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AIR TOXICS EVALUATION OF ABB COMBUSTION ENGINEERING LOW-EMISSION BOILER SYSTEMS

July 27, 1993

Work Performed Under Contract No. AC22-92PC92159

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By
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18 Mason, Irvine CA 92718

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ASEA BROWN BOVERI

FOREWORD

By: James D. Wesnor, ABB Environmental System

The following are the major comments to the EER report concerning hazardous air pollutant emissions from the Low-Emission Boiler Systems.

Overall, the EER report is an accurate representation of the state-of-the-art in emissions modeling and control of hazardous air pollutants. The report also provides great detail on present and expected legislation, test methods, and control technologies.

However, comments on the estimating procedures and results are in order.

<u>Partitioning of Trace Metals in/on Flyash:</u> Models were developed from existing pulverized coal-fired boilers to formulate and validate the metals partitioning model. However, general models may not accurately predict the partitioning of trace metals among specific coals.

Most trace metals of concern are associated with the coal ash and are carried from the furnace by one of two methods: the metal vaporizes in the combustion furnace and condenses onto the flyash surface as the gas cools, or the metal remains in the solid phase as a flyash particle. Flyash formation occurs in one of two ways: it melts into a glassy sphere or aerosol particle, or it remains solid, but of a size small enough to be entrained with the flue gas.

Trace metal partitioning will depend greatly upon trace metal concentration and distribution throughout the coal. Larger trace metal deposits, typical of uneven distributions, should form larger flyash particles, while smaller, more evenly distributed deposits should form sub-micron particles, typical of aerosol formations. Effects such as these may be overlooked in the general model.

<u>Effect of APC Systems beyond PCS</u>: The report does a good job at estimating the hazardous air pollutant emissions from the combustion furnace and from the particulate control system (PCS). However,

little work was done on emissions from additional air pollution control (APC) systems downstream of the PCS. Once it was determined that the PCS emissions were below EER's "regulatory limits", work was halted.

Data is now available that should allow adequate modeling of these APC systems. It is expected that both the Advanced Wet FGD and ThioClear systems will provide efficient control by absorption of water-soluble metal forms, in particular mercury, and additional control by direct impaction by droplets of water-insoluble metal forms.

The SNOx process should provide efficient control of most metals. In data recently presented, efficient control (in excess of 99 % entering the boiler) of As, Cd, Cr, Ni, Pb, and Se was demonstrated. However, significant emissions of B and Hg were found from the stack. It is believed that the NO_x oxidation catalyst will provide some reduction in organic emissions, although this is presently not quantified.

The Hot SNOx process is assumed to perform no better than the SNOx process concerning metals emissions, primarily due to the fly ash being collected at a temperature above the condensation temperature of some metals. Therefore, most emissions of As, Cr, and Pb will be vaporous and will depend solely upon the adsorption of these compounds onto the SO_2/SO_3 oxidation catalyst (thought to be minor) or the absorption of these metal compounds into the sulfuric acid. However, oxidation of the organic compounds should be significantly better, due to the elevated reaction temperature. Dioxin/furan formation should be reduced, due to the elevated flyash collection temperature.

Metal Removal Estimates in PCS: Metal capture estimates were for an advanced electrostatic precipitator (ESP), catalytic fabric filter, and catalytic ceramic filter. In addition, estimates of the metal capture efficiency for a HEPA filter and baghouse were provided.

For background, in the LEBS systems the electrostatic precipitator operates at approximately 280°F while the catalytic filters operate in excess of 750°F.

It was estimated that the catalytic filters, while providing no additional particulate removal, will provide greater metal capture than the ESP. Studies have shown that while a typical baghouse should provide greater Class I (non-volatile) and II (semi-volatile) metals control than a typical ESP, both operating at the same mass removal efficiency, this difference is quite small and that both systems will provide in excess of 99 % removal of both metals classes. Also, because of the elevated collection temperature, Class II and III (volatile) metal removal in the catalytic filters would be less than that of the ESP.

Possible explanations for this difference may be the characteristic system performance, where the catalytic filters will act as "absolute filters"- achieving 100 % removal of all particulates above a certain size - while the ESP operates with near 100 % removal throughout the entire particle size range with relative minimum removal efficiencies occurring in the 0.3-0.5 and 10-15 micron range. Calculations support these statements made regarding typical baghouse and ESP performance. Furthermore, it is doubtful that the effect of particulate size would outpace the effect of operating temperature in the LEBS subsystems.

October 26, 1993

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1.0 INTRODUCTION

The Department of Energy's (DOE's) Pittsburgh Energy Technology Center (PETC) is funding a program entitled "Combustion 2000". The intent of the program is to support development of high efficiency/low emission coal combustion devices for the generation of electric power in the 21st century. ABB/CE was awarded a contract to develop their high efficiency low emission boiler (LEB) concept. While the program focusses on ultra low emissions of NO_x, SO_2 and particulate matter, ABB/CE is also concerned about how their design will the impact the emissions of air toxics. As a result, they have subcontracted Energy and Environmental Research to evaluate this aspect of their design.

1.1 Objectives and Scope

The specific goals of the program are to identify air toxic compounds that might be emitted from the new boiler with its various APCD alternatives in levels of regulatory concern. For the compounds thought to be of concern, potential air toxic control methodologies will be suggested, and a Test Protocol will be written to be used in the Proof of Concept and full-scale tests. To accomplish these goals, the following task structure was defined:

- Task 1: Define Regulations and Standards
- Task 2: Identify Air Toxic Pollutants of Interest to Utility Boilers
- Task 3: Assessment of Air Toxic By-Products
- Task 4: State of the Art Assessment of Toxic By-Product Control Technologies
- Task 5: Test Protocol Definition

A brief description of each task is provided in the following paragraphs.

In Task 1, federal and state regulations pertaining to air toxic emissions from coal-fired utility boilers are identified. For state regulations, the National Air Toxic Clearinghouse database was used. On the federal level, the 1990 Clean Air Act (CAA) amendments under Title III were reviewed. Because the CAA amendments have set aside utility boilers from regulation until EPA's current studies have been completed, the intent of Task 2 has been to identify which of the 189 compounds are of interest to utility boilers. In this task, the 189 compounds were broken up into 5 different categories ranging from "known to be emitted in levels of regulatory concern" to "can not be emitted from coal-fired combustion systems". The classification was performed by utilizing various databases, computer modeling, and engineering estimates. In all cases, a conservative approach was adopted.

In Task 3, air toxic emission levels from the LEB are estimated. This is done by first using available data and engineering methods to estimate the uncontrolled levels of air toxic compounds. Next, removal efficiencies of the various compounds via the three alternative Air Pollution Control Devices (APCD) systems being considered for the LEB were determined and applied to the uncontrolled emissions to determine at the stack emission levels of the 189 air toxic compounds of interest. The emission levels were compared to allowable levels (based on a risk assessment) to determine which compounds are of concern for the LEB. In Task 4, the types of control measures for the toxic by-products identified in Task 3 and their development status are discussed.

Finally, in Task 5, a Test Plan is written to serve as a guide for performing measurements of air toxic emissions during the Proof on Concept Tests

1.2 Overview

Section 2 of this report provides a background on air toxic emissions from fossil fuel combustion. Formation and destruction mechanisms of different classes of organics are discussed. In addition, the partitioning of metals introduced with coal between the bottom ash, captured fly ash, and stack gas is considered. The implications of Title III of the CAA Amendments and various state regulations pertaining to coal fired utility boilers are presented in Section 3. A comprehensive assessment of air toxic measurement programs conducted to date is presented in Section 4, with emphasis on the absence of toxic organic information. Section 5 presents the detailed methodology used to classify the 189 air toxic compounds, and the results of the analysis as they pertain to the LEB. Section 6 provides a description of several technologies which are available to destroy emissions of compounds that may not be captured by any of the alternative control technologies currently being considered for the boiler.

2.0 BACKGROUND

Common coal combustion devices include pulverized, spreader stoker, and cyclone coal-fired systems. Coal in high-volume installations frequently is pulverized prior to use. The finely-ground coal is suspended in a gaseous atmosphere while burning. Good mixing between coal and air produces high combustion efficiency and high temperature. Pulverized systems are characterized by ash removal methods such as dry or wet bottom. In the U.S., the utility sector is dominated by pulverized dry bottom coal-fired units since wet bottom coal-fired boilers are unable to meet NO_x emission standards (Brooks, 1989).

Stoker coal-fired units can be divided into two types, overfeed and underfeed stokers, depending on how the air reaches the coal. In overfeed stokers, coal is placed above the air flow. In underfeed stokers, coal is placed under the air flow. There are several designs for each type. Stoker boilers, currently accounting for less than 1% of the total, are obsolete due to their inefficiency and are being removed from service (Brooks, 1989).

In cyclone coal-fired systems, the coal is injected from the front end of the cyclone and a swirl is imparted to the crushed coal in the same rotation as the main combustion air. The main combustion air is injected tangentially creating a swirling motion which throws the large coal particles against the cyclone inside surface where they are trapped in the slag layer and burn to completion. The hot gases then exit through the cyclone core and depart into the main boiler furnace. While coal-fired cyclone boilers are no longer sold in the U.S. due to their inability to meet NO_x emission standards (Brooks, 1989), there are many units still in operation today.

This section and the remainder of the document will focus on pulverized coal-fired systems because of their widespread use in both the U.S. and Europe. Pulverized coal-fired systems also are the main focus of the document because the ABB low emission boiler (LEB) which will be evaluated in section 5.0 has a pulverized coal-firing system. The following sections provide a general background on the mechanisms which impact organic and metal emissions in pulverized coal-fired systems. These sections do not address ABB's LEB specifically and are included to provide background material to support discussions in sections 3-7.

2.1 Organics

Organic emissions from coal fired utility boilers can arise from two sources: Lack of destruction of organics in the coal or combustion byproduct formation. Mixing and kinetic inadequacies may likely be the limiting factors for destruction of organics in coal combustion systems. Numerous studies on the kinetics of nonflame thermal oxidation of pure and mixed organic compounds have been carried out. More recently several studies have been conducted on detailed chemical kinetics of flame zone processes of simple hazardous organic compounds. The nonflame studies have been used to define the temperature at which a two second residence time is sufficient to produce 99.99% oxidation of the starting compound even in the absence of flame radical concentrations. These temperatures are generally below 1650 °F (900 °C) for most organics of interest as summarized in Table 2.1. Also provided in Table 2.1 is the first order global Arrhenius parameters for destruction under nonflame conditions. All coal combustion systems are designed to operate at significantly higher temperatures (2200 °F, 1200 °C at the exit of the boiler furnace) and thus should be conservative relative to kinetic requirements. Kinetic modeling studies by Tsang (Tsang, 1990) using available elementary rate data suggested the importance of the reaction mixture and mixing on the destruction of chlorinated organics. Research by Lyon from

TABLE 2.1. SUMMARY OF THERMAL DECOMPOSITION DATA

Compound	Empirical Formula	$T_{onset}(2)$ (°C)	$T_{99}(2)$ (°C)	$T_{99.99}(2)$ (°C)	$A(s^{-1})$	E_a (kcal/mole)
Acetonitrile	C_2H_3N	760	900	~ 950	$4.7x10^7$	40
Tetrachloroethylene	C_2Cl_4	660	850	920	$2.6x10^6$	33
Acrylonitrile	C_3H_3N	650	830	860	$1.3x10^6$	31
Methane	CH_4	660	830	870	$3.5x10^9$	48
Hexachlorobenzene	C_6Cl_6	650	820	880	$2.5x10^8$	41
1,2,3,4,-Tetrachlorobenzene	$C_6H_2Cl_4$	660	800	850	$1.9x10^6$	30
Pyridine	C_6H_5N	620	770	840	$1.1x10^5$	24
Dichloromethane	CH_2Cl_2	650	770	780	$3.0x10^{13}$	64
Carbon Tetrachloride	CCl_4	600	750	820	$2.8x10^5$	26
Hexachlorobutadiene	C_4Cl_6	620	750	780	$6.3x10^{12}$	59
1,2,4-Trichlorobenzene	$C_6H_3Cl_3$	640	750	790	$2.2x10^8$	39
1,2-Dichlorobenzene	$C_6H_4Cl_2$	630	740	780	$3.0x10^8$	39
Ethane	C_2H_6	500	735	785	$1.3x10^5$	24
Benzene	C_6H_6	630	730	760	$2.8x10^8$	38
Aniline	C_6H_7N	620	730	750	$9.3x10^{15}$	71
Monochlorobenzene	C_6H_5Cl	540	710	780	$8.0x10^4$	23
Nitrobenzene	$C_6H_5NO_2$	570	670	700	$1.4x10^{15}$	64
Hexachloroethane	C_2Cl_6	470	600	640	$1.9x10^7$	29
Chloroform	$CHCl_3$	410	590	620	$2.9x10^{12}$	49
1,1,1-Trichloroethane	$C_2H_3Cl_3$	390	570	600	$1.9x10^8$	32

Note:
$T_{99}(2)$ - Minimum temperature required to achieve 99% destruction at 2.0 seconds gas residence time.
$T_{99}(2)$ - Minimum temperature required to achieve 99.99% destruction at 2.0 seconds gas residence time.

EER (Lyon, 1990) suggests that the extent to which a compound is destroyed by combustion may be dependent on its concentration due to a kinetic threshold of oxidation that exists at low concentrations. His work suggests that the kinetic threshold arises from the fact that generating a high enough equilibrium concentration of free radicals to sustain the oxidation rate requires a minimum amount of fuel. Laboratory studies in a flow reactor (Lyon, 1990) have indicated that the dependence of destruction on concentration for benzene, chloroform, and chlorobenzene is strong and can be accelerated with the addition of a co-oxidizing fuel at higher concentrations in order to generate higher concentrations of radicals as shown in Figure 2.1. Thus, these data suggest that kinetic limitations can be important at low concentrations even at the high temperatures normally encountered in coal combustion systems.

The other parameter that can limit organic destruction is poor mixing of the organics with air. Kramlich (Kramlich, 1990) from EER observed that the absolute emissions levels of organic emissions were relatively constant and independent of initial concentration of the organic in the fuel. He suggested that the unmixed fuel pockets are convected through the flame and a fraction of these are mixed with the hot vitiated combustion products forming a certain fraction of fuel-rich pockets. These fuel-rich pockets approach thermochemical equilibrium in composition and when less than 10 percent theoretical air is present, the equilibrium concentrations of organics rises to high levels. The fuel rich pockets can be subsequently convected out of the flame region where they can be quenched. The quenched pockets containing unburned hydrocarbons yield a base level of organics that is difficult to lower without substantial improvements in mixing.

Thus there appears to be some kinetic or mixing limits that exist in practical coal combustion devices that preclude complete destruction of organics and leads to a low level of mass emissions. However, the kinetic or mixing hypothesis discussed above must be further quantified and shown to account for the observed concentration dependence of destruction efficiency of organics.

It is unlikely that the lack of destruction can account for the emissions of organics from coal fired plants. Another major source of emissions is the formation of combustion byproducts. There is clearly a broad range of organic compounds that can be formed in the combustion process of coal combustion systems in trace amounts including volatile, semivolatile and nonvolatile species. Models that can deal with this myriad of organic compounds in a such a complex and diverse set of combustion systems have not yet been developed. The state of the art in designing and operating combustion systems for minimization of organic emissions has been based upon a phenomenological approach. This approach uses insights gained from smaller scale studies and engineering analysis combined with full scale field studies which have examined the impact of design and operating parameters on organic emissions.

Much of the attention relative to combustion byproduct emissions from combustion systems has been focussed on polychlorinated dibenzo(p) dioxin and furans (PCDD/PCDF) since it was first reported to be present in the exhaust of municipal waste combustion in 1977 (Olie et al., 1977). The phenomenological mechanisms developed for this class of species can be used to indicate the behavior of coal combustion systems relative to other types of trace organic byproduct emissions. It is now clear that several global mechanisms contribute to the emissions of PCDD/PCDF and the relative importance of each of the formation pathways depends on the specific design and operation of the combustor and the fuel properties.

The PCDD/PCDF emission mechanisms can be grouped into four categories as shown in Figure 2.2. The first category of mechanisms involves the lack of destruction of PCDD/PCDF that is originally in the fuel stream (Lustenhower et al., 1980; Graham et al., 1986). Since very low

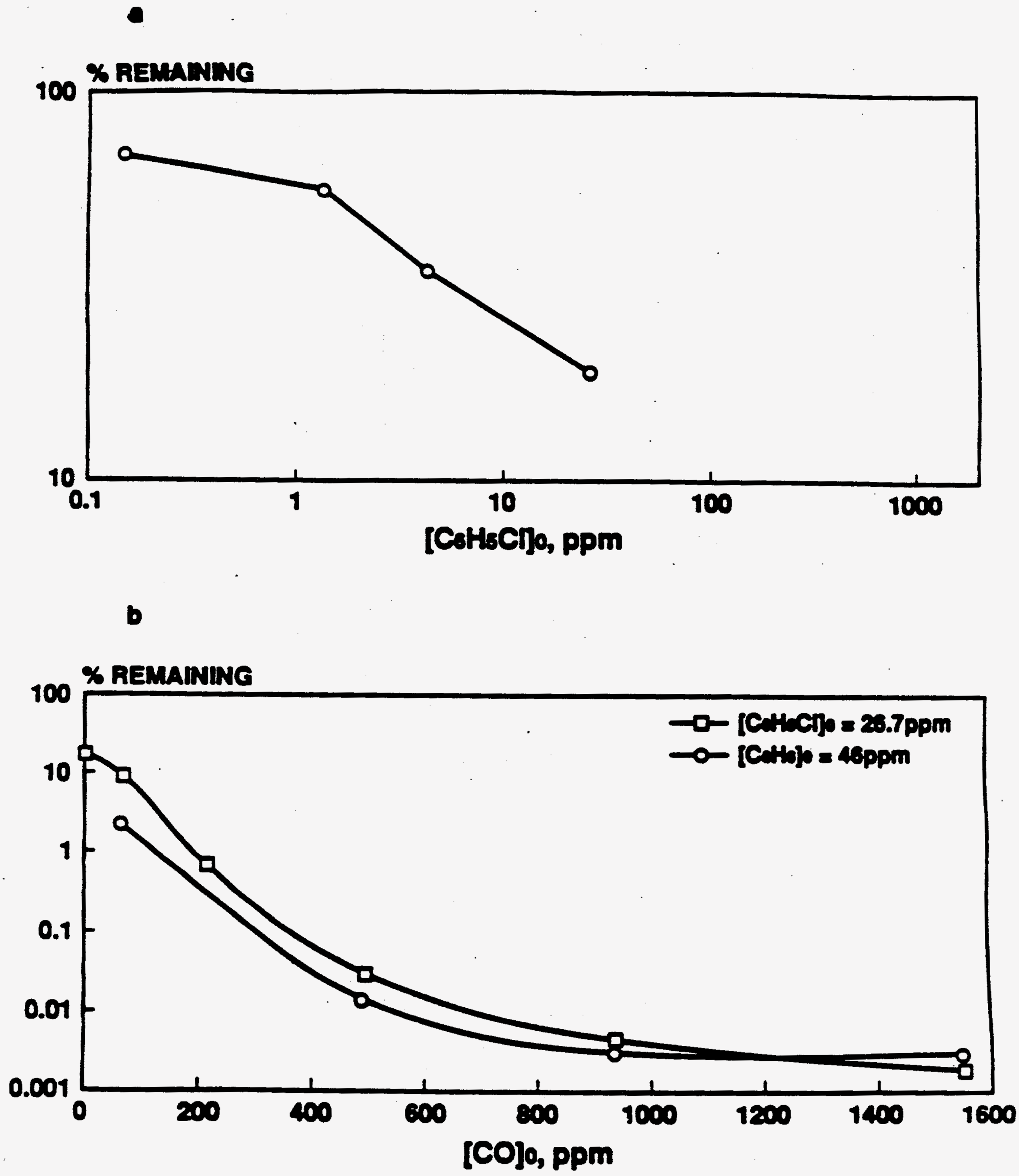


Figure 2.1. Lab scale data on the impacts of reactant concentration on destruction efficiency of benzene and chlorobenzene (a) impacts of reactant concentration (b) impacts of CO (800 C, 0.8 sec, 4.8% O2, 1.5% H_2O)

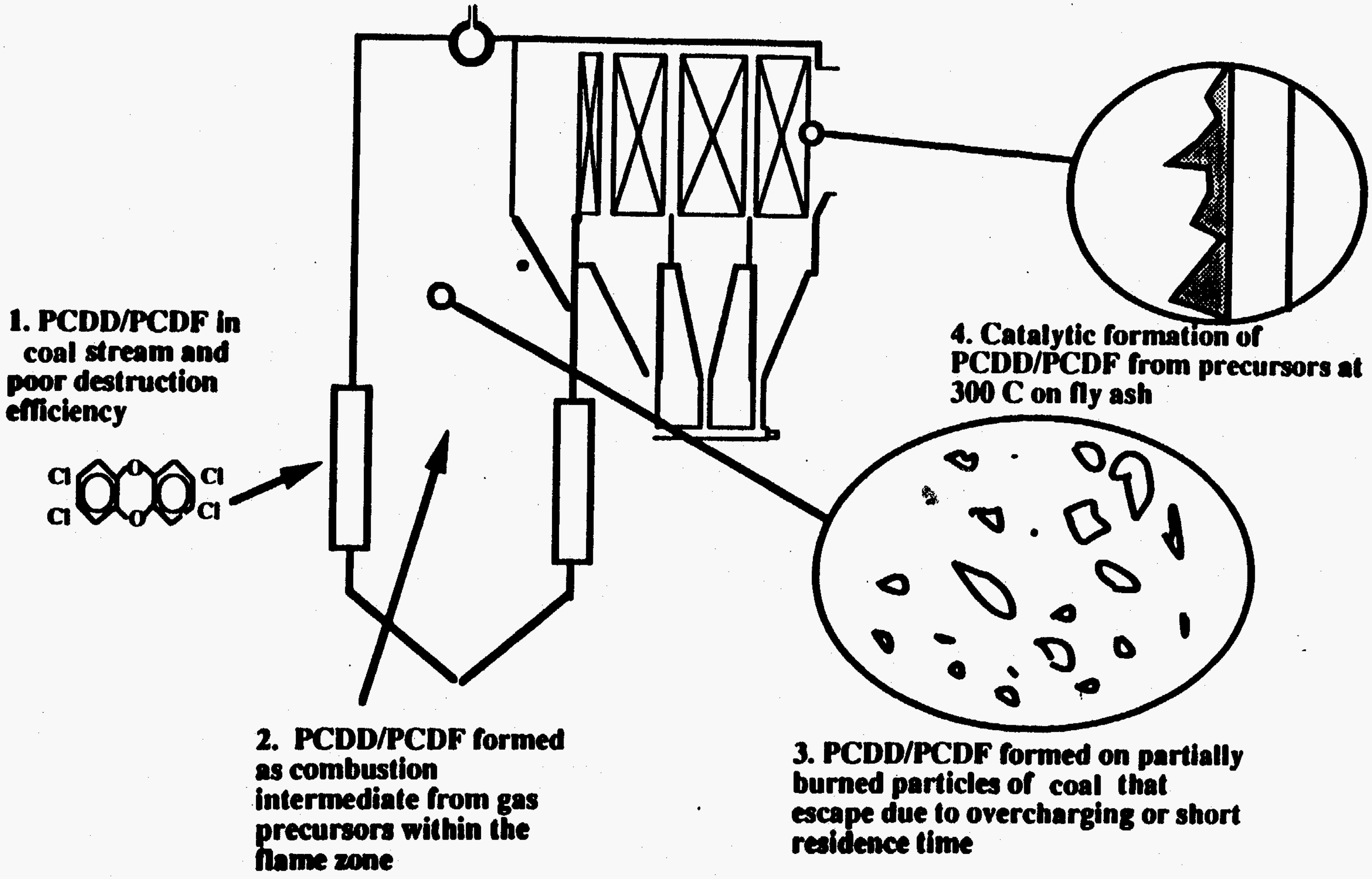


Figure 2.2. Mechanisms of PCDD/PCDF formation in combustion systems.

levels of emissions are of interest, very small amounts of dioxin in the fuel stream could account for the emission levels if they were not destroyed during the combustion process. Also at very low initial concentrations the destruction efficiency is generally low. This mechanism, however, does not likely account for most of PCDD/PCDF emissions since dioxin concentrations in the fuel are probably low.

The second category of mechanisms involves the formation of PCDD/PCDF from vapor phase reactions within the combustion zone. Two types of reactions have been proposed: those involving unchlorinated hydrocarbons and a chlorine donor and those involving gas phase reactions of chlorinated hydrocarbons with similar structures. Bumb et al. (Bumb et al., 1980) and Crummet (Crummet, 1980) first suggested that dioxins formed due to "trace chemistry of flames" involving gas phase reactions of unchlorinated hydrocarbons and chlorine compounds. The ubiquitous nature of hydrocarbons and chlorine makes the formation of dioxin an inevitable consequence of combustion of many materials. This global mechanism is highly controversial and supported by no direct evidence. There are data that indicate that some gas phase chlorine, likely either HCl or Cl_2 is required to form PCDD/PCDF under certain conditions. Ballschmiter et al. (Ballschmitter et al., 1983) and Benefenati et al. (Benefenati et al., 1983) examined emissions from full scale waste combustors and found a close relationship between the dioxin emissions and the quantity of polychlorobenzenes and polychlorinated phenols in the exhaust. They interpreted this to indicate that dioxins are formed by reactions involving these gas phase species which were in the fuel or were formed in the combustion process. Shaub and Tsang (Shaub and Tsang, 1983) developed a kinetic model to study the characteristics of the reactions involving chlorinated hydrocarbons alone.

The third category of mechanisms are heterogeneous mechanisms within the combustion zone, likely related to the particulate matter. Barton et al. (Barton et al., 1990) from EER first pointed out the strong correlation between PCDD emissions and the amount of particulate matter entrained from the combustion zone of a mass burn municipal waste combustion unit. This strong relationship was later confirmed to exist for a range of municipal waste combustion systems including refuse derived fuel fired spreader stokers (Seeker et al., 1989) and starved air medical waste incinerators (Barton et al., 1990). Recent pilot-scale municipal waste combustion studies in our laboratory have indicated that the PCDD/PCDF formed within the combustion zone is largely associated with the large, partially burned particles indicating a heterogeneous mechanism rather than a condensation mechanism. Thus it is not sufficient merely to burn out the gas phase volatiles but rather it is important to completely burn all particulate matter that might exit the boiler.

The final category of mechanisms involves processes downstream of the combustion zone. In these mechanisms, PCDD/PCDF and potentially other organics are formed by low-temperature, catalyzed reactions associated with the flyash. Data supporting this category were first provided by Vogg et al. (Vogg et al., 1986) and Stieglitz et al (Stieglitz et al, 1986). They found that heating fly ash from waste combustion in an oven to 250-350 °C resulted in the formation of PCDD/PCDF on the fly ash. This occurred despite the fact that no additional chlorine was added to the material. They were able to identify the importance of catalytic metals such as copper chloride, on the formation process. Karasek and Dickson (Karasek and Dickson, 1987), also found that dioxins form on fly ash particles in the absence of gas phase chlorine. In addition, Karasek found that it is possible for adsorbed inorganic chlorides to chlorinate aromatic rings and promote the formation of chlorinated dioxin. The importance of the downstream mechanism has now been confirmed in a series of full scale and pilot scale tests that indicate that if fly ash particles are held in the temperature window of 250-350 °C such as in a hot side electrostatic precipitator, PCDD/PCDF will form. The downstream reactions appear to be a "magnifier" of the combustion formation causing an increase of the PCDD/PCDF escaping the combustion zone by as much as an order of magnitude.

The insight gained from combustion science has resulted in the establishment of good combustion practice that can significantly lower trace organic emissions. For PCDD/PCDF, the different mechanisms have been identified and found to become dominant under different conditions. All of the formation mechanisms for all types of organics must be addressed if total mass emissions of trace organics are to be minimized. The basis of combustion control strategies must be to attack the temporal and spatial variations in temperatures and mixing that allow any organics to escape the combustion zone. These organics can be a toxic pollutant in their own right or can be precursors to the formation of organics that are more toxic. At the same time, conditions must be established that minimize the entrainment and maximize the burnout of particulate matter. A key failure of coal combustion operation is operating at too high of load that can cause an overcharging of the primary combustion zone that results in a large release of unburned materials. Finally, conditions downstream of the combustion zone must also be avoided which will hold up particles in the temperature window of 250-350 °C. Below 200 °C, semi-volatiles will condense onto particulate matter that can be removed by high performance particulate control devices. Even though the organics are not destroyed they will at least not be dispersed into the air. However, it is clearly better to prevent the formation of the trace organics in the combustion zone instead of just removing the materials from the emissions. Substantial additional research is required to adequately understand the formation of other trace organics in the full range of coal combustion equipment and allow for optimum control.

2.2 Metals

Much is known about the behavior of metals in waste combustion devices, largely as a result of the ongoing projects supported by the EPA. Barton et al. (1988) summarized the knowledge in the field in a comprehensive EPA Final Report. Continuing research and regulatory activities are expanding this knowledge. Rizeq et al. (1992a, 1992d), under EPA support, began work on a project to expand and update the knowledge of metals behavior, creating a "Metals Bible."

During coal combustion, it is important to determine not only the quantity of the metal which partitions to the combustion gas but also its form. Metals may partition to the combustion gas by particulate entrainment and/or vaporization depending on the volatility of the metal. Metals which partition to the gas in particulate form are relatively large (above 0.1 μm) and are effectively removed in most particulate air pollution control devices (APCDs). Metals which vaporize are swept away with the combustion gas and, as the gas cools, tend to condense into and/or onto the surfaces of very fine particles which are in the size range that is least effectively removed in most APCDs. Predictions of the portions of metals which vaporize will help determine the distribution of condensed metals on entrained particles through studying the aerosol dynamics upstream of the APCD. Knowledge of the APCD's particulate capture efficiency as a function of particle size, and the distribution of metals on fly ash particles will allow predictions of the controlled metals partitioning and emissions at the stack. The outcome of such modeling will help the owner/operator of a facility identify metals which are likely to be emitted at concentrations above Local, State, or Federal regulatory risk-based limits and others which are likely to be emitted at concentrations below regulatory limits. This will lead to the development of better testing plans, operating conditions decisions, and the selection of MACT for metals capture.

This section presents mechanisms of metals partitioning, the methodology employed to predict metals partitioning and emissions from coal-fired power systems which will be used in

Section 5.1.9 as an indicator to assess metal emission levels from the ABB LEB pulverized bituminous coal-fired boiler, coal type and combustion parameters used in the modeling, prediction results and comparison to field data to validate the modeling approach, and conclusions.

2.2.1 Mechanisms of Metals Partitioning

Metals may exit a coal combustion system by any of several pathways. Figure 2.3 illustrates many potential pathways. Only a few of the pathways may apply to a given coal combustion system. Some of the metals in a coal pass through the furnace combustion chamber unchanged and are found in the residual bottom ash . The fly ash captured in the heat recovery and flue gas cleaning equipment will also contain some metals. A fraction of the metals originally in the coal may also be found in the exhaust gases emitted from the system. This division of metals between different emission streams is referred to as "partitioning."

Figure 2.4 illustrates the mechanisms thought to control metals behavior in a variety of combustion systems such as coal-fired utility boilers (Neville and Sarofim, 1982). Metals are usually present in a coal as inorganic compounds. Most of these compounds are not affected by the combustion environment and pass through the combustor unchanged. These metals will be found in residual ash generated by a facility (Quann and Sarofim, 1982). If the coal is pulverized, nearly all the particles are 1-100 µm in diameter (Goldstein and Siegmund, 1976). The combustion gases entrain a fraction of the smaller ash particles while the remaining material is removed from the combustion chamber as bottom ash. The quantity of material entrained is a function of the size, shape, and density of the ash particles as well as the combustor operating conditions (Li, 1974). The entrained particles generally are generally less than 50 µm (Petersen, 1984).

Some metals and metal species found in coal are volatile and vaporize under the conditions which occur in the combustion volume (Vogg et al., 1986). The vapors diffuse into the exhaust gas stream which then carries them through the combustor system. As the exhaust gas is cooled, the vapors condense both homogeneously to form new particles and heterogeneously on the surfaces of the entrained ash particles (Senior and Flagan, 1982). Homogeneous condensation produces particles less than 1 µm in diameter (Friedlander, 1977). Heterogeneous condensation also tends to favor small particles due to their high surface area to weight ratio (Linak and Peterson, 1984). Thus, the small entrained particles have higher concentrations of volatile metals than the original coal. The concentrations of metals such as arsenic, cadmium, lead and antimony in particles emitted from coal combustion facilities have been found to be 4 to 10 times higher than would be expected if no vaporization had occurred (Meij, 1992).

Metal containing materials may also react in the high temperature combustion zone. Two types of reactions have been observed. In the first type, reactive elements released during the combustion of organic materials in the coal combine with the metals. Chlorine and sulfur are the most common of these reactive constituents. The second class of reactions occurs because of the formation a high temperature, reducing environment near the burning coal particle. This environment forms in nearly all coal combustion systems even though the furnace is operated at overall excess air conditions due to mass transfer rates (Quann and Sarofim, 1982). The reactions principally involve the reduction of metal oxides. The newly formed compounds often volatilize more readily than the original species. Once the vapors diffuse away from the coal particles and encounter lower temperatures and higher oxygen concentrations, they undergo secondary reactions, convert back to their original, more refractory forms and condense (Senior and Flagan, 1982). Both homogeneous and heterogeneous condensation occur.

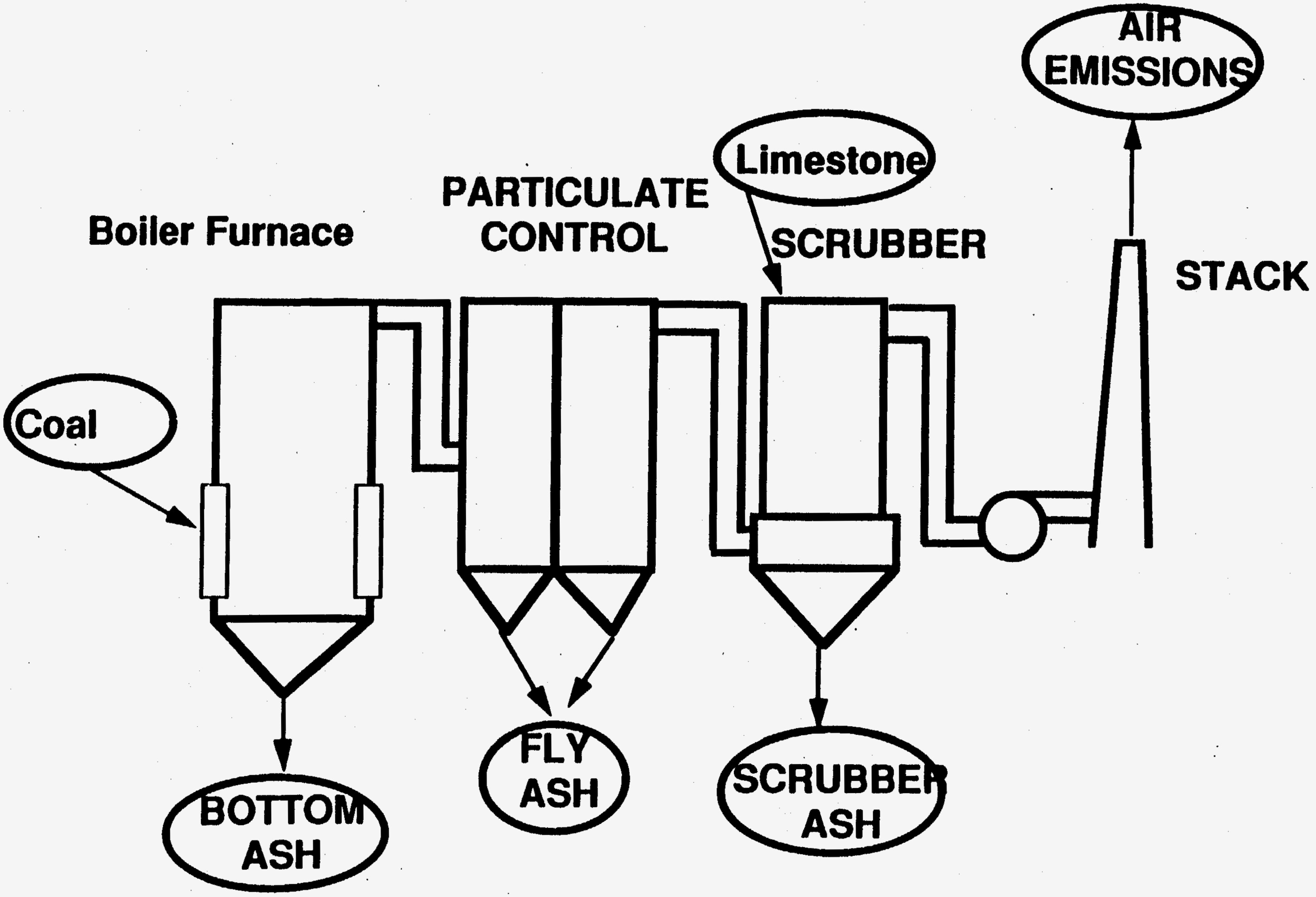


Figure 2.3 Metal Pathwasys in Coal Fired Utility Boilers

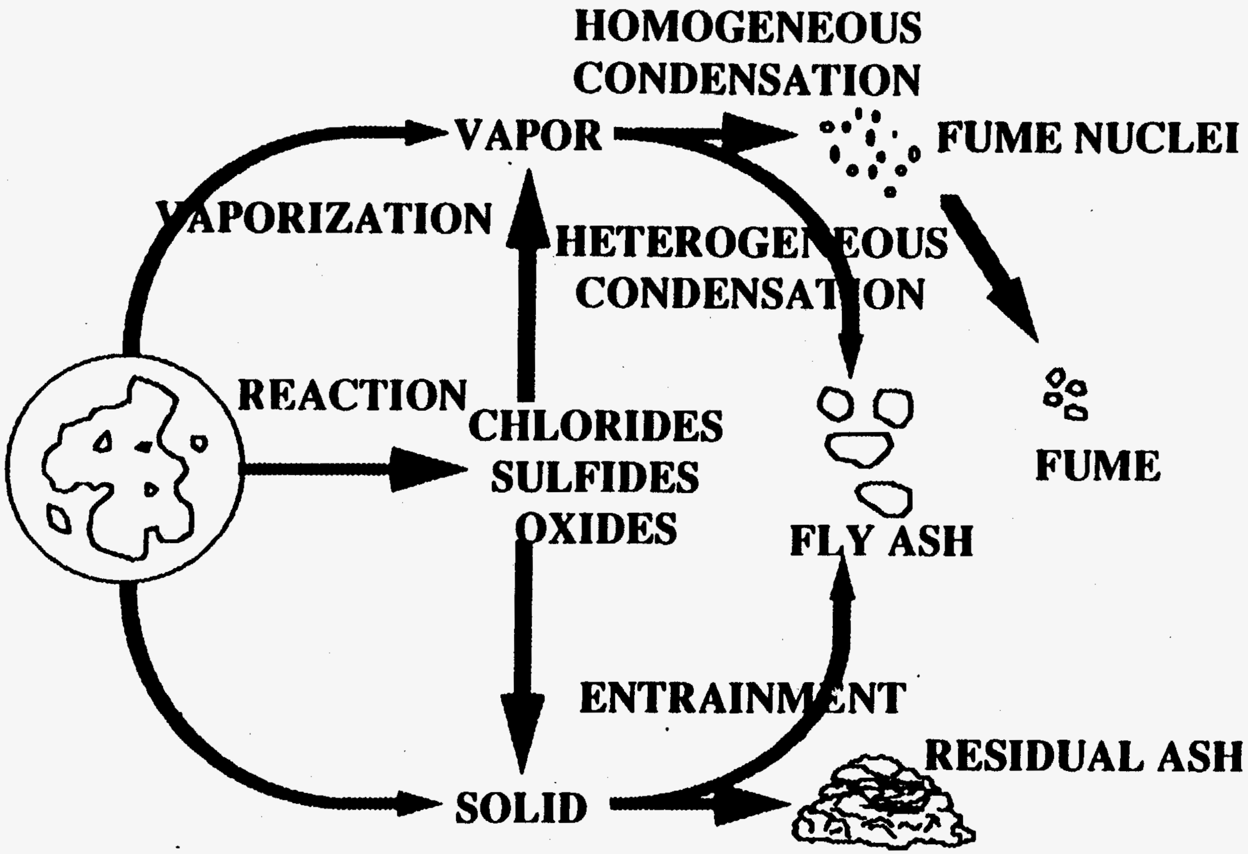


Figure 2.4. Mechanisms thought to Control Metals Behavior in a Coal Fired Utility Boiler (Adapted from Neville and Sarofim, 1982)

A computational model based on the above mechanisms was developed to extend data obtained from other systems to coal combustion systems. The model was used to estimate the importance of key boiler operating parameters on metals behavior and to develop a scientifically defensible method for assessing the ability of combustion systems to limit metals emissions. Details of the partitioning model are presented below.

2.2.2 Metals Partitioning Modeling Approach

A metals partitioning model was developed to predict the fate of metals in waste combustion devices (Barton et al., 1988; 1990). This model has been updated and modified for the ABB LEB study to predict metals partitioning and emissions from coal-fired power systems. The model consists of a group of computer submodels (Figure 2.5) structured to simulate the physical and chemical mechanisms which influence metals behavior in combustion systems. The phenomena simulated include:

- Combustion chamber thermal behavior
- Metals reactions and vaporization
- Particle entrainment
- Aerosol dynamics (nucleation, condensation, and coagulation)
- Particulate capture

The temperature and stoichiometry history of the combustor is established first to define the background environment for the burning fuel and metals vaporization, as well as for the post-flame and the condensing metal vapors. Details for the remaining steps of the modeling approach are presented below.

Metals Reactions and Vaporization. Metals related chemical reactions and phase behavior are determined using the program developed by NASA's Lewis Research Center, CET85 (Gordon and McBride, 1974). This program makes use of a free energy minimization approach which is based on two assumptions:

- all reactions achieve equilibrium at local conditions; and
- all elements (coal and combustion air) are intimately mixed.

This equilibrium approach provides conservative estimates for uncontrolled metals emissions and allows the impact of various parameters on metals reactions to be assessed (Mathews, 1987). It is recognized that equilibrium may not be maintained throughout a coal combustor; however, it is believed that the equilibrium assumption is reasonable at the high temperatures typical of coal combustion chambers. Sufficient kinetic data are not presently available to develop a detailed kinetic model of metals behavior.

The equilibrium program can be used to predict the vapor pressure of each metal species and the resulting amount of each metal which partitions to the combustion gas by vaporization during coal combustion. Additionally, the program provides metals speciation information for both the condensed and vapor phases. The ability to predict and analyze the metals vaporization process is largely dependent on the accuracy and the completeness of the data on the thermodynamic properties of metal species. The equilibrium program has to be provided with thermodynamic data on all of the possible combinations of metal compounds which may form under combustion conditions. The thermodynamics database normally provided with the NASA code has limited data on toxic metals. For example, metals such as Sb, As, Cd, Se, Tl, and many toxic metal-earth element (Ca, Al, Si) compounds are not included in the NASA thermodynamics database. This is because

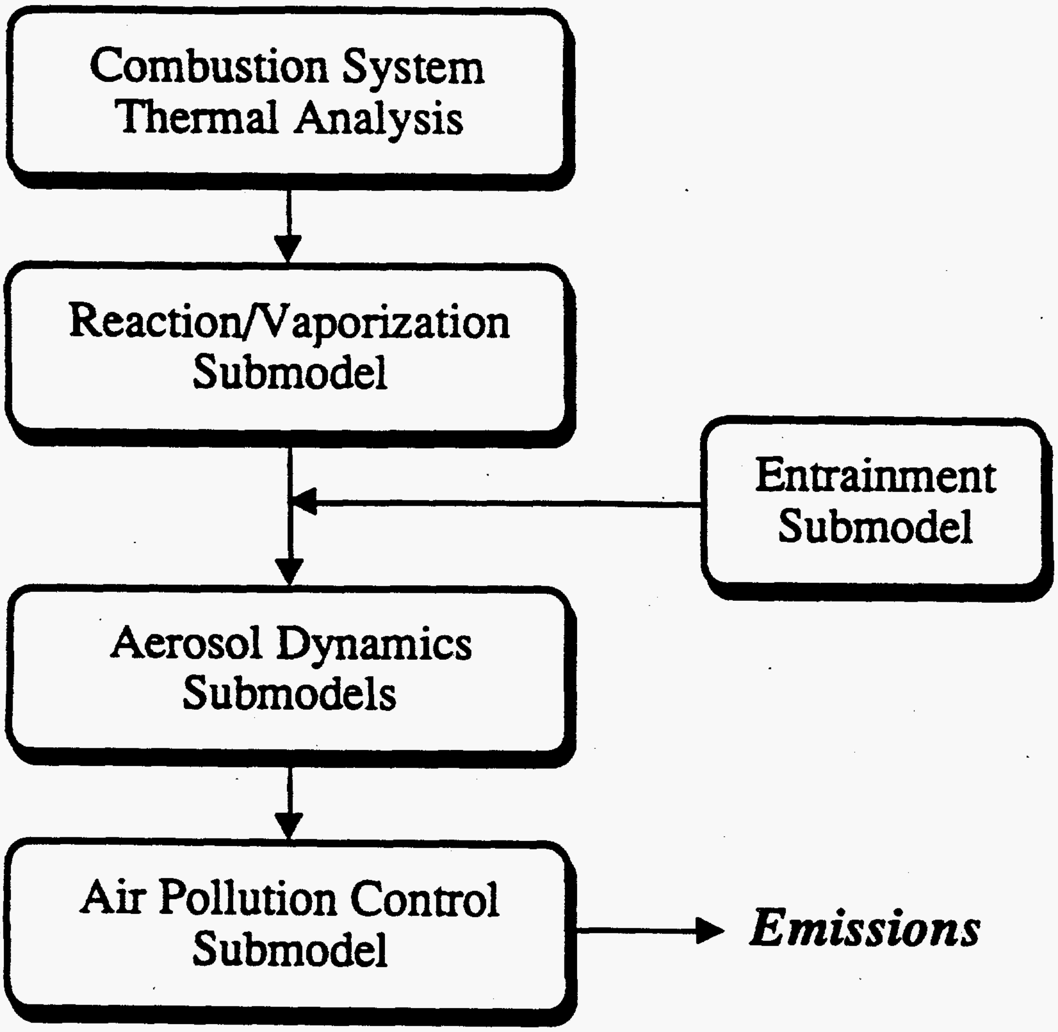


Figure 2.5. Metals Partitioning Model.

the NASA thermodynamics database is based largely on data from the JANAF Tables (Chase et al., 1985) which focus on substances of importance to fuel combustion and jet and rocket propulsion.

Recently, a considerable effort was undertaken to update the thermodynamics database (Rizeq et al., 1992d; 1993) with the latest thermochemical property data on toxic metals. An extensive literature search was conducted to identify major sources of data. Two primary sources of data were utilized; the first was the Barin tables (Barin, 1989) for gaseous and condensed metal species, and the second was data from Ebbinghaus (1992) on gaseous chromium species from his recent work at Lawrence Livermore National Laboratory. As a result of this effort, the thermodynamics database incorporated in the metals partitioning model was upgraded by adding data for a number of new metal species (Sb, As, Cd, Se, and Tl) and increasing the number of compounds for several metals (Ba, Be, Cr, Pb, Hg, Ni, and Ag) in both the condensed and vapor phases. This increase in the number of gas and condensed phase metal species allows better predictions of metals behavior under a variety of combustion conditions.

Uncontrolled partitioning of metals due to vaporization was calculated from the saturated vapor pressure of metals under anticipated operating conditions and coal composition. The saturated concentration of each metal was then estimated and compared to the available concentration of the same metal. The available concentration was calculated based on the concentration of the metal in the coal. As explained in earlier publications (Rizeq et al., 1992a; 1992b; 1992c), it is expected that the uncontrolled emissions of a metal due to vaporization is controlled by its saturated concentration if the available concentration is larger than the saturated concentration. The uncontrolled emission in this case corresponds to the saturated concentration. However, if the available concentration of the metal is smaller than the saturated concentration, the uncontrolled emission due to vaporization of the metal is expected to correspond to the feed rate of the metal.

Particle Entrainment. If a metal has not completely vaporized at combustion conditions (saturated metal), additional partitioning of the metal to the gas phase can occur due to ash entrainment. Metals partitioning to the gas phase due to ash entrainment can be accounted for through an estimate of the percent of ash entrained in the combustor. The percent of ash entrained is calculated using the particulate loading in the gas and the coal ash content, or by using entrainment models which simulate the conditions of the combustion system (Li, 1974). The amount of ash entrained depends on the size, shape, and density of the ash, as well as on the coal type, combustor design, and operating characteristics of the coal combustion system. In many systems, the fraction of particulate entrainment is known as shown in Table 2.2 (Brooks, 1989). The total uncontrolled emissions of metals were calculated by adding the vaporized and entrained portions of the metals.

TABLE 2.2. COAL ASH DISTRIBUTION BY BOILER TYPE (BROOKS, 1989)

Furnace Type	**% Fly Ash / % Bottom Ash (Bituminous Coal)†**
Pulverized Dry Bottom	80/20
Pulverized Wet Bottom	65/35
Cyclone	13.5/86.5
Stoker	60/40

† Based on several studies of coal ash from large and intermediate size coal-fired boilers.

Aerosol Dynamics. By knowing the vapor pressure of metals at the combustor exit and at the control equipment inlet, the entrained particle size distribution at the coal combustor exit, and the temperature profile of the gas upstream of the APCD, aerosol dynamics (nucleation, condensation, and coagulation) modeling can be performed and the fraction of metals condensed onto or into each particle size range can be calculated at the APCD inlet. Nucleation and condensation are key processes since they account for the enrichment of metals on small particles. A computer model simulating both nucleation and condensation has been developed. Details of the condensation and nucleation submodels are presented elsewhere (Barton et al., 1990).

Particulate Capture and Overall Partitioning. The removal of particles from the gas stream by flue gas cleaning equipment associated with entrainment, nucleation and condensation must be determined. The efficiency of particle removal typically depends on the particle size and on the design and operation of the flue gas cleaning equipment. Efficiency curves were used to predict the percent of metal capture in a given control equipment. The percent of metal capture depends on the fraction of metals condensed on each particle size; for example, volatile metals may condense largely on submicron particles generated by metal nucleation. Since most APCDs are least efficient in capturing submicron particles, volatile metals have a higher chance of escaping particulate removal devices. Combining calculations from the vaporization and entrainment step, aerosol dynamics process, and particulate capture, allows the estimation of controlled metals partitioning in the coal-fired combustion system.

2.2.3 Coal Type and Combustion Parameters

The composition of a typical bituminous coal was used in this study to predict metals vapor pressures and metals uncontrolled emissions due to vaporization. Bituminous coal was chosen because it is widely used in the U.S. and Europe. On a fuel consumption basis, approximately 95% of all coal combusted in the U.S. is bituminous (Brooks, 1989). The bituminous coal ultimate analysis (Table 2.3) was taken from the study by R. Meij (1992), performed by N.V. KEMA in the Netherlands. This coal analysis was chosen so that we can compare the predicted results to KEMA's measured results and validate the modeling approach. The element concentrations of bituminous coal, bottom ash, fly ash, and air pollution control equipment ash, as well as vapor phase metals in the flue gas downstream of the electrostatic precipitator were investigated in the KEMA study. The operating parameters (Table 2.4) were chosen to represent typical coal combustion conditions and also to represent conditions in the KEMA study for comparison reasons.

2.2.4 Modeling Results

In this study, pulverized coal-fired systems were modeled because of their wide spread use in both the U.S. and Europe, because they resemble the ABB LE boiler, and because of available test data for model validation. The partitioning model was executed to determine metals behavior during coal combustion. The following subsections present results for the uncontrolled partitioning of metals, aerosol dynamics, and particulate capture and overall partitioning of metals in a pulverized bituminous coal-fired combustion system.

Uncontrolled Partitioning of Metals. Metals vaporization and entrainment in the combustion chamber constitute metals uncontrolled emissions at the combustor exit. Determination of the amount vaporized relative to the amount entrained for each metal is important for the aerosol dynamics study upstream of the APCD, and for the determination of the fraction of metals condensing on each particle size at the APCD inlet.

TABLE 2.3. COMPOSITION OF KEMA's BITUMINOUS COAL (MEIJ, 1992).

Components	Percent by Weight
C	72.56
H	4.86
O	15.04
N	1.53
S	0.70
Cl	0.07
Al	1.81
Ca	0.25
Si	3.13
As	0.0007
Ba	0.035
Be	0.0004
Cd	0.000015
Cr	0.002
Hg	0.00002
Ni	0.0015
Pb	0.0015
Sb	0.00015
Se	0.0003
Tl	0.00005

TABLE 2.4. OPERATING PARAMETERS.

Type of combustor	Pulverized dry bottom
Type of coal	Bituminous
Combustor exit temperature (°K)	1473
APCD inlet temperature (°K)	450
Overall stoichiometric ratio	1.2
Particulate entrainment rate	88%
APCD type	High efficiency electrostatic precipitator (ESP)
Particulate loading upstream of the ESP (g/m^3-standard)	12.8
Quench rate (°K/s)	335
Particulate Size Distribution at the Combustor Exit	
Mean Particle Size (μm)	Percent by Weight
0.5	1
1.5	4
3.5	25
7.5	30
20	40

Predictions of uncontrolled emissions of metals in a pulverized bituminous coal-fired combustor at 1200°C and 20% excess air are illustrated in Figure 2.6. In order to eventually compare predictions of controlled partitioning of metals to KEMA's measured results (Meij, 1992), the analysis in Figure 2.6 corresponds to the bituminous coal composition of Table 2.3 which is representative of KEMA's bituminous coal analysis. Additionally, the entrainment rate of the portion of metals which do not vaporize was considered 88%, also corresponding to the average inorganic particulate entrainment in KEMA's tests.

