114 information request responses
06/19/91-08/22/91	U. S. Environmental Protection Agency	Revised drafts of BID Chapters 3 to 8, and Appendix C submitted
08/28/91	U. S. Environmental Protection Agency	Technical memorandum: Analysis of drift rate data from NIST and Allied tests
09/20/91	U. S. Environmental Protection Agency	Technical memorandum: Data for economic impacts analysis
10/01/91	U. S. Environmental Protection Agency	Draft BID summary report

TABLE A-1. (continued)

Date	Company, consultant, or agency/location	Nature of action
10/24/91	U. S. Environmental Protection Agency	Docket transmitted to Air Docket Office
11/20/91	National Air Pollution Control Techniques Advisory Committee	Meeting
11/21/91	U. S. Environmental Protection Agency	BID Chapters 3 to 8 and Appendix C revised
01/10/92	U. S. Environmental Protection Agency	Start action request submitted
02/28/92	U. S. Environmental Protection Agency	OAQPS decision meeting
04/06/92	Work Group	Informational meeting
04/20/92	U. S. Environmental Protection Agency	OAR decision meeting
04/24/92	U. S. Environmental Protection Agency	BID Chapter 9 revised
05/20/92	Work Group	Options selection meeting
06/03/92	U. S. Environmental Protection Agency	BID Appendix D revised
07/09/92	Work Group	Meeting on preamble and regulation

APPENDIX B.

INDEX TO ENVIRONMENTAL IMPACT CONSIDERATIONS

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INDEX TO ENVIRONMENTAL IMPACT CONSIDERATIONS

This appendix consists of a reference system which is cross-indexed with the October 21, 1974, Federal Register (39 FR 37419) containing the Agency guidelines concerning the preparation of environmental impact statements. This index can be used to identify sections of the document which contain data and information germane to any portion of the Federal Register guidelines.

TABLE B-1. CROSS-INDEXED REFERENCE SYSTEM TO HIGHLIGHT ENVIRONMENTAL IMPACT PORTIONS OF THE DOCUMENT

Agency guidelines for preparing regulatory action environmental impact statements (39 FR 37419)	Location within the background information document
1. BACKGROUND AND SUMMARY OF REGULATORY ALTERNATIVES	
Summary of regulatory alternatives	The regulatory alternatives from which standards will be chosen for proposal are summarized in Chapter 1, Section 1.1; a detailed description of the control techniques is provided in Chapter 4, Section 4.1.
Statutory basis for proposing standards	The statutory basis for proposing standards is summarized in Chapter 2, Section 2.1.
Relationship to other regulatory agency actions	The relationships between EPA and other regulatory agency actions are discussed in Chapter 7.
Industries affected by the regulatory alternatives	A discussion of the industries affected by the regulatory alternatives is presented in Chapter 3, Section 3.1 and Chapter 5, Section 5.3. Further details covering the business and economic nature of the industry are presented in Chapter 9, Section 9.1.
Specific processes affected by the regulatory alternatives	The specific processes and facilities affected by the regulatory alternatives are summarized in Chapter 5, Sections 5.1 and 5.3. A detailed technical discussion of the processes affected by the regulatory alternatives is presented in Chapter 3, Section 3.3.

TABLE B-1. (continued)

Agency guidelines for preparing regulatory action environmental impact statements (39 FR 37419)	Location within the background information document
2. REGULATORY ALTERNATIVES	
Control techniques	The alternative control techniques are discussed in Chapter 4.
Regulatory alternatives	The various regulatory alternatives are defined in Chapter 6. A summary of the major alternatives considered is included in Chapter 1, Section 1.1.
3. ENVIRONMENTAL IMPACT OF THE REGULATORY ALTERNATIVES	
Primary impacts directly attributable to the regulatory alternatives	The primary impacts on mass emissions and ambient air quality due to the alternative control systems are discussed in Chapter 7, Sections 7.1 through 7.4. A matrix summarizing the environmental impacts is included in Chapter 1.
Secondary or induced impacts	Secondary impacts for the various regulatory alternatives are discussed in Chapter 7, Sections 7.1 through 7.4.
4. OTHER CONSIDERATIONS	A summary of the potential adverse environmental impacts associated with the regulatory alternatives is included in Chapter 1, Section 1.2, and Chapter 7. Potential socio-economic and inflationary impacts are discussed in Chapter 9, Section 9.2.

APPENDIX C.

SUMMARY OF TEST DATA

APPENDIX C. SUMMARY OF TEST DATA

This appendix presents the results of seven EPA-conducted tests for hexavalent chromium (Cr^{+6}) emissions from industrial process cooling towers (IPCT's). The test data were considered in developing emission factors and in quantifying the performance of high-efficiency drift eliminators (HEDE's) versus low-efficiency drift eliminators (LEDE's) as described in Chapter 4. The emission data include mass emissions and particle size distributions. For each test series, Section C.1 presents descriptions of the physical and operating parameters of the cooling tower and of the water treatment program. The test results are tabulated in Section C.2. Section C.3 presents an evaluation of the proposed test method, based on the results of the two most recent EPA-sponsored emission tests.

C.1 DESCRIPTION OF TESTS

C.1.1 Department of Energy, Gaseous Diffusion Plant, Paducah, Kentucky[1]

C.1.1.1 Process Description. The Department of Energy facility at Paducah, Kentucky, is operated by Martin Marietta Energy Systems, Inc. This facility enriches uranium in the U^{235} isotope using a gaseous diffusion (cascade) process. The diffusion process involves pressure-induced flow of the uranium hexafluoride (UF_6) process gas through microporous barriers. The heat of compression is removed from the process gas by thermosyphon refrigerant systems to control the operating temperature. The refrigerant is vaporized in process gas coolers and is transferred to water-cooled heat exchangers, where it is condensed before it returns to the gas coolers. Recirculating cooling water is pumped from a basin to the process condensers

and returned to the cooling towers, where waste process heat is rejected to the atmosphere. The UF_6 is cooled indirectly for safety and reliability considerations.

The process cooling tower system consists of two towers that are designated C-637-2A and C-637-2B. A schematic of the C-637-2A and C-637-2B system is shown in Figure C-1. The C-637-2A tower was selected for source testing; this tower is a seven-cell Marley Cooling Tower Company (Marley) crossflow design with two fans per riser cell and is equipped with both LEDE's (herringbone) and HEDE's (Thermatec Spectra). Riser cell Nos. 1 through 5 are equipped with LEDE's and redwood splash fill. The HEDE riser cell Nos. 6 and 7 contain polyvinyl chloride (PVC) splash fill.

The tower was originally constructed in the early 1950's with redwood splash fill and herringbone drift eliminators in all the riser cells. Riser cell Nos. 6 and 7 were recently modified by the installation of the PVC splash fill and Thermatec Spectra drift eliminators. The water systems of towers C-637-2A and C-637-2B are served by a common pumphouse that has a total nominal capacity of 605,670 liters per minute (ℓ/min) (160,000 gallons per minute [gal/min]): six pumps are rated for 75,709 ℓ/min (20,000 gal/min) each and four pumps are rated for 37,854 ℓ/min (10,000 gal/min) each. Each of the tower systems is constructed with a water basin having a capacity of 15.9 million liters (4.2 million gallons). Makeup water from the Ohio River is softened and clarified and then supplied through a 76.2-centimeter (cm) (30-inch [in.]) pipeline to the pumphouse.

Two 152.4-cm (60-in.) cooling water supply and return loops ("G" and "H" on Figure C-1) are used to recirculate the tower water through the process building. The return lines of each loop are connected by a "crossover" pipeline that allows water to be directed to either the C-637-2A or 2B tower for cooling. Another "crossover" pipeline interconnects the process cooling water supply lines. The recirculating water enters the tower after the flow is split into seven branches (riser pipes) that serve each of the seven riser cells. The flow from each of the

riser pipes is split and conveyed into the water distribution decks of each of the two fan cells.

The water distribution decks are located directly above the splash fill sections of the fan cells and equipped with gravity flow nozzles for even distribution of the recirculating water in a cascade over the fill material. Propeller fans measuring 6.7 meters (m) (22 feet [ft]) in diameter that are located in the stack of each cell provide 17,273 cubic meters per min (m^3/min) (610,000 cubic feet per min [ft^3/min]) of induced horizontal airflow through the fill sections.

Sodium bichromate with a target concentration of 18 to 20 parts per million (ppm) is added to the recirculating cooling water to inhibit corrosion in the heat exchangers. Chromate additions are made manually, and the chromate levels are measured daily. A chlorine residual of 0.5 ppm is the target concentration for controlling biological organisms in the recirculating water. Chlorine is continuously injected into the system at a constant flow rate. The pH of the water is monitored continuously by a pH probe and meter. Additions of sulfuric acid are made manually to maintain the 6.0 to 6.1 target pH range. The calcium hardness is maintained at concentrations between 350 and 500 ppm in the recirculating water by controlling the blowdown rate.

C.1.1.2 Operating Conditions During Testing. The C-637-2A cooling tower operating parameters that were monitored throughout the test period were the fan motor amperage, pump outlet pressures, total water flow, basin water temperature, return water temperature, chlorine addition rate, makeup water flow rate, pH, wet well temperature, and blowdown rate. Meteorological data were obtained from the National Weather Service (NWS) at the Paducah Airport for each day that tests were performed and included hourly observations of dry bulb temperature, dew point, wind speed, and wind direction. Table C-1 is a summary of the cooling tower operating parameters and meteorological data recorded and obtained during the test period.

The cooling tower was not operating at the recirculating water design capacity during the tests due to low process cooling demands. It was necessary to increase the water flow rates of the riser cells being tested to between 90 and 100 percent of design capacity (30,564 to 33,959 ℓ/min [8,074 to 8,971 gal/min], respectively) by directing some of the recirculating water in the riser cells not being tested to the riser cells that were being tested. This was accomplished by partially closing the isolation valve for the riser cells not being tested. Additionally, the distribution of the riser cell water to each of the fan cells was balanced by adjusting the individual flow control valves on each fan cell until the depth of water appeared to be equal in the distribution decks. The blowdown rate was maintained at zero throughout the test period to minimize the loss of sodium bromide that was added to the recirculating water as a tracer chemical.

On the day prior to the first test series, the recirculating water flow rates on riser cell Nos. 4 and 7 were adjusted while the water flow rates were measured. Water flow rates were established at 32,176 ℓ/min (8,500 gal/min) and 32,555 ℓ/min (8,600 gal/min) for riser cell Nos. 4 and 7, respectively. A water flow measurement on riser pipe No. 7 concurrent with the first test series indicated that the flow was at 85 percent of capacity, or 28,390 ℓ/min (7,500 gal/min). The reason for this variation is not known, but there may have been a leak in the pitot tube during the pretest flow rate measurement. Inspection of the drift eliminator in fan cell No. 13 indicated the presence of a significant water leak from the distribution deck into the tower on the fan side of the drift eliminator section. The first test on riser cell No. 7 was invalidated because the water flow rate was less than 90 percent of the design flow rate and because of the water leak into the tower on the fan side of the drift eliminator. The tests on riser cell No. 7 were successfully repeated after the pitot tube was repaired and a broken redwood plank in the side of the water distribution deck was replaced. The remaining tests on riser cell Nos. 4, 5, and 6 were completed

under acceptable conditions with respect to the test plan and Cooling Tower Institute (CTI) guidelines.

C.1.2 National Institute of Standards and Technology, Gaithersburg, Maryland[2]

C.1.2.1 Process Description. The National Institute of Standards and Technology (NIST), formerly the National Bureau of Standards, is a Federal Government research facility near Gaithersburg, Maryland. On the grounds are seven laboratory/office buildings with a total floor area of 58,066 square meters (m^2) (625,000 square feet [ft^2]) and a number of support buildings with a floor area of 62,711 m^2 (675,000 ft^2). Comfort cooling and cooling for laboratory processes (lasers, ovens, etc.) are both provided by a four-cell Marley tower located near the western boundary of the facility. The tower was installed in the early 1960's.

A schematic of the cooling tower system is provided in Figure C-2. The tower is a crossflow design with redwood splash fill and one fan per cell. Propeller fans measuring 6.7 m (22 ft) in diameter are located in the stack of each cell. In 1985, the tower was retrofitted with high-efficiency Munters D-15 drift eliminators.

The capacity of the water basin is about 1.893×10^6 ℓ (500,000 gal). Four pumps each rated for 33,312 ℓ/min (8,800 gal/min) circulate the water to the chillers. The water from the chillers is combined and returned to the tower through a 106.7-cm (42-in.) riser pipe. Above the tower, the flow is split into four branches and distributed to each of the cells. The water distribution decks are located directly above the fill and are equipped with gravity flow nozzles. In winter, heated water is sprayed up into the rear of the tower to prevent icing.

A solution of molybdate and polyacrylate is used to inhibit corrosion in the heat exchangers. The target concentration of molybdate in the recirculating water is about 15 ppm. Conductivity and pH are monitored continuously, and blowdown occurs automatically when the conductivity reaches 1,800 micromhos (μmhos). Blowdown averages about 227,126 liters

per day (ℓ/d) (60,000 gallons per day [gal/d]) in summer and about 7,571 ℓ/d (2,000 gal/d) in winter.

Makeup water is provided by the City of Gaithersburg. The conductivity is generally about 300 μmhos, but after heavy rains and after salt has been applied to the roads in the winter, the conductivity increases. Makeup requirements average about 1.136×10^6 ℓ/d (300,000 gal/d) in summer and about 208,200 ℓ/d (55,000 gal/d) in winter. Most of the water has first been used for once-through cooling of oil and air compressors.

Biological growth is controlled by manually adding 24.6 ℓ (6.5 gal) of a solution containing disodium cyanodithiocarbamate (7.35 percent) and potassium methyldithiocarbamate (10.15 percent) once a week.

C.1.2.2 Operating Conditions During Testing. Eight test series were conducted. The cooling tower operating parameters that were monitored during each test series included the recirculating water temperatures into and out of the chiller, recirculating water flow rate, daily blowdown and water makeup, wind speed, and wind direction. Meteorological data were also obtained from the NWS at Washington National Airport.

The design water flow was achieved on each of the test days, but one chiller was not operated; water simply circulated through it. The low ambient temperature and low demand during Test Series 5, 6, and 7 necessitated turning off a second chiller and one fan. Table C-2 is a summary of the cooling tower operating parameters and meteorological data recorded during the test period.

It was determined from the estimated system volume that adding about 90.7 kilograms (kg) (200 lb) of crystalline sodium dichromate would result in a Cr^{+6} concentration of slightly over 15 ppm in the recirculating water. This amount of sodium dichromate was added on the day before the first test, and lesser amounts were added on following days to replenish the estimated losses via blowdown and drift. To determine the actual Cr^{+6} concentration, water samples were taken during each test series and later analyzed for Cr^{+6}. Sodium bromide also was added to

the recirculating water to evaluate bromide as a surrogate for chromium in drift emissions testing.

A pretest walk-through of the tower was conducted on Tuesday, August 19, 1986. Inspection of the drift eliminators revealed a number of water leaks into the fan side of the eliminator sections. This was most significant in the first cell, but in no case did the airflow appear to be shearing droplets away from the water stream. Inspection of the water flow along the outside of the tower revealed an unequal distribution that was most pronounced on the windiest days. The strongest winds were evident on Wednesday, August 20, when the anemometer mounted atop a nearby building indicated gusts of up to 22.5 kilometers per hour (km/h) (14 miles per hour [mph]). On the tower itself, an anemometer indicated 22.5 km/h (14 mph), and the NWS reported winds of 16.1 to 24.1 km/h (10 to 15 mph) for that day. In no instance, however, was drift observed from the sides of the tower. All tests were completed under acceptable conditions with respect to the test plan and CTI guidelines.

C.1.3 Exxon Refinery, Ethylene Production, Baytown, Texas[3]

C.1.3.1 Process Description. Tower No. 68 provides cooling for the catalytic light-end units, which recover ethylene and other light-end products. The tower handles a constant heat load 24 hours per day. Figure C-3 is a schematic of tower No. 68. This tower consists of four counterflow cells and one Marley crossflow cell. Each cell has one single-speed fan and redwood herringbone drift eliminators. The counterflow section has redwood splash fill and is served by two risers that distribute the water over the fill through a manifold and pressure spray nozzles. The crossflow section has plastic splash fill and is served by one riser that supplies a water distribution deck equipped with gravity flow nozzles. Two pumps circulate water from the northern end of the common basin to the process heat exchangers, and a third pump is on standby. Blowdown is withdrawn from the system before the water is returned to the tower. Makeup water from the San Jacinto River is supplied through a 10.2-cm (4-in.) pipeline to the basin. The fans are

5.5 m (18 ft) in diameter in the counterflow cells and 7.3 m (24 ft) in diameter in the crossflow cell.

The corrosion inhibitor is a chromate/zinc formulation that is supplied by Betz Industrial (Betz). The target concentration of chromate in the recirculating water is 10 to 15 ppm. The solution is added automatically at a rate that is set manually. Dispersant is added in the same manner. A free chlorine residual of 0.2 to 0.5 ppm is the target for control of microbiological growth. Chlorine gas is injected into a side stream of the makeup water and added to the southern end of the basin. The pH of the water is monitored continuously, but it is not used as an automatic controller. When pH exceeds the critical control range of 6.0 to 9.0, it must be corrected by manually adding acid or caustic soda. Blowdown is dictated by the conductivity, which should not exceed 1,500 μmhos.

C.1.3.2 Operating Conditions During Testing. The operating parameters that were monitored throughout the test period include fan motor amperage, pump outlet pressure, hot water line pressure, water flow in each riser, temperature in each riser, basin water temperature, pH, conductivity, wind speed and direction, wet bulb temperature, and dry bulb temperature. In addition, the makeup water flow rate was measured and the blowdown was estimated concurrently with the fourth test series. Table C-3 is a summary of the cooling tower operating parameters and meteorological data recorded during the test period.

On the day prior to the first test, the recirculating water flow rates were measured. The flow in the crossflow cell was about 20 percent greater than the flow in each of the counterflow cells. However, because the pump outlet pressures and fan amperages were constant and within design specifications, no changes were made to the air or water flow rates for the test.

The drift eliminator on one side of the crossflow cell was determined to be in good condition based on visual inspection. The drift eliminators in the counterflow cells could not be inspected. However, it appeared that a similar quantity of drift was being emitted from each stack, although the amount may have

been slightly less from cell No. 1. The quantity of steam rising from cell No. 1 also appeared to be slightly less than that from the other cells. Some of the nozzles in the distribution deck on cell No. 5 were plugged, and a few of the redwood slats in the lower sections of the counterflow cells were broken, but the overall condition of the tower was reasonably good.

Water meters are not installed on the makeup and total blowdown lines so alternative methods were attempted to estimate these flows. During the fourth test series, a meter was connected to the pressure taps on an existing orifice plate in the makeup line. This indicated an average flow of about 1,060 ℓ/min (280 gal/min) over the 6 hours of monitoring (greater in the afternoon than in the morning) but did not include the 56.8 to 75.1 ℓ/min (15 to 20 gal/min) diverted for chlorine injection or the amount leaking through a valve into the system from a nearby tower (No. 58), which is treated with a phosphate inhibitor from Calgon Corporation (Calgon). The Betz representative used the phosphate concentration in the recirculating water of tower No. 68 to calculate a gain of about 94.6 ℓ/min (25 gal/min). Later work by Exxon confirmed that this estimate was correct.

To estimate the tower No. 68 blowdown, the flow was diverted to a 208-ℓ (55-gal) drum. The amount of time required to fill the drum a couple of times was recorded. This estimated flow rate was within 20 percent of the estimate calculated by the Betz representative based on cycles of concentration and an estimate of evaporation.

Water temperatures also are not monitored by on-line equipment. Therefore, fittings were attached to taps on the three risers and the hot water return line itself. Mercury-in-glass thermometers were used to record the temperature. The basin temperature was determined about 5 ft from the basin wall below cell Nos. 1, 2, and 5. A mercury-in-glass thermometer was placed in a perforated can that was attached to a length of conduit. With this method, it was not possible to determine the

actual temperature drop in each cell, but the average basin temperature in all three locations was the same.

Two sources of meteorological data were available: one station set up at the tower and one maintained by Exxon refinery personnel less than a mile from the tower. Both stations indicated that the wind direction was from the southeast, and very few directional changes deviated more than 45 degrees from the southeast. Both average and peak wind speeds, however, were considerably higher at the tower station. The differences may have been the result of instrument calibration differences, or they may have been caused by a slight tunneling effect created at the tower station where the wind had to pass between the cooling tower and a cryogenic process column (and other shorter equipment) 27.4 to 36.6 m (30 to 40 yards) downwind of the station. Gusts rarely exceeded 24.1 km/h (15 mph), and drift was never visible from the sides of the crossflow tower. The ambient temperature also varied between the stations. The actual temperature is probably that obtained at the tower site since the several thermometers that were used recorded the same levels.

Three days prior to the first test, the Exxon process personnel responsible for the tower disconnected the chlorine injection line to preclude any possible adverse health effects on test personnel. Chlorine will also react with most hydrocarbons. Thus, a decrease in the free chlorine residual concentration (normally determined once per shift) is the best indicator of a process fluid leak into the water. Alternatively, gas traps on the hot water return line, visual inspection of the surface of the water in the basin and the distribution deck of cell No. 5, and the chromate concentration were used to confirm that the process heat exchangers were not leaking. The chromate concentration, as determined by the operators each shift, was essentially constant and within the desired control range during the testing period. The Betz analysis on Tuesday agreed with

that of the operators. The pH and conductivity were also within control ranges.

C.1.4 Exxon Refinery, Lube Oil Production, Baytown, Texas[3]

C.1.4.1 Process Description. Cooling for the vacuum distillation unit for lube oil is provided by tower No. 84. Although the tower is operating at less than design capacity, it handles a constant heat load 24 hours per day. Figure C-4 is a schematic of tower No. 84. The tower is a Marley counterflow design with four riser cells and four fan cells. Each fan cell has one 6.7-m (22-ft)-diameter constant-speed fan. The average measured airflow per fan ranged from 222 to 287 dry standard cubic meters per minute (dsm^3/min) (470,000 to 609,000 dry standard cubic feet per minute [dscfm]). Each cell is equipped with PVC film fill and a high-efficiency Marley XCEL-15 drift eliminator. Water is distributed over the fill through a manifold and spray nozzles. Two pumps circulate the water from the basin extension at the south end of the tower through the process heat exchangers. A recent potassium retention time study determined that the system volume was about 2.082×10^6 ℓ (550,000 gal) of water.

Blowdown is designed to be controlled by the conductivity of the recirculating water. At certain set points, a valve is actuated in a line off the main hot water return. Most of the makeup water is supplied through a 15.2-centimeter (6-inch) pipe to the basin extension, but part of it is diverted continuously into five smaller lines. The inhibitor, dispersant, chlorine, sulfuric acid, and caustic soda are injected into the smaller lines automatically.

The corrosion inhibitor is a 7:1 chromate/zinc formulation that is supplied by Nalco Chemical Company (Nalco). The target chromate concentration in the recirculating water is 8 to 12 ppm. The solution is injected into one of the small makeup lines for a specific fraction of every 10-minute interval. The on/off time fraction can be changed by entering new values into the computer memory. The dispersant is injected into another makeup line in an identical manner. Acid and caustic are injected based on pH

set points within the control range of 6.8 to 7.5. Chlorine gas is injected continuously at a rate controlled by a free chlorine residual monitor that is generally set to keep the concentration in the range of 0.3 to 0.5 ppm. The conductivity of the makeup water is about 150 μmhos, and the control range for the number of cycles is 6 to 8.

C.1.4.2 Operating Conditions During Testing. The operating parameters monitored throughout the test period were fan motor amperage, pump outlet pressures, cold water line pressure, water flow in each riser, temperature in three of the risers, basin temperature, temperature in pump inlet lines, pH, conductivity, wind speed and direction, and dry bulb temperature. The computerized system that monitors inlet and outlet temperatures and the makeup, blowdown, and recirculating water flow rates was not calibrated correctly at the start of the test. With the exception of the blowdown, attempts at calibration were not successful. These problems are not considered to affect the amount of drift, and only the makeup and blowdown could not be monitored directly by the test personnel. Table C-4 is a summary of the cooling tower operating parameters and meteorological data recorded during the test period.

On the day prior to the first test series, the water flow rates in each riser were measured. The flows in Risers A and B were about 15 percent less than the flows in Risers C and D. The total flow was 25 percent greater than the tower design and 20 percent greater than the pump ratings. From the pump head pressure and the manufacturer's pump curves, it was calculated that the flow should be about 77,980 ℓ/min (20,600 gal/min). The measured rate was about 10 percent greater than this calculated rate. As scale and fouling increase, and with additional process heat loads, the head pressure will increase slightly and cause a decrease in the flow rate. The conditions as measured (and with all the fans running) represented normal operation. Therefore, no attempt was made to equalize the flow in the risers or to reduce the overall flow to the design rate.

The drift eliminators could be inspected through a porthole in the fan stack below the fan. The drift eliminator in Cell A is assumed to have at least one defect because entrained droplets were observed periodically in the same area of the stack. The other drift eliminators appeared to be in good condition. The water distribution through the fill was even, although it did cascade along some vertical beams at a greater rate than along others.

The quantity of blowdown was not easily determined because the conductivity control was not working and the valves in the line were closed. Also, recirculating water can be withdrawn from the system in the process area for general ground-cleaning purposes. The operators, however, indicated that they had not been using any of this water on the test days. Finally, a water balance on the process side of the overhead vacuum condensers indicated an excess of about 189 ℓ/min (50 gal/min). This is approximately the amount that the Nalco representative calculated for the blowdown based on the cycles of concentration and an estimate of the evaporation loss.

The recirculating water temperature was measured with mercury-in-glass thermometers in fittings attached to taps in three of the risers. The basin temperature was determined with a mercury-in-glass thermometer at the intersection of the main basin and the basin extension. The temperatures indicated by gauges on the lines to the pumps were also recorded; they were consistently 2 degrees lower than the thermometer reading.

Meteorological data were available both at the tower site and from the Exxon meteorological station almost a mile away. The wind direction continued to be steady from the southeast, and the wind speeds were higher on the chart recorder at the tower station. At this site, there were no obstructions around the station except for the tower itself.

The operator log indicated that the chromate concentration in the recirculating water was constant at the upper limit of the control range over the 2-day test period. The concentration agreed with that obtained by the Nalco representative on

August 29. The pH, conductivity, and free chlorine residual were also within the control ranges.

C.1.5 A Southeastern Manufacturing Facility[4]

C.1.5.1 Process Description. This plant has indicated that the type of cooling water treatment program is confidential business information and would place the company at a competitive disadvantage if known by other manufacturers of its product. The EPA and the company have agreed that rather than maintaining the type of cooling water treatment as confidential information pending a formal determination, the Agency would treat the company name, plant location, type of manufacturing process, and the names of plant personnel as confidential.

Cooling Tower No. 22-900 was constructed in 1979 and serves the heating, ventilation, and air conditioning (HVAC) system for the plant. It is a Marley Class 500 tower (Model 575-68-02). The two-cell, crossflow, induced-draft tower has molded polypropylene, ladder-type splash fill and high-efficiency Marley XCEL-10 drift eliminators. The tower is about 12.5 meters (m) (41 feet [ft]) wide, 17 m (56 ft) long, and 6.7 m (22 ft) high to the top of the distribution deck (9.8 m [32 ft] high to the top of the stacks). The tower is designed to cool 28,390 ℓ/min (7,500 gal/min) of water from 38°C to 29°C (100°F to 85°F) when the wet bulb temperature is 26°C (78°F). Single-speed fans in both cells are operated by 44.7-kilowatt (kW) (60-horsepower [hp]) motors and produce a design airflow of 13,390 actual cubic meters per minute (m^3/min) (472,700 actual cubic feet per minute [acfm]) each. Typically, the fans shut off automatically when the outside temperature is less than 17°C (62°F); however, the fans can also be operated manually. The design evaporation rate is 428 ℓ/min (113 gal/min), and the chromate concentration in the recirculating water is maintained at 450 to 600 ppm. Chromate generally is not added to the recirculating water of this tower; however, the chromate concentration is maintained by adding blowdown containing chromate from the adjacent process tower. Ladders at each end provide access to the top of the tower, and

electrical power is available at the site. Figure C-5 is a schematic of the HVAC tower (tower No. 22-900).