In Figure 2.6, two sets of results are shown for Cr; Cr-1.2 corresponds to Cr behavior if the local conditions near the burning coal were at SR= 1.2, and Cr-1.0 corresponds to Cr behavior if the local conditions near the burning coal were at SR= 1.0 or below. As will be shown in Section 5.3.2, the other metals are not impacted by stoichiometry so the SR of 1.2 was used. Figure 2.6 indicates that the total amounts of Cr-1.2, Cd, Pb, As, Sb, Tl, Se, and Hg are predicted to vaporize; while, 0% of U and Ba vaporizes, 88% is entrained, and 12% remains in the bottom ash; 10% of Ni vaporizes, 80% is entrained, and 10% remains in the bottom ash; 49% of Be vaporizes, 44% is entrained, and 7% partitions to the bottom ash; and approximately 8% of Cr-1.0 vaporizes, 82% is entrained, and 10% partitions to the bottom ash. As will be shown in the following subsection, the percent of vaporization for each metal will impact its aerosol dynamics upstream of the APCD, and its distribution on the various sizes of flue gas entrained particles.

The vaporization behavior of Cr at SR= 1.0 is believed to be the representative behavior of the uncontrolled partitioning of Cr due to the local reducing atmospheres near the burning coal as will be discussed in Section 5.3.2 (Impacts of Combustor Operating Parameters on Uncontrolled Metal Emissions).

Aerosol Dynamics. The vaporized metals (Figure 2.6) are expected to condense onto and/or into submicron particles as the gas cools upstream of the air pollution control equipment. This process will enrich the emitted fly ash particles with these metals (their concentration in the emitted fly ash will exceed their concentration in the coal ash). The total amount of metals captured in the particulate APCD depends to a great extent on the distribution of condensed metals on the nucleated and fly ash particles. The fly ash particle size distribution at the combustor exit (Table 2.4) was taken from a representative pulverized coal combustion system. The overall metals distribution at the APCD inlet was determined by modeling the aerosol dynamics of metals as the gas cools upstream of the APCD.

Figure 2.7a shows the percent of each metal which condenses on the various nucleated and fly ash particles in the flue gas. The nucleated and then agglomerated metal particles are generally less than 0.1µm and the fly ash particle sizes are generally above 0.1µm. Figure 2.7a lists metals in the order of increasing volatility (left to the right). It is clear from this figure that as the volatility of metals increases a larger fraction of metals condense on the smallest nucleated particles. This occurs because, metals with lower volatility nucleate first generating small particles with large surface area on which the higher volatility metals condense later as the temperature cools further upstream of the APCD. Figure 2.7a shows that more than 40% of the vaporized metals (except Hg) condense onto or into particles less than 1µm. Therefore, metals which vaporize completely in the combustion chamber are enriched in these submicron particles due to condensation; the high volatility metals are enriched the most. Most particulate APCDs are least efficient in capturing submicron size particles. The vapor pressure of mercury was predicted to be non-saturated at the APCD temperature of 180°C and, thus, remain in the vapor phase as shown in Figure 2.7a.

There are several factors which may influence the distribution of condensed metals. These include flue gas quenching rate, percent of particulate entrainment and particulate loading in the flue

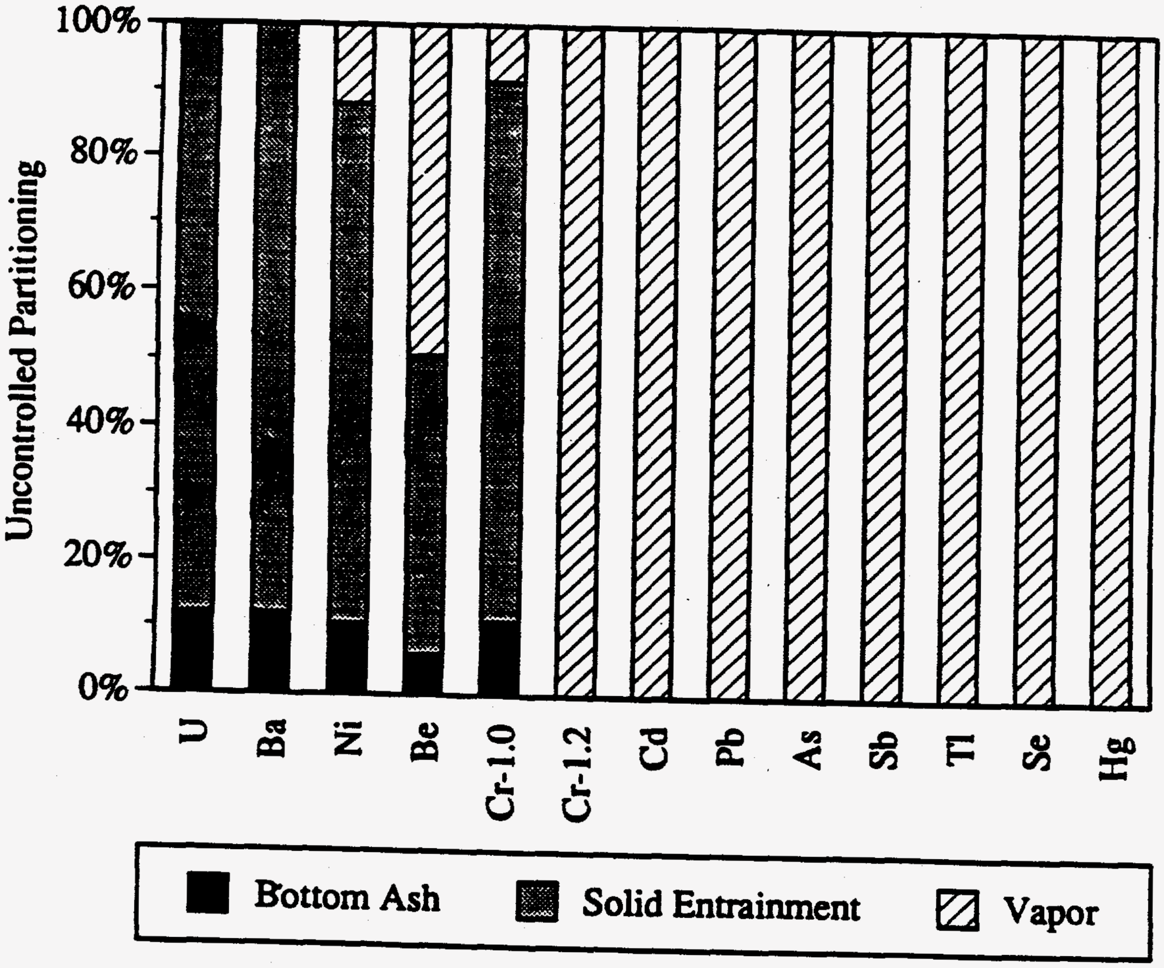


Figure 2.6. Uncontrolled metals partitioning in a pulverized bituminous coal-fired boiler.

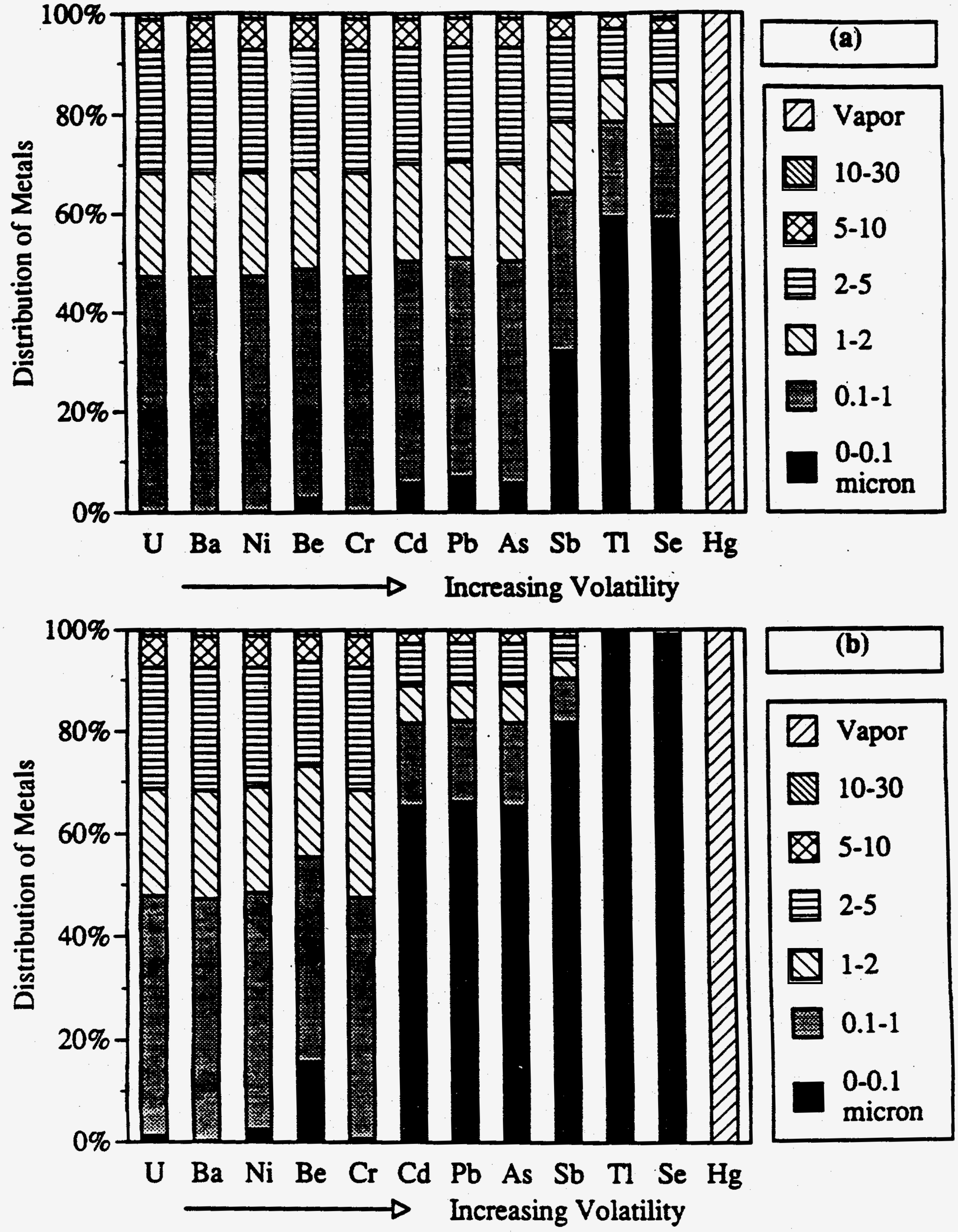


Figure 2.7. Condensed metals distribution at control equipment inlet.
(a): entrainment rate = 88%; (b): entrainment rate = 15%.

gas, the difference between the combustor exit temperature and the APCD inlet temperature, the portion of each metal which vaporizes, and the entrained particle size distribution at the combustor exit. The impact of such variations on metals distribution upstream of the APCD can be studies using the aerosol dynamics model. For example, Figure 2.7b shows the distribution of condensed metals if the particulate entrainment rate decreases to 15% which causes particulate loading in the gas to also decrease. This situation occurs in cyclone coal-fired boilers where approximately 15% of the particulate matter is entrained rather than over 80% in pulverized systems. For the lower particulate loading case, Figure 2.7b shows that the fraction of the volatile metals condensing on submicron particles increases relative to Figure 2.7a. This is primarily due to the increase in the relative surface area generated by the nucleated particles to the surface area of the entrained particles. This new distribution allows for less efficient capture of the volatile metals. Such a behavior may indicate that an increase in gas particulate loading may be helpful for better capture of volatile metals since less metals may condense on the smallest nucleated particles. This conclusion depends on the particulate removal efficiency at the control equipment.

The effect of flue gas quench rate on the distribution of metals upstream of the APCD was also investigated using the aerosol dynamics model. It was found that if the quench rate downstream of the combustor exit is 500K per second or smaller, there is no significant impact on metals distribution. The quench rate of 500K per second represents a high quench rate for such combustion systems.

Enrichment. Based on Figure 2.7 (a and b), it is expected that Cd, Pb, As, Sb, Tl, and Se will be enriched in the emitted fly ash due to their complete vaporization and further nucleation and condensation into and onto submicron particles upstream of the APCD. This expected enrichment is confirmed from KEMA's measurements. The relative enrichment of Cd, Pb, As, Sb, Tl, and Se in the emitted fly ash were reported by Meij (1992) to be 9, 6, 5, 6, 5, and 7, respectively. Meij defines the relative enrichment factor (ER) as:

The measured enrichment of Hg is reported to be 1; this is expected since Hg remains in the vapor phase even as the temperature decreases to the APCD temperature due to its high vapor pressure (Figure 2.7). The measured enrichment of Cr is also reported to be 1, which indicates that Cr in KEMA's tests partitioned as particulate matter to the gas phase and no significant vaporization occurred. This confirms earlier predictions of local reduced environment effects on the reduction of Cr vaporization and supports the decision of considering vapor pressures of Cr at SR of 1.0.

KEMA's measurements indicate that Ba, Be, Ni, and U were slightly enriched in the emitted fly ash (ER= 1.8, 2.1, 3.5, and 2.1, respectively). According to the predicted metals vaporization results in Figure 2.6, some enrichment is expected for Be and Ni but not for Ba and U. This indicates that a larger percentage of Ba and U vaporized in KEMA's tests than what is predicted in this study. Considering the sensitivity of the vapor pressure of non-volatile metals to temperature changes (as will be illustrated in Section 5.3.2, Figure 5.3a), a test temperature higher than the temperature used for predictions (1200°C) could have caused a larger fraction of Ba and U to vaporize.

Particulate Capture and Overall Partitioning. In this study, a high efficiency electrostatic precipitator (ESP) was considered for particulate capture since many coal combustion facilities in the U.S. and Europe employ ESPs for particulate capture and also because it resembles the ESP used in the KEMA study. As described in the Methodology section, the amount of each metal captured was calculated considering the efficiency of the ESP for each particle size range and the fraction of condensed metals on each particle size, as well as the fraction of each metal in the entrained fly ash.

Figure 2.8 shows the overall partitioning of metals in a pulverized bituminous coal-fired combustion facility employing a high efficiency ESP. This figure also compares the predicted partitioning results to the measured results from the KEMA study (Meij, 1992). The predicted and measured results for each metal are located adjacent to each other in Figure 2.8. The measured result for each metal is indicated by adding a "-m" to the symbol of the metal; for example, the measured value of U is illustrated as U-m. In general, Figure 2.8 shows that the predicted values of overall partitioning of metals compare well with the measured values. This provides additional confidence in the modeling and testing procedures approach.

One obvious difference, however, is between the predicted and measured results of Cr. The measured bottom ash value of Cr is 25% versus the predicted value of 8%. The measured value indicates that Cr was the least volatile metal in their tests. The reason for that is not clear. It is surprising to see this result for Cr since earth elements, such as Al and Si, entrained at 88% in the KEMA tests. The volatility of Cr is higher than earth elements and, therefore, it is expected that the uncontrolled partitioning of Cr should be at least 88% rather than 75%. A measurement error or detectability limit problem may have been a factor in the larger than expected bottom ash Cr.

In Figure 2.8, both predicted and measured results indicate that over 99% of the non-volatile metals (U, Ba, Ni, Be, nd Cr), and approximately 97-99% of the medium volatility metals (Cd, Pb, As, Sb, and Tl) are captured in the collected ESP ash and bottom ash. The predicted Hg result indicates that Hg is not expected to be captured in the system since 0% was assumed for the ESP capture of vapor phase compounds. The measured result, however, indicate that approximately 10% of Hg was captured in the ESP. This may have happened due to the adsorption of Hg on the surfaces of some of the entrained particles in the ESP. Figure 2.8 indicates that the measured vapor phase controlled partitioning of Se is higher than the predicted value. This means that the predicted vapor pressure of Se at the modeled ESP temperature of 180°C may be smaller than the measured value. The vapor pressure of Se is very sensitive to temperature changes at low APCD temperatures; therefore, if the ESP temperature in the KEMA study was slightly higher than 180°C, this will explain the difference in the amount of Se remaining in the vapor phase.

2.2.5 Conclusions

Several conclusions can be drawn from the above study:

- Combustion temperature changes and variations in coal-chlorine content influence the vaporization of non-volatile metals (Ba, Ni, Be, and Cr), but do not influence volatile metals (Cd, Pb, As, Sb, Tl, Se, and Hg) which are predicted to partition to the gas at 100% between 800°C and 1800°C. Additionally, local reducing atmosphere conditions ($SR \leq 1.0$) near the burning coal may cause Cr vaporization to be reduced significantly even though the overall stoichiometry is fuel lean. This conclusion is dependent on the coal type and the range of operating conditions used in this study.

- The dominant chemical form of Hg at the combustor exit is predicted to be elemental Hg and the dominant form at the APCD inlet is predicted to be $HgCl_2$. $HgCl_2$ is soluble and will be partially absorbed by wet scrubbers.

- The percent of a metal condensing into or onto small nucleated particulates in the flue gas increases as the volatility of the metal increases, and also increases as the particulate loading in the gas decreases. The quench rate has no significant impact on metals distribution if the cooling rate is 500K per second or smaller.

Figure 2.8. Comparison of predicted and measured (-m) overall metals partitioning in a pulverized bituminous coal-fired boiler.

- Predictions of the controlled partitioning of metals in a pulverized bituminous coal combustor employing high efficiency ESP indicate that over 99% of the non-volatile metals (U, Ba, Ni, Be, and Cr), and approximately 97-99% of the medium volatility metals (Cd, Pb, As, Sb, and Tl) are captured in the ESP ash and the bottom ash. The highly volatile Hg is predicted to remain in the vapor phase at the APCD temperature and escape without capture. Approximately 95% of Se is predicted to be captured in the ESP.

- The results from this study illustrate the importance of using representative operating conditions and fuels during a test to determine representative emissions. It is also critical to use the correct composition of the fuel to obtain better predictions of metals behavior during combustion. The comparison to the KEMA data was favorable, but may have been improved if detailed information on operating conditions were available, especially for the temperature profile and residence time of the flue gas downstream of the combustor.

- The favorable comparison between predictions and measured data provide confidence in the modeling approach and indicates that using this modeling approach can be effective in planning tests and optimizing operating conditions prior to conducting actual compliance tests.

- The model also can be used to determine the impact of different combustor and APCD types, operating conditions, and coal types on metals emissions. This will help facilities prepare for the Clean Air Act Amendments of 1990 (CAAA).

3.0 DEFINITION OF REGULATION AND STANDARDS

The purpose of Task 1 of this program was to identify air toxic emission regulations of interest to coal-fired utility boilers. To determine which HAPs are either currently regulated or potentially regulated in the future, the Clean Air Act Amendments (CAAA) and state regulations were reviewed. The following sections detail the results of this task effort.

3.1 Federal Regulations

Prior to the 1990 Amendments, Section 112 of the CAA required EPA to determine which substances were to be considered hazardous air pollutants (HAP) and to develop standards of control. These standards are known as National Emission Standards for Hazardous Air Pollutants, or NESHAP. To date, EPA has only designated eight HAPs: asbestos, benzene, beryllium, coke oven emissions, inorganic arsenic, mercury, radionuclides and vinyl chloride. The 1990 Amendments, specifically Title III, attempt to address this inadequacy. Under Title III, Congress designated 189 pollutants (including NESHAP compounds) as air toxics, and defined an approach for the control of these pollutants. Table 3.1 provides a list of the 189 HAPs. EPA may add to or delete from this list. A substance must be deleted if it is determined that it may not reasonably be anticipated to cause any adverse effects to human health or the environment.

Title III is applicable to major sources, defined as any stationary source (or sources under common control) which emits, or has the potential to emit, 10 tpy of a single listed HAP or 25 tpy of multiple HAPs. A proposed list of source categories was published in the Federal Register on June 21, 1991 (FR 56 June 21,1991, 28552). While the industry group "Fuel Combustion Sources" was proposed, utility boilers were temporarily exempted pending further investigation by EPA. EPA is required to conduct a comprehensive study to evaluate emissions of the 189 HAPs from utility boilers, the risk imposed by these emissions, potential control technologies, and costs of these technologies. The results of the study are to be presented to Congress by November of 1995. EPA may delete any source category from its list if it determines that no source in the category either causes a lifetime cancer risk greater than one in a million to a maximum exposed individual, or, will emit noncarcinogenic pollutants which below a level adequate to protect public health with an ample margin of safety.

If coal fired utility boilers are determined to impose a risk, then EPA must promulgate regulations establishing emission standards. These regulations are to require the maximum degree of reduction in emissions of a pollutant that EPA determines is technologically achievable taking into consideration cost, non air quality health and environmental impacts, and energy requirements. This technology based standard is defined as the maximum achievable control technology or MACT. MACT may include process changes, substitution of material, and work practices, as well as add-on control equipment.

TABLE 3.1. 189 CLEAN AIR ACT POLLUTANTS

Chemical Name	Chemical Name
Acetaldehyde	p-Cresol
Acetamide	Cumene
Acetonitrile	2,4-D, salts and esters
Acetophenone	DDE
2-Acetylaminofluorene	Diazomethane
Acrolein	Dibenzofurans
Acrylamide	1,2-Dibromo-3-chloropropane
Acrylic acid	Dibutylphthalate
Acrylonitrile	1,4-Dichlorobenzene(p)
Allyl chloride	3,3-Dichlorobe zidene
4-Aminobiphenyl	Dichloroethyl ether (Bis(2-chloroethyl)ether)
Aniline	1,3-Dichloropropene
o-Anisidine	Dichloros
Asbestos	Diethanolamine
Benzene (including benzene from gasoline)	N,N-Diethyl aniline (N,N-Dimethylaniline
Benzidine	Diethyl sulfate
Benzotrichloride	3,3-Dimethoxybenzidine
Benzyl chloride	Dimethyl aminoazobenzene
Biphenyl	3,3'-Dimethyl benzidine
Bis-(2-ethylhexyl)phthalate (DEHP)	Dimethyl carbamoyl chloride
Bix(chloromehyl)ether	Dimenthyl formamide
Bromoform	1,1-Dimethyl hydrazine
1,2-Butadiene	Dimethyl phthalate
Calcium Cyanamide	Dimethyl sulfate
Caprolactam	4,6-Dinitro-o-cresol, and salts
Captan	3,4-Dinitrophenol
Carbaryl	2,4-Dinitrotoluene
Carbon disulfide	1,4-Dioxane (1,4-Diethyleneoxide)
Carbon tetrachloride	1,2-Diphenylhydrazine
Carbonyl sulfide	Ephichlorohydrin (1-Chloro-2,3-epolypropane)
Catechol Chloramben	1,2-Epoxybutane
Chloramben	Ethyl Benzene
Chlordane	Ethyl Carbamate (Urethane)
Chlorine	Ethyl chloride (Chloroethane)
Chloroacetic acid	Ethylene dibromide (Dibromoethane)
2-Chloroacetophenone	Ethylene dichloride (1,2-Dichloroethane)
Chlorobenzene	Ethylene glycol
Chlorobenzilate	Ethylene imine (Aziridine)
Chloroform	Ethylene oxide
Chloromethyl methyl ether	Ethylene thiourea

TABLE 3.1. 189 CLEAN AIR ACT POLLUTANTS (CONTINUED)

Chemical Name	Chemical Name
Cresols/Cresylic acid (isomers and mixtue)	Formaldehyde
o-Cresol	Heptachlor
m-Cresol	Hexachlorobenzene
Hexachlorobutadiene	Phosphorus
Cexachlorocyclopentadiene	Phthalic anhydride
Hexachloroethane	Polychlorinated biphenyls (Aroclors)
Hexamethylene-1,6-diisocyanate	1,3-Propane sultone
Hexamethylphosphoramide	beta-Propiolacetone
Hexane	Propionaldehyde
Hydrazine	Propoxur (Baygon)
Hydrochloric acid	Propylene dichloride (1,2-Dichloropropane)
Hydrogen fluoride (Hydrofluoric acid)	Propylene oxide
Hydrogen sulfide	1,2-Propylenimine (2-Methyl aziridin)
Hydroquinone	Quinoline
Isophonone	Quinone
Lindane (all isomers	Styrene
Maleic anhydride	Styrene oxide
Methanol	2,3,7,8-Tetrachlorodibenzo-p-dioxin
Methoxychlor	1,1,2,2-Tetrachloroethane
Methyl bromide (Bromomethane)	Tetrachloroethylene (Perchloroethylene)
Methyl chloride (Chloromethane)	Titanium tetrachloride
Methyl chloroform (1,1,1-Trichloroethane)	Toluene
Methyl ethyl ketone (2-Butanone)	2,4-Toluene diamine
Methyl hydrazine	2,4-Toluene diisocyanate
Methyl iodide (Iodomethan)	o-Toluidine
Methyl isobutyl ketone (Mexone)	Toxaphene (chlorinated camphene)
Methyl isocyanate	1,2,4-Trichlorobenzene
Methyl methacrylate	1,1,2-Trichloroethane
Methyl tert butyl ether	Trichloroethylene
4,4-Methylene bis(2-chloroaniline)	2,4,5-Trichlorophenol
Methylene chloride (Dichloromethane)	2,4,6-Trichlorophenol
Methylene diphenyl diisocyanate (MDI)	Triethylamine 1
4-4'-Methylenedianiline	Trifluralin
Naphthalene	2,2,4-Traimethylpentane
Niitrobenzene	Vinyl acetate
4-Nitrobihenyl	Vinyl bromide
4-Nitrophenol	Vinyl choride
2-Nitropropane	Vinylidene chloride (1,1-Dichloroethylene)
N-Nitroso-N-methylurea	Xylenes (isomers and mixture)
N-Nitrosodiumethylamine	o-Xylenes

TABLE 3.1. 189 CLEAN AIR ACT POLLUTANTS (CONTINUED)

Chemical Name	Chemical Name
N-Nitrosomopholine	m-Xylenes
Parathion	p-Xylenes
Pentachloronitrobenzene (Quintobenzene)	
Pentachlorophenol	
Phenol	
p-Phenlynediamine	
Phosphine	

Assuming that coal–fired utility boilers are to be regulated, MACT would be established according to the following discussion. For new sources, MACT must not be less stringent than the level of emission control achieved in practice by the best controlled similar source. For existing sources, MACT must not be less stringent than the average emissions limit achieved by the best performing 12 percent of existing sources. If there are fewer than 30 sources in the source category, MACT must not be less stringent than is achievable by the best performing five existing sources. If there is an established health threshold for the substance, EPA can consider it, with an ample margin of safety, when setting MACT standards. EPA must review and revise as necessary MACT standards at least every eight years. In addition, MACT standards do not replace any stricter state or local standards.

For new sources, MACT standards are effective upon promulgation. For existing sources, compliance must be achieved no later than three years after promulgation, with a possible one year extension granted by permit if the time is needed to install control technology. Benefits are available for facilities that show early reductions. Sources are eligible for a six year extension if they make voluntary reductions of at least 90 percent from their 1987 levels before the applicable MACT standard is proposed. In addition, sources can obtain a five year extension if they install Best Available Control Technology (BACT) or Lowest Achievable Emission Rate (LAER) technology for that pollutant prior to promulgation of the applicable MACT standard.

After the application of MACT standards, EPA is to determine the residual risk associated with each controlled source and source category. By 1996, EPA is to report to Congress on methods of calculating the remaining public health risk after application of MACT standards, the significance of this remaining risk, methods of reducing such remaining risk, and recommendations for legislation. If Congress does not act upon EPA's recommendations, EPA must within eight years after promulgating MACT standards, promulgate additional standards based on their residual risk findings, if necessary to provide an ample margin of safety to protect public health. These additional standards are known as residual risk standards. For carcinogenic pollutants, EPA must promulgate residual risk standards where MACT standards do not reduce risk to less than one in one million.

Residual risk standards will be effective upon promulgation. However, existing sources may obtain a two year waiver if it is necessary to install controls, provided the source will ensure the protection of health of the persons effected from imminent endangerment during the interim. Also, if a source commences construction after an applicable MACT standard is proposed, but before an applicable residual risk standard is proposed, the facility must comply with the MACT standard but need not comply with the residual risk standard until ten years after construction commences.

3.2 State Regulations

Due to heightened awareness regarding air toxic emissions and the lagging implementation of federal regulations, many states have adopted or are considering adopting programs for the control of air toxic pollutants. This section presents the current status, scope and approach taken by states to implement air toxic control programs (ATCPs).

3.2.1 Current Status of State Air Toxic Control Programs (ATCPs)

Information about state ATCPs can be obtained from the National Air Toxics Information Clearing House (NATICH). The information supplied by NATICH is a result of a survey of individual states. The resulting database contains information on the states' ATCPs including:

1. The structure of the state ATCP, such as a program based on guidelines rather than formally adopted regulations.

2. The scope of the state programs, which may include:

    - A list of pollutants
    - A list of sources or source categories
    - Permitting of new sources/permit renewal for air toxics
    - Requirements for accident prevention and/or emergency response planning
    - Submittal of emission inventory information

3. The extent of enforcement

If the permit renewal process is used to control air toxics, the regulating agency may use acceptable ambient concentration guidelines (AACG) for air toxics or formally adopted standards (AACS). Some or all of the AACG or AACS may be based on the application of an uncertainty factor to an established Occupation Exposure Level and/or the results of a health effects literature review by the agency. Alternatively, a technology based control requirement may be used, such as "State of the Art' control for identified sources of specified pollutants. Risk assessments for cancer causing or systemic pollutants may also be required.

Table 3.2 provides the results of the NATICH survey. Responses from 43 states are presented, indicating whether they have a current program, a future program, or no program. All of the states responding have some type of control program in place. Of particular interest are the states which currently have programs in place. Table 3.3 shows which states have a current air toxic control program (32) and which merely have NESHAP authority or regulations which apply only to NESHAP like pollutants and sources (17). Table 3.3 also identifies the 21 states with ATCPs based on promulgated regulations rather than guidelines. For the states which do have a current ATCP for which information was available, the characteristics of these programs are summarized in Table 3.4.

TABLE 3-2. SUMMARY OF STATES' APPROACHES TO THE CONTROL OF AIR TOXIC EMISSIONS

	AK	AL	AZ	CO	CA	CT	DE	FL	HI	IA	ID	IL	IN	KS	KY	LA	MA	MD	ME	MI	MO	MT	NC	ND	NE	NH	MS	NJ	NM	NY	OH	OK	OR	PA	RI	SC	SD	TX	VA	VT	WA	WI	WY
State have ATCP in addition to NESHAP?	c	c	c	c	c	c	n	f	f	n	n	f	c	c	c	c	c	c	f	c	c	n	c	f	c	c	f	c	c	c	c	c	c	n	c	c	n	c	c	c	c	c	c
ATCP Based on Promulgated Regulation?	c	f	f	c	c	c	f	f	n	n	c	f	n	n	c	c	n	c	f	c	f	n	c	n	c	f	f	c	c	n	n	c	f	f	c	f	n	c	c	c	c	c	n
ATCP Based on Guidelines rather than Regulations	c	c	c	n	n	n	c	c	n	n	n	c	c	c	n	n	c	n	c	n	c	n	n	c	n	n	c	c	n	c	c	n	c	c	n	c	c	c	n	n	n	n	c
ATCP Regulate Specific List of Pollutants?	f	n	c	c	c	c	f	f	n	n	c	f	c	c	c	c	n	c	c	n	f	n	c	c	c	c	f	c	c	n	n	n	n	f	c	c	f	n	n	c	c	c	n
ATCP Regulate List of Sources or Categories?	f	n	n	n	n	n	n	f	n	n	n	n	n	n	n	c	n	n	n	n	n	n	n	n	n	n	c	f	n	n	n	n	n	c	n	n	n	n	n	n	c	n	n
ATCP Address Permitting of New Sources?	c	c	c	c	c	c	c	c	n	n	c	c	f	c	c	c	c	c	c	c	c	n	c	c	c	c	c	c	c	c	c	c	c	c	c	c	f	c	c	c	c	c	c
ATCP Address Evaluation of Existing Sources?	f	n	c	c	c	c	c	f	n	n	c	c	c	f		c	f	c	c	f	f	n	c	c	c	c	f	c	c	c	c	c	c	f	c	f	f	c	c	c	f	c	f
Facility size or other cutoffs exempting sources?	f	n	c	c	c	n	c	f	n	n	c	n	f	n	c	n	c	c	c	f	f	c	f	n	c	n	n	n	c	n	f	c	c	f	c	n	n	c	c	c	n	c	n
Are AAQS or AAQG used in permit review process?	c	c	c	n	n	c	n	c	n	n	c	c	c	c	n	c	c	c	f	c	n	c	c	c	c	c	c	n	c	c	c	n	f	c	c	c	f	c	c	n	c	n	c
Have AAQS or AAQG been formally adopted?	f	n	c	n	n	f	n	f	n	n	c	n	n	n	c	n	n	c	f	n	f	n	n	n	n	n	n	n	c	n	n	c	n	n	c	f	f	n	c	c	c	c	n
AAQS/AAQG based on occupational health level	n	c	c	n	n	c	c	f	n	n	c	n	c	c	c	c	c	c	c	c	f	c	c	c	n	c	c	n	n	c	c	c	f	f	n	c	f	c	c	c	c	c	c
AAQS/AAQG based on lit review of health effects?	c	n	n	n	n	f	c	f	n	n	f	c	c	c	c	c	c	c	f	c	f	n	c	n	n	f	f	n	n	c	c	c	f	n	c	c	n	c	c	c	n	f	c
Use technology based control regulation?	n	n	c	c	c	c	f	c	n	n	c	n	c	n	c	c	c	c	c	c	f	n	f	c	c	c	c	c	n	c	c	c	f	n	c	n	n	c	c	c	c	c	c
ATCP require cancer risk assessments?	n	c	c	n	n	c	f	n	n	n	n	c	c	c	n	c	n	c	c	c	f	f	c	c	n	f	c	c	n	c	c	f	c	f	c	n	n	n	c	c	n	c	c
ATCP require non cancer risk assessments?	c	n	c	n	n	c	f	n	n	n	n	c	c	n	c	c	n	c	c	c	f	n	f	n	n	f	c	c	n	c	f	f	c	f	c	n	n	n	c	n	n	c	n
Regulating agency maintain toxics emission inventory?	n	c	n	c	c	c	c	f	n	f	c	c	c	c	f	c	f	c	c	f	c	n	c	c	c	c	f	n	c	c	c	c	f	f	c	c	c	c	f	c	c	c	c
Regulatory Agency enforce control of air toxics?	c	n	c	f	f	c	c	n	n	n	c	c	n	n	n	c	c	c	c	c	c	n	n	c	n	c	f	n	c	c	c	c	f	c	c	f	n	c	c	c	n	c	n
ATCP use permit renewal to require toxic control?	n	c	c	f	f	c	n	c	n	n	f	c	f	n	n	c	f	c	c	n	f	n	c	c	n	c	c	n	c	c	n	n	f	n	c	f	n	c	n	n	n	c	n
ATCP require accident prevention plans?	n	n	n	f	f	f	c	n	n	f	c	c	n	n	n	f	n	n	n	c	n	n	n	n	n	f	f	c	f	c	n	f	f	f	n	f	n	c	n	n	n	n	n
ATCP require emergency response planning?		n	n	f	f	c	c	n	n	n	c	c	n	n	n	f	n	n	n	n	c	n	n	n	c	f	f	c	c	c	n	f	f	f	n	f	c	n	n	n	n	n	n

All information from NATICH Air Toxics Database as of March 25 1993

AAQG = ambient air quality guidelines
AAQS = ambient air quality standards

c = current program
n = no program
f = future program

TABLE 3.3. SUMMARY OF STATES WITH AIR TOXICS PROGRAMS

State	ATCP regulates NESHAP pollutants / sources only	ATCP regulates sources/pollutants besides those regulated under NESHAP	ATCP based on promulgated regulations	ATCP based on guidelines rather than formal regulations
AL		X		X
AK(1)		X	X	
AR(2)	X			
AZ		X		X
CO(1)		X	X	
CA		X	X	
CT		X	X	
DE	X			
FL	X			
GA(2)	X			
HI	X			
ID	X			
IL	X			
IN		X		X
IA	X			
KS		X		X
KY		X	X	
LA		X	X	
ME	X			
MA		X		X
MD		X	X	
MI(1)		X	X	
MS	X			
MO		X		X
MT	X			
NE(1)		X	X	
NH		X	X	
NJ		X	X	
NM		X	X	
NV(2)		X		
NY		X		X
NC		X	X	
ND	X			
OH		X		X
OK		X	X	
OR		X		X
PA	X			
RI		X	X	
SC		X	X	
SD	X			
TN(2)	X			
TX		X	X	
UT(2)	X			
VT		X	X	
VA		X	X	
WA		X	X	
WI		X	X	
WV(2)	X			
WY		X		X

(1) For the following states with ATCP's based on promulgated regulation, no information from the Bureau of National Affairs was found: AK, CO, MI, and NE.

(2) For the following states, no information was available from the NATICH Air Toxics Database: AR, GA, NV, TN, UT, and WV.

Note: No information was found for the state of Minnisota.

TABLE 3.4. CHARACTERIZATION OF AIR TOXICS CONTROL PROGRAMS (ATCP) FOR STATES WITH A PROGRAM CURRENTLY IN PLACE

State/Question	AL	AK	AZ	CO	CA	CT	IN	KS	KY	LA	MA	MD	MI	MO	NC	NE	NH	NJ	NM	NY	OH	OK	OR	RI	SC	TX	VA	VT	WA	WI	WY
Does the regulating agency maintain an emission inventory for air toxics?	X			X	X	X	X	X		X				X		X	X		X	X	X	X		X	X	X		X	X	X	X
Is a specified list of polutants regulated under the ATCP?			X	X	X	X	X	X	X	X		X			X	X	X	X	X					X	X			X	X	X	
Is a specified list of sources and source categories regulated under the ATCP?										X																			X		
Are there facility size or other cutoffs under which certain source types or pollutants are exempt?			X	X	X				X		X	X				X			X			X	X	X		X	X	X		X	
Does the ATCP require the use of a minimum technology requirement such as BACT?			X	X	X	X	X		X	X	X	X	X			X	X	X		X	X	X		X		X	X	X	X	X	X
Does the ATCP require risks assessments for air toxics to be performed?	X	X	X			X	X	X	X	X		X	X					X		X	X		X	X			X	X		X	X

All information based on that which was available from the NATICH Air Toxics Database as of 3-25-93.
No information for the state of Nevada was available from the NATICH data base in regards to their ATCP.

3.2.2 State Regulations Applicable to Coal–Fired Units

For the 21 states having a current ATCP based on promulgated regulations, descriptions of the individual regulations were obtained from the Bureau of National Affairs. These regulations were then assessed as to their applicability to coal–fired units. Table 3.5 presents a summary of state air toxic regulations which may be applicable to coal–fired units. Most identified state regulations specify a general applicability (ie: new, modified, or existing stationary source). The standards imposed by each of the state regulations follow one of six approaches. These approaches can be summarized as follows:

Approach A - Emissions shall not exceed a calculated site specific stack emission limit;

Approach B - Emissions shall not exceed a specified stack emission limit;

Approach C - Emission shall not endanger human health and/or the environment;

Approach D - Emissions shall not cause or contribute to a violation of an AAQS;

Approach E - Emissions shall not cause or contribute to a violation of an AAQS for those sources which emit above a specified significant level;

Approach F - Applicable source shall perform specified activities such as registration and emission inventory reporting.

A description of these approaches follows.

Approach A. Under Approach A the standard directly specifies that no person shall cause or permit the emission of any listed HAP to exceed its stack emission limit. Determination of a stack emission limit is based on an equation which takes into account site specific parameters such as stack height and distance to point of pollutant impact. If the source complies with the calculated emission limit, then it is assumed that the owner or operator does not cause or exacerbate a violation of the applicable ambient air quality standard (AAQS). This is demonstrated by the use of air quality models, data bases and other approved procedures to determine the ambient air concentration that is a result of the emission in question and then comparison of this value with the AAQS.

If the source does not meet the calculated stack emission limit, then the owner or operator is required to install and use BACT or some other specified equivalent, in addition to demonstrating that the source will not cause an impact in excess of the applicable AAQS. In some cases BACT is only required for new or modified sources and a less stringent Reasonably Available Control Technology (RACT) requirement is imposed on existing sources.

TABLE 3.5. SUMMARY OF STATE AIR TOXIC REGULATIONS APPLICABLE TO COAL FIRED UNITS

State	Regulation	Applicability	Standard	Possible Applicability to Coal Fired Units
AK	(1)	(1)	(1)	(1)
CA	AB2588	Any existing source which formulates, manufactures, uses, and emits a listed air toxic.	All sources shall submit a comprehensive air toxics emission inventory.	Facilities releasing less than 10 tpy are currently not regulated
CO	(1)	(1)	(1)	(1)
CT	CT 22a-174-29	Any new or modified stationary source permitted after Oct 1, 1986 which emits or may emit an air toxic	No source shall emit any listed air toxic at a concentration at the discharge point (ie; stack) in excess of the maximum allowable stack concentration (MASC)	Y
KY	401 KAR 63:020	Any existing stationary source which emits a listed air toxic above a specifed significant level.	No source shall emit any listed air toxic in excess of the allowable emission limit as determined through the use of a specified equation and a specified acceptable ambient air concentration limit. For sources with no acceptable ambient air concentration, resonable available control technology (RACT) must be applied.	Y
KY	401 KAR 63:022	Any new or modified stationary source which emits a listed air toxic above a specified significant level.	No source shall emit any listed air toxic in excess of the allowable emission limit as determined through the use of a specified equation and a specified acceptable ambient air concentration level For source with no acceptable ambient air concentration, best available control technology (BACT) must be applied?	Y
LA	LAC 33, Part III, Chapt 51	Any stationary source which emits or has the potential to emit , in the aggregate, 10 pty or more or 25 tpy of any combination of a listed air toxic.	No source shall emit any listed air toxic which will cause a violation of a specified acceptable AAQS.	Emissions from the combustion of coal, vented from a stack with an approved height which minimizes downwash are exempt
MD	COMAR 26.11.15	Any source which emits a listed air toxic and is required to obtain a permit under COMAR 26.11.02.03-.16.	The total allowable air toxic emissions from a source shall not unreasonably endanger human health. This may be demonstrated by comparison to a specified acceptable AAQS or AAQG.	Emission from qualifying small quantity dischargers and fuel burning equipment as defined by COMAR 26.11.18.01 are exempt
MI	(1)	(1)	(1)	(1)
NC	15A NCAC 1101	Any facility which emits a listed air toxic and is required to obtain a permit under 15A NCAC 2H .0610.	No facility shall emit a listed air toxic in such quantities that may adversely affect human health. This may be demonstrated by comparison to a specified acceptable AAQS	Y
NE	(1)	(1)	(1)	(1)
NH	NHAD, ENV-A 1300	Any stationary source which emits any air toxic which meets specified identification criteria.	No source shall emit any air toxic (which meets identification criteria) which will cause a violation of a specified acceptable AAQS (2)	Y

TABLE 3.5. SUMMARY OF STATE AIR TOXIC REGULATIONS APPLICABLE TO COAL FIRED UNITS (CONTINUED)

State	Regulation	Applicability	Standard	Possible Applicability to Coal Fired Units
NJ	NJAC 27:17	Any source operation or equipment (ie: Storagge tank; Cl transfer operation)	No source shall emit any listed air toxic unless registered and permitted	N
NM	(3)	Any new or modified source which is believed to emit any air toxic.	No source shall emit any listed air toxic which will cause a violation of a specified acceptable AAQS.	Y
		Any source which has a total potential emission of air toxics which exceed a specified emission level.	All sources must register and supply air toxics emission inventory information	Y
OK	Reg No. 3.8	Any stationary source which emits any air toxic	No source shall emit any listed air toxic which will cause a violation of a specified acceptable AAQS (4)	Y
RI	Reg No. 22	Any new or modified stationary source	No source shall emit any listed air toxic which will cause a violation of a specified acceptable AAQS.	Y
		Any stationary source which used or emitted greater than a minimum level of air toxics.	All sources must register and supply air toxic emission inventory information	Y
SC	(3)	Any stationary source which emits air toxics	No source shall emit any listed air toxic which will cause a violation of a specified acceptable AAQS.	Does not apply to fuel burning sources which burn only virgin fuel or used oil.
TX	TAC, NRCIII 115	Any source operation (ie: spray chamber with the potential to exist VOC's coating)	(3)	N
VA	Rule 4-3	Any stationary source which emits or may emit any air toxic above a specified significant level.	No facility shall emit any air toxic in such quantities that may cause or contribute to the endangerment of human health. This may be demonstrated by comparison to a specified acceptable AAQS or AAQG (4)	Y
VT	VSA 5-261	Any stationary source which emits a listed air toxic above a specified significant level	No source shall emit any listed air toxic which will cause a violation of a specified acceptable AAQS.	Y

TABLE 3.5. SUMMARY OF STATE AIR TOXIC REGULATIONS APPLICABLE TO COAL FIRED UNITS (CONTINUED)

State	Regulation	Applicability	Standard	Possible Applicability to Coal Fired
WA	WAC 173-460	New stationary sources which emit HAP's	Air toxic emission from a source shall be sufficiently low as to protect human health and safety from potential carcinogenic and /or other toxic effects. This may be demonstrated by comparison to a specified acceptable AAQS.	Y
WI	WIAC NR445.04	New or modified stationary sources which commenced after Oct 1, 1988	No source shall emit a listed air toxic at a concentration at the stack in excess of the specified emision limit.	Emission from the combustion of coal vented from a stack with an approved height which minimizes downwash are exempt
	WAIC NR445.05	Existing stationary sources which commenced before Oct 1, 1988	No source shall emit a listed HAP at a concentration at the stack in excess of a specified emision limit	Emission from the combustion of coal vented from a stack with an approved height which minimizes downwash are exempt

(1) No information was available from the Bureau of National Affairs.
(2) No AAQS's have been specified as of 12-21-90
(3) No information was available at the time of which this report was prepared.
(4) The concentration limits are based on Occupational Exposure Limits (OEL), therefore the regulation is directed towards worker safety.

Both Connecticut and Kentucky use this type of approach. Kentucky has an additional level of applicability in that only sources which emit air toxics above a specified significant amount need to calculate an emission limit to demonstrate compliance. This screens out small quantity generators from even being regulated under the standard.

Approach B. The standard directly specifies that no person shall cause or permit the emission of any listed HAP to exceed its applicable stack emission limit. In contrast to Approach A, the stack emission limits are specified rather than calculated. This may result in a more stringent standard in that the benefit of a limit calculated using site specific parameters is not utilized. If the source does not meet the specified stack emission limit, then the owner or operator is required to install and use BACT or equivalent, and demonstrate that the source will not cause an impact in excess of an applicable AAQS. The states of Louisiana and Wisconsin employ this type of approach.

Approach C. In Approach C, the standard does not specify a limit but rather calls for the total allowable emissions of any listed HAP to not reasonably endanger human health and/or the environment. This requirement may be demonstrated by a variety of methods including comparison of resulting ambient air concentration with specified AAQS. Usually BACT or the equivalent is required regardless of the human health assessment.

Approach C is utilized by Maryland, North Carolina, Washington and Virginia. Under the Maryland program, an owner or operator may demonstrate compliance with the human health standard by comparing an ambient air concentration due to the facility's noncarcinogenic emissions with specified standards. Based on the result, a risk assessment must be conducted for carcinogenic pollutants to determine if these cause more than a 1 in 100,000 increase in a person's lifetime cancer risk.

The North Carolina and Washington programs are somewhat less stringent in that resulting ambient air concentrations need only compare favorably to an applicable AAQS to demonstrate compliance to the standard, regardless if the pollutant is carcinogenic or noncarcinogenic. Both states require the use of BACT or some state specified equivalent. Virginia's program is similar to this approach, but in addition, the size of the facilities regulated is limited. This is achieved by emission screening limits. For facilities which emit air toxics below their applicable screening limit, the regulation does not apply.

Approach D. Under Approach D the standard directly specifies that no person shall cause or permit the emission of any listed HAP in such concentrations as to cause or contribute to a violation of an AAQS. Similar to the previous approaches, this is demonstrated by the use of air quality models, data bases and other approved procedures to determine an ambient air concentration impact resulting from the facility of concern and then comparison of this value with an applicable AAQS.

Consequences for sources not meeting the specified AAQS, vary from state to state. In general, most require the owner or operator to install and use BACT. Some states which use this approach, allow the use of the less stringent RACT requirement for those pollutants identified as being of low or moderate toxicity. Other state programs are more stringent in that they specify an additional risk assessment requirement for new sources or those that emit highly toxic pollutants. New Mexico, New Hampshire, and South Carolina, all use Approach D.

Approach E. Approach E is essentially the same as Approach D but the size of the facility to which the regulation is applicable is indirectly limited. For example, in Virginia, screening emission limits are specified below which a facility is not regulated.

Approach F. Approach F is all other programs which do not specify a standard or limit but merely require activities such as registration of source, public notice and/or quantification of emissions for inventory purposes. Regulations imposed at a state level by California and New Mexico fall into this category.

3.2.3 State Specified Air Toxic Pollutants

Seven states with current ATCPs based on promulgated regulations were identified in the preceding section as being possibly applicable to coal–fired utility boilers. Appendix A lists the corresponding acceptable ambient air quality standards, illustrating the type and to what level air toxics are regulated by these programs. For the states employing approach A or B, acceptable emission rates instead of AAQSs are specified or a method to calculate such values is provided.

3.2.4 Local District Control

Air toxics can be regulated, and often are, at a local level by air quality management districts. Table 3.6 gives a list of local agencies with air toxic programs as identified by the Air Toxics Clearing House (NATICH).

TABLE 3.6. LOCAL AGENCIES WITH ATC PROGRAMS

STATE	AGENCY
Alaska	Jefferson County Air Pollution Control Program
California	Bay Area Air Quality Management District South Coast Air Quality Management District San Diego Air Pollution Control District Colusa County Air Pollution Control District Ventura County Air Pollution Control District Lassen County APCD North Coast Unified AQMD Sacramento Metropolitan AQMD
Florida	Hillsborough Co. Environmental Protection Commission Broward County Office of Natural Resource Protection Orange County Air Pollution Control Board Pinellas County Air Pollution Control Board
Iowa	Polk County Physical Planning Dept.
Kansas	Wyandotte Co. Health Dept.; Bur. of Air & Wate Mgmt. Wichita-Sedgwick County Dept. of Community Health
Maryland	Prince George's County Health Department
North Carolina	Mecklenburg County Dept. of Environmental Protection
Ohio	Toledo Environmental Services Division Southwest Ohio Air Pollution Control Agency North Ohio Valley Air Authority
Oklahoma	Tulsa City-County Health Dept., Air Quality Control
Pennsylvania	Phil. Dept. of Public Health, Air Management Services
Tennessee	Chattanooga-Hamilton Co. Air Pollution Control Bureau
Washington	Puget Sound Air Pollution Control Agency Grant County Clean Air Authority South West Air Pollution Control Authority Northwest Air Pollution Authority Benton-Franklin-Walla Counties APCA

4.0 AIR TOXICS MONITORING PROGRAMS

In today's regulatory framework, the control of emissions is first written into law; it is then up to polluters to test for the regulated compounds and manage them according to residual risk. Rarely, is this process reversed, allowing sources to determine emissions of concern, categorize them according to risk, and then have legislators enact risk-based laws for the EPA to enforce as appropriate. It is no wonder then that because the enforcement of the 1990 Clean Air Act Amendments (CAAA) is still, from a regulatory standpoint, "new", there is little emissions data for the 189 substances listed under Title III. This lack of data makes it difficult for the EPA to determine whether regulation of any source, much less utility boilers, is necessary.

An exhaustive literature search was conducted to ascertain exactly how much emissions data from coal-fired utility boilers are available, how current the data are, and how many substances on the CAAA Title III list does the existing data base cover. The search began using the Dialog® Information Retrieval Service and the University of California On-Line MELVYL® Catalog. Environmental, pollution, and energy abstracts were the focus with a total of 42 unique databases searched. Using these results, several documents were ordered from the National Technical Information Service (NTIS). A brief review of these documents showed there were other primary sources of information. After locating and reviewing these new sources, it was clear that the same data circulates among several sources, and when a new source was supposedly found, it referenced data from documents already in house. In short, the present data are finite and extremely limited in scope.

The existing emissions data from coal-fired utility boilers covers mainly inorganics, specifically metals. What little organic emissions data exists is close to ten years old and can no longer be considered accurate because of the test methods used. Efforts are presently underway to verify the current data and fill the gaps in the existing emissions data base. This section briefly discusses these air toxics monitoring programs and assesses the present "state of knowledge" of air toxic emissions from coal-fired power plants.

4.1 Studies in Progress

The research currently being conducted to characterize air toxic emissions from coal-fired utility power plants is an attempt to expand the scope of the current data base of emissions. The new analytical data obtained from these studies will help the EPA determine the potential air toxics from coal-fired boilers and whether regulation of these facilities is appropriate and necessary. This determination is slated for November 1995. There are four investigations currently in progress and one that is planned to assess hazardous air pollutants (HAPs) from coal-fired utility power plants. Two are sponsored by the Electric Power Research Institute (EPRI) and Ontario Hydro of Canada, and three are being conducted by the Department of Energy's (DOE) Pittsburgh Energy Technology Center (PETC). No data from these studies were available for analysis.

4.1.1 PISCES

In 1988, EPRI initiated a program to assess the emissions of HAPs from power plants under the acronym PISCES (Power Plant Integrated Systems: Chemical Emission Studies). The study evaluates the presence and fate of chemicals in air, water, and solid waste discharges. This holistic approach allows controls to be applied with full knowledge of impacts on other plant process streams (Chow, 1991). The program also includes a relational database on chemical species in power plant systems. The database allows users to draw relationships between chemicals, process streams, and plant configurations. To date, the database includes 80,000 records of reported quantity data from 10 utility sites for 36 of the 189 hazardous air pollutants listed in Title III of the CAAA (Chow, 1991). Table 4.1 lists the 36 hazardous air pollutants for which data are available. This list of compounds is based on whether or not the substance was detected in the flue gas; it is not ranked according to actual risk.