Cooling Tower No. 22-901 was constructed in 1979 and serves process equipment such as the vacuum pumps, compressors, various heat exchangers, and other process equipment. The two-cell, crossflow, induced-draft tower, which also is a Marley Class 500 tower (Model 597-94-02), has molded polypropylene, ladder-type splash fill (identical to that in Cooling Tower No. 22-900) and slat-type LEDE's. The drift eliminators consist of two layers of redwood slats. The slats in both layers run 45° from horizontal in opposite directions such that they are perpendicular to each other. Because the slats are inclined, they return collected water to the basin more efficiently than typical horizontal slats. The tower is about 17.4 m (57 ft) wide, 20.7 m (68 ft) long, and 8.5 m (28 ft) high to the top of the distribution deck (11.6 m [38 ft] high to the top of the stacks). The tower is designed to cool 19,990 ℓ/min (5,281 gal/min) of water from 39°C to 28°C (102.8°F to 82°F) when the wet bulb temperature is 26°C (78°F). Two-speed fans in both cells are operated by 55.9-kW (75-hp) motors and produce a maximum design airflow of 19,660 m^3/min (694,300 acfm) each. The design evaporation rate is 613 ℓ/min (162 gal/min), the chromate concentration in the recirculating water is maintained by the plant at 250 to 300 ppm, and blowdown is used as part of the makeup for tower No. 22-900. The tower operates 24 hours per day, ladders at each end provide access to the top of the tower, and electrical power is available at the site. Figure C-6 is a schematic of the process tower (tower No. 22-901).

The power house supervisor was not sure what the cycles of concentration were for the HVAC tower but indicated that the process tower operated at approximately 12 cycles of concentration. The recirculating water treatment program depends upon chromate as the only corrosion inhibitor. Because zinc and/or other synergistic inhibitors are not contained in the treatment program, substantially higher levels of chromate are necessary than when a blended treatment is used. Corrosion

protection is provided for heat exchanger surfaces, compressors, and pumps. Carbon steel (No. 4140) is used as the material of construction for some heat exchanger surfaces. Organic biocides and an iron dispersant also are added to the recirculating water. Currently, an aqueous solution of chromate is added manually once a week to the recirculating water to maintain the target concentrations (250 to 300 ppm for the process tower and 450 to 600 ppm for the HVAC tower). The calcium hardness of the makeup water is 22 ppm, and a continuous blowdown of 18.9 to 22.7 ℓ/min (5 to 6 gal/min) is used to control the cycles of concentration.

The majority of the makeup water is steam condensate added as a result of the manufacturing process. Adding the remaining makeup water, which can be either softened water or city water, is controlled manually. The blowdown from the process tower is used as makeup for the HVAC tower. The HVAC blowdown is collected along with other wastewater in an above-ground holding tank. A precipitation-type wastewater treatment process is used to remove heavy metals before the water is discharged to the local publicly owned treatment works (POTW).

C.1.5.2 Operating Conditions During Testing. Eight test series were conducted Monday through Friday, July 13-17, 1987. Operating parameters for both cooling towers were monitored simultaneously during testing to ensure that representative conditions existed. The parameters monitored included the operation of the pumps and fans on each tower, the inlet water temperatures at the distribution decks, the cold water basin temperatures, distribution deck water levels, and the characteristics of the tower interior during testing (leak checks). Table C-5 is a summary of the cooling tower operating parameters and meteorological data recorded during the test period.

During pretest measurements, the HVAC tower water flow rate was determined to be 40,000 ℓ/min (10,600 gal/min), which is approximately 7,600 ℓ/min (2,000 gal/min) over the design flow rate. On Monday, the inside of the cooling tower was inspected under this flow condition. Cooling water was overflowing the

distribution deck onto the fan deck, falling through the spaces between the fan deck planking into the interior of the cooling tower (thus bypassing the drift eliminators), and causing "rain" inside the tower. Many of these drops were being drawn up through the fan stack, creating an artificially high drift rate. This is improper cooling tower operation, and, thus, testing could not take place until the flow rate was adjusted to the design flow.

Plant personnel adjusted the flow rate on the HVAC tower by bypassing some of the flow from the distribution deck to the cold water well. In addition, cracks between plywood decking over the distribution box were caulked to prevent overflow onto the fan deck. Both water diversion and caulking were continued until maximum water flow to the distribution deck was obtained without causing "rain" inside the tower. The flow rate was measured to be at the design flow rate under these conditions, and testing was then possible for this tower.

The process cooling tower was running at full pump capacity, but the distribution decks of both cells had a water level of only 1.9 to 3.8 cm (0.75 to 1.5 in.) out of a possible 15.2 cm (6 in.). Plant personnel said that this was the normal operating condition for this tower. It was further discovered that the cooling water loop for this tower had a 61,300 ℓ (16,200 gal) holding tank for a portion of the process water. All of the cooling water that leaves one particular process enters this tank. It is served by four pumps, rated at 2,400 ℓ/min (630 gal/min) each, that return the water to the cooling tower. The pumps are level-activated such that at a low tank level no pumps operate. As the level rises, successive pumps turn on so that the tank does not overflow. During testing, two pumps were normally operating. Under this condition, the holding tank water level usually fluctuated less than 30.5 cm per hour (1 foot per hour) depending upon how much cooling water was needed for the process. Occasionally, one pump or three pumps were in service, but at no time during the test were all four pumps seen on or off simultaneously. Therefore, the flowrate fluctuations during

tests were of little consequence when compared to the total flow of the cooling tower. However, the tank level was measured, and water samples of this hot well were taken whenever mass balance samples were taken from the cooling towers to account for the level change in the mass balance tests.

After correcting these minor problems, the first test began on the afternoon of Monday, July 13, 1987. On Tuesday morning, a review of the process tower airflow and water flow rate results from Monday's test showed the tower to have a liquid-to-gas (L/G) ratio of 0.5 to 0.6. This is much lower than is typical for most towers. Plant personnel agreed to divert the flow from both cells into one cell to double the L/G ratio. The L/G ratio for the HVAC tower was determined to be approximately 1.8 (near the typical maximum for cooling tower design). However, the flow rate to the distribution deck in this tower could not be reduced significantly because nearly the entire cooling capacity of the tower was required for proper chiller operation. Discussions with J. D. Holmberg of Marley indicated that tests at Marley using the isokinetic heated bead sampler followed by filters have shown that the L/G ratio should have little or no effect on the drift rate unless the flow was so low that some of the distribution deck was not receiving any water (which was not the case). However, diverting the flow to one cell would allow testing on a more representative tower because most process towers operate at an L/G ratio between 1.0 and 2.0.[1] Runs 1 and 2 were completed with flow in both cells. Run 3 on the process tower on Tuesday afternoon was performed with flow diverted into Cell C. Runs 4 and 5 on Wednesday were performed with flow in both cells while results were analyzed on Run 3. Runs 6 and 7 on Thursday and Run 8 on Friday were performed with flows in one cell. Thus, four runs were completed under each L/G ratio condition.

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[1]Taken from a July 14, 1987, telephone conversation with J. D. Holmberg of Marley.

On Friday, July 17, the Power House Supervisor provided information on the replacement and operation of process heat exchangers during the test week that indicated a steady heat load was present and few new heat exchanger surfaces came in contact with the cooling water.

Additional observations concerning the tests at the

A pretest walk-through was conducted prior to the start of the first run. Some leakage from the hot water basins was observed bypassing the drift eliminators, but the rate of leakage was considered to be negligible. Because the hot water basins were covered, it was not possible to check water levels during the test. However, there was no reason to suspect unequal distribution of water among the four cells of the tower.

The first run was begun with all four condensers operating. However, near the end of the run, the flow to condenser No. 1 was shut off. During the remaining four runs, only condenser Nos. 2, 3, and 4 were operated. During the last two days of the test, the sample lines in the trains used on Cell 2 were changed from Teflon™ to PVC. No other changes in the trains were made during the test, and all test runs were completed under acceptable conditions with respect to CTI guidelines.

C.1.7 Allied Fibers, Moncure, North Carolina[6]

C.1.7.1 Process Description. Allied Fibers manufactures high-strength polyester fiber that is used in tire cord, belts and hoses, ropes, seat belts, and other products. Terephthalic acid and ethylene glycol are mixed with a catalyst and other materials to form a paste, which then undergoes a three-stage process to produce polyester yarn strands or filaments.

Two identical towers, TW-2 and TW-3, are associated with the polymer process. Both are two-cell, induced draft, crossflow towers with splash fill. TW-2 was constructed in 1973, and TW-3 was constructed in 1975. Both towers were rebuilt in 1988. At that time, Marley XCEL-15 drift eliminators were installed on both towers. The towers share a common sump and have a combined recirculation rate of 12,870 to 13,248 ℓ/min (3,400 to 3,500 gal/min). There is one fan per cell, and the design airflow capacity is 5,239 actual cubic meters per minute (acmm) (185,000 actual cubic feet per minute [acfm]). The design cooling water temperature range is from 40° to 34°C (104° to 93°F) in the summer and 21° to 13°C (70° to 56°F) in the winter. A schematic of tower TW-3 is shown in Figure C-7.

Water treatment chemicals are supplied by Nalco, and no corrosion inhibitor is used. The water treatment program includes two biocides, a dispersant, an antifoam agent, and pH control additives. The recirculating water has a total solids content of 0.86 percent, and the pH is maintained between 6.0 and 7.0. Because TW-2 and TW-3 serve a direct contact spray heat exchanger, the recirculating water also contains approximately 9.5 percent ethylene glycol.

C.1.7.2 Operating Conditions During Testing. Testing was originally planned for both TW-2 and TW-3. However, because of leakage from the hot water basins and fan deck into the plenum of TW-2, only TW-3 was tested.

Because of the high solids and ethylene glycol content of the recirculating water, the interior structural members of the tower were coated with material. Some of this material was loose and had the potential to be carried out the fan stack. In addition, in the mornings, heavy condensation formed in the tower plenum. It is also possible that some of the encrusted material on the internal members of the tower was dissolved and carried out the fan stack with the condensate.

Foam presented another problem during the initial stages of testing. The recirculating water discharging into the hot water basins formed a thick foam, which occasionally overflowed the basins or was blown onto the fan deck, where it reverted to a liquid. The fan deck included several drain holes to prevent accumulation of the liquid. This was also a concern during the testing because of the liklihood that the draining liquid could be carried out the fan stacks by the air flow. To prevent this from occurring, the drain holes were plugged during the test runs, and additional antifoaming agent was batch added to the basins when needed.

During the test, the recirculation rate for the combined flow to TW-2 and TW-3 and the inlet and outlet temperatures were monitored. Meteorological data recorded included dry bulb temperature, relative humidity, barometric pressure, and wind speed and direction. These data are summarized in Table C-8.

The drift tests were conducted on both cells of TW-3 using two pairs of sampling trains--one pair per cell. To reduce the possibility of contamination of the samples by the nozzles, glass nozzles were used instead of the stainless steel nozzles as had been used on previous tests. In addition, three wet impingers were used in the train instead of the usual two. Following one trial and one aborted run, testing was conducted over a period of 4 days with four runs per day. As with the second NIST test, this test was designed to determine the drift rate based on selected native elements in the recirculating water. The test was completed in accordance with CTI guidelines.

C.2 SUMMARY OF TEST DATA

The results of the EPA isokinetic and the absorbent paper emission tests at the Department of Energy's, Gaseous Diffusion Plant in Paducah, Kentucky, are summarized in Table C-9.[1] For the tower tested, each riser supplies water to two fan cells. Stack emissions were sampled from fan cell Nos. 7 through 14 (riser cell Nos. 4 through 7). For most tests, half of the sample was collected from each of the fan stacks corresponding to a riser cell. All data for the isokinetic emission tests are reported in Table C-9 as being greater than the value presented because only about one-third of the chromium was transferred with the liquid to the vial used for analysis after the sample was concentrated. The balance of the chromium remained in the beaker used to evaporate the water from the sample and required rinsing with aqua regia to solubilize the chromium for analysis. This method of rinsing was not performed with the beakers used to concentrate samples collected at the Department of Energy's, Gaseous Diffusion Plant in Paducah, Kentucky.

The results of the first Method 13-type and absorbent paper emission tests at NIST in Gaithersburg, Maryland, are summarized in Table C-10.[2] The results of the Method 13 and absorbent paper emission tests at Tower 68 at the Exxon refinery in Baytown, Texas, are summarized in Table C-11.[3] Although there are three riser cells and five fan stacks, individual tests were conducted on each fan stack. The results of the Method 13-type, absorbent

paper, and ion exchange emission tests at Tower 84 at the Exxon refinery in Baytown, Texas, are summarized in Table C-12.[3] The results of the Method 13-type and absorbent paper tests at the Southeastern Manufacturing facility are summarzied in Table C-13.[4] Sensitive paper drift measurements at three test sites (Paducah, Gaithersburg, Baytown) are summarized in Table C-14.[1-3]

The results of the second Method 13-type emission test at NIST in Gaithersburg, Maryland, are summarized in Table C-15, and the results of the Method 13-type emission test at Allied Fibers are summarized in Table C-16.[5-6] For both of these tests, emission rates were determined for a number of selected elements.

C.3 ANALYSIS OF TEST METHOD[7]

The cooling tower emission test method used in the second NIST and Allied tests currently is under consideration for approval by EPA. This method, which has been used extensively by CTI, uses surrogate element concentrations of minerals that are native to the recirculating water for determining drift rate. The method requires isokinetic sampling of cooling tower drift emissions and determining mineral concentrations in the recirculating water and drift by inductively coupled argon plasma spectroscopy. Elements that are found in the sample in concentrations that are close to the detection limit and other "unreliable" elements are screened out. (In previous tests conducted by a testing firm retained by CTI, several elements were found to give inconsistent results for drift rate determinations, and, thus, are considered to be unreliable.) Mineral-specific drift rates are then determined from these data for the remaining elements (i.e., those that were not screened out), and the overall tower drift rate for a specific test run is determined by averaging the mineral-specific drift rates for that run.

Because of the high variability in test data from the two EPA-sponsored tests in which this test method was used, the data from the second NIST and Allied tests were analyzed to evaluate the reliability of the test method in distinguishing between an

LEDE-equipped tower and an HEDE-equipped tower. The specific objectives of this analysis were to evaluate the procedure for screening elements for average drift rate determinations and to determine whether the method has sufficient precision to distinguish between the emission levels for HEDE's and LEDE's in a typical compliance setting.

The results of this analysis suggest that the test method does have significant limitations in its ability to distinguish between drift rates for towers equipped with HEDE's and for towers equipped with LEDE's within an acceptable number of test runs. In addition, improvements in the test method are unlikely due to cooling tower stack test conditions, which generally are inappropriate for obtaining a representative sampling of the exhaust stream. The following sections describe in detail the approach and the results of the analysis of the test method.

C.3.1 Procedure for Screening Elements

Although there is general agreement that the detection limit criteria is reasonable for screening out elements, additional procedures have been considered for screening out unreliable data for the remaining elements. Two possible criteria that have been proposed are chemical characteristics and identification of outliers.

C.3.1.1 Chemical Class. Historically, drift tests conducted by CTI have used alkali metals to determine drift rate. These elements are reported to be more reliable in terms of repeatability. Drift rates from the second NIST test indicate a bimodal distribution with the alkali or alkaline earth metals behaving quite differently from the transition metals. However, the Allied data show no such systematic differences. Although some questions have been raised about a number of factors that may have affected the magnitude of the drift rates at Allied (as described in Section C.1.7.2), the Allied data are noteworthy in that (1) the element-specific drift rates for Allied were less variable than those for NIST; (2) as mentioned previously, variations in the Allied data do not appear to be related to specific classes of elements; and (3) the overall drift rates

based on all elements above detection limit were comparable for the Allied and second NIST tests. Therefore, the data available provide no compelling reason for screening out elements based on chemical class.

C.3.1.2 Outlier Identification. Several approaches are available for identifying outliers. A simple method uses a cutoff of two times the standard deviation--all data points that differ from the mean by more than twice the standard deviation are considered outliers. In a normally distributed population, the range defined by this criteria includes 95 percent of the distribution. This approach is more liberal than approaches in some texts, which suggest ranges of three or even four times the standard deviation. However, applying this approach to log transforms of the NIST and Allied data, which were found to be more normally distributed than the raw drift rates, yields no outlying points.

C.3.2 Precision of Test Method

The precision of the test method was evaluated by analyzing the standard deviations of the run-specific drift rates. The data suggest that a reasonable estimate for the standard deviation of the drift rates is 60 to 100 percent of the mean, and for the purpose of the analysis, a standard deviation of 80 percent was assumed.

A variety of approaches could be used to evaluate whether a method has sufficient precision to differentiate between an HEDE-equipped tower and an LEDE-equipped tower. The method selected because of its straightforward, intuitive interpretation involved a hypothetical comparison of HEDE- and LEDE-equipped towers that were assumed to have "true" drift rates of 0.01 percent and 0.03 percent of the recirculation rate, respectively. It was also assumed that the HEDE tower would have to achieve a drift rate of at least 0.01 percent lower than the LEDE tower (i.e., the HEDE drift rate must be no greater than 0.02 percent of the recirculation rate) in order for the HEDE tower drift rate to be considered to be significantly lower. The frequency with which the test method would fail to demonstrate that the HEDE tower

achieves a significantly lower emissions rate than the emissions rate from the LEDE tower was then determined. Based on a maximum error of 5 percent, it was determined that a minimum of 18 test runs would be required to reliably characterize the magnitude of the drift rate for a typical tower equipped with HEDE's.

SYSTEM DATA

PARAMETER	VALUE	PARAMETER	VALUE
TOWER AGE, YEARS	31	DIAMETER OF FAN STACKS, FT	22
AIRFLOW CAPACITY PER FAN, FT^3/MIN	478,000	BASIN CAPACITY--NORTH & SOUTH, GALLONS EACH	4,200,000
TOTAL AIRFLOW RATE, FT^3/MIN	6,690,000	PUMP SIZE, GAL/MIN	
RECIRCULATION RATE, GAL/DAY	101,600,000	6 PUMPS @ 1,250 HP	20,000
NO. OF RISER CELLS	7	4 PUMPS @ 450 HP	10,000
NO. OF FAN CELLS PER RISER CELLS	2	FAN MOTOR SIZE, HP	75

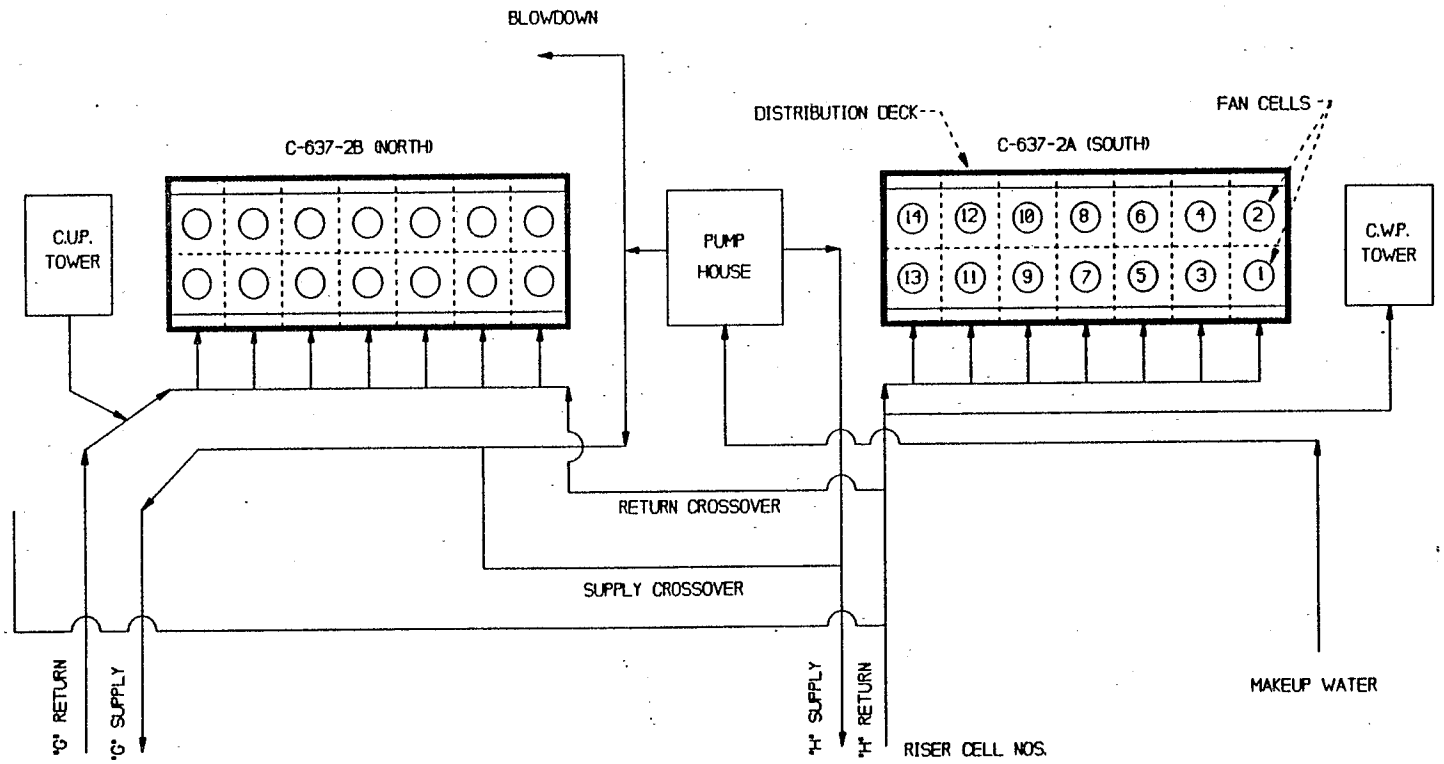


Figure C-1. Tower C-637-2A at Department of Energy gaseous diffusion plant.

SYSTEM DATA

PARAMETER	VALUE
RECIRCULATION RATE, GAL/MIN	35,000
DIAMETER OF FAN STACKS, FT.	22
WATER BASIN CAPACITY, GAL	500,000

PARAMETER	VALUE
MAKEUP FLOWRATE, GAL/DAY	
WINTER	55,000
SUMMER	300,000
BLOWDOWN RATE, GAL/DAY	
WINTER	2,000
SUMMER	60,000

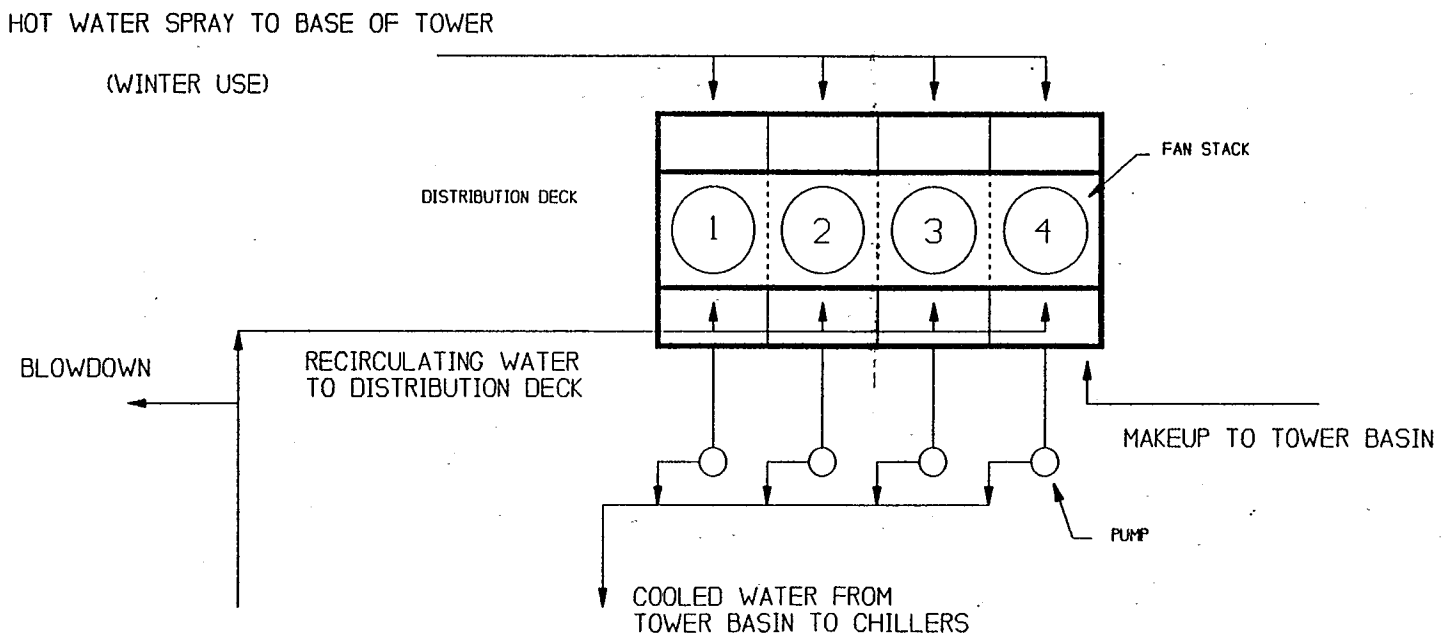


Figure C-2. Cooling tower at NIST facility in Gaithersburg, Maryland.

SYSTEM DATA

PARAMETER	VALUE
TOWER AGE (ORIGINAL SECTION), years	31
NO. OF FAN CELLS	5
AIRFLOW, dry scfm	
CELLS 1-4, AVERAGE PER CELL	3.0×10^{-3}
CELL 5	8.9×10^{-3}
DIAMETER OF FAN STACKS, ft	
CELLS 1-4	18
CELL 5	24

PARAMETER	VALUE
NO. OF RISERS	3
RECIRCULATION RATE, gal/min	
RISERS 1 AND 2, EACH	7,300
RISER 3 FOR CELL 5	8,800

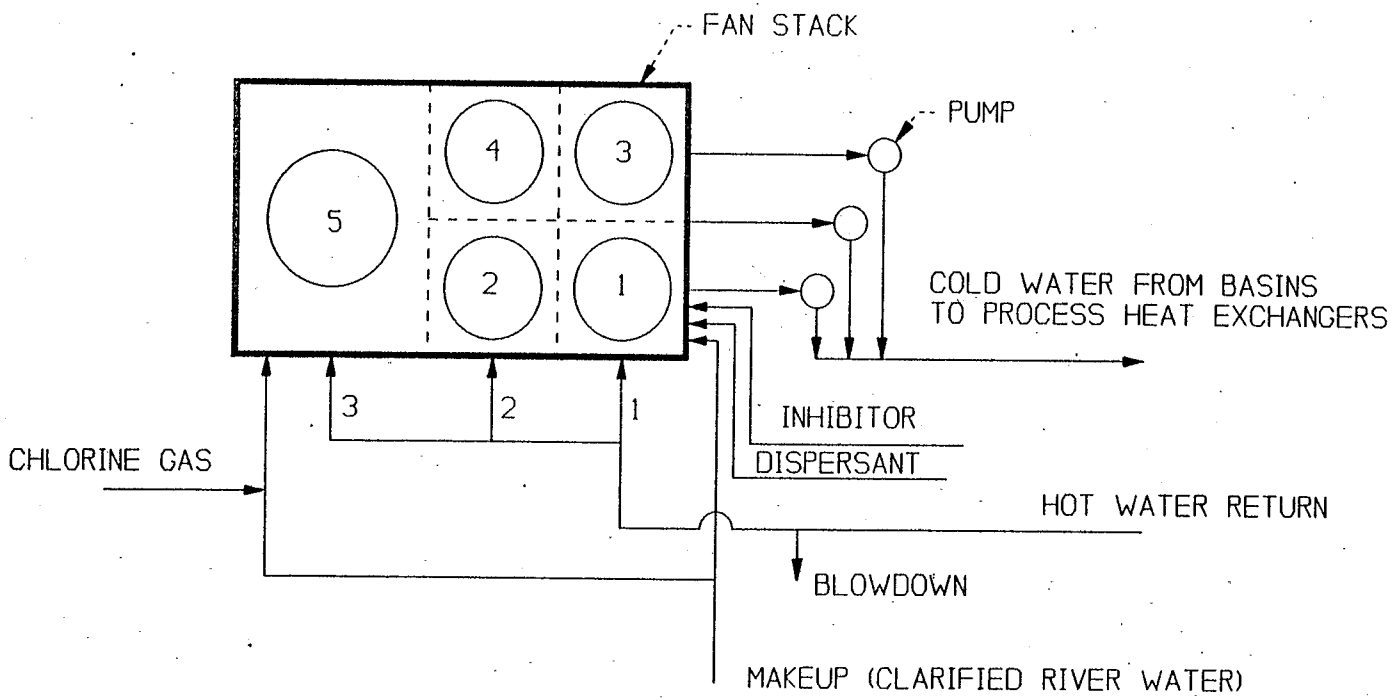


Figure C-3. Tower 68 at Exxon-Baytown refinery.

SYSTEM DATA

PARAMETER	VALUE
TOWER AGE, YEARS	<1
RECIRCULATION RATE, gal/min	22,700
AVERAGE AIR FLOW PER FAN, dry scfm	550,000
DIAMETER OF FAN STACKS, ft	22
NO. OF RISERS	4
NO. OF FAN CELLS	4

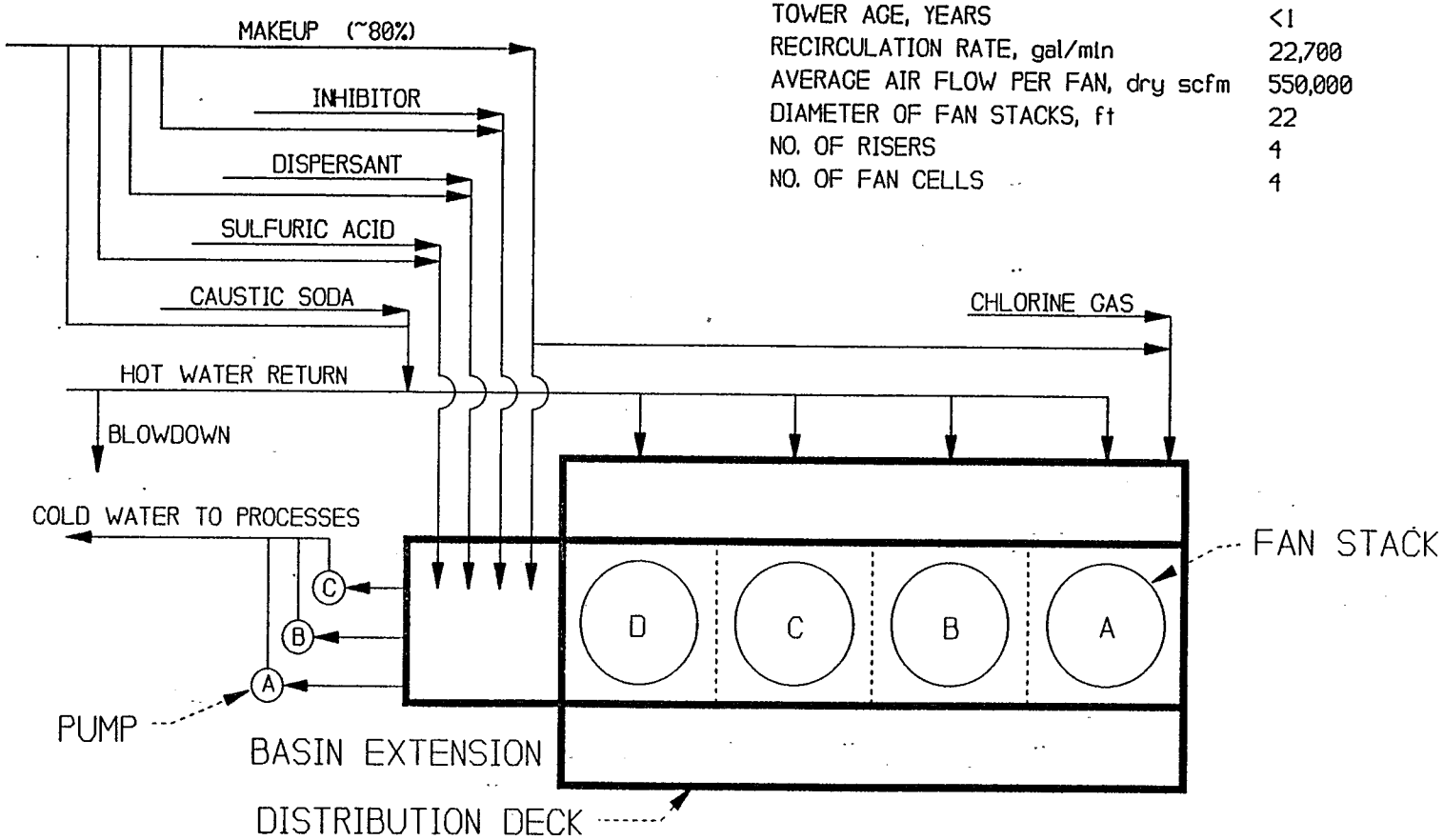


Figure C-4. Tower 84 at Exxon-Baytown refinery.

SYSTEM DATA

PARAMETER	VALUE	PARAMETER	VALUE
RECIRCULATION RATE, GAL/MIN	7,500	AIRFLOW RATE PER CELL, FT^3/MIN	472,700
TOWER AGE, YEARS	18	EVAPORATION RATE, GAL/MIN	113
FAN STACK DIAMETER, FT	16	FAN MOTOR SIZE, HP	60
NO. OF FAN CELLS	2		

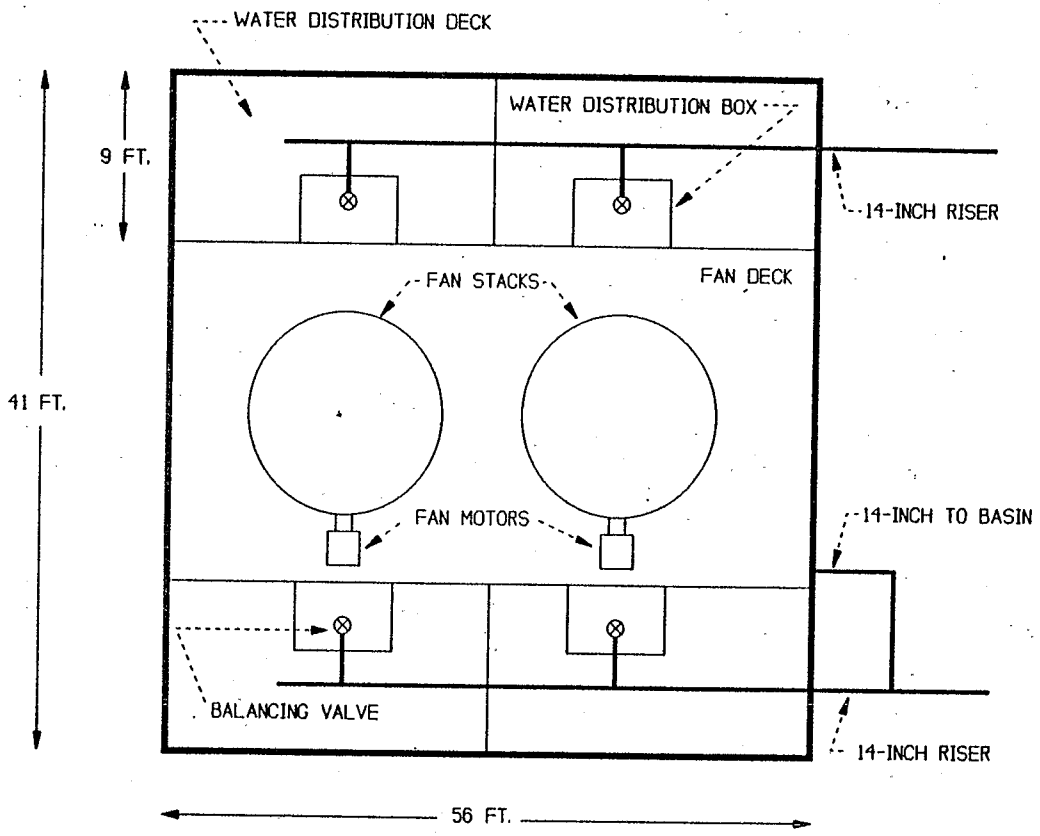


Figure C-5. Cooling tower No. 22-900 at a Southeastern manufacturing facility.

SYSTEM DATA

PARAMETER	VALUE	PARAMETER	VALUE
RECIRCULATION RATE, GAL/MIN	5,281	AIRFLOW RATE PER CELL, FT^3/MIN	694,300
TOWER AGE, YEARS	18	EVAPORATION RATE, GAL/MIN	162
FAN STACK DIAMETER, FT	22	FAN MOTOR SIZE, HP	75
NO. OF FAN CELLS	2		

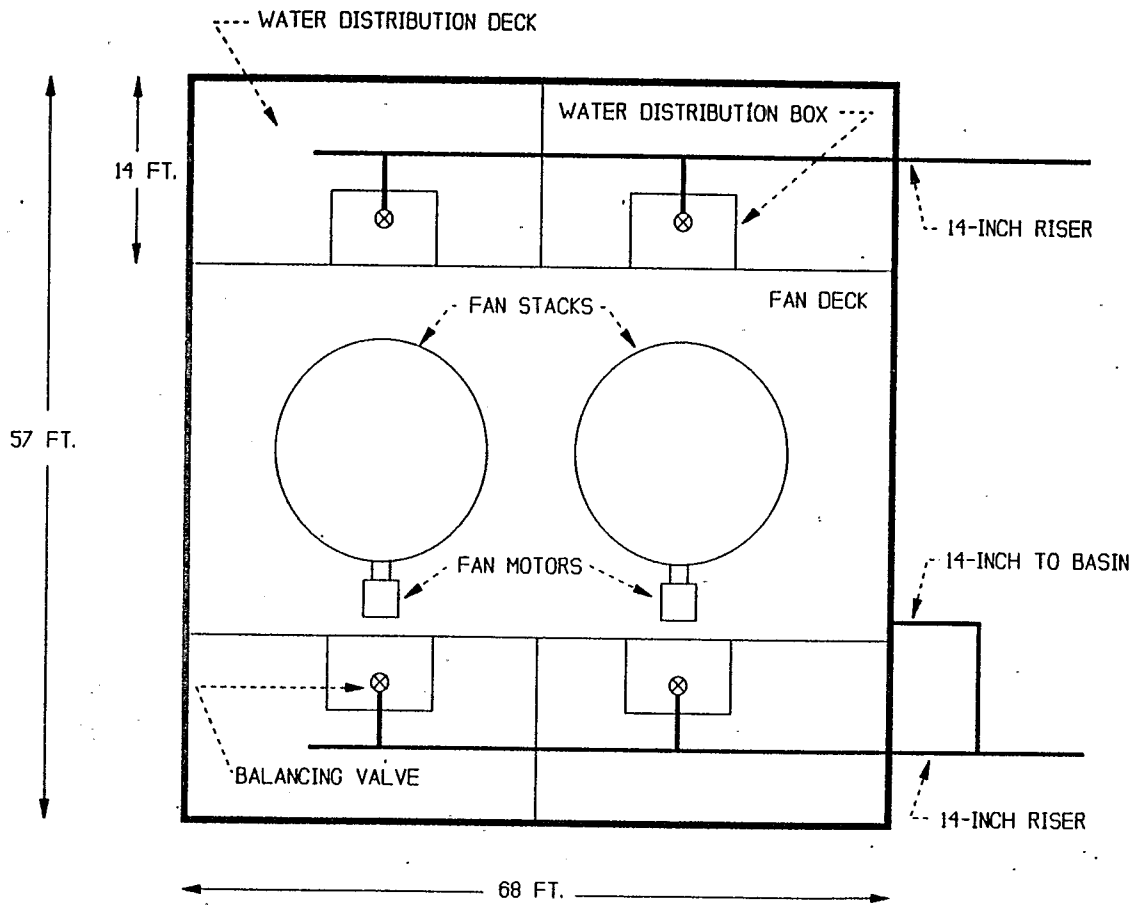
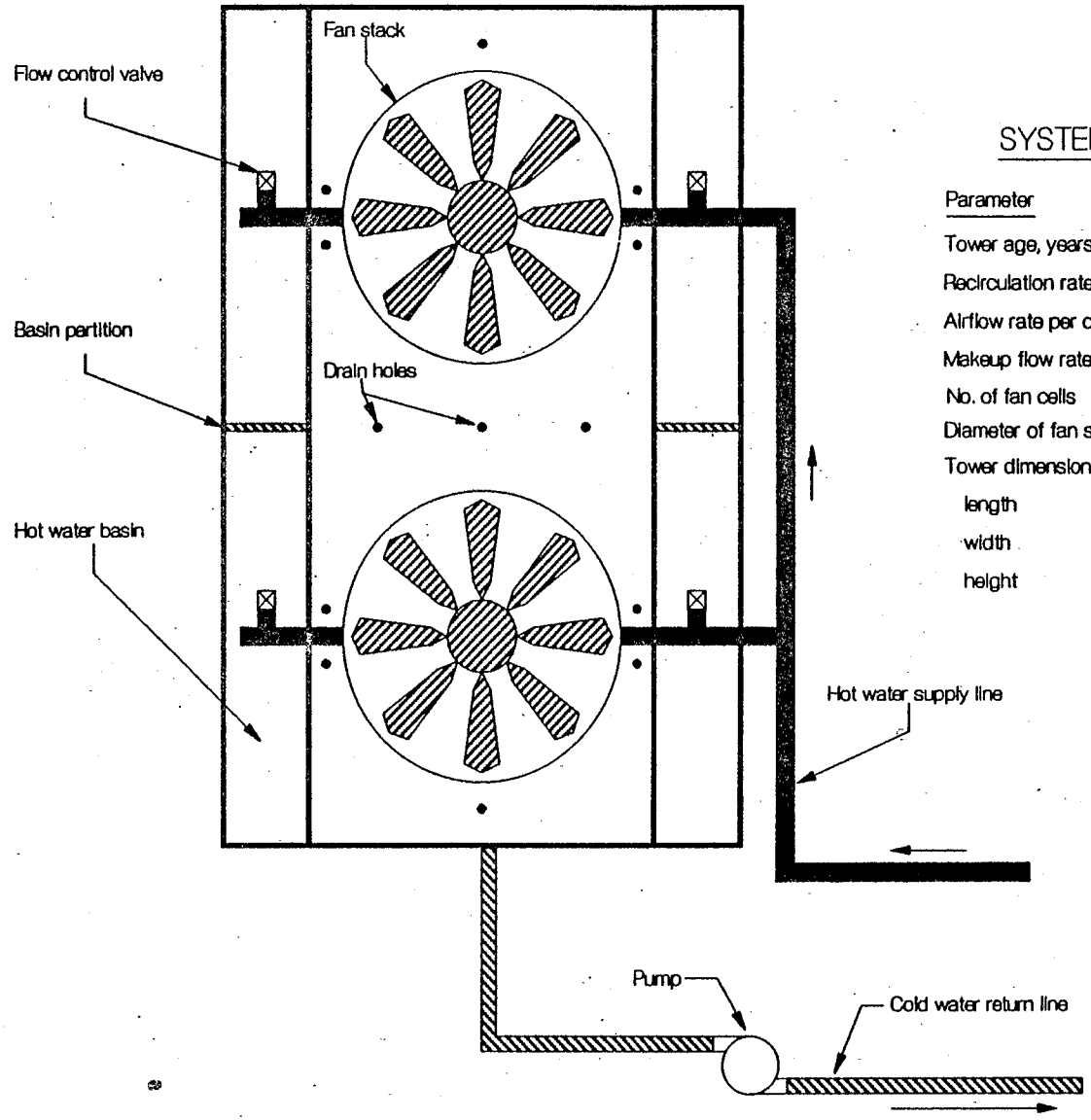


Figure C-6. Cooling tower No. 22-901 at a Southeastern manufacturing facility.



SYSTEM DATA

Parameter	Value
Tower age, years	9
Recirculation rate, gal/min	1,750
Airflow rate per cell, ft^3/min	185,000
Makeup flow rate, gal/min	4
No. of fan cells	2
Diameter of fan stack, ft	10
Tower dimensions, ft	
length	40
width	23
height	12.9

Figure C-7. Tower TW-3 at Allied Fibers.

TABLE C-1. SUMMARY OF OPERATING PARAMETERS AND METEOROLOGICAL DATA DURING TESTS AT THE DEPARTMENT OF ENERGY'S GASEOUS DIFFUSION PLANT, PADUCAH, KENTUCKY

Parameter	Test series No. 1	Test series No. 2	Test series No. 3	Test series No. 4	Test series No. 5	Test series No. 6	Test series No. 7	Test series No. 8
Date	6/24/86	6/24/86	6/25/86	6/25/86	6/26/86	6/26/86	6/27/86	6/27/86
Run Nos.	4-(8,7)-1	4-(7,8)-2	5-(10,9)-3	5-(9,10)-4	5-(10,9)-5	4-(7,8)-6	7-(14,13)-7	7-(13,14)-8
Recirculating waterflow, L/min (gal/min)								
"G" Loop	74,333 (19,640)	73,425 (19,400)	70,965 (18,750)	71,987 (19,020)	72,933 (19,270)	72,441 (19,140)	72,333 (19,270)	72,933 (19,270)
"H" Loop	53,858 (14,230)	52,571 (13,890)	53,214 (14,060)	53,858 (14,230)	53,858 (14,230)	53,858 (14,230)	53,858 (14,230)	53,858 (14,230)
Riser 4	30,740 (8,122)	30,740 (8,122)	-- (--)	-- (--)	-- (--)	32,405 (8,562)	-- (--)	-- (--)
Riser 5	-- (--)	31,807 (8,404)	31,047 (8,203)	31,047 (8,203)	31,266 (8,261)	-- (--)	-- (--)	-- (--)
Riser 6	-- (--)	33,605 (8,879)	32,663 (8,630)	32,663 (8,630)	32,636 (8,623)	-- (--)	-- (--)	-- (--)
Riser 7	24,417 (7,244)	27,417 (7,244)	-- (--)	-- (--)	-- (--)	31,300 (8,270)	31,527 (8,330)	31,527 (8,330)
Fan amperage, amps								
Cell 7	66-68	66-67	--	--	67-68	67-68	67-68	67-68
Cell 8	63-64	63-64	--	--	64	63-64	64	64-65
Cell 9	67-68	67	66-67	67	68	67-68	68-69	67-68
Cell 10	72-73	72-73	72-73	72-73	72-73	73-74	72-73	72-73
Cell 11	70	70	70-72	70-71	70-71	69-70	71-72	70-71
Cell 12	65-76	66	66	65-66	64-65	66-67	66-67	66-67
Cell 13	74	74	--	--	--	72-74	72-73	72-73
Cell 14	71-72	71-72	--	--	--	71-72	71-73	71-72
Makeup water flow L (gal/min)	9,159 (2,420)	9,159 (2,420)	8,554 (2,260)	9,462 (2,500)	9,084 (2,400)	8,478-9,803 (2,240-2,590)	8,474-9,462 (2,240-2,500)	9,273 (2,450)
Total water pressure, kg/cm^2 (psig)	5.3 (76)	5.4-5.5 (77-78)	5.4-5.6 (77-79)	5.2-5.4 (74-77)	5.3 (76)	5.2-5.3 (74-76)	5.3 (76)	5.3 (75-76)
Water temperature, °C (°F) Basin								
• North	34-35 (93-95)	33-34 (91-92.5)	33-37 (92-97.5)	33-37 (95-99)	33-36 (95-97)	36 (93)	31 (87-88)	31 (88)
• South	23-30 (85-86)	23-30 (85-86)	31-32 (87-89)	32 (89-90)	28-29 (83-85)	31-32 (88-90)	31 (87)	31 (87)

TABLE C-1. (continued)

Parameter	Test series No. 1	Test series No. 2	Test series No. 3	Test series No. 4	Test series No. 5	Test series No. 6	Test series No. 7	Test series No. 8
"G" return	56 (132)	56 (132)	55-56 (131-132)	56 (132)	55 (131)	55 (131)	56 (132)	56 (132)
"H" return	52-53 (126-127)	52-53 (125-126)	52 (125)	52 (125)	51-52 (124-126)	52 (125)	51 (124)	51 (124)
Wet well	33 (91-92)	33 (91)	32-33 (90-92)	34 (93-94)	33 (92)	33-34 (91-92.5)	33 (91.5-91.8)	33 (92-92.5)
Blowdown rate, L/min (gal/min)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Water chemistry								
Control/feed								
• pH	6.04	6.05	6.0-6.05	6.05-6.08	6.06-6.08	6.06-6.10	6.02-6.11	5.98-6.02
• Chlorine, Kg/d (lb/d)	109 (240)	109 (240)	109 (240)	109 (240)	109 (240)	109 (240)	109 (240)	109 (240)
• Orocol, L/d (gal/d)	17.0 (4.5)	17.0 (4.5)	34.1 (9.0)	34.1 (9.0)	0 (0)	0 (0)	34.1 (.0)	34.1 (9.0)
Lab analysis (Daily)								
• pH	6.0	6.0	6.1	6.1	6.2	6.2	6.2	6.2
• Residual Cl_2, ppm	–	–	0.54	0.54	–	–	0.82	0.82
• Ca hardness, ppm	431	431	422	422	422	422	426	426
• Chromate, $CR0_4$, ppm	18.1	18.1	17.9	17.9	18.9	18.9	18.4	18.4
• Total dissolved solids, ppm	–	–	2,149	2,149	–	–	2,199	2,199
Meteorological Data								
Wind speed, m/sec (ft/sec)	2-4(7-12)	1-4 (4-13)	4 (12-33)	3-4 (9-12)	3-4 (9-12)	4-5 (12-16)	4-6 (13-19)	6 (18-19)
Wind direction (00-360)	330-060	340-060	060-090	050-090	140-180	160-190	210-230	190-210
Ambient Temperature, °C (°F)	28-31 (83-87)	31-32 (88-90)	26-27 (78-81)	27-29 (81-84)	23-31 (82-88)	33 (91-92)	29-32 (84-89)	32-33 (89-82)
Dew point temperature, °C (°F)	19-21 (67-70)	18-21 (65-70)	14-15 (57-59)	15-162 (59-60)	18 (64-65)	21-23 (70-73)	22-23 (72-73)	22-23 (72-73)

[a]"G" and "H" loop waterflows were taken from venturi readings, and the riser waterflows were taken with a pitot tube. In test No. 2, the total flows from the two methods differ by about 2 percent, probably due to the fact that the venturi readings were in the bottom 10 percent of their range.

TABLE C-2. SUMMARY OF OPERATING PARAMETERS AND METEOROLOGICAL DATA DURING TESTS AT THE NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY, GAITHERSBURG, MARYLAND (FIRST TEST)

Parameter	Test series No.1	Test series No. 2	Test series No.3	Test series No. 4	Test series No. 5	Test series No. 6	Test series No. 7	Test series No. 8
Date	8-19-86	8-19-86	8-20-86	8-20-86	8-21-86	8-21-86	8-22-86	8-22-86
Run Nos.	A-1	A-2	B-1	B-2	C-1	C-2	D-1	D-2
Recirculating water flow in riser, L/min (gal/min)	136,662 (36,108)	136,662 (36,108)	137,873 (36,428)	137,873 (36,428)	137,702 (36,383)	137,702 (36,383)	135,348 (35,761)	135,348 (35,761)
Fans	All 4 high	All 4 high	All 4 high	All 4 high	3 high, 1 off	3 high, 1 off	All 4 high	All 4 high
Blowdown, L/d (gal/d)	353,500 (93,400)	353,500 (93,400)	189,997 (50,200)	189,997 (50,200)	120,357 (31,800)	120,357 (31,800)	171,073 (45,200)	171,073 (45,200)
Makeup, L/d (gal/d)	1,273,900 (336,600)	1,273,900 (336,600)	962,900 (254,400)	962,900 (254,400)	760,700 (201,000)	760,700 (201,000)	615,000 (162,500)	615,000 (162,500)
Chillers	3 on, 1 off	3 on, 1 off	3 on, 1 off	3 on, 1 off	2 on, 2 off	2 on, 2 off	2 on, 2 off for 1 hr 3 on, 1 off for 1 hr	3 on, 1 off
Water temperature, °C (°F)								
Entering condenser, avg.	24-26 (75-78)	26-27 (79-80)	26 (77-78)	26 (78-79)	24-26 (75-77)	26 (77-78)	23 (73-75)	23-24 (75-76)
Leaving condenser, avg.	27-29 (81-85)	29-30 (85-86)	28-29 (83-84)	29 (84-85)	27-28 (80-82)	28 (82-83)	26-27 (77-81)	27-28 (81-82)
Water chemistry pH	--	--	--	--	--	--	8.5	8.6
Conductivity, μmhos	1,700	1,700	1,700	1,700	1,700	1,700	1,750	1,750
Biocide addition, L (gal)	0 (0)	0 (0)	24.6 (6.5)	24.6 (6.5)	0 (0)	0 (0)	0 (0)	0 (0)
Meteorological data								
Wind speed, m/sec (ft/sec)	0-2.2 (0-7)	0-2.7 (0-9)	0-6.3 (0-21)	0-4.9 (0-16)	0-2.2 (0-7)	0-2.2 (0-7)	0-4.9 (0-16)	0-2.2 (0-7)
Wind direction (00-360)	0-75	15-90	45-90	90-105	0	0-90	270-360	270-360

TABLE C-3. SUMMARY OF OPERATING PARAMETERS AND METEOROLOGICAL DATA DURING TESTING OF TOWER 68 AT EXXON'S REFINERY, BAYTOWN, TEXAS

Parameter	Pretest	Test Series No. 1	Test Series No. 2
Date	08/31/86	09/01/86	09/02/86
Run Nos.		CT-68-1-1	CT-68-4-1
		CT-68-2-1	CT-68-5-3
		CT-68-5-1	
		CT-68-5-2	
Recirculating water flow, L/min (gal/min)			
Riser 1	27,656 (7,307)		
Riser 2	27,478 (7,260)		
Riser 3	33,408 (8,827)		
Fan amperage, amps			
Cell 1		85	84-85
Cell 2		90	89-90
Cell 3		78	77-78
Cell 4		90	90
Cell 5		120	120
Pump outlet pressure, kg/cm^2 (psig)			
Pump 3		5.6 (80)	5.6 (80)
Pump 3B		5.6 (80)	5.6 (80)
Hot water line pressure, psig		2.0 (28)	2.0 (28)
Water temperature, °C (°F)			
Basin 1/3		27-30 (82-85.5)	28-29 (83-85)
Basin 2/4		29 (85)	28-29 (83-84.5)
Basin 5		28-30 (83-85.5)	28-29 (83-85)
Hot water line, °C (°F)		38-39 (99.5-102)	38-39 (100-102)
Riser 1		38-39 (100-102)	– (–)
Riser 2		39 (103)	– (–)
Riser 3		38-39 (100-102)	38-39 (101-102)
Makeup water flow, L/min (gal/min)			~1,230 (~325)
Blowdown, P/min (gal/min)			~265 (~70)
Water chemistry on-line monitor			
pH		7.87-7.96	7.90-8.04
Conductivity, μmhos		1,029-1,056	1,026-1,038
Operator analysis			
pH		7.7	7.9-8.1
Conductivity, μmhos		1,000-1,057	1,022-1,035
Free chlorine, ppm		0.2	0-0.1
Chromate, ppm		12	13-14

TABLE C-3. (continued)

Parameter	Pretest	Test Series No. 1	Test Series No. 2
Vendor analysis[a]			
pH			7.9
Conductivity,)mhos			1,020
m-alkalinity, ppm			80
Chromate, ppm			14
Free chlorine, ppm			0
Calcium, ppm			226
Cycles			5.9
Chromate inhibitor feed rate, L/d (gal/d)			15.1 (4.0)
Meteorological data at tower			
Wind speed, m/sec (ft/sec)		2-11 (6-37)	0.4-9 (1-29)
Wind direction, 00-360		180-360	Unknown
Ambient temperture, °C (°F)		32 (89)	31-33 (87-91)
Meteorological data at Exxon station			
Wind speed, m/sec (ft/sec)		2-5 (7-18)	3-6 (10-21)
Wind direction, 00-360		90-180	90-180
Ambient temperature, °C (°F)		25.4-30.2 (77.8-86.4)	29-30 (84-86)

[a]Vendor analysis only performed on date of second test series.