As part of the literature review, EPRI was contacted to investigate further details of the PISCES database and to possibly obtain a copy of a relevant data printout. However, according to EPRI, the database is still undergoing verification and some data collection remains to be done. Currently, the chemical data in the database is limited to inorganic species in the liquid and solid process streams and includes few organic compounds. EPRI hopes to include data for more organic species in all three process streams and inorganic species in the gaseous process streams when it becomes available. Since PISCES currently contains little data of interest, and the data qualitv had yet to be verified, no emissions data were used from this source.

4.1.2 Ontario Hydro

At great expense, Ontario Hydro, a publicly owned utility that supplies electricity to the province of Ontario, Canada, has been characterizing organic emissions from all six of their fossil-fuel fired generating stations in anticipation of Canadian regulations (Curtis, 1991). Four of their plants fire bituminous coal: Lakeview, Lambton, Nanticoke, and Thunderbay. Of these four, only Lakeview and Lambton have completed the testing and data analysis. When all of the data have been collected and verified, it will become part of the PISCES database. The parameters measured at the two completed sites are given below:

Lambton - dioxins, furans, chlorobenzenes, chlorophenols, polychlorinated biphenyls (PCBs), and polyaromatic hydrocarbons (PAHs).

Lakeview - 32 metals and acid gas anions, a wide range of chlorinated aromatics, aldehydes, ketones, and 38 PAH compounds.

A strong attempt was made to acquire this data; but, since the data from Nanticoke and Thunderbay have yet to be verified, Ontario Hydro was somewhat reluctant to release the information.

4.1.3 Battelle and Radian

The Pittsburgh Energy Technology Center has two current projects to assess the air toxics emissions from coal-fired utility boilers. The DOE has contracted the Battelle Memorial Institute and Radian Corporation to investigate which air toxics tend to associate with various size distributions of particulate matter emitted from the stack (Brown, 1993). The selected compounds for these studies are again mostly inorganics, but benzene, toluene, formaldehyde, and polycyclic aromatic hydrocarbons (PAHs) are also being investigated.

Battelle Memorial Institute (BMI) and its subcontractor Keystone/IEA are correlating the air toxics produced by a laboratory-scale combustor with those from two full-scale, coal-fired electric utility boilers. To help determine how well the lab-scale combustor simulates emissions from a full-scale system, BMI is firing the same coals used at the two coal-fired electric utilities. Once the emissions from the lab combustion work are quantified, the DOE and EPRI can use this information to assist them in determining which air toxics to sample in future emissions characterization studies (Brown, 1993).

TABLE 4.1. HAZARDOUS AIR POLLUTANTS IN THE PISCES DATABASE

Compound
Acetaldehyde
Antimony Compounds
Arsenic Compounds
Benzene
Beryllium Compounds
Biphenyl
Bis(2-ethylhexyl)phthalate (DEHP)
Cadmium Compounds
Carbon disulfide
Carbon tetrachloride
Carbonyl sulfide
Chlorine
Chlorobenzene
Chloroform
Chromium Compounds
Cobalt Compounds
Dibenzofurans
1,4-Dichlorobenzene(p)
Formaldehyde
Hexachlorobenzene
Hydrochloric acid
Hydrogen fluoride
Lead Compounds
Manganese Compounds
Mercury Compounds
Naphthalene
Nickel Compounds
Pentachlorophenol
Phenol
Phosphorous
Selenium Compounds
2,3,7,8-Tetrachlorodibenzo-p-dioxin
Tetrachlororethylene (Perchloroethylene)
Toluene
Trichloroethylene
2,4,5-Trichlorophenol

Source: (Chow, 1991)

The Radian Corporation will collect size-fractionated particles from the stack of a full-scale coal-fired utility boiler and characterize the particles for both bulk and surface chemical composition (Brown, 1993). Sampling will take place during a high-load season (winter), a lower-load season (spring), and load swings. Each test period will last three to four weeks. Particulate samples will be collected at the stack under both hot-stack and dilution-cooled conditions. To date, Radian has also evaluated several sample preparation procedures and analysis techniques to determine which procedures to use on the flyash samples collected from both the hot and cooled stack gas. Two bulk-composition and three surface-leaching techniques have been chosen.

The bulk composition of the flyash particles will be determined by neutron activation and glow discharge mass spectrometry (GDMS). To identify the surface composition of the flyash, the particles will first be exposed to three leaching agents: nitric acid digestion, gastric fluid, and acetic acid. All three leachate samples will then be analyzed using inductively coupled argon plasma mass spectrometry (ICP-MS). ICP-MS provides lower detection limits and improved precision compared to the conventional inductively coupled argon plasma emission spectrophotometry (ICP) or graphite furnace atomic absorption spectrophotometry (GFAA) (Brown, 1993).

Results from this program will allow the DOE and EPA to better determine which air toxics are of primary concern in coal combustion and which analytical techniques to use to characterize them. These data, however, are not yet available, and could not be used in this study.

4.1.4 Comprehensive Assessment of Toxic Emissions from Coal-Fired Power Plants

Since there are large gaps in the existing air toxics data from power plants and little or no analytical data on the removal of toxics using an electrostatic precipitator (ESP), baghouse, or wet lime scrubber, the DOE has just initiated a program to assess toxic emissions from 8 different coal-fired power plants with various types of control technologies. The program is a collaborative effort between the DOE, the Utility Air Regulatory Group (URGA), EPRI, and the EPA.

The undertaking will involve measurements at eight power plants having different boiler designs, NO_x control methods, particulate control devices, and SO_2 removal systems (wet and dry). The tests will include measurements of all elements and compounds denoted in Table 4.2. Of the 189 substances listed as air toxics, approximately 80 will be measured in the DOE program. All the tests will use the same testing and analytical procedures. Solid, liquid, and gaseous samples will be taken at collection points both entering and leaving the plant to determine the concentrations of pollutants at each stage (DOE, 1993). The major objectives of the tests at each site are:

- To determine the ability of various types of pollution control equipment to capture toxic air emissions;
- To determine the material balances of selected pollutants;
- To determine how the level of the emissions in the flue gases varies by the size of the particles;
- To measure the relative levels of the emissions in the particles and vapor of the flue gases.

Work under the program will begin later this spring, with testing to conclude at all sites by July. The DOE hopes to have the reports finalized by the end of the year so the EPA may begin the

TABLE 4.2. FLUE GAS SAMPLE TRAINS AND ANALYTES FOR DOE'S AIR TOXICS ASSESSMENT PROGRAM

Isokinetic Trains	Nonisokinetic Trains
MM5 •SVOCs •PCDD/PCDF •POM •PAH •Velocity •Moisture Multi-Metals Train •Metals (As through V) •Velocity •Moisture Carbon Trap •Metals (As, Hg, Se) •Velocity •Moisture M5 •Total particulate emissions •Radionuclides •Bulk fly ash analysis Carbon Chloride Flouride Sulfates Phosphates •Sulfates (impingers) •Phosphates (impingers) •Velocity •Moisture	VOST •VOCs M26 •HCl and Cl2 •HF •NH3 •HCN •Total Organic Carbon Aldehydes •Formaldehyde plus 7 others Cyclones (pseudo-isokinetic) •Fractionated particulate for chemical analysis Impactors (pseudo-isokinetic) •Particulate size distribution

review process by early 1994. The five firms selected to conduct the tests along with the planned test sites are given below:

Southern Research Institute, Birmingham, AL
Northern Indiana Public Service Co. Bailley Station, Gary, IN
Tucson Electric Springerville Station, Springerville, AZ

Battelle Memorial Institute, Columbus, OH
Ohio Edison Niles Station, Niles, OH
Cooperative Power Association Coal Creek Station, Underwood, ND

Roy F. Weston, Inc., West Chester, PA
Minnesota Power Co. Clay Boswell Station, Cohasset, MN
Illinois Power Co. Baldwin Station, Baldwin, IL

Radian Corporation, Austin, TX
Georgia Power Co. Plant Yates, Newnan, GA

Energy and Environmental Research, Inc., Irvine, CA
Ohio Power Company Cardinal Station, Brilliant, OH

4.2 Sources of Information

The current state of knowledge concerning air toxics from coal-fired utility boilers is not defined by one authoritative source of information. Instead, one must assemble bits of data from several different sources to gain a comprehensive view of the subject. Discussed below are the sources of information in which the limited emissions data were found for this project. For each document, a general description of the research conducted and data provided is given. If discussed in the final report, the study's quality assurance procedures are also mentioned. Except for those studies that recommended otherwise, all information used from these documents was based on measured data. A list of substances from each report for which emissions data were used is also provided. Emissions information for 47 HAPs is reviewed and summarized in the following sections. Each section describes a different report or information source.

4.2.1 Estimating Air Toxic Emissions from Coal and Oil Combustion Sources (Brooks)

This report contains emission factors for arsenic, beryllium, cadmium, chromium, copper, lead, manganese, mercury, nickel, radionuclides, formaldehyde, and POM emissions from coal and oil combustion sources. The emission factors are organized in the following hierarchy:

- Fuel type
- Pollutant
- Combustion sector
- Boiler type

Controlled and uncontrolled factors are presented for all pollutants. For trace metals, the data are presented in terms of measured factors (based on source tests) and calculated factors (based on levels of trace metals in the fuels and theoretical partitioning assumptions). In addition to the emission factors, control device effectiveness percentages are provided for the trace metals based on source test results.

The emission factors for coal-fired combustion sources are derived from a combination of measured data and calculated emission factors. The literature was reviewed for test data from which trace element emission factors could be derived. The report lists about 35 references which reported measured emission factors for one or more of the trace pollutants and types of combustion sources under study. The report's emission factors, however, should not be construed to represent a fully characterized or representative emission rate for the given combustion source situation. Extensive data quality assurance procedures, necessary to reasonably characterize a data set as representative of a particular source, were not performed in this study. Instead, the factors given are simply straightforward calculations of emission factor averages and ranges based on data presented in the reviewed literature. With this in mind, the emission factors selected from this document are for the following compounds:

- Arsenic
- Beryllium
- Cadmium
- Chromium
- Formaldehyde
- Lead
- Manganese
- Mercury
- Nickel
- Radionuclides

4.2.2 Toxic Air Pollutant Emission Factors: A Compilation for Selected Air Toxic Compounds and Sources, Second Edition (Pope, 1990)

The report contains emission factors for selected air toxic compounds and sources, and associates the factors with levels of source activity. The emission factors, compiled from a review of the literature, are sorted by pollutant and source. Each factor is identified by pollutant name, CAS number, process and emission source descriptions, SIC code and SCC's. There are approximately 270 compounds and 470 sources having emission factors in this edition of the compilation. However, only 18 compounds are covered for coal-fired boilers. From this list of 18 compounds, only the data that were based on actual source tests were selected. The emission factors for coal-fired boilers extracted from this report include the following compounds:

- Chlorine
- 2,3,7,8-polychlorinated dibenzo-p-dioxins
- Polycyclic organic matter (POM)
- Selenium

The quality of emission factors presented in this compilation vary considerably. Emission factors are derived in a variety of ways including source tests, theoretical calculations, or a combination of both tests and calculations. Analyses of several source tests or a single source test may be used to determine some of the factors in this report. Other factors are calculated by using mass balances or national emissions estimates divided by national production capacities for chemicals. Because insufficient data exist to determine the accuracy and validity of the emission factors in this compilation, no estimates can be made of the error that results from using these factors to calculate toxic air emissions from any given facility.

4.2.3 The Fate of Trace Elements at Coal-Fired Power Plants (Meij, 1992)

In this research program, N.V. KEMA of the Netherlands studied the element concentrations of coal, bottom ash, pulverized-fuel ash (PFA, ash collected in the ESPs) and fly ash from a coal-fired utility boiler equipped with an ESP and a flue-gas desulfurization (FGD) device. Special attention was given to minor and trace elements present in the vapor phase in the flue gases downstream of the ESP (As, B, Br, Cl, F, Hg, I, Se). In order to establish relationships between the elements in the different streams, material balances were determined to obtain a good impression of the accuracy of the measurements. The research established that an ESP removes hardly any gaseous inorganic trace elements. This study proved to be a good source of information. The data presented here were used to predict the amount of halogenated organics that might be emitted from a utility boiler.

4.2.4 Hydrogen Chloride and Hydrogen Fluoride Emission Factors for the NAPAP Emission Inventory (Misenheimer, 1986)

In this report, sources emitting hydrogen chloride (HCl) and hydrogen fluoride (HF) were identified and rates of emissions for each source were estimated. When available, the emission factors based on source tests by a sound methodology and accompanied by adequate background data were chosen from the reviewed literature. Emission factors were evaluated using a system similar to the one used in AP-42. The scaling system is as follows: A represents data from a large data base covering a good cross section of the industry, determined from valid test methods, and with a high confidence level; E represents data from a small database, not necessarily representative of the industry, and with a low confidence level; B through D represent data with intermediate confidence levels. The two emission factors chosen from this report are rated an A:

- Hydrogen Chloride
- Hydrogen Fluoride

4.2.5 Emissions Assessment of Conventional Stationary Combustion Systems; Volume III. External Combustion Sources for Electricity Generation (Shih, 1980)

This study employed a phased approach to assess the emissions from coal combustion sources. The assessment method first involved a critical examination of existing emissions data, followed by a source testing program to fill the data gaps based on phased sampling and analysis. Data acquired as a result of the measurement program and existing data were then evaluated together.

Specifically, the phased approach uses two levels of sampling and analysis. Level I utilizes semiquantitative techniques of sample collection and laboratory and field analyses to: provide preliminary emissions data for waste streams and pollutants not adequately characterized; identify potential problem areas; and prioritize waste streams and pollutants in those streams for further, more quantitative testing. Using the information from Level I, available resources can be directed toward Level II testing which involves specific, quantitative analysis of components of those streams which contain significant pollutant loadings.

By comparing the emission factors calculated from data collected during this program with the corresponding emission factors derived from existing data, this study showed there is poor agreement between the two. This discrepancy is not surprising because of the differences in trace element contents of various coals and differences in the efficiency of particulate control devices. The report claims the emission factors from the existing data are more reliable than the emission factors from the current study since the existing data are based on average nationwide concentrations of trace elements in bituminous coal, average collection efficiency of particulate control devices, and trace element data determined using more reliable techniques such as atomic absorption spectrometry. Therefore, the emission factors chosen from this report include those from the existing data base not the ones generated during this study. The emission factors chosen are for the following compounds:

- Antimony
- Biphenyl
- Cobalt
- Naphthalene

4.2.6 Air Emissions Species Manual: Volume I Volatile Organic Compound Species Profiles, Second Edition (EPA, 1990)

This document is a compilation of over 250 original volatile organic compound (VOC) profiles. Of these profiles, the majority are newly developed from existing data or based on engineering judgement. The other portion are from the 1980 VOC Data Manual or new data from the VOC species field program. Each profile contains the following information:

Profile Name

Profile Number

Profile Data Quality

Control Device Identification

References

Data Source

Source Classification Code (SCC)

Chemical Species Identified By: SAROAD code, CAS number, species name, molecular weight, weight percent

Date

To assist the user in identifying the data quality, the report uses an arbitrary scheme (A, B, C, D, E) similar to the one used in AP-42 to rank each profile. The following criteria were used to assign data quality indicators (EPA, 1990):

Data Quality A:	Data set based on a composite of several tests using analytical techniques such as GC/MS and can be considered representative of the total population.
Data Quality B:	Data set based on a composite of several tests using analytical techniques such as GC/MS and can be considered representative of a large percentage of the total population.

Data Quality C:	Data set based on a small number of tests using analytical techniques such as GC/MS and can be considered reasonably representative of the total population.
Data Quality D:	Data set based on a single source using analytical techniques such as GC/MS; or data set from a number of sources where data are based on engineering calculations.
Data Quality E:	Data set based on engineering calculations from one source; data set(s) based on engineering judgement; data set(s) with no documentation provided; may not be considered representative of the total population.

Of the 250 VOC profiles in this document, only two are from coal-fired boilers. These two profiles quantify four of the air toxics listed under Title III of the 1990 Clean Air Act Amendments (CAAA). The data quality for these two profiles are given a ranking of D and E. These rankings are understandable considering the limited amount of organic emissions data available. The following compounds and their emission factors were selected from this report:

- Ethylbenzene
- Hexane
- Toluene
- Xylene

4.2.7 Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and The Area Sources, Fourth Edition (EPA AP-42, 1988)

Volume One of the two volume series, contains emission data obtained from source tests, material balance studies, and engineering estimates, which have been compiled for use by individuals and groups responsible for conducting air pollution emission inventories. The document covers most of the common stationary and area source emission categories: fuel combustion; combustion of solid wastes; evaporation of fuels; solvents and other volatile substances; various industrial processes; and miscellaneous sources. Emission factors given in the document include most of the familiar pollutants associated with these sources' emissions: criteria pollutants; volatile organic compounds (VOCs); aldehydes; and hydrocarbons.

To date, the air toxic emissions factors in this document are limited to a few compounds. The air toxics data are based on uncontrolled emissions and are mostly calculated, not measured. Consequently, these data were not selected during the review process.

4.2.8 Canadian Electric Association (Brown, 1993)

During the first phase of a two-phase program, the Canadian Electric Association conducted a study to examine air, water, and ash pathways for trace constituents released to the environment from four Canadian coal-fired power plants. All the major input and output streams of the utility plant were sampled for up to 45 elements. Material balances were made based on the average of several runs. Material balance closures to within 20% were found for 37 elements. Closure was not obtained for fluorine, silicon, phosphorus, cadmium, mercury, and boron. Table 4.3 summarizes the emission of elements from this program that are on the list of 189 substances. The second phase of this study dealt with the environmental dispersion and biological implications of the release.

TABLE 4.3. FLUE GAS TRACE ELEMENT RELEASES FROM SELECTED CANADIAN COAL-FIRED POWER PLANTS

Element	% of Total Element in Coal Released with the Flue Gas
Chlorine	49 - 99.0
Chromium	0.1 - 8.7
Manganese	0.1 - 1.0
Cobalt	0.09 - 1.5
Arsenic	0.74 - 9.3
Selenium	3.5 - 73.0
Antimony	0.2 - 2.5
Mercury	79.0 - 87.0
Lead	0.2 - 1.4

Source: (Brown, 1993)

Since the data from this study are nearly 10 years old and most of the analytes are inorganic species for which there are newer data, no information from this report was extracted during the literature review.

4.2.9 National Dioxin Study: Tier 4 - Combustion Sources (EPA, 1986)

The main objective of this study was to determine the magnitude and scope of chlorinated dibenzo-p-dioxin (CDD) compound releases from combustion sources. It was designed to determine which combustion source categories emit dioxins and in what concentrations. The focus was on releases to the ambient air; however, other samples, such as ash and scrubber water, were also obtained to determine if these compounds are released to other media. In terms of coal-fired boilers, the study did not detect any dioxin releases.

4.2.10 Background Information Document for the Development of Regulations for PIC Emissions from Hazardous Waste Incinerators (EPA, 1989)

Since the literature discussed above turned up little information on organics, attention was focused on other sources of information during the final phase of the literature review. This document summarizes current knowledge concerning products of incomplete combustion (PICs), total hydrocarbons (THC), and CO emissions from hazardous waste incinerators (HWI) and boilers and industrial furnaces (BIFs). This study supplies emissions concentrations for many of the organic species listed in Title III of the CAAA that many sources do not. Since the emissions given in this report are from BIFs, the data are not totally representative of organic emissions from coal-fired utility boilers. However, because some BIFs supplement their primary feed with hazardous waste, these data could be considered a worst case condition for many coal-fired power plants. Table 4.4 lists the compounds for which emission factors were selected from this report.

TABLE 4.4. SELECTED PICS FROM BOILERS AND INDUSTRIAL FURNACES AND THEIR LEVEL OF EMISSIONS

Substance	Emission Concentration (ng/L)
Acetonitrile	0.26
Benzene (including benzene from gasoline)	4928
Bis(2-ethylhexyl)phthalate (DEHP)	77.7
Carbon tetrachloride	99.5
Chloroform	1407
1,4-Dichlorobenzene(p)	86.5
Ethylidene chloride (1,1-Dichloroethane)	3.37
Formaldehyde	892.2
Hexachlorobenzene	8.95
Methyl ethyl ketone (2-Butanone)	33.2
Methylene chloride (Dichloromethane)	1755.3
Pentachlorophenol	9.3
Phenol	33.1
2,3,7,8-Tetrachlorodibenzo-p-dioxin	0.00157
1,1,2,2-Tetrachloroethane	17
Tetrachlororethylene (Perchloroethylene)	297
Toluene	550.5
1,2,4-Trichlorobenzene	77
1,1,2-Trichloroethane	36.7
Trichloroethylene	81.8
2,4,5-Trichlorophenol	143.6
Vinyl chloride	14
Vinylidene chloride (1,1-Dichloroethylene)	31.6

Source: (EPA, 1989)

5.0 AIR TOXICS EVALUATION OF ABB COMBUSTION ENGINEERING LOW EMISSION BOILER (LEB) AND ITS CONTROL ALTERNATIVES

The Clean Air Act Amendments (CAAA) of 1990 list 189 hazardous air pollutants (HAPs) which must be controlled from various types of sources. Extensive resources would be required to quantify and determine maximum achievable control technology (MACT) for each of the 189 HAPs for each source type. To reduce the resources required, various agencies and industry groups are attempting to eliminate HAPs from consideration based on previous research and testing. For coal fired utility boilers, several studies have been conducted to try and eliminate some of the compounds from consideration. For example, the Power Plant Integrated Systems: Chemical Emissions Study (PISCES) developed a list of 36 air toxics of concern (see Table 4.1). The limitation of the PISCES study is that it only considered those substances which have been measured to date and did not specify which substances would be emitted at levels of concern to regulatory agencies.

Only a limited set of the 189 HAPs have been measured to date from coal fired utility boilers as discussed in Section 4.0. Most of the testing focused on metals and only a few tests have been conducted for organics. If testing programs are planned which only seek to quantify those substances which have already been measured, the expected levels of a large number of the 189 HAPs will not be determined. Many of these unquantified substances could pose a substantial risk to the pubic even if they are emitted at low levels from utility boilers. To determine if substances which have not been quantified in past testing programs could be present, techniques such as mass balance should be considered. For example, there may not be enough chlorine in the feed to produce hexachlorobenzene emissions of regulatory concern. Source test data from similar types of systems also can be used to estimate potential emissions from coal fired systems.

Another important topic that most studies have neglected is the relative toxicity of the 189 HAPs. To determine if a substance will be a critical concern, HAP emissions must be compared to applicable state, federal, and local limits. Emissions which exceed acceptable regulatory levels should be given special attention when developing MACT. If high risk substances are not controlled, they will have a significant impact on the residual risk standards which will be implemented 8 or 9 years after the MACT standards (Quarles, 1990). The residual risk standards may lead to additional controls on utility boilers.

The objective of this study is to address the concerns outlined above for ABB's LEB. Specifically, the objective of this study was to examine each of the 189 HAPs and rank the substances into several classes depending on the degree of certainty that the compounds would be found at levels of regulatory concern in ABB's LEB flue gas. Five categories were defined including:

Category I:	HAPs known to be emitted in quantities sufficient to be of regulatory concern based upon prior measurements.
Category II:	HAPs may be emitted in quantities sufficient to be of regulatory concern based upon theoretical analysis or measurements but stronger data or analysis is required to confirm.
Category III:	HAPs are not expected to be emitted in quantities sufficient to be of regulatory concern based upon theoretical analysis or measurements but stronger data or analysis is required to confirm.

Category IV: HAPs with a low probability of being emitted in quantities sufficient to be of regulatory concern based upon theoretical analysis or measurements.

Category V: HAPs with a very low probability of being emitted in quantities sufficient to be of regulatory concern based upon theoretical analysis, measurements, or chemical/physical restraints.

Where possible, emissions levels have been determined using representative measurements. Unfortunately, little organic emission information exists for coal fired utility boilers. However, there is a large database for metals emissions as discussed in Section 4.0. To achieve the project objective of categorizing all of the 189 HAPs, other indicators of emissions potential had to be examined. Some of the indicators examined include:

Dayton Ranking:	Relative thermal stability of organics.
Boiling Point:	Ability of particulate control equipment to remove HAPs.
Water Solubility:	Ability of wet scrubbers (WS) to remove HAPs.
Chemical Structure:	Formation potential of HAPs.
Primary Emission Source:	Key HAP emission sources.
Mass Balance:	Maximum emission level.
Total Organic Compounds:	Maximum emission level.
Hazardous Waste Emissions:	Maximum emission level.
Metals Partitioning Model:	Predictions of controlled and uncontrolled metal emissions.

Section 5.1 provides additional details on each of these parameters. Conservative emission limits are determined and described in Section 5.2. Using the estimated emissions levels, key parameters and emission limits, each HAP is classified in Section 5.3 as Category I, II, III, IV or V for ABB's LEB <u>without</u> post combustion controls. The influence of combustor operating parameters on uncontrolled metals emissions is also discussed in Section 5.3. In Section 5.4, the three potential control alternatives being considered for the LEB are evaluated in terms of control of air toxics emissions. Based on the evaluation, some of the toxic compounds classified as Category I and II in the uncontrolled flue gas are moved to lower probability Categories. The revised categories for the LEB post combustion control Alternatives 1, 4, and 6 are provided in Section 5.4.

5.1 Key Parameters

To determine which HAPs are likely to be present in emissions from ABB's LEB, several indicators of thermal stability, control equipment effectiveness, and emissions were examined. By considering each of these indicators, the relative emission potential of each of the 189 HAPs can be determined. Each HAP emission potential indicator is described in the following sections. Values for the indicators are provided in Appendix B.

5.1.1 Dayton Ranking (Thermal Stability)

In a combustion system, organics emissions may result from the incomplete destruction of organics in the coal or as products of incomplete combustion (PICs). In the first case some of the HAPs in the fuel do not react as they pass through the system and are emitted in the same form present in the coal. PICs result from either the decomposition of the HAPs present in the fuel or reactions between elements in the system which produce HAPs. For example, chlorobenzene can decompose to form benzene and hydrochloric acid and methane and chlorine can react to form chloromethane.

Destruction of HAPs present in the fuel and PIC formation are controlled by the combustor temperature, residence time of gases at combustion temperatures, overall stoichiometry, and the degree of mixing between the fuel and air. Generally, higher combustion temperatures, longer residence times, and excess air provide good destruction of HAPs. Models which accurately account for the impact of each of these variables on HAP emissions are still unavailable. However, several researchers have developed models which can be used to determine which HAPs are more likely to be destroyed in a combustor. One such model was developed at the University of Dayton Research institute (US EPA 625/8-89/019). The Dayton model provides the minimum temperature ($T_{99}(2)$(°C)) for 99% destruction at 2.0 seconds gas residence time under fuel rich conditions in the post-flame zone. This model assumes that gas-phase residence time and temperature in the post-flame zone controls the relative emissions of most HAPs. Fuel rich conditions are assumed because oxygen-starved emission pathways in the combustor are the main source of HAP emissions. Assuming oxygen-starved conditions will generally provide a worst case estimation of thermal stability since most of the combustion gases have excess air.

The Dayton ranking classifies substances into one of seven groups based on the theoretical or measured $T_{99}(2)$ temperature. The classification system is shown below.

Class	$T_{99}(2)$ (°C)
1	900–1590
2	800–895
3	705–790
4	604–695
5	425–600
6	360–415
7	100–320

Class 1 compounds would require temperatures from 900 to 1590°C under starved-oxygen conditions with a 2 second residence time to provide a destruction efficiency of 99 percent. Class 7 compounds would require a much lower temperature for adequate destruction. Appendix B provides the Dayton classification for many of the 189 HAPs. A complete listing of Dayton rankings is not available at this time.

The Dayton ranking can be used to determine which substances would most likely be emitted from coal fired boilers using residence time and temperature data for a typical unit. Figure 5.1 shows a temperature vs. residence time profile for a pulverized coal system with tangential firing (Widmer, 1993). This profile shows that the boiler maintains a temperature of over 727°C for approximately 2 seconds. Thus it is expected that substances with a Dayton ranking of 4 or less will be easily destroyed in the combustor. Substances with a Dayton ranking of 3 or more may not have sufficient time for complete combustion and may be emitted.

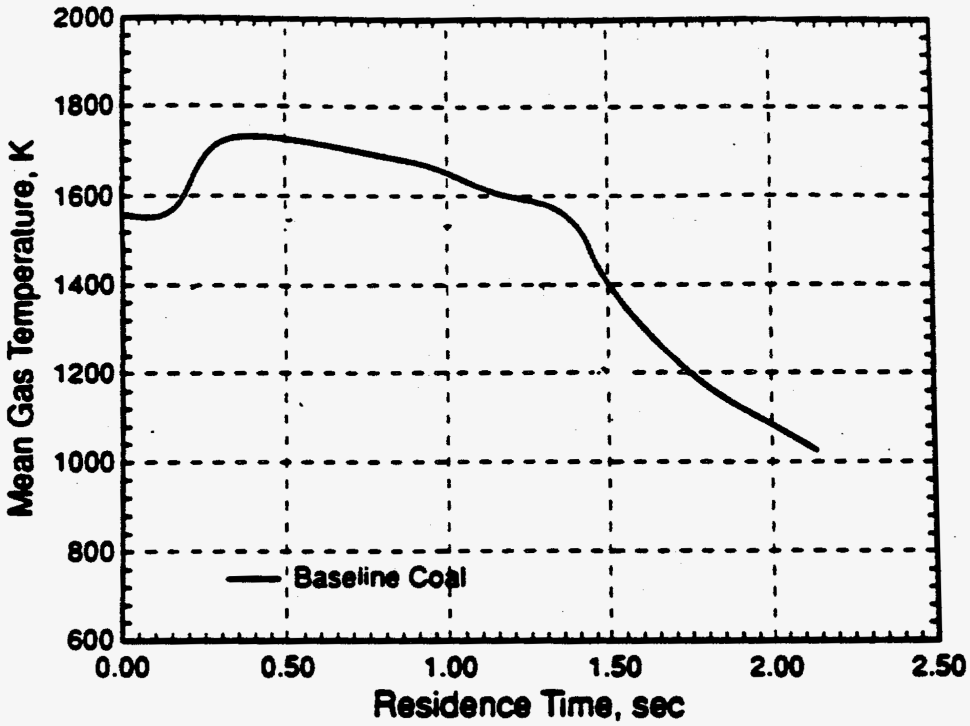


Figure 5–1. Example of a furnace time–temperature profile.

5.1.2 Boiling Point and Water Solubility

HAPs which are emitted from the boiler can be removed from the flue gas by one or more of the following mechanisms:

- Condensation
- Absorption
- Adsorption

Condensation is an effective removal mechanism for those HAPs which have boiling points well above the particulate control device inlet temperature. Removal efficiencies over 80% can be obtained as long the inlet concentration is greater than a few thousand ppmv (Buonicore, 1992). To determine the potential for capture by condensation, boiling points are included in Appendix B (MERC Index, 1983; Handbook of Chemistry and Physics, 1979). If the boiling point is greater than 175°C, typical air preheater exit temperature, some condensation may occur. If a particulate control system is present, some of the condensed material may be captured.

HAPs with boiling points less than 175°C remain in the gas phase and exit the system unless they are absorbed or adsorbed. In absorption, the gas phase HAPs are dissolved into a liquid phase. The liquid phase might include a scrubber liquor or moisture condensing in the stack gases as the temperature drops below the saturation point. In general, the removal efficiency of absorption depends on the HAP concentration in the gas phase, the liquid to gas ratio, and the solubility of the gas phase in the liquid. For soluble HAPs present in concentrations above a few hundred ppmv, removal efficiencies in the upper 90's can be achieved (Buonicore, 1992). To determine the potential for removal of HAPs by absorption, HAPs which are water soluble have been noted in Appendix B (MERC Index, 1983; Handbook of Chemistry and Physics, 1985; McCoy, 1992). If the solubility is greater than 90,000 mg/L at 77F, the HAP is considered soluble. This standard was taken from the Handbook of Chemistry and Physics, 1985.

Gas phase HAPs also may be removed from the system by adsorption on the surface of solid or liquid particles (adsorbent). In adsorption, the gas phase molecules are retained on the surface of the adsorbent and do not become dispersed throughout the adsorbent. The removal efficiency of HAPs by adsorption depends on the properties of the adsorbent and the gas being adsorbed, the surface area of the adsorbent, the temperature, and the pressure of the gas. Common adsorbents include activated carbon, activated alumina, silica gel, and molecular sieves. Activated carbon can achieve removal efficiencies greater than 95% for gas phase concentrations exceeding 1000 ppmv (Buonicore, 1992). Carbon adsorption efficiency for some HAPs are provided Table 5.1. Perchloroethylene has the greatest potential for removal by carbon adsorption of the compounds listed.

5.1.3 Chemical Structure

The chemical structure of a HAP also will provide an indication of its stability and potential for emission. For example, the aromatic ring structure is very stable as a result of the π–electron delocalization. Therefore, simple aromatic structures such as benzene and toluene tend to be more stable. Complex aromatic structures such as DEHP are not as stable because of the large chains which are substituted in the hydrogen positions on the ring. While these complex aromatics generally do no survive combustion, the aromatic ring(s) contained in these substances can survive as PICs. Structures for many of the 189 HAPs are provided in Appendix B. By examining these structures it is possible to determine if a substance is likely to survive the combustion process.

TABLE 5.1. PHYSICAL PROPERTIES OF COMMON VOCs.

	Boiling Point (°F)	Molecular Weight	Soluble in Water	Flammable	Lower Explosive Limit[a] (vol%)	Carbon Adsorption Efficiency[b]
Acetone	133	58.1	Yes	Yes	2.15	8
Benzene	176	78.1	No	Yes	1.4	6
Butyl acetate	259	116.2	No	Yes	1.7	8
Butyl alcohol	241	74.1	Yes	Yes	1.7	8
Carbon tetrachloride	170	153.8	No	No	—	10
Ethyl acetate	171	88.1	Yes	Yes	2.2	8
Ethyl alcohol	165	46.1	Yes	Yes	3.3	8
Heptane	209	100.2	No	Yes	1	6
Hexane	156	86.2	No	Yes	1.36	6
Isobutyl alcohol	241	74.1	Yes	Yes	1.68	8
Isopropyl alcohol	205	60.1	Yes	Yes	2.5	8
Methyl alcohol	153	32	Yes	Yes	6	7
Methylene chloride	104	84.9	Yes	No	—	10
Methylethyl ketone	174	72.1	Yes	Yes	1.81	8
Methylisobutyl ketone	237	100.2	Yes	Yes	1.4	7
Perchloroethylene	250	165.8	No	No	—	20
Toluene	231	92.1	No	Yes	1.27	7
Trichloroethane	189	131.4	No	No	—	15
Trichlorotrifluoroethane	117.6 (113)	186.3	No	No	—	8
Naphtha	208	—	No	No	0.81	7
Xylene	292	106.2	No	Yes	1	10

[a] Lower explosive limit: the lowest concentration value of a vapor that will support propagation of a flame upward through a cylindrical tube.

[b] Carbon adsorption efficiency, lbs adsorbed/100 lbs carbon; efficiencies are based on 200 cfm of 100°F solvent-laden air per 100 pounds of carbon per hour at concentrations above 15 ppm.

5.1.4 Primary Emission Sources

Key emissions sources have been compiled for many of the HAPs. For example, the California Air Resources Board generated a list of primary emission sources and other properties for toxic air contaminants (TACs) as required by assembly bill 1807 (Jones, 1989). The TAC listing is an important resource because it identifies pesticides and other substances which would generally not be present in the exhaust from a combustor. The Merck index also provides information on the key uses of many of the 189 HAPs (Merck, 1983). The primary emission sources for many of the 189 HAPs are provided in Appendix B. Since few measurements have been conducted on utility boilers, the list of primary emission sources given in Appendix B is not complete. Therefore, if boilers are not listed as a primary emission source for a HAP, the HAP will not necessarily be excluded as an emission of concern for ABB's LEB.

5.1.5 HAP Emissions From Bituminous Pulverized Coal Systems

One of the best ways to determine if HAPs will be present in the exhaust of a coal fired boiler is to sample and analyze the emissions. As discussed in Section 4.0, only a few HAPs have been quantified in emissions from utility boilers. Most of the HAP emission data were collected in the 80's and focused on inorganic emissions. As a result, there is little information available for organic emissions and the data available are of questionable quality. Several studies are underway to improve both the scope and quality of the existing database. These studies are described in Section 4.0.

Several controlled and uncontrolled HAP emission factors were located for bituminous pulverized coal systems. A description of each emission factor is provided in Section 4.0. Emission rates for ABB's LEB were calculated using the emission factors and the ABB LEB heat input rate of 2,857 MMBtu/hr (Regan, 1993). The emission rates are provided in Appendix B. Since metal emission rates are strongly affected by the concentration of metals in the coal, the measured metals emission rates provided in Appendix B may not be representative of emissions from ABB's LEB. To determine metals emission rates which can be expected for Illinois #6 coal, ABB LEB fuel, EER's metals partitioning model was used. This model is discussed in Section 5.1.9 and the predicted metal emission rates are provided in Appendix B.

5.1.6 HAP Emissions From Other Types Systems

As discussed in Section 5.1.5, little organic emission information is available for bituminous pulverized coal boilers similar to ABB's LEB. To determine the levels of organics which could be present in emissions from these systems, a search was conducted for emission factors from other types of coal systems. As a result of this search, eleven additional organic emission factors were located. A discussion of the source of each emission factor is provided in Section 4.0. The emission factors were used to determine emissions rates from ABB's LEB (see Appendix B). Since these emission rates may not be representative of ABB's LEB, they were used only to determine if a HAP may be of concern (Category II). Thus additional testing would be required to determine if the HAP is actually a concern (Category I) for ABB's LEB.

Even with the emission factors from other types of coal fired systems, the organic emissions database is still limited. To further increase the scope of the database, a search of hazardous waste incinerator emissions was conducted. Hazardous waste systems have similar operating practices (i.e. residence time, temperature and stoichiometry) as coal fired systems, therefore, comparable removal of organics in the combustor and air pollution control system is expected. Emission concentrations for over 30 HAPs were located in the literature for hazardous waste incinerators. A discussion of the source of these emission concentrations is provided in Section 4.0. Emission rates for ABB's LEB were estimated using the hazardous waste incinerator emission concentrations (see Appendix B). The hazardous waste incinerator concentrations are conservative in most cases because HAPs were spiked into the waste to determine destruction efficiency. In general, coal does not contain high HAP concentrations. If a HAP concentration for a hazardous waste incinerator is less than the regulatory limit, the corresponding coal fired boiler emission concentration probably will be lower than the limit.

5.1.7 Mass Balance

Over 40 HAP emission rates were estimated for ABB's LEB using coal fired utility boiler and hazardous waste incinerator emissions data. To determine if the remaining HAPs could be emitted at levels of regulatory concern, sulfur, halogen (Cl, Br, I, and F) and metal mass balances were conducted. The goal of these mass balances was not to determine the exact level of emissions of each HAP but to determine the maximum emission level that can be expected. If the maximum emission level of a HAP is less than the corresponding regulatory limit, it is unlikely that the HAP will be a key concern for the ABB's LEB.

To estimate the maximum amount of HAPs containing sulfur, metals and halogens that could be formed from burning coal, sulfur, metal and halogen elemental mass balances were performed. These balances were conducted by calculating the total number of moles of sulfur, metals and halogens that could be present in the stack gases based on a typical Illinois #6 coal analysis. A large fraction of the sulfur and halogen moles in the stack were assumed to react to form kinetically favored products such as HCl, HF, HBr, SO_2, etc. The remaining sulfur and halogen moles were assumed to react to form HAPs containing sulfur and halogens. The complete mass balance equation is shown below.

$$EF = \frac{(F_{EC})(CF)(M_{HAP})}{(M_{EC})(HV)(N_{EHAP})}$$

Where:

EF = Estimated emission factor for HAP (lbm/Btu).
F_{EC} = Weight fraction of mass balance element in fuel.
CF = Weight fraction of mass balance element available for HAP formation.
M_{HAP} = Molecular weight of HAP.
M_{EC} = Molecular weight of mass balance element.
HV = Heating value for coal (Btu/lbm).
N_{EHAP} = Number of moles of mass balance element in HAP.

Ultimate analyses (F_{EC}) and a heating value (HV) are provided in Table 5.2 for #6 Illinois coal. These analyses were taken from the ABB Combustion Engineering evaluation report, a study conducted in the Netherlands by KEMA (see Section 4.2.3), and a study conducted by Consol (Devito, 1993).

TABLE 5.2. PULVERIZED COAL ANALYSES.

Heating Value (Btu/lbm)	11477 (Regan, 93)
Composition Percent Basis	
Ash	18.2 (Regan, 93)
Hydrogen	4.2 (Regan, 93)
Carbon	65.3 (Regan, 93)
Sulfur	4.5 (Regan, 93)
Nitrogen	1 (Regan, 93)
Oxygen	6.6 (Regan, 93)
Chlorine	0.47 (Devito, 93)
Composition ppm - Whole - Coal - Basis	
As	9.57 (Devito, 93)
Be	1.1 (Devito, 93)
Cd	0.11 (Devito, 93)
Co	4.44 (Devito, 93)
Cr	10.5 (Devito, 93)
F	48.8 (Devito, 93)
Hg	0.08 (Devito, 93)
Ni	14.6 (Devito, 93)
Mn	9.77 (Devito, 93)
Pb	16.8 (Devito, 93)
Sb	1.13 (Devito, 93)
Se	1.32 (Devito, 93)
Br	8 (KEMA, 92)
Ca	2500 (KEMA, 92)
P	100 (KEMA, 92)
I	2.3 (KEMA, 92)
Ti	700 (KEMA, 92)

Another key parameter which must be specified to conduct the elemental mass balances is the weight fraction of sulfur and halogens available for HAP formation. If it is assumed that all of the sulfur and halogens in the coal are available for HAP formation, HAP emissions will exceed the regulatory limits in most cases. In combustion systems, however, most of the sulfur and halogens available in the coal react to form SO_2, HCl, HBr, HI, and HF (AP–42, 1993; IEA Coal Research, 1992). Therefore, only a small fraction of the available sulfur and halogens exit the system in the form of HAPs. Few studies have been conducted to date to determine the fraction of sulfur and halogens in coal that are available for HAP formation. Hazardous waste incinerator data is available which can be used to estimate the ratio of total stack organic chlorine to waste chlorine. In a series of tests conducted by Castaldini (Castaldini, 1987) on industrial boilers co–firing hazardous waste and fossil fuels, the ratio of total stack organic chlorine to total input chlorine was less than 1E–04 for most tests. Based on Castaldini's research, it was assumed that 0.01% of the total halogen input remained in the organic form. This study assumes that Br, I and F have that same behavior in the combustion system as Cl. Results from the halogen mass balance are provided in Appendix B.

The ratio of total stack organic sulfur to total input sulfur was based partly on a hazardous incinerator testing program conducted by the Midwest Research Institute (Trenholm, 1984). During this testing program, the total feed rate of sulfur and the emission rate of organic compounds containing sulfur were determined. The measured mass ratio of emitted to input sulfur was 0.02%. Sulfur mass balances also have been conducted internally at EER. These balances have shown that approximately 0.3% of the sulfur input to coal fired systems cannot be accounted for by SO_2 and SO_3 emissions. To remain conservative, the higher stack organic sulfur to input sulfur estimate of 0.3% was used in the sulfur mass balance.

5.1.8 Total Organic Compounds

Even when the sulfur and halogen mass balances, hazardous waste incinerator emission factors, and coal fired boiler emission factors are used, emission levels for over 70 HAPs still were not available. To determine an order of magnitude emission estimate for the remaining HAPs, it was decided that two groupings of total organic compounds (TOCs) should be used. The first TOC group included compounds with one to six carbon atoms excluding methane and the second group included compounds with more than seven carbon atoms. For pulverized dry bottom ash coal combustion, TOC emissions for each group are provided below.

Group	Percent of TOC	lb/1e12Btu
C1–C6 (With CH4)	94	3387
C7 or Greater	6	216

The TOC percentages were taken from a detailed study on combustion system emissions by Shih (Shih, 1980). The TOC levels were calculated using Shih's percentages and an AP–42 TOC emission factor of 3604 lb/1E12Btu (AP–42, 1993). A Non–methane C1–C6 TOC emission factor was calculated using the AP–42 methane emission factor of 1441 lb/1E12Btu. The final TOC numbers used in Appendix B are listed below.

Group	lb/1e12Btu
C1–C6 (No CH4)	1947
C7 or Greater	216

These numbers provide very conservative estimates of organic HAP emissions from ABB's LEB. Therefore, if the appropriate TOC emission level is less than the emission limit for a HAP, it is very unlikely that the HAP will be emitted at levels of concern for ABB's LEB. Since the emission levels are high for C1–C6 and C7 or greater TOC groups, the emission limit will generally have to be high to exclude a HAP using the procedure given above.

5.1.9 Metals Partitioning Model

Metals behavior and mechanisms of metals partitioning during coal combustion as well as the metals partitioning modeling approach and the validation of the modeling results were presented in Section 2.2. Based on the understanding of metals behavior during combustion, the modeling procedure was used to predict metals partitioning and emissions from a pulverized bituminous coal-fired combustion system simulating the operating conditions and coal composition (Table 5.2) of the ABB LEB. This treatment is not intended to be a substitute for actual compliance tests but as an indicator to help planners and engineers predict metal emission levels from their coal–fired power systems, and to understand the impact of operating conditions on metals behavior during coal combustion (predicted impact of combustor parameters on the uncontrolled emissions of metals are presented in Section 5.3.2).

As discussed in more detail in Section 2.2, uncontrolled emissions of metals are dependent on several parameters including the volatility of the metal, metal and halogen (especially chlorine) concentrations in the coal, and the combustor operating conditions (e.g., temperature and excess air). Table 5.3 summarizes the predicted metals partitioning between the bottom ash and the flue gas of the combustor (entrained and vaporized), and metals uncontrolled emissions from ABB's pulverized bituminous coal–fired LEB. The partitioning model in this case was used as an indicator to establish conservative estimates of metals emissions upstream of the control equipment. Table 5.3 indicate that most metals are expected to vaporize during combustion except for chromium and nickel which are predicted to partition partly to the bottom ash (17.1 percent and 15.8 percent) and mainly to the flue gas as solid particles (68.3 percent and 63.2 percent), respectively. Based on the operating conditions of the LEB, Table 5.3 indicate that the uncontrolled emissions of metals may range between 0.02 lb/h (Hg) to 4.18 lb/h (Pb). As described in Section 2.2, uncontrolled metal emission values can be used in conjunction with aerosol dynamic study downstream of the combustor to estimate metal stack emissions for a given air pollution control system. These results will be presented in Section 5.4.1 for the LEB emission control alternatives.

TABLE 5.3. PREDICTED UNCONTROLLED PARTITIONING AND EMISSIONS OF METALS FROM ABB's BITUMINOUS PULVERIZED COAL–FIRED LEB.

Metal	Bottom Ash (percent)	Particulate Entrainment (percent)	Vapor (percent)	Uncontrolled Emissions (percent)	Uncontrolled Emissions (lb/h)
As	0.0	0.0	100.0	100.0	2.38
Be	0.0	0.0	100.0	100.0	0.27
Cd	0.0	0.0	100.0	100.0	0.03
Cr	17.1	68.3	14.6	82.9	2.17
Hg	0.0	0.0	100.0	100.0	0.02
Ni	15.8	63.2	21.0	84.2	3.06
Pb	0.0	0.0	100.0	100.0	4.18
Sb	0.0	0.0	100.0	100.0	0.28
Se	0.0	0.0	100.0	100.0	0.33

Estimates of uncontrolled metal emissions from coal-fired boilers are useful for the determination of the load and form of each metal to the air pollution control device (APCD). This knowledge is important for choosing an appropriate APCD. For example, if a metal partitions to the flue gas in the form of solid entrained particles, it is likely that most of these particles are above 1-µm which are most effectively removed in particulate APCDs. However, a metal which vaporizes will eventually condense into and/or onto submicron particles which are least effectively removed in APCDs. For such small particles, it is important to choose the appropriate APCD so that metal emissions are minimized. The model predictions indicator is also useful in determining whether the uncontrolled emission level of each metal is of concern in comparison with regulatory risk-based limits. If the uncontrolled emission level of a particular metal is not of concern, there is a good chance that its controlled emission level is also not of concern, and therefore, the form and load of this metal should not influence the decision of which APCD to choose. Comparison of predicted controlled emissions (stack emissions) with regulatory limits for ABB's LEB control alternatives and other alternatives will be presented in Section 5.4.1. Uncontrolled metal emissions results from Table 5.3 and from field measurements will be used in Section 5.3.1 to rank metals based on comparison with regulatory limits.

5.2 Regulatory Limits

Once HAPs having the potential to be emitted from the LEB have been identified, the emission levels must be compared to applicable regulatory limits. If a HAP emission level exceeds the regulatory limit, the HAP will be a key concern when MACT is determined. Since emission limits are based on risk, to determine at the stack emission limits, ambient concentrations limits for each HAP and a dispersion procedure had to be specified. The following sections list the ambient concentration limits and describe the dispersion procedures used to estimate conservative stack regulatory emission limits.

5.2.1 State Limits

Appendix A lists acceptable ambient concentrations for over 700 substances. This table is described in Section 3.0. The minimum and maximum State HAP concentrations from Appendix A are summarized in Table 5.3.

5.2.2 Risk Based Limits

Another source of emission limits are chronic and acute Reference Air Concentrations (RAC) for noncarcinogenic compounds and unit risk factors for carcinogenic compounds. RACs and unit risk factors have been used by the EPA and States such as California to determine if emissions pose a significant risk to the public. For instance, the EPA used RACs and unit risk factors to develop metals and THC limits for boilers and industrial furnaces (BIFs) burning hazardous waste (EPA, 1989; EPA BIF Rules). Unit risk factors and RACs from the EPA and the California Air Pollution Control Officers Association (CAPCOA) are listed in Table 5.4.

The unit risk is a measure of the likelihood of an individual developing cancer as a result of a lifetime of exposure to 1 unit concentration of a carcinogenic pollutant. Since unit risk factors are commonly expressed in units of risk/(ug/m^3), a unit risk of 10^{-6} would constitute a one in a million chance of developing cancer from an exposure to one micrograms of the specified substance over a lifetime. A unit cancer risk factor can be multiplied by the actual or expected dose an individual

TABLE 5.4. AMBIENT AIR CONCENTRATION LIMITS.

SUBSTANCE	State Regulatory Limit (µg/m3)		Unit Risk Factor 1/(µg/m3)	Carcinogenic Concentration (1) (µg/m3)	RAC Chronic Concentration (µg/m3)	RAC Acute Concentration (µg/m3)	Regulatory Limit Summary (µg/m3)	
	Max	Min					Max	Min
Acetaldehyde	4.29E+03	4.50E-01	2.20E-06 (2)	4.55E-01	9.00E+00 (2)		S 4.29E+03	S 4.50E-01
Acetamide	4.88E-05	4.88E-05	2.00E-05 (2)	5.00E-02			O 5.00E-02	S 4.88E-05
Acetonitrile	7.00E+03	2.33E+02			10 (3)		S 7.00E+03	O 1.00E+01
Acetophone					100 (3)		O 1.00E+02	O 1.00E+02
2-Acetylaminofluorene							NA	NA
Acrolein	5.40E+00	8.00E-01			2.00E-02 (2)	2.50E+00 (2)	S 5.40E+00	O 2.00E-02
Acrylamide	3.00E+00	1.00E-02	1.30E-03 (2)	7.69E-04	7.00E-01 (2)		S 3.00E+00	O 7.69E-04
Acrylic acid	3.00E+02	9.99E+01					S 3.00E+02	S 9.99E+01
Acrylonitrile	4.50E+01	1.50E-02	2.90E-04 (2)	3.45E-03	2.00E+00 (2)		S 4.50E+01	O 3.45E-03
Allyl chloride	7.14E+01	2.90E-01					S 7.14E+01	S 2.90E-01
4-Aminodiphenyl	1.00E+01	1.00E+01					S 1.00E+01	S 1.00E+01
Aniline	1.81E+02	1.00E-02	7.40E-06 (3)	1.35E-01			S 1.81E+02	S 1.00E-02
Anisidine	5.00E+00	1.00E+00					S 5.00E+00	S 1.00E+00
Asbestos	2.40E-06	2.80E-11	1.90E-04 (2)	5.26E-03			O 5.26E-03	S 2.80E-11
Benzene	1.20E+01	1.20E-03	2.90E-05 (2)	3.45E-02	7.10E+01 (2)		O 7.10E+01	S 1.20E-03
Benzidine	4.00E-02	1.50E-05	1.40E-01 (2)	7.14E-06	1.00E+01 (2)		O 1.00E+01	O 7.14E-06
Benzotrichloride	7.00E-04	7.00E-04					S 7.00E-04	S 7.00E-04
Benzyl chloride	5.00E+01	1.00E-02			1.20E+01 (2)	5.00E+01 (2)	S 5.00E+01	S 1.00E-02
Biphenyl	3.10E+01	1.00E-02					S 3.10E+01	S 1.00E-02
Bis(2-ethylhexyl)phthalate (DEHP)			2.40E-07 (3)	4.17E+00	7.00E+01 (2)		O 7.00E+01	O 4.17E+00
Bis(chloromethyl)ether	5.00E-02	1.60E-05	6.20E-02 (3)	1.61E-05			S 5.00E-02	S 1.60E-05
Bromoform	5.00E+01	1.00E-02					S 5.00E+01	S 1.00E-02
1,3-Butadiene	7.33E+01	1.74E-03	2.80E-04 (2)	3.57E-03			S 7.33E+01	S 1.74E-03
Calcium cyanamide	5.00E+00	1.70E+00					S 5.00E+00	S 1.70E+00
Caprolactam (vapor)	2.00E+02	6.66E+01					S 2.00E+02	S 6.66E+01
Captan	5.00E+01	1.67E+01					S 5.00E+01	S 1.67E+01
Carbaryl	5.00E+01	1.67E+01					S 5.00E+01	S 1.67E+01
Carbon disulfide	7.14E+02	8.60E+01					S 7.14E+02	S 8.60E+01
Carbon tetrachloride	6.70E+00	3.00E-02	4.20E-05 (2)	2.38E-02	2.40E+00 (2)	1.90E+02 (2)	O 1.90E+02	O 2.38E-02
Carbonyl sulfide	2.43E+01	2.43E+01					S 2.43E+01	S 2.43E+01
Catechol	2.00E+02	6.66E+01					S 2.00E+02	S 6.66E+01
Chloramben							NA	NA
Chlordane	5.00E+00	2.70E-03	3.70E-04 (3)	2.70E-03			S 5.00E+00	S 2.70E-03
Chlorine	3.75E+01	1.00E+01			4.00E-01 (4)	2.30E+01 (2)	S 3.75E+01	O 4.00E-01
Chloroacetic acid							NA	NA
a-Chloroacetophenone	3.00E+00	1.00E+00					S 3.00E+00	S 1.00E+00
Chlorobenzene	3.50E+03	8.33E+02			7.00E+01 (2)		S 3.50E+03	O 7.00E+01
Chlorobenzilate							NA	NA
Chloroform	5.00E+02	4.00E-02	2.30E-05 (3)	4.35E-02	3.50E+01 (2)		S 5.00E+02	S 4.00E-02
Chloromethyl methyl ether	1.00E+02	1.00E+02	2.70E-03 (3)	3.70E-04			S 1.00E+02	O 3.70E-04
Chloroprene	8.57E+02	1.00E-02	1.30E-07 (2)	7.69E+00			S 8.57E+02	S 1.00E-02
Cresols/Cresylic acid	2.76E+02	7.33E+01			1.80E+02 (2)		S 2.76E+02	S 7.33E+01
o-Cresol	2.76E+02	7.33E+01			1.80E+02 (2)		S 2.76E+02	S 7.33E+01
m-Cresol	2.76E+02	7.33E+01			1.80E+02 (2)		S 2.76E+02	S 7.33E+01
p-Cresol	2.76E+02	7.33E+01			1.80E+02 (2)		S 2.76E+02	S 7.33E+01
Cumene	5.86E+03	5.83E+02					S 5.86E+03	S 5.83E+02
2,4-D	1.00E+02	3.30E+01					S 1.00E+02	S 3.30E+01
DDE							NA	NA
Diazomethane	4.00E+00	1.00E-02					S 4.00E+00	S 1.00E-02
Dibenzofurans							NA	NA
1,2-Dibromo-3-chloropropane			6.30E-03 (3)	1.59E-04	2.00E-01 (2)		O 2.00E-01	O 1.59E-04
Dibutyl phthalate	5.00E+02	1.67E+01					S 5.00E+02	S 1.67E+01
1,4-Dichlorobenzene(p)	1.07E+04	1.50E+03	1.10E-05 (2)	9.09E-02	7.00E+02 (2)		S 1.07E+04	O 9.09E-02

TABLE 5.4. AMBIENT AIR CONCENTRATION LIMITS.