TABLE C-4. SUMMARY OF OPERATING PARAMETERS AND METEROLOGICAL DATA DURING TESTING OF TOWER 84 AT EXXON'S REFINERY BAYTOWN, TEXAS

Parameter	Pretest	Test series No. 1	Test series No. 2
Date	09/03/86	09/04/86	09/05/86
Run Nos.		CT-84-A-1	CT-84-B-1
		CT-84-A-2	CT-84-B-2
		CT-84-C-1	CT-84-D-1
		CT-84-C-2	CT-84-D-2
Recirculating water flow, L/min (gal/min)			
Riser A	20,000 (5,300)		
Riser B	19,600 (5,200)		
Riser C	23,000 (6,100)		
Riser D	23,000 (6,100)		
Fan amperage, amps			
Cell A	60	60	60
Cell B	60	60	60
Cell C	60	60	60
Cell D	63	63	63
Pump outlet pressure, kg/cm^2 (psig)			
Pump 84A		6 (80)	6 (80)
Pump 84B		6 (80)	6 (80)
Cold water line pressure, kg/cm^2 (psig)			
Water temperature, °C (°F)			
Basin		29 (85)	29 (84-85)
Line to pump 84A		27-28 (82-83)	27-28 (82-83)
Line to pump 84B		27-28 (82-83)	27-28 (82-83)
Riser A		37.5-38 (99.5-100)	36.9-38 (98.5-100)
Riser C		37.5-38 (99.5-100)	36.9-38 (98.5-100)
Riser D		37.5-38 (99.5-100)	36.9-38 (98.5-100)
Makeup flow rate, L/min (gal/min)			
Blowdown, L/min (gal/min)			
Water chemistry on-line monitoring			
pH		6.8-7.1	6.8-7.0
Conductivity,)mhos		Unknown	Unknown
Free chlorine, ppm		0.35-0.57	0.15-0.30
Operator analysis			
pH		7.25	7.0
Conductivity,)mhos		1,200	1,100

TABLE C-4. (continued)

Parameter	Pretest	Test series No. 1	Test series No. 2
Makeup conductivity,)mhos		160	150
Chromate, ppm		12.5	12.5
Vendor analysis[a]			
pH			6.9
Free chlorine, ppm			0.2
Chromate, ppm			12.5
Conductivity,)mhos			1,100
Cycles			7.3
Chromate feed rate, L/d (gal/d)			11.4 (3.0)
Meteorological data at tower			
Wind speed, m/sec (ft/sec)		1-9.8 (4-32)	2-8 (6-26)
Wind direction, 00-360		270-360	270-360
Ambient temperature, °C (°F)		33 (92)	29-33 (84-91)
Meteorological data at Exxon station			
Wind speed, m/sec (ft/sec)		2-4.5 (7-15)	0.4-2 (1-7)
Wind direction, 00-360		90-110	120-180
Ambient temperature, °C (°F)		30-31 (86-87)	30 (86)

[a]Vendor analysis only performed on date of second test series.

TABLE C-5. SUMMARY OF OPERATING PARAMETERS AND METEOROLOGICAL DATA DURING TESTS AT A SOUTHEASTERN MANUFACTURING FACILITY

	Run Nos.							
	1[a]	2[b]	3[c]	4	5	6[d]	7	8
Date	07/13/87	07/14/87	07/14/87	07/15/87	07/15/87	07/16/87	07/16/87	07/17/87
Water temperatures, °C (°F)								
HVAC return	32 (90)	26-32 (78-90)	32-33 (90-91)	21-23 (70-74)	24 (75-76)	19-28 (67-83)	29-30 (84-86)	23-32 (73-89)
HVAC basin	29 (84-84.5)	24-29 (76-85)	26-28 (79-83)	18-21 (65-70.5)	21 (70-70.5)	18-24 (64-75.5)	24 (75-76)	22-26 (71-79)
Process return	34-35 (94-95)	33 (91-91.5)	36-37 (96.5-98)	33-34 (91-93)	34 (94)	33 (91-96)	34 (94)	33-35 (92-95)
Process basin	24-25 (76-77.5)	24 (75.5-75)	25-28 (77-79)	22-23 (71-73)	23 (72.5-73)	22-25 (71.5-77)	24 (75.5)	24-26 (75.6-78)
Blowdown rates, L/min (gal/min)								
HVAC tower	14.72 (3.89)	--	14.12 (3.73)	11.92 (3.15)	11.85 (3.13)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Process tower	19.95 (5.27)	--	21.84 (5.77)	N/A[e]	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Water flow conditions								
HVAC tower	2 cells	2 cells	2 cells	2 cells	2 cells	2 cells	2 cells	2 cells
Process tower	2 cells	2 cells	1 cell	2 cells	2 cells	1 cell	1 cell	1 cell
Cell tested								
HVAC	A	A	A	A	B	B	B	B
Process	C	C	C	C	D	D	D	D
Meteorological data								
Wind speed, m/sec (ft/sec)	0.4-5 (1-19)	0.4-4 (1-12)	0.9-6.3 (3-21)	0.9-5.8 (3-19)	0.9-5.4 (3-18)	0.9-4.9 (3-16)	0.4-5.8 (1-19)	0.4-4 (1-13)
Wind direction (00-360)	210-10	210-60	240-30	240-60	220-60	270-155	250-110	250-150
Ambient temperature, °C (°F)	31-32 (88-90)	22-28 (72-83)	26-29 (78-84)	21-26 (70-79)	27-29 (81-85)	24-28 (76-82)	29-31 (85-88)	21-24 (69-84)

TABLE C-5. (continued)

	Run Nos.							
	1[a]	2[b]	3[c]	4	5	6[d]	7	8
Dew point temperature, °C (°F)	25-26 (77-79)	21-23 (69-73)	23-24 (73-75)	18-19 (65-67)	19-20 (66-68)	19-20 (67-68)	21 (69-70)	19-21 (66-70)
Relative humidity, percent	57-64	63-86	61-83	48-77	39-45	48-64	39-42	53-85
Recirculating waterflow, L/min (gal/min)								
HVAC tower	16,699 (4,412)	15,881 (4,196)	15,998 (4,227)	16,585 (4,382)	16,888 (4,462)	16,627 (4,393)	16,456 (4,348)	16,203 (4,281)
Process tower	9,568 (2,528)	9,591 (2,534)	19,253 (5,272)	10,401 (2,748)	10,420 (2,753)	19,567 (5,154)	19,590 (5,176)	20,533 (5,425)

[a]Temperatures for this run recorded using plant instrumentation.
[b]Temperatures for this run initially measured by plant instrumentation, then temperatures at end of run recorded using actual thermometers placed in basin and distribution deck. All subsequent runs reflect temperatures using thermometers in the basin and distribution deck.
[c]Overflowing distribution deck caused leak into HVAC tower for approximately 10 minutes during the 3-hour test run.
[d]Significant leaks into process cooling tower from distribution deck bypassing drift eliminators were noticed during this run.
[e]Blowdown meter failed during test; blowdown shut off.

TABLE C-6. OBSERVATIONS DURING EMISSION TESTS AT SOUTHEASTERN MANUFACTURING FACILITY JULY 13, 1987, THROUGH JULY 17, 1987

8:00 a.m. to 8:20 a.m	Pretest inspection of both towers shows that HVAC tower has a higher than design flow rate (measured in pretest as 10,600 gal/min). Water overflowing rim of distribution deck (a 2 in. x 6 in. plank) on outside and inside edge of both cells. Outside edge overflow can be tolerated, but inside edge overflow spills onto fan deck, therefore bypassing drift eliminators and causing a high drift rate.
	Process tower appears to have low flow rate because water is only 0.75 in. to 1.5 in. deep in distribution deck. However, water is flowing into every distribution nozzle except for three nozzles in each deck of the north side of the tower because they were located in warped floorboards of the distribution deck. The warped boards caused the nozzles to protrude above the surface of the water.
8:35 a.m.	Discussion with Manager of Facilities Engineering to divert some water from top of HVAC tower to cold water well until it does not overflow the distribution deck. The Manager of Facilities Engineering confers with the Power House Supervisor; they will reduce flow to top as long as the cold water basin temperature does not exceed 85°F.
9:00 a.m.	The Power House Shift Lead shows us the "hot well" and discusses the operation of the pumps. Some process water returns to this tank before being pumped back to the process tower. Four pumps are activated by a level controller. The level in the tank is constantly changing. Currently, two pumps are operating at 630 gal/min each, and the tank level is decreasing very slowly. However, the inlet flow rate is dependent on the process cooling needed and is not constant. The Shift Lead indicates that two pumps are usually on, and a third pump (also 630 gal/min) is activated when the level gets a little higher. Seldom are all four pumps used at once.
	The changing level adds an accumulation term to the mass balance. However, it is decided to measure the concentration and level at the start and end of each run so it can be considereed for the mass balance.
	From engineering drawings, the tank is a 12-ft x 20-ft cylinder with a 16,200-gallon capacity. An 18-inch neck on the tank allows measurement of the distance from the water level to the neck. Subtracting that distance from 12 feet gives the level in the tank.
9:30 a.m.	Two in-line blowdown flowmeters are in place for each tower. Direct readout in gallons.
10:00 a.m.	Head pressure in chillers is too high because cold basin temperature is exceeding 85°F, according to the Power House Supervisor. After inspecting the distribution deck of the HVAC tower, it is discovered that the water is only about 3 in. deep. Because this level can be raised to about 6 in. without overflowing the distribution deck, we agree to increase flow to the top until it is to the brim of the distribution deck and observe the temperature. The final level that achieves an acceptable basin temperature for HVAC operation and does not overflow onto the fan deck is about 0.25 to 0.50 in. higher than the outboard plank of the distribution deck. Therefore, some water is overflowing the outboard edge, but it is not splashing outside the tower to the ground because the louvers redirect this flow back toward the fill.
10:45 a.m.	Because water level is relatively high again; water near the header outlet is bubbling up through the cracks between the plywood boards placed over the distribution box to control header splashing. It is worst on the north side of Cell B. The water spills under the fan stack, causing "rain" inside the cooling tower. We reduce water flow, dry the area, and caulk the space between the plywood boards on this cell. This stops the leak, and the water remains at the 6-in.-deep level established previously.
11:00 a.m.	Pretest temperatures show that the HVAC tower basin is at 84°F and the return water is 90°F.
12:00 noon	HVAC basin temperature is now 84.5°F. The return water is still 90°F.
12:40 p.m.	HVAC basin temperature is now 85°F. The return water is steady at 90°F.
1:30 p.m.	Approximate start time for Run No. 1. No "rain" in any of the four cells.
3:00 p.m.	No "rain" in any of the four cells.
3:40 p.m.	The first smoke test is observed. Smoke canister is held on the downwind side of Cell A stack rim. The smoke does not enter the plume very well but does not appear to be recirculating much at all.

TABLE C-6. (continued)

4:30 p.m.	Approximate end-of-run time for Run No. 1. The hot well has fallen from 69.25 in. below the neck to 73.5 in. below the neck with two pumps on. No "rain" in any of the four cells.
Run No. 2 (July 14, 1987)	
7:30 a.m.	Mass balance results show a lot of missing chrome, almost 3 lbs per hour for HVAC tower and 0.8 lbs per hour for the process tower. Is Cr^{+6} plating out this quickly? Is Cr^{+6} being reduced to Cr^{+3}? Should duplicate samples be taken?
8:00 a.m.	From yesterday's data, the process tower has an approximate liquid-to-gas ratio of 0.5 (thus, the low depth in the cell yesterday). This is not common for most process cooling towers. Will it affect the drift rate? The 4G ratio for the HVAC tower is approximately 1.8, which is on the upper end of the range typical for HVAC tower operation. In a meeting between Ron Myers, Bruce Nicholson, Dan Bivins, and Bill DeWees, the possible effects of L/G ratios on the emissions were discussed. Both towers are operating at opposite extremes of normal design L/G ratios. The process tower L/G ratio is especially low when the water is distributed in both cells. Although we agree that there is little possibility of changing the water flow of the HVAC tower, we decide to explore with the plant the possibility of diverting the water flow of the process tower into a single cell.
8:20 a.m.	We discuss the possibility of diverting all of the flow into one cell with the Power House Supervisor. He says they normally run the tower that way in the winter to minimize ice buildup, and he could run it that way for our tests if we want. We will keep tower as is for now but consider diverting flow for a later run and compare the different emission rates. We will also consult J. D. Holmberg of Marley Cooling Tower Company to see if L/G has an effect on drift rate and whether we should be concerned with the low water depth of the process tower.
8:35 a.m.	Temperatures as read from the gauges in the chiller plant appear to be somewhat erroneous because they equal the wet bulb temperature. A mercury thermometer dipped in the basin as a check reads 75.5°F, whereas the chiller plant temperature gauge reads 74°F.
9:00 a.m.	As a result, we decide to obtain three more thermometers at a local hardware store. A calibration check of the purchased alcohol-in-glass thermometers shows that two measure the same temperature as the EMB mercury-in-glass thermometer. The remaining thermometer is adjusted in its holder so that it reads the same as the EMB mercury-in-glass thermometer. Thus, one of the new thermometers is placed in the distribution deck of each tower, and the mercury thermometer is used to measure the basin temperatures.
9:15 a.m.	Approximate run start time.
11:15 a.m.	New thermometers are in place and will be used for the remainder of the test runs.
12:00 noon	Discussion with J. D. Holmberg to determine if the low flow rate in the process tower will affect the drift results. Holmberg says that L/G has had little or no effect on their drift tests using the isokinetic heated- bead sampler followed by a particulate filter. They report drift on a concentration basis in ppm (which can be easily converted to $\mu g/m^3$). He explained that there is an optimum air velocity through the drift eliminator at which drift is a minimum. Using the airflow rates and drift eliminator sizes, he calculated that the velocity through the fill in both towers is just under 400 ft/min, and, therefore, the towers should be comparable in emissions if they had the same drift eliminators installed. At this velocity, both drift eliminators should be operating near optimum. He would be concerned about the drift results if some nozzles in the distribution deck were dry (which is not the case for the process tower). This would cause uneven water distribution. The L/G ratio for the process tower is 0.5. This is very low according to Holmberg. If we did divert all of the water to one cell and raise the L/G to approximately 1.0, the tower would be more representative of the industry average, which is between 1.0 and 2.0. It should also not affect the cooling range too much. Based on this information, we decide to divert the flow from Cell D into Cell C for the next test run this afternoon. This will allow us to independently evaluate the effects of L/G ratio on emissions.
12:15 p.m.	Approximate end-of-run time.
1:00 p.m.	The water to Cell D is shut off. The entire flow is diverted to Cell C. The water level rises from 0.75 in. to 4.5 in. The tower basin is 76°F.
2:30 p.m.	Sudden rain shower starts. Hard rain for 20 minutes.
3:00 p.m.	Rain ends--temperature in basin of process tower has equilibrated at 78°F.

TABLE C-6. (continued)

Run No. 3 (July 14, 1987)	
4:00 p.m.	Approximate run start time. Basin temperatures remain steady throughout test. No "rain" is seen inside either tower.
7:00 p.m.	Approximate end-of-run time. Diverted flow back to both cells.
Run No. 4 (July 15, 1987)	
7:45 a.m.	While the results of run No. 3 are analyzed, the runs today will be with flow in both cells. Therefore, four runs will have flow in both cells, and four runs will have flow in a single cell. This type of test will determine the effects of L/G using the EPA test method and may be valuable data for setting the format of the standard. Condition of towers: HVAC--only one pump out of two is running and the water level of distribution deck is about 0.75 to 1 in. The tower is at half flow rate because of the low cooling demand this morning. Process--fan in Cell C on low, fan in Cell D on high.
8:30 a.m.	Plant personnel start pump No. 2 to HVAC tower at our request. Also set fan on Cell C to high and D to low because testing is on Cell C today.
9:00 a.m.	Approximate start time. No "rain" in either tower.
10:50 a.m.	Blowdown flowmeters for process tower stop functioning. Plastic parts inside have broken. Plant personnel indicate they could stop the blowdown on the process tower for the remainder of the test week without any problem. Blowdown is stopped for the remainder of the run for the process tower only. Entropy orders four new flowmeters for the long-term mass balance test.
12:00 noon	Approximate end-of-run time.
12:30 p.m.	Plant personnel provide information about the chromate treatment system. The process adds acid gas to the wastewater to take pH down to approximately 2. The mixture is then neutralized in a separate tank at pH 9. Diatomaceous earth is added as a filler to the precipitate in a mixing tank. The slurry is filter-pressed into cake and packaged into 55-gallon drums for removal from the plant. The plant handles up to 30 gal/min, and the waste cake fills approximately 200 drums annually.
Run No. 5 (July 15, 1987)	
2:45 p.m.	Approximate run start time. This run is with zero blowdown for process tower and normal blowdown for the HVAC tower. Have switched cells for testing from A and C to B and D. Process tower has water flow in both cells evenly distributed and both fans are on high.
3:35 p.m.	Plant personnel inadvertently switch fan in Cell D to low because the basin temperature is less than 72°F. We correct by having plant personnel put Cell C on low and put Cell D back on high.
5:45 p.m.	Approximate end-of-run time.
6:45 p.m.	Turned blowdown off for both towers and will try to determine the mass balance overnight. Removing the blowdown variable may help.
Run No. 6 (July 16, 1987)	
7:45 a.m.	Pretest observations: Lower heat demand this morning than previous mornings because it is cooler today. HVAC tower--only one chiller is running, but both pumps are running. Cell C is on low fan and Cell D fan is off (process tower). Equal water levels in both cells.
8:10 a.m.	Diverted water flow in Cell C to Cell D (test cell). Put fan in Cell D on high speed and fan in Cell C off. Water going into basin is 70.5°F. This is too low for the process to handle. After conferring with the Shift Lead, he adds heat to the system by bypassing some of the returning process water from an initial cooling heat exchanger. This raises the distribution deck temperature 5°F. The basin temperature is 77°F.
8:30 a.m.	Approximate run start time. Just before test is started, the fan in Cell C also is put on high.
10:00 a.m.	"Rain" inside Cell D is noticed. Droplets forming on structural members.

TABLE C-6. (continued)

10:30 a.m.	"Rain" is now much worse especially at north side of cell. A running leak is seen coming from seal around a conduit for a fire sprinkler. Ron tries to take picture of it, but there is not enough light. Decide to continue run but note the occurrence, then repair the leak with caulk before the next run.
11:30 a.m.	Approximate end-of-run time.
Run No. 7 (July 16, 1987)	
2:00 p.m.	Caulk in place to stop leak in Cell D. Cell is refilled and checked. No leaks seen. This run is made with zero blowdown and flow for process tower in Cell D only.
2:30 p.m.	Approximate run start time. No leaks seen; no "rain" inside cooling tower.
4:10 p.m.	Leak discovered on HVAC tower when test crew sees droplets coming from stack. Water leaked around electrical conduit where it went through the vertical distribution deck plank. Originally, the water was prevented from leaking around the conduit by some duct tape that was stuffed between the conduit and the plank. Water dripped through deck into cooling tower internals bypassing the drift eliminator. The water level in that cell is lowered about 1 in., the leak is caulked, and the water level is raised back to original level. It is estimated by the test crew that the leak was present for 10 minutes during the run before being repaired.
4:30 p.m.	No "rain" seen in either tower.
5:30 p.m.	Approximate end-of-run time.
Run No. 8 (July 17, 1987)	
6:45 a.m.	Both towers show visible condensate plumes. Process tower plume is heavier. Previous days, only the process tower had a visible plume.
7:00 a.m.	HVAC tower: Only one pump running--low flow in both cells. Fan in Cell B running; fan in Cell A is off. Process tower: Fan in Cell C is on low speed, and fan in Cell D is off. All water flow is diverted to Cell D.
	The ground beneath the tower overhang is slightly wet from water droplets splashing out through the louvers. This occurs only when the fan is off or on low speed.
7:45 a.m.	Plant personnel put both pumps on for HVAC tower, and fan in Cell D on high speed. What appears to be diesel smoke from a generator 120 ft upwind of the process tower is drawn into tower.
8:00 a.m.	Approximate run start time. Smoke from diesel generator has stopped.
8:45 a.m.	No leaks seen; however, structural members in both towers seem wetter today than yesterday. Drops form on bottom of structural member, and, occasionally, one falls. All drops except those formed at the very top of the tower appear to fall into the basin. Those formed at the top appear to fall if they are heavy enough; otherwise they are drawn out the top of the stack. In both towers, it is estimated that two to three drops exit per second. A slight mist can be seen coming through the herringbone eliminators in the process tower.
10:15 a.m.	HVAC tower still shows wet structural members. Process tower has wet members too, and droplets are streaming off upper level members at a high rate.
11:00 a.m.	No leaks seen. Approximate end-of-run time.

TABLE C-7. SUMMARY OF OPERATING PARAMETERS AND METEOROLOGICAL DATA DURING TESTS AT THE NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY, GAITHERSBURG, MARYLAND (SECOND TEST)

Parameter	Day No. 1	Day No. 2	Day No. 3	Day No. 4
Date	July 9, 1990	July 10, 1990	July 11, 1990	July 12, 1990
Run Nos.	2-1, 2-2, 3-1, 3-2	2-3, 2-4, 1-1, 1-2	2-5, 2-6, 3-3, 3-4	2-7, 2-8, 4-1, 4-2
Recirculation rate per cell, L/min (gal/min)	26,659 (7,042)	22,557 (5,959)	22,448 (5,938)	22,413 (5,921)
Fan speed	high	high	high	high
Meteorological data				
Time	1450-2030	0930-1900	0930-1630	0900-1630
Barometric pressure, mm Hg (in. Hg)	752-752 (29.61-29.62)	753.6-751.6 (29.67-29.59)	753.6-753.6 (29.67-29.67)	752.1-750.8 (29.61-29.56)
Dry bulb temperature, °C (°F)	37-26 (98-78)	27-31 (80-88)	29-22 (85-71)	23-22 (73-72)
Relative humidity, percent	46-84	74-63	59-87	94-94
Wind direction	180-225	315-225	270	225
Wind speed, m/sec (ft/sec)	5.7-3.6 (18.6-11.8)	3.6-5.1 (11.8-16.9)	3.6-3.1 (11.8-10.1)	2.6-2.6 (8.4-8.4)

TABLE C-8. SUMMARY OF OPERATING PARAMETERS AND METEOROLOGICAL DATA DURING TESTS AT ALLIED FIBERS, MONCURE, NORTH CAROLINA

Date	Run Nos.	Time	Recirculation rate,		Temperature,		Barometric pressure,		Wind speed		Wind direction
			L/min	gal/min	°C	°F	mm Hg	in Hg	m/sec	ft/sec	(0-360)
1/18/91	6, 7, 8	10:15	3,099	819	7.7	45.9	759.7	29.91	2.4	7.9	252
		11:15	2,545	673	11.4	52.5	759.5	29.90	3.4	11.3	257
		12:15	2,531	669	12.4	54.3	758.4	29.86	6.0	19.8	285
		13:15	2,460	650	13.3	55.9	757.9	29.84	5.4	17.8	297
		14:15	2,498	660	13.9	57.0	758.2	29.85	4.7	15.6	294
		15:15	2,508	663	14.1	57.3	758.2	29.85	5.7	18.8	294
1/21/91	9,10,11,12	11:15	3,208	848	8.4	47.1	750.3	29.54	5.1	16.9	299
		12:15	3,160	835	8.5	47.3	750.3	29.54	4.3	14.2	324
		13:15	3,208	848	8.3	46.9	750.1	29.53	5.0	16.3	299
		14:15	3,198	845	7.8	46.1	749.8	29.52	5.2	17.2	310
		15:15	3,236	855	7.3	45.2	750.3	29.54	4.6	15.3	302
		16:15	3,189	843	6.8	44.3	750.8	29.56	4.3	14.1	295
1/22/91	13,14,15,16	10:45	3,383	894	-0.9	30.3	758.4	29.86	3.9	12.8	331
		11:45	--	--	-0.3	31.4	758.4	29.86	2.9	9.4	322
		12:45	3,293	870	0.6	33.0	758.2	29.85	3.6	11.9	341
		13:45	3,217	850	1.0	33.8	757.7	29.83	3.0	9.8	295
		14:45	3,255	860	1.4	34.5	757.7	29.83	2.6	8.7	313
		15:45	3,075	813	1.6	34.9	757.9	29.84	2.5	8.1	323
1/23/91	17,18,19,20	10:15	3,194	844	1.9	35.5	760.5	29.94	3.4	11.0	189
		11:15	3,198	845	4.6	40.3	760.2	29.93	3.3	10.7	227
		12:15	3,123	845	5.9	42.7	759.2	29.89	4.5	14.7	241
		13:15	3,028	800	6.9	44.4	758.4	29.86	4.1	13.3	239
		14:15	3,028	800	7.9	46.2	757.4	29.82	3.7	12.0	232
		15:15	--	--	8.6	47.5	756.9	29.80	3.8	12.5	245

TABLE C-9. SUMMARY OF EMISSION TEST RESULTS--DEPARTMENT OF ENERGY'S GASEOUS DIFFUSION PLANT, PADUCAH, KENTUCKY

Data/Units	Run No.[a]							
	4-(8,7)-1	4-(7,8)-2	4-(7,8)-6	5-(10,9)-3	5-(9,10)-4	5-(10,9)-5	6-(12,11)-3	6-(11,12)-4
General								
Date	6/24/86	6/24/86	6/26/86	6/25/86	6/25/86	6/26/86	6/25/86	6/25/86
Start time	09:25	12:58	13:12	09:15	12:22	08:25	09:14	12:22
Sampling period, min	120	120	120	120	120	120	120	120
Isokinetic ratio, percent	98.5	97.9	97.3	98.5	99.3	98.2	95.3	98.9
Cell recirculation rate, L/min (gal/min)	15,370 (4,061)	15,370 (4,061)	15,370 (4,061)	15,525 (4,102)	15,525 (4,102)	15,525 (4,102)	16,331 (4,315)	16,331 (4,315)
Barometric pressure, mm Hg (in. Hg)	753.36 (29.66)	753.36 (29.66)	754.89 (29.72)	755.65 (29.75)	755.65 (29.75)	754.89 (29.72)	755.65 (29.75)	753.36 (29.66)
CR^{+6} concentration in cooling water, ppm	7.97	7.99	8.62	8.04	7.64	8.52	8.09	8.09
Gas stream								
Temperature, °C (°F)	38 (100)	40 (104)	41 (106)	41 (105)	41 (106)	39 (102)	30 (86)	34 (93)
Moisture, percent by volume	6.5	7.3	7.8	7.5	7.8	6.9	4.2	5.3
Flow rate, m^3/min (acfm)	17,289 (610,553)	17,591 (621,217)	16,359 (577,715)	17,517 (618,599)	16,898 (596,746)	17,411 (614,870)	16,140 (569,966)	14,287 (504,534)
Flow rate, dsm^3/min (dscfm)	15,104 533,384	15,129 (534,290)	13,976 (493,548)	15,054 (531,616)	14,452 (510,363)	15,124 (534,108)	14,863 (524,892)	12,806 (452,235)
CR^{+6} emissions measured by Method-13 x 10^6[c]								
Concentration, mg/dsm^3 (gr/dscf)	>385 (>0.168)	>612 (>0.267)	>1,040 (>0.456)	>439 (>0.192)	>877 (>0.384)	>268 (>0.117)	>748 (>0.327)	>145 (>0.063)
Emissions, kg/hr (lb/hr)	>344 (>759)	>544 (>1,200)	>853 (>1,880)	>391 (>862)	>756 (>1,670)	>239 (>528)	>637 (>1,400)	>110 (>242)
Total chromium emissions measured by Method-13 x 10^6								
Concentration, mg/dsm^3 (gr/dscf)	>386 (>0.169)	>618 (>0.270)	>1,050 (>0.460)	>478 (>0.209)	>929 (0.406)	>272 (>0.119)	>757 (>0.331)	>145 (>0.063)
Emissions, kg/hr (lb/hr)	>345 (>760)	>549 (>1,210)	>859 (>1,890)	>426 (>939)	>801 (>1,770)	>242 (>534)	>644 (>1,420)	>110 (>243)
Total chromium emissions measured by absorbent paper x 10^6								
Emission, kg/hr (lb/hr)	343 (756)	345 (761)	1,140 (2,510)	828 (1,830)	1,066 (2,350)	1,058 (2,330)	142 (313)	442 (974)

[a]The run No. identifies the riser cell, fan stack(s) and test series, respectively.
[b]Emissions results for these runs were not included in the averages because the recirculating water flow rates were less than 90 percent of the design flow rates. In addition, during run No. 7- (14,13)-1 water was leaking through the side of the distribution deck and running down the fan-side of the drift eliminator.
[c]Because of analysis error, a fraction of the CR^{+6} was not analyzed in these samples. Therefore, the emissions are presented with "greater than" symbols.

TABLE C-9. (continued)

Data/Units	Run No.[a]							
	6-(2,11)-5	7-(14,13)-1[b]	7-(14,14)-2[b]	7-(14,13)-6	7-(14-13)-7	7-(13-14)-8	7-(14)-9	7-(13)-9
General								
Date	6/26/86	6/24/86	6/24/86	6/26/86	6/27/86	6/27/86	6/27/86	6/27/86
Start time	08:25	09:24	13:02	13:12	09:23	08:29	11:14	11:10
Sampling period, min	120	120	120	120	120	120	60	60
Isokinetic ratio, percent	101.3	95.7	96.6	102.5	95.4	99.3	96.1	98.8
Cell recirculation rate, L/min (gal/min)	16,331 (4,315)	13,709 (3,622)	13,709 (3,622)	15,760 (4,164)	15,760 (4,164)	15,760 (4,164)	15,760 (4,164)	15,760 (4,164)
Barometric pressure, mm Hg (in. Hg)	754.9 (29,72)	753.4 (29.66)	753.4 (29.66)	754.9 (29.72)	754.9 (29.72)	754.9 (29.72)	754.9 (29.72)	754.9 (29.72)
CR^{+6} concentration in cooling water, ppm	8.52	7.99	7.99	8.50	8.32	8.29	8.29	8.32
Gas stream								
Temperature, °C (°F)	34 (93)	32 (89)	35 (95)	34 (94)	38 (101)	31 (87)	40 (104)	36 (96)
Moisture, percent by volume	5.3	4.6	5.6	5.4	6.7	4.3	7.2	5.8
Flow rate, M^3/min (acfm)	15,477 (546,571)	17,463 (616,712)	15,191 (536,468)	14,779 (521,901)	14,580 (590,275)	14,129 (457,448)	14,402 (589,771)	11,837 (470,411)
Flow rate, dsm^3/min (dscfm)	13,903 (490,960)	15,885 (560,981)	13,520 (477,453)	13,234 (467,373)	16,715 (514,891)	12,954 (498,942)	16,701 (508,593)	13,320 (418,032)
CR^{+6} emissions measured by Method-13x 10^{6o}								
Concentration, mg/dsm^3 (gr/dscf)	>332 (>0.145)	>2,656 (>1.161)	>229 (>0.100)	>452 (>0.198)	>406 (>0.178)	>422 (>0.185)	>599 (>0.262)	>469 (>0.205)
Emissions, kg/kr (lb/hr)	>281 (>620)	>2,427 (>5,351)	>180 (>397)	>369 (>813)	>340 (>750)	>327 (>721)	>498 (>1,100)	>329 (>726)
Total chromium emissions measured by Method-13 x 10^6								
Concentration, mg/dsm^3 (gr/dscf)	>335 (>0.146)	>2,668 (>1.166)	>230 (>0.101)	>455 (>0.199)	>409 (>0.179)	>425 (>0.186)	>602 (>0.263)	>471 (0.206)
Emissions, kg/hr (lb/hr)	>283 (>624)	>2,438 (>5,375)	>181 (>399)	>371 (>818)	>342 (>755)	>329 (>724)	>501 (>1,100	>331 (>730)
Total chromium emissions measured by absorbent paper x 10^6								
Emissions, kg/hr (lb/hr)	510 (1,124)	132 (291)	51 (112)	111 (245)	93 (205)	95 (209)	157 (346)	75 (165)

TABLE C-10. SUMMARY OF EMISSION TEST RESULTS--NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY GAITHERSBURG, MARYLAND (FIRST TEST)

Data/Units	Run No.[a]							
	A1	A2	B1	B2	C1	C2	D1	D2
General								
Date	8/19/86	8/19/86	8/20/86	8/20/86	8/21/86	8/21/86	8/22/86	8/22/86
Start time	09:59	12:47	09:45	12:10	09:19	11:43	9:23	12:05
Sampling period, min	120	120	120	120	120	120	120	120
Isokinetic ratio, percent	101	101.9	100.5	100.1	99.4	99.2	98.8	99.6
Cell recirculation rate, L/min (gal/min)	34,165 (9,027)	34,165 (9,027)	34,423 (9,095)	34,423 (9,095)	34,419 (9,094)	34,419 (9,094)	33,832 (8,939)	33,832 (8,939)
Barometric pressure, mm Hg (in. Hg)	762.00 (30.00)	762.00 (30.00)	764.54 (30.10)	764.54 (30.10)	764.5 (30.1)	764.5 (30.1)	767.1 (30.2)	767.1 (30.2)
Cr^{+6} concentration in cooling water, ppm	16.90	17.00	17.20	17.50	17.20	17.20	18.20	18.10
Gas stream								
Temperature, °C (°F)	26.5 (79.7)	27.9 (82.2)	25.2 (77.4)	26.4 (79.5)	24.4 (76.0)	24.3 (75.8)	24.7 (76.5)	25.6 (78.1)
Moisture, percent by volume	3.40	3.66	3.07	3.38	2.99	2.97	2.98	3.18
Flow rate, m^3/min (acfm)	18,680 (659,700)	18,680 (659,721)	20,895 (737,918)	21,794 (769,652)	19,377 (684,281)	19,341 (683,083)	20,682 (730,358)	20,196 (713,213)
Flow rate, dsm^3/min (dscfm)	17,698 (625,018)	17,570 (620,448)	20,014 (706,771)	20,726 (731,919)	18,624 (657,695)	18,603 (656,943)	19,928 (703,747)	19,361 (683,716)
Cr^{+6} emissions measured by Method-13 $x10^6$								
Concentration, mg/dsm^3 (gr/dscf)	606 (0.265)	4,207 (1.838)	575 (0.251)	285 (0.125)	568 (0.248)	2,647 (1.157)	375 (0.164)	448 (0.196)
Emissions, kg/hr (lb/hr)	650 (1,432)	4,521 (9,958)	694 (1,530)	355 (781)	631 (1,391)	2,930 (6,454)	443 (975)	518 (1,141)

TABLE C-10. (continued)

Data/Units	Run No.[a]							
	A1	A2	B1	B2	C1	C2	D1	D2
Total chromium emissions measured by Method-13 x10^6								
Concentration, mg/dsm^3 (gr/dscf)	606 (0.265)	4,208 (1.838)	576 (0.252)	285 (0.125)	569 (0.248)	2,649 (1.157)	375 (0.164)	448 (0.196)
Emissions, kg/hr (lb/hr)	650 (1,432)	4,521 (9,958)	695 (1,532)	355 (782)	632 (1,391)	2,932 (6,458)	443 (976)	519 (1,142)
Total chromium emissions measured by absorbent paper x10^6								
Emissions, kg/hr (lb/hr)	86.6 (191)	62.4 (138)	18.6 (41.0)	40.7 (89.7)	90.7 (200)	89.6 (198)	76.2 (168)	12.5 (27.6)

[a]The run No. identifies the cell number and test series, respectively.

TABLE C-11. SUMMARY OF EMISSION TEST RESULTS FOR TOWER 68 AT EXXON'S REFINERY, BAYTOWN, TEXAS

Data/Units	Run No.[a]						
	CT-68-1-1	CT-68-2-1	CT-68-3-1	CT-68-4-1	CT-68-5-1	CT-68-5-2	CT-68-5-3
General							
Date	9/1/86	9/1/86	9/2/86	9/2/86	9/1/86	9/1/86	9/2/86
Start time	14:17	14:17	09:33	12:29	10:50	14:00	10:33
Sampling period, min	120	120	120	120	120	120	120
Isokinetic ratio, percent	104.0	99.7	104.9	103.6	102.9	102	102.8
Cell recirculation rate, L/min (gal/min)	15,870 (4,193)	13,288 (3,511)	13,288 (3,511)	15,870 (4,193)	27,089 (7,157)	27,089 (7,157)	27,089 (7,157)
Barometric pressure, mm Hg (in. Hg)	768.35 (30.25)	768.35 (30.25)	767.1 (30.2)	767.08 (30.20)	768.35 (30.25)	768.35 (30.25)	767.08 (30.20)
Cr^{+6} concentration in cooling water, ppm	7.64	7.58	7.45	7.33	7.44	7.82	7.65
Gas stream							
Temperature, °C (°F)	28.9 (84.1)	30.8 (87.5)	33.2 (91.8)	31.7 (89.0)	30 (86)	31.7 (89.1)	30.7 (87.3)
Moisture, percent by volume	3.90	4.34	4.98	4.57	4.14	4.57	4.32
Flow rate, m^3/min (acfm)	9,604 (339,149)	8,463 (298,864)	9,307 (328,656)	&9,038 (319,185)	26,143 (923,231)	27,880 984,581)	27,557 (962,591)
Flow rate, dsm^3/min (dscfm)	9,055 (319,790)	7,894 (278,777)	8,541 (301,626)	8,732 (295,673)	24,505 (865,368)	25,868 (913,507)	25,396 (896,828)
Cr^{+6} emissions measured by Method-13 $x10^6$							
Concentration, mg/dsm^3 (gr/dscf)	44,356 (19.380)	8,713 (3.8070)	983 (0.4293)	528 (0.2305)	38,691 (16.9051)	3,542 (1.5476)	1,628 (0.7111)
Emissions, kg/h (lb/h)	9,055 (55,192)	4,115 (9,063)	528 (1,163)	275 (605)	58,562 (128,991)	5,606 (12,348)	2,548 (5,613)

TABLE C-11. (continued)

Data/Units	Run No.[a]						
	CT-68-1-1	CT-68-2-1	CT-68-3-1	CT-68-4-1	CT-68-5-1	CT-68-5-2	CT-68-5-3
Total chromium emissions measured by Method-13 x10^6							
Concentration, mg/dsm^3 (gr/dscf)	44,486 (19.437)	8,713 (3.807)	991 (0.433)	528 (0.231)		3,308 (1.445)	1,628 (0.711)
Emissions, kg/h (lb/h)	25,131 (55,355)	4,115 (9,063)	533 (1,174)	275 (605)	58,562 (128,991)	5,235 (11,531)	2,548 (5,613)
Total chromium emissions measured by absorbent paper x10^6							
Emissions, kg/h (lb/h)	149.4 (329)	79.8 (176)	136.8 (302)	144.9 (319)	175.1 (386)	145.6 (321)	-- (--)

[a]The run No. identifies the cooling tower, cell number, and test series, respectively.

TABLE C-12. SUMMARY OF EMISSION TEST RESULTS FOR TOWER 84 AT EXXON'S REFINERY BAYTOWN, TEXAS

Data/Units	Run No.[a]							
	CT-84-A-1	CT-84-A-2	CT-84-B-1	CT-84-B-2	CT-84-C-1	CT-84-C-2	CT-84-D-1	CT-84-D-2
General								
Date	9/4/86	9/4/86	9/5/86	9/5/86	9/4/86	9/4/86	9/5/86	9/5/86
Start time	9:50	12:30	08:50	11:30	9:53	12:24	08:35	11:04
Sampling period, min	120	120	120	120	120	120	120	120
Isokinetic ratio, percent	109.5	111.5	105.9	107.7	106.1	106.8	102.5	104.0
Cell recirculation rate, L/min (gal/min)	19,098 (5,046)	19,098 (5,046)	20,135 (5,320)	20,135 (5,320)	22,913 (6,054)	22,913 (6,054)	23,008 (6,079)	23,008 6,079
Barometric pressure, mm Hg (in. Hg)	770.89 (30.35)	770.89 (30.35)	768.35 (30.25)	768.35 (30.25)	770.89 (30.35)	770.89 (30.35)	768.35 (30.25)	768.35 (30.25)
Cr^{+6} concentration in cooling water, ppm	8.19	8.33	8.33	8.68	8.17	8.47	8.05	8.71
Gas stream								
Temperature, °C (°F)	33.1	31.0	32.6	32.6	34.1	33.5	32.4	33.7
	(91.5)	(87.9)	(90.6)	(90.8)	(93.4)	(92.4)	(90.3)	(92.7)
Moisture, percent by volume	4.92	4.38	4.79	4.81	5.21	5.04	4.75	5.11
Flow rate, m^3/min (acfm)	17,305	17,659	18,070	18,720	16,598	16,567	15,859	14,470
	(611,105)	(620,455)	(638,138)	(661,075)	(585,805)	(585,069)	(560,063)	(511,002)
Flow rate, dsm^3/min (dscfm)	15,978	16,423	16,679	17,271	15,254	15,290	14,689	13,295
	(564,258)	(579,964)	(589,016)	(609,927)	(538,701)	(539,977)	(518,718)	(469,513)
Cr^{+6} emissions measured by Method-13 $x10^6$								
Concentration, mg/dsm^3 (gr/dscf)	4,042	389	650	205	8,665	373	232	11,927
	(1.7660)	(0.1700)	(0.2841)	(0.0896)	(3,787)	(0.163)	(0.1014)	(5.2113)
Emissions, kg/hr (lb/hr)	4,244	427	689	229	8,418	365	210	9,898
	(9,348)	(941)	(1,519)	(504)	(18,558)	(804)	(462)	(21,801)
Total chromium emissions measured by Method-13 $x10^6$								
Concentration, mg/dsm^3 (gr/dscf)	4,065 (1.776)	402 (0.175)	652 (0.285)	206 (0.090)	8,993 (3.930)	375 (0.164)	234 (0.102)	11,957 (5.224)
Emissions, kg/hr (lb/hr)	4,269 (9,402)	441 (972)	691 (1,522)	230 (506)	8,737 (19,262)	368 (811)	211 (466)	9,923 (21,856)

TABLE C-12. (continued)

Data/Units	Run No.[a]							
	CT-84-A-1	CT-84-A-2	CT-84-B-1	CT-84-B-2	CT-84-C-1	CT-84-C-2	CT-84-D-1	CT-84-D-2
Total chromium emissions measured by absorbent paper x10^6								
Emissions, kg/hr (lb/hr)	68.7 (151)	-- (--)	126.6 (279)	-- (--)	50.6 (112)	-- (--)	46.8 (103)	-- (--)
Total chromium emissions measured by ion exchange paper x10^6								
Emissions, kg/hr (lb/hr)	-- (--)	-- (--)	-- (--)	132.9 (293)	-- (--)	48.8 (107)	-- (--)	53.1 (117)

TABLE C-13. SUMMARY OF EMISSION TEST RESULTS--SOUTHEASTERN MANUFACTURING FACILITY

Data/Units	Run No.[a]					
	IA-IMP-1	IA-IMP-2	1-A-CTI	1-C-IMP-1	1-C-IMP-2	IC-CTI
General						
Date	7/13/87	7/13/87	7/13/87	7/13/87	7/13/87	7/13/87
Start time	1:35	1:35	1:41	1:30	1:35	1:35
Sampling period, min	180	180	173	180	180	170
Isokinetic ratio, percent	104.8	102.8	95.6	96.5	90.5	97.5
Cell recirculation rate, L/min (gal/min)	16,699 (4,412)	16,699 (4,412)	16,699 (4,412)	9,568 (2,528)	9,568 (2,528)	9,568 (2,528)
Barometric pressure, mm Hg (in. Hg)	742.19 (29.22)	742.19 (29.22)	742.19 (29.22)	742.19 (29.22)	742.19 (29.22)	742.19 (29.22)
Cr^{+6} concentration in cooling water, ppm	193-201	193-201	193-201	103-112	103-112	103-112
Gas stream						
Temperature, °C (°F)	32 (90)	33 (91)	32 (90)	29 (84)	29 (84)	29 (84)
Moisture, percent by volume	1.85	1.90	1.29	1.75	2.02	1.33
Flow rate, m^3/min (acfm)	9,063 (320,000)	10,000 (353,000)	10,240 (362,000)	17,105 (604,000)	17,247 (609,050)	18,450 (651,480)
Flow rate, dsm^3/min (dscfm)	8,342 (295,000)	9,183 (324,000)	9,473 (335,000)	15,940 (562,900)	16,023 (565,800)	17,222 (608,200)
Cr^{+6} emissions measured by Method-13 $x10^6$						
Concentration, mg/dsm^3 (gr/dscf)	2,007 (0.877)	3,055 (1.335)	4,122 (1.801)	1,677 (0.733)	3,363 (1.469)	1,780 (0.788)
Emissions, kg/hr (lb/hr)	1,004 (2,214)	1,683 (3,710)	2,343 (5,165)	1,603 (3,534)	3,232 (7,126)	1,839 (4,053)
Total chromium emissions measured by Method-13 $x10^6$						
Concentration, mg/dsm^3 (gr/dscf)	20,075 (8.77)	41,268 (18.0)	37,134 (16.2)	37,835 (16.531)	19,004 (8.303)	33,035 (14.434)
Emissions, kg/hr (lb/hr)	10,045 (22,146)	22,736 (50,125)	21,103 (46,525)	36,179 (79,760)	18,267 (40,271)	34,131 (75,245)

[a]The run No. identifies the cell number and test series respectively.

TABLE C-13. (continued)

Data/Units	Run No.[a]					
	IC-ALG	1-C-BKW	2A-IMP-1	2A-IMP-2	2-A-CTI	2C-IMP-1
General						
Date	7/13/87	7/13/87	7/14/87	7/14/87	7/14/87	7/14/87
Start time	1:35	1:35	9:10	9:10	9:20	9:14
Sampling period, min	180	180	180	180	162	180
Isokinetic ratio, percent	93.2	99.4	99.4	97.9	103.7	103.5
Cell recirculation rate, L/min (gal/min)	9,568 (2,528)	9,568 (2,528)	15,881 (4,196)	15,881 (4,196)	15,881 (4,196)	9,591 (2,534)
Barometric pressure, mm Hg (in. Hg)	742.19 (29.22)	742.19 (29.22)	742.19 (29.22)	742.19 (29.22)	744.22 (29.30)	744.22 (29.30)
Cr^{+6} concentration in cooling water, ppm	103-112	103-112	177-191	177-191	177-191	96-102
Gas stream						
Temperature, °C (°F)	29 (85)	29 (85)	28 (83)	29 (84)	28 (82)	25 (78)
Moisture, percent by volume	3.70	3.76	3.20	2.95	2.57	2.81
Flow rate, m^3/min (acfm)	17,460 (616,600)	17,440 (615,900)	9,482 (334,800)	10,290 (363,300)	10,100 (356,700)	16,575 (585,350)
Flow rate, dsm^3/min (dscfm)	15,910 (561,800)	15,880 (560,900)	8,722 (308,000)	9,468 (334,400)	9,383 (331,400)	15,492 (547,100)
Cr^{+6} emissions measured by Method-13 $x10^6$						
Concentration, mg/dsm^3 (gr/dscf)	1,947 (0.851)	1,523 (0.666)	1,765 (0.771)	2,270 (0.992)	590 (0.258)	1,437 (0.628)
Emissions, kg/hr (lb/hr)	1,858 (4,097)	1,451 (3,200)	923 (2,036)	1,289 (2,842)	332 (732)	1,335 (2,944)
Total chromium emissions measured by Method-13 $x10^6$						
Concentration, mg/dsm^3 (gr/dscf)	11,069 (4.84)	6,601 (2.88)	14,005 (6.12)	56,928 (24.87)	3,601 (1.57)	13,792 (6.03)
Emissions, kg/hr (lb/hr)	10,563 (23,288)	6,289 (13,865)	7,327 (16,154)	32,337 (71,290)	2,027 (4,468)	12,817 (28,258)

TABLE C-13. (continued)

Data/Units	Run No.[a]					
	2-C-IMP-2	2C-CTI	2-C-ALG	2-C-BKW	3A-IMP-1	3-A-IMP-2
General						
Date	7/14/87	7/14/87	7/14/87	7/14/87	7/14/87	7/14/87
Start time	9:14	9:12	9:15	9:15	15:40	15:40
Sampling period, min	180	177	180	180	180	180
Isokinetic ratio, percent	97.8	100.0	90.8	96.3	101.7	97.9
Cell recirculation rate, L/min (gal/min)	9,591 (2,534)	9,591 (2,534)	9,591 (2,534)	9,591 (2,534)	15,998 (4,227)	15,998 (4,227)
Barometric pressure, mm Hg (in. Hg)	744.22 (29.30)	744.22 (29.30)	744.22 (29.30)	744.22 (29.30)	744.22 (29.30)	744.22 (29.30)
Cr^{+6} concentration in cooling water, ppm	96-102	96-102	96-102	96-102	177-191	177-191
Gas stream						
Temperature, °C (°F)	25 (77)	25 (78)	29 (85)	29 (85)	28 (82)	29 (84)
Moisture, percent by volume	3.52	2.04	2.66	2.51	1.78	2.59
Flow rate, m^3/min (acfm)	15,847 (559,600)	17,947 (633,800)	24,442 (863,100)	24,433 (862,900)	9,778 (345,300)	9,592 (338,700)
Flow rate, dsm^3/min (dscfm)	14,710 (519,500)	16,910 (597,200)	22,572 (797,100)	22,600 (798,100)	9,155 (323,300)	8,875 (313,400)
Cr^{+6} emissions measured by Method-13 $x10^6$						
Concentration, mg/dsm^3 (gr/dscf)	4,854 (2.12)	2,101 (0.918)	1,750 (0.764)	991 (0.433)	3,458 (1.51)	3,914 (1.71)
Emissions, kg/hr (lb/hr)	4,284 (9,444)	2,131 (4,699)	2,369 (5,223)	1,343 (2,961)	1,899 (4,186)	2,084 (4,595)
Total chromium emissions measured by Method-13 $x10^6$						
Concentration, mg/dsm^3 (gr/dscf)	17,134 (7.49)	NA (NA)	3,376 (1.48)	2,804 (1.22)	31,824 (13.9)	10,956 (4.79)
Emissions, kg/hr (lb/hr)	15,121 (33,337)	NA (NA)	4,571 (10,078)	3,802 (8,381)	17,478 (38,532)	5,833 (12,860)

TABLE C-13. (continued)

Data/Units	Run No.[a]					
	3A-CTI	3-C-IMP-1	3-C-IMP-2	3-C-CTI	3-C-ALG	3-C-BKW
General						
Date	7/14/87	7/14/87	7/14/87	7/14/87	7/14/87	7/14/87
Start time	15:40	15:40	15:40	3:45	3:25	3:25
Sampling period, min	174.15	180	180	152.02	180	180
Isokinetic ratio, percent	99.8	103.7	97.7	94.6	87.4	92.8
Cell recirculation rate, L/min (gal/min)	15,998 (4,227)	19,953 (5,272)	19,953 (5,272)	19,953 (5,272)	19,953 (5,272)	19,953 (5,272)
Barometric pressure, mm Hg (in. Hg)	744.22 (29.300)	744.22 (29.300)	744.22 (29.300)	744.22 (29.300)	744.22 (29.300)	744.22 (29.300)
Cr^{+6} concentration in cooling water, ppm	177-191	96-102	96-102	96-102	96-102	96-102
Gas stream						
Temperature, °C (°F)	28 (83)	27 (81)	27 (81)	27 (80)	30 (86)	30 (86)
Moisture, percent by volume	1.22	2.89	3.21	2.51	2.98	2.81
Flow rate, m^3/min (acfm)	11,370 (401,600)	16,712 (590,200)	16,510 (583,000)	17,801 (628,600)	23,844 (842,000)	23,836 (841,800)
Flow rate, dsm^3/min (dscfm)	10,700 (377,900)	15,504 (547,500)	15,266 (539,100)	16,605 (586,400)	21,908 (773,700)	21,939 (774,800)
Cr^{+6} emissions measured by Method-13 $x10^6$						
Concentration, mg/dsm^3 (gr/dscf)	2,268 (0.991)	5,661 (2.474)	2,774 (1.212)	2,435 (1.064)	13,953 (6.096)	3,045 (1.330)
Emissions, kg/hr (lb/hr)	1,456 (3,210)	5,265 (11,608)	2,540 (5,600)	2,426 (5,348)	18,338 (40,428)	4,008 (8,836)
Total chromium emissions measured by Method-13 $x10^6$						
Concentration, mg/dsm^3 (gr/dscf)	12,521 (5.471)	19,490 (8.516)	30,413 (13.288)	13,228 (5.780)	16,514 (7.215)	6,187 (2.703)
Emissions, kg/hr (lb/hr)	8,038 (17,721)	18,127 (39,963)	27,853 (61,405)	13,177 (29,050)	21,704 (47,850)	8,144 (17,954)

TABLE C-13. (continued)

Data/Units	Run No.[a]					
	4-A-IMP-1	4-A-IMP-2	4-A-CTI	4-C-IMP-1	4-C-IMP-2	4-C-CTI
General						
Date	7/15/87	7/15/87	7/15/87	7/15/87	7/15/87	7/15/87
Start time	9:12	9:10	9:13	9:03	9:00	9:03
Sampling period, min	180	180	169.28	180	180	175.3
Isokinetic ratio, percent	102.4	95.5	110.0	102.7	105.6	98.6
Cell recirculation rate, L/min (gal/min)	16,585 (4,382)	16,585 (4,382)	16,585 (4,382)	10,401 (2,748)	10,401 (2,748)	10,401 (2,748)
Barometric pressure, mm Hg (in. Hg)	745.49 (29.350)	745.49 (29.350)	744.474 (29.310)	745.49 (29.350)	745.49 (29.350)	745.49 (29.350)
Cr^{+6} concentration in cooling water, ppm	163-172	163-172	163-172	99-107	99-107	99-107
Gas stream						
Temperature, °C (°F)	23 (73)	22 (72)	22 (72)	24 (75)	24 (75)	23 (74)
Moisture, percent by volume	3.16	2.31	1.54	3.39	3.43	2.70
Flow rate, m^3/min (acfm)	9,873 (348,700)	9,846 (347,700)	10,531 (371,900)	17,122 (604,700)	17,544 (619,600)	16,646 (587,900)
Flow rate, dsm^3/min (dscfm)	9,295 (328,200)	9,359 (330,500)	10,080 (356,000)	16,013 (565,500)	16,414 (579,600)	15,705 (554,600)
Cr^{+6} emissions measured by Method-13 $x10^6$						
Concentration, mg/dsm^3 (gr/dscf)	1,137 (0.497)	1,162 (0.508)	1,294 (0.565)	2,005 (0.876)	2,339 (1.022)	1,234 (0.539)
Emissions, kg/hr (lb/hr)	634 (1,398)	653 (1,439)	782 (1,725)	1,926 (4,245)	2,303 (5,077)	1,162 (2,563)
Total chromium emissions measured by Method-13 $x10^6$						
Concentration, mg/dsm^3 (gr/dscf)	24,850 (10.858)	12,045 (5.263)	5,709 (2.494)	49,088 (21.448)	22,665 (9.903)	17,010 (7.432)
Emissions, kg/hr (lb/hr)	13,857 (30,549)	6,763 (14,909)	3,452 (7,610)	47,156 (103,960)	22,318 (49,202)	16,026 (35,330)