SUBSTANCE	State Regulatory Limit (µg/m3)		Unit Risk Factor 1/(µg/m3)	Carcinogenic Concentration (1) (µg/m3)	RAC Chronic Concentration (µg/m3)	RAC Acute Concentration (µg/m3)	Regulatory Limit Summary (µg/m3)	
	Max	Min					Max	Min
3,3-Dichlorobenzidine	4.00E-02	2.00E-03	3.40E-04 (2)	2.94E-03			S 4.00E-02	S 2.00E-03
Dichloroethyl ether	3.00E+02	3.10E-03					S 3.00E+02	S 3.10E-03
1,3-Dichloropropene	1.07E+02	1.07E+02	2.90E-05 (3)	3.45E-02			S 1.07E+02	O 3.45E-02
Dichlorvos	1.00E+01	3.30E+00					S 1.00E+01	S 3.30E+00
Diethanolamine	1.50E+02	5.00E+01					S 1.50E+02	S 5.00E+01
Dimethylaniline	2.50E+02	8.33E+01					S 2.50E+02	S 8.33E+01
Diethyl sulfate							NA	NA
3,3-Dimethoxybenzidine							NA	NA
Dimethyl aminoazobenzene			1.30E-03 (2)	7.69E-04			O 7.69E-04	O 7.69E-04
3,3-Dimethyl benzidine							NA	NA
Dimethyl carbamoyl chloride	1.00E+02	1.00E+02					S 1.00E+02	S 1.00E+02
Dimethylformamide	3.00E+02	9.99E+01					S 3.00E+02	S 9.99E+01
1,1-Dimethyl hydrazine	1.00E+01	3.30E+00	4.90E-04 (2)	2.04E-03			S 1.00E+01	O 2.04E-03
Dimethylphthalate	1.20E+02	1.67E+01					S 1.20E+02	S 1.67E+01
Dimethyl sulfate	5.00E+00	1.00E-02	4.00E-03 (2)	2.50E-04			S 5.00E+00	O 2.50E-04
Dinitro-o-cresol	2.00E+00	7.00E-01					S 2.00E+00	S 7.00E-01
2,4-Dinitrophenol					2 (3)		O 2.00E+00	O 2.00E+00
2,4-Dinitrotoluene	3.57E+01	1.10E-02	8.80E-05 (3)	1.14E-02			S 3.57E+01	S 1.10E-02
1,4-Dioxane	9.00E+02	1.00E-02	1.40E-06 (3)	7.14E-01	20 (3)		S 9.00E+02	S 1.00E-02
1,2-Diphenylhydrazine	4.50E-03	4.50E-03	2.20E-04 (3)	4.55E-03			O 4.55E-03	S 4.50E-03
Epichlorohydrin (1-Chloro-2,3-epoxypropane	2.00E+02	3.50E-01	2.30E-05 (2)	4.35E-02	3.00E-01 (2)		S 2.00E+02	O 4.35E-02
1,2-Epoxybutane							NA	NA
Ethyl acrylate	4.76E+02	6.66E+01			4.80E+01 (2)		S 4.76E+02	O 4.80E+01
Ethyl Benzene	4.35E+04	1.45E+03					S 4.35E+04	S 1.45E+03
Ethyl Carbamate (Urethane			2.90E-04 (2)	3.45E-03			O 3.45E-03	O 3.45E-03
Ethyl chloride (Chloroethane)	8.66E+03	8.66E+03			1.00E+04 (2)		O 1.00E+04	S 8.66E+03
Ethylene dibromide (Dibromoethane)	4.00E-01	8.50E-05	7.10E-05 (2)	1.41E-02	4.60E+00 (2)		O 4.60E+00	S 8.50E-05
Ethylene dichloride (1,2-Dichloroethane)	4.00E+02	3.80E-02	2.00E-05 (2)	5.00E-02	9.50E+01 (2)		S 4.00E+02	S 3.80E-02
Ethylene glycol	3.02E+03	1.20E+02					S 3.02E+03	S 1.20E+02
Ethyleneimine	1.00E+01	3.30E+00					S 1.00E+01	S 3.30E+00
Ethylene oxide	2.00E+01	1.00E-02	1.00E-04 (3)	1.00E-02	6.00E+02 (2)		O 6.00E+02	S 1.00E-02
Ethylene thiourea			1.30E-05 (2)	7.69E-02			O 7.69E-02	O 7.69E-02
Ethylidene chloride (1,1 Dichloroethane)	1.90E+04	8.10E-01	2.60E-05 (3)	3.85E-02			S 1.90E+04	O 3.85E-02
Formaldehyde	7.60E+00	7.70E-02	1.30E-05 (2)	7.69E-02	3.60E+00 (2)	3.70E+02 (2)	O 3.70E+02	O 7.69E-02
Heptachlor	5.00E+00	7.70E-04	1.30E-03 (3)	7.69E-04			S 5.00E+00	O 7.69E-04
Hexachlorobenzene	2.00E-01	2.00E-03	5.10E-04 (2)	1.96E-03	2.80E+00 (2)		O 2.80E+00	O 1.96E-03
Hexachlorobutadiene	2.40E+00	4.50E-02	2.00E-05 (3)	5.00E-02			S 2.40E+00	S 4.50E-02
Hexachlorocyclopentadiene	1.00E+00	3.00E-01			2.40E-01 (2)		S 1.00E+00	O 2.40E-01
Hexachloroethane	1.00E+03	2.50E-01	4.00E-06 (3)	2.50E-01			S 1.00E+03	S 2.50E-01
Hexamethylene diisocyanate	1.00E-01	1.00E-01					S 1.00E-01	S 1.00E-01
Hexamethylphosphoramide	4.00E-01	4.00E-01					S 4.00E-01	S 4.00E-01
N-Hexane	4.29E+03	5.99E+02					S 4.29E+03	S 5.99E+02
Hydrazine	1.00E+00	3.00E-04	4.90E-03 (2)	2.04E-04	2.40E-01 (2)		S 1.00E+00	O 2.04E-04
Hydrochloric acid	6.00E+02	7.00E+00			7.00E+00 (2)	3.00E+03 (2)	O 3.00E+03	S 7.00E+00
Hydrogen fluoride	6.19E+01	8.00E+00			5.90E+00 (2)	5.80E+02 (2)	O 5.80E+02	O 5.90E+00
Hydroquinone	2.00E+01	6.70E+00					S 2.00E+01	S 6.70E+00
Isophorone	2.50E+02	8.33E+01					S 2.50E+02	S 8.33E+01
Lindane	5.00E+00	1.60E+00					S 5.00E+00	S 1.60E+00
Maleic anhydride	2.38E+01	3.30E+00			2.40E+00 (2)	1.00E+01 (2)	S 2.38E+01	O 2.40E+00
Methanol	6.24E+03	6.24E+03			6.20E+02 (2)		S 6.24E+03	O 6.20E+02
Methoxychlor	1.00E+02	3.33E+01			50 (3)		S 1.00E+02	S 3.33E+01
Methyl bromide (Bromomethane)	2.00E+02	1.00E-02			8.00E-01 (3)		S 2.00E+02	S 1.00E-02
Methyl chloride	1.05E+03	1.00E-02					S 1.05E+03	S 1.00E-02

TABLE 5.4. AMBIENT AIR CONCENTRATION LIMITS.

SUBSTANCE	State Regulatory Limit (µg/m3)		Unit Risk Factor 1/(µg/m3)	Carcinogenic Concentration (1) (µg/m3)	RAC Chronic Concentration (µg/m3)	RAC Acute Concentration (µg/m3)	Regulatory Limit Summary (µg/m3)	
	Max	Min					Max	Min
Methyl chloroform (1,1,1-Trichloroethane)	1.90E+05	4.55E+03			3.20E+02 (2)	1.90E+05 (2)	S 1.90E+05	O 3.20E+02
Methyl ethyl ketone	1.40E+04	1.96E+03			80 (3)		S 1.40E+04	O 8.00E+01
Methyl hydrazine	3.50E+00	1.20E+00	3.10E-04 (3)	3.23E-03			S 3.50E+00	O 3.23E-03
Methyl iodide	1.00E+02	1.00E-02					S 1.00E+02	S 1.00E-02
Methyl isobutyl ketone	4.88E+03	6.83E+02					S 4.88E+03	S 6.83E+02
Methyl isocyanate	5.00E-01	2.00E-01			3.60E-01 (2)		S 5.00E-01	S 2.00E-01
Methyl methacrylate	4.10E+04	1.37E+03			9.80E+02 (2)		S 4.10E+04	O 9.80E+02
Methyl tert butyl ether							NA	NA
4,4-Methylene bis (2-chloroaniline)	2.20E+00	7.00E-01	3.70E-05 (2)	2.70E-02			S 2.20E+00	O 2.70E-02
Methylene chloride (Dichloromethane)	3.50E+03	2.00F-01	4.10E-06 (3)	2.44E-01	3.00E+03 (2)	3.50E+03 (2)	S 3.50E+03	S 2.00E-01
Methylene diphenyl diisocyanate							NA	NA
4,4'-Methylenedianiline	8.00E+00	2.60E+00	3.40E-04 (2)	2.94E-03	1.90E+00 (2)		S 8.00E+00	O 2.94E-03
Naphthalene	5.00E+02	1.20E+02			1.40E+01 (2)		S 5.00E+02	O 1.40E+01
Nitrobenzene	1.19E+02	1.67E+01			8.00E-01 (3)		S 1.19E+02	O 8.00E-01
4-Nitrodiphenyl	1.90E+02	1.90E+02					S 1.90E+02	S 1.90E+02
4-Nitrophenol							NA	NA
2-Nitropropane	1.17E+02	1.00E-02	2.70E-02 (3)	3.70E-05	2.00E+01 (2)		S 1.17E+02	O 3.70E-05
N-Nitroso-N-methylurea							NA	NA
N-Nitrosodimethylamine	5.00E-02	5.00E-02	4.30E-02 (3)	2.33E-05			S 5.00E-02	O 2.33E-05
N-Nitrosomorpholine			1.90E-03 (2)	5.26E-04			O 5.26E-04	O 5.26E-04
Parathion	1.00E+00	3.00E-01					S 1.00E+00	S 3.00E-01
Pentachloronitrobenzene (Quintobenzene)			7.30E-05 (3)	1.37E-02			O 1.37E-02	O 1.37E-02
Pentachlorophenol	5.00E+00	1.19E+00			30 (3)		O 3.00E+01	S 1.19E+00
Phenol	1.90E+03	6.33E+01			4.50E+01 (2)		S 1.90E+03	O 4.50E+01
p-Phenylene diamine	1.00E+00	3.00E-01					S 1.00E+00	S 3.00E-01
Phosgene	4.00E+01	1.30E+00				1.30E+01 (2)	S 4.00E+01	S 1.30E+00
Phosphine	4.00E+01	1.30E+00			1.00E+01 (2)		S 4.00E+01	S 1.30E+00
Phosphorus	1.00E+00	3.00E-01			7.00E-02 (2)		S 1.00E+00	O 7.00E-02
Phthalic anhydride	6.00E+02	2.00E+01			7.00E+03 (2)		O 7.00E+03	S 2.00E+01
Polychlorinated biphenyls (Aroclors)	8.30E-02	8.10E-04	1.40E-03 (2)	7.14E-04	1.20E+00 (2)		O 1.20E+00	O 7.14E-04
1,3-Propane sultone	4.00E+01	4.00E+01	6.90E-04 (2)	1.45E-03			S 4.00E+01	O 1.45E-03
B-Propiolactone	5.00E+00	5.00E+00					S 5.00E+00	S 5.00E+00
Propionaldehyde	4.29E+03	4.29E+03					S 4.29E+03	S 4.29E+03
Propoxur	5.00E+00	1.70E+00					S 5.00E+00	S 1.70E+00
Propylene dichloride	3.50E+03	1.00E-02					S 3.50E+03	S 1.00E-02
Propylene oxide	5.00E+02	1.00E-02	3.70E-06 (2)	2.70E-01	3.00E+01 (2)	1.00E+03 (2)	O 1.00E+03	S 1.00E-02
1,2-Propylenimine							NA	NA
Quinoline							NA	NA
Quinone	4.00E+00	1.30E+00					S 4.00E+00	S 1.30E+00
Styrene	5.07E+03	3.00E+01	5.70E-07 (2)	1.75E+00	7.00E+02 (2)		S 5.07E+03	O 1.75E+00
Styrene oxide							NA	NA
Tetrachlorodibenzo-p-dioxin	3.00E-06	3.00E-06	50 (3)	2.00E-08			S 3.00E-06	O 2.00E-08
1,1,2,2-Tetrachloroethane	7.00E+01	1.70E-02	5.80E-05 (3)	1.72E-02			S 7.00E+01	S 1.70E-02
Tetrachloroethylene (Perchloroethylene)	1.05E+02	4.10E-01	5.80E-07 (2)	1.72E+00	3.50E+01 (2)	6.80E+03 (2)	O 6.80E+03	S 4.10E-01
Titanium Tetrachloride							NA	NA
Toluene	8.93E+03	1.25E+03			2.00E+02 (2)		S 8.93E+03	O 2.00E+02
2,4-Toluene diamine							NA	NA
2,4-Toluene diisocyanate	1.00E+00	1.00E-01	1.10E-05 (2)	9.09E-02	9.50E-02 (2)		S 1.00E+00	O 9.09E-02
0-Toluidine	3.00E+01	1.00E-02					S 3.00E+01	S 1.00E-02
Toxaphene (chlorinated camphene)	3.00E-03	3.00E-03	3.20E-04 (3)	3.13E-03			O 3.13E-03	S 3.00E-03
1,2,4-Trichlorobenzene	4.00E+02	1.33E+02			20 (3)		S 4.00E+02	O 2.00E+01
1,1,2-Trichloroethane	4.50E+02	6.10E-02	1.60E-05 (3)	6.25E-02			S 4.50E+02	S 6.10E-02

TABLE 5.4. AMBIENT AIR CONCENTRATION LIMITS.

SUBSTANCE	State Regulatory Limit (µg/m3)		Unit Risk Factor 1/(µg/m3)	Carcinogenic Concentration (1) (µg/m3)	RAC Chronic Concentration (µg/m3)	RAC Acute Concentration (µg/m3)	Regulatory Limit Summary (µg/m3)	
	Max	Min					Max	Min
Trichloroethylene	2.70E+03	3.00E-01	2.00E-06 (2)	5.00E-01	6.40E+02 (2)		S 2.70E+03	S 3.00E-01
2,4,5-Trichlorophenol					1.00E+02 (3)		O 1.00E+02	O 1.00E+02
2,4,6-Trichlorophenol	1.80E-01	1.80E-01	5.70E-06 (3)	1.75E-01			S 1.80E-01	O 1.75E-01
Triethylamine	4.00E+02	1.33E+02					S 4.00E+02	S 1.33E+02
Trifluralin							NA	NA
2,2,4-Trimethylpentane							NA	NA
Vinyl acetate	8.30E+02	9.99E+01					S 8.30E+02	S 9.99E+01
Vinyl bromide	6.66E+01	6.66E+01					S 6.66E+01	S 6.66E+01
Vinyl chloride	1.19E+00	2.30E-02	7.80E-05 (2)	1.28E-02	2.60E+01 (2)		O 2.60E+01	O 1.28E-02
Vinylidene chloride (1,1-Dichloroethylene)	2.00E+03	2.00E+00			3.20E+01 (2)		S 2.00E+03	S 2.00E+00
Xylene (isomers and mixture)	4.35E+04	7.00E+02			3.00E+02 (2)	4.40E+03 (2)	S 4.35E+04	O 3.00E+02
o-Xylene	4.35E+04	7.00E+02			3.00E+02 (2)	4.40E+03 (2)	S 4.35E+04	O 3.00E+02
m-Xylene	4.35E+04	7.00E+02			3.00E+02 (2)	4.40E+03 (2)	S 4.35E+04	O 3.00E+02
p-Xylene	4.35E+04	7.00E+02			3.00E+02 (2)	4.40E+03 (2)	S 4.35E+04	O 3.00E+02
							NA	NA
Antimony (and compound)	5.00E+01	1.70E+00			0.3 (4)		S 5.00E+01	O 3.00E-01
Arsenic Compounds	2.00E-02	2.00E-04	3.30E-03 (2)	3.03E-04	5.00E-01 (2)		O 5.00E-01	S 2.00E-04
Beryllium Compounds	4.00E-02	2.40E-04	2.40E-03 (2)	4.17E-04	4.80E-03 (2)		S 4.00E-02	S 2.40E-04
Cadmium Compounds	5.00E-01	5.60E-04	4.20E-03 (2)	2.38E-04	3.50E+00 (2)		O 3.50E+00	O 2.38E-04
Chromium Compounds	2.00E+00	8.30E-05	1.40E-01 (2)	7.14E-06	2.00E-03 (2)		S 2.00E+00	O 7.14E-06
Cobalt (total)	1.00E+00	1.20E-01					S 1.00E+00	S 1.20E-01
Coke Oven Emissions	1.60E-03	1.60E-03	6.20E-04 (2)	1.61E-03			O 1.61E-03	S 1.60E-03
Cyanide Compounds							NA	NA
Glycol ethers	5.71E+02	5.71E+02					S 5.71E+02	S 5.71E+02
Lead Compounds	1.50E+00	1.50E+00	8.00E-05 (2)	1.25E-02	9.00E-02 (4)		S 1.50E+00	O 1.25E-02
Manganese Compounds	1.19E+02	1.67E+01			4.00E-01 (2)		S 1.19E+02	O 4.00E-01
Mercury Compounds	1.19E+00	1.20E-01			8.00E-02 (4)		S 1.19E+00	O 8.00E-02
Fine mineral fibers					2.40E+01 (2)		O 2.40E+01	O 2.40E+01
Nickel Compounds	1.00E+01	2.00E-03	2.60E-04 (2)	3.85E-03	2.40E-01 (2)		S 1.00E+01	S 2.00E-03
Polynuclear aromatic hydrocarbons	6.00E-02	6.00E-04					S 6.00E-02	S 6.00E-04
Radionuclides							NA	NA
Selenium Compounds	4.80E+00	7.00E-01	1.40E-04 (2)	7.14E-03	4.00E+00 (4)		S 4.80E+00	O 7.14E-03

(1) - Based on 1e-06 risk and unit risk factor.

(2) - California Air Pollution Control Officers Association, January, 1992.

(3) - EPA Background information document for hazardous waste incinerators, October, 1989.

(4) - EPA Technical information document for BIF, March, 1992.

receives to estimate the cancer risk to that individual attributable to that actual or expected dose. For example, the risk due to inhalation associated with the exposure to a concentration of 5 ug of Acetamide per cubic meter of ambient air is given by;

$$\text{Risk}_{\text{actual}} = \frac{5 \text{ ug of Acetamide}}{\text{m}^3 \text{ of Ambient Air}} \bullet \frac{1 \times 10^{-6} \text{ risk}}{1 \text{ ug/m}^3}$$

where the unit risk factor already takes into account the characteristics of the exposed individual (ie: an adult male at rest respiratory rate is equal to 7.5 l/min.). Conversely, an ambient concentration (or limit) can be calculated assuming an acceptable level of risk;

$$\text{Acceptable Concentration (ug/m}^3\text{)} = \frac{\text{Acceptable level of risk}}{\text{Unit risk factor (m}^3\text{/ug)}}$$

For each carcinogenic compound identified in Table 5.4, an ambient air concentration limit was estimated from the equation above and assuming a level of risk equal to $1X10^{-6}$. A value of $1X10^{-6}$ was assumed since most agencies currently implement similar values as an acceptable level of risk and residual risk assessments to be conducted for the CAAA under Title III will be based on $1X10^{-6}$. Unit risk factors were obtained from both the EPA's PIC Emissions Background Information Document (EPA, 1989), CAPCOA Risk Assessment Guidelines (CAPCOA, 1992), and Boiler and Industrial Furnace (BIF) technical information document (EPA, 1992).

For noncarcinogenic compounds there is an identifiable exposure threshold below which adverse health effects do not usually occur. Therefore, protection against the adverse health effects of a noncarcinogenic compound is likely to be achieved by preventing exposure levels from exceeding this threshold dose. EPA has defined the RAC as a fraction of this threshold dose. All RAC's shown in Table 5.4 were obtained from EPA's PIC Emissions Background Information Document (EPA, 1989), the CAPCOA Risk Assessment Guidelines (CAPCOA, 1992), and Boiler and Industrial Furnace (BIF) technical information document (EPA, 1992)..

5.2.3 Dispersion Estimation

To determine if the emission levels expected at the stack are of regulatory concern, stack emission limits had to be estimated from the ambient concentrations listed in Table 5.4. To accomplish this task, a conservative dispersion screening procedure was used (SCAQMD, 1991; EPA, 1992). The screening procedure utilizes a dispersion factor which equals:

Dispersion Factor, DF = X/Q

Where, X = HAP ambient concentration (µg/m3)
Q = HAP emission limit (lb/day)

The dispersion factor is a function of the stack height and the type of terrain. A dispersion factor of 0.0009 µg/m³/lb/day was used to estimate the stack emission limits (EPA, 1989). This assumes a stack height of 400 ft in an urban terrain. The actual design stack height for the ABB LEB is 500 ft (Regan, 1993), however, the EPA only provides dispersion factors for stacks up to 400 ft. Since the dispersion factor does not decrease significantly as the stack height increases above 300 ft, a dispersion factor for a 400 ft stack should provide reasonable emission limits for the ABB LEB. In addition, the dispersion factor for a 400 ft stack will provide conservative emission limits which is an objective of this study. The least and most conservative State ambient concentration, carcinogen unit risk factor, or RAC were used for the HAP ambient concentration, X, in the dispersion equation. These concentrations are listed in the last two columns in Table 5.4. The final controlled and uncontrolled categorization of the HAPs was based on the most conservative ambient concentration.

Appendix B lists the emission limits derived from the procedure given above and the ambient concentrations listed in Table 5.4. The emission limits are expressed in lb/hr. The emission limits can be compared to the emissions rates to classify the emission potential of each HAP.

5.3 Evaluation of Uncontrolled HAP Emissions from ABB's LEB

One of the objectives of this study was to evaluate and categorize HAP emissions from ABB's LEB without post combustion controls. Specifying uncontrolled emissions of concern will aid in the selection of appropriate post combustion controls. Section 5.3.1 ranks the 189 HAPs using emissions levels, indicators of emission potential, and emission limits. Another objective was to determine the impact of combustor operating parameters including excess air, temperature, and coal composition on uncontrolled emissions from ABB's LEB. Section 5.3.2 discusses the impact of these parameters on metals emissions. A general discussion of the influence of combustor operation on organic emissions is presented in Section 2.0 and 6.0.

5.3.1 Uncontrolled HAP Ranking

The guidelines displayed in Figure 5.2 were used to classify each HAP into Category I, II, III, IV, or V for ABB's LEB. Again, the categories are described as follows:

Category I:	HAPs known to be emitted in quantities sufficient to be of regulatory concern based upon prior measurements.
Category II:	HAPs may be emitted in quantities sufficient to be of regulatory concern based upon theoretical analysis or measurements but stronger data or analysis is required to confirm.
Category III:	HAPs are not expected to be emitted in quantities sufficient to be of regulatory concern based upon theoretical analysis or measurements but stronger data or analysis is required to confirm.
Category IV:	HAPs with a low probability of being emitted in quantities sufficient to be of regulatory concern based upon theoretical analysis or measurements.
Category V:	HAPs with a very low probability of being emitted in quantities sufficient to be of regulatory concern based upon theoretical analysis, measurements, or chemical/physical restraints.

The procedures listed in Figure 5.2 rely on the Dayton Ranking (Section 5.1.1), uncontrolled emissions levels (Sections 5.1.5 and 5.1.6), mass balance (Section 5.1.7), total organic emissions (Section 5.1.8), metals partitioning (Section 5.1.9) and emission limits (Section 5.2) provided in

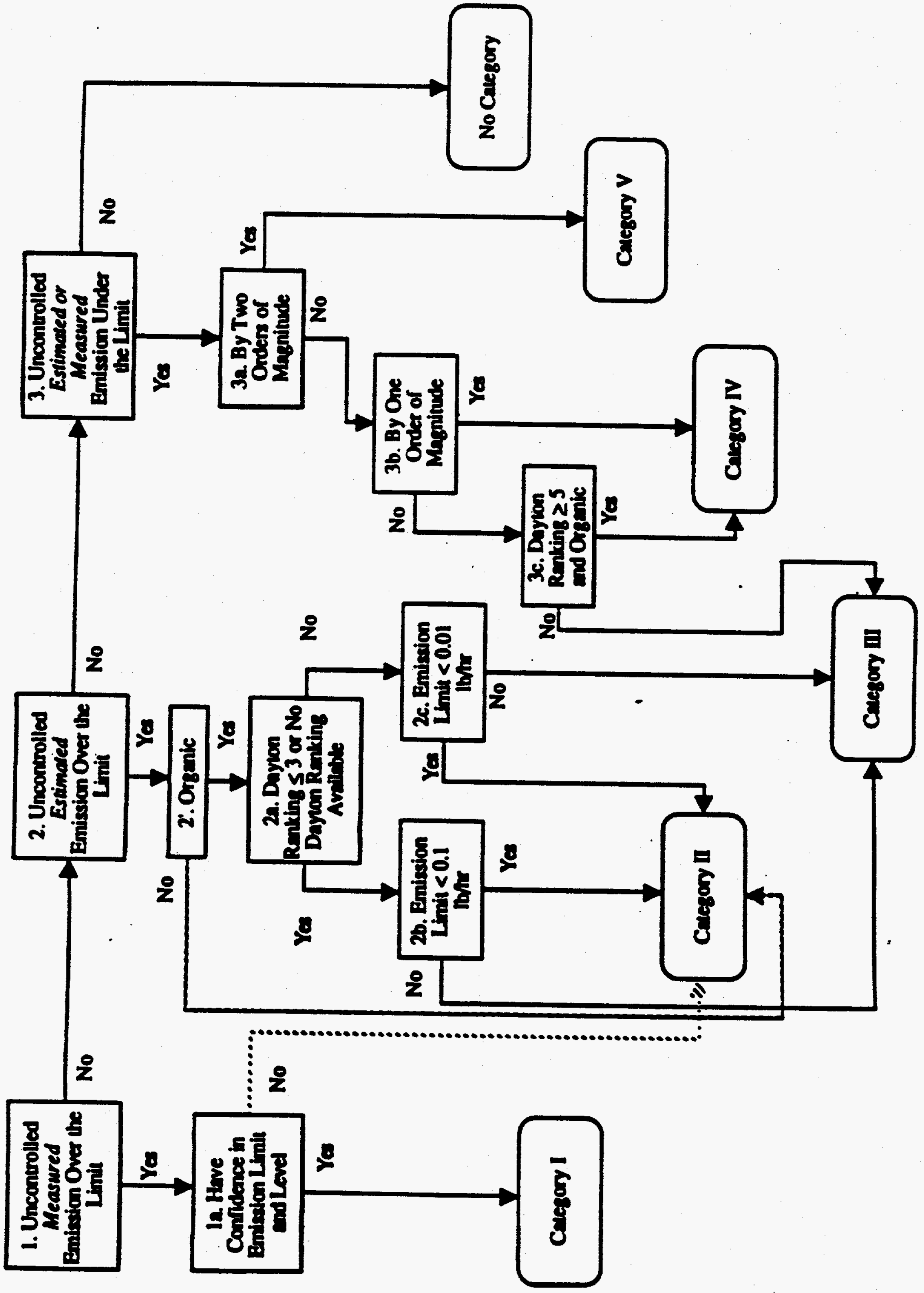


Figure 5.2. Uncontrolled emission classification flow chart.

Appendix B. Since this section does not consider the impact of post combustion control equipment on emissions, parameters such as solubility, boiling point, and controlled emission levels are not considered. Sections 5.4 and 5.5 discuss the impact of post combustion controls on emissions from the ABB LEB.

Several decision points in Figure 5.2 require further discussion. If the estimated emission level of a HAP exceeds the emission limit, the assigned category is based on the Dayton Ranking and magnitude of the emission limit (see Box 2). After reviewing hazardous waste incinerator data, it was found that HAPs with a Dayton Ranking of 3 or less can be present at levels of 0.1 lb/hr. Therefore, if the emission limit is less than 0.1 lb/hr and the Dayton Ranking is less than 4 (see Boxes 2a and b), there is a higher probability that the HAP may be present in boiler emissions at levels of regulatory concern. In these cases, the HAP is assigned to Category II and further emissions studies are necessary. Hazardous waste incinerator data also show that HAPs with a Dayton Ranking of 4 or greater can be present at levels of 0.01 lb/hr. Therefore, if the emission limit is less than 0.01 lb/hr and the Dayton Ranking is 4 or greater (see Box 2a and c), there also is a higher probability that the HAP may be present in boiler emissions at levels of regulatory concern. In these cases, the HAP is assigned to Category II and further emissions studies are necessary. In all cases were the uncontrolled emission estimate is greater than the emission limit, a category no greater than III can be assigned and additional emission study is recommended. This procedure is necessary since the emission limit guidelines in Boxes 2a, b and c are based largely on hazardous waste incinerator conditions and may not be representative of those found in utility boilers.

If the estimated or measured uncontrolled emission of a HAP is less than the emission limit, the HAP will be assigned to Category III, IV, or V (See Box 3). Either Category IV or V is assigned if the emission limit is one or two orders of magnitude above the emission level, respectively (See Box 3a and b). Since Category IV and V require no additional testing, the assignment procedures are designed to be as conservative as possible. If the emission level is the same order of magnitude as the emission limit and the Dayton Ranking is 5 or greater, a Category of IV is assigned (See Box 3b and c). In general, HAPs with Dayton Rankings of 5 or greater will be easily destroyed in the combustion process (See Section 5.1.1). For substances with Dayton Rankings of 4 or less, however, there is a higher probability that a substance could be emitted from the boiler and Category of III is assigned.

To illustrate the procedures given in Figure 5.2, two examples are provided below.

(1)–Chromium. The measured uncontrolled emission level and risk based limit for chromium are 5.37 lb/hr and 0.0003 lb/hr, respectively. Since the emission level is measured and exceeds the emission limit, chromium is a concern for ABB's LEB (see Box 1). The emission limit of 0.0003, however, was derived for Hexavalent Chromium. Since it is unlikely that all of the chromium in the stack will be in the hexavalent form, chromium is categorized as Category II (see Box 1a). Additional testing is required to determine the speciation of chromium.

(2)–2,3,7,8 Tetrachlorodibenzo–p–dioxin (TCDD). The estimated uncontrolled emission level and risk based limit for TCDD are 1.8e–05 lb/hr and 9.26e–07 lb/hr, respectively. The emission level is estimated because TCDD has not been detected in boiler stack emissions and is based on a detection limit. Since the estimated emission level exceeds the emission limit, TCDD may be a concern for ABB's LEB (see Box 2). Since TCDD is relatively difficult to destroy (Dayton Ranking of 2) and the emission limit is low (<0.1 lb/hr), TCDD may escape the combustor at levels of regulatory concern and is assigned to Category II

(see Box 2a and b). Additional testing is required to determine if TCDD is emitted at levels of regulatory concern. The testing must be conducted with a detection limit which is lower than the regulatory limit.

Tables 5.5 and 5.6 list HAPs assigned to Categories I, II, III, IV, and V for ABB's LEB. If an emission level and/or limit for a HAP was not available, the HAP was not categorized. As shown in Table 5.7, 26 HAPs could not be categorized. Table 5.5 shows that only arsenic, beryllium, and cadmium are likely to enter the post combustion control equipment in quantities sufficient to be of regulatory concern based on prior measurements (Category I). 20 HAPs may be emitted and require further study (Category II). 38 HAPs are not likely to be emitted, but further studies are required to verify this conclusion (Category III). 102 HAPs have a low to very low probability of being emitted (Category IV and V) and require no further study. It should be noted that the categories in Tables 5.5 and 5.6 only apply to uncontrolled emissions from the ABB LEB. Control Alternatives 1, 4, or 6 may provide sufficient removal to reclassify many of the Category I, II, or III HAPs. Control alternatives are evaluated in Sections 5.4 and 5.5.

Several other studies have been conducted to determine which HAPs will be emitted from coal combustion systems. As mentioned earlier, these studies usually only specify if a substance could be emitted and do not consider if the emission level is significant. In 1992 Moskowitz et al. (Moskowitz, 1992) identified HAPs which are unlikely to exist in effluents from clean coal technology demonstration projects (see Table 5.8). To compare the results from Moskowitz's study to those given in this study, unlikely emissions were assumed to correspond to Categories III through V (see Table 5.5 and 5.6). 1,1–Dimethyl Hydrazine was the only substance predicted to have greater emission potential in this study than the Moskowitz study. This excellent agreement is surprising since the Moskowitz study did not consider risk. According to the Moskowitz study, HAPs with the highest potential emission concentrations include:

- Metals – Arsenic, Cadmium, Chromium, Lead, and Selenium
- Organics – Polycyclic organic matter including primarily benzo–a–pyrene.

These HAPs are predicted to have high emission potential (Category I and II) in this study. Beryllium also is listed as a substance which may be emitted from ABB's LEB (see Table 5.5). Since Beryllium has the same emission limit and level as Cadmium, it should be considered a critical substance.

The PISCES project (see Section 4.0) identified 36 HAPs which have been emitted from coal fired boilers as shown in Table 4.1. One of the HAPs on the PISCES list, Dibenzofuran, could not be categorized because emission limits were not available. Of the remaining 35 PISCES HAPs, 12 were classified as likely to be emitted at levels of regulatory concern (Category I, or II) and 23 were classified as unlikely to be emitted at levels of regulatory concern (Category III, IV or V) in this study. This indicates that a majority of the substances identified by PISCES may not be emitted at levels of regulatory concern. This illustrates the importance of considering risk as well as the emission level.

5.3.2 Impact of Combustor Operating Parameters on Uncontrolled Metal Emissions

The major parameters which may influence vaporization and speciation of metals are: combustion system temperature, air to fuel ratio, and fuel composition, including metals and halogens content. The effect of these parameters on metals vapor pressures are discussed below.

TABLE 5.5. UNCONTROLLED CATEGORY I, II, AND III HAPs FOR ABB LEB (Stack Height 400 ft).

Category I	
Arsenic Compounds	
Beryllium Compounds	
Cadmium Compounds	
Category II	
Acetamide	Hexachlorobenzene
Acrylamide	Lead Compounds (b)
Benzene	Nickel Compounds (c)
Benzidine	2-Nitropropane
1,3-Butadiene	Phosphorus
Chlorine	Polychlorinated biphenyls (Aroclors)
Chromium Compounds (a)	1,3-Propane sultone
3,3-Dichlorobenzidene	2,3,7,8-Tetrachlorodibenzo-p-dioxin
1,1-Dimethyl hydrazine	Polycyclic Organic Matter
Dimethyl sulfate	Selenium Compounds (d)
Category III	
Acrolein	Ethylene thiourea
Acrylonitrile	Heptachlor
Aniline	Hexamethylphosphoramide
Benzotrichloride	Hydrazine
Benzyl chloride	Hydrochloric acid
Biphenyl	Manganese Compounds
Bis(chloromethyl)ether	Methyl chloride (Chloromethane)
Chlordane	Methyl hydrazine
Chloromethyl methyl ether	Methyl isocyanate
Chloroprene	4,4'-Methylenedianiline
Cobalt Compounds	N-Nitrosodimethylamine
Diazomethane	N-Nitrosomorpholine
Dichloroethyl ether (Bis (2-chloroethyl) ether)	p-Phenylenediamine
Dimethyl aminoazobenzene	Propylene dichloride (1,2-Dichloropropane)
2,4-Dinitrotoluene	Propylene oxide
1,4-Dioxane(1,4-Diethyleneoxide)	1,1,2,2-Tetrachloroethane
1,2-Diphenylhydrazine	o-Toluidine
Ethyl carbamate (Urethane)	Toxaphene (chlorinated camphene)
Ethylene oxide	Vinyl chloride

(a) Chromium is categorized as a 2 instead of a 1 because the emission limit is for hexavalent Chromium. It has not been confirmed that all chromium is emitted as hexavalent chromium.

(b) Lead is categorized as a 2 instead of a 1 because the emission limit is based on a screening value for the California Air Pollution Control Officers Association. The screening value does not have to be applied to all facilities.

(c) Nickel is categorized as a 2 instead of a 1 because the EPA BIF rules do not consider Nickel as a carcinogen. Under the BIF rules Nickel would not be a risk.

(d) Selenium is categorized as a 2 instead of a 1 because the emission limit is based on a screening value for the California Air Pollution Control Officers Association. The screening value does not have to be applied to all facilities.

TABLE 5.6. UNCONTROLLED CATEGORY IV AND V HAPs FOR ABB LEB (Stack Height 400 ft).

Category IV

- Acetaldehyde
- Allyl chloride
- Antimony Compounds
- Calcium cyanamide
- Carbon tetrachloride
- Chloroform
- 1,2-Dibromo-3-chloropropane
- 1,4-Dichlorobenzene(p)
- 1,3-Dichloropropene
- 4,6-Dinitro-o-cresol, and salts
- 2,4-Dinitrophenol
- Epichlorohydrin (1-Chloro-2,3-epoxypropane
- Ethylene dibromide (Dibromoethane)
- Ethylene dichloride (1,2-Dichloroethane)
- Ethylene imine (Aziridine)
- Ethylidene chloride (1,1-Dichloroethane)
- Formaldehyde
- Hexachlorocyclopentadiene
- Hexachlorobutadiene
- Hexamethylene-1,6-diisocyanate
- Hydrogen fluoride
- Hydroquinone
- Maleic anhydride
- Mercury Compounds
- 4,4-Methylene bis (2-chloroaniline)
- Methylene chloride (Dichloromethane)
- Nitrobenzene
- Parathion
- Pentachloronitrobenzene (Quintobenzene)
- beta-Propiolactone
- Quinone
- 2,4-Toluene diisocyanate
- 1,1,2-Trichloroethane
- Trichloroethylene
- 2,4,6-Trichlorophenol

Category V

- Acetonitrile
- Acetophenone
- Acrylic acid
- 4-Aminobiphenyl
- o-Anisidine
- Asbestos
- Bis(2-ethylhexyl)phthalate (DEHP)
- Bromoform
- Caprolactam
- Captan
- Carbaryl
- Carbon disulfide
- Carbonyl sulfide
- Catechol
- 2-Chloroacetophenone
- Chlorobenzene
- Cresols/Cresylic acid
- o-Cresol
- m-Cresol
- p-Cresol
- Cumene
- 2,4-D, salts and esters
- Dibutylphthalate
- Dichlorvos
- Diethanolamine
- N,N-Diethylaniline (N,N-Dimethylaniline)
- Dimethyl carbamoyl chloride
- Dimethyl formamide
- Dimethyl phthalate
- Ethyl acrylate
- Ethyl benzene
- Ethyl chloride (Chloroethane)
- Ethylene glycol
- Hexachlororethane
- Hexane
- Isophorone
- Lindane (all isomers)
- Methanol
- Methoxychlor
- Methyl bromide (Bromomethane)
- Methyl chloroform (1,1,1-Trichloroethane)
- Methyl ethyl ketone (2-Butanone)
- Methyl iodide (Iodomethane)
- Methyl isobutyl ketone (Hexone)
- Methyl methacrylate
- Naphthalene
- 4-Nitrobiphenyl
- Pentachlorophenol
- Phenol
- Phosgene
- Phosphine
- Phthalic anhydride
- Propionaldehyde
- Propoxur (Baygon)
- Styrene
- Tetrachlororethylene (Perchloroethylene)
- Toluene
- 1,2,4-Trichlorobenzene
- 2,4,5-Trichlorophenol
- Triethylamine
- Vinyl acetate
- Vinyl bromide
- Vinylidene chloride (1,1-Dichloroethylene)
- Xylene (isomers and mixture)
- o-Xylenes
- m-Xylenes
- p-Xylenes

TABLE 5.7. HAPs WHICH COULD NOT BE ASSIGNED TO A CATEGORY

2-Acetylaminofluorene
Chloramben
Chloroacetic acid
Chlorobenzilate
DDE {1,1-Dichloro-2,2-Bis (4-Chlorophenyl)ethylene}
Dibenzofurans
Diethyl sulfate
3,3-Dimethoxybenzidine
3,3'-Dimethyl benzidine
1,2-Epoxybutane
Methyl tert butyl ether
Methylene diphenyl diisocyanate (MDI)
4-Nitrophenol
N-Nitroso-N-methylurea
1,2-Propylenimine (2-Methyl aziridine)
Quinoline
Styrene oxide
Titanium tetrachloride
2,4-Toluene diamine
Trifluralin
2,2,4-Trimethylpentane
Coke Oven Emissions
Cyanide Compounds
Glycol ethers
Fine mineral fibers
Radionuclides (including radon)

TABLE 5.8 TITLE III POLLUTANTS WHICH ARE UNLIKELY TO EXIST IN EFFLUENTS FROM COAL FIRED BOILERS (MOSKOWITZ, 92)

Bromoform
Calcium cyanamide
Captan
Carbaryl
Chloramben
Chlordane
Chloroacetic acid
Chloroform
Diazomethane
Dichloroethyl ether (Bis(2-chloroethyl)ether)
1,3-Dichloropropene
Diethanolamine
Dimethyl carbamoyl chloride
Dimethyl formamide
1,1-Dimethyl hydrazine
Hexachlorocyclopentadiene
Hexachloroethane
Hexamethylphosphoramide
Hydrazine
Methyl methacrylate
4,4-Methylene bis(2-chloroaniline)
Methylene diphenyl diisocyanate (MDI)
4,4-Methylenedianiline
N-Nitrosomorpholine
Parathion
Pentachloronitrobenzene (Quintobenzene)
Phosgene
Phosphine
Propionaldehyde
Styrene oxide
1,1,2,2-Tetrachloroethane
Titanium tetrachloride
Toxaphene (chlorinated camphene)
1,1,2-Trichloroethane
Vinyl acetate
Vinyl bromide
Vinylidene chloride (1,1-Dichloroethylene)

Impact of Temperature. Figure 5.3a illustrates the change in metals vapor pressures as the combustion temperature changes between 800°C and 1800°C during coal combustion at 20 percent excess air. This figure shows that vapor pressures of volatile metals (Cd, Pb, As, Sb, Tl, Se, and Hg) do not change as the temperature changes between 800°C and 1800°C and, therefore, are not expected to be saturated in the gas phase. This indicates that these metals may partition to the combustor gas as vapors. Figure 5.3a also shows that vapor pressures of non–volatile metals (Ba, Ni, Be, and Cr) decrease as the temperature decreases for the plotted temperature range. This indicates that vapor pressures of these metals are saturated in the gas phase and that these metals may partially vaporize depending on the temperature and the corresponding magnitude of their saturated vapor pressures. Figure 5.3a indicates that vapor pressures of Ba, Be, and Ni are most sensitive to temperature changes between 800°C and 1800°C, and vary by a few orders of magnitude; however, the vapor pressure of Cr is less sensitive to temperature changes above 1000°C. The vapor pressure of Cr becomes saturated below 1200°C in Figure 5.3a.

The saturated vapor pressure of a metal corresponds to the maximum amount of that metal which may vaporize at a given temperature. Therefore, an increase in a saturated metal's concentration in the coal will not increase its vaporization but will increase the portion which partitions to the bottom ash and its entrainment. An increase of a non–saturated metal's concentration in the coal, however, will increase its vapor pressure and, hence, the total amount which vaporizes.

Mercury is highly volatile and is predicted to remain in the vapor phase even at air pollution control device (APCD) temperatures of 180°C. The chemical form of Hg in the vapor phase at the inlet of an APCD plays a role in determining the appropriate APCD which may be used to scavenge Hg from the gas. Figure 5.3b illustrates the impact of temperature on the vapor phase species of Hg as the flue gas cools from the 1200°C (Combustor exit) to 180°C (APCD inlet). This figure indicates that at the high combustion temperature, elemental Hg is the dominant species and remains dominant up to approximately 600°C. Below approximately 400°C, the dominant form of Hg changes to the chloride form ($HgCl_2$). Between 400°C and 600°C, both Hg and $HgCl_2$ exist. HgO is also formed but is a minor species for the plotted temperature range in Figure 5.3b.

Since particulate APCDs do not capture Hg from the vapor phase effectively, several other methods have been employed in conjunction with regular particulate APCDs to clean Hg from flue gases (Guest, 1992; Christiansen and Brown, 1992; White et al., 1992). These include using a spray dryer to scrub Hg from the gas by converting it to a soluble form such as chlorides. Some field tests have shown better removal of Hg in systems firing high chlorine coals. Figure 5.3b shows that the chloride form ($HgCl_2$) is dominant at low temperatures and, therefore, spray dryers may be a viable choice for Hg removal. Another method is adsorption of Hg utilizing activated carbon sorbents. This can be accomplished through spraying finely ground activated carbon in the control device or by passing the gas through an activated carbon bed.

Impact of Stoichiometric Ratio (SR). Figure 5.4 illustrates the impact of stoichiometry on metals vapor pressures during coal combustion at 1200°C. This figure clearly shows that stoichiometry only impacts the behavior of chromium. The vapor pressure of Cr drops by two orders of magnitude as SR approaches 1.0. This change resembles a step function: when $SR > 1.0$, Cr is approximately 1×10^{-6} atm, and when $SR \leq 1.0$, Cr is approximately 3×10^{-8}. This is a significant change for Cr since its vapor pressure above SR of 1.0 at 1200°C is not saturated and, therefore, all of the Cr input with the coal may vaporize; however, the vapor pressure of Cr at $SR \leq 1.0$ is saturated and only a portion of Cr vaporizes. Though the combustor may be operated at overall excess air conditions, the formation of a high temperature, reducing environment near the

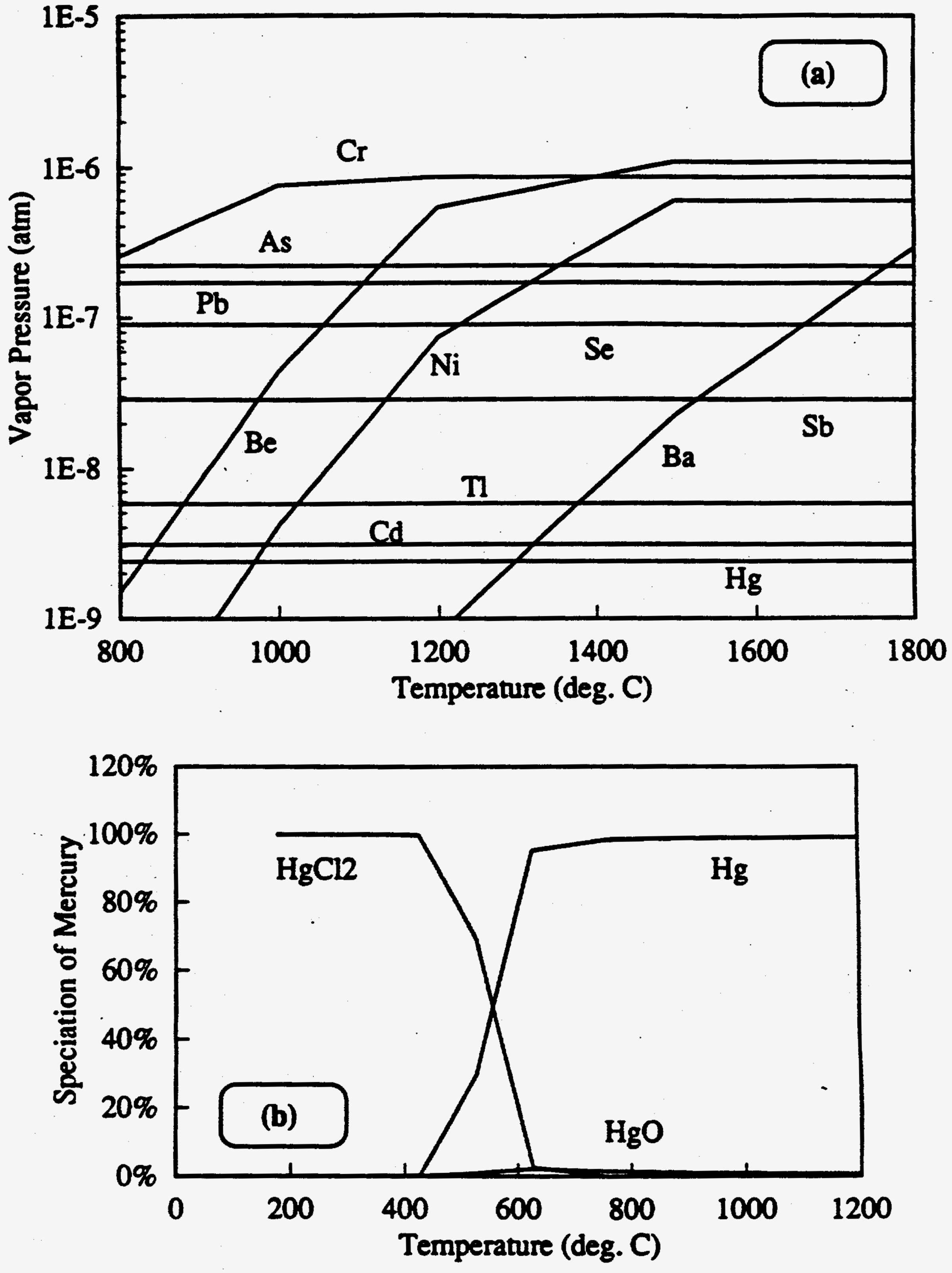


Figure 5.3. Impact of temperature on metals vaporization (a) and on mercury speciation (b).