TABLE C-13. (continued)

Data/Units	Run No.[a]					
	4-C-ALG	4-C-BKW	5-B-IMP-1	5-B-IMP-2	5-B-CTI	5-D-IMP-1
General						
Date	7/15/87	7/15/87	7/15/87	7/15/87	7/15/87	7/15/87
Start time	9:00	9:00	15:00	15:01	15:04	14:55
Sampling period, min	180	180	180	180	172.07	180
Isokinetic ratio, percent	96.0	99.2	103.6	96.4	104.8	108.0
Cell recirculation rate, L/min (gal/min)	10,401 (2,748)	10,401 (2,748)	16,888 (4,462)	16,888 (4,462)	16,888 (4,462)	10,420 (2,753)
Barometric pressure, mm Hg (in. Hg)	745.49 (29.350)	745.49 (29.350)	745.49 (29.350)	745.49 (29.350)	745.49 (29.350)	745.49 (29.350)
Cr^{+6} concentration in cooling water, ppm	99-107	99-107	163-172	163-172	163-172	99-107
Gas stream						
Temperature, °C (°F)	24 (75)	24 (75)	23 (73)	23 (73)	23 (74)	24 (75)
Moisture, percent by volume	3.46	3.35	2.32	2.13	1.28	2.63
Flow rate, m^3/min (acfm)	22,384 (790,500)	22,379 (790,300)	9,819 (346,800)	9,141 (322,800)	10,280 (363,000)	16,190 (571,700)
Flow rate, dsm^3/min (dscfm)	20,920 (738,800)	20,939 (739,400)	9,316 (329,000)	8,689 (306,900)	9,842 (347,600)	15,252 (538,600)
Cr^{+6} emissions measured by Method-13 x10^6						
Concentration, mg/dsm^3 (gr/dscf)	2,858 (1.249)	414 (0.181)	1,525 (0.666)	1,842 (0.805)	2,133 (0.932)	1,592 (0.696)
Emissions, kg/hr (lb/hr)	3,587 (7,908)	520 (1,147)	852 (1,879)	960 (2,117)	1,260 (2,777)	1,457 (3,212)
Total chromium emissions measured by Method-13 x10^6						
Concentration, mg/dsm^3 (gr/dscf)	6,014 (2.628)	3,217 (1.406)	17,184 (7.508)	36,401 (15.905)	8,586 (3.751)	8,491 (3.710)
Emissions, kg/hr (lb/hr)	7,547 (16,639)	4,041 (8,910)	9,604 (21,173)	18,975 (41,833)	5,070 (11,177)	7,769 (17,128)

TABLE C-13. (continued)

Data/Units	Run No.[a]					
	5-D-IMP-2	5-D-CTI	5-B-ALG	5-B-BKW	6-B-IMP-1	6-B-IMP-2
General						
Date	7/15/87	7/15/87	7/15/87	7/15/87	7/16/87	7/16/87
Start time	14:55	14:55	2:35	2:35	9:00	9:00
Sampling period, min	180	174.12	180	180	180	180
Isokinetic ratio, percent	102.3	97.7	96.9	98.5	105.8	97.3
Cell recirculation rate, L/min (gal/min)	10,420 (2,753)	10,420 (2,753)	16,888 (4,462)	16,888 (4,462)	16,627 (4,393)	16,627 (4,393)
Barometric pressure, mm Hg (in. Hg)	745.49 (29.350)	745.49 (29.350)	745.49 (29.350)	745.49 (29.350)	741.68 (29.20)	741.68 (29.20)
Cr^{+6} concentration in cooling water, ppm	99-107	99-107	163-172	163-172	156-184	156-184
Gas stream						
Temperature, °C (°F)	24 (76)	24 (75)	27 (80)	27 (80)	24 (75)	22 (72)
Moisture, percent by volume	3.10	1.97	2.00	1.97	2.45	2.99
Flow rate, m^3/min (acfm)	15,367 (542,700)	17,442 (616,000)	13,261 (468,300)	13,260 (468,300)	10,202 (360,300)	9,418 (332,600)
Flow rate, dsm^3/min (dscfm)	14,401 (508,600)	16,559 (584,800)	12,465 (440,200)	12,468 (440,300)	9,582 (338,400)	8,845 (312,400)
Cr^{+6} emissions measured by Method-13 $x10^6$						
Concentration, mg/dsm^3 (gr/dscf)	2,317 (1.012)	1,495 (0.653)	1,020 (0.445)	1,058 (0.462)	2,113 (0.923)	2,283 (0.997)
Emissions, kg/hr (lb/hr)	2,002 (4,413)	1,485 (3,275)	762 (1,681)	792 (1,745)	1,215 (2,678)	1,211 (2,671)
Total chromium emissions measured by Method-13 $x10^6$						
Concentration, mg/dsm^3 (gr/dscf)	14,186 (6.198)	31,136 (13.604)	3,809 (1.664)	2,282 (0.997)	29,501 (12.9)	25,579 (11.2)
Emissions, kg/hr (lb/hr)	12,255 (27,018)	30,929 (68,187)	2,848 (6,279)	1,707 (3,762)	16,957 (37,384)	13,574 (29,925)

TABLE C-13. (continued)

Data/Units	Run No.[a]					
	6B-CTI	6-D-IMP-1	6-D-IMP-2	6-D-CTI	6-B-ALG	6-B-BKW
General						
Date	7/16/87	7/16/87	7/16/87	7/16/87	7/16/87	7/16/87
Start time	9:00	9:02	9:02	9:02	9:02	9:02
Sampling period, min	181	180	180	162	180	180
Isokinetic ratio, percent	104.2	105.5	98.9	103.7	94.5	99.0
Cell recirculation rate, L/min (gal/min)	16,627 (4,393)	19,507 (5,154)	19,507 (5,154)	19,507 (5,154)	16,627 (4,393)	16,627 (4,393)
Barometric pressure, mm Hg (in. Hg)	741.68 (29.20)	747.27 (29.42)	747.27 (29.42)	747.27 (29.42)	747.27 (29.42)	747.27 (29.42)
Cr^{+6} concentration in cooling water, ppm	156-184	94-106	94-106	94-106	156-184	156-184
Gas stream						
Temperature, °C (°F)	24 (76)	26 (78)	26 (78)	26 (78)	27 (80)	27 (80)
Moisture, percent by volume	1.59	3.58	3.42	2.26	2.41	2.30
Flow rate, m^3/min (acfm)	10,413 (367,800)	15,760 (556,600)	15,542 (548,850)	17,387 (614,000)	14,230 (502,500)	13,227 (502,400)
Flow rate, dsm^3/min (dscfm)	9,862 (348,300)	14,665 (517,900)	14,485 (511,500)	16,403 (579,300)	13,352 (471,500)	13,363 (471,900)
Cr^{+6} emissions measured by Method-13 $x10^6$						
Concentration, mg/dsm^3 (gr/dscf)	1,280 (0.559)	2,689 (1.18)	6,524 (2.85)	2,365 (1.03)	2,353 (1.03)	670 (0.293)
Emissions, kg/hr (lb/hr)	757 (1,669)	2,366 (5,216)	5,669 (12,499)	2,327 (5,130)	1.885 (4,155)	537 (1,185)
Total chromium emissions measured by Method-13 $x10^6$						
Concentration, mg/dsm^3 (gr/dscf)	3,558 (1.56)	33,911 (14.8)	13,290 (5.81)	8,636 (3.77)	21,672 (5.54)	5,423 (2.37)
Emissions, kg/hr (lb/hr)	2,105 (4,641)	29,835 (65,775)	11,548 (25,460)	8,499 (18,736)	10,149 (22,375)	4,347 (9,584)

TABLE C-13. (continued)

Data/Units	Run No.[a]					
	7-B-IMP-1	7-B-IMP-2	7-B-CTI	7-D-IMP-1	7-D-IMP-2	7-D-CTI
General						
Date	7/16/87	7/16/87	7/16/87	7/16/87	7/16/87	7/16/87
Start time	15:00	14:36	14:30	14:20	14:20	14:20
Sampling period, min	180	180	182	180	190	177
Isokinetic ratio, percent	92.7	97.6	101.3	106.9	98.5	101.8
Cell recirculation rate, L/min (gal/min)	16,456 (4,348)	16,456 (4,348)	16,456 (4,348)	19,590 (5,176)	19,590 (5,176)	19,590 (5,176)
Barometric pressure, mm Hg (in. Hg)	747.27 (29.42)	747.27 (29.42)	741.68 (29.20)	747.27 (29.42)	747.27 (29.42)	747.27 (29.42)
Cr^{+6} concentration in cooling water, ppm	156-184	156-184	156-184	94-106	94-106	94-106
Gas stream						
Temperature, °C (°F)	30 (86)	28 (82)	29 (84)	27 (80)	27 (80)	27 (80)
Moisture, percent by volume	2.85	2.70	1.44	3.76	2.73	2.35
Flow rate, m^3/min (acfm)	9,707 (342,800)	9,213 (325,300)	11,040 (390,000)	15,468 (546,300)	15,482 (546,800)	18,492 (653,000)
Flow rate, dsm^3/min (dscfm)	8,965 (316,600)	8,578 (302,950)	10,305 (363,900)	14,307 (505,200)	14,475 (511,200)	17,355 (612,900)
Cr^{+6} emissions measured by Method-13 $x10^6$						
Concentration, mg/dsm^3 (gr/dscf)	3,053 (1.33)	4,345 (1.90)	4,879 (2.13)	5,008 (2.19)	5,641 (2.46)	2,418 (1.06)
Emissions, kg/hr (lb/hr)	1,642 (3,619)	2,236 (4,930)	3,016 (6,649)	4,298 (9,475)	4,898 (10,799)	2,518 (5,551)
Total chromium emissions measured by Method-13 $x10^6$						
Concentration, mg/dsm^3 (gr/dscf)	35,558 (15.5)	28,123 (12.3)	16,402 (7.17)	26,762 (11.7)	33,664 (14.7)	19,925 (8.71)
Emissions, kg/hr (lb/hr)	19,122 (42,157)	14,473 (31,907)	10,139 (22,353)	22,968 (50,636)	29,232 (64,446)	20,746 (45,736)

TABLE C-13. (continued)

Data/Units	Run No.[a]					
	7-B-ALG	7-B-BKW	8B-IMP-1	8B-IMP-2	8-B-CTI	8D-IMP-1
General						
Date	7/16/87	7/16/87	7/17/87	7/17/87	7/17/87	7/17/87
Start time	14:47	14:47	8:00	8:00	8:00	8:00
Sampling period, min	132	132	180	180	184	180
Isokinetic ratio, percent	93.0	100.2	96.6	99.2	105.9	105.5
Cell recirculation rate, L/min (gal/min)	16,456 (4,348)	16,456 (4,348)	16.203 (4,281)	16,203 (4,281)	16,203 (4,281)	20,533 (5,425)
Barometric pressure, mm Hg (in. Hg)	741.68 (29.20)	513.08 (20.20)	749.30 (29.50)	749.30 (29.50)	749.30 (29.50)	749.30 (29.50)
Cr^{+6} concentration in cooling water, ppm	156-184	156-184	169-174	169-174	169-174	104-108
Gas stream						
Temperature, °C (°F)	27 (80)	27 (80)	26 (78)	30 (87)	25 (78)	26 (80)
Moisture, percent by volume	3.48	3.23	2.82	3.01	1.61	3.90
Flow rate, m^3/min (acfm)	12,665 (447,300)	12,658 (447,000)	10,202 (360,250)	9,333 (329,600)	10,313 (364,200)	14,267 (503,800)
Flow rate, dsm^3/min (dscfm)	11,665 (411,900)	11,690 (412,800)	9,590 (338,650)	8,618 (304,400)	9,828 (347,100)	13,232 (467,300)
Cr^{+6} emissions measured by Method-13 $x10^6$						
Concentration, mg/dsm^3 (gr/dscf)	2,621 (1.14)	1,519 (0.664)	2,031 (0.888)	1,475 (0.644)	5,242 (2.29)	1,870 (0.817)
Emissions, kg/hr (lb/hr)	1,834 (4,043)	1,065 (2,348)	1,169 (2,576)	763 (1,681)	3,091 (6,814)	1,484 (3,273)
Total chromium emissions measured by Method-13 $x10^6$						
Concentration, mg/dsm^3 (gr/dscf)	NA (NA)	3,188 (1.39)	25,837 (11.3)	27,662 (12.1)	17,380 (7.59)	24,464 (10.7)
Emissions, kg/hr (lb/hr)	NA (NA)	2,236 (4,929)	14,864 (32,769)	14,302 (31,531)	10,248 (22,593)	19,419 (42,811)

TABLE C-13. (continued)

Data/Units	Run No.[a]			
	8-D-IMP-2	8D-CTI	8-B-ALG	8-B-BKW
General				
Date	7/17/87	7/17/87	7/17/87	7/17/87
Start time	8:00	8:00	7:57	7:57
Sampling period, min	189	172	180	180
Isokinetic ratio, percent	97.8	101.0	94.7	99.5
Cell recirculation rate, L/min (gal/min)	20,533 (5,425)	20,533 (5,425)	16,203 (4,281)	16,203 (4,281)
Barometric pressure, mm Hg (in. Hg)	749.30 (29.50)	749.30 (29.50)	749.30 (29.50)	749.30 (29.50)
Cr^{+6} concentration in cooling water, ppm	104-108	104-108	169-174	169-174
Gas stream				
Temperature, °C (°F)	26 (79)	26 (79)	27 (80)	(27 (80)
Moisture, percent by volume	4.12	2.45	2.50	2.38
Flow rate, m^3/min (acfm)	14,327 (506,000)	16,930 (597,900)	14,085 (495,600)	14,032 (495,500)
Flow rate, dsm^3/min (dscfm)	13,257 (468,200)	15,943 (563,000)	13,192 (465,900)	13,205 (466,300)
Cr^{+6} emissions measured by Method-13 $x10^6$				
Concentration, mg/dsm^3 (gr/dscf)	2,406 (1.05)	4,663 (2.04)	2,464 (1.08)	1,246 (0.544)
Emissions, kg/hr (lb/hr)	1,913 (4,219)	4,459 (9,831)	1,950 (4,299)	987 (2,176)
Total chromium emissions measured by Method-13 $x10^6$				
Concentration, mg/dsm^3 (gr/dscf)	24,328 (10.6)	28,199 (12.3)	3,795 (1.66)	2,830 (1.24)
Emissions, kg/hr (lb/hr)	19,349 (42,657)	26,969 (59,457)	3,003 (6,621)	2,242 (4,942)

[a]The run No. identifies the cell number and test series, respectively.

TABLE C-14. SUMMARY OF SENSITIVE PAPER DRIFT MEASUREMENTS

Site/location	Cell	Sensitive paper drift rate percent of recirculation
Department of Energy, Paducah, KY	4	0.0083
	5	0.0093
	6	0.0009
	7	0.0003
National Institute of Standards and Technology, Gaithersburg, MD	A	0.0002
	B	0.0004
	C	0.0001
	D	0.0001
Exxon Refinery, Baytown, TX (Tower 68)	1	0.0047
	2	0.0103
	3	0.0072
	4	0.0040
	5	0.0045
Exxon Refinery, Baytown, TX (Tower 84)	A	0.0009
	B	0.0006
	C	0.0005
	D	0.0008

TABLE C-15. SUMMARY OF EMISSION TEST RESULTS--NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY'S STEAM AND WATER CHILL PLANT, GAITHERSBURG, MARYLAND (SECOND TEST)

Data/Units	Run No.				
	1C-1	1C-2	2C-1	2C-2[a]	2C-3
General					
Date	7/10/90	7/10/90	7/09/90	7/09/90	7/10/90
Start time	0932	0930	1452	1450	0927
Sampling period, min	342.50	342.50	254.25	254.25	345.78
Isokinetic ratio, percent	102.0	102.7	103.1	102.8	105.3
Cell recirculation rate, L/min, (gal/min)	22,557 (5,959)	22,557 (5,959)	26,657 (7,042)	26,657 (7,042)	22,557 (5,959)
Barometric pressure, mm Hg (in. Hg)	762.00 (30.00)	762.00 (30.00)	746.76 (29.40)	746.76 (29.40)	762.00 (30.00)
Recirculating water concentrations, ppm					
Calcium	378.28	378.28	369.27	369.27	378.28
Magnesium	113.13	113.13	109.29	109.29	113.13
Sodium	213.20	213.20	205.32	205.32	213.20
Strontium	2.09	2.09	2.03	2.03	2.09
Aluminum	0.13	0.13	0.24	0.24	0.13
Chromium	0.007	0.007	0.017	0.017	0.007
Copper	0.064	0.064	0.104	0.104	0.064
Iron	0.19	0.19	0.451	0.451	0.19
Manganese	0.024	0.024	0.040	0.040	0.024
Titanium	0.068	0.068	0.068	0.068	0.069
Zinc	0.083	0.083	0.116	0.116	0.083
Gas stream					
Temperature, °C, (°F)	35 (95)	36 (97)	39 (103)	40 (104)	36 (97)
Moisture, percent by volume	4.2	4.1	4.6	4.6	4.4
Flow rate, m^3/min (acfm)	43,849 (1,548,509)	43,826 (1,547,698)	40,944 (1,445,924)	40,944 (1,445,924)	40,198 (1,419,568)
Flow rate, dsm^3/min (dscfm)	40,435 (1,427,941)	40,456 (1,428,683)	36,713 (1,296,506)	36,713 (1,296,506)	36,857 (1,301,573)

TABLE C-15. (continued)

Data/Units	Run No.				
	1C-1	1C-2	2C-1	2C-2[a]	2C-3
Drift rates, percent of recirculating water					
Calcium	0.0029	0.0041	0.0035	--	0.0026
Magnesium	0.0027	0.0048	0.0038	--	0.0034
Sodium	0.0045	0.0079	0.0092	--	0.0061
Strontium	0.0024	0.0058	0.0055	--	0.0048
Aluminum	2.8614	2.5226	3.4949	--	3.8641
Chromium	0.7134	3.0738	4.2803	--	2.7572
Copper	0.1529	0.4213	0.6070	--	0.2382
Iron	0.6904	3.0275	0.9379	--	1.0164
Manganese	1.3987	0.3705	0.4005	--	0.9348
Titanium	0.3201	--	0.6631	--	0.2779
Zinc	0.7127	0.3613	1.5570	--	0.7035

TABLE C-15. (continued)

Data/Units	Run No.				
	1C-1	1C-2	2C-1	2C-2[a]	2C-3
Emissions measured by Method 13					
Concentration, mg/dscm (g/dscf) x10^6					
Aluminum	2,822.00 (0.07991)	2,485.60 (0.07038)	10,272.80 (0.29089)		4,180.70 (0.11838)
Calcium	10,953.60 (0.31017)	15,420.00 (0.43665)	18,814.70 (0.53277)		10,788.90 (0.30551)
Chromium	50.30 (0.00142)	216.30 (0.00612)	1,053.60 (0.02983)		213.10 (0.00603)
Copper	98.50 (0.00279)	271.10 (0.00768)	914.00 (0.02588)		168.30 (0.00477)
Iron	1,257.70 (0.03561)	5,509.80 (0.15602)	5,907.80 (0.16729)		2,031.00 (0.05751)
Magnesium	3,056.70 (0.08656)	5,406.20 (0.15309)	6,112.90 (0.17310)		4,253.50 (0.12045)
Manganese	830.50 (0.02352)	219.80 (0.00622)	811.90 (0.02299)		608.90 (0.01724)
Sodium	9,600.50 (0.27186)	16,916.00 (0.47901)	27,224.80 (0.77092)		14,335.80 (0.40594)
Strontium	51.00 (0.00144)	122.40 (0.00347)	162.20 (0.00459)		110.90 (0.00314)
Titanium	222.90 (0.00631)	2,711.20 (0.07677)	652.90 (0.01849)		211.70 (0.00599)
Zinc	595.40 (0.01686)	301.50 (0.00854)	2,615.20 (0.07405)		644.60 (0.01825)

TABLE C-15. (continued)

Data/Units	Run No.				
	1C-1	1C-2	2C-1	2C-2[a]	2C-3
Emissions, kg/h (lb/h) x 10^6					
Aluminum	0.00767 (0.01688)	0.00378 (0.00832)	0.02577 (0.05669)		0.01076 (0.02367)
Calcium	0.02978 (0.06552)	0.02347 (0.05164)	0.04720 (0.10383)		0.02776 (0.06108)
Chromium	0.00014 (0.00030)	0.00033 (0.00072)	0.00264 (0.00581)		0.00055 (0.00121)
Copper	0.00027 (0.00059)	0.00041 (0.00091)	0.00229 (0.00505)		0.00043 (0.00095)
Iron	0.00342 (0.00752)	0.00839 (0.01845)	0.01482 (0.03260)		0.00540 (0.01188)
Magnesium	0.00831 (0.01828)	0.00823 (0.01811)	0.01533 (0.03374)		0.01095 (0.02408)
Manganese	0.00226 (0.00497)	0.00033 (0.00074)	0.00204 (0.00448)		0.00157 (0.00345)
Sodium	0.02610 (0.05742)	0.02575 (0.05665)	0.06829 (0.15025)		0.03689 (0.08116)
Strontium	0.00014 (0.00030)	0.00019 (0.00041)	0.00041 (0.00089)		0.00028 (0.00063)
Titanium	0.00061 (0.00133)	0.00413 (0.00908)	0.00164 (0.00360)		0.00054 (0.00120)
Zinc	0.00162 (0.00356)	0.00046 (0.00101)	0.00656 (0.01443)		0.00166 (0.00365)

[a]No data were available for this run.
[b]Some data were not available for this run.
[c]No concentration data were available for this run.

TABLE C-15. (continued)

Data/Units	Run No.				
	2C-4[a]	2C-5	2C-6[a]	2C-7	2C-8[a]
General					
Date	7/10/90	7/11/90	7/11/90	7/12/90	7/12/90
Start time	0925	0937	0935	0917	0915
Sampling period, min	345.75	369.25	369.25	351.25	351.25
Isokinetic ratio, percent	107.2	102.2	102.5	145.4	104.7
Cell recirculation rate, L/min, (gal/min)	22,557 (5,959)	22,478 (5,938)	22,478 (5,938)	22,413 (5,921)	22,413 (5,921)
Barometric pressure, mm Hg, (in. Hg)	762.00 (30.00)	762.00 (30.00)	762.00 (30.00)	741.68 (29.20)	741.68 (29.20)
Recirculating water concentrations, ppm					
Calcium	378.28	357.97	357.97	370.80	370.80
Magnesium	113.13	108.18	108.18	111.14	111.14
Sodium	213.20	203.33	203.33	211.32	211.32
Strontium	2.09	1.99	1.99	2.08	2.08
Aluminum	0.13	0.094	0.094	0.082	0.082
Chromium	0.007	0.008	0.008	0.005	0.005
Copper	0.064	0.038	0.038	0.040	0.040
Iron	0.19	0.112	0.112	0.063	0.063
Manganese	0.024	0.022	0.022	0.021	0.021
Titanium	0.069	0.066	0.066	0.066	0.066
Zinc	0.083	0.015	0.015	0.015	0.015
Gas stream					
Temperature, °C (°F)	39 (103)	31 (87)	37 (98)	31 (87)	39 (103)
Moisture, percent by volume	4.4	3.3	3.4	3.8	4.1
Flow rate, m^3/min (acfm)	40,198 (1,419,568)	42,161 (1,488,904)	42,173 (1,489,310)	40,749 (1,439,031)	40,772 (1,439,842)
Flow rate, dsm^3/min (dscfm)	36,857 (1,301,573)	39,604 (1,398,590)	39,574 (1,397,524)	37,064 (1,308,892)	36,969 (1,305,546)

TABLE C-15. (continued)

Data/Units	Run No.				
	2C-4[a]	2C-5	2C-6[a]	2C-7	2C-8[a]
Drift rates, percent of recirculating water					
Calcium	--	0.0032	--	0.0034	--
Magnesium	--	0.0025	--	0.0041	--
Sodium	--	0.0031	--	0.0045	--
Strontium	--	0.0034	--	0.0033	--
Aluminum	--	7.5288	--	2.8356	--
Chromium	--	7.6024	--	--	--
Copper	--	0.7840	--	0.8469	--
Iron	--	3.4830	--	--	--
Manganese	--	0.6236	--	2.6424	--
Titanium	--	0.1008	--	0.2907	--
Zinc	--	--	--	3.7621	--

TABLE C-15. (continued)

Data/Units	Run No.				
	2C-4[a]	2C-5	2C-6[a]	2C-7	2C-8[a]
Emissions measured by Method 13					
Concentration, mg/dscm (g/dscf) x 10^6					
Aluminum		5,447.90 (0.15427)		1,701.70 (0.04819)	
Calcium		11,501.20 (0.32568)		13,814.50 (0.39118)	
Chromium		697.30 (0.01975)			
Copper		303.60 (0.00860)		376.50 (0.01066)	
Iron		3,975.80 (0.11258)		16,135.80 (0.45691)	
Magnesium		2,722.80 (0.07710)		5,018.20 (0.14210)	
Manganese		254.20 (0.00720)		881.00 (0.02495)	
Sodium		6,331.70 (0.17929)		10,678.80 (0.30239)	
Strontium		68.00 (0.00193)		76.70 (0.00217)	
Titanium		67.80 (0.00192)		213.20 (0.00604)	
Zinc		2,237.30 (0.06335)		627.20 (0.01776)	

TABLE C-15. (continued)

Data/Units	Run No.				
	2C-4[a]	2C-5	2C-6[a]	2C-7	2C-8[a]
Emissions, kg/h (lb/h) x10^6					
Aluminum		0.01462 (0.03217)		0.00608 (0.01338)	
Calcium		0.03087 (0.06792)		0.04937 (0.10861)	
Chromium		0.00187 (0.00412)		0.00000 (0.00000)	
Copper		0.00082 (0.00179)		0.00135 (0.00296)	
Iron		0.01067 (0.02348)		0.05766 (0.12686)	
Magnesium		0.00731 (0.01608)		0.01793 (0.03945)	
Manganese		0.00068 (0.00150)		0.00315 (0.00693)	
Sodium		0.01700 (0.03739)		0.03816 (0.08395)	
Strontium		0.00018 (0.00040)		0.00027 (0.00060)	
Titanium		0.00018 (0.00040)		0.00076 (0.00168)	
Zinc		0.00601 (0.01321)		0.00224 (0.00493)	

TABLE C-15. (continued)

Data/Units	Run No.					
	3C-1	3C-2	3C-3[b]	3C-4	4C-1	4C-2
General						
Date	7/09/90	7/09/90	7/11/90	7/11/90	7/12/90	7/12/90
Start time	1454	1452	934	932	0919	0918
Sampling period, min	235.75	235.75	317.50	325.00	385.00	385.00
Isokinetic ratio, percent	98.5	107.4	101.5	102.0	146.3	101.5
Cell recirculation rate, L/min, (gal/min)	26,657 (7,042)	26,657 (7,042)	22,478 (5,938)	22,478 (5,938)	22,413 (5,921)	22,413 (5,921)
Barometric pressure, mm Hg (in. Hg)	746.76 (29.40)	746.76 (29.40)	762.00 (30.00)	741.68 (29.20)	741.68 (29.20)	741.68 (29.20)
Recirculating water concentrations, ppm	0.017	0.017	0.009	0.009	0.005	0.005
Calcium	369.27	369.27	357.97	357.97	370.80	370.80
Magnesium	109.29	109.29	108.18	108.18	111.14	111.14
Sodium	205.32	205.32	203.33	203.33	211.32	211.32
Strontium	2.03	2.03	1.99	1.99	2.08	2.08
Aluminum	0.24	0.24	0.094	0.094	0.082	0.082
Chromium	0.017	0.017	0.008	0.008	0.005	0.005
Copper	0.104	0.104	0.038	0.038	0.040	0.040
Iron	0.451	0.451	0.112	0.112	0.063	0.063
Manganese	0.040	0.040	0.022	0.022	0.021	0.021
Titanium	0.068	0.068	0.066	0.066	0.066	0.066
Zinc	0.116	0.116	0.015	0.015	0.015	0.015
Gas stream						
Temperature, °C (°F)	39 (103)	38 (101)	31 (88)	33 (91)	31 (88)	33 (92)
Moisture, percent by volume	4.8	4.5	3.2	3.3	3.6	3.7
Flow rate, m^3/min (acfm)	45,537 (1,608,114)	45,502 (1,606,897)	45,112 (1,593,111)	45,147 (1,594,328)	46,605 (1,645,823)	46,616 (1,646,229)
Flow rate, dsm^3/min (dscfm)	40,599 (1,433,718)	40,696 (1,437,148)	42,497(1,500,777)	42,486 (1,500,371)	42,635 (1,505,621)	42,601 (1,504,429)

TABLE C-15. (continued)

Data/Units	Run No.					
	3C-1	3C-2	3C-3[b]	3C-4	4C-1	4C-2
Drift rates, percent of recirculating water						
Calcium	0.0048	0.0055				
Magnesium	0.0062	0.0053				
Sodium	0.0117	0.0146				
Strontium	0.0067	0.0076				
Aluminum	1.1731	3.7051				
Chromium	2.7683	2.0045				
Copper	0.6063	0.7452				
Iron	0.7984	0.7610				
Manganese	0.3356	2.5497				
Titanium	--	0.2720				
Zinc	2.3804	2.6943				

[a]The run number identifies the fan cell number and run number for that cell, respectively.
[b]Contamination was apparent in some elements of these runs; instead of selective use of numbers, all the data from these sample trains were not used in the original report.

TABLE C-15. (continued)

Data/Units	Run No.					
	3C-1	3C-2	3C-3[b]	3C-4[b]	4C-1[b]	4C-2[b]
Emissions measured by Method 13						
Concentration, mg/dscm (g/dscf) $x10^6$						
Aluminum	3,122.70 (0.08842)	9,825.10 (0.27822)				
Calcium	23,141.30 (0.65529)	26,709.10 (0.75632)				
Chromium	617.10 (0.01747)	445.20 (0.01261)				
Copper	828.60 (0.02346)	1,012.40 (0.02867)				
Iron	4,553.90 (0.12895)	4,324.30 (0.12245)				
Magnesium	8,827.10 (0.24996)	7,542.10 (0.21357)				
Manganese	616.20 (0.01745)					
Sodium	31,431.20 (0.89003)					
Strontium	178.80 (0.00506)	200.60 (0.00568)				
Titanium	4,765.80 (0.13495)	241.70 (0.00684)				
Zinc	3,620.80 (0.10253)	4,082.70 (0.11561)				

TABLE C-15. (continued)

Data/Units	Run No.					
	3C-1	3C-2	3C-3[b]	3C-4[b]	4C-1[b]	4C-2[b]
Emissions, kg/h (lb/h) x10^6						
Aluminum	0.00855 (0.01881)	0.01573 (0.03460)	0.01584 (0.03484)	0.02356 (0.05183)	0.02113 (0.04649)	0.01770 (0.03895)
Calcium	0.06337 (0.13942)	0.04276 (0.09407)	0.01852 (0.04074)	0.07385 (0.16246)	0.03740 (0.08229)	0.09974 (0.21943)
Chromium	0.00016 (0.00035)	0.00011 (0.00025)	0.00629 (0.01384)	0.01288 (0.02833)	0.05289 (0.11637)	0.15146 (0.33320)
Copper	0.00227 (0.00498)	0.00162 (0.00357)	0.00270 (0.00595)	0.00080 (0.00176)	0.00594 (0.01307)	0.01027 (0.02259)
Iron	0.01247 (0.02744)	0.00692 (0.01523)	0.03810 (0.08381)	0.05151 (0.11332)	0.21662 (0.47657)	0.68291 (1.50240)
Magnesium	0.02417 (0.05318)	0.01207 (0.02656)	0.00651 (0.01432)	0.02756 (0.06063)	0.00552 (0.01215)	0.03798 (0.08355)
Manganese	0.00169 (0.00371)	0.00000 (0.00000)	0.00133 (0.00292)	0.00272 (0.00599)	0.04799 (0.10558)	0.07598 (0.16716)
Sodium	0.08607 (0.18936)	0.00000 (0.00000)	0.01655 (0.03642)	0.05468 (0.12030)	0.01456 (0.03202)	0.07290 (0.16039)
Strontium	0.00049 (0.00108)	0.00032 (0.00071)	0.00036 (0.00078)	0.00044 (0.00096)	0.00011 (0.00025)	0.00053 (0.00117)
Titanium	0.01305 (0.02871)	0.00039 (0.00085)	0.00102 (0.00224)	0.00016 (0.00036)	0.00046 (0.00101)	0.00051 (0.00113)
Zinc	0.00992 (0.02181)	0.00654 (0.01438)	0.00774 (0.01703)	0.00210 (0.00461)	0.04977 (0.10949)	0.01173 (0.02581)

TABLE C-16. SUMMARY OF EMISSIONS TEST RESULTS--ALLIED FIBERS, MONCURE, NORTH CAROLINA

Data/Units	Run No.							
	6	7	8	9	10	11	12	13
General								
Date	1/18/91	1/18/91	1/18/91	1/21/91	1/21/91	1/21/91	1/21/91	1/22/91
Start time	10:20	10:30	10:30	11:15	11:15	11:10	11:11	10:55
Sampling period, min	289.9	275.2	275.2	256.0	256.0	199.7	275.2	256.0
Isokinetic ratio, percent	108.3	106.6	97.3	105.9	102.4	104.8	106.8	110.1
Cell recirculation rate, L/min (gal/min)	10,368 (2,739)	10,368 (2,739)	10,368 (2,739)	12,730 (3,363)	12,730 (3,363)	12,730 (3,363)	12,730 (3,363)	12,961 (3,424)
Barometric pressure, mm Hg (in Hg)	775 (30.5)	775 (30.5)	775 (30.5)	747 (29.4)	747 (29.4)	747 (29.4)	747 (29.4)	762 (30.0)
Concentration in cooling water, ppm								
Aluminum	1.12	1.12	1.12	1.41	1.41	1.41	1.41	1.05
Barium	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.02
Calcium	9.21	9.21	9.21	4.20	4.20	4.20	4.20	2.90
Iron	12.74	12.74	12.74	7.62	7.62	7.62	7.62	4.49
Potassium	30.90	30.90	30.90	30.90	30.90	30.90	30.90	16.52
Magnesium	2.57	2.57	2.57	2.44	2.44	2.44	2.44	2.08
Manganese	0.28	0.28	0.28	0.18	0.18	0.18	0.18	0.12
Sodium	1,671.30	1,671.30	1,671.30	1,519.30	1,519.30	1,519.30	1,519.30	1,529.10
Phosphorus	12.60	12.60	12.60	9.70	9.70	9.70	9.70	8.40
Antimony	85.35	85.35	85.35	74.60	74.60	74.60	74.60	74.78
Silicon	3.70	3.70	3.70	3.60	3.60	3.60	3.60	3.30
Strontium	0.07	0.07	0.07	0.05	0.05	0.05	0.05	0.04
Titanium	0.06	0.06	0.06	0.12	0.12	0.12	0.12	0.04
Zinc	0.41	0.41	0.41	0.27	0.27	0.27	0.27	0.19
Gas Stream								
Temperature, °C (°F)	17.8 (64)	17.8 (64)	17.8 (64)	15.6 (60)	15.6 (60)	15.6 (60)	15.6 (60)	10.0 (50)
Moisture, percent by volume	2.0	1.8	1.9	1.6	1.9	2.0	1.6	1.3

TABLE C-16. (continued)

Data/Units	Run No.							
	6	7	8	9	10	11	12	13
Flow rate, m^3/min (acfm)	4,380 (154,678)	5,166 (182,429)	5,166 (182,452)	5,082 (179,460)	5,082 (179,469)	4,883 (172,431)	5,113 (180,560)	4,761 (168,133)
Flow rate, dsm^3/min (dscfm)	4,407 (155,621)	5,211 (184,018)	5,208 (183,915)	4,987 (176,127)	4,979 (175,827)	4,784 (168,949)	5,019 (177,262)	4,882 (172,422)

TABLE 16. (continued)

Data/Units	Run No. 6	7	8	9	10	11	12	13
Emissions measured by Method 13, x 10^6								
Concentration, mg/dsm^3 (gr/dscf)								
Aluminum	2,582 (1.128)	4,076 (1.781)	4,476 (1.956)	3,064 (1.339)	3,174 (1.387)	4,467 (1.952)	7,484 (3.271)	4,495 (1.964)
Barium	197 (0.086)	344 (0.15)	411 (0.18)	226 (0.099)	112 (0.049)	272 (0.119)	143 (0.062)	215 (0.094)
Calcium	11,838 (5.173)	20,363 (8.899)	42,821 (18.713)	10,604 (4.634)	13,696 (5.985)	13,199 (5.768)	13,815 (6.037)	10,953 (4.786)
Iron	11,578 (5.06)	44,886 (19.615)	34,965 (15.28)	7,267 (3.176)	10,652 (4.655)	18,294 (7.994)	11,859 (5.182)	8,247 (3.604)
Potassium	0 (0)	12,775 (5.583)	29,381 (12.839)	113,237 (49.485)	220,772 (96.477)	321,611 (140.544)	221,306 (96.711)	384,596 (168.068)
Magnesium	1,083 (0.473)	3,333 (1.457)	4,909 (2.145)	2,394 (1.046)	1,674 (0.732)	4,766 (2.083)	3,044 (1.33)	1,935 (0.846)
Manganese	1,109 (0.485)	1,318 (0.576)	2,494 (1.09)	3,205 (1.401)	820 (0.358)	1,347 (0.589)	501 (0.219)	2,246 (0.982)
Sodium	80,293 (35.088)	98,455 (43.025)	195,760 (85.547)	170,775 (74.629)	255,713 (111.747)	1,605,469 (701.59)	256,176 (111.949)	429,226 (187.572)
Phosphorus	1,493 (0.652)	3,900 (1.704)	6,415 (2.803)	1,015 (0.444)	1,472 (0.643)	3,089 (1.35)	1,733 (0.757)	6,395 (2.795)
Antimony	9,046 (3.953)	8,171 (3.571)	20,990 (9.173)	4,466 (1.952)	5,468 (2.39)	1,373 (0.6)	6,721 (2.937)	3,101 (1.355)
Silicon	9,008 (3.936)	3,356 (1.467)	7,513 (3.283)	5,063 (2.213)	7,940 (3.47)	31,688 (13.848)	7,373 (3.222)	14,253 (6.229)
Strontium	83 (0.036)	100 (0.044)	208 (0.091)	61 (0.027)	58 (0.025)	58 (0.025)	81 (0.035)	65 (0.028)
Titanium	111 (0.049)	846 (0.37)	130 (0.057)	675 (0.295)	152 (0.066)	965 (0.422)	201 (0.088)	66 (0.029)
Zinc	4,776 (2.087)	3,003 (1.312)	5,337 (2.332)	1,123 (0.491)	1,184 (0.517)	3,125 (1.366)	1,965 (0.859)	1,831 (0.8)
Emissions, kg/hr (lb/hr)								
Aluminum	682 (1,504)	1,276 (2,813)	1,400 (3,087)	916 (2,019)	947 (2,088)	1,283 (2,830)	2,253 (4,968)	1,316 (2,901)

TABLE 16. (continued)

Data/Units	Run No. 6	7	8	9	10	11	12	13
Emissions, kg/hr (lb/hr)								
Barium	53 (117)	106 (234)	128 (283)	69 (152)	33 (72)	78 (171)	42 (93)	64 (142)
Calcium	3,131 (6,904)	6,366 (14,038)	13,382 (29,507)	3,172 (6,995)	3,233 (7,128)	3,933 (8,672)	3,976 (8,767)	4,046 (8,922)
Iron	3,062 (6,752)	14,037 (30,951)	10,929 (24,098)	2,176 (4,798)	3,182 (7,016)	5,251 (11,578)	3,572 (7,877)	2,417 (5,330)
Potassium	0 (0)	3,996 (8,812)	9,182 (20,246)	33,891 (74,729)	65,960 (145,441)	92,329 (203,586)	66,661 (146,987)	112,682 (248,465)
Magnesium	286 (630)	1,041 (2,296)	1,534 (3,383)	715 (1,577)	499 (1,100)	1,369 (3,020)	916 (2,019)	568 (1,253)
Manganese	294 (647)	413 (910)	778 (1,716)	961 (2,118)	245 (540)	388 (855)	151 (332)	659 (1,454)
Sodium	21,232 (46,816)	30,787 (67,886)	61,178 (134,897)	51,108 (112,694)	76,399 (168,459)	460,905 (1,016,295)	77,164 (170,147)	125,758 (277,297)
Phosphorus	394 (869)	1,219 (2,689)	2,006 (4,424)	305 (673)	439 (968)	887 (1,956)	521 (1,149)	1,875 (4,135)
Antimony	2,393 (5,277)	2,555 (5,633)	6,560 (14,464)	1,338 (2,950)	1,634 (3,604)	393 (867)	2,024 (4,463)	908 (2,003)
Silicon	2,383 (5,254)	1,051 (2,317)	2,347 (5,175)	1,514 (3,339)	2,372 (5,231)	9,098 (20,060)	2,220 (4,895)	4,175 (9,206)
Strontium	21 (47)	31 (69)	66 (145)	18 (40)	18 (40)	17 (38)	24 (53)	18 (39)
Titanium	29 (64)	266 (586)	41 (90)	204 (449)	45 (99)	276 (608)	60 (133)	21 (45)
Zinc	1,264 (2,787)	938 (2,068)	1,669 (3,680)	24,278 (53,532)	353 (777)	899 (1,981)	593 (1,308)	536 (1,182)

TABLE 16. (continued)

	Run No.						
Date/Units	14	15	16	17	18	19	20
General							
Date	1/22/91	1/22/91	1/22/91	1/23/91	1/23/91	1/23/91	1/23/91
Start time	10:55	11:00	11:01	10:20	10:20	10:27	10:27
Sampling period, min	256.0	275.2	275.2	170.7	170.7	183.4	183.4
Isokinetic ratio, percent	105.1	102.8	107.0	113.0	91.3	104.0	104.0
Cell recirculation rate, L/min (gal/min)	12,961 (3,424)	12,961 (3,424)	12,961 (3,424)	12,458 (3,291)	12,458 (3,291)	12,458 (3,291)	12,458 (3,291)
Barometric pressure, mm Hg (in Hg)	762 (30.0)	762 (30.0)	762 (30.0)	772 (30.4)	772 (30.4)	772 (30.4)	772 (30.4)
Concentration in cooling water, ppm							
Aluminum	1.05	1.05	1.05	1.22	1.22	1.22	1.22
Barium	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium	2.90	2.90	2.90	3.55	3.55	3.55	3.55
Iron	4.49	4.49	4.49	5.41	5.41	5.41	5.41
Potassium	16.52	16.52	16.52	18.44	18.44	18.44	18.44
Magnesium	2.08	2.08	2.08	2.19	2.19	2.19	2.19
Manganese	0.12	0.12	0.12	0.14	0.14	0.14	0.14
Sodium	1,529.10	1,529.10	1,529.10	1,508.90	1,508.90	1,508.90	1,508.90
Phosphorus	8.40	8.40	8.40	8.90	8.90	8.90	8.90
Antimony	74.78	74.78	74.78	73.96	73.96	73.96	73.96
Silicon	3.30	3.30	3.30	3.60	3.60	3.60	3.60
Strontium	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Titanium	0.04	0.04	0.04	0.17	0.17	0.17	0.17
Zinc	0.19	0.19	0.19	0.21	0.21	0.21	0.21
Gas Stream							
Temperature, °C (°F)	10.0 (50)	10.6 (51)	10.6 (51)	14.4 (58)	14.4 (58)	12.8 (55)	12.8 (55)
Moisture, percent by volume	1.4	1.4	1.4	1.3	1.7	2.0	1.6
Flow rate, m^3/min (acfm)	4,759 (168,052)	4,141 (146,229)	4,140 (146,211)	5,014 (177,067)	5,016 (177,139)	4,696 (165,823)	4,701 (166,008)
Flow rate, dsm^3/min (dscfm)	4,880 (172,340)	4,233 (149,506)	4,233 (149,488)	5,126 (181,039)	5,111 (180,494)	4,818 (170,153)	4,824 (170,343)

TABLE 16. (continued)

	Run No.						
Date/Units	14	15	16	17	18	19	20
Emissions measured by Method 13, x 10^6							
Concentration, mg/dsm^3 (gr/dscf)							
Aluminum	1,759 (0.769)	2,526 (1.104)	3,154 (1.378)	4,506 (1.969)	6,781 (2.963)	771 (0.337)	5,259 (2.298)
Barium	171 (0.075)	360 (0.157)	324 (0.142)	592 (0.259)	1,230 (0.538)	769 (0.336)	567 (0.248)
Calcium	18,765 (8.2)	15,894 (6.946)	33,709 (14.731)	6,716 (2.935)	16,456 (7.191)	6,720 (2.937)	16,460 (7.193)
Iron	10,410 (4.549)	7,659 (3.347)	23,420 (10.235)	8,541 (3.732)	61,982 (27.086)	2,156 (0.942)	9,224 (4.031)
Potassium	340,990 (149.013)	407,397 (178.032)	489,186 (213.774)	1,191,969 (520.89)	1,441,388 (629.887)	108,191 (47.279)	1,122,775 (490.653)
Magnesium	1,060 (0.463)	2,305 (1.007)	2,177 (0.951)	2,980 (1.302)	3,445 (1.505)	388 (0.17)	1,991 (0.87)
Manganese	1,083 (0.473)	1,271 (0.555)	647 (0.283)	2,142 (0.936)	989 (0.432)	1,486 (0.649)	5,144 (2.248)
Sodium	355,918 (155.536)	483,281 (211.194)	544,183 (237.808)	1,180,126 (515.715)	1,404,377 (613.713)	191,840 (83.834)	1,088,224 (475.554)
Phosphorus	1,829 (0.799)	5,589 (2.442)	5,547 (2.424)	3,295 (1.44)	16,371 (7.154)	0 (0)	3,980 (1.739)
Antimony	4,268 (1.865)	4,860 (2.124)	17,795 (7.776)	4,393 (1.92)	38,881 (16.991)	2,043 (0.893)	6,859 (2.997)
Silicon	16,001 (6.992)	12,394 (5.416)	10,419 (4.553)	23,726 (10.368)	32,486 (14.196)	8,783 (3.838)	9,350 (4.086)
Strontium	68 (0.03)	84 (0.037)	92 (0.04)	95 (0.042)	192 (0.084)	18 (0.008)	73 (0.032)
Titanium	57 (0.025)	314 (0.137)	191 (0.083)	148 (0.065)	283 (0.124)	1,090 (0.476)	472 (0.206)
Zinc	2,469 (1.079)	2,151 (0.94)	3,579 (1.564)	3,157 (1.38)	10,840 (4.737)	1,337 (0.584)	1,723 (0.753)
Emissions, kg/hr (lb/hr)							
Aluminum	515 (1,136)	643 (1,417)	800 (1,764)	1,387 (3,059)	2,079 (4,585)	223 (491)	1,523 (3,357)

TABLE 16. (continued)

Data/Units	Run No. 14	15	16	17	18	19	20
Emissions, kg/hr (lb/hr)							
Barium	50 (110)	91 (202)	81 (179)	182 (400)	377 (832)	223 (491)	165 (364)
Calcium	3,207 (7,071)	4,766 (10,509)	4,036 (8,900)	8,770 (19,339)	10,339 (22,797)	1,943 (4,284)	4,764 (10,505)
Iron	3,049 (6,722)	1,946 (4,291)	5,949 (13,118)	2,627 (5,793)	19,009 (41,916)	625 (1,377)	2,669 (5,885)
Potassium	99,858 (220,186)	103,498 (228,214)	124,262 (273,997)	366,683 (808,537)	442,077 (974,780)	31,281 (68,975)	324,989 (716,601)
Magnesium	310 (684)	587 (1,294)	554 (1,221)	917 (2,021)	1,058 (2,333)	113 (249)	576 (1,270)
Manganese	316 (697)	323 (711)	165 (364)	658 (1,452)	304 (670)	431 (950)	1,488 (3,281)
Sodium	104,230 (229,827)	122,775 (270,720)	138,230 (304,797)	363,041 (800,505)	430,726 (949,751)	55,467 (122,304)	314,989 (694,550)
Phosphorus	536 (1,182)	1,420 (3,131)	1,410 (3,109)	1,012 (2,232)	5,021 (11,071)	0 (0)	1,152 (2,540)
Antimony	1,250 (2,757)	1,235 (2,722)	4,521 (9,970)	1,350 (2,978)	11,925 (26,294)	590 (1,301)	1,986 (4,378)
Silicon	4,686 (10,332)	3,148 (6,941)	2,647 (5,835)	7,300 (16,097)	9,965 (21,972)	2,565 (5,655)	2,706 (5,968)
Strontium	20 (45)	20 (45)	23 (50)	31 (68)	58 (128)	6 (13)	20 (45)
Titanium	18 (39)	79 (174)	48 (106)	46 (102)	86 (189)	315 (695)	136 (300)
Zinc	723 (1,595)	546 (1,204)	909 (2,005)	972 (2,143)	3,325 (7,331)	387 (854)	498 (1,098)

C.4 REFERENCES FOR APPENDIX C

1. Entropy Environmentalists, Inc. Emission Test Report: Department of Energy Gaseous Diffusion Plant, Paducah, KY. Prepared for U. S. Environmental Protection Agency. Research Triangle Park, NC. EMB Report 85-CCT-2. October 1986. 53 pp.

2. Entropy Environmentalists, Inc. Emission Test Report: Natural Bureau of Standards Steam and Water Chill Plant, Gaithersburg, MD. Prepared for U. S. Environmental Protection Agency. Research Triangle Park, NC. EMB Report 86-CCT-4. October 1986. 44 pp.

3. Entropy Environmentalists, Inc. Emission Test Report: Exxon Company, U.S.A., Baytown, TX. Prepared for U. S. Environmental Protection Agency. Research Triangle Park, NC. EMB Report 86-CCT-3. November 1986. 62 pp.

4. Entropy Environmentalists, Inc. Emission Test Report: Southeastern Manufacturing Facility. Prepared for U. S. Environmental Protection Agency. Research Triangle Park, NC. EMB Report 86-CCT-04. July 1988. 75 pp.

5. McClintock, S., and W. Kirk (Entropy Environmentalists, Inc.). Emission Test Report: National Institute of Standards and Technology, Gaithersburg, MD. Prepared for U. S. Environmental Protection Agency. Research Triangle Park, NC. EMB Report 91-CCT-5. June 1991.

6. McClintock, S., and W. Kirk (Entropy Environmentalists, Inc.). Emission Test Report: Mineral Drift Emission Testing of a Cooling Tower--Chromium NESHAP Development, Allied Fibers Process Cooling Tower, Moncure, NC. Prepared for U. S. Environmental Protection Agency. Research Triangle Park, NC. EMB Report 91-CCT-__. August 1991.

7. Memorandum. Wallace, D., and R. Marinshaw, MRI, to Myers, R., EPA:ISB. August 28, 1991. Analysis of Drift Rate Data From the NIST and Allied Tests.

APPENDIX D.

EMISSION MEASUREMENT OF COOLING TOWERS

APPENDIX D - EMISSION MEASUREMENT OF COOLING TOWERS

D.1 INTRODUCTION

Between June 1986 and January 1991, The EPA's Emission Measurement Branch sponsored a total of six emission testing programs at five cooling tower facilities. The data were collected to support a chromium National Emission Standards for Hazardous Air Pollutants (NESHAP). The test sites were selected based principally upon (1) cooling tower design, (2) drift eliminator design, and (3) additives and mineral concentrations in the cooling tower water. Secondary considerations included availability and funding.

The specific objectives of these test programs were:

- To determine the total chromium and hexavalent chromium emissions from cooling tower facilities.
- To determine the mineral drift emission rates from cooling tower facilities and whether one or more surrogate compounds could be used to establish the emission rates for all compounds.
- To assess the performance of various methods for the determination of particulate emissions from cooling towers.
- To assess the performance of new methods for the sampling and analysis of hexavalent chromium.
- To assess the performance of available methods for the determination of cooling tower drift emissions.

To accomplish these objectives, the following types of data were obtained:

- Emission concentrations of minerals, total chromium, and hexavalent chromium (Cr^{+6}) through the use of isokinetic sampling equipment.

- Emission concentrations of surrogate compounds through the use of isokinetic sampling equipment.
- Particle size distribution and concentration in cooling

D.2 EMISSION MEASUREMENT METHODS

D.2.1 Scope of Test Programs

Table D-1 summarizes the types of data collected at each test site and the measurement locations. The test methods used for collection and analysis are discussed in Section D.2.2.

D.2.1.1 Facility Selection - As previously mentioned, EPA's Emission Measurement Branch (EMB) sponsored a total of six test programs at five cooling tower facilities from 1986 through 1991. Facilities in reasonably good condition, with at least some cells of the cooling tower system equipped with high-efficiency drift eliminators, were selected for testing.

All the cooling tower systems selected were mechanically-induced draft cooling towers built by Marley.* These towers use a large fan to force air through the cooling tower and out the top of the fan stack. The most common type of cooling tower systems function as a heat exchanger for air conditioner systems in large office or administrative complexes. Cooling towers are also used to cool process equipment or products within an industrial facility. Depending on tower size and the needs of the facility, between 1,500 and 70,000 gallons of water may circulate through the tower each minute.

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*Mention of company or product names does not constitute endorsement by the US. Environmental Protection Agency.

TABLE D-1. SUMMARY OF EPA-SPONSORED COOLING TOWER TEST PROGRAMS

Test Program Dates	Facility Test No. of Fan Cells Drift Eliminator	Sample Type or Method	Pollutants/ Parameters Measured
June 1986	NBS (NIST), MD	Emissions/M13	Soluble Cr Total Cr
	Four Fan Cells	Emissions/Sensitive Paper	Drift Rate, Drift Size
	All Equipped with Munters D-15 HEDE's	Tower Water	Cr^{+6}, Soluble Cr, Total Cr
June 1986	Paducah Gaseous Diffusion Plant, KY	Emissions/M13	Total Cr, NaBr
	Seven Fan Cells	Emissions/Disk Sizing	Total Cr < 15 μm
	Five cells equipped with standard efficiency and two cells equipped with Thermatec Spectra HEDE's	Emissions/Sensitive Paper, Absorbent Paper	Drift Rate, Drift Size
		Tower Water	Cr^{+6}, Total Cr
September 1986	Exxon Company, TX	Emissions/M13	Total Cr
	Five Fan Cell System-Standard Efficiency Drift Eliminators	Emissions/Sensitive Paper, Absorbent Paper	Drift Rate, Drift Size
	Four Fan Cell System - equipped with Marley XCEL-15 HEDE's	Tower Water	Cr^{+6}, Total Cr
July 1987	Southeastern Manufacturing Facility	Emissions/M13 (CTD)	C^{+6}, Total Cr
	Four Fan Cells, two cells equipped with Marley XCEL-10 HEDE's, and two cells equipped with standard efficiency drift eliminators	Emissions/Backward Nozzle	Total Cr < 4 μm
		Ambient Air/MM5	Total Cr
		Tower Water	Cr^{+6}, Total Cr
July 1990	NIST, MD	Emissions/M13 (CTD)	32 Minerals
	Four Fan Cells, all equipped with Munters D-15 HEDE's	Emissions/MM5	PM10
		Ambient Air/MM5	32 Minerals
		Tower Water	32 Minerals, suspended dissolved solids
January 1991	Allied Fibers, NC	Emissions/M13 (CTD)	32 Minerals
	Four Fan Cells, all equipped with Marley XCEL-15 HEDE's	Emissions/MM5	PM10
		Ambient Air (CTD)	32 Minerals
		Tower Water	32 Minerals, suspended dissolved solids

M13: Modified Method 13 sample train.
MM5: Modified Method 5 sample train.