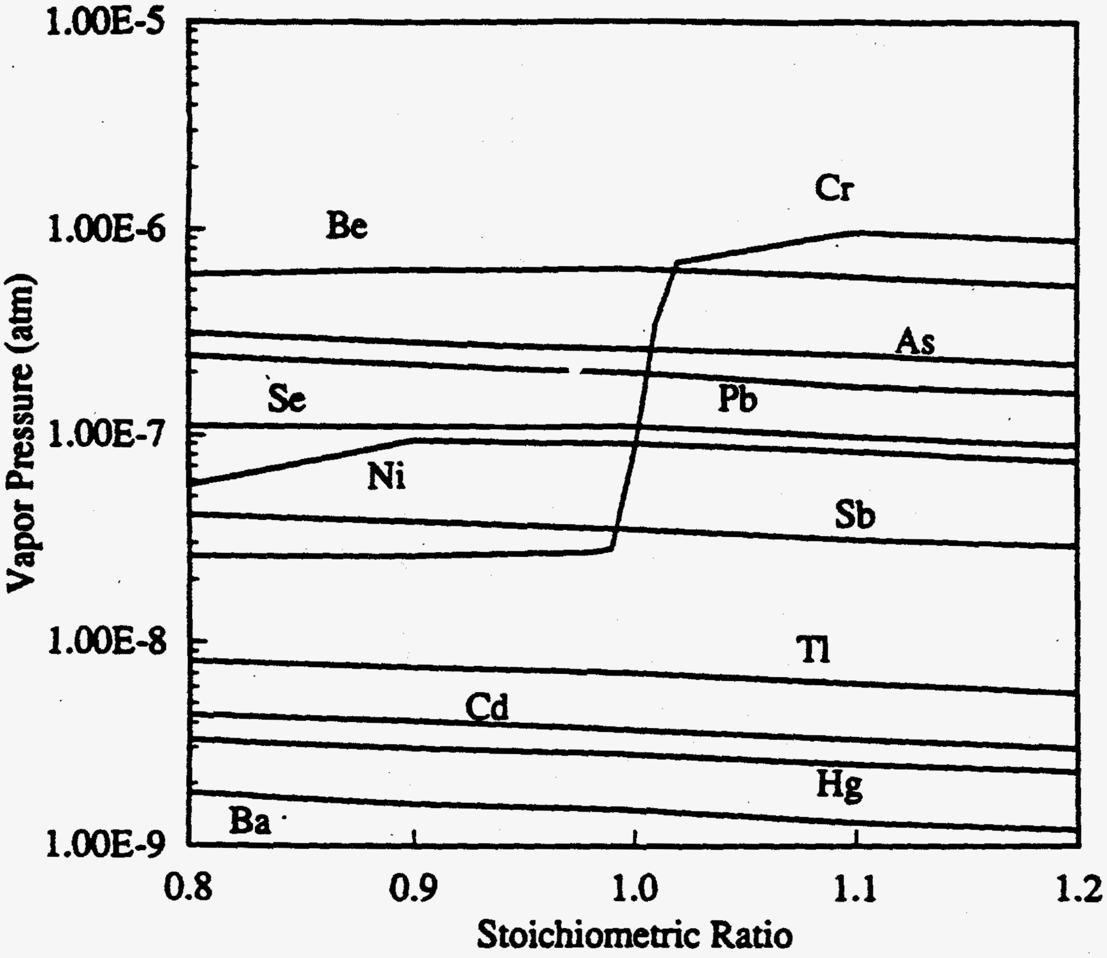


Figure 5.4. Impact of stoichiometry on metals vaporization.

burning coal particles may cause Cr vaporization to be reduced. These local reducing environments decrease Cr uncontrolled emissions. From Figure 5.4, it can be concluded that the local and overall stoichiometry during combustion of coal will significantly influence Cr vaporization and its uncontrolled emissions, but will not influence the other metals shown in the figure. Since the LEB will have the Combustion Engineering Concentric Firing system which employs a fuel rich core, emissions of chromium may be lower than for conventional coal fired boilers.

Impact of Coal–Chlorine Content. As indicated earlier, the composition of the fuel influences the vapor pressure and speciation of most metals. For example, the halogen content, particularly chlorine, increases the vapor pressure of many metals because of the formation of metal chloride species instead of metal oxides. Metal chlorides are more volatile than metal oxides. Modeling results of bituminous coal combustion indicate that vapor phase metals are dominated by metal oxide species; this may be a consequence of the relatively small concentration of chlorine in the bituminous coal (Table 5.2). The saturated vapor pressure of Ba and Ni will increase if the chlorine content of the bituminous coal were to increase. This is due to a shift in the compounds that will dominate; for example, $Ni(OH)_2$ will shift to $NiCl_2$ and $Ba(OH)_2$ will shift to $BaCl_2$. An increase in the saturated vapor pressure for Ba and Ni will increase the vaporized portion of these metals.

Summary. The previous results indicate that temperature changes and possible variations in coal–chlorine content will influence the vaporization of non–volatile metals (Ba, Ni, Be, and Cr). The more volatile metals (Cd, Pb, As, Sb, Tl, Se, and Hg), are predicted to partition to the gas at 100 percent, and are less influenced by temperature and chlorine changes for the temperature range shown in Figure 5.3a. Additionally, Figure 5.4 indicates that local reducing conditions near the burning coal causes Cr vaporization to be reduced significantly.

5.4 Evaluation of Controlled HAP Emissions from ABB's LEB

The primary objective of this task was to determine the impact of the post combustion control Alternatives 1, 4 and 6 being considered for the LEB on the Category I and II organic and inorganic substances identified in Section 5.3 and listed in Table 5.4. A secondary objective was to identify post combustion control alternatives for those Category I and II HAPs which cannot be controlled to acceptable levels using Alternatives 1, 4 and 6.

The primary components of ABB's post combustion control systems are listed in Table 5.9. Alternatives 1 and 4 each include an advanced ESP and FGD. The Alternative 1 and 4 FGDs use wet limestone and magnesium sulfite, respectively, to scrub SO_2 from the flue gas. The magnesium sulfite provides a higher SO_2 removal efficiency than wet limestone. The ESPs for Alternatives 1 and 4 will use ammonia and sulfur trioxide injection to promote agglomeration of fine particulate which may reduce PM10 emissions.

Alternative 6, the SNOx Process, does not include any of the components used in alternatives 1 and 4. In addition to particulate and SO_2 control, the SNOx Process provides NOx control. In the SNOx Process, ammonia is injected into the flue gas before the air preheater. The gases then pass through a particulate collection device which has a catalyst for NOx control. Since the particulate control device is located before the preheater, it operates at 700°F. This high temperature may reduce the capture efficiency of volatile organics and inorganics. After the flue gas passes from the particulate control device, it enters the Hot DeSOx system where SO_2 is removed.

TABLE 5.9. ABB POST COMBUSTION CONTROL ALTERNATIVE SUMMARY.

Post Combustion Control Alternative	Key Alternative System Component (1)	Inlet Temperature (C)	Description
1	Advanced ESP	135	• 99.5% particulate removal • Wider plate spacing up to 16 inches • Gas conditioning with the use of SO3/ammonia • Pulsed energization • Improved energy management
	Advanced FGD	132	• 95% SO2 removal • Open spray tower design with counter current flow • Wet limestone injection • Organic buffer additives • Improved gypsum crystal size and dewatering system • Lower auxiliary power consumption
4	Advanced ESP	135	• Same as Alternative 1
	Thio-Clear ABS	132	• 98 to 99% SO2 removal • Design very similar to advanced FGD except magnesium sulfite is used a reagent
6	NH3 Injection Grid	370	• Ammonia injected into hot stack gases before air preheater
	Catalytic Baghouse (or) Catalytic Ceramic Filter	370 370	• 99.5% particulate removal • 80% NOx removal with Integral NOx SCR • 99.9% particulate removal • 80% NOx removal with Integral NOx SCR
	Hot DeSOx	370	• 96 to 98% SOx removal • Catalytic reactor for SOx removal

(1) Devices listed in the order which they appear in the system traveling from the boiler to the stack.

The impacts of Alternatives 1, 4, and 6 on toxic inorganic and organic emissions are discussed in Section 5.4.1 and 5.4.2. Due to the high toxicity of metals and the quantity of emissions results and models available, the control of metals was the primary focus of the analysis.

5.4.1 Metals

The primary objective of this section is to determine the impact of the LEB post combustion control Alternatives 1, 4, and 6 on the reduction of metals emissions, particularly Category I and II metals. Metals in Category I for uncontrolled flue gas are As, Be, and Cd. The uncontrolled Category II metals are Cr, Ni, Pb, and Se. It is very likely that when the potential LEB control devices are considered, the number of metals in Categories I and II will be reduced. This section presents and discusses the following:

- Impact of LEB Control Alternatives 1, 4, and 6 on Metal Emissions.
- Impact of Other Post Combustion Control Alternanives on Metal Emissions.
- Revised Ranking for Category I and II Metals Based on Controlled Emissions.
- Impact of Metal Speciation and Physical Properties on Metals Removal in APCDs.

Impact of LEB Control Alternatives 1, 4, and 6 on Metal Emissions. Before the flue gas exhausts from the boiler stack, air pollution control devices (APCDs) will be needed to remove the Category I and II metals. More than one control device may be required due to the diversity in the physical and chemical forms of HAPs at different operating conditions. For example, a fraction of the metals partition to the flue gas during combustion due to vaporization and particulate entrainment. As the gas cools, most metals condense onto and/or nucleate into small particles which are removed in particulate APCDs such as baghouses and ESPs. Highly volatile metals (such as mercury and selenium) remain in the gas phase even at low control equipment temperatures and require other means of capture, such as liquid scrubbers for soluble compounds, solid sorbents, and other catalytic materials which facilitate reactions between HAPs and sorbents.

Category I and II metals range from low volatility to medium volatility metals and their vaporized portions are expected to condense/nucleate into small particles which can be effectively removed using filters, ESPs, and other particulate APCDs. The metals partitioning model, described in Section 2.2 and 5.1.9, was executed to determine metals partitioning and stack emissions from the LEB equipped with Control Alternatives 1, 4, and 6. The following modeling results illustrate the impact of the advanced ESP on metals capture for Alternatives 1 and 4, and the effect of the catalytic baghouse and the catalytic ceramic filter on metals capture for Alternative 6. The temperature at the inlet to the ESP for Alternatives 1 and 4 is 135°C and at the inlet to the catalytic baghouse and the catalytic ceramic filter for Alternative 6 is 370°C.

Control Alternatives 1 and 4. Table 5.10 shows the predicted partitioning and emission results for Category I and II metals for Control Alternatives 1 and 4 employing an ESP. Mercury and antimony (Category 4 metals) are also included in this and other tables for comparison purposes. Table 5.10, and other tables in this section, also show maximum and minimum regulatory metal emission limits. These emission limits are not necessarily based on promulgated rules but were derived to provide a conservative level of emissions and are discussed in Section 5.2.

Results in Table 5.10 indicate that the use of an advanced ESP reduces most metal emissions (except arsenic and chromium) to below the minimum regulatory limit and reduces all of the metals to below the maximum regulatory limit. For Category I and II metals, except for Se, the overall ESP removal efficiency ranged between approximately 98.3 percent for As, Cd, and Pb (volatile metals) to 99.6 percent for chromium (non-volatile metal).

TABLE 5.10. PREDICTED METALS PARTITIONING AND STACK EMISSIONS IN COMPARISON WITH REGULATORY LIMITS FOR ABB's LEB CONTROL ALTERNATIVES 1 & 4.

Metal	Partitioning			ESP Removal Efficiency	Stack Emissions (lb/h)	Regulatory Limits	
	Bottom Ash	ESP Ash	Stack Emissions			Maximum (lb/h)	Minimum (lb/h)
As	0.00%	98.31%	1.69%	98.31%	4.04E-02	2.31E+01	9.26E-03
Be	0.00%	98.57%	1.43%	98.57%	3.92E-03	1.85E+00	1.11E-02
Cd	0.00%	98.31%	1.69%	98.31%	4.64E-04	1.62E+02	1.10E-02
Cr	17.08%	82.59%	0.33%	99.60%	8.68E-03	9.26E+01	3.31E-04
Hg	0.00%	0.00%	100.00%	0.00%	1.99E-02	5.51E+01	3.70E+00
Ni	15.80%	83.78%	0.42%	99.50%	1.54E-02	4.63E+02	9.26E-02
Pb	0.00%	98.25%	1.75%	98.25%	7.30E-02	6.94E+01	5.79E-01
Sb	0.00%	97.31%	2.69%	97.31%	7.58E-03	2.31E+03	1.39E+01
Se	0.00%	0.00%	100.00%	0.00%	3.29E-01	2.22E+02	3.31E-01

Table 5.10 also shows partitioning of metals between combustor bottom ash, ESP collected ash, and stack emissions. This partitioning indicates that the majority of metals end up in the collected ESP ash. Mercury and selenium however are highly volatile and are predicted to remain in the vapor phase at the ESP inlet temperature. The ESP model does not account for capture of metals in the vapor phase and, therefore, these metals are predicted to escape the ESP. Uncontrolled emissions of selenium and mercury meet the conservative minimum regulatory limits as shown in Table 5.10. If the mercury or selenium content of the coal increases, however, other methods of control may be needed to reduce their emissions to acceptable levels. Controls which have worked successfully for mercury include wet scrubbers and activated carbon adsorbers (Guest, 1992; Christiansen and Brown, 1992; and White et al., 1992).

The use of an advanced FGD unit, which uses wet limestone injection in Control Alternative 1 and magnesium sulfite in Control Alternative 4, for SO_2 abatement can also be effective in removing additional metals from the flue gas and especially metals that are still in the vapor phase such as mercury. The wet limestone and magnesium sulfite may work as scrubbers for soluble metal compounds and/or adsorbers of gas phase metals. Field measurements from pulverized bituminous coal–fired utility boilers in the Netherlands (Meij, 1992) equipped with ESPs and FGDs indicate additional removal of some metals from the flue gas including mercury. The solubility of metal compounds and other physical properties are presented later in this section.

Control Alternative 6. As indicated in Table 5.9, Control Alternative 6 may include a catalytic baghouse or a catalytic ceramic filter. Predictions of metals partitioning and emissions from the LEB equipped with each of the filters were performed and the results are presented in Table 5.11 for the catalytic baghouse and in Table 5.12 for the catalytic ceramic filter. Results indicate that the range of the catalytic baghouse removal efficiencies of metals (99.7 percent – 99.8 percent) in Table 5.11 are generally higher than the range of the ESP removal efficiencies (98.3 percent – 99.6 percent) in Table 5.10. As in the ESP case, Table 5.11 shows that most of the metals end up in the catalytic baghouse collected ash. Table 5.11 also shows that, except for chromium, stack emissions of Category I and II metals are below the conservative minimum regulatory limits, and all Category I and II metal emissions are below the maximum regulatory limits. Table 5.12 indicates that, in general, the catalytic ceramic filter was slightly more effective in removing metals than the catalytic baghouse; the ceramic filter removal efficiencies ranged between 99.76 percent (Pb) and 99.91 percent (Cr) for Category I and II metals. The catalytic ceramic filter results in Table 5.12 also indicate that stack emissions of Category I and II metals, except chromium, are below the minimum regulatory emission limits, and all Category I and II metal emissions are below the maximum regulatory limits.

The predicted controlled emissions of total chromium from the LEB employing the catalytic baghouse and the catalytic ceramic filter options of Control Alternative 6 (Tables 5.11 and 5.12, respectively) are approximately one order of magnitude higher than the minimum regulatory limit for hexavalent chromium shown in the same tables. There are two factors to consider, however, before concluding that chromium emissions may be a problem. First, the percentage of hexavalent chromium relative to the total chromium in the flue gas is generally less than 20 percent, as indicated in a recent compilation of compliance test data of hazardous waste incinerators (Rizeq et al, 1992d), especially at high temperatures and metal feed rates. The minimum regulatory chromium limit was calculated based on a risk factor for hexavalent chromium; therefore, if a risk based limit for the total chromium were to be calculated, the emission levels are expected to meet the limit. Second, the total chromium emissions in Tables 5.10 through 5.12 meet the hexavalent maximum regulatory limit. Therefore, the controlled emission levels of total chromium from the LEB with any of the control alternatives are not likely to pose significant risk to the public.

TABLE 5.11. PREDICTED METALS PARTITIONING AND STACK EMISSIONS IN COMPARISON WITH REGULATORY LIMITS FOR ABB's LEB CONTROL ALTERNATIVE 6 (CATALYTIC BAGHOUSE).

Metal	Partitioning			Baghouse Removal Efficiency	Stack Emissions (lb/h)	Regulatory Limits	
	Bottom Ash	Catalytic Baghouse Ash	Stack Emissions			Maximum. (lb/h)	Minimum (lb/h)
As	0.00%	99.78%	0.22%	99.78%	5.17E-03	2.31E+01	9.26E-03
Be	0.00%	99.76%	0.24%	99.76%	6.59E-04	1.85E+00	1.11E-02
Cd	0.00%	99.78%	0.22%	99.78%	5.95E-05	1.62E+02	1.10E-02
Cr	17.08%	82.65%	0.27%	99.68%	6.97E-03	9.26E+01	3.31E-04
Hg	0.00%	0.00%	100.00%	0.00%	1.99E-02	5.51E+01	3.70E+00
Ni	15.80%	83.94%	0.26%	99.69%	9.58E-03	4.63E+02	9.26E-02
Pb	0.00%	99.79%	0.21%	99.79%	8.88E-03	6.94E+01	5.79E-01
Sb	0.00%	99.69%	0.31%	99.69%	8.77E-04	2.31E+03	1.39E+01
Se	0.00%	0.00%	100.00%	0.00%	3.29E-01	2.22E+02	3.31E-01

TABLE 5.12. PREDICTED METALS PARTITIONING AND STACK EMISSIONS IN COMPARISON WITH REGULATORY LIMITS FOR ABB's LEB CONTROL ALTERNATIVE 6 (CERAMIC FILTER).

Metal	Partitioning			Ceramic Filter	Stack	Regulatory Limits	
	Bottom Ash	Ceramic Filter Ash	Stack Emissions	Removal Efficiency	Emissions (lb/h)	Maximum (lb/h)	Minimum (lb/h)
As	0.00%	99.77%	0.23%	99.77%	5.46E-03	2.31E+01	9.26E-03
Be	0.00%	99.80%	0.20%	99.80%	5.42E-04	1.85E+00	1.11E-02
Cd	0.00%	99.77%	0.23%	99.77%	6.27E-05	1.62E+02	1.10E-02
Cr	17.08%	82.85%	0.07%	99.91%	1.93E-03	9.26E+01	3.31E-04
Hg	0.00%	0.00%	100.00%	0.00%	1.99E-02	5.51E+01	3.70E+00
Ni	15.80%	84.12%	0.08%	99.90%	3.07E-03	4.63E+02	9.26E-02
Pb	0.00%	99.76%	0.24%	99.76%	9.83E-03	6.94E+01	5.79E-01
Sb	0.00%	99.47%	0.53%	99.47%	1.49E-03	2.31E+03	1.39E+01
Se	0.00%	0.00%	100.00%	0.00%	3.29E-01	2.22E+02	3.31E-01

Impact of Other Post Combustion Control Alternatives on Metal Emissions. The only metal that was not reduced below the minimum regulatory limit using the LEB Control Alternatives 1, 4, and 6 was total chromium. As discussed above, the predicted total chromium emissions may not pose significant risk to the public since the minimum limit is based on hexavalent chromium risk factor and it has not been shown that the total chromium is 100 percent hexavalent. However, if at some point it is required to reduce total chromium to below the hexavalent chromium minimum limit, there are other particulate control devices to consider.

HEPA Filter. Table 5.13 shows the predicted partitioning and emissions of Category I and II metals from the LEB employing a HEPA filter which is located after the preheater at 135°C. This table indicates that the HEPA filter reduces emissions of all Category I and II metals, including total chromium, to below the conservative minimum regulatory limits. Table 5.13 also shows that the overall HEPA filter removal efficiencies for all Category I and II metals range between 99.995 percent to 99.998 percent which are more effective than Control Alternatives 1, 4, and 6. HEPA filters seem to be a good choice to reduce particulate matter from the flue gas to very low limits. The cost of HEPA filters and their operational constraints (such as temperature and possibly gas particulate loading), however, may be more restrictive than other Control Alternatives. Therefore, the economical and technical feasibility of using HEPA filters have to be considered prior to the decision of installing this alternative. For example, the use of a catalytic baghouse or ceramic filter in Control Alternative 6 may be sufficient (as shown previously in Tables 5.11 and 5.12) to control metals to below minimum metal regulatory limits, particularly if the chromium limit does not have to be as stringent as the minimum limit based on hexavalent chromium risk factor.

Baghouse. The location of the particulate control device in Control Alternative 6 is upstream of the preheater where the gas temperature (370°C) is higher than the gas temperature (135°C) at the inlet to the ESP in Control Alternatives 1 and 4. The higher gas temperature causes portions of the vaporized volatile metals to remain in the vapor phase and their removal efficiencies in the control equipment suffers. Particulate control equipment are generally more effective in capturing volatile metals when located at lower temperatures. Table 5.14 shows the predicted partitioning and emissions of Category I and II metals from the LEB employing a baghouse located after the preheater at 135°C. This table indicates that the baghouse removal efficiency of antimony (a volatile metal) is higher than the catalytic baghouse Control Alternative 6 (Table 5.11) removal efficiency. The removal efficiencies of non–volatile and medium volatility metals are not affected since they completely condense at gas temperatures at the preheater inlet.

Revised Ranking for Category I and II Metals Based on Controlled Emissions. Based on the comparison between controlled emissions of metals and their minimum regulatory limits presented in Tables 5.10 through 5.12, the number of Category I and II metals were reduced for COntrol Alternatives 1,4, and 6. Table 5.15 presents the revised ranking of the previously ranked Category I and II metals based on the controlled emissions of these metals from the LEB Control Alternative 6 (either a catalytic baghouse or a catalytic ceramic filter, Tables 5.11 and 5.12, respectively) and from Alternatives 1 and 4 (Table 5.10).

TABLE 5.13. PREDICTED METALS PARTITIONING AND STACK EMISSIONS IN COMPARISON WITH REGULATORY LIMITS FOR ABB's LEB HEPA FILTER CONTROL ALTERNATIVE.

Metal	Partitioning			HEPA Filter Removal Efficiency	Stack Emissions (lb/h)	Regulatory Limits	
	Bottom Ash	HEPA Filter Ash	Stack Emissions			Maximum (lb/h)	Minimum (lb/h)
As	0.000%	99.995%	0.005%	99.995%	1.12E-04	2.31E+01	9.26E-03
Be	0.000%	99.995%	0.005%	99.995%	1.40E-05	1.85E+00	1.11E-02
Cd	0.000%	99.995%	0.005%	99.995%	1.29E-06	1.62E+02	1.10E-02
Cr	17.079%	82.919%	0.002%	99.998%	3.95E-05	9.26E+01	3.31E-04
Hg	0.000%	0.000%	100.000%	0.000%	1.99E-02	5.51E+01	3.70E+00
Ni	15.796%	84.202%	0.002%	99.998%	6.42E-05	4.63E+02	9.26E-02
Pb	0.000%	99.995%	0.005%	99.995%	1.93E-04	6.94E+01	5.79E-01
Sb	0.000%	99.997%	0.003%	99.997%	8.70E-06	2.31E+03	1.39E+01
Se	0.000%	0.000%	100.000%	0.000%	3.29E-01	2.22E+02	3.31E-01

TABLE 5.14. PREDICTED METALS PARTITIONING AND STACK EMISSIONS IN COMPARISON WITH REGULATORY LIMITS FOR ABB's LEB BAGHOUSE CONTROL ALTERNATIVE.

Metal	Partitioning			Baghouse Removal Efficiency	Stack Emissions (lb/h)	Regulatory Limits	
	Bottom Ash	Baghouse Ash	Stack Emissions			Maximum (lb/h)	Minimum (lb/h)
As	0.00%	99.78%	0.22%	99.78%	5.17E-03	2.31E+01	9.26E-03
Be	0.00%	99.76%	0.24%	99.76%	6.59E-04	1.85E+00	1.11E-02
Cd	0.00%	99.78%	0.22%	99.78%	5.95E-05	1.62E+02	1.10E-02
Cr	17.08%	82.65%	0.27%	99.68%	6.97E-03	9.26E+01	3.31E-04
Hg	0.00%	0.00%	100.00%	0.00%	1.99E-02	5.51E+01	3.70E+00
Ni	15.80%	83.94%	0.26%	99.69%	9.58E-03	4.63E+02	9.26E-02
Pb	0.00%	99.79%	0.21%	99.79%	8.88E-03	6.94E+01	5.79E-01
Sb	0.00%	99.87%	0.13%	99.87%	3.58E-04	2.31E+03	1.39E+01
Se	0.00%	0.00%	100.00%	0.00%	3.29E-01	2.22E+02	3.31E-01

TABLE 5.15. REVISED METALS RANKING BASED ON CONTROLLED EMISSIONS FROM ABB's LEB CONTROL ALTERNATIVE 6.

Metal	Uncontrolled Category (*Previous*)	Controlled Category (*Revised Based on Alternatives 1 & 4*)	Controlled Category (*Revised Based on Alternative 6*)
As	I	II	III
Be	I	IV	V
Cd	I	V	V
Cr	II	II	II
Ni	II	III	IV
Pb	II	IV	V
Se	II	III	III

Table 5.15 shows that previously ranked Category I and II metals (except chromium) are all in new categories based on their controlled emissions. Beryllium and cadmium have been most effectively controlled. For Control Alternative 6, lead moved from Category II to Category V, nickel from Category II to Category IV, arsenic form Category I to Category III, and selenium from Category II to Category III. For Control Alternatives 1 and 4, lead moved from Category II to Category IV, nickel from Category II to Category III, arsenic from Category I to Category II (above the minimum regulatory limit), and selenium from Category II to Category III. Results in Table 5.15 indicate that As, Be, Ni, and Pb were better controlled using Control Alternative 6 instead of Control Alternatives 1 and 4. For each Alternative, chromium remained in the same category. However, as mentioned above, the control limit is for hexavalent chromium, and in the calculations 100 percent of the chromium was assumed to be hexavalent (to be conservative). However, it is expected that only 20 percent of the total chromium is in hexavalent form and therefore, chromium is not expected to pose a risk, though its emissions should be measured. The only other metal emission of concern is arsenic for Control Alternatives 1 and 4.

Impact of Metal Speciation and Physical Properties on Metals Removal in APCDs. The composition of the fuel influences the vapor pressure and speciation of most metals. Speciation of metals during coal combustion to both the vapor and condensed phases are important because they may impact the decision of which post combustion control equipment to choose. Metal chlorides, for example, are more volatile than metal oxides and tend to vaporize to a larger degree and form, upon condensation, submicron particles which are least effectively removed in particulate APCDs. Speciation of metals during coal combustion and other physical properties of metal compounds (solubilities and boiling points) are presented in Table 5.16. The condensed and vapor phase metal species that may be present during coal combustion were determined from the metals partitioning model based on a metals thermodynamic database including bench scale experimental results (Srinivasachar et al., 1992). Solubility of metals and phase change temperatures of metal compounds were obtained from Perry's Chemical Engineering Handbook (Perry and Green, 1984).

Modeling results of metals speciation during bituminous coal combustion (Table 5.16) indicate that vapor phase metals (except Ni) are dominated by metal oxide and oxyhydroxide species; this may be a consequence of the relatively small concentration of chlorine in the bituminous coal (Table 5.2). The saturated vapor pressure of Ni will increase if the chlorine content of the bituminous coal were to increase. This is due to a shift in the compounds that will form and dominate; for example, most of the $Ni(OH)_2$ will shift to $NiCl_2$. An increase in the saturated vapor

TABLES 5.16. SPECIATION, SOLUBILITY @ 0°C, AND BOILING POINTS FOR METALS IN ABB's LEB.

Speciation During Coal Combustion			Solubilities and Boiling Points		
Metals	**Vapor Phase**	**Condensed Phase**	**Metal Compounds**	**Solubility g/100-g H_2O**	**Boiling Point (°C)**
As	As_4O_6 (≤ 1100 K)	$AlAsO_4$ (≤ 800 K)	As_4O_6 As_2O_5	12 59	MP 312 DC @ 315°C
Be	$Be(OH)_2$ (1473 - 409 K)	$BeAl_2O_4$ (1473 - 644 K) $BeSO_4$ (644 - 409 K)	Be $BeAl_2O_4$ $BeSO_4$	insoluble insoluble insoluble	2767 MP 1870 DC @ 550°C
Cd	Cd, CdO (1473 - 409 K)	$CdSO_4$ (800 - 409 K)	Cd CdO $CdSO_4$	insoluble insoluble 76	767 DC @ 900 MP 1000
Co	---	---	Co $CoCl_2$	insoluble 45	2900 1049
Cr	$CrO_2(OH)_2$ (1473 - 800 K) CrO_2Cl_2 (800 - 400 K)	Cr_2O_3 (1180 - 800 K) $Cr_2(SO_4)_3$ (800 - 409 K)	Cr_2O_3 CrO_2Cl_2 $Cr_2(SO_4)_3$	insoluble DC insoluble	MP 1900 117 ---
Hg	Hg (1473 - 800 K) $HgCl_2$ (800 - 407 K)	---	Hg $HgCl_2$	insoluble 3.6	357 304
Mn	---	---	Mn $MnCl_2$	DC 63.4	1900 1190
Ni	$NiCl_2$ (1473 - 409 K) $Ni(OH)_2$ (≤ 1180 K)	$NiAl_2O_4$ (1473 - 800 K) $NiSO_4$ (800 - 409 K)	$NiCl_2$ $NiSO_4$	53.8 27.2	973 MP 840
Pb	PbO (1473 - 1180 K) $PbCl_2$ (1180 - 409 K)	$PbSO_4$ (800 - 409 K)	PbO $PbCl_2$ $PbSO_4$	0.0068 0.673 0.0028	MP 888 954 MP 1170
Sb	SbO (1473 - 800 K) $SbCl_3$ (800 - 409 K)	Sb_2O_4 (800 - 409 K)	Sb_2O_3 Sb_2O_4 $SbCl_3$	v.sl.s v.sl.s 601	1570 MP 930 220
Se	SeO_2 (1473 - 409 K)	---	Se SeO_2	insoluble 38	688 SP 340

MP: Melting Point SP: Sublimation Point DC: Decomposes
v.sl.s.: Very Slightly Soluble

pressure of Ni will increase the vaporized portion of this metal and consequently increase its flue gas load which has to be removed by the APCD. The condensed phase species of metals, as shown in Table 5.16, are metal oxides, metal sulfates, and metals associated with aluminum. Most of these condensed phase metals remain in the bottom ash of the combustor.

The solubility of metal compounds that may exist during combustion are also shown in Table 5.16. The solubility of a metal is important since soluble metals which end up in the bottom ash or in control equipment ash may cause leaching problems if not disposed of properly. The solubility of metals in the vapor phase is also important since it may influence selection of pollution control equipment. For example, mercury is expected to remain in the vapor phase at APCD temperatures and, therefore, can not be removed effectively by conventional particulate APCDs such as baghouses or ESPs. The solubility of the vapor phase mercury species in this case is important if using wet scrubbers. The vapor phase mercury ($HgCl_2$) at APCD temperatures, as shown in Table 5.16, is partly soluble in cold water and, therefore, wet scrubbers may be effective in removing mercury. Recent experimental results confirm that wet scrubbers can be effective in removing mercury from the vapor phase (Christiansen and Brown, 1992). Most of the metal compounds in Table 5.16 are insoluble or very slightly soluble in cold water, particularly metal oxides. The most soluble metal compounds in Table 5.16 are metal chlorides.

Phase change temperatures (boiling, melting, and sublimation points) for metal compounds are also shown in Table 5.16 to provide an additional indicator for metals volatility. The lower the boiling point of a metal compound, the more volatile is. Table 5.16 indicates that Be, Co, and Mn are the least volatile metals and Hg and Se are the most volatile at typical combustion temperatures.

Summary. In general, the LEB Control Alternatives 1, 4, and 6 are very effective in controlling uncontrolled Category I and II metal emissions to below conservative minimum regulatory limits. Most of the uncontrolled Category I and II metals partition to the collected ash of Control Alternatives 1, 4, and 6 and the removal efficiency of these metals ranged between 98.3 percent and 99.6 percent for Alternatives 1 and 4, and between 99.7 percent and 99.9 percent for Control Alternative 6. For each Control Alternative, chromium remained in Category II. However, as mentioned above, the control limit is for hexavalent chromium, and in the calculations 100 percent of the chromium was assumed to be hexavalent (to be conservative). It is expected that only 20 percent of the total chromium is in hexavalent form and therefore, chromium is not expected to pose a risk, though this should be verified through measurements. The only other metal emission of concern is arsenic for Control Alternatives 1 and 4. Arsenic is downgraded to Category III for Alternative 6.

5.4.2 Organics

The impact of Control Alternatives 1, 4, and 6 (see Table 5.9) on Category II uncontrolled organic emissions (there are no Category I organics) is discussed in this section. Category II uncontrolled organics are those substances in the flue gas upstream of the post combustion control equipment which are emitted in quantities sufficient to be of regulatory concern based upon theoretical analysis or measurements but stronger data or analysis is required for confirmation. Category II organics are listed in Table 5.17. This table also lists important information for each Category II substance including: whether the substance is being quantified in the DOE test program; key properties affecting the control of the substances (see sections 5.1.2 and 5.1.3); emission estimates for the LEB control alternatives and other potential post combustion control options; and estimated conservative emission limits. In addition to the coal fired boiler emission

TABLE 5.17. ABB 350 MWe LOW EMISSION BOILER EVALUATION TABLE FOR CONTROLLED CATEGORY II ORGANIC EMISSIONS (Stack Height 400 ft in an Urban Area, Substances sorted by regulatory limit).

Substance	DOE Test Program (Y/N)	Boiling Point (C)	Water Soluble (Y/N)	Chemical Structure	Utility Boiler Emissions (lb/hr)	Municipal Waste Incinerator (lb/hr)	Hazardous Waste Incinerator (lb/hr)	Emission Limit (lb/hr)
TCDD	Y			(C6H2)2Cl4O2	ND 1.8e-05	5.97e-05 (ESP) 1.53e-07 (DSI/FF) 6.70e-08 (SD/FF)	3.30E-06	9.26E-07
Benzidine	Y	400	N	2-H2NC6H4-C6H4NH2-2			NA	3.31E-04
2-Nitropropane	Y	120	N	(CH3)2CHNO2			NA	1.71E-03
Acetamide	Y	221.2	Y	CH3CONH2			NA	2.26E-03
Dimethyl sulfate	Y	188	N	(CH3O)2SO2			NA	1.16E-02
Polycyclic Organic Matter	Y	Various	Various	Various	0.053 (ESP) 0.024 (WS)		NA	2.78E-02
Polychlorinated biphenyls	N	Various	Various	Various		5.4e-03 (ESP) 1.1e-04 (SD/FF)	NA	3.31E-02
Acrylamide	Y	125	Y	H2C=CHCONH2			NA	3.56E-02
Benzene	Y	80.1	N	C6H6	0.24		1.03E+01	5.56E-02
1,3-Propane sultone	Y	180		C3H6O3S			NA	6.71E-02
1,3-Butadiene	Y	-4.4	N	CH2=CH-CH=CH2			NA	8.06E-02
Hexachlorobenzene	Y	323-326	N	C6Cl6			1.88E-02	9.08E-02
3,3-Dichlorobenzidene	Y		N	C12H10Cl2N2			NA	9.26E-02
1,1-Dimethyl hydrazine	Y	62-64	Y	(CH3)2NNH2			NA	9.45E-02

TCDD - 2,3,7,8 Tetrachlorodibenzo-p-dioxin
FF - Fabric Filter
SD - Spray Dryer
DSI - Dry Sorbent Injection
ESP - Electrostatic Precipitator
WS - Wet Scrubber

estimates, hazardous and municipal waste incinerator data were considered because of the lack of good boiler air toxic data. Emissions from the LEB were estimated using municipal and hazardous waste emission concentrations (AP–42,1992; EPA, 1989) and ABB's estimated stack gas flow rate of 3.3e07 dry standard cubic feet per hr (dscfh). The emissions are considered conservative. The emission limits were derived in Section 5.2. These limits are not necessarily based on promulgated rules but were derived to provide a conservative level of emissions that boilers may have to comply with at a future date. The information in Table 5.17 will be used throughout this section to evaluate the effectiveness and Category II HAP emission potential of ABB's alternatives.

As illustrated in Table 5.17, limited organics emissions data are available which can be used to evaluate the LEB's post combustion control alternatives. Most of the testing conducted to date has focused on metal emissions even for municipal and hazardous waste incinerators. The DOE test program (see section 4.1.4), however, is attempting to eliminate the uncertainty surrounding organic emissions. As shown in Table 5.17, all of the Category II substances except PCBs are currently being quantified in emissions from coal fired boilers. Once this information becomes available, a more comprehensive evaluation of the LEB will be possible. At this time, however, a less direct approach using emission estimates and fundamental emission mechanisms must be taken to evaluate the potential control alternatives.

The HAPs listed in Table 5.17 can be removed from the flue gas by one or more of the following mechanisms:

- Condensation and Capture
- Absorption
- Adsorption
- Reactions with Reagents

The potential for removal of the Category II HAPs by each of these mechanisms is described in the following subsections for Alternatives 1, 4, and 6. Adsorption and reactions with reagents are presented in the same section due to the lack of testing results and research conducted to date. Additional details on these capture mechanisms are provided in Section 5.1.2 and Section 6.0.

Condensation and Capture. One of most promising mechanisms for removal of organics is condensation and capture. The flue gas cools as it travels through the boiler, allowing semi–volatile HAPs to condense when the flue gas temperature drops below their saturation temperature. The degree of condensation increases as the flue gas temperature drops further below the HAP saturation temperatures. The condensed and particulate phase HAPs are removed from the flue gas by the particulate control equipment. The quantity of condensed and particulate phase HAPs removed depends on the design and operation of the control equipment.

Without knowing the vapor pressure of each HAP, it is not possible to determine flue gas temperature at which HAPs will begin to condense. However, the boiling temperature can be used as an indicator of the relative potential of substances to condense and be captured. For example, since the inlet temperature to the particulate control device for Control Alternative 6 is 370°C, HAPs with boiling points below 370°C will be in the vapor phase and will not condense and therefore cannot be captured. Category II HAPs which may be controlled by condensation and capture for each ABB alternative are listed below.

HAPs which may be removed by Condensation and Capture

Alternatives 1 and 4:

- 2,3,7,8 Tetrachlorodibenzo–dioxin
- Benzidine
- Acetamide
- Dimethyl Sulfate
- Polycyclic Organic Matter (Heavier Compounds)
- Polychlorinated Biphenyls
- 1,3 Propane Sultone
- Hexachlorobenzene
- 3,3 Dichlorobenzidene

Alternative 6:

- 2,3,7,8 Tetrachlorodibenzo–dioxin
- Benzidine
- Polycyclic Organic Matter (Some)
- Polychlorinated Biphenyls

Alternatives 1 and 4 have the same potential for removal of organics because both systems have ESPs which operate at 135°C. 2–Nitropropane, Acrylamide, 1,3 Butadiene, and 1,1 Dimethyl hydrazine are too volatile and will not be captured by Alternatives 1, 4, or 6.

From the information provided above, Alternatives 1 and 4 seem to be the best choice because of the wider range of HAPs which can be controlled. However, the ceramic or fabric filter used for Alternative 6 may provide better removal effectiveness than the Alternative 1 and 4 ESPs. In general, fabric and ceramic filters are more effective at removing small particulate than ESPs. Small particulate are of concern because they can travel deep within the lungs. Congener specific removal efficiencies for ESP and Fabric Filter systems are listed in Table 5.18 for dioxins and furans (Neilsen et. al., 1985). This data illustrates that fabric filters have higher dioxin and furan removal efficiencies especially at low temperature. In another study conducted by Environmental Canada (Environmental Canada 1986), the removal effectiveness of Fabric Filter systems for various organics was determined at different operating temperatures for municipal waste incinerators (see Table 5.19). Results from this study indicate that organics are controlled effectively by Dry Sorbent Injection/Fabric Filter systems and Spray Dryer/Fabric Filter systems at operating temperatures of 140°C or lower. At higher temperatures, a greater fraction of organics will be in the vapor phase and will not be captured. Since the Alternative 6 fabric filter will be operated at temperatures well in excess of 200°C, it may not be as effective as the Alternative 1 and 4 ESPs which are operated at much lower temperatures. The best solution would be to replace the low temperature ESPs in Alternatives 1 and 4 with fabric filters.

In addition to providing less potential for condensation of HAPs, the operating temperature for Alternative 6 also may contribute to the formation of dioxins and furans. Barton et. al. (Barton, 1990) identified an important dioxin and furan formation mechanism for municipal waste combustion systems involving reactions between hydrocarbons and chlorine on entrained particulate matter. Data from these facilities indicate that emissions of dioxins and furans can increase across a hot ESP or baghouse. The mechanism involves a series of steps. First, ash or unburned waste, in this case coal, are entrained by the gas flow. A very small fraction of hydrocarbons in the waste escapes destruction in the combustor. Upon reaching the reaction zone, the hydrocarbons react with HCl on the surfaces of the particles to form dioxins and furans. This proposed mechanism is consistent with recent studies which indicate that dioxin and furans reactions occur on solid particles at temperatures between 200 and 400°C. Since the Alternative 1 and 4 flue gases are cooled quickly in the air preheater to temperatures below 200°C, this formation

TABLE 5.18. ELECTROSTATIC PRECIPITATOR AND FABRIC FILTER CONTROL OF DIOXINS AND FURANS (Neilsen et. al., 1985)

SUBSTANCE	Control System Removal Efficiency (%)		
	SD+ESP	SD+FF High Temp	SD+FF Low Temp
Dioxins			
Tetra	48	52	97
Penta	51	75	99.6
Hexa	73	93	99.5
Hepta	83	82	99.6
Octa	89	NA	99.8
Furans			
Tetra	65	98	99.4
Penta	64	88	99.6
Hexa	82	86	99.7
Hepta	83	92	99.8
Octa	85	NA	99.8

TABLE 5.19. FABRIC FILTER REMOVAL EFFICIENCY OF ORGANICS AND IMPACT OF OPERATING TEMPERATURE (Environment Canada, 1986).

SUBSTANCE	DSI/FF				SD/FF
	110 C	125 C	140 C	>200 C	140 C
Chlorobenzenes	95	98	98	62	99
PCBs	72	99	99	54	99
PAHs	84	82	84	98	99
Chlorophenols	97	99	99	56	99
PCDD	99.9	99.9	99.9	99.9	99.9
PCDF	99.3	99.9	99.9	99.8	99.9

DSI - Dry Sorbent Injection
SD - Spray Dryer
FF - Fabric Filter

mechanism may not be important. However, the Alternative 6 combustion gases are not cooled in the air preheater prior to the control system and remain in the reaction temperature range longer. This may contribute to an overall higher dioxin and furan generation rate for Alternative 6.

Estimated 2,3,7,8 Tetrachlorodibenzo–p–dioxin (TCDD), polycyclic organic matter (POM), and polychlorinated biphenyl (PCB) emission levels for post combustion control equipment similar to ABB's are provided in Table 5.17. The emission rates were determined using utility boiler and municipal waste incinerator emission factors and the LEB process rates. TCDD has not been detected in utility boiler emissions but the detection limit is not low enough to determine if TCDD would be emitted at levels of concern. TCDD has been detected in municipal and hazardous waste incinerator emissions. Table 5.17 shows that TCDD may be controlled to acceptable levels using Fabric Filters (Alternative 6). This conclusion is probably conservative since municipal waste combustors have higher emissions of dioxins than coal fired boilers (EPA, 1986). Even though fabric filters have been shown to have the ability to control TCDD to acceptable levels, Alternative 6 may not provide acceptable control because of the high inlet temperature as discussed earlier. Alternatives 1 and 4 use ESPs for PM control and therefore could have unacceptable emissions levels TCDD as shown in Table 5.1.2. This conclusion may not be realistic since it is based on municipal waste incinerator data.

Table 5.17 shows that POM may be controlled to acceptable levels using a wet scrubber (Alternatives 1 and 4). Due to the uncertainty in the data source and the lack of Fabric Filter emission results, additional testing is necessary to determine if Alternatives 1, 4, and 6 will control POM to acceptable levels. The current DOE test program should provide an accurate and extensive POM data set for evaluation of each LEB alternative.

PCBs may be controlled to acceptable levels by Alternatives 1, 4, and 6 as shown in Table 5.17. Fabric Filter systems provide better control of PCBs than ESPs based on municipal waste incinerator data. This conclusion may not apply directly to Alternative 6, however because the system is operated at higher temperatures and a lower efficiency may result. Unfortunately these observations cannot be verified for utility boilers because the DOE program does not include PCB testing. Testing conducted by Ontario Hydro (Curtis et. al., 1992) has positively identified PCB emissions from a 300 MWe utility boiler with an ESP under normal operating conditions and at cold startup. This clearly indicates the need for additional PCB testing on utility boilers. The test plan presented in this document includes PCB testing.

Absorption. Only Alternatives 1 and 4 have the potential for significant absorption because FGD is not used in Alternative 6. In the FGD process, a limestone slurry is injected counter current into the gas stream. Since the slurry is intimately mixed with the gas, soluble HAPs may be absorbed into the slurry drops. Since these drops are collected at the bottom of the spray tower soluble HAPs will be removed from the system. The following substances may be partly controlled by the FGD.

<u>HAPs which may be removed by Absorption</u>

Alternatives 1 and 4:	• Acetamide • Acrylamide • 1,1–Dimethyl hydrazine
Alternative 6:	None

Testing is required to determine the impact of the FGD on the soluble HAPs. The DOE program should provide data which can be used to determine the effectiveness of FGD systems at removing soluble substances.

Adsorption and Reagent Reactions. Adsorption of HAPs onto entrained fly ash and the reaction of HAPs with reagents also may provide some control for Alternatives 1, 4, and 6. There are limited data that show spray drying followed by fabric filtration is an effective VOC control technique (EPA, 1986). Lower VOC control effectiveness can be expected from spray drying followed by ESP particulate control. The mechanism for VOC control in these types of spray drying systems may be VOC attack and capture by caustic reagents. A similar type of behavior may be present in the FGD processes used on Alternatives 1 and 4. There is little information available which can be used to evaluate the degree of control which can be expected through adsorption and/or reagent reactions from Alternatives 1, 4, and 6. The DOE program as mentioned earlier will provide the information needed to determine the impact of adsorption and reagents in systems similar to those proposed by ABB.

Summary. As discussed in Section 5.4.2.1, Alternatives 1 and 4 have the capability of controlling more of the Category II HAPs because of the low ESP operating temperature. However, since ESPs generally have a lower removal effectiveness than fabric and ceramic filters, Alternative 6 may provide better control for some of the Category II HAPs. A potential disadvantage of Alternative 6 may be the increased potential for the generation of dioxin and furans because of the high operating temperature. To provide better Category II HAP control, the operating temperature of the Alternative 6 fabric or ceramic filter should be lowered to the Alternative 1 and 4 ESP operating temperature or the Alternative 1 and 4 ESPs should be replaced with fabric filters. These options may not be necessary if it is determined through further testing that the combustor destroys organics to acceptable levels and conditions in the boiler convective section and post combustion control system do not promote organic emissions. The current DOE testing program will provide the information necessary to characterize most Category II organic emissions from Alternatives 1 and 4, however additional testing will need to be conducted to characterize emissions from Alternative 6 and PCB emissions from Alternatives 1 and 4. The DOE program will also provide additional insight on the impact of adsorption, absorption, and reagent reactions on organic control for Alternatives 1, 4, and 6.

6.0 AIR TOXIC EMISSION CONTROL TECHNOLOGIES

The previous section provided the results of an analysis to estimate which of the 189 CAAA air toxic compounds would be present in the LEB uncontrolled flue gas, and in the flue gas downstream of Pollution Control Alternatives 1, 4 and 6. The results indicate that arsenic may be emitted in quantities of regulatory concern with Alternatives 1 and 4, and chromium may be of concern for all three systems. Measurements will be required to verify these results. Specific recommendations concerning control of chromium and arsenic were made in Section 5. The analysis also indicates that emissions of toxic organics may be more of a problem than metals. Potential control methods for organic vapors are described here, along with an estimate of their costs as applied to a 350 MWe boiler.

6.1 Available and Developing Organic Vapor Control Methods

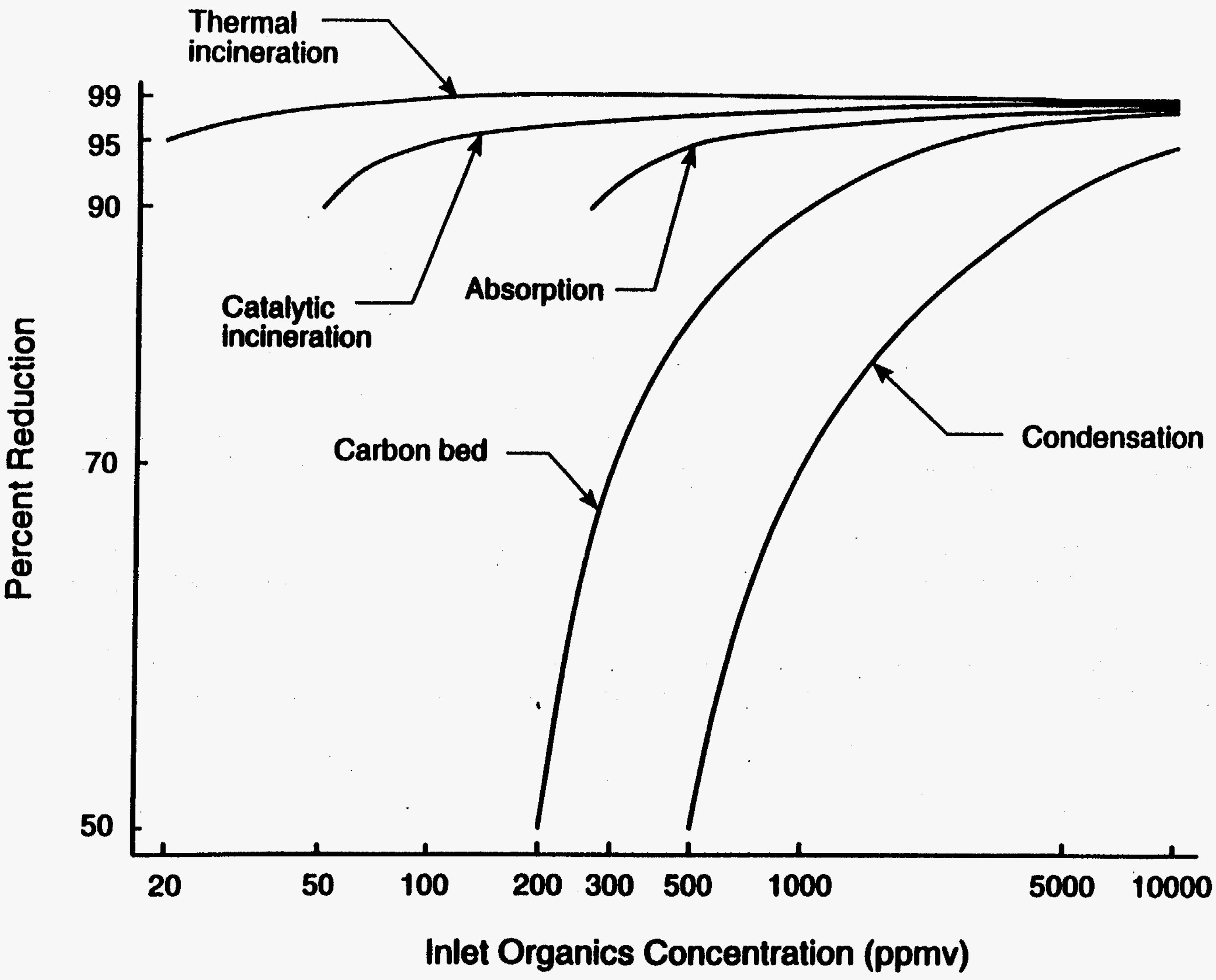
There are two main types of strategies for the control of organic vapors from combustion sources. Typically, good control of the combustion process and/or air pollution control devices are employed. Minimization of organic emissions by combustion control can be accomplished by (U.S. EPA, 1987):

- Limiting the variations in excess air, temperature, and mixing in the combustor that may allow organics to escape untreated from the combustion zone. These organics may be toxic, or may be precursors to the formation of other toxic compounds.
- Minimizing the entrainment, and maximizing the burnout of particle matter. If the waste combustion zone is overcharged, and/or gas velocities are excessive, a large release of unburned material may result.
- Increasing the particle residence time in the combustion zone.
- Assuring proper operating temperatures and excess air to allow for complete destruction.
- Avoiding conditions downstream of the combustion zone which hold particles in the dioxin formation temperature window of 250-350°C (Barton et. al., 1990).

In addition to good combustion practice, there are a number of flue gas cleaning methods for the control of volatilized organic emissions. Depending upon the flue gas temperature and compound volatility, some organics will condense onto/into particles, and some may remain in a gaseous state. Control of particles was discussed in Section 6.1.1. The more commonly applied control devices for volatile organics include:

- Destruction Techniques: Afterburner (thermal incinerator) and Catalytic Incinerator
- Capture Techniques: Carbon adsorption, Absorbtion, and Condensers

Figure 6-1 provides typical control levels for the various downstream devices used to control volatilized organic emissions.



Note: Compiled from U.S. EPA (1990).

Figure 6-1. Organics control device performance as function of inlet organics concentration.

6.1.1 Thermal Incinerators

In some applications, afterburners are used to complete the destruction of organics in the flue gas. Here, the organics are simply destroyed by the high temperatures resulting from the combustion of residual compounds within the flue gas which act as a source of fuel. The design and operation of such devices have been treated in most handbooks on stationary combustion devices. Like other incinerators, the afterburner performance depends largely on the combustion chamber temperature, stoichiometry, and residence time.

Thermal incinerators are typically applied to emission streams that are dilute mixtures of volatile organic compounds (VOC) less than 20 ppmv and air (U.S. EPA, 1991). Due to safety reasons the VOC content is usually limited to 25 percent of the lower explosion limit (U.S. EPA, 1991). If the flue gas entering the afterburner is not hot enough, the afterburner is supplemented with auxiliary fuel. The potential drawbacks of thermal incinerators include:

- Additional fuel requirements under fuel lean conditions.
- Increased operating temperature above 600°C without the use of a catalyst, creating potential for vaporization of some metals.
- Adds to the original flue gas flow rate.

The afterburner system requires periodic maintenance on the burners, air and fuel lines, and control system. However, afterburners are used frequently in hazardous waste applications due to their relatively low maintenance requirements, low capital cost (compared to catalytic systems), and high destruction efficiency.

6.1.2 Catalytic Incinerators

Catalytic incinerators are similar to thermal incinerators in design and operation except that they employ a catalyst to aid in the destruction of VOCs. The main advantage over thermal incinerators is that the catalyst allows destruction at low temperatures, thus minimizing the use of auxiliary fuel. The catalyst acts to accelerate the reaction rate. The efficiency of the incinerator depends on temperatures, residence time in contact with the catalyst, and organic concentration.

Catalyst types include platinum, palladium, and other noble metals. The catalyst usually has a honeycomb formation to maximize catalyst surface area. Poisoning of the catalyst sites is a major concern in regards to catalyst efficiency. Materials such as phosphorus, and chlorine, can severely affect catalyst performance. Catalysts such as chrome/alumina, cobalt oxide, and copper oxide/manganese oxide have been demonstrated to effectively control emissions of chlorinated compounds. Platinum based catalysts are used for control of sulfur containing VOCs, but are sensitive to chlorine poisoning.