Figure D-1 is a schematic of the cooling tower system located at the National Institute of Standards and Technology in Gaithersburg, Maryland. This system is typical of most cooling tower designs.

Water droplets and aerosols that leave the cooling tower through the fan cells are referred to as drift. Emissions or drift from the cooling tower are reduced by high-efficiency drift eliminators. Drift eliminators are designed to reduce cooling tower drift by forcing the exhaust air through several directional changes which cause water droplets in the air to impact the drift eliminator surface and drain into the cold water basin of the tower. The drift eliminators tested in this study were made by Marley, Munters, and Thermatec.

D.2.1.2 Types of Samples and Data Collected - Samples and data collected from cooling towers fall into four major categories:

- Tower Emission Samples
- Cooling Water Samples
- Ambient Air Samples
- Meteorological Data

Emissions were analyzed for:

- Total Chromium
- Hexavalent Chromium
- Minerals (32 elements)
- Surrogate compounds, such as Sodium Bromide
- Total Particulate
- PM_{10}

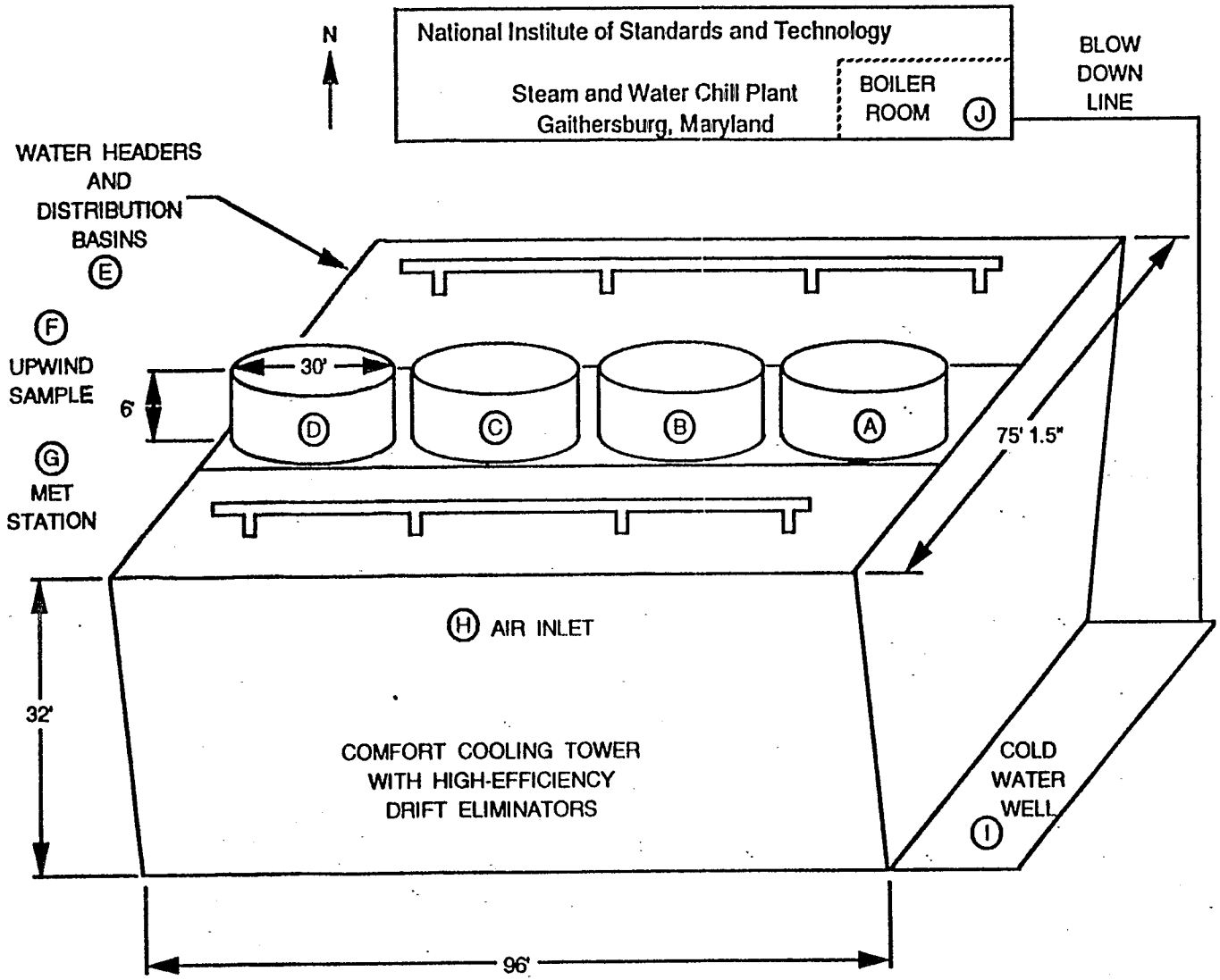

Figure D-1. Schematic of Marley Comfort cooling tower with Munters D-15 high efficiency drift eliminators.

Cooling tower water samples were collected for measuring the concentrations of the following:

- Total dissolved and suspended solids
- Minerals (32 elements)
- Total chromium
- Hexavalent chromium

Ambient air samples were analyzed for:

- Minerals (32 elements)
- Total chromium

As an integral part of all the test programs, process operation data were monitored and recorded. These data typically included:

- Recirculating water flow and water pressure
- Water blowdown rates (if applicable)
- Water temperature in the basin or riser
- Water chemistry and/or additives
- Fan speed or amperage

Depending on the availability and compatibility of data acquisition systems, these data were collected either automatically or manually. In some cases, the same data were collected both ways as a quality assurance check on the data.

D.2.1.3 Emission and Process Sampling Locations - Stack emissions from a cooling tower fan cell were generally sampled at the top of the fan stack directly over the fan blade. The sampling equipment was traversed across the fan cell between the hub of the fan blade and the edge of the cell wall. The traverse

points were determined using an annular area formula along radii that formed 90° angles to each.

Ambient air samples were taken about 100 meters upwind of the test site. Occasionally, ambient air sampling locations were moved from one day to another due to changes in wind direction.

Cooling water samples were taken either from the deck located on top of the cooling tower or from a spigot on the riser pipe.

Meteorological (met) data were taken on-site for temperature and barometric readings of the day. Locally available met stations at airports or industrial facilities were used to supply detailed weather analysis data (such as dew points, wind speed and direction, etc.) during the test program.

D.2.2 Selection of Sampling and Analytical Methods

Several toxic and many non-toxic pollutant emissions were measured during the test programs. This section discusses the rationale behind the selection of the test method(s) used to measure each pollutant and describes the application of these methods during the test programs.

D.2.2.1 Total Chromium and Hexavalent Chromium Emissions -

Hexavalent chromium has been the primary concern in air emissions from cooling tower facilities. Hexavalent chromium, a carcinogen, as chromate is used in some cooling tower systems for corrosion control. Since emissions of chromium have been routinely measured by industry, one of the first objectives of

these test programs was to ascertain the makeup of chromium emissions in terms of total chromium and Cr^{+6}. A modified Method 13 train was selected for this purpose. Before the first test, it was assumed that the ratio of Cr^{+6} to total chromium in the air emissions was the same as the ratio of Cr^{+6} to total chromium in the cooling tower recirculating water.

The first test program produced results for total chromium emissions that approximated those concentrations anticipated through the use of mass-balance equations. The analysis was done using Neutron Activation Analysis (NAA). A graphite furnace atomic absorption spectrometer (GFAA) was used in tandem with the NAA for quality control studies. However, Cr^{+6} emissions were less than 25% of the anticipated values.

Over the next three test programs, various methods were used to determine Cr^{+6} emissions, but none were successful. One of the biggest obstacles to the test program was the inability to prevent Cr^{+6} from converting to trivalent chromium during the sampling phase of the test. Though a test method for Cr^{+6} was later developed under another EPA study, attempts to verify Cr^{+6} emissions from cooling towers were dropped after the failure of the July 1987 test program to quantify Cr^{+6} emissions.

D.2.2.2 <u>Minerals and Surrogate Compounds</u> - The June 1986 test program was the first attempt for this series of test programs to quantify emissions by measuring a surrogate compound for C^{+6}. In theory, the ratio of the surrogate to other components in the cooling water was believed to be the same as in the emissions.

The use of surrogate compounds had been used by industry in previous emissions tests to establish the drift rates of cooling towers. Cooling tower drift rate (i.e., the emission rate of water droplets and aerosols) is defined as the mass emission rate of a compound (typically in units of micrograms per hour [μg/hr]) divided by its mass circulation rate in the water (also in μg/hr) times 100%. Industry test programs utilized emission sampling methods similar to Method 13 and another method which used heated, glass beads. Industry test teams have reported drift rates that closely match the expected drift rate of 0.005%.

In the EPA-sponsored test programs, a modification of the Cooling Tower Institute test method, similar to Method 13, was used in determining cooling tower drift emissions (see Figure D-2). These modifications included:

- The use of 0.5 molar (M) nitric acid for a reagent instead of 0.1 M nitric acid, and the use of 0.5 M nitric acid for rinsing the probe and sampling glassware instead of 1.0 M nitric acid. This step made the molarity of nitric acid in the combined reagent/rinse sample consistent.

- The use of three impingers with a total of 250 milliliters (mL) of reagent instead of two impingers with 200 mL of reagent, and using the filter only as a quality control step. Removing the filter from the sample analysis results eliminated ambiguities due to high blank levels of the target compounds.

- Using acetone to first rinse the nozzle and probe of the sampling equipment. Formerly, only the nitric acid was used as a rinse reagent. Because of the long length of the sampling probe, it was believed that rinsing with an additional reagent would assure complete sample collection.

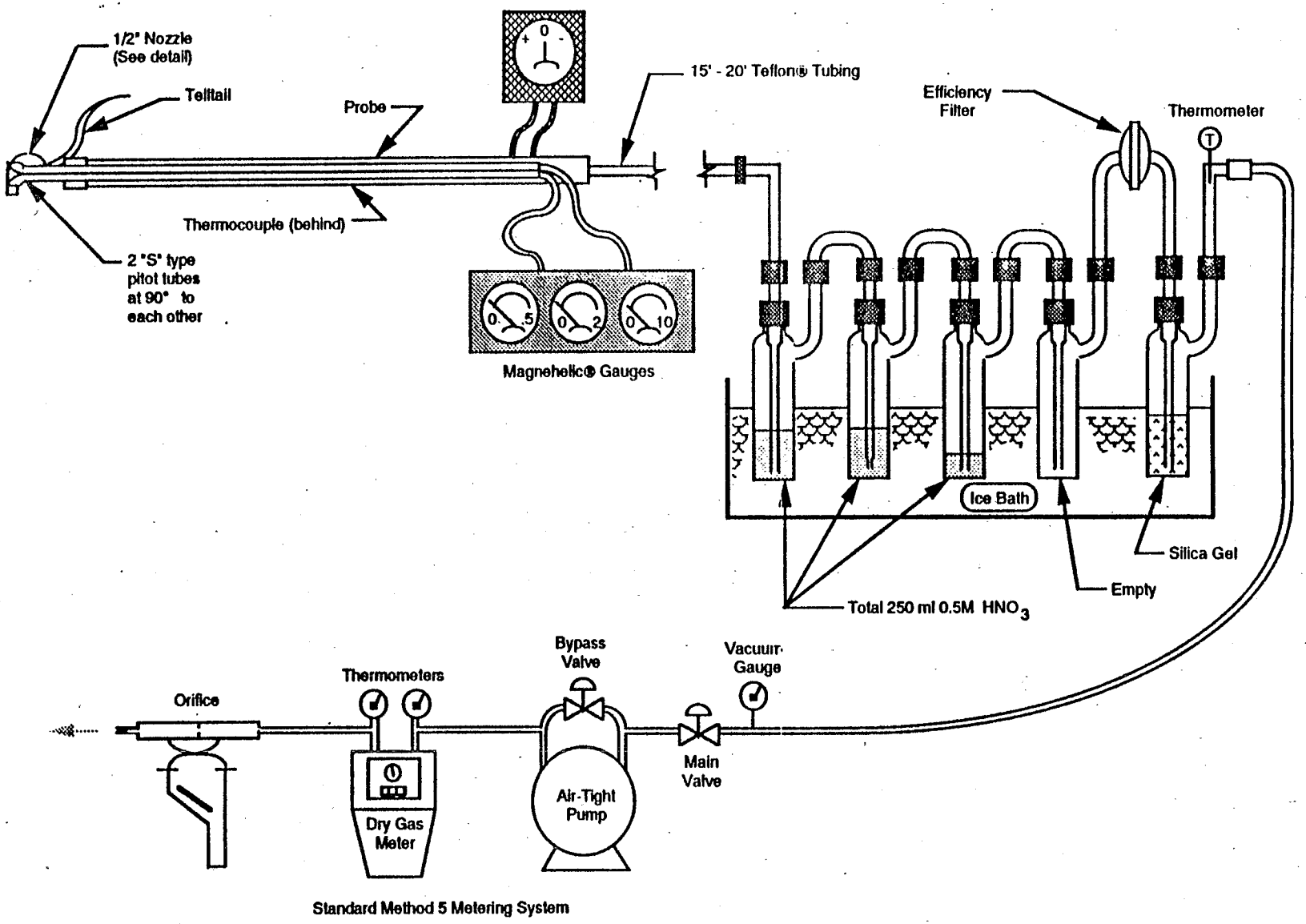

Figure D-2. Schematic of CTD emission test method sampling train.

The modified test method, known as EPA's Draft Cooling Tower Drift (CTD) Emission Test Method, or the CTD method, was utilized in the last two test programs at NIST, Maryland and Allied Fibers, North Carolina. For the Allied Fibers test, the relative standards deviations (RSD) among five sets of paired trains ranged from 39 to 154% depending upon the element analyzed. Previous test programs by both EPA and industry had RSD's usually exceeding 200%. These large variances in precision are usually attributed to the unique characteristics of cooling towers, particularly the large stack diameter to be sampled and considerable cyclonic flow that prevents a uniform distribution of emissions across the stack opening.

However, the drift rates among the compounds tested varied sharply from the expected "single-value" drift number that had been assumed. The NIST drift rate averages ranged from a value of 0.007%, which is comparable to industry estimates, to values up to 6.0%. The Allied Fibers drift rate averages ranged from 0.02 to 2.00%. Data assessment suggests that a linear relationship existed between the solubility of a compound and its drift rate, but no theory is proposed as to why this relationship occurred, and the relationship was not consistent enough to use as the basis for predicting emissions with surrogate compounds.

Inspection of previous industry test reports show that this pattern of inconsistent drift rates was always present. Several reports cited drift rates of 0.005% for cooling towers; however, the results were based on calculations using only those elements associated with low drift rates, such as sodium and magnesium.

Data presented in the appendices of these reports did not present the actual element-specific drift rates, but when calculated, the drift values for elements such as iron and copper were orders of magnitude greater than those presented in the report.

Based on the test programs at Allied Fibers and NIST, together with a reevaluation of previous industry test reports, the use of surrogate compounds to determine emissions of other pollutants is not recommended.

D.2.2.3 Particle Size - Evaluating the test methodology used to determine the particle size of drift emissions progressed through several stages. During the first three test programs, both a sensitive paper (SP) sampling method and an absorbent paper (AP) sampling method were used in determining particle counts and sizes. Both methods showed good mutual agreement, but fell well short of approximating the values calculated by mass balance. The SP and AP techniques are believed to have significantly underestimated the small droplet flux downstream of high-efficiency drift eliminators.

In response to the inconsistency noted above, the Southern Research Institute suggested another method of particulate/PM_{10} collection. This method employed a modified Method 5 sampling train in tandem with an impaction paper (IP) sampling device. The modified Method 5 train consisted of a glass nozzle followed by 6 inches of heated glass probe and a 47-millimeter (mm) total particulate filter. The IP device consisted of a 47-mm absorbent paper placed near the nozzle in a heated Teflon™ holder. In

theory, the IP device would capture particles larger than 30 microns (μ) in diameter, whereas smaller particles would flow around the impaction device. The 30-μ size was considered optimal in that water droplets of this size or smaller would evaporate and form PM_{10} particles.

This system, when employed during the NIST test, provided no usable data because the gravimetric analysis of the total particulate filters was either negligible or negative. The same system, when used at the Allied Fibers test, provided data, but interpretation of the data remained circumspect due to: (a) the inability to provide an <u>accurate</u> assessment of how much of the particulate captured by the impaction device could be compared to the total particulate sampled through the nozzle, and (b) the fact that the Allied Fibers cooling tower was considerably different from the majority of cooling towers, with higher amounts of dissolved and suspended solids present in the cooling water, and large amounts of additives/pollutants.

D.2.2.4 <u>Ambient Air</u> - During the last three test programs at Southeastern Manufacturing Facility (SMF), NIST, and Allied Fibers, ambient air samples were taken upwind of the cooling tower. The ambient air system for SMF and NIST consisted of a modified Method 5 train consisting of a filter holder with a 3-inch filter collecting the air sample. Because of the high blank values of filters (with respect to air emissions), the last test at Allied Fibers used a CTD sampling train without a probe to capture ambient air samples.

Since a full battery of air samples was not taken, the ambient air samples were not used to correct the emission results from the cooling tower. This step was primarily a quality control step in the case of a local phenomenon affecting the test program.

D.3 COOLING TOWER OPERATIONS AND MONITORING

The emission rate is a function of air velocity through the fill, type of fill, type of drift eliminator, recirculation rate, concentration of cooling water constituents, and tower condition. Air velocity is generally considered to be the most important factor in drift or emission rate. Improper maintenance of the drift eliminators, basins, or fan cells can result in high drift rates.

D.4 QUALITY ASSURANCE/QUALITY CONTROL FOR TEST PROGRAMS

A vital part of any sampling and analysis program is provision for procedures that assure the quality of data obtained. These procedures are termed quality assurance and quality control (QA/QC) and serve to (1) document the quality (accuracy, precision, completeness, representativeness, and comparability) of generated data (QA); (2) maintain the quality of data within predetermined control limits for specific sampling and analysis procedures (QC); and (3) provide guidelines for corrective actions if QC data indicate that a particular procedure is out of control.

Cooling tower test programs are complex and the test methods applied to these sources are not routinely done. Therefore, EPA recognized that a rigorous QA/QC program was essential to successful test programs. This section describes both the QA/QC procedures for the EPA-sponsored cooling tower test programs and the recommended QA/QC procedures for future cooling tower testing.

D.4.1 QA/QC for Previous EPA Cooling Tower Test Programs

A QA/QC Procedures Section was included in each work plan (site-specific test plan) for all test programs. The QA/QC section was reviewed by all test team participants, including the Work Assignment Manager, prior to each test program. Though not always stated in each QA/QC section, the following elements were implicit in each QA/QC plan for each test program:

- Title Page
- Table of Contents
- Project Description
- Project Organization and Responsibility
- QA Objectives
- Sampling Procedures
- Sample Custody
- Calibration Procedures and Frequency
- Analytical Procedures
- Data Reduction, Validation, and Reporting
- Internal QC Checks
- Performance and System Audits
- Preventive Maintenance
- Assessment of Data Precision, Accuracy, and Completeness
- Corrective Action
- Reports to Management

The following discussions will utilize the QA/QC elements to highlight the QA/QC procedures and QA/QC content for the EPA cooling tower test programs.

D.4.1.1 Title Page and Table of Contents - Self-explanatory.

D.4.1.2 Project Description - A general description of the test program and the process to be tested was provided. In the majority of cases, a test matrix table was prepared. A schedule with anticipated dates for completion of significant subtasks was prepared.

D.4.1.3 Project Organization and Responsibility - Because all the cooling tower test programs were complex, and most involved interaction of several parties, the delineation of test program organization and responsibilities was crucial to the success of the project. The responsibilities of key personnel and organizations were described in the text of each work plan.

D.4.1.4 Quality Assurance Objectives - The QA objectives were generally based on previous experience in the application of the various measurement/sampling systems.

D.4.1.5 Sampling Procedures - Detailed descriptions of all sampling procedures used were included in each work plan. These descriptions addressed the following areas:

- Sampling location specification and guidelines used to select them.
- Specific sampling procedures to be used (by reference for standard protocol and by detailed description for nonstandard protocols).
- Figures to illustrate sampling locations, sampling equipment, charts or flow diagrams to summarize procedural steps.

- Description of containers, procedures, reagents, etc. for sample collection, preservation, transport, and storage.
- Special procedures for equipment preparation.
- Sample preparation procedures (concentration, dilution, cleanup).
- Forms for sample collection, recovery, and transport.

D.4.1.6 Sample Custody - Each work plan addressed the procedures used to ensure sample integrity.

D.4.1.7 Calibration Procedures and Frequency - When required, each work plan included a description of the calibration procedures for each critical measurement system. This included listing the procedures for reference to standard operating procedures, the frequency of calibration, and information on the calibration standards used (source, traceability, purity).

D.4.1.8 Analytical Procedures - As for the sampling procedures, details of the analytical procedures were established in the work plan. This involved reference to standard protocols, complete description of procedures for nonstandard protocols, and flow diagrams and charts summarizing procedures.

D.4.1.9 Data Reduction, Validation, and Reporting - For each critical measurement parameter, the following were considered:

- The data reduction scheme planned on the collected data.
- All equations used to calculate the concentration or value of the measured parameter and the reporting units.

- The principal procedures used to validate data integrity during collecting, transferring (if applicable), and reporting of data.
- The methods used to identify and treat outliers.
- The data flow or reporting scheme from collection of raw data through storage and validation of results.

D.4.1.10 Internal QC Checks - The section on internal QC checks addressed the acceptance criteria and control limits used to control the data quality in the field. Table D-2 summarizes the typical control limits for the EPA cooling tower test programs along with corrective actions.

Also included in the internal QC checks were the QC samples analyzed to document the validity of the data and control its quality. QC samples for the cooling tower test program included blank samples, analytical replicates, and spiked samples.

D.4.1.11 Performance and System Audits - Performance and technical systems audits were conducted for each cooling tower test program. Technical systems audits consist of an evaluation of all components of a critical measurement system to determine their proper selection and use. They include a careful evaluation of both field and laboratory quality control procedures. Systems audits were typically performed before or shortly after systems were operational, and were sometimes repeated depending on the measurement system and the test program duration.

TABLE D-2.

SUMMARY OF ACCEPTANCE CRITERIA, CONTROL LIMITS, AND CORRECTIVE ACTIONS

Criteria	Control Limits	Corrective Action
Manual Sampling		
Flow Alignment	Avg. resultant angle within 20°	Adjust flow data to correct for misalignment based on misalignment angles
Isokinetics	100 ± 10%	Qualify data
Final Leak rate (after each port)	≤ 0.02 acfm or 4% of sampling rate, whichever is less	Adjust sample volume for port
Dry Gas Meter Calibration	Post average factor (Y) agrees ± 5% of pre-factor	Adjust sample volumes using the Y that gives smallest volume
Individual Correction Factor (Y_i)	Agree with 2% of average factor	Redo correction factor
Average Correction Factor	1.00 ± 1%	Adjust the dry gas meter and recalibrate
Intermediate Dry Gas Meter	Calibrated every six months against standard	Recalibrate against EPA standard
Analytical Balance (top loader)	0.1g of NIST Class S Weights	Repair balance and recalibrate
Barometric Pressure	Within 2.5 mm Hg of a mercury-in-glass barometer	Recalibrate
Mineral (Element) Analytical Results		
Instrument Calibration Standard Check (every 10 samples)	± 10% of true value	Recalibrate
Instrument Calibration Blank Check (every 10 samples)	± 3 times the standard deviation of the mean blank value	Identify and correct problem, recalibrate and reanalyze previous 10 samples
Instrument Interference Check (before and after every analytical run or at least once every 4 hours)	± 20% of true value	Reverify interelement and background correction factors
Duplicate (every 10 samples)	± 20% relative percent difference	Reanalyze

TABLE D-2. (continued)

Criteria	Control Limits	Corrective Action
Duplicate Matrix Spike Recovery (every 10 samples)	± 20% of true value	Reanalyze
Hexavalent Chromium Analytical Results		
Instrument Calibration Check Sample (every 10 samples)	± 10% of true value	Recalibrate
Matrix Spike (every 10 samples)	± 10% of true value	Reanalyze
Duplicate (every 10 samples)	± 20% relative percent difference	Reanalyze
Calibration Linearity Check (6 points, prior to analysis of sample)	± 10% of true value for each point	Remake and/or reanalyze standards
Particle Sizing		
Analytical Balance	< ± 2 mg of NIST Class S weights	Adjust or repair balance and recalibrate
Constant Weight	± 0.5 mg for sequential weighings ≥ 6 hours apart	Desiccate and reweigh until criteria are met

[e]Relative difference (%) for duplicate analyses, where:

$$\text{Percent Difference} = \frac{\text{First Value} - \text{Second Value}}{0.5\ (\text{First} + \text{Second Value})} \times 100\%$$

D.4.1.12 Preventive Maintenance - The work plan addressed procedures for preventive maintenance activities relevant to the sampling and analysis efforts. Preventive maintenance tasks were performed to minimize downtime during the test programs.

D.4.1.13 Assessment of Data Precision, Accuracy, and Completeness - Specific procedures (calculations, etc.) to assess data precision, accuracy, and completeness were included in each work plan.D.4.1.14 Corrective Action - Depending on the scope of the test program, work plans presented a corrective action scheme including staff responsibilities to be followed when a measurement system was found to be out of control.

D.4.1.14 Corrective Action - Depending on the scope of the test program, work plans presented a corrective action scheme including staff responsibilities to be followed when a measurement system was found to be out of control.

D.4.1.15 QA Reports to Management - For each cooling tower test program, a mechanism was established for reporting to management on the performance of critical measurement systems and data quality. Items reported included:

- Changes to the work plan, if any.
- Limitations or constraints on the use or applicability of the data, if any.
- Quality programs, quality accomplishments, and status of corrective actions.
- Results of QA systems and/or performance evaluation audits.

- Assessments of data quality in terms of precision, bias, completeness, representativeness, and comparability.

The final reports for all test programs included a separate QA section, documenting QA activities that support the data quality and validity of the conclusions.

D.4.2 Recommended QA/QC for Performance Testing

Because of the complexity of cooling tower testing, special attention must be paid to the QA/QC procedures for these programs. It is recommended that QA/QC procedures be an integral part of every performance test program. The essential elements of QA/QC for cooling tower test programs have been identified and defined in the previous section. The control limits, acceptance criteria, and data quality objectives used in the EPA-sponsored cooling tower test programs and presented in the previous section may be used as guidelines. Since the analysis of drift emissions is not currently a routine procedure, some key QA/QC procedures for conducting these analyses and assessing the data for cooling tower test programs are discussed below.

Generally, emission concentrations from cooling towers are measured in amounts below 50 μg per cubic meter. Consistency, care, and planning in sampling procedures, recovery procedures, and analysis are necessary to ensure all QA/QC objectives are met, and that the cause of the problems can be traced down when encountered.

If the analytical detection limits are high, the percent recoveries of the internal standards in the samples should be examined. The analytical detection limit is affected by many

factors, some of which can be controlled to some degree by the analytical laboratory (sample size, final volume, percent recovery of standards, level of standards spiked, and instrument sensitivity) and other factors (sample matrix and interferences) that cannot be controlled by the laboratory. If the sample internal standards are within the QC limits, the high detection limits are most likely a result of sample interferences. If they are poor, the percent recoveries for the laboratory method blank should be examined. If these are within the QC limits, the high detection limits are caused by sample matrix effects and an alternate sample reagent or cleanup procedure may offer improvement.

Blanks and replicate samples, respectively, can be useful in assessing sample contamination and in monitoring the precision of the drift emissions sampling and analysis. If blanks/replicates are used, a suggested sampling frequency is provided below:

- Field Blank - One per sampling location.
- Proof Rinse Blank - One per sampling train and one for a representative number of sample containers. Analyze one of each prior to the field test.
- Reagent and Solvent Blanks - One for each new lot number of reagent used.
- Laboratory Method Blank - One replicate for no more than 10 samples of a given matrix.
- Laboratory Replicate - One replicate for no more than 10 samples of a given matrix.