Pressure drop across the catalyst bed, and the inlet and outlet gas temperature are monitored to assure proper operation. Inlet temperature is monitored to ensure that the catalyst operates within its specified temperature zone. Total hydrocarbon monitoring is used to indicate organic destruction efficiency.

6.1.3 Carbon Adsorbers

Carbon beds can be used for the removal of VOCs from combustion flue gas. The flue gas passes through a bed of granular activated carbon solids. The activated solids are highly porous and have large surface to volume ratios. The volatile organic compounds are selectively adsorbed on the surface of the bed material. The pressure drop across the bed, and the gas inlet temperature are monitored to assure proper operating performance. Pressure drop is monitored to detect for holes, leaks and bed pluggage. Inlet temperature is monitored to assure that the bed operates within the specified temperature range. Total hydrocarbon monitoring is used to indicate carbon bed performance.

The carbon bed, like the catalytic converter, has relatively few maintenance requirements except for bed regeneration. In normal situations, after the carbon bed has been saturated to a state where it will not adsorb any more organics, it must be cleaned or replaced. Cleaning (desorption of the carbon bed) involves heating the carbon bed to its regeneration temperature using steam, followed by drying and cooling of the bed to the operating temperature. For continuous operation, multiple fixed bed adsorbers are employed to ensure that one bed is always available.

Volatile organic removal efficiencies up to 95 to 99 percent can be achieved with adsorption either by carbon or impregnated carbon as shown in Figure 6-2 (U.S. EPA, 1991). Parameters impacting destruction efficiency of a carbon bed include:

- Flue gas temperature (< 130°F)
- Flue gas pressure ($\eta \propto$ pressure)
- Residence time
- Concentration of organic compounds
- Flue gas humidity (dry carbon preferred)
- Carbon bed age

Improvements in carbon bed technology have occurred to a large degree in Europe. For example, a carbon bed is utilized in the Stadtwerke Dusseldorf system. This system is a three stage process for sulphur, chlorine, fluorine, heavy metals and nitrous oxides. In the first and third stages, lime is used to remove the acidic components and NH_3 is used to remove NO_x. In the second stage, an activated charcoal bed filter is used to adsorb vaporous heavy metals and chlorinated hydrocarbons. This system has been demonstrated to achieve Germany's emission limits for waste incineration plants (Hg-0.05 mg/m^3, Cd-0.05 mg/m^3 and PCDD/PCDF, 0.10 ng/m^3). As of 1986, approximately 48 waste incineration plants in Germany have been retrofitted with activated coke treatment systems (Streng and Kassenbohm, 1993). Current developments include the impregnation of the carbon with compounds to enhance removal efficiency. Iodine and sulfur impregnated carbon has recently been demonstrated to improve removal efficiency in spray dryer applications where the carbon is injected into the flue gas stream (Felsvang et.al, 1993)

6.1.4 Absorbers

In addition to particulate removal, scrubbers may be used for the control of organic emissions. Similar absorption devices such as spray columns and packed or plate towers may also be used for such applications. The absorption process involves the transfer of volatile organics in the flue gas to a nonvolatile liquid. Absorption occurs when the concentration of the organic species in the liquid phase is lower than the equilibrium concentration in the vapor phase.

In a spray column the solvent is injected into a vessel as a finely atomized spray. Organics present in the flue gas which are soluble in the solvent are dissolved into the small liquid droplets. The droplets fall to the bottom of the vessel where they are collected and removed. A packed or plate tower follows the same basic design as a spray column except that the vessel is full of either irregular solid packing material or contains a number of perforated plates. This addition to the vessel aids in absorption efficiency by providing a contact surface area. In both tower designs, ordinarily, the gas and solvent streams flow countercurrent in order to obtain the greatest rate of absorption. Key parameters impacting performance include: liquid to gas ratio, operating pressure, and concentration of the organic compounds. The range of organic vapor capture efficiency for absorbers in general is given in Figure 6-1. In general, absorbers are not practical due to required height of absorption tower to provide sufficient contact times.

6.1.5 Condensers

Condensers are widely used as raw material or product recovery devices. Condensation involves the contact of a volatile organic compound within the flue gas at its saturation point with a surface whose temperature is below the compounds saturation temperature. Heat is transferred and an accompanying phase change occurs (the volatile organic condenses). Condensers are usually applied to flue gas streams with high VOC concentrations (greater than 5,000 ppmv) with improved removal efficiency at a concentration of 10,000 or more (U.S.EPA, 1991).

To monitor the proper operation and performance of a condenser, the outlet stream temperature is the fundamental indicator. Maintenance for such devices (mainly contact condensers) may include the disposal of contaminated spent coolant. Condenser performance in regards to VOC control is shown in Figure 6-2. Typically, parameters impacting condenser efficiencies are fluctuations in inlet flue gas temperature and organic concentration.

6.1.6 Developing Technologies

Takacs and Moilanene (1991) evaluated the Occidental ammonia control system used to provide simultaneous control of PCDD/PCDF, HCl, NO_x and to a lesser degree SO_2. In this system, PCDD/PCDF control is believed to work on the principle that NH_3 can prevent the formation of PCDD/PCDF by competing with the hydrocarbon precursors present in the flue gas for the available chlorine. Because NH_3 is much more reactive with chlorine than the hydrocarbons, ammonia chloride is more likely to form than PCDD/PCDF. Lab scale testing using this process was very encouraging; PCDD, PCDF and HCl removal efficiencies were 94, 100, and 97 percent respectively (Takacs and Moilanene, 1991).

A recent paper by Blumbach and Nethe (1992) presented results based on practical experience with the German Sorbalit® system. This system is intended for use to control both toxic metals and organics. It has been used extensively on waste incinerators throughout Europe. The Sorbalit® agent is produced by mixing calcium hydroxide with surface-activated substances such as carbon or lignite coke. In application, the Sorbalit® agent is injected into the flue gas, followed by a baghouse downstream. At one waste-to-energy plant, PCDD/PCDF emissions were reduced from 9-10 $ngTEQ/Nm^3$ to 0.02-0.06 $ngTEQ/Nm^3$ with similar reductions for mercury emissions. The values given are Total Equivalence values (TEQ) which are weighted values to account for the different degrees of toxicity of the various dioxin congeners. At a hazardous waste incineration facility, the level of polychlorinated biphenyls (PCB) content in the untreated gas was

130 ng/Nm^3, while in the treated gas the various types of PCB's were no longer detectable (Jager and Obermeier, 1990). At another hazardous waste facility, the reduction in polyaromatic hydrocarbons (PAH) was from 0.169 μg/Nm^3 in the untreated gas to 0.011 g/Nm^3 after the Sorbalit® process (Nethe).

6.2 Estimated Costs of Organic Air Toxic Control Devices

In this section, capital and operating costs for the thermal and catalytic incinerators, carbon bed, absorbers, and condensors are estimated for application to the 350 MWe LEB. The cost estimates are based on an EPA cost estimating procedure given in the Handbook of Control Technologies for Hazardous Air Pollutants. The procedure provides cost correlations for various air toxic control devices and is intended to provide costs within +/-30 percent error. Unfortunately, the correlations are generally utilized for waste incinerators with flue gas flow rates lower than the example boiler's 884,000 dscf/min. In some cases, costs had to be extrapolated past the sizes provided in the handbook and therefore, the costs presented here are to be considered as an order of magnitude estimate. To adjust costs to the higher flowrate of the LEB, the following correlation was used.

$$\mathrm{Cost}_{\mathrm{boiler\ 1}} = \left(\frac{\mathrm{MW}_{\mathrm{boiler\ 1}}}{\mathrm{MW}_{\mathrm{boiler\ 2}}}\right)^{0.6} \mathrm{X}\ \mathrm{Cost}_{\mathrm{boiler\ 2}}$$

$\mathrm{MW}_{\mathrm{boiler\ 1}}$ is the rating of the example case utility boiler and $\mathrm{MW}_{\mathrm{boiler\ 2}}$ is the rating of the facility upon which an initial cost estimate was made. It should be noted that the equation shown above is a rule of thumb approximation. In addition, all cost values calculated were modified to 1993 dollar values using price indices of 121.07 percent and 131.40 percent for the conversion from 1988 and 1986 dollar values to 1993 values (Consumer Price Index Hotline).

For each device, the total capital cost was calculated based on the purchased equipment cost and EPA cost factors. These factors are given in the EPA cost estimating handbook and specify individual indirect or direct capital cost items as a percentage of the purchased equipment cost. The total capital cost for each device was therefore found by summing the purchased equipment cost and the individual indirect and direct capital costs. Annual operating cost items were given in the EPA handbook as a percentage of the total capital cost. It was assumed that the boiler capacity factor is 90 percent. The total annual operating cost was calculated by summing both the direct and indirect operating costs.

For the incinerators and carbon bed, the following correlation was employed to calculate purchased equipment cost:

$\mathrm{Cost} = 21{,}342\ Q_{fg}^{0.25}$ for thermal incinerators

$\mathrm{Cost} = 1{,}215\ \ Q_{fg}^{0.5575}$ for catalytic incinerators

$\mathrm{Cost} = 271\ S^{0.778} + 2C_{req}$ for carbon beds

where S is the vessel surface area (ft^2) and C_{req} is the pounds of carbon required.

For the absorber and condenser, graphs were provided in the handbook. In addition, the following assumptions were made about each device to arrive at a purchase price:

Thermal Incinerator

- The thermal incinerator was sized for a destruction efficiency of 99 percent.
- The combustion temperature and residence time were assumed to be 1,800°F and 0.75 sec.
- Heat recovery in a heat exchanger was assumed to be 70 percent based on a value recommended by EPA (U.S. EPA, 1991).
- Supplemental fuel was assumed to be natural gas

Catalytic Incinerator

- Design was assumed to be a fixed bed.
- The catalyst bed inlet temperature was assumed to be 600°F while the outlet temperature and space velocity were assumed to range from between 1,000-1,200°F, and 30,000-40,000 1/hr, respectively, based on values specified by the EPA (U.S. EPA, 1991) for a precious metal catalytic incinerator able to achieve a 95 percent destruction efficiency.
- Heat recovery in the heat exchanger was assumed to be 50 percent based on a value recommended by EPA (U.S. EPA, 1991).
- Supplemental fuel was assumed to be natural gas.

Carbon Bed

- Design was assumed to be a fixed bed.
- The bed was sized to achieve a design removal efficiency of 95 percent.
- A default value of 0.100 for carbon bed working capacity was assumed based on a value specified by EPA (U.S. EPA, 1991).
- 304 stainless steel was chosen as the material of construction
- Steam was assumed to be the regeneration agent at one pound of steam per pound carbon.

Absorber

- The design of the absorber was assumed to be a single bed absorption column packed with 2 inch porcelain rings.
- The absorber was sized to achieve a design removal efficiency of 98 percent.

The cost of operating labor was based on an operator wage of $12.96/hr (1988 dollars) and a time requirement of 0.5 hours per 8 hour shift for each device. The cost of maintenance for most devices was based on a wage rate of $14.26/hr (1988 dollars) and a time requirement of 0.5 hours per 8 hour shift for each device. Supervisor costs were taken as 15 percent of the operator labor costs.

The capital cost estimate for each device is shown in Table 6-1. As may be seen, capital costs for the incinerators is much higher than for the other devices. This is mainly due to the complex instrumentation required, as well as the cost of materials and construction. The capital costs for the carbon bed and absorber are similar and are slightly more than half of the cost of the incinerators. The condensor has the lowest capital cost.

Table 6–2 provides the operating costs for each organic control device. Again the incinerators are the most expensive option – an order of magnitude higher than the other devices. The catalytic incinerator has the highest operating cost because of catalyst replacement. Table 6–3 summarizes capital and operating costs for each control option discussed. The catalytic incinerator is the most expensive, while the condenser type device is the least expensive.

It should be emphasized that these types of control equipment are very size and site dependent, and that the costs shown should be used as order of magnitude estimates only.

TABLE 6-1. CAPITAL COST ESTIMATES FOR A THERMAL INCINERATOR, A CATALYTIC INCINERATOR, A CARBON BED, AN ABSORBER AND A CONDENSER

Costs		Factors for Thermal Incinerators (1)	Estimated Costs ($\$ \times 10^5$)	Factors for Catalytic Incinerators (1)	Estimated Costs ($\$ \times 10^5$)	Factors for Carbon Bed (1)	Estimated Costs ($\$ \times 10^5$)	Factors for Absorber (1)	Estimated Costs ($\$ \times 10^5$)	Factors for Condenser (1)	Estimated Costs ($\$ \times 10^5$)
Direct Costs											
Purchased Equipment	Device	As estimated=EC	20.45	As estimated=EC	21.93	As estimated=EC	11.29	As estimated=EC	8.42	As estimated=EC	5.04
	Instru. & controls	Included with EC	0	Included with EC	0	Included with EC	0	0.10 EC	0.84	Included with EC	0
	Taxes	0.03 EC	0.61	0.03 EC	0.65	0.03 EC	0.34	0.03 EC	0.25	0.03 EC	0.15
	Freight	0.05 EC	1.02	0.05 EC	1.09	0.05 EC	0.56	0.05 EC	0.42	0.05 EC	0.25
	Purchased Equipment Costs (PEC)	PEC = 1.18 EC	22.08	PEC = 1.18 EC	23.67	PEC = 1.08 EC	12.19	PEC = 1.18 EC	9.93	PEC = 1.08 EC	5.44
Installation	Foundation & Supports	0.08 PEC	1.77	0.08 PEC	1.89	0.08 PEC	0.97	0.12 PEC	1.19	0.08 PEC	0.43
	Erection & Handling	0.14 PEC	3.09	0.14 PEC	3.31	0.14 PEC	1.71	0.40 PEC	3.97	0.14 PEC	0.76
	Electrical	0.04 PEC	0.88	0.04 PEC	0.95	0.04 PEC	0.49	0.01 PEC	0.1	0.08 PEC	0.43
	Piping	0.02 PEC	0.44	0.02 PEC	0.47	0.02 PEC	0.24	0.30 PEC	2.98	0.02 PEC	0.11
	Painting	0.01 PEC	0.22	0.01 PEC	0.24	0.02 PEC	0.24	0.01 PEC	0.1	0.01 PEC	0.05
	Insulation	0.0 PEC	0	0.0 PEC	0	0.0 PEC	0	0.01 PEC	0.1	0.1 PEC	0.54
	Total Direct Costs (DC)	DC = 1.29 PEC	28.48	DC = 1.29 PEC	30.53	DC = 1.30 PEC	15.84	1.85 PEC	18.37	DC = 1.43 PEC	7.76
Indirect Costs											
Engineering & supervision		0.10 PEC	2.21	0.10 PEC	2.37	0.10 PEC	1.22	0.10 PEC	0.99	0.10 PEC	0.54
Construction & field expenses		0.05 PEC	1.1	0.05 PEC	1.18	0.15 PEC	1.83	0.10 PEC	0.99	0.05 PEC	0.27
Contractor fee		0.10 PEC	2.21	0.10 PEC	2.37			0.10 PEC	0.99	0.10 PEC	0.54
Start-up fee		0.02 PEC	0.44	0.02 PEC	0.48	0.03 PEC	0.36	0.01 PEC	0.1	0.02 PEC	0.11
Performance test		0.01 PEC	0.22	0.01 PEC	0.24			0.01 PEC	0.1	0.01 PEC	0.05
Contingencies		0.03 PEC	0.66	0.03 PEC	0.71	0.03 PEC	0.36	0.03 PEC	0.3	0.03 PEC	0.16
	Total Indirect Costs (IC)	IC = .31 PEC	6.84	IC = .31 PEC	7.35	IC = .31 PEC	3.77	IC = 0.35 PEC	3.47	IC = .31 PEC	1.67
Total Capital Costs (TCC = IC + DC)		1.60 PEC	35.32	1.60 PEC	37.88	1.61 PEC	19.61	2.20 PEC	21.84	1.74 PEC	9.36

1. Source – U.S. EPA (1991)
2. Purchased equipment costs shown have been estimated in 1993 dollars.

TABLE 6-2. ANNUAL OPERATING COST ESTIMATES FOR VOLATILE ORGANIC CONTROL METHODS

		Thermal Incinerator Costs ($\$ \times 10^5$/yr)	Catalytic Incinerator Costs ($\$ \times 10^5$/yr)	Carbon Bed Costs ($\$ \times 10^5$/yr)	Absorber Costs ($\$ \times 10^5$/yr)	Condenser Costs ($\$ \times 10^5$/yr)
Direct Annual Costs (2)						
Utilities	Natural gas: $3.99/1000 ft^3	21.05	19.45			
	Electricity: $0.071/KWH	2	1.64	1.19	0.66	0.23
	Replace Catalyst: $3,632/ft^3 metal oxide		4.83			
	Carbon: $2.42/lb carbon			0.23		
	Steam: $7.26/1000 lb steam			1.61		
	Cooling water: $0.24/1000 gal			0.18	0.71	
	Refrigerent: $0.0/lb refrigerant					0
Operation	Operator: $15.69/hr	0.08	0.08	0.08	0.08	0.08
	Supervisor: 15% of operating labor cost	0.01	0.01	0.01	0.01	0.01
Maintenance	Labor: $17.26 / hr	0.08	0.08	0.08	0.08	0.08
	Materials: 100% of maintenance labor cost	0.08	0.08	0.08	0.08	0.08
Direct Annual Cost (DAC)		23.3	26.2	3.5	1.6	0.5
Indirect Annual Costs						
	Overhead: 6% of operating & maintenance labor cost	0.015	0.015	0.015	0.015	0.015
	Adminstrative: 2% of total capital cost (TCC)	0.71	0.76	0.39	0.17	0.18
	Property taxes: 1% of TCC	0.35	0.38	0.2	0.08	0.09
	Insurance: 1% of TCC	0.35	0.38	0.2	0.08	0.09
(3)	Capital recovery: 16.28% of TCC less 108% cat cost	5.75	5.32	3.19	1.37	1.45
Indirect Annual Costs (IAC)		7.175	6.855	3.995	1.715	1.825
Total Annual Costs (TAC = IAC + DAC)		24.8	33.03	7.46	3.34	2.305

1. Source U.S. EPA (1991)
2. Factors have been modified to reflect inflation since 1988. A price index of 121.07 percent was utilized (Consumer Index Hotline).
3. Capital recovery factor is i(1+i)n/(1-i)n-1 where i = interest rate (10%) and n = equipment life

TABLE 6-3. SUMMARY OF CAPITAL AND OPERATING COSTS FOR ORGANIC VAPOR CONTROL DEVICES.

Device	Capital Cost (millions)	Annual Operating Cost (millions)
Thermal Incinerator	3.53	2.48
Catalytic Incinerator	3.79	3.3
Carbon Bed	1.96	0.75
Absorber	2.18	0.33
Condenser	0.89	0.23

Note: Costs represent an order of magnitude estimate only.

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7.0 AIR TOXIC TEST PROTOCOL FOR ABB COMBUSTION ENGINEERING LOW EMISSION BOILER (LEB)

The Department of Energy's (DOE's) Pittsburgh Energy Technology Center (PETC) is funding a program entitled "Combustion 2000". The intent of the program is to support development of high efficiency/low emission coal combustion devices for the generation of electric power in the 21st century. While the program focusses on ultra low emissions of NO_x, SO_2 and particulate matter, ABB/CE is also concerned about how their design will impact the emission of air toxics.

In Section 5.0, CAAA air toxic compounds were identified that might be emitted from ABB's LEB in levels of regulatory concern (see Table 5.5). Due to the lack of emissions test results for these air toxics, additional testing must be conducted to evaluate the LEB and Control Alternatives 1, 4 and 6 emission levels. Many of the data gaps will be filled by the DOE test program. However, several critical substances such as PCBs are not being quantified during the DOE program and will require further efforts. In addition, many of the design aspects of the LEB boiler are not represented by the units being tested in the DOE program. Therefore, it is essential that additional testing be conducted to characterize CAAA substances of concern for the LEB design.

This section provides a draft test protocol for the evaluation of toxic by-product emissions from pilot scale tests and full scale utility boilers using state of the art testing methods. Many of the methods outlined below are being used in the DOE test program and have gained wide acceptance. However, several of the proposed methods have not been validated and require further study and validation efforts before they are used.

The focus of the testing will be on compounds which are either known to be emitted, expected to be emitted, or expected to be impacted by the application of new low emissions technology. The substances of concern, critical properties, and sampling and analytical methods are identified in Section 7.1. Required detection limits and sample times are provided and discussed in Section 7.2. Process sample considerations are provided Section 7.3. Flue gas sampling methods are described in Section 7.4. Flow charts outlining key sampling procedures are provided in Appendix C. These charts must be customized to the ABB site before they can be used to quantify air toxic emissions.

7.1 Sampling and Analytical Methods

In Section 5.0, CAAA air toxics were categorized into five groups based on their potential to be emitted at levels of regulatory concern with and without post combustion control equipment. The pollutants assigned to the first three categories could be emitted from the LEB and are targeted for detection through emission measurements. These three categories include:

Category I: HAPs known to be emitted in quantities sufficient to be of regulatory concern based upon prior measurements.

Category II: HAPs may be emitted in quantities sufficient to be of regulatory concern based upon theoretical analysis or measurements but stronger data or analysis is required to confirm.

Category III: HAPs are not expected to be emitted in quantities sufficient to be of regulatory concern based upon theoretical analysis or measurements but stronger data or analysis is required to confirm.

Category I, II, and III air toxics for ABB's LEB without post combustion controls are listed in Table 7.1. Uncontrolled Category I, II, and III air toxics are being considered in order to evaluate the LEB Control Alternatives 1, 4, and 6. Table 7.1 also lists proposed sampling and analytical methods for each air toxic substance of concern. All inorganic substances except hexavalent chromium should be sampled using EPA's Multiple Metals sampling train (EPA 29) and analyzed using atomic absorption spectroscopy (AAS) or iductively coupled plasma spectrometry (ICP). Hexavalent chromium will be sampled using EPA Method 306 and analyzed using ion chromatography (IC). Semi-volatile organics (boiling point > 100°C) will be sampled using the EPA semi-volatile sampling train (EPA Method 10) and analyzed using gas chromatography/mass spectrometry (GC/MS) or high performance liquid chromatography (HPLC). Volatile organics (boiling point between 30 and 100°C) will be sampled using the EPA volatile organic sampling train (EPA 0030) and analyzed using GC/MS. Very volatile organics (boiling point < 30°C) are not effectively sampled using EPA 0030, therefore a whole gas sample will be taken using EPA 18. The sample will be analyzed using GC/MS or GC/FID. Since 1,3 butadiene reacts readily with substances in the stack gases, an on-site GC is recommended.

All of the sampling and analytical methods listed in Table 7.1 are based on EER's experience gained during the previously mentioned DOE test program, recommendations from the EPA, the EPA's hazardous waste incineration measurement guidance manual (EPA, 1989), and the EPA's water sampling guidelines (EPA, 1992). While many of the methods have been extensively validated, some of the proposed methods have not been extensively tested and further validation may be required before testing can begin.

7.2 Required Detection Limits and Sample Times

Specification of analytical detection limits and sampling volumes is an important consideration when developing a test plan. If appropriate detection limits and sampling volumes are not specified and a high risk substance is not detected in the stack gases, the resulting stack concentration may be too large to prove emissions are not a risk. For most substances, the stack concentration is computed using the following equation.

Stack Concentration = (Quantity of Substance Detected) / (Sample Volume)

If a measurable quantity of a target substance is detected, the stack concentration can be used to accurately evaluate the contribution of the substance to the overall risk of the boiler emissions. However, if a measurable quantity of a substance is not found in the stack gases, the detection limit must be used to calculate the stack concentration. If either the detection limit is too large and/or the sample volume is too small, the calculated stack concentration may be exceed the acceptable risk based concentration. In this case, the substance must be considered a risk even though the substance was not detected. To reduce the occurrence of this type of problem, the analytical detection limit should be low enough and/or the sample should be large enough so the resulting stack concentration does not exceed the acceptable risk based stack concentration.

Detection limits are largely determined by the analytical technique while the sample volume is the product of the sample time and rate. Since the analytical detection limit and sample rate are fixed by the analytical and sampling methods and stack conditions, the stack concentration for nondetected data is a function of the sample time. Therefore, to ensure that stack concentrations for

TABLE 7.1. TARGET AIR TOXICS SPECIES AND TEST METHODS.

Hazardous Air Pollutant	Boiling Point (C) (1)	Soluble (Y/N) (1,2)	Structure	Sampling Method	Analytical Method
Category I					
Arsenic	na	Y	VP-As4O6 CP-AlAsO4	EPA 29	AAS, ICP
Beryllium	na	na	VP-Be(OH)2 CP-BeSO4	EPA 29	AAS, ICP
Cadmium	765	N	VP-Cd,CdO CP-CdSO4	EPA 29	AAS, ICP
Category II					
Acetamide	221.2	Y	CH3CONH2	EPA 0010	GC/MS
Acrylamide	125	Y	H2C=CHCONH2	EPA 0010	GC/MS
Benzene	80.1	N	C6H6	EPA 0030	GC/MS
Benzidine	400	N	2-H2NC6H4-C6H4NH2-2	EPA 0010	HPLC or GC/MS
1,3-Butadiene	-4.4	N	CH2=CH-CH=CH2	CARB 422.102	On-site GC
Chlorine	-34.6	N	Cl2	EPA 26	IC
Chromium (Hexavalent)	117	D	VP-CrO2Cl2 CP-Cr2(SO4)3	EPA 306	EPA 306
3,3-Dichlorobenzidene	na	N	C12H10Cl2N2	EPA 0010	HPLC or GC/MS
1,1-Dimethyl hydrazine	62-64	Y	(CH3)2NNH2	EPA 0030	GC/MS
Dimethyl sulfate	188	N	(CH3O)2SO2	EPA 0010	GC/MS
Hexachlorobenzene	323-326	N	C6Cl6	EPA 0010	GC/MS
Lead Coumpounds	954	N	VP-PbCl2 CP-PbSO4	EPA 29	AAS, ICP
Nickel Compounds	na	na	VP-Ni(OH)2 CP-NiSO4	EPA 29	AAS, ICP
2-Nitropropane	120	N	(CH3)2CHNO2	EPA 0010	GC/MS
Phosphorus	280	N	P4	EPA 29	AAS, ICP
Polychlorinated biphenyls (Aroclors)	Various	Various	Various	EPA 0010	GC/MS
1,3-Propane sultone	180	na	C3H6O3S	EPA 0010	GC/MS
Polycyclic Organic Matter	Various	Various	Various	EPA 0010	Fluoresence
2,3,7,8 - Tetrachlorodibenzo-p-dioxin	na	na	(C6H2)2Cl4O2	EPA 23	HRGC/HRMS
Selenium Compounds	350	Y	VP-SeO2	EPA 29	AAS, ICP

(1) - Metal solubility and boiling point for vapor phase.

(2) - Soluble if 100,000 mg disolve in 1L.

D - Decomposes

VP - Vapor phase

CP - Condensed phase

HPLC - High performance liquid chromatography

GC/MS - Gas chromatograpyh mass spectrometry

AAS - Atomic absorption spectroscopy

ICP - Inductively coupled plasma spectrometry

TABLE 7.1. TARGET AIR TOXICS SPECIES AND TEST METHODS.

Hazardous Air Pollutant	Boiling Point (C) (1)	Soluble (Y/N) (1,2)	Structure	Sampling Method	Analytical Method
Category III					
Acrolein	52.5	Y	CH2=CHCHO	EPA 0011	HPLC or GC/MS
Acrylonitrile	77.5	N	CH2=CHCN	EPA 0030	GC/MS
Aniline	184	Y	C6H5NH2	EPA 0010	GC/MS
Benzotrichloride	220.6	N	C6H5CCl3	EPA 0010	GC/MS
Benzyl chloride	179.3	N	C6H5CH2Cl	EPA 0010	GC/MS
Biphenyl	255.9	N	C6H5-C6H5	EPA 0010	GC/MS or HPLC
Bis(chloromethyl)ether	104	N	ClCO2CCl2	EPA 0030	GC/MS
Chlordane	na	N	C10H6Cl8	EPA 0010	GC/MS
Chloromethyl methyl ether	55-57	na	ClCH2OCH3	EPA 0030	GC/MS
Chloroprene	59.4	N	CH2=CCl-CH=CH2	EPA 0030	GC/MS
Cobalt Compounds	na	na	na	EPA 29	AAS, ICP
Diazomethane	-23	na	CH2=N2	EPA 18	GC/MS/FID
Dichloroethyl ether (Bis (2-chloroethyl) eth	178	N	(ClCH2CH2)2O	EPA 0010	GC/MS
Dimethyl aminoazobenzene	na	N	C6H5N=NC6H4N(CH3)2	EPA 0010	GC/MS
2,4-Dinitrotoluene	na	na	CH3C6H3(NO2)2	EPA 0010	GC/MS or HPLC
1,4-Dioxane (1,4-Diethyleneoxide)	101	Y	C4H8O2	EPA 0010	GC/MS
1,2-Diphenylhydrazine	131	N	C6H5NHNHC6H5	EPA 0010	GC/MS
Ethyl carbamate (Urethane)	198	N	H2NNHCO2C2H5	EPA 0010	GC/MS
Ethylene oxide	13.2	Y	C2H5O	EPA 18	GC/MS/FID
Ethylene thiourea	na	Y	C3H6-N2S	EPA 0010	HPLC or GC/MS
Heptachlor	na	N	C10H5Cl7	EPA 0010	GC/MS
Hexamethylphosphoramide	230-232	na	[(CH3)2N]3P(O)	EPA 0010	GC/MS
Hydarzine	113.5	Y	H2NNH2	EPA 0010	GC/MS
Hydrochloric acid	-84.9	Y	HCl	EPA 26	IC
Manganese Compounds	na	na	na	EPA 29	AAS, ICP
Methyl chloride (Chloromethane)	-24.2	N	CH3Cl	EPA 18	GC/MS/FID
Methyl hydrazine	87	Y	CH3NHNH2	EPA 0030	GC/MS
Methyl isocyanate	39.1-40.1	Y	CH3NCO	EPA 0030	HPLC
4,4-Methylenedianiline	398-399	N	CH2(C6H4NH2)2	EPA 0010	GC/MS
N-Nitrosodimethylamine	153	Y	(CH3)2NNO	EPA 0010	GC/MS
N-Nitrosomorpholine	224	Y	C4H8N2O2	EPA 0010	HPLC or GC/MS
p-Phenylenediamine	267	N	1,4-(H2N)2C6H4	EPA 0010	GC/MS
Propylene dichloride (1,2-Dichloropropane)	95-96	N	CH3CH(Cl)CH2Cl	EPA 0030	GC/MS
Propylene oxide	34.3	Y	C3H6O	EPA 18	GC/MS
1,1,2,2-Tetrachloroethane	147	N	Cl2CHCHCl2	EPA 0010	GC/HRMS
o-Toluidine	199-200	N	CH3C6H4NH2	EPA 0010	HPLC or GC/MS
Toxaphene (chlorinated camphene)	na	N	C10H10Cl8	EPA 0010	GC/MS
Vinyl chloride	-13.4	N	CH2=CHCl	EPA 18	GC/MS

nondetected substances are acceptable, the appropriate sample time must be specified so that a sufficient sample volume can be collected. Table 7.2 lists the stack concentration limit, analytical detection limit, and sampling rates for group I, II, and III substances. The stack concentration limits were derived in section 5.2 and the detection limit and sample rates were taken from the appropriate sampling and analytical methods and the DOE test program (DOE, 1993). From these values, the sample time can be calculated using the equation given below.

$$\text{Sample Time} = [(DL)(SF)]/[(SR)(C)]$$

DL = Analytical Detection Limit
SF = Safety Factor
SR = Sample Rate
C = Stack Concentration Limit

A safety factor of 10 was used to account for matrix and analytical interferences which may increase the analytical detection limit. The required sample times are listed in Table 7.2. In general, a one hour sample time is sufficient for most substances. However, several substances have large analytical detection limits in comparison to the stack concentration limit and require a six hour sample time. Based on the results in Table 7.2, the following sample times are required to achieve a safety factor of 10.

Required Sample Times

EPA 0010/23 - 6 hours
EPA 0011 - 1 hour
EPA 0030 - 6 hours
EPA 26 - 1 hour
EPA 29 - 6 hours
EPA 306 - 3 hours

EPA Method 18 is a whole stack gas sample and therefore does not concentrate the target substances. For this method, enough stack gas should be collected for the analytical procedures – five liters is usually sufficient. The 6 hour sample time required for volatile organic sample train (EPA 0030) may result in breakthrough of some target substances, therefore, a reduced sample time is recommended. All of the EPA 0030 compounds except chloroprene require a one hour sample time. To reduce chances of breakthrough, a two hour sample time (DOE, 1993) is recommended for EPA 0030. This will provide a reduced safety factor of five for chloroprene if the detection limit cannot be reduced. A safety factor of five should still provide sufficient protection. The recommended sample times for each method are listed below.

Recommend Sample Times

EPA 0010/23 - 6 hours
EPA 0011 - 1 hour
EPA 0030 - 2 hours
EPA 26 - 1 hour
EPA 29 - 6 hours
EPA 306 - 3 hours

Since several of the substances do not have analytical detection limits as shown in Table 7.2, the sample times given above may not be sufficient. Ideally, validation studies should be conducted

TABLE 7-2. TARGET DETECTION LIMITS AND SAMPLE TIMES.

Substance		Mass Flow Limit (lb/hr)	Concent. Limit (µg/Ncm)	Sampling Method	Detection	(ng)	Sampling Rate (dscf/hr)	Required Sample Time (Hrs)
Category I								
Arsenic Compounds	E	5.17E-03	2.54E+00	EPA 29	GFAA	450	45	3.0
Beryllium Compounds	E	3.00E-04	1.47E-01	EPA 29	GFAA	90	45	6.0
Cadmium Compounds	E	4.64E-04	2.28E-01	EPA 29	GFAA	45	45	3.0
Category II								
1,3-Butadiene	RL	8.06E-02	3.96E+01	CARB 422		(3)	NA	NA
Acetamide	RL	2.26E-03	1.11E+00	EPA 0010		NA	NA	NA
Acrylamide	RL	3.56E-02	1.75E+01	EPA 0010		NA	NA	NA
Benzidine	RL	3.31E-04	1.62E-01	EPA 0010	HPLC (1)	40	45	3.0
3,3-Dichlorobenzidene	RL	9.26E-02	4.55E+01	EPA 0010	GC/MS	10	45	1.0
Dimethyl sulfate	RL	1.16E-02	5.69E+00	EPA 0010		NA	NA	NA
Hexachlorobenzene	RL	9.08E-02	4.46E+01	EPA 0010	GC/MS	10	45	1.0
2-Nitropropane	RL	1.71E-03	8.43E-01	EPA 0010	GC/MS	10	45	1.0
Polychlorinated biphenyls (Aroclors)	RL	3.31E-02	1.62E+01	EPA 0010	GC/MS	1000	45	1.0
Polycyclic Organic Matter	RL	2.78E-02	1.37E+01	EPA 0010	GC/MS (2)	10	45	1.0
1,3-Propane sultone	RL	6.71E-02	3.30E+01	EPA 0010		NA	NA	NA
Benzene	RL	5.56E-02	2.73E+01	EPA 0030	GC/MS	10	1	1.0
1,1-Dimethyl hydrazine	RL	9.45E-02	4.64E+01	EPA 0030		NA	NA	NA
2,3,7,8-Tetrachlorodibenzo-p-dioxin	RL	9.26E-07	4.55E-04	EPA 23	HRGC/HRMS	0.01	45	1.0
Chlorine	RL	1.85E+01	9.10E+03	EPA 26	IC	25000	45	1.0
Lead Compounds	E	8.88E-03	4.36E+00	EPA 29	GFAA	450	45	1.0
Nickel Compounds	E	9.58E-03	4.71E+00	EPA 29	ICP	2000	45	6.0
Phosphorus	RL	3.24E+00	1.59E+03	EPA 29	ICP	33750	45	1.0
Selenium Compounds	E	8.60E-02	4.23E+01	EPA 29	GFAA	900	45	1.0
Chromium (Hexavalent)	RL	3.31E-04	1.62E-01	EPA 306	EPA 306	50	45	3.0
Category III								
Aniline	RL	4.63E-01	2.27E+02	EPA 0010		10000	45	1.0
Benzotrichloride	RL	3.24E-02	1.59E+01	EPA 0010		NA	NA	NA
Benzyl chloride	RL	4.63E-01	2.27E+02	EPA 0010	GC/MS (1)	50000	45	3.0
Biphenyl	E	1.00E-04	4.91E-02	EPA 0010	HPLC (1)	20	45	6.0
Chlordane	RL	1.25E-01	6.14E+01	EPA 0010	GC/MS	10000	45	3.0
Dichloroethyl ether (Bis(2-chloroethyl)ether)	RL	1.44E-01	7.05E+01	EPA 0010	GC/MS	5000	45	1.0
Dimethyl aminoazobenzene	RL	3.56E-02	1.75E+01	EPA 0010	GC/MS	10000	45	6.0
2,4-Dinitrotoluene	RL	5.09E-01	2.50E+02	EPA 0010	GC/MS	10	45	1.0
1,4-Dioxane(1,4-Diethyleneoxide)	RL	4.63E-01	2.27E+02	EPA 0010	GC/MS (1)	25000	45	1.0
1,2-Diphenylhydrazine	RL	2.08E-01	1.02E+02	EPA 0010	CGC/MS (1)	10000	45	1.0
Ethyl carbamate (Urethane)	RL	1.60E-01	7.84E+01	EPA 0010	GC/MS	50000	45	6.0
Ethylene thiourea	RL	3.56E+00	1.75E+03	EPA 0010	CGC/MS (1)	50000	45	1.0
Heptachlor	RL	3.56E-02	1.75E+01	EPA 0010	GC/MS	10000	45	6.0
Hexamethylphosphoramide	RL	1.85E+01	9.10E+03	EPA 0010	CGC/MS (1)	10000	45	1.0
Hydrazine	RL	9.45E-03	4.64E+00	EPA 0010		NA	NA	NA
4,4'-Methylenedianiline	RL	1.36E-01	6.69E+01	EPA 0010		NA	NA	NA
N-Nitrosodimethylamine	RL	1.08E-03	5.29E-01	EPA 0010	CGC/MS (1)	2500	45	Reduce DL
N-Nitrosomorpholine	RL	2.44E-02	1.20E+01	EPA 0010	CGC/MS (1)	5000	45	6.0
o-Toluidine	RL	4.63E-01	2.27E+02	EPA 0010	GC/MS	10000	45	1.0
p-Phenylenediamine	RL	1.39E+01	6.82E+03	EPA 0010	GC/MS	10000	45	1.0
1,1,2,2-Tetrachloroethane	RL	7.87E-01	3.87E+02	EPA 0010	GC/MS	10	45	1.0
Toxaphene (chlorinated camphene)	RL	1.39E-01	6.82E+01	EPA 0010		NA	NA	NA
Acrolein	RL	9.26E-01	4.55E+02	EPA 0011	HPLC	2550	45	1.0
Acrylonitrile	RL	1.60E-01	7.84E+01	EPA 0030	GC/MS (1)	25000	1	Reduce DL
Bis(chloromethyl)ether	RL	7.41E-04	3.64E-01	EPA 0030		NA	NA	NA
Chloromethyl methyl ether	RL	1.71E-02	8.43E+00	EPA 0030		NA	NA	NA
Chloroprene	RL	4.63E-01	2.27E+02	EPA 0030	GC/MS (1)	2500	1	6.0
Methyl hydrazine	RL	1.49E-01	7.34E+01	EPA 0030		NA	NA	NA
Methyl isocyanate	RL	9.26E+00	4.55E+03	EPA 0030		NA	NA	NA
Propylene dichloride (1,2-Dichloropropane)	RL	4.83E-01	2.27E+02	EPA 0030	GC/MS	10	1	1.0
Diazomethane	RL	4.63E-01	2.27E+02	EPA 18		(3)	NA	NA
Ethylene oxide	RL	4.63E-01	2.27E+02	EPA 18		(3)	NA	NA
Methyl chloride (Chloromethane)	RL	4.63E-01	2.27E+02	EPA 18		(3)	NA	NA
Propylene oxide	RL	4.63E-01	2.27E+02	EPA 18		(3)	NA	NA
Vinyl chloride	RL	5.94E-01	2.92E+02	EPA 18		(3)	NA	NA
Hydrochloric acid	RL	3.24E+02	1.59E+05	EPA 26	IC	25000	45	1.0
Cobalt Compounds	E	5.30E-02	2.60E+01	EPA 29	ICP	2000	45	1.0
Manganese Compounds	E	8.00E-02	3.93E+01	EPA 29	ICP	900	45	1.0

(1) - Water sample detection limit. Extract volume of 500 ml assumed.

(2) - Detection limit for PAH.

(3) - Detection limit does not depend on the sample time for bag samples.

E - Estimated or measured coal fired boiler emissions

RL - Risk based limit or State ambient air concentrati

DL - Detection limit

to determine detection limits before testing begins. These detection limits can then be used to determine if longer sample times are required. Two substances, n-nitrosodimethylamine and acrylonitrile, would require sample times in excess of 6 hours. Sample times longer than 6 hours can result in sampling problems including train failure and breakthrough. Therefore, it is recommended that the detection limit be reduced for these two compounds before extended sample times are used.

7.3 Process Sampling Considerations

Process sampling locations should be selected on the basis of project objectives. Process sampling is critical to achieving the project objectives and factors such as representativeness, sample contamination and worker safety must be considered.

Representativeness: Sampling locations and procedures must be chosen to ensure that the sample obtained is representative of the process material. Given that the homogeneity of the material is a primary criterion, the following general principles have been applied in developing sampling location and procedures:

- For solid and slurry streams, a series of samples should be collected under normal operating conditions clearly defined by process parameters. These samples may be split, composited or archived for the purpose of ensuring sample integrity.
- All process samples will, to the extent possible, be collected simultaneously. In practical terms, this means that samples will be collected over the same interval of time. In the case of an extended process upset, failure of a critical sampling operation, or other circumstances which would cause non-simultaneous sampling or non-representative process operation for more than 10 minutes, all process sampling will be temporarily halted until the process is stabilized or until all sampling activities can be resumed.

Sample Contamination (Quality Assurance): Sample locations have been chosen so that the probability of sample contamination within the sampling procedure itself or by outside media is minimized. Contamination of the samples after collection should be minimized or eliminated through the use of comprehensive sample custody procedures.

Worker Safety: Sampling locations should be chosen to avoid those that might create a condition which is unsafe for either the workers or the environment.

7.4 Flue Gas Sampling Procedures

Flue gas sampling will involve both manual sampling methods and continuous instrumental methods. The sampling methods and corresponding target substances for the boiler flue gas are summarized in Table 7.3. The target lists should be expanded to include additional CAAA substances that are on the normal method target list. This will provide information to validate the procedures used to determine critical substances in Section 5.0. The methods listed in Table 7.3 are described in the following subsections:

7.1.1 EPA Method 0030 (SW-846) - Volatile Organic Compounds

TABLE 7.3. TARGET SUBSTANCES FOR EACH SAMPLING METHOD.

SAMPLING METHOD	TARGET SUBSTANCES	
EPA 0010/23	Acetamide	2,4-Dinitrotoluene
	Acrylamide	1,4-Dioxane (1,4-Diethyleneoxide)
	Benzidine	1,2-Diphenylhydrazine
	3,3-Dichlorobenzidene	Ethyl carbamate (Urethane)
	Dimethyl sulfate	Ethylene thiourea
	Hexachlorobenzene	Heptachlor
	2-Nitropropane	Hexamethylphosphoramide
	Polychlorinated biphenyls (Aroclors)	Hydarzine
	1,3-Propane sultone	4,4-Methylenedianiline
	Polycyclic Organic Matter	N-Nitrosodimethylamine
	Aniline	N-Nitrosomorpholine
	Benzotrichloride	p-Phenylenediamine
	Benzyl chloride	1,1,2,2-Tetrachloroethane
	Biphenyl	o-Toluidine
	Chlordane	Toxaphene (chlorinated camphene)
	Dichloroethyl ether (Bis (2-chloroethyl) e	2,3,7,8 - Tetrachlorodibenzo-p-dioxin
	Dimethyl aminoazobenzene	
EPA 0011	Acrolein	
EPA 0030	Benzene	Chloroprene
	1,1-Dimethyl hydrazine	Methyl hydrazine
	Acrylonitrile	Methyl isocyanate
	Bis(chloromethyl)ether	Propylene dichloride (1,2-Dichloropropane)
	Chloromethyl methyl ether	
EPA 18	Diazomethane	Propylene oxide
	Ethylene oxide	Vinyl chloride
	Methyl chloride (Chloromethane)	
EPA 26	Chlorine	Hydrochloric acid
EPA 29	Arsenic	Phosphorus
	Beryllium	Selenium Compounds
	Cadmium	Cobalt Compounds
	Lead Coumpounds	Manganese Compounds
	Nickel Compounds	
EPA 306	Chromium (Hexavalent)	
CARB 422.102	1,3-Butadiene	

7.1.2 EPA Method 0010/23 (SW-846) - Semi-Volatile Organic Compounds

7.1.3 EPA Method 29 - Multiple Metals

7.1.4 EPA Method 18 - Measurement of Gaseous Organic Compound Emissions

7.1.5 CARB Method 422 - 1,3 - Butadiene

7.1.6 EPA Method 26 - Hydrogen Chloride, and Chloride

7.1.7 EPA Method 0011 - Aldehydes

7.1.8 EPA Method 306 - Hexavalent Chromium

7.1.9 Flue Gas Temperature, Velocity, Moisture, Molecular Weight, and Flow Rate

7.1.10 Continuous Emissions Monitoring

The discussions below briefly summarize each method, highlighting site-specific procedures or deviations from standard methods where necessary. It is important to note that the sampling procedures must be customized to the LEB site before they can be used to quantify emissions.

7.4.1 EPA Method 0030 (SW-846) - Volatile Organic Compounds

Volatile organic compounds (VOC's) will be measured at the control equipment inlet and at the stack using Method 0030 (EPA SW-846, September 1986). Method 0030 is designed to determine VOC's with boiling point between 30°C and 100°C in the flue gas of waste incinerators. The following figures summarize the method and site-specific procedures:

Method Overview:	Figure C-1
Glassware Preparation:	Figure C-2
Train Assembly:	Figure C-3
Train Schematic:	Figure C-4
Sampling Procedure:	Figure C-5
Leak check Procedure:	Figure C-6
Recovery Procedure:	Figure C-7

Sampling will be performed non-isokinetically at a single point in the flue gas according to the method. Three slow VOST runs will be performed sequentially for each test condition. Each VOST run will consist of 40 minutes of sampling at 1 dscf/hr for a total sampling time of 120 minutes. If the stack temperature is over 350°F, probe heating will not be required. Target substances are listed in Table 7.3.

Modifications

Modifications to the standard methodology which will be made in consideration of high SO_2 and particulate loading before the control equipment are:

- Insertion of an additional impinger containing 30% H_2O_2 solution upstream of the last impinger to scrub SO_2, protecting the pump and metering equipment;
- Addition of a nozzle to the probe which will face downstream to minimize particulate entrainment and plugging.

Two additional modifications are also under consideration to account for interference from SO_2 during sample analysis. The first alternative is addition of an H_2O_2 impinger upstream of the Tenax traps to remove SO_2 prior to the trap. The impinger would be analyzed for VOC's following the test. The second alternative is to add H_2O_2 to the condenser used during sample analysis. The need for these modifications will be determined based on the preliminary tests.

7.4.2 EPA Method 0010 (SW-846) and Method 23 - Semi-Volatile Organic Compounds

Semivolatile organic compounds (SVOC), including polychlorinated dibenzo[p]dioxins and dibenzofurans (PCDD/PCDF) will be determined at the control equipment inlet and at the stack. Method 0010 (SW-846) is designed to determine SVOC's (boiling points > 100° C) in the flue gas of stationary sources. EPA Method 23 (40 CFR 60 Appendix A, July 1, 1992) is very similar but is intended for characterization of PCDD/PCDF only. The methods will be combined to quantify the substances listed in Table 7.3.

The following figures summarize the method and site-specific procedures to be used:

Method Overview:	Figure C-8
Glassware Preparation:	Figure C-9
Train Assembly:	Figure C-10
Train Schematic:	Figure C-11
Leak Check Procedure:	Figure C-12
Recovery Procedure:	Figure C-13

Sampling will be performed isokinetically over a full point-to-point traverse of the sampling location. The sampling times will be 6 hours at the control equipment inlet and the stack, respectively. The target flow rate is 45 dscf/hr, yielding a total sample volume of 270 dscf.

Modifications

Modifications to the standard methodology which will be made in consideration of high SO_2 and particulate loading are:

- Modified sample train recovery procedures;

- Use of Teflon probe liners instead of glass or quartz liners to prevent breakage due to the long probe length required. A 1/2" thick walled Teflon liner, in conjunction with a 28/15" glass ball to the filter holder, will be used. The nozzle to the probe will be made of glass or quartz.

- Insertion of an additional impinger containing 30% H_2O_2 solution upstream of the last impinger to scrub SO_2, protecting the pump and metering equipment;

- Use of a glass cyclone preceding the filter at the control equipment inlet only to reduce filter plugging due to the very high particulate loading.

7.4.3 EPA Method 29 - Multiple Metals

Trace metals and particulate matter will be determined at the inlet to the control equipment and stack. EPA Method 29 is intended to determine metal emissions from waste incinerators. Target metals are listed in Table 7.3.

The following figures summarize the method and site-specific procedures to be used:

Method Overview:	Figure C-14
Glassware Preparation:	Figure C-15
Reagent Preparation:	Figure C-16
Train Assembly:	Figure C-17
Train Schematic:	Figure C-18
Leak Check Procedure:	Figure C-19
Recovery Procedure:	Figure C-20

Sampling will be performed isokinetically over a full point-to-point traverse of the sampling location. The sample flow rate will be 45 dscf/hr. Sampling times will be 6 hours at the control equipment inlet and stack, yielding total sample volume of 270 dscf. A 4.5-inch diameter filter will be used at the control equipment inlet to accommodate the high particulate loading. A 3-inch diameter filter will be used at the stack to reduce the significance of any target substances found in the filter materials.

Modifications

The following modifications will be made to the standard field sampling procedures in consideration of the high particulate loading and SO_2 concentration at the control equipment inlet.

- An acetone rinse of the probe, cyclone, filter housing, and connecting "front-half" glassware will be performed to enable particulate matter determination (allowed in the method);

- Use of Teflon probe liners instead of glass or quartz liners to prevent breakage due to the long probe length required. A 1/2" thick walled Teflon liner, in conjunction with a 28/15" glass ball to the filter holder, will be used. The nozzle to the probe will be made of glass or quartz.

- Use of a glass cyclone preceding the filter at the control equipment inlet only to reduce filter plugging due to the very high particulate loading.

7.4.4 EPA Method 18 - Measurement of Gaseous Organic Compound Emissions

Method 18 is designed to determine very volatile organic compounds from stationary sources. This method, published in 40 CFR 60 Appendix A dated February 13, 1991 places an empty tedlar bag in a rigid container which is then sealed and evacuated by a vacuum pump which draws a grab sample into the Tedlar bag. The EPA 18 target substances are shown in Table 7.3.

The following figures summarize the method and site-specific procedures to be used:

Method Overview:	Figure C-21
Leakcheck Procedure;	Figure C-22
Train Assembly/Operation:	Figure C-23
Sampling System:	Figure C-24
Recovery Procedure:	Figure C-25

7.4.5 CARB Method 422.102 - 1,3 - Butadiene

California Air Resources Board Method 422.102, December 13, 1991, will be used to sample and quantify 1,3 - Butadiene emissions during the test. The method includes the use of an on-site gas chromatograph to perform multi-dimensional GC analysis, using a flame ionization detector or photoionization detector. On-site sampling and quantification are necessary because 1,3 - Butadiene is very reactive and its concentration will decay within a few hours of sampling.

7.4.6 EPA Method 26 - Hydrogen Chloride and Chloride Emissions

Measurements of gas-phase hydrogen chloride and chloride emissions will be made at the control equipment inlet and at the stack only. EPA Method 26 (40 CFR 60 Appendix A, revised October 10, 1992) is intended to determine hydrogen halides, binary chloride and binary bromide from waste incinerators in the absence of other chloride-containing volatile species. The analysis procedure for this method can be adapted to determine total organic carbon and hydrogen cyanide without modification of the field sampling train. The following figures summarize the method and site-specific procedures to be used:

Method Overview:	Figure C-26
Glassware Preparation:	Figure C-27
Reagent Preparation:	Figure C-28
Train Assembly:	Figure C-29
Train Schematic:	Figure C-30
Leak Check Procedure:	Figure C-31
Recovery Procedure:	Figure C-32

Sampling will be performed non-isokinetically at a single point for each location. The target sample flow rate will be 45 dscf/hr. The sampling system will be run for 1 hour at the control equipment inlet and at the stack, resulting in a total sample volume of 45 dscf at both locations.

Modifications

Modifications to the standard procedure will be made to accommodate the high particulate loading at the control equipment inlet and high SO_2 concentrations. The modifications are:

- Use of Teflon probe liners instead of stainless steel or glass liners for consistency with other sampling equipment. A 1/2-inch, thick-walled Teflon liner, in conjunction with a 28/15 glass ball connector to the filter holder, will be used. The nozzle to the probe will be made of stainless steel, glass, or quartz;

- Use of a glass cyclone preceding the filter at the control equipment inlet only to reduce filter plugging due to the very high particulate loading;
- Addition of a nozzle to the probe which will face downstream to minimize particulate entrainment and filter plugging.

7.4.7 EPA Method 0011 - Aldehydes and Ketones

Emissions of eight aldehydes, including acrolein will be measured at the control equipment inlet and stack only. EPA Method 0011 (SW-846, June 26, 1990) is intended for use to determine aldehyde emissions from stationary sources. The following figures summarize the method and site-specific procedures to be used:

Preliminary Field Determinations:	Figure C-33
Reagent Preparation:	Figure C-34
Train Assembly:	Figure C-35
Train Schematic:	Figure C-36
Leak Check Procedure:	Figure C-37
Recovery Procedure:	Figure C-38

The sample is drawn through a series of chilled impingers containing aqueous acidic 2,4-dinitrophenylhydrazine (DNPH). No filter is used so that any target substances adsorbed on the fly ash are immediately fixed in the DNPH solution. Sampling will be performed isokinetically at a single point for each location. The sample flow rate will be 45 dscf/hr. Total sampling time will be 1 hour at each location, yielding a total sample volume of 45 dscf.

Modifications

Modifications to the standard procedure will be made in consideration of the high SO_2 concentration and particulate loading at the control equipment inlet. These are:

- Use of Teflon probe liners instead of glass or quartz liners to prevent breakage due to the long probe length required. A 1/2-inch, thick-walled Teflon liner, in conjunction with a 28/15 glass ball connector to the filter holder, will be used. The nozzle to the probe will be made of glass or quartz.

7.4.8 EPA Method 306 - Hexavalent Chromium

Hexavalent chromium (Cr^{VI}) will be measured at the control equipment inlet and stack. Draft EPA Method 306 will be used. Figure C-39 illustrates the sample train. A glass or Teflon probe and nozzle assembly is used to extract a sample from the flue gas. The sample train utilizes a recirculating spray quench probe arrangement to ensure all hexavalent chromium is immediately absorbed. Dilute sodium hydroxide solution from the first impinger is pumped to the probe spray nozzle, which is located such that the spray is introduced into the probe near the nozzle exit. There is no particulate filter used in the sample train. The first three impingers containing sodium hydroxide solution will be of Teflon construction. The remainder of the sampling train is similar to conventional Method 5 trains. Analysis of the sample is by ion chromatography with a post column reactor utilizing diphenyl carbazide.

Sampling will be performed isokinetically over a full point-to-point traverse of the stack. The flue gas sample flow rate will be 45 dscf/hr. Total sampling time will be 3 hours for each run, yielding a total sample volume of 135 dscf.

Modifications

The standard method procedures will be modified in consideration of the high SO_2 concentration as recommended by Steinsberger et. al. (EPRI Workshop on Trace Metals, Scottsdale, Arizona, April 1993) as follows:

- The normality of the first impinger solution will be increased to 6.1 and the quantity of solution in this impinger will be increased to 250 ml assuming 1800 ppm SO_2 according to the following formula:

  N=(SO_2, ppm)*(sample volume, dscm)/(6000*first impinger volume, liters)

- pH of the solution will be monitored during sampling by adding cresol red indicator to the impinger solutions. If the indicator turns, sampling will be halted and additional 6.1 N sodium hydroxide solution will be added.

7.4.9 Flue Gas Temperature, Velocity, Moisture, Molecular Weight, and Flow Rate

All of the manual flue gas sampling trains which sample isokinetically over full point-to-point traverses of the duct also will measure the temperature, velocity, and moisture content of the flue gas according to EPA Methods 1, 2, 3, and 4. These measurements combined with O_2 measurements described below and measurement of the duct cross-sectional area will enable the molecular weight and flow rate of the flue gas to be calculated. Measurements will be performed at the controlled and uncontrolled sampling locations during the test program.

Flue gas molecular weight at the control equipment inlet will be based on O_2 measurements made using a portable Teledyne fuel cell type analyzer, in conjunction with O_2 and CO_2 measurements made at the stack using continuous emissions monitors. The Teledyne analyzer will be calibrated with certified calibration gases. CO_2 at the control equipment inlet will be assumed to the same as at the stack, corrected for any difference in O_2 concentrations between these locations. Molecular weight at the stack will be based directly on continuous emissions monitor measurements.

7.4.10 Continuous Emissions Monitoring

Measurements will be made at the stack to determine emissions of NO_X, SO_2, CO, and total hydrocarbons (THC). These measurements will be made using continuous emissions analyzers according to the following methods:

NO_X EPA Method 7E

SO_2	EPA Method 6C
CO	EPA Method 10
THC	EPA Method 25A

The design of the sample acquisition and conditioning system is illustrated in Figure C-40. Samples will be withdrawn from the stack using a stainless steel probe equipped with an in-stack stainless steel fritted filter. The sample will not be diluted and the probe will be equipped with 3-way valve for introduction of calibration gases. Samples for all species except THC will be transported via heated Teflon tubing maintained at approximately 250±25°F to a sample conditioning unit. The sample conditioning unit, which will be located at the stack, filters the sample and removes moisture in a glass refrigerant condenser. The filtered and dried sample will be transported to the analyzer system via unheated Teflon lines. A separate unheated Teflon line will also carry calibration gases to the probe. Samples for THC analysis will be transported to the THC analyzer via a separate heated Teflon line and will be maintained at approximately 250±25°F through to the point of analysis. The sample will be filtered but not dried prior to analysis. The THC analyzer is equipped with a separate pump. The temperature of all heated lines will be monitored using thermocouples placed under the heating jacket.

The procedures for monitoring flue gas composition include:

- CEMS calibration and maintenance;
- CEMS QC checks;
- CEMS operation;
- CEMS data reduction and reporting.

QC checks such as stratification and bias response will be performed prior to the start of testing. Calibration and bias checks also will be performed at intervals during the test program.

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APPENDIX A - STATE AIR TOXIC AMBIENT CONCENTRATION LIMITS

APPENDIX A. INDIVIDUAL STATE AMBIENT AIR CONCENTRATION LIMITS FOR AIR TOXICS

Pollutant /State	LA		MD		NC		NM		RI		VT		WA	
	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time
Acetaldehyde	4.29E+03	8					1.80E+03	8			1.80E+03	8	4.50E-01	1
Acetic acid							2.50E+02	8			2.50E+02	8	8.33E+01	24
Acetic anahydride							2.00E+02	8			2.00E+02	8	6.66E+01	24
Acetone											1.78E+05	8	5.93E+03	24
Acetonitrile	9.40E+02	8					7.00E+02	8			7.00E+03	8	2.33E+02	24
Acetylene tretrabromide							1.50E+03	8					5.00E+01	24
Acetylsalicylic acid							5.00E+01	8						
Acrolein	5.40E+00	8					2.50E+00	8			2.50E+00	8	8.00E-01	24
Acrylamide	8.00E-02	1					3.00E+00	8			1.00E-02	1	1.00E-01	24
Acrylic acid	1.40E+02	8					3.00E+02	8					9.99E+01	24
Acrylonitrile	1.47E+00	1			1.50E-01	1	4.50E+01	8	7.00E-02	1	1.50E-02	1	1.50E-02	1
Aldrin							2.50E+00	8					2.00E-04	1
Allyl alcohol							5.00E+01	8					1.67E+01	24
Allyl chloride	7.14E+01	8					3.00E+01	8			2.90E-01	1		
Allyl glycidol ether							2.20E+02	8					7.33E+01	24
Allyl propyl disulfide							1.20E+02	8					4.00E+01	24
Alluminum							1.00E+02	8					3.33E+01	24
4-Aminodophenyl							1.00E+01	8						
2-Aminopyridine							2.00E+01	8					6.70E+00	24
Amitrole							2.00E+00	8					6.00E-01	24
Ammonia	6.40E+02	8	3.30E+02	8			1.80E+02	8			1.80E+03	8	5.99E+01	24
Ammonia chloride fume							1.00E+02	8					3.33E+01	24
Ammonia chromate					8.30E-05	1	8.30E-07	1						
Ammonia dichromate					8.30E-05	1	8.30E-07	1						
Ammonia perfluoroctanoate													3.00E-01	24
Ammonia sulfamate							1.00E+02	8			2.38E+01	24	3.33E+01	24
n-Amyl acetate							5.30E+03	8			5.30E+04	8	1.76E+03	24
sec-Amyl acetate							6.65E+03	8			6.65E+04	8	2.21E+03	24
Aniline	1.81E+02	8					5.00E+00	8	3.00E+00	24	1.00E-02	1	3.33E+01	24
Anisidine							5.00E+00	8	1.00E+00	24			1.70E+00	24
Antimony (and compound)	1.19E+01	8					5.00E+00	8	4.00E+01	1	5.00E+01	8	1.70E+00	24
Antimony trioxide											1.00E-02	1	1.70E+00	24
Arsenic (and compounds)	2.00E-02	1			2.30E-04	1			2.00E-04	1	2.30E-04	1	2.30E-04	1
Arsine							2.00E+00	8			1.00E-02	1	7.00E-01	24
Asbestos (friable)					2.80E-11	1							2.40E-06	1
Atrazine							5.00E+01	8					1.67E+01	24
Azinphos-methyl							2.00E+00	8					7.00E-01	24

APPENDIX A. INDIVIDUAL STATE AMBIENT AIR CONCENTRATION LIMITS FOR AIR TOXICS

Pollutant /State	LA		MD		NC		NM		RI		VT		WA	
	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time
Aziridine					6.00E+00	24								
Barium (and compound)	1.19E+01	8					5.00E+00	8			1.19E+01	1	1.70E+00	24
Benomyl							1.00E+02	8					3.33E+01	24
Benzene	1.20E+01	1					1.20E-03	1	1.00E-01	1	1.20E-01	1	1.20E-01	1
Benzidine and salts					1.50E-05	1	4.00E-02	8	2.00E-05	1	1.50E-05	1	1.50E-05	1
Benzo(a)pyrene					3.30E-02	1	4.00E-02	8			3.00E-04	1	6.00E-04	1
Benzoly peroxide							5.00E+01	8					1.67E+01	24
Benzotrichloride									7.00E-04	1				
Benzyl chloride							5.00E+01	8	1.00E-02	1			1.67E+01	24
Beryllium	4.00E-02	1			4.10E-03	1					1.30E-03	1	2.40E-04	1
Biphenyl	3.10E+01	8					1.50E+01	8	7.00E+00	24	1.00E-02	1	5.00E+00	24
									4.00E-01	1				
Bis(chloromethyl)ether					3.70E-04	1	5.00E-02	8					1.60E-05	1
Bis (2-Chloroethyl) ether	3.00E-01	1											3.00E-03	1
Bismuth telluride							5.00E+01	8					3.33E+01	24
Borates, tetra, sodium salts, anahydrous							1.00E+01	8					3.30E+00	24
Borates, tetra, sodium salts, decahydrate							5.00E+01	8					1.67E+01	24
Borates, tetra, sodium salts, pentahydrate							1.00E+01	8					3.30E+00	24
Boron oxide							1.00E+02	8					3.33E+01	24
Boron tribbromide							1.00E+02	8					3.33E+01	24
Boron trifluoride							3.00E+01	8					1.00E+01	24
Bromacil							1.00E+02	8					3.33E+01	24
Bromine							7.00E+00	8					2.30E+00	24
Bromine pentafluoride							7.00E+00	8					2.30E+00	24
Bromoform							5.00E+01	8			1.00E-02	1	1.67E+01	24
2-Butoxyethanol							1.20E+03	8			1.20E+04	8	4.00E+02	24
n-Butyl acetate							7.10E+03	8			7.10E+03	8	2.36E+03	24
sec-Butyl acetate							9.50E+03	8			9.50E+04	8	3.16E+03	24
Butane													6.33E+03	24
tert-Butyl acetate							9.50E+03	8			9.50E+04	8	3.16E+03	24
Butyl acrylate							5.50E+02	8					1.83E+02	24
n-Butyl alcohol							1.50E+03	8			3.60E+02	24	5.00E+02	24
sec-Butyle alcohol							3.05E+03	8			3.05E+03	8	1.02E+03	24
tert-Butyl alcohol							3.00E+03	8			3.00E+03	8	9.99E+02	24

APPENDIX A. INDIVIDUAL STATE AMBIENT AIR CONCENTRATION LIMITS FOR AIR TOXICS

Pollutant /State	LA		MD		NC		NM		RI		VT		WA	
	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time
Butylamine							1.50E+02	8					5.00E+01	24
tert-Butyl chromate							1.00E+00	8					3.00E-01	24
n-Butyl gylcidol ether							1.35E+03	8					4.50E+02	24
n-Butyl lactate													8.33E+01	24
Butly mercaptan							1.50E+01	8					5.00E+00	24
O-sec-Butylphenol							3.00E+02	8					9.99E+01	24
p-tert-Butyltoluene							6.00E+02	8			1.43E+02	24	2.00E+02	24
1,3-Butadiene	9.20E-01	1					1.74E-03	1			3.50E-02	1	7.33E+01	24
Cadmium (and compounds)	6.00E-02	1			5.50E-03	24	5.00E-01	8	6.00E-04	1	5.70E-04	1	5.60E-04	1
Calcium chromate							8.30E-07	1						
Calcium cyanamide							5.00E+00	8					1.70E+00	24
Calcium hydroxide							5.00E+01	8					1.67E+01	24
Calcium oxide							2.00E+01	8			2.00E+01	8	6.70E+00	24
Camphor (synthetic)							1.20E+02	8					4.00E+01	24
Caprolactam (dust)							1.00E+01	8					3.30E+00	24
Caprolactam (vapor)							2.00E+02	8					6.66E+01	24
Captafol							1.00E+00	8					3.00E-01	24
Captan							5.00E+01	8					1.67E+01	24
Carbaryl							5.00E+01	8					1.67E+01	24
Carbofuran							1.00E+00	8					3.00E-01	24
Carbon black							3.50E+01	8					1.17E+01	24
Carbon disulfide	8.60E+01	8			1.86E+02	24	3.00E+02	8			7.14E+02	24	9.99E+01	24
Carbon tetrabromide							1.40E+01	8					4.70E+00	24
Carbon tetrachloride	6.67E+00	1			6.70E+00	1	6.70E-02	1	3.00E-02	1	6.70E-02	1	6.70E-02	1
Carbonyl fluoride							5.00E+01	8					1.67E+01	24
Carbonyl sulfide	2.43E+01	8												
Catechol							2.00E+02	8					6.66E+01	24
Cesium hydroxide							2.00E+01	8					6.70E+00	24
Chlordane							5.00E+00	8					2.70E-03	1
Chlorinated camphene							5.00E+00	8					1.70E+00	24
Chlorinated dibenzo-p-dioxins	3.00E-03	1									.02ps/m3	1		
Chlorinated dibenzo Furans	3.00E-03	1									.02ps/m3	1		
Chlorinated diphenyl oxide							5.00E+00	8					1.70E+00	24
Chlorine	3.57E+01	8			3.75E+01	24	3.00E+01	8			3.00E+01	8	1.00E+01	24
Chlorine dioxide	6.67E+00	8	5.00E+00	8			3.00E+00	8			3.00E+00	8	1.00E+00	24

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Pollutant /State	LA		MD		NC		NM		RI		VT		WA	
	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time
Chlorine trifluoride							4.00E+00	8					1.30E+00	24
Chlororacetaldehyde							3.00E+01	8					1.00E+01	24
a-Chloroacetophenone							3.00E+00	8					1.00E+00	24
Chloroacetyl chloride							2.00E+00	8					7.00E-01	24
0-Chlorobenylidene malonitrile							4.00E+00	8					1.30E+00	24
Chlorobenzene	1.10E+03	8			2.20E+03	1	3.50E+03	8			8.33E+02	1	1.17E+03	24
Chlorobromomethane													3.50E+03	24
Chlorodifluoromethane													1.17E+04	24
Chloroethane	6.29E+04	8												
Chloroform	4.30E+00	1			4.30E+00	1	5.00E+02	8	4.00E-02	1	4.30E-02	1	4.30E-02	1
Chloromethane	5.56E+01	1												
Chloromethyl methyl ether							1.00E+02	8						
1-Chloro-1-nitropropane							1.00E+02	8					3.33E+01	24
Chloropentafluoroethane													2.10E+04	24
Chlorophenols													1.80E-01	1
Chloropicrin							7.00E+00	8					2.30E+00	24
Chloroprene	8.57E+02				4.40E+02	1	3.50E+02	8			1.00E-02	1	1.17E+02	24
0-Chlorostryrene							2.85E+03	8					9.49E+02	24
o-Chlorotoluene													8.33E+02	24
Chlorpyrifus							2.00E+00	8					7.00E-01	24
Chromium (and compounds)	1.00E-02	1					2.00E+00	8	9.00E-05	1	8.50E-05	1	8.30E-05	1
Chromic acid					8.30E-05	1								
Chromium (IV)					8.30E-05	1	5.00E-01	8						
Chromyl chloride							1.50E+00	8					5.00E-01	24
Chrysene							1.00E-02	8						
Clopidol							1.00E+02	8					3.33E+01	24
Cobalt (total)							1.00E+00	8			1.20E-01	24	2.00E-01	24
Cobalt carbonyl							1.00E+00	8					3.00E-01	24
Cobalt hydrocarbonyl							1.00E+00	8					3.00E-01	24
Coke oven emissions													1.60E-03	1
Copper (and compound)	2.38E+01	8					1.00E+01	8			1.00E+02	8	3.30E+00	24
Cresol	2.76E+02	8					2.20E+02	8					7.33E+01	24
Crotonaldehyde							6.00E+01	8					2.00E+01	24
Crufomate							5.00E+01	8					1.67E+01	24
Cumene	5.86E+03	8					2.45E+03	8			5.83E+02	1	8.16E+02	24
Cyanamide							2.00E+01	8					6.70E+00	24
Cycnides							5.00E+01	8			5.20E+02	8	1.67E+01	24
Cyanogens							2.00E+02	8					6.66E+01	24
Cyanogen chloride							6.00E+00	8					2.00E+00	24

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Pollutant /State	LA		MD		NC		NM		RI		VT		WA	
	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time
Cyclohexane							1.05E+04	8			1.05E+04	8	3.50E+03	24
Cyclohexanol							2.00E+03	8			2.00E+03	8	6.66E+02	24
Cyclohexanone							1.00E+03	8			2.40E+02	24	3.33E+02	24
Cyclohexene							1.02E+04	8			2.42E+03	1	3.38E+03	24
Cyclohexylamine							4.00E+02	8					1.33E+02	24
Cyclonite							5.00E+00	8					5.00E+00	24
Cyclopentadiene							2.00E+03	8					6.66E+02	24
Cyclopentane													5.73E+03	24
Cyhexatin							5.00E+01	8					1.67E+01	24
2,4-D							1.00E+02	8					3.30E+01	24
Decarborane							3.00E+00	8					1.00E+00	24
Demeton							1.00E+00	8			7.10E-01	24	3.00E-01	24
Diactone alcohol							2.40E+03	8					7.99E+02	24
Diaminotoluene	1.81E+02	8												
Diazinon							1.00E+00	8					3.00E-01	24
Diazomethane							4.00E+00	8			1.00E-02	1	1.30E+00	24
Diborane							1.00E+00	8					3.00E-01	24
1,2-Dibromoethane	4.50E-01	1											4.00E-02	1
Dibutyl phosphate							5.00E+01	8					1.67E+01	24
Dibutyl phthalate	1.19E+02	8					5.00E+01	8			5.00E+02	8	1.67E+01	24
2-N-Dibutylaminoethanol							1.40E+02	8					4.66E+01	24
Dichloroacetylene							4.00E+00	8					1.30E+00	24
1,4-Dichlorobenzene	1.07E+04	8											1.50E+03	24
O-Dichlorobenzene							3.00E+03	8			3.00E+03	8	9.99E+02	24
p-Dichlorobenzene							4.50E+03	8					1.50E+03	24
3,3-Dichlorobenzidine							4.00E-02	8	2.00E-03	1				
Dichlorodifluoromethane					2.48E+01	24					1.18E+02	24	1.65E+04	24
1,3-Dichloro-5,5-dimethyl hydantion							2.00E+00	8					7.00E-01	24
1,1 Dichloroethane							8.10E-01	8			1.90E+04	24	2.63E+03	24
1,2-Dichloroethane	3.85E+00	1											4.00E-02	1
1,2-Dichloroethylene							7.90E+03	8			7.90E+04	8	2.63E+03	24
Dichloroethyl ether							3.00E+02	8			3.10E-03	1	9.99E+01	24
Dichlorofluoromethane					5.00E+01	24	4.00E+02	8					1.33E+02	24
Dichloromethane	2.13E+02	1											2.00E+00	1
1,1-Dichloro-1-nitroethane							1.00E+02	8					3.33E+01	24
1,2-Dichloropropane	8.26E+03	8											1.17E+03	24
Dichloropropene							5.00E+01	8					1.67E+01	24
2,2-Dichloropronionic acid							6.00E+01	8					2.33E+04	24

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Pollutant /State	LA		MD		NC		NM		RI		VT		WA	
	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time
1,3-Dichloropropylene	1.07E+02	8												
s-Dichlorotetrafluoroethane											1.67E+05	24	2.33E+04	24
Dichlorvas							1.00E+01	8					3.30E+00	24
Dicrotophos							2.50E+00	8					8.00E-01	24
Dicyclopentadiene							3.00E+02	8					9.99E+01	24
Dicyclopentadienyl iron							1.00E+02	8					3.33E+01	24
Dieldrin							2.50E+00	8					2.00E-04	1
Diethanolamine							1.50E+02	8					5.00E+01	24
Diethylamine							3.00E+02	8			7.14E+01	24	9.99E+01	24
Diethylaminoethanol							5.00E+02	8					1.67E+02	24
Diethylene triamine							4.00E+01	8					1.33E+01	24
Di(2-ethylhexly)phthalate					3.00E+01	24							1.67E+01	24
Diethyl ketone							7.05E+03	8					2.35E+03	24
Diethyl phthalate							5.00E+01	8					1.67E+01	24
Difluorodibromomethane							8.60E+03	8					2.86E+03	24
Diglycidyl ether							5.00E+00	8					1.70E+00	24
Diisobutyl ketone							2.50E+03	8					5.00E+02	24
Diisopropylamine							2.00E+02	8					6.66E+01	24
Dimethoxymethane											7.38E+03	24		
Dimethyl acetamide							2.50E+02	8					1.17E+02	24
Dimethylamine							1.80E+02	8			4.29E+01	24	5.99E+01	24
Dimethylaniline							2.50E+02	8					8.33E+01	24
Dimethyl carbamoyl chloride							1.00E+02	8						
Dimethylformamide							3.00E+02	8					9.99E+01	24
1,1-Dimethylhydrazine							1.00E+01	8					3.30E+00	24
Dimethylphthalate							5.00E+01	8			1.20E+02	1	1.67E+01	24
Dinitolmide							5.00E+01	8					1.67E+01	24
Dinitro-o-cresol							2.00E+00	8					7.00E-01	24
Dinitrobenzene							1.00E+01	8					3.30E+00	24
Dioxathion							2.00E+00	8					7.00E-01	24
1,2-Diphenylhydrazine													4.50E-03	1
Diproryl ketone							2.35E+03	8					7.83E+02	24
Dipropylene glycol methyl ether							6.00E+03	8			6.00E+03	8	2.00E+03	24
Di(2-eththyl)phthalate					3.00E+01	24								
Dimethyl sulfate					3.00E+00	1	5.00E+00	8			1.00E-02	1	1.60E+00	24
2,4-Dinitrotoluene	3.57E+01	8									1.10E-02	1		
2,6-Dinitrotoluene	3.57E+01	8												

APPENDIX A. INDIVIDUAL STATE AMBIENT AIR CONCENTRATION LIMITS FOR AIR TOXICS

Pollutant /State	LA		MD		NC		NM		RI		VT		WA	
	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time
Dioctyl phthalate									2.00E+02	24				
									5.00E-01	1				
1,4-Dioxin	2.14E+03	8			5.60E+02	1					1.00E-02	1	3.00E+02	24
Dioxane							9.00E+02	8			1.00E-02	1		
Diphenylamine									2.00E+02	1			3.33E+01	24
Diquat							5.00E+00	8					1.70E+00	24
Disulfiram							2.00E+01	8					6.70E+00	24
Disulfoton							1.00E+01	8					3.00E-01	24
2.6-Ditert butyl-p-cresol							1.00E+02	8					3.33E+01	24
Diuron							1.00E+02	8					3.33E+01	24
Divinyl benzene							5.00E+02	8					1.67E+02	24
Endosulfan													3.00E-01	24
Endrin													3.00E-01	24
Enflurane													1.91E+03	24
Epichlorohydrin	8.30E+01	1			8.30E+01	1	1.00E+02	8	2.00E+02	24	3.50E-01	1		
									8.00E-01	1				
Ethanolamine							8.00E+01	8			1.90E+02	1	2.66E+01	24
2-Ethoxyethanol							1.90E+02	8			4.52E+01	24	6.33E+01	24
2-Ethoxyethyl acetate							2.70E+02	8			6.43E+01	24	8.99E+01	24
Ethyl acetate							1.40E+04	8			1.40E+05	8	4.66E+03	24
Ethyl acrylate	4.76E+02	8					2.00E+02	8					6.66E+01	24
Ethylamine							1.80E+02	8			4.29E+01	8	5.99E+01	24
Ethyl amyl ketone							1.30E+03	8					4.33E+02	24
Ethyl Benzene	1.03E+04	8					4.35E+03	8			4.35E+04	8	1.45E+03	24
Ethyl bromide							8.90E+03	8			8.90E+03	8	2.96E+03	24
Ethyl butyl ketone							2.30E+03	8					7.66E+02	24
Ethyl chloride													8.66E+03	24
Ethyl ether							1.20E+04	8			1.20E+05	8	4.00E+03	24
Ethyl formate							3.00E+03	8					9.99E+02	24
Ethyl mercaptan							1.00E+01	8					3.30E+00	24
Ethyl silicate							8.50E+02	8					2.83E+02	24
Ethylene chlorohydrin							3.00E+01	8					1.00E+01	24
Ethylenediamine					3.00E+01	24	2.50E+02	8					8.33E+01	24
Ethylene dibromide					4.00E-01	1	2.00E-02	8			8.50E-05	1	4.50E-03	1
Ethylene dichloride					3.80E+00	1	4.00E+02	8	4.00E-02	1	3.80E-02	1		

APPENDIX A. INDIVIDUAL STATE AMBIENT AIR CONCENTRATION LIMITS FOR AIR TOXICS

Pollutant /State	LA		MD		NC		NM		RI		VT		WA	
	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time
Ethylene glygol	3.02E+03	8			1.20E+02	24	1.25E+03	8					4.16E+02	24
Ethylene glycol dinitrate							3.00E+00	8					1.00E+00	24
Ethyleneimine							1.00E+01	8					3.30E+00	24
Ethylene oxide	1.00E+00	1			2.70E-02	1	2.00E+01	8	1.00E-02	1	1.00E-02	1	1.00E-02	1
Ethylidene norbornene													8.33E+01	24
N-Ethylmorpholine							2.30E+02	8					7.66E+01	24
Fenamiphos							1.00E+00	8					3.00E-01	24
Fenthion							2.00E+00	8					7.00E-01	24
Ferbam							1.00E+02	8					3.33E+01	24
Ferrovanadium dust							1.00E+01	8					3.30E+00	24
Febrous glass dust							1.00E+02	8					3.33E+01	24
Fensulfothion							1.00E+00	8					3.00E-01	24
Fluoride					1.60E+01	24	2.50E+01	8			5.95E+01	1	8.30E+00	24
Fonofos							1.00E+00	8					3.00E-01	24
Florine							2.00E+00	8			2.00E+02	8	6.70E+00	24
Formamide							3.00E+02	8					5.00E+01	24
Formic acid							9.00E+01	8			9.00E+01	8	3.00E+01	24
Furfural							8.00E+01	8			8.00E+01	8	2.66E+01	24
Furfuryl alcohol							4.00E+02	8					1.33E+02	24
Formaldehyde	7.69E+00	1					1.50E+01	8			8.00E-02	1	7.70E-02	1
Germanium tetrahydride							6.00E+00	8					2.00E+00	24
Glutaraldehyde							7.00E+00	8					2.30E+00	24
Glycidol							7.50E+02	8					2.50E+02	24
Glycol ethers	5.71E+02													
Hafnium							5.00E+00	8					1.70E+00	24
Halothane													1.33E+03	24
Heptachlor							5.00E+00	8					7.70E-04	1
Heptane											1.60E+04	8	5.33E+03	24
Hexachloro-1,3-Butadiene	4.55E+00	1											8.00E-01	24
Hexachlorobenzene	2.00E-01	1									2.10E-03	1	2.00E-03	1
Hexachlorobutadiene							2.40E+00	8			4.50E-02	1	8.00E-01	24
Hexachlorocyclopentadiene					6.00E-01	24	1.00E+00	8					3.00E-01	24
Hexachlororethane	2.50E+01	1					1.00E+03	8			2.50E-01	1	2.50E-01	1
Hexachloronaphthalene							2.00E+00	8					7.00E-01	24
Hexafluoroacetone							7.00E+00	8					2.30E+00	24
Hexamethylene diisocyanate													1.00E-01	24

APPENDIX A. INDIVIDUAL STATE AMBIENT AIR CONCENTRATION LIMITS FOR AIR TOXICS

Pollutant /State	LA		MD		NC		NM		RI		VT		WA	
	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time
Hexamethylphosphoramide							4.00E-01	8						
2-Hexanone													6.66E+01	24
sec-Hexyl acetate							3.00E+03	8					9.99E+02	24
Hexylene glycol							2.50E+00	8					4.16E+02	24
Hydrazine	2.00E-02	1			6.00E-01	24	1.00E+00	8	3.00E-04	1				
Hydrochloric acid	1.80E+02	8												
Hydrogen bromide							1.00E+02	8					3.33E+01	24
Hydrogen chloride			7.00E+00	1			7.00E+01	8	6.00E+02	24	1.67E+01	24	2.33E+01	24
Hydrogen cyanide	2.60E+02				1.40E+02	24	1.00E+02	8					3.33E+01	24
Hydrogen floride	6.19E+01				3.00E+01	24	2.50E+01	8			5.95E+01	24	8.30E+00	24
Hydrogen peroxide							1.50E+01	8			1.50E+01	8	5.00E+00	24
ZHydrogen selenide							2.00E+00	8					7.00E-01	24
Hydrogen sulfide	3.30E+02	8									3.33E+01	24	4.66E+01	24
Hydroquinone							2.00E+01	8					6.70E+00	24
2-Hydroxypropyl acrylate							3.00E+01	8					1.00E+01	24
Indene							4.50E+02	8					1.80E+02	24
Indium (and compound)							1.00E+00	8					3.00E-01	24
Iodine							1.00E+01	8			1.00E+02	8	3.30E+00	24
Iodoform							1.00E+02	8					3.33E+01	24
Iron oxide fumes							5.00E+01	8					1.67E+01	24
Iron pentacarbonyl							8.00E+00	8					2.70E+00	24
Iron salts							1.00E+01	8					3.30E+00	24
Isoamyl acetate							5.25E+03	8			5.25E+03	8	1.75E+03	24
Isoamyl alcohol							3.60E+03	8			3.60E+03	8	1.20E+03	24
Isobutyl acetate							7.00E+03	8			7.00E+03	8	2.33E+03	24
Isobutyl alcohol							1.50E+03	8			1.50E+03	8	5.00E+02	24
Isocytl alcohol							2.70E+03	8					8.99E+02	24
Isophorone							2.50E+02	8					8.33E+01	24
Isophorone diisocyanate							9.00E-01	8					1.00E-01	24
Isopropoxyethanol							1.05E+03	8					3.50E+02	24
Isopropyl acetate							9.50E+03	8			9.50E+03	8	3.16E+03	24
Isopropyl alcohol							9.80E+03	8			9.80E+04	8	3.26E+03	24
Isopropylamine							1.20E+02	8			1.20E+02	8	4.00E+01	24
Isopropy ether							1.05E+04	8			1.05E+04	8	3.50E+03	24
Isopropyl glycidyl ether							2.40E+03	8					7.99E+02	24
N-Isopropylaniline							1.00E+02	8					3.33E+01	24
Ketene							9.00E+00	8					3.00E+00	24
Lead (and inorganic compounds)											1.50E+00	1		

APPENDIX A. INDIVIDUAL STATE AMBIENT AIR CONCENTRATION LIMITS FOR AIR TOXICS

Pollutant /State	LA		MD		NC		NM		RI		VT		WA	
	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time
Lead arsenate													6.00E-01	24
Lead chromate							5.00E-01	8					2.00E-01	24
Liquified petroleum gas													5.99E+03	24
Lindane							5.00E+00	8					1.60E+00	24
Lithium chromate					8.eE-5	1								
Lithium hydride							2.50E-01	8					1.00E-01	24
Maleic anhydride	2.38E+01	8			1.20E+01	24	1.00E+01	8					3.30E+00	24
Manganese (and compounds)	2.76E+01	8			3.10E+01	24	5.00E+01	8			1.19E+02	1	1.67E+01	24
Manganese cyclopentadienyltricarbonyl					6.00E-01	24	1.00E+00	8					3.00E-01	24
Manganese tetroxide					6.20E+00	24	1.00E+00	8						
Mercury (and Compounds)	1.19E+00										1.20E-01	1	3.00E-01	24
Mercure, allkyl					6.00E-02	24							3.00E-02	24
Mercure, aryl and inorganics					6.00E-01	24							3.00E-01	24
mercure vapor					6.00E-01	24							2.00E-01	24
Mesityl oxide							6.00E+02	8					2.00E+02	24
Methacrylic acid							7.00E+02	8					2.33E+02	24
Methnol	6.24E+03	8												
Methomyl							2.50E+02	8					8.30E+00	24
Methoxychlor							1.00E+02	8					3.33E+01	24
Methoxyethanol							1.60E+02	8			3.81E+02	1	5.33E+01	24
2-Methoxyethylacetate							2.40E+02	8					7.99E+01	24
4-Methoxyphenol							5.00E+01	8					1.67E+01	24
Methyl 2-cyanoacrylate							8.00E+01	8					2.66E+01	24
Methyl acetate							6.10E+03	8			1.45E+03	24	2.03E+03	24
Methyl acetylene													5.49E+03	24
Methyl acetylene-propadiene													5.99E+03	24
Methyl acrylate							3.50E+02	8					1.17E+02	24
Methyl alcohol							2.60E+03	8			6.19E+03	24	8.66E+02	24
Methylamine							1.20E+02	8			1.20E+02	8		
N- Methyl aniline							2.00E+01	8					6.70E+00	24
Methyl bromide							2.00E+02	8			1.00E-02	1	6.66E+01	24
Methyl cellosolve									1.00E+02	24				24
Methyl chloride							1.05E+03	8			1.00E-02	1	3.50E+02	24
Methyl chloroform					1.20E+04	24							6.33E+03	24
Methylcyclohexanol							2.35E+03	8			5.60E+02	24		
Methyl demeton													1.70E+00	24

APPENDIX A. INDIVIDUAL STATE AMBIENT AIR CONCENTRATION LIMITS FOR AIR TOXICS

Pollutant /State	LA		MD		NC		NM		RI		VT		WA	
	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time
Methyl ethyl ketone	1.40E+04	8			3.70E+03	24	5.90E+03	8			5.90E+03	8	1.96E+03	24
Methyl ethyl ketone proxide							1.50E+01	8			1.50E+01	8	5.00E+00	24
Methyl formate							2.50E+03	8					8.33E+02	24
Methyl hydrazine							3.50E+00	8					1.20E+00	24
Methyl iodine														
Methyl isoamyl ketone							2.40E+03	8					7.99E+02	24
Methyl isobutyl carbinol							1.00E+03	8					3.33E+02	24
Methyl isobutyl ketone	4.88E+03	8			2.56E+03	24	2.05E+03	8					6.83E+02	24
Methyl iodide							1.00E+02	8			1.00E-02	1	3.33E+01	24
Methyl isocyanate							5.00E-01	8					2.00E-01	24
Methyl isopropyl ketone							7.05E+03	8					2.35E+03	24
Methyl mercaptan							1.00E+01	8					3.30E+00	24
Methyl methacroylate	9.76E+03	8					4.10E+03	8			4.10E+04	8	1.37E+03	24
Methyl n-amyl ketone							2.35E+03	8					7.83E+02	24
Methyl n-butyl ketone													6.66E+01	24
1-Methyl-2-pyrrolidone											9.60E+02	24		
Methyl parathion							2.00E+00	8					7.00E-01	24
Methyl propyl ketone							7.00E+03	8					2.33E+03	24
Methyl silicate							6.00E+01	8					2.00E+01	24
a-Methyl styrene							2.40E+03	8					7.99E+02	24
Methylacrylonitrile													1.00E+01	24
Methylal													1.03E+04	24
Methylamine													4.00E+01	24
Methylcyclohexane													5.33E+03	24
Methylcyclohexanol													7.83E+02	24
o-Methylcyclohexanone							2.30E+03	8					7.66E+02	24
Methylcyclopentadienyl manganese tricarbonyl							2.00E+00	8					7.00E-01	24
Methylene bis(4-cyclo-hexylisocyanate)							1.00E+00	8					2.00E-01	24
Methylene bisphenyl isocyanate							2.00E+00	8	2.00E-01	24	4.80E-01	24	2.00E-01	24
4,4-Methylene bis(2-chloroaniline)							2.20E+00	8	1.00E+00	24			7.00E-01	24
Methylene chloride					2.40E+01	1	3.50E+03	8	2.00E-01	1	2.50E-01	1		
Methylenedianiline							8.00E+00	8					2.60E+00	24
Metrubuzin							5.00E+01	8					1.67E+01	24
Mevinphos							1.00E+00	8					3.00E-01	24
Molybdenum (as Mo soluble coumpounds)							5.00E+01	8					1.67E+01	24
Molybdenum (as insoluble compounds)							1.00E+02	8					3.33E+01	24

APPENDIX A. INDIVIDUAL STATE AMBIENT AIR CONCENTRATION LIMITS FOR AIR TOXICS

Pollutant /State	LA		MD		NC		NM		RI		VT		WA	
	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time
Monocrotophos							2.50E+00	8					8.00E-01	24
Morpholine							7.00E+02	8					2.33E+02	24
N-Butyl alcohol	3.62E+03	8												
N-Hexane	4.19E+03	8			1.10E+03	24	1.80E+03	8			4.29E+03	24	5.99E+02	24
N-nitrosodimethylamine					5.00E-02	1								
Naled							3.00E+01	8					1.00E+01	24
Naphthalene							5.00E+02	8			1.20E+02	1	1.67E+02	24
Nickel (and compounds)	2.10E-01	1			6.00E-01	24	1.00E+01	8	2.00E-03	1	3.30E-03	1	3.30E+00	24
Nickel (refinery dust)	4.20E-01	1												
Nickel carbonyl							3.50E+00	8			1.00E-02	1		
Nickel subsulfide					2.10E-03	1	1.00E+01	8						
Nicotine							5.00E+00	8					1.70E+00	24
Nitrapyrin							1.00E+02	8					3.33E+01	24
Nitric acid	1.20E+02	8					5.00E+01	8			5.00E+02	8	1.67E+01	24
Nitric oxide											7.14E+01	24	9.99E+01	24
p-Mitroaniline							3.00E+01	8					1.00E+01	24
5-Nitro(o-anisidine)									8.00E-02	1				
Nitrobenzene	1.19E+02	8			6.00E+01	24	5.00E+01	8			1.19E+02	24	1.67E+01	24
p-Nitrochlorobenzene							3.00E+01	8			7.14E+01	24	2.00E+00	24
4-Nitrodephenyl							1.90E+02	8						
Nitroethane							3.10E+03	8			7.38E+02	24	1.03E+03	24
Nitrogen trifluoride							3.00E+03	8					9.99E+01	24
Nitroglycerin							5.00E+00	8					1.70E+00	24
Nitromethane							2.50E+03	8			2.50E+03	8	8.33E+02	24
1-Nitropropane							9.00E+02	8			9.00E+02	8	3.00E+02	24
2-Nitropropane	2.00E+01	1							2.00E-01	1	1.00E-02	1	1.17E+02	24
Nitrotoulene							1.10E+02	8			2.62E+02	24	3.66E+01	24
Nonane							1.05E+04	8					3.50E+03	24
Octachloronapthalene											2.40E-01	1	3.00E-01	24
Octane							1.45E+04	8					4.83E+03	24
Oil mist							5.00E+01	8					1.67E+01	24
Osmium tetroxide							2.00E-02	8					7.00E-03	24
Oxalic acid							1.00E+01	8			1.00E+02	8	3.30E+00	24
Oxygen difluoride							1.00E+00	8					3.00E-01	24
Parafin wax fumes							2.00E+01	8					6.70E+00	24
Paraquat							1.00E+00	8					3.00E-01	24
Parathion							1.00E+00	8					3.00E-01	24

APPENDIX A. INDIVIDUAL STATE AMBIENT AIR CONCENTRATION LIMITS FOR AIR TOXICS

Pollutant /State	LA		MD		NC		NM		RI		VT		WA	
	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time
Pentaborane							1.00E-01	8					0.00E+00	24
Pentchloronapthalene							5.00E+00	8			1.19E+00	1	1.70E+00	24
Pentane													5.99E+03	24
Perchloromethyl mercaptan							8.00E+00	8					2.70E+00	24
Perchloryl fluoride							1.40E+02	8					4.66E+01	24
Pentachlorophenol					3.00E+00	24	5.00E+00	8			1.19E+00	1	1.70E+00	24
Perchloroethylene					1.90E+02	1	3.35E+03	8	5.00E-02	1			1.10E+00	1
Phenathrene											1.30E+00	1		
Phenol	4.52E+02	8					1.90E+02	8			1.90E+03	8	6.33E+01	24
Phenithiazine							5.00E+01	8					1.67E+01	24
Phenyl ether							7.00E+01	8			7.20E+02	8	2.33E+01	24
Phenyl glycidyl ether							6.00E+01	8					2.00E+01	24
Phenyl mercaptan							2.00E+01	8					6.70E+00	24
p-Phenylene diamine							1.00E+00	8					3.00E-01	24
Phenylphosphine							2.50E+00	8					8.00E-01	24
Phorate							5.00E-01	8					2.00E-01	24
Phenylhydrazine							2.00E+02	8					6.66E+01	24
Phosgene	9.50E+00	8			2.50E+00	24	4.00E+00	8			4.00E+01	8	1.30E+00	24
Phosphine							4.00E+00	8			4.00E+01	8	1.30E+00	24
Phosphoric acid							1.00E+01	8			1.00E+02	8	3.30E+00	24
Phosphorus							1.00E+00	8					3.00E-01	24
Phosphorus oxychloride							6.00E+00	8					2.00E+00	24
Phosphorus pentachloride							1.00E+01	8			1.00E+01	8	3.30E+00	24
Phosphorus pentasulfide							1.00E+01	8			1.00E+01	8	3.30E+00	24
Phosphorus trichloride							1.50E+01	8			1.50E+01	8		
Phthalic anhydride	1.45E+02	8					6.00E+01	8			6.00E+02	8	2.00E+01	24
m-Phthalodinitrile							5.00E+01	8					1.67E+01	24
Picloram							1.00E+02	8					3.33E+01	24
Picric acid							1.00E+00	8			2.40E-01	24	3.00E-01	24
Pindone							1.00E+00	8					3.00E-01	24
Piperazine dihydrochloride							5.00E+01	8					1.67E+01	24
Plattium							1.00E+01	8			5.00E-03	24	3.30E+00	24
Polychlorinated biphenyls					8.30E-02	1					8.10E-04	1		
Polynuclear aromatic hydrocarbons	6.00E-02	1											6.00E-04	1
Potassium chromate					8.30E-05	1								
Potassium dichromate					8.30E-05	1								

APPENDIX A. INDIVIDUAL STATE AMBIENT AIR CONCENTRATION LIMITS FOR AIR TOXICS

Pollutant /State	LA		MD		NC		NM		RI		VT		WA	
	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time
Potassium hydroxide							2.00E+01	8			2.00E+01	8	6.70E+00	24
Propane sultone							4.00E+01	8						
Propargy alcohol							2.00E+01	8					6.70E+00	24
B-Propiolactone													5.00E+00	24
Propionaldehyde	4.29E+03	8												
Propoxur							5.00E+00	8					1.70E+00	24
Proprionic acid							3.00E+02	8					9.99E+01	24
n-Propyl acetate							8.40E+03	8					2.80E+03	24
n-Propyl alcohol							5.00E+03	8			5.00E+04	8	1.67E+03	24
n-Propyl nitrate													3.50E+02	24
Propylene dichloride							3.50E+03	8			1.00E-02	1	1.17E+03	24
Propylene glycol dinitrate							3.00E+00	8					1.00E+00	24
Propylene glycol mon-methyl ether							3.60E+03	8					1.15E+03	24
Propylene imine							5.00E+00	8			1.00E-02	1	1.67E+01	24
Propylene oxide	2.70E+01	1					5.00E+02	8			1.00E-02	1		
Pyrene											3.40E+00	1		
Pyrethrum							5.00E+01	8					1.67E+01	24
Pyridine	3.81E+02	8					1.50E+02	8			3.57E+02	1	5.00E+01	24
Quinone							4.00E+00	8					1.30E+00	24
Resorcinol							4.50E+02	8					1.50E+02	24
Rhodium metal							1.00E+01	8					3.30E+00	24
Rhodium (insoluble compounds)							1.00E+01	8					3.30E+00	24
Rhodium (soluble compounds)							1.00E+00	8					3.00E-02	24
Ronnel							1.00E+02	8					3.33E+01	24
Rotenone							5.00E+01	8					1.67E+01	24
Rubber solvent (Naptha)													5.33E+03	24
Selenium (and compounds)	4.76E+00	8					2.00E+00	8			4.80E+00	1	7.00E-01	24
Selenium hexafluoride							2.00E+00	8					7.00E-01	24
Sesone							1.00E+02	8					3.33E+01	24
Silica, amorphous											2.40E+02	1		24
Silica, cyrstalline											1.12E+02	1		24
Silica, fused											2.40E-01	1		24
Sodium chromate					8.30E-05	1								
Sodium hydroxide														
Silicon tetrahydride							7.00E+01	8			1.67E+01	1	2.33E+01	24
Silver (total)											2.40E-01	1		
Silver metal							1.00E+00	8					3.00E-01	24

APPENDIX A. INDIVIDUAL STATE AMBIENT AIR CONCENTRATION LIMITS FOR AIR TOXICS

Pollutant /State	LA		MD		NC		NM		RI		VT		WA	
	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time
Silver (soluble compounds)							1.00E-01	8					3.00E-02	24
Sodium azide							3.00E+00	8					1.00E+00	24
Sodium bidulfite							5.00E+01	8					1.67E+01	24
Sodium dichromate					8.30E-05	1								
Sodium fluoriacetate													2.00E-01	24
Sodium hydroxide											2.00E+01	8	6.70E+00	24
Sodium metbisulfite							5.00E+01	8					1.67E+01	24
Stibine							5.00E+00	8					1.70E+00	24
Stoddard solvent							5.25E+03	8			1.25E+04	1		
Stronium chromate					8.30E-05	1								
Strychnine							1.50E+00	8					5.00E-01	24
Styrene	5.07E+03	8			1.34E+03	24	2.15E+03	8	3.00E+01	1	5.12E+02	1	7.16E+02	24
Subtilisins							6.00E-04	8					0.00E+00	24
Sulfotep							2.00E+00	8					7.00E-01	24
Sulfur hexafluoride													2.00E+04	24
Sulfur pentafluoride							1.00E+00	8					3.00E-01	24
Sulfur tetrafluoride							4.00E+00	8					1.30E+00	24
Sulfuric acid	2.38E+01	8			1.20E+01	24					2.38E+01	24	3.30E+00	24
Sulfur monochloride							6.00E+01	8			6.00E+02	8	2.00E+01	24
Sulfuryl fluoride							2.00E+02	8					6.66E+01	24
Sulprofos							1.00E+01	8					3.30E+00	24
Tantalum (metal and oxide dust)							5.00E+01	8					1.67E+01	24
Tellurium							1.00E+00	8			2.40E+00	1	3.00E-01	24
Tellerium hexafluoride							2.00E+00	8					7.00E-01	24
Temephos							1.00E+02	8					3.33E+01	24
Terphenyls							5.00E+01	8					1.67E+01	24
Tetrachlorodibenzo-p-dioxin					3.00E-06	1								
1,1,1 or 2,2-Tetrachloro-2,2-difluoroethane					5.20E+04	24					9.93E+03	24	1.39E+04	24
1,1,2,2-Tetrachloroethane	1.70E+00	1			6.30E+01	1	7.00E+01	8			1.70E-02	1	2.33E+01	24
Tetrachlororethylene	1.05E+02	1									4.10E-01	1		
Tetrachloronapthalene							2.00E+01	8			4.80E+00	1	6.70E+00	24
Tetraethyl lead													3.00E-01	24
Tetrahydofuran							5.90E+03	8			1.41E+04	24	1.96E+03	24
Tetramethyl lead													5.00E-01	24
Tetramethyl sucinonitrile							3.00E+02	8					1.00E+01	24
Tetranitromethane							8.00E+01	8					2.66E+01	24

APPENDIX A. INDIVIDUAL STATE AMBIENT AIR CONCENTRATION LIMITS FOR AIR TOXICS

Pollutant /State	LA		MD		NC		NM		RI		VT		WA	
	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time
Tetrasodium pyrophosphate							5.00E+01	8					1.67E+01	24
Tetryl							1.50E+01	8					5.00E+00	24
Thallium (soluble compound)							1.00E+00	8					3.00E-01	24
4,4-Thiobib(6-tert,butyl-m-cresol)							1.00E+02	8					3.33E+01	24
Thioglycolic acid							4.00E+01	8					1.33E+01	24
Thionyl chloride							5.00E+01	8					1.67E+01	24
Tin metal							2.00E+01	8					6.70E+00	24
Tin (organic compounds)							1.00E+00	8					3.00E-01	24
Tin (inorganic and oxide)							2.00E+01	8					6.70E+00	24
Toluene	8.90E+03	8			4.70E+03	24	3.75E+03	8	2.00E+03	24	8.93E+03	24	1.25E+03	24
Toluene-2,4-Diisocyanate	8.60E-01	8			5.00E-01	24	4.00E-01	8	2.00E-01	24	1.00E-01	24	1.00E+00	24
Toluene-2,6-Diisocyanate	8.60E-01	8												
0-Toluidine							1.10E+01	8	4.00E-02	1	1.00E-02	1	3.00E+01	24
m-Toluidine							9.00E+01	8					3.00E+01	24
p-Toluidine													3.00E+01	24
Toxaphene													3.00E-03	24
Tributyl phosphate							2.50E+01	8					8.30E+00	24
Trichloroacetic acid							7.00E+01	8					2.33E+01	24
1,2,4-Trichlorobenzene							4.00E+02	8					1.33E+02	24
1,1,2-Trichloroethane	6.25E+00	1					4.50E+02	8	7.00E+00	1	6.10E-02	1	1.50E+02	24
1,1,1-Trichloroethane	4.55E+03	8									1.90E+05	8	6.33E+03	24
Trichloroethylene	5.88E+01	1					2.70E+03	8	3.00E-01	1	4.20E-01	1	8.00E-01	1
Trichlorofluoromethane													1.86E+04	24
Trichloronaphthlene							5.00E+01	8			1.19E+01	1	1.67E+01	24
2,4,6-Trichlorophenol											1.80E-01	1	1.80E-01	1
1,2,3-Trichloropropane							3.00E+03	8			1.43E+01	24	2.00E+02	24
1,1,2-Trichloro1,2,2-trifluoroethane											1.81E+05	24	2.53E+04	24
Triethylamine							4.00E+02	8	3.00E+02	24			1.33E+02	24
Trifluorobromomethane											1.45E+04	1	2.03E+04	24
Trimellitic anhydride							4.00E-01	8					1.00E-01	24
Trimethyl benzene							1.25E+03	8					4.16E+02	24
Trimethyl phosphite							1.00E+02	8					3.33E+01	24
Trimethylamine							2.40E+02	8					7.99E+01	24
2,4,6-Trinitrotoluene							5.00E+00	8					1.70E+00	24
Triorthocresyl phosphate							1.00E+00	8			2.40E-01	24	3.00E-01	24
Triphenyl amine							5.00E+01	8					1.67E+01	24

APPENDIX A. INDIVIDUAL STATE AMBIENT AIR CONCENTRATION LIMITS FOR AIR TOXICS

Pollutant /State	LA		MD		NC		NM		RI		VT		WA	
	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time	Limit	Time
Triphenyl phosphate							3.00E+01	8					1.00E+01	24
Tungsten (insoluble compounds)							5.00E+01	8					1.67E+01	24
Tungsten (soluble compounds)							1.00E+01	8					3.30E+00	24
Turpentine							5.60E+03	8					1.86E+03	24
Uranium (insoluble and soluble)							2.00E+00	8					7.00E-01	24
VN&P Naptha							3.50E+00	8			3.21E+03	24	4.50E+03	24
n-Valeraldehyde							1.75E+03	8					5.83E+02	24
Vanadium as V2O5													2.00E-01	24
Vinyl acetate	8.30E+02	8					3.00E+02	8					9.99E+01	24
Vinyl bromide													6.66E+01	24
Vinyl cyclohexene dioxide													2.00E+02	24
Vinyl chloride	1.19E+00	1			3.80E-01	1					2.00E-01	1	2.30E-02	1
Vinyl toluene											5.71E+03	24	7.99E+02	24
Vinylidene chloride	2.00E+00	1			1.20E+02	24	2.40E+03	8					6.66E+01	24
Warfarin							2.00E+02	8					3.00E-01	24
Welding fumes													1.67E+01	24
m-Xylene a,a-diamine							1.00E+00	8					3.00E-01	24
Xylene (Mixed isomers)	1.03E+04	8			2.70E+03	24	4.35E+04	8	7.00E+02	24	1.04E+03	1	1.45E+03	24
Xylidine													3.33E+01	24
Yttrium (metals and coumpounds)													3.30E+00	24
Zinc (and compounds)	1.19E+02	8									1.20E+01	24		
Zinc chloride											2.40E+00	24	3.30E+00	24
Zinc chromates													3.00E-02	24
Zinc oxide fumes													1.67E+01	24
Zirconium compounds													1.67E+01	24

All values are based on those cited in the actual state regulations as supplied by the Bureau of National Affairs
All values are in ug/m3 unless otherwise specified
Both values given for asbestos are in fibers/ml

8 = The limit is based on an eight hour average concentration
24 = The limit is based on a twenty-four hours average concentration
1 = The limit is based on a annual average concnetration

APPENDIX B - AIR TOXIC PROPERTY AND EMISSION TABLE

APPENDIX B. EMISSIONS EVALUATION TABLE FOR ABB'S 350 MWe LOW EMISSION BOILER (Stack Height 400 ft in Urban Area).

Substance	Dayton Ranking (1) (P)	Boiling Point (2,3,4,5)	Water Soluble (2,3,4,5)	Chemical Structure (2,3,4,5)	Primary Sources (5,6)	Emission Rate Pulverized Bituminous Coal (lb/hr)				Other Coal Fired Systems (lb/hr)	Mass Balance (lb/hr) (12,13,14,15)	Hazardous Waste Incinerator (16) (lb/hr)	Regulatory Limit (lb/hr) (16,17,18)		Uncontrolled Category	Estimated Removal Efficiency (b) (%)
						Uncontrolled	Controlled: ESP	WS	WS/ESP				Max	Min		
Acetaldehyde		20.8	Y	CH3CHO	Motor Vehicles						HC 3.54E+00	NA	S 1.99E+05	S 2.08E+01	4	NCN
Acetamide		221.2	Y	CH3CONH2							HC 3.54E+00	NA	O 2.31E+00	S 2.28E-03	2	99.3594
Acetonitrile	1	81.6	Y	CH3CN							HC 3.54E+00	3.46E-04	S 3.24E+05	O 4.63E+02	3	NCN
Acetophenone	3	202.6	N	C6H5COCH3							HC 6.17E-01	NA	O 4.63E+00	O 4.63E+03	3	NCN
2-Acetylaminofluorene	2										NA	NA	NA	NA	NA	NA
Acrolein	4	52.5	Y	CH2=CHCHO	Chemical Production, Combustion Product						HC 3.54E+00	NA	S 2.30E+02	O 9.26E-01	3	83.3537
Acrylamide	2	125	Y	H2C=CHCONH2							HC 3.54E+00	NA	S 1.39E+02	O 3.54E-02	2	99.3594
Acrylic acid		141.6	Y	CH2=CHCO2H							HC 3.54E+00	NA	S 1.39E+04	S 4.63E+03	3	NCN
Acrylonitrile	1	77.3	N	CH2=CHCN	Feedstock, Resins, Rubber						HC 3.54E+00	NA	S 2.08E+00	O 1.60E-01	3	97.1299
Allyl chloride		45	N	ClCH2CH=CH2	Chemical Production						Cl 3.23E-01	NA	S 3.31E+00	S 1.34E+01	4	NCN
4-Aminobiphenyl	2	191		C6H5C6H4NH2							HC 6.17E-01	NA	S 4.63E+02	S 4.63E+02	3	NCN
Aniline	2	184	N	C6H5NH2							HC 3.54E+00	NA	S 8.30E+03	S 4.63E-01	3	91.6768
o-Anisidine		224	N	2-(CH3O)C6H4NH2							HC 6.17E-01	NA	S 2.31E+02	S 4.63E+01	3	NCN
Asbestos				[Mg6(Si4O10)(OH)8]	Milling, Mining						NA	NA	O 2.44E-01	S 1.30E-09	3	NA
Benzene	1	80.1	N	C6H6	Gasoline, Combustion Product					0.24 (7)	HC 3.54E+00	1.03E+01	O 3.29E+03	S 3.58E-02	2	78.8519
Benzidine	3	400	N	2-H2NC6H4-C6H4NH2-2							HC 6.17E-01	NA	O 4.63E+02	O 3.31E-04	2	99.9464
Benzotrichloride	4	220.6	N	C6H5CCl3							Cl 2.75E-01	NA	S 3.24E-02	S 3.24E-02	3	88.2191
Benzyl chloride	4	179.3	N	C6H5CH2Cl	Chemical Intermediate						Cl 3.34E-01	NA	S 2.31E+03	S 4.63E-01	3	13.3330
Biphenyl		255.9	N	C6H5-C6H5			0.0026 (8)	0.0001 (8)			HC 6.17E-01	NA	S 1.44E+03	S 4.63E-01	3	25.0082
Bis(2-ethylhexyl)phthalate (DEHP)	6	384	N	C6H4-1,2-[CO2CH2CH(C2H5)(CH2)3CH3]2	Plasticizer, Resins						HC 6.17E-01	1.63E-01	O 3.24E+03	O 1.93E+02	3	NCN
Bis(chloromethyl)ether	3	104	N	ClCH2OCH2Cl							Cl 2.29E-01	NA	S 2.31E+00	S 7.41E-04	3	99.6780
Bromoform	3	150-151		CHBr3							Br 2.69E-04	NA	S 2.31E+03	S 4.63E-01	3	NCN
1,3-Butadiene		-4.4	N	CH2=CH-CH=CH2	Chemical Feedstock, Resin Production						HC 3.54E+00	NA	S 3.39E+03	S 8.08E-02	2	98.3518
Calcium cyanamide				CaCN2							HC 3.54E+00	NA	S 2.31E+02	S 7.87E+01	4	NCN
Caprolactam		139	Y	CH2(CH2)4CO							HC 3.54E+00	NA	S 9.26E+03	S 3.08E+03	3	NCN
Captan			N	C9H8Cl3-NO2S	Fungicide						Cl 4.23E-01	NA	S 2.31E+03	S 7.73E+02	3	NCN
Carbaryl			N	C12H11NO2	Pesticide						HC 6.17E-01	NA	S 2.31E+03	S 7.73E+02	3	NCN
Carbon disulfide		46.2	N	CS2							HC 3.54E+00	NA	S 3.31E+04	S 3.98E+03	3	NCN
Carbon tetrachloride	4	76.7	N	CCl4	Grain Fumigant						Cl 1.62E-01	2.09E-01	O 8.80E+00	O 1.10E+00	4	NCN
Carbonyl sulfide		-50	N	COS							HC 3.54E+00	NA	S 1.13E+03	S 1.13E+03	3	NCN
Catechol		245	Y	2-HOC6H4OH							HC 3.54E+00	NA	S 9.26E+03	S 3.08E+03	3	NCN
Chloramben			N	C7H5Cl2NO2	Herbicide						Cl 4.35E-01	NA	NA	NA	NA	NA
Chlordane	3		N	C10H6Cl8	Pesticide						Cl 2.16E-01	NA	S 2.31E+02	S 1.25E-01	3	42.2081
Chlorine		-34.6	N	Cl2						240 (9)	NA	NA	S 1.74E+03	O 1.85E+01	2	92.2840
Chloroacetic acid		187.8	Y	ClCH2CO2H							Cl 3.99E-01	NA	NA	NA	NA	NA
2-Chloroacetophenone				ClC6H4COCH3							HC 6.17E-01	NA	S 1.39E+02	S 4.63E+01	3	NCN
Chlorobenzene	1	132.2	N	ClC6H5	Solvent, Pesticide Production						Cl 4.75E-01	NA	S 1.62E+05	O 3.24E+03	3	NCN
Chlorobenzilate	3		N	C16H14Cl2O3	Pesticide						HC 6.17E-01	NA	NA	NA	NA	NA

APPENDIX B. EMISSIONS EVALUATION TABLE FOR ABB'S 350 MWe LOW EMISSION BOILER (Stack Height 400 ft in Urban Area).

Substance	Dayton Ranking (1) (P)	Boiling Point (2,3,4,5)	Water Soluble (2,3,4,5)	Chemical Structure (2,3,4,5)	Primary Sources (5,6)	Emission Rate Pulverized Bituminous Coal (lb/hr)				Other Coal Fired Systems (lb/hr)	Mass Balance (lb/hr) (12,13,14,15)	Hazardous Waste Incinerator (16) (lb/hr)	Regulatory Limit (lb/hr) (16,17,18)		Uncontrolled Category	Estimated Removal Efficiency (%) (%)
						Uncontrolled	Controlled									
							ESP	WS	WS/ESP				Max	Min		
Chloroform		60.5-61.5	N	CHCl3	Solvent, Chemical Intermediate						Cl 1.08E-01	2.95E+00	S 2.31E+04	S 1.85E+00	4	NCN
Chloromethyl methyl ether	3	55-57		ClCH2OCH3							Cl 3.40E-01	NA	S 4.63E+03	O 1.71E-02	3	94.9547
Chloroprene		59.4	N	CH2=CCl-CH=CH2	Rubber Manuf.						Cl 3.74E-01	NA	S 3.97E+04	S 4.63E-01	3	NCN
Cresols/Cresylic acid	3		N	C7H8O	Resin Production						HC 6.17E-01	NA	S 1.28E+04	S 3.39E+03	3	NCN
o-Cresol	3	191	N	2-CH3C6H4OH	Disinfectant, Motor Vehicles						HC 6.17E-01	NA	S 1.28E+04	S 3.39E+03	3	NCN
m-Cresol	3	202.2	N	3-CH3C6H4OH	Same						HC 6.17E-01	NA	S 1.28E+04	S 3.39E+03	3	NCN
p-Cresol	3	201.9	N	4-CH3C6H4OH	Same						HC 6.17E-01	NA	S 1.28E+04	S 3.39E+03	3	NCN
Cumene		152.4	N	(CH3)2CHC6H5							HC 6.17E-01	NA	S 2.71E+05	S 2.70E+04	3	NCN
2,4-D, salts and esters		160	N	C8H6Cl2O3	Herbicide, Lawn Production						Cl 4.67E-01	NA	S 4.63E+03	S 1.33E+03	3	NCN
DDE (1,1-Dichloro-2,2-Bis (4-Chlorophenyl)ethylene)	2			(ClC6H4)2C=CCl2							Cl 3.34E-01	NA	NA	NA	NA	NA
Diazomethane		-23		CH2=N2							HC 3.34E+00	NA	S 1.85E+02	S 4.63E-01	3	91.6768
Dibenzofurans		287	N	C12H8O	Combustion Product						HC 6.17E-01	NA	NA	NA	NA	NA
1,2-Dibromo-3-chloropropane	5			Br2C3H5Cl							Br 3.77E-04	NA	O 9.26E+00	O 7.35E-03	4	NCN
Dibutylphthalate		340		C6H4-1,2-[CO2(CH2)3CH3]2							HC 6.17E-01	NA	S 2.31E+04	S 7.73E+02	3	NCN
1,4-Dichlorobenzene(p)	1	173	N	C6H4Cl2	Room Deodorant, Moth Repellent, Combustion Product						Cl 3.10E-01	1.82E-01	S 4.95E+05	O 4.21E+00	4	NCN
3,3-Dichlorobenzidene	3		N	C12H10Cl2N2	Azo Dyes Manuf.						Cl 3.34E-01	NA	S 1.85E+00	S 9.26E-02	2	82.6666
Dichloroethyl ether (Bis (2-chloroethyl) ether)	4	178	N	(ClCH2CH2)2O							Cl 3.02E-01	NA	S 1.39E+04	S 1.44E-01	3	52.4520
1,3-Dichloropropene	4	105-108		ClCH2CH=CHCl							Cl 2.34E-01	NA	S 4.95E+03	O 1.60E+00	4	NCN
Dichlorvos		140	N	C4H7Cl2O4P	Pesticide						Cl 4.67E-01	NA	S 4.63E+02	S 1.33E+02	3	NCN
Diethanolamine		217	Y	(HOCH2CH2)2NH							HC 3.34E+00	NA	S 6.94E+03	S 2.31E+03	3	NCN
N,N-Diethylaniline (N,N-Dimethylaniline)		193-194		C6H5N(CH3)2							HC 6.17E-01	NA	S 1.16E+04	S 3.88E+03	3	NCN
Diethyl sulfate		208		(C2H5O)2SO2							HC 3.34E+00	NA	NA	NA	NA	NA
3,3-Dimethoxybenzidine	3			[C6H3(OCH3)NH2]2							HC 6.17E-01	NA	NA	NA	NA	NA
Dimethyl aminoazobenzene	3		N	C6H5N=NC6H4N(CH3)2							HC 6.17E-01	NA	O 3.56E-02	O 3.56E-02	3	94.2314
3,3'-Dimethyl benzidine	3			[C6H3(CH3)-4-NH2]2 2HCl							Cl 6.10E-01	NA	NA	NA	NA	NA
Dimethyl carbamoyl chloride	4	167-168		(CH3)2NCOCl							Cl 4.54E-01	NA	S 4.63E+03	S 4.63E+03	3	NCN
Dimethyl formamide		153		HCON(CH3)2							HC 3.34E+00	NA	S 1.39E+04	S 4.63E+03	3	NCN
1,1-Dimethyl hydrazine		63-64	Y	(CH3)2NNH2							HC 3.34E+00	NA	S 4.63E+02	O 9.45E-02	2	98.3014
Dimethyl phthalate		282		C6H4-1,2-(CO2CH3)2							HC 6.17E-01	NA	S 5.56E+03	S 7.73E+02	3	NCN
Dimethyl sulfate		188	N	(CH3O)2SO2	Chemical Reagent						HC 3.34E+00	NA	S 2.31E+02	O 1.16E-02	2	99.7919
4,6-Dinitro-o-cresol, and salts	4			CH3C6H2(NO2)2OH							HC 6.17E-01	NA	S 9.26E+01	S 3.24E+01	4	NCN
2,4-Dinitrophenol	4			(O2N)2C6H3OH							HC 3.34E+00	NA	O 9.26E+01	O 9.26E+01	4	NCN
2,4-Dinitrotoluene	4			CH3C6H3(NO2)2							HC 6.17E-01	NA	S 1.85E+03	S 3.09E-01	3	17.5090
1,4-Dioxane (1,4-Diethyleneoxide)	4	101	Y	C4H8O2	Solvent						HC 3.34E+00	NA	S 4.17E+04	S 4.63E-01	3	91.6768
1,2-Diphenylhydrazine	5		N	C6H5NHNHC6H5							HC 6.17E-01	NA	O 2.10E-01	S 2.08E-01	3	66.2537
Epichlorohydrin (1-Chloro-2,3-epoxypropane)		115-117		C3H5ClO							Cl 3.91E-01	NA	S 9.26E+03	O 2.01E+00	4	NCN
1,2-Epoxybutane		63.3	N	CH3CH2CH-CH2							HC 3.34E+00	NA	NA	NA	NA	NA

APPENDIX B. EMISSIONS EVALUATION TABLE FOR ABB'S 350 MWe LOW EMISSION BOILER (Stack Height 400 ft in Urban Area).

Substance	Dayton Ranking (1) (F)	Boiling Point (2,3,4,5)	Water Soluble (2,3,4,5)	Chemical Structure (2,3,4,5)	Primary Sources (5,6)	Emission Rate Pulverized Bituminous Coal (lb/hr) Uncontrolled	Controlled ESP	Controlled WS	Controlled WS/ESP	Other Coal Fired Systems (lb/hr)	Mass Balance (lb/hr) (12,13,14,15)	Hazardous Waste Incinerator (16) (lb/hr)	Regulatory Limit (lb/hr) (16,17,18) Max	Regulatory Limit (lb/hr) (16,17,18) Min	Uncontrolled Category	Estimated Removal Efficiency (b) (%)
Ethyl acrylate		99		H2C=CHCO2C2H5	Chemical Intermediate						HC 3.54E+00	NA	S 2.20E+04	O 2.22E+03	3	NCN
Ethyl benzene		136.2	N	C6H5CH2CH3						0.36 - 0.71 (7)	HC 6.17E-01	NA	S 2.01E+06	S 6.71E+04	3	NCN
Ethyl carbamate (Urethane)	3	198	N	H2NNHCO2C2H5							HC 3.54E+00	NA	O 1.80E-01	O 1.80E-01	3	97.1299
Ethyl chloride (Chloroethane)	4	12.3	N	C2H5Cl							Cl 2.72E-01	NA	O 4.63E+05	S 4.01E+05	3	NCN
Ethylene dibromide (Dibromoethane)		131-132		BrCH2CH2Br	Gasoline, Pesticides, Combustion Product						Br 3.00E-04	NA	O 2.13E+02	S 3.94E-03	4	NCN
Ethylene dichloride (1,2-Dichloroethane)		82.5-84.3	N	ClCH2CH2Cl	Gasoline, Solvents, Pesticides, Combustion Product						Cl 2.09E-01	NA	S 1.35E+04	S 1.78E+00	4	NCN
Ethylene glycol		198	Y	HOCH2CH2OH							HC 3.54E+00	NA	S 1.40E+05	S 3.56E+03	3	NCN
Ethylene imine (Aziridine)		56	Y	C2H5N							HC 3.54E+00	NA	S 4.63E+02	S 1.33E+02	4	NCN
Ethylene oxide	4	13.2	Y	C2H4O	Sterilize Agent Manuf of Surfactant						HC 3.54E+00	NA	O 2.78E+04	S 4.63E-01	3	91.6768
Ethylene thiourea	7		Y	C3H6-N2S							HC 3.54E+00	NA	O 3.56E+00	O 3.56E+00	3	33.9487
Ethylidene dichloride (1,1-Dichloroethane)	4			ClCH2CH2Cl							Cl 2.09E-01	7.08E-03	S 8.80E+05	O 1.78E+00	4	NCN
Formaldehyde	2	-21	Y	HCHO	Chemical, Combustion Product	0.37 (10)					HC 3.54E+00	1.87E+00	O 1.71E+04	O 3.56E+00	4	NCN
Heptachlor	4		N	C10H5Cl7							Cl 2.25E-01	NA	S 2.31E+01	O 3.56E-02	3	84.1859
Hexachlorobenzene	1	323-326	N	C6Cl6	Solvent, Pesticide						Cl 2.00E-01	1.88E-02	O 1.30E+02	O 9.08E-02	2	54.7137
Hexachlorobutadiene	3	210-220		Cl2C=CClCCl=CCl2							Cl 1.84E-01	NA	S 1.11E+02	S 2.08E+00	4	NCN
Hexachlorocyclopentadiene	4	239		NA							NA	NA	S 4.63E+01	O 1.11E+01	4	NA
Hexachloroethane	3			Cl6C2							Cl 1.67E-01	NA	S 4.63E+04	S 1.16E+01	3	NCN
Hexamethylene-1,6-diisocyanate		255		OCN(CH2)6NCO							HC 6.17E-01	NA	S 4.63E+00	S 4.63E+00	4	NCN
Hexamethylphosphoramide		230-232		[(CH3)2N]3P(O)							HC 3.54E+00	NA	S 1.85E+01	S 1.85E+01	3	NCN
Hexane		69	N	C6H14						0.49 - 0.80 (7)	HC 3.54E+00	NA	S 1.59E+05	S 2.70E+04	3	NCN
Hydrazine	4	113.5	Y	H2NNH2							N 2.84E+03	NA	S 4.63E+01	O 9.45E-03	3	99.9997
Hydrochloric acid		-84.9	Y	HCl						225 (11)	NA	NA	O 1.39E+05	S 3.24E+02	3	NCN
Hydrogen fluoride		19.54	Y	HF	Combustion Product					27 (11)	NA	NA	O 2.69E+04	O 2.73E+02	4	NCN
Hydroquinone		285	Y	1,4-(HO)2C6H4							HC 3.54E+00	NA	S 9.26E+02	S 3.10E+02	4	NCN
Isophorone		214	N	C9H14O							HC 6.17E-01	NA	S 1.16E+04	S 3.88E+03	3	NCN
Lindane (all isomers)			N	C6H6Cl6	Pesticide						Cl 2.05E-01	NA	S 2.31E+02	S 7.41E+01	3	NCN
Maleic anhydride	3	197-199	N	C4H2O3	Resin Manuf.						HC 3.54E+00	NA	S 1.10E+03	O 1.11E+02	4	NCN
Methanol		65	Y	CH3OH							HC 3.54E+00	NA	S 2.89E+05	O 2.87E+04	3	NCN
Methoxychlor	3		N	C16H15Cl3O2	Pesticide						Cl 4.84E-01	NA	S 4.63E+03	S 1.54E+03	3	NCN
Methyl bromide (Bromomethane)	1	4	N	CH3Br	Pesticide, Solvent						Br 3.03E-04	NA	S 9.26E+03	S 4.63E-01	3	NCN
Methyl chloride (Chloromethane)	1	-24.2	N	CH3Cl	Solvent						Cl 2.13E-01	NA	S 4.84E+04	S 4.63E-01	3	NCN
Methyl chloroform (1,1,1-Trichloroethane)	3	74-76	N	CH3CCl3	Solvent						Cl 1.88E-01	NA	S 8.80E+06	O 1.40E+04	3	NCN
Methyl ethyl ketone (2-Butanone)	3	79.6	Y	C2H5COCH3							HC 3.54E+00	6.97E-02	S 6.48E+05	O 3.70E+03	3	NCN
Methyl hydrazine	3	87	Y	CH3NHNH2							HC 3.54E+00	NA	S 1.62E+02	O 1.49E-01	3	97.3151
Methyl iodide (Iodomethane)	3	41-43		CH3I							I 8.14E-05	NA	S 4.63E+03	S 4.63E-01	3	NCN
Methyl isobutyl ketone (Hexone)		117-118	N	(CH3)2CHCH2COCH 3							HC 3.54E+00	NA	S 2.26E+05	S 3.16E+04	3	NCN
Methyl isocyanate	2	39.1-40.1	Y	CH3NCO							HC 3.54E+00	NA	S 2.31E+01	S 9.26E+00	3	NCN
Methyl methacrylate	2	100	N	H2C=C(CH3)CO2CH 3							HC 3.54E+00	NA	S 1.90E+06	O 4.54E+04	3	NCN
Methyl tert butyl ether											NA	NA	NA	NA	NA	NA
4,4-Methylene bis (2-chloroaniline)	3			C13H12Cl2N2							Cl 3.64E-01	NA	S 1.02E+02	O 1.25E+00	4	NCN

APPENDIX B. EMISSIONS EVALUATION TABLE FOR ABB'S 350 MWe LOW EMISSION BOILER (Stack Height 400 ft in Urban Area).

Substance	Dayton Ranking (1) (P)	Boiling Point (2,3,4,5)	Water Soluble (2,3,4,5)	Chemical Structure (2,3,4,5)	Primary Sources (5,6)	Emission Rate Pulverized Bituminous Coal (lb/hr)				Other Coal Fired Systems (lb/hr)	Mass Balance (lb/hr) (12,13,14,15)	Hazardous Waste Incinerator (16) (lb/hr)	Regulatory Limit (lb/hr) (16,17,18)		Uncontrolled Category	Estimated Removal Efficiency (b) (%)
						Uncontrolled	Controlled BSP	Controlled WS	Controlled WS/BSP				Max	Min		
Methylene chloride (Dichloromethane)	2	39.8-40	N	CH_2Cl_2							CI 1.79E-01	3.69E+00	S 1.62E+05	S 9.26E+00	4	NCN
Methylene diphenyl diisocyanate											NA	NA	NA	NA	NA	NA
4,4'-Methylenedianiline		398-399	N	$CH_2(C_6H_4NH_2)_2$	Chemical Intermediate						HC 6.17E-01	NA	S 3.70E+02	O 1.38E-01	3	77.3456
Naphthalene	1	218	N	$C_{10}H_8$	Combustion Product		0.0043 (8)	ND 0.0007 (8)			HC 6.17E-01	NA	S 2.31E+04	O 6.48E+03	3	NCN
Nitrobenzene	4	210-211		$C_6H_5NO_2$	Chemical Intermediate						HC 3.54E+00	NA	S 5.31E+03	O 3.70E+01	4	NCN
4-Nitrobiphenyl				$C_6H_5C_6H_4NO_2$							HC 6.17E-01	NA	S 8.80E+03	S 8.80E+03	3	NCN
4-Nitrophenol	4	279		$O_2NC_6H_4OH$							HC 3.54E+00	NA	NA	NA	NA	NA
2-Nitropropane		120	N	$(CH_3)_2CHNO_2$							HC 3.54E+00	NA	S 5.40E+00	O 1.71E-03	2	99.9492
N-Nitroso-N-methylurea	7										NA	NA	NA	NA	NA	NA
N-Nitrosodimethylamine	7	153	Y	$(CH_3)_2NNO$	Additive for Lubricants						HC 3.54E+00	NA	S 2.31E+00	O 1.08E-03	3	99.3806
N-Nitrosomorpholine	7	224	Y	$C_4H_8N_2O_2$	Detergents, Corrosion Inhibitor						HC 3.54E+00	NA	O 2.44E-02	O 2.44E-02	3	99.3619
Parathion	3	375	N	$C_{10}H_{14}NO_5PS$	Pesticide						HC 6.17E-01	NA	S 4.63E+01	S 1.39E+01	4	NCN
Pentachloronitrobenzene (Quintobenzene)	3			$C_6Cl_5NO_2$							CI 2.49E-01	NA	O 6.34E-01	O 6.34E-01	4	NCN
Pentachlorophenol	4	310		C_6Cl_5OH							CI 2.23E-01	1.93E-02	O 1.39E+03	S 5.31E+01	3	NCN
Phenol	3	181.7	Y	C_6H_5OH	Resin Manuf., Combustion Product						HC 3.54E+00	6.95E-02	S 8.80E+04	O 2.08E+03	3	NCN
p-Phenylenediamine	3	267	N	$1,4-(H_2N)_2C_6H_4$							HC 3.54E+00	NA	S 4.63E+01	S 1.39E+01	3	NCN
Phosgene	2	7.6	N	$COCl_2$							CI 2.09E-01	NA	S 1.85E+03	S 6.02E+01	3	NCN
Phosphine		[illegible]		$(F_3C)_2PH$							P 2.32E-03	NA	S 1.85E+03	S 6.02E+01	3	NCN
Phosphorus		280	N	P_4							P 2.49E+01	NA	S 4.63E+01	O 3.24E+00	2	88.9941
Phthalic anhydride	4	295	N	$1,2-C_6H_4(CO)_2O$							HC 6.17E-01	NA	O 3.24E+05	S 9.26E+02	3	NCN
Polychlorinated biphenyls (Aroclors)		Various	Various	Various	Combustion Product						NA	NA	O 3.54E+01	O 3.31E-02	2	NA
1,3-Propane sultone		180		$C_3H_6O_3S$							HC 3.54E+00	NA	S 1.85E+03	O 6.71E-02	2	NA
beta-Propiolactone		162	N	CH_2CH_2CO							HC 3.54E+00	NA	S 2.31E+02	S 2.31E+02	4	NCN
Propionaldehyde		48.8	Y	CH_3CH_2CHO							HC 3.54E+00	NA	S 1.99E+05	S 1.99E+03	3	NCN
Propoxur (Baygon)			N	$C_{11}H_{15}NO_3$	Pesticide						HC 6.17E-01	NA	S 2.31E+02	S 7.87E+01	3	NCN
Propylene dichloride (1,2-Dichloropropane)	4	95-96	N	$CH_3CH(Cl)CH_2Cl$							CI 2.30E-01	NA	S 1.62E+05	S 4.63E-01	3	NCN
Propylene oxide		34.3	Y	C_3H_6O	Resin Manuf., Surfactant						HC 3.54E+00	NA	O 4.63E+04	S 4.63E-01	3	91.6768
1,2-Propylenimine (2-Methyl aziridine)	3	66-67									NA	NA	NA	NA	NA	NA
Quinoline		238	N	C_9H_7N							HC 6.17E-01	NA	NA	NA	NA	NA
Quinone			N	$1,4-O=C_6H_4=O$							HC 3.54E+00	NA	S 1.85E+02	S 6.02E+01	4	NCN
Styrene		145.2	N	$C_6H_5CH=CH_2$	Chemical Feedstock						HC 6.17E-01	NA	S 2.35E+05	O 8.12E+01	3	NCN
Styrene oxide		194.1	N								NA	NA	NA	NA	NA	NA
2,3,7,8-Tetrachlorodibenzo-p-dioxin	2			$(C_6H_2)_2Cl_4O_2$	Combustion Product					ND 1.8e-05 (9)	CI 3.40E-01	3.30E-06	S 1.39E-04	O 9.26E-07	2	94.2580
1,1,2,2-Tetrachloroethane	4	147	N	$Cl_2CHCHCl_2$							CI 1.77E-01	3.37E-02	S 3.24E+03	S 7.87E-01	3	NCN
Tetrachloroethylene (Perchloroethylene)	2	121	N	$Cl_2C=CCl_2$							CI 1.75E-01	6.24E-01	O 3.13E+05	S 1.90E+01	3	NCN
Titanium tetrachloride		136.4		$TiCl_4$							CI 2.00E-01	NA	NA	NA	NA	NA
Toluene	2	110.6	N	$C_6H_5CH_3$						0.36 - 0.53 (7)	HC 6.17E-01	1.16E+00	S 4.13E+05	O 9.26E+03	3	NCN
2,4-Toluene diamine	3	283-285	Y	$CH_3C_6H_3(NH_2)_2$							HC 6.17E-01	NA	NA	NA	NA	NA
2,4-Toluene diisocyanate		251	N	$C_9H_6N_2O_2$	Raw Material for Polyurethane						HC 6.17E-01	NA	S 4.63E+01	O 4.21E+00	4	NCN

APPENDIX B. EMISSIONS EVALUATION TABLE FOR ABB'S 350 MWe LOW EMISSION BOILER (Stack Height 400 ft in Urban Area).

Substance	Dayton Ranking (1) (P)	Boiling Point (2,3,4,5)	Water Soluble (2,3,4,5)	Chemical Structure (2,3,4,5)	Primary Sources (5,6)	Emission Rate Pulverized Bituminous Coal (lb/hr)				Other Coal Fired Systems (lb/hr)	Mass Balance (lb/hr) (12,13,14,15)	Hazardous Waste Incinerator (16) (lb/hr)	Regulatory Limit (lb/hr) (16,17,18)		Uncontrolled Category	Estimated Removal Efficiency (b) (%)
						Uncontrolled	Controlled ESP	Controlled WS	Controlled WS/ESP				Max	Min		
o-Toluidine		199-200	N	CH3C6H4NH2							HC 6.17E-01	NA	S 1.39E+03	S 4.63E-01	3	25.0002
Toxaphene (chlorinated camphene)			N	C10H10Cl8	Pesticide						Cl 2.10E-01	NA	O 1.45E-01	S 1.39E-01	3	36.4076
1,2,4-Trichlorobenzene	1	214	N	C6H3Cl3							Cl 2.55E-01	1.02E-01	S 1.85E+04	O 9.26E+02	3	NCN
1,1,2-Trichloroethane	4	110-115		ClCH2CHCl2							Cl 2.05E-01	7.71E-02	S 2.08E+04	S 2.82E+00	4	NCN
Trichloroethylene	2	86.9	N	ClCH=CCl2	Solvent, Chemical						Cl 1.85E-01	1.72E-01	S 1.25E+05	S 1.39E+01	4	NCN
2,4,5-Trichlorophenol	4	248		Cl3C6H2OH							Cl 2.70E-01	3.02E-01	O 4.63E+03	O 4.63E+03	3	NCN
2,4,6-Trichlorophenol	4	246		Cl3C6H2OH	Herbicide, Wood Preservative						Cl 2.70E-01	NA	S 8.33E+00	O 8.12E+00	4	NCN
Triethylamine		89.3	Y	(C2H5)3N							HC 3.54E+00	NA	S 1.85E+04	S 6.17E+03	3	NCN
Trifluralin		140	N	C13H16F3N3O4	Herbicide						F 9.14E-03	NA	NA	NA	NA	NA
2,2,4-Trimethylpentane		98-99		(CH3)2CHCH2C(CH3)3							HC 6.17E-01	NA	NA	NA	NA	NA
Vinyl acetate		72.2	N	CH3CO2CH=CH2							HC 3.54E+00	NA	S 3.84E+04	S 4.63E+03	3	NCN
Vinyl bromide		15.8	N	CH2=CHBr							Br 3.41E-01	NA	S 3.08E+03	S 3.08E+03	3	NCN
Vinyl chloride	3	-13.4	N	CH2=CHCl	Landfill By-Product						Cl 2.64E-01	2.94E-03	O 1.20E+03	O 3.94E-01	3	NCN
Vinylidene chloride (1,1-Dichloroethylene)	2	30-32		H2C=CCl2	Resin Manuf., Packaging						Cl 2.05E-01	6.64E-02	S 9.26E+04	S 9.26E+01	3	NCN
Xylene (isomers and mixture)		137-144		C6H4(CH3)2	Solvent, Reagent, Motor Vehicles						HC 6.17E-01	NA	S 2.01E+06	O 1.39E+04	3	NCN
o-Xylene		143-145	N	1,2-(CH3)2C6H4	Same					0.17 - 0.35 (7)	HC 6.17E-01	NA	S 2.01E+06	O 1.39E+04	3	NCN
m-Xylene		138-139	N	1,3-(CH3)2C6H4	Same					2.5 (7)	HC 6.17E-01	NA	S 2.01E+06	O 1.39E+04	3	NCN
p-Xylene		138	N	1,4-(CH3)2C6H4	Same					0.75 (a,7)	HC 6.17E-01	NA	S 2.01E+06	O 1.39E+04	3	NCN
												NA				
Antimony Compounds	NA	(c)	(c)	(c)		0.28 (MP)	0.087 (8)	0.0086 (8)			Sb 2.31E-01	2.10E-01	S 2.31E+03	O 1.39E+01	4	NCN
Arsenic Compounds	NA	(c)	(c)	(c)	Fuel Combustion, Pesticides	1.95 (10), 2.30 (MP)	0.11 (10)	0.049 (10)	0.0428 (10)		As 2.30E+00	1.26E-02	O 2.31E+01	S 9.26E-03	1	99.8113
Beryllium Compounds	NA	(c)	(c)	(c)	Metals Alloys, Fuel Combustion	0.23 (10), 0.27 (MP)	0.01 (10)	0.0003 (10)			Be 2.74E-01	2.10E-02	S 1.85E+00	S 1.11E-02	1	95.9423
Cadmium Compounds	NA	(c)	(c)	(c)	Secondary Smelter, Fuel	0.13 (10), 0.027 (MP)	0.014 (10)	0.0046 (10)			Cd 2.74E-02	8.40E-02	O 1.62E+02	O 1.10E-02	1	99.1743
Chromium Compounds	NA	(c)	(c)	(c)	Chrome Plating	5.37 (10), 2.17 (MP)	0.82 (10)	0.061 (10)	0.049 (10)		Cr 2.61E+00	4.20E-02	S 9.26E+01	O 3.31E-04	2 (d)	99.9840
Cobalt Compounds	NA	(c)	(c)	(c)			.053 (8)	0.052 (8)			Co 9.58E-01	NA	S 4.63E+01	S 5.56E+00	3	NCN
Coke Oven Emissions	NA				Coke Ovens						NA	NA	O 7.47E-02	S 7.41E-02	NA	NA
Cyanide Compounds											NA	NA	NA	NA	NA	NA
Glycol ethers					Fuel & Solvent Additive						NA	NA	S 2.64E+04	S 2.64E+04	NA	NA
Lead Compounds	NA	(c)	(c)	(c)	Auto Exhaust, Fuel	0.9 (10), 4.18 (MP)	0.14 (10)	0.048 (10)			Pb 4.10E+00	2.10E-01	S 6.94E+01	O 5.79E-01	2 (e)	98.1823
Manganese Compounds	NA	(c)	(c)	(c)	Motor Vehicles, Steel Manuf.	8.89 (10)	1.8 (10)	0.13 (10)	0.08 (10)		Mn 2.73E+00	8.40E-02	S 3.31E+03	O 1.85E+01	3	NCN
Mercury Compounds	NA	(c)	(c)	(c)	Electronic, Paper Pulp Manuf.	0.1 (10), 0.0199 (MP)	0.03 (10)	ND (10)			Hg 1.59E-02	4.20E-01	S 3.31E+01	O 3.70E+00	4	NCN
Fine mineral fibers	NA										NA	NA	O 1.11E+03	O 1.11E+03	NA	NA

APPENDIX B. EMISSIONS EVALUATION TABLE FOR ABB'S 350 MWe LOW EMISSION BOILER (Stack Height 400 ft in Urban Area).

Substance	Dayton Ranking (1) (P)	Boiling Point (2,3,4,5)	Water Soluble (2,3,4,5)	Chemical Structure (2,3,4,5)	Primary Sources (5,6)	Emission Rate Pulverized Bituminous Coal (lb/hr)				Other Coal Fired Systems (lb/hr)	Mass Balance (lb/hr) (12,13,14,15)	Hazardous Waste Incinerator (16) (lb/hr)	Regulatory Limit (lb/hr) (16,17,18)		Uncontrolled Category	Estimated Removal Efficiency (b) (%)
						Uncontrolled	Controlled									
							ESP	WS	WS/ESP				Max	Min		
Nickel Compounds	NA	(c)	(c)	(c)	Alloy, Plating Ceramics, Dyes,	4.22 (10), 3.06 (MP)	1.0 (10)	0.19 (10)	0.033 (10)		Ni 3.63E+00	1.08E-01	S 4.63E+02	S 9.29E-02	2 (f)	98.97/41
Polycyclic Organic Matter		Various	Various	Various	Fuel Combustion		0.053 (9)	0.024 (9)			NA	NA	S 2.78E+00	S 2.78E-02	2	NA
Radionuclides (including radon)	NA				Research, Medicine, Fuel Combustion		1.3e06 (10, h)	3.1e05 (10, h)	1.3e05 (10, h)		NA	NA	NA	NA	NA	NA
Selenium Compounds	NA	(c)	(c)	(c)		1.1 (9), 0.33 (MP)	0.086 (9)	0.11 (9)			Se 3.29E-01	2.10E-02	S 2.22E+02	O 3.31E-01	2 (g)	NCN

(a) Mass rate includes meta and para-xylenes
(b) Removal efficiency based on minimum regulatory limit and either the mass balance, pulverized coal, or other coal uncontrolled emission rate.
(c) Metal water solubility, and structure are discussed in Section 5.4.
(d) Chromium is categorized as a 2 instead of a 1 because the emission limit is for hexavalent Chromium. It has not been confirmed that all chromium is emitted as hexavalent chromium.
(e) Lead is categorized as a 2 instead of a 1 because the emission limit is based on a screening value for the California Air Pollution Control Officers Association. The screening value does not have to be applied to all facilities.
(f) Nickel is categorized as a 2 instead of a 1 because the EPA BIF rules do not consider Nickel as a carcinogen. Under the BIF rules Nickel would not be a risk.
(g) Selenium is categorized as a 2 instead of a 1 because the emission limit is based on a screening value for the California Air Pollution Control Officers Association. The screening value does not have to be applied to all facilities.
(h) pCi/hr for U238 and T232

MP - Calculated using the metals partitioning model.

NA - Not Available.

S - Limit based on promulgated State ambient concentration limit, stack height of > 50 ft, and receptor distance > 1000 m.

O - Limit based on EPA or CAPCOA unit risk factor or acute or chronic ambient concentration limit, stack height of > 50 ft, and receptor distance > 1000 m.

NCN - No Control Necessary.

MASS BALANCE (MB) NOTES:

HC - Hydrocarbon MB, Cl - Chlorine MB, Br - Bromine MB, N - Nitrogen MB, I - Iodine MB, F - Fluorine MB, P - Phosphorus MB,

Sb - Antimony MB, As - Arsenic MB, Be - Beryllium MB, Cd - Cadmium MB, Cr - Chromium MB, Co - Cobalt MB, Pb- Lead MB,

Mn - Manganese MB, Hg - Mercury MB, Ni - Nickel MB, Se - Selenium MB.

REFERENCES
1-(EPA, 92), 2-(Weast, 88), 3-(Aldrich), 4-(McCoy, 92), 5-(Windholz, 83),
6-(Jones, 89), 7-(Brooks, 90), 8-([illegible], 80), 9-(Pope, 90), 10-(Brooks, 90), 11-([illegible], 90),
12-([illegible], 92), 13-(Devito, 93), 14-(Oberacker, 84), 15-(Castaldini, 87), 16-(EPA, 90),
17-(Various State with ATCPs), 18-(CAPCOA Risk Assessment Guidelines)

APPENDIX C - TEST METHODS

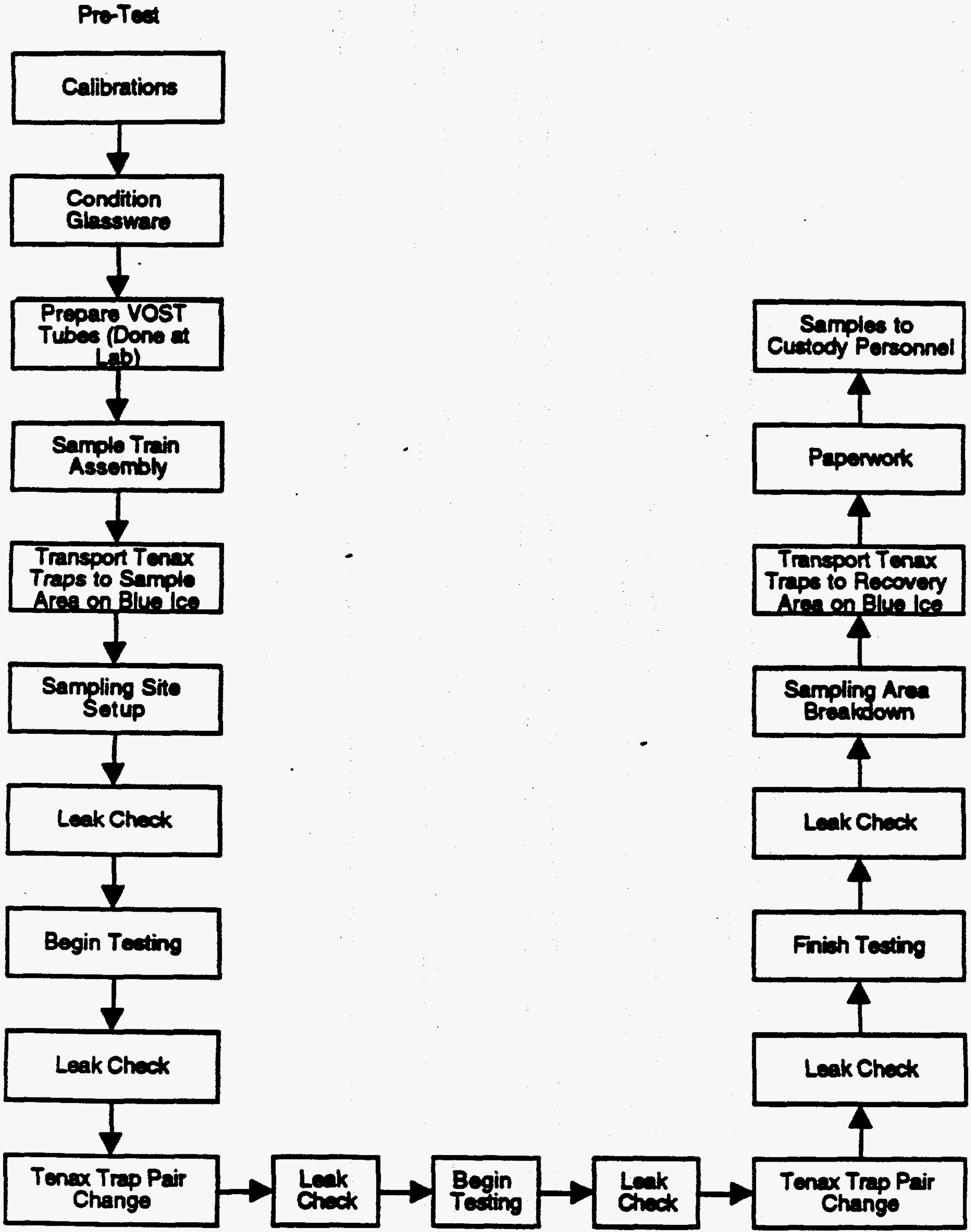


Figure C-1. M0030 sampling procedure overview.

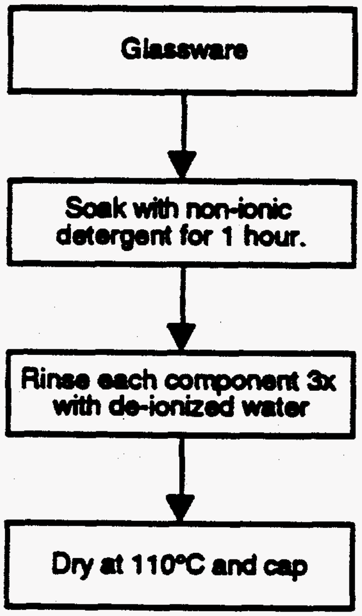


Figure C-2. M0030 glassware preparation procedure.

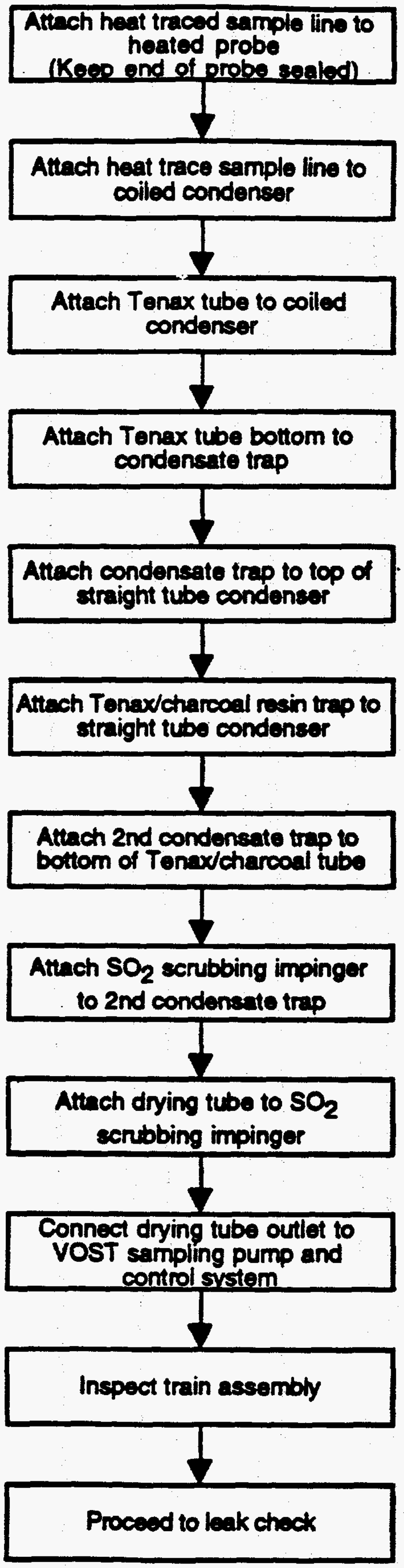


Figure C-3. M0030 sampling train assembly procedure.

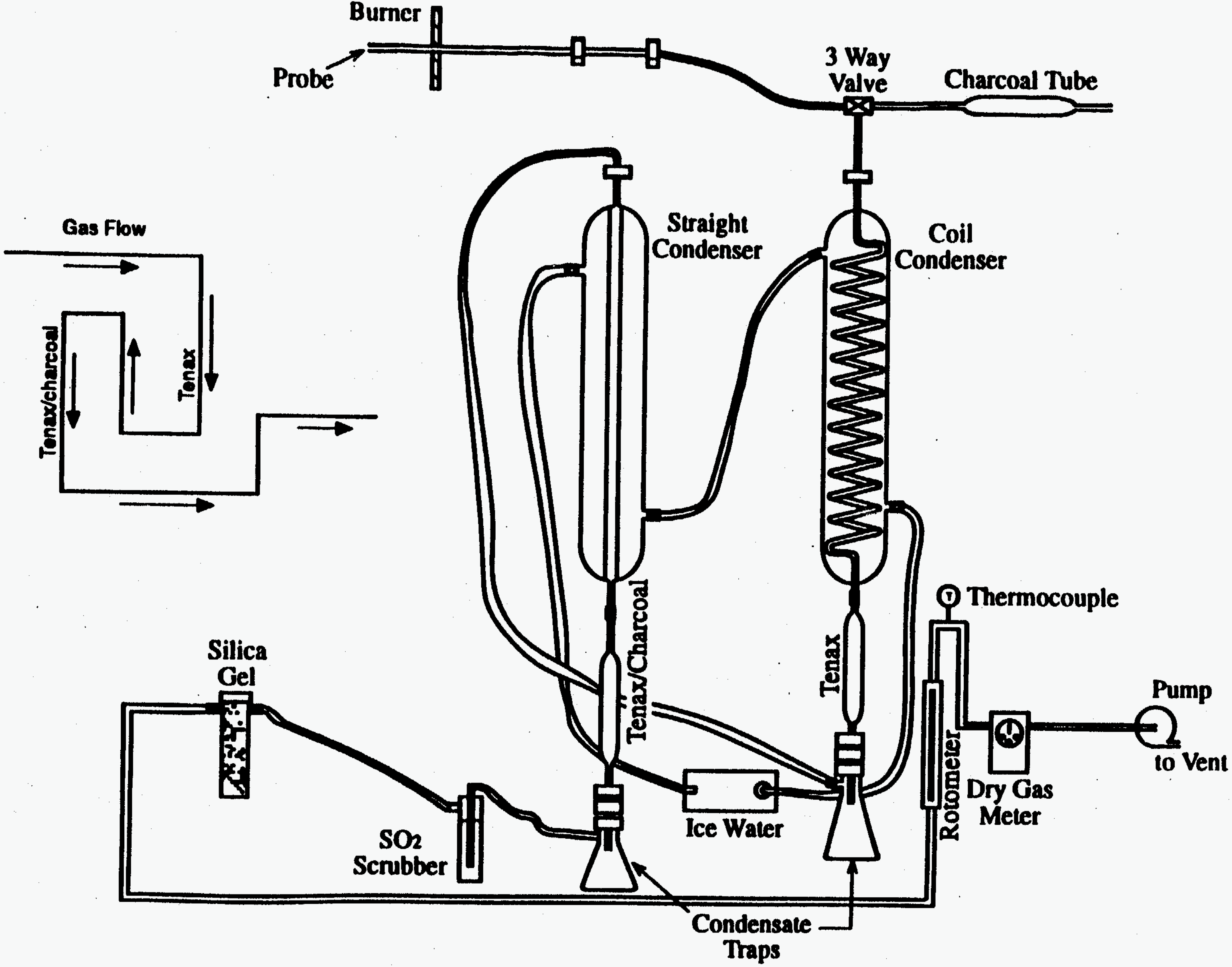


Figure C-4. M0030 sampling system schematic.

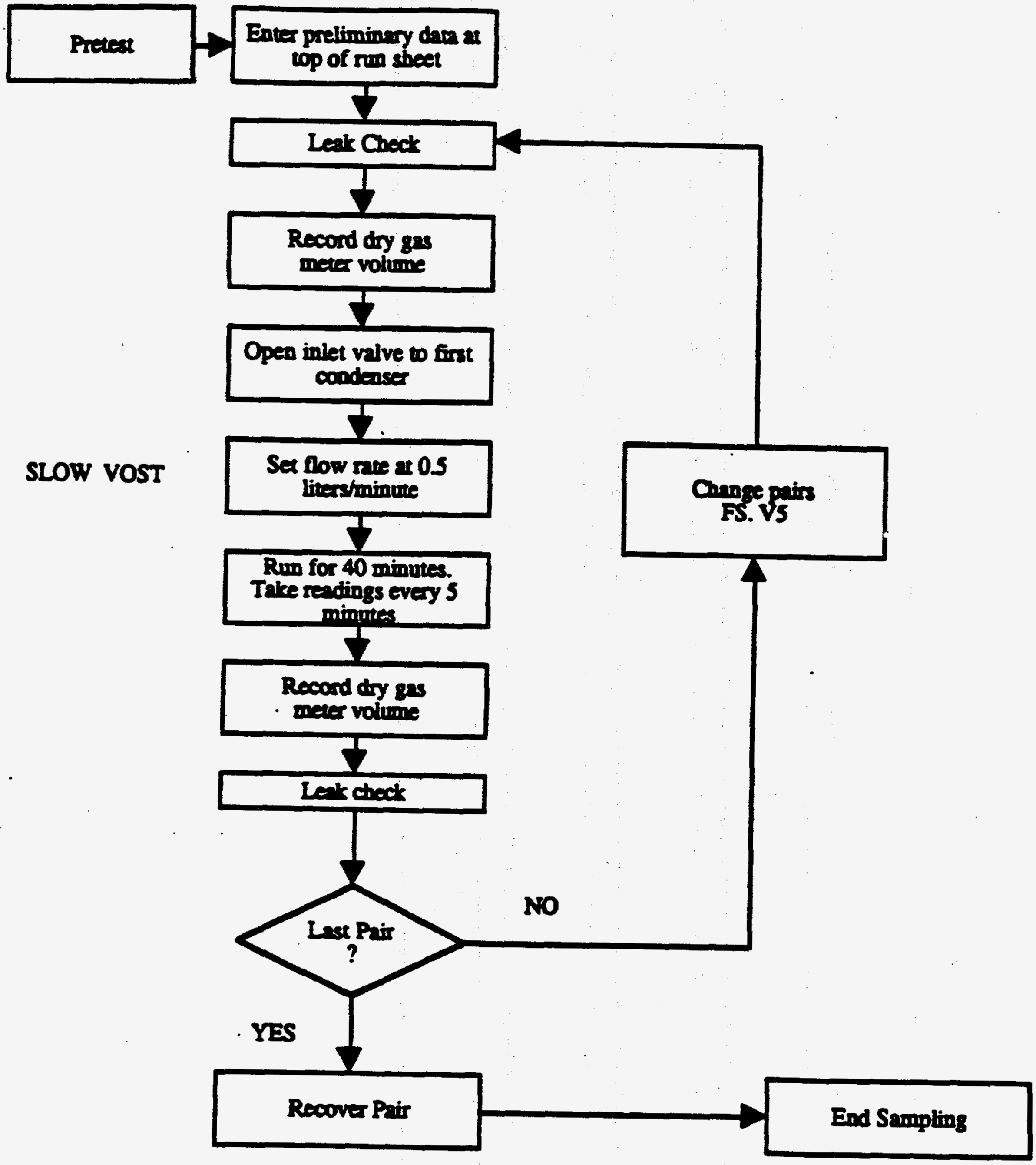


Figure C-5. M0030 Sampling Procedure.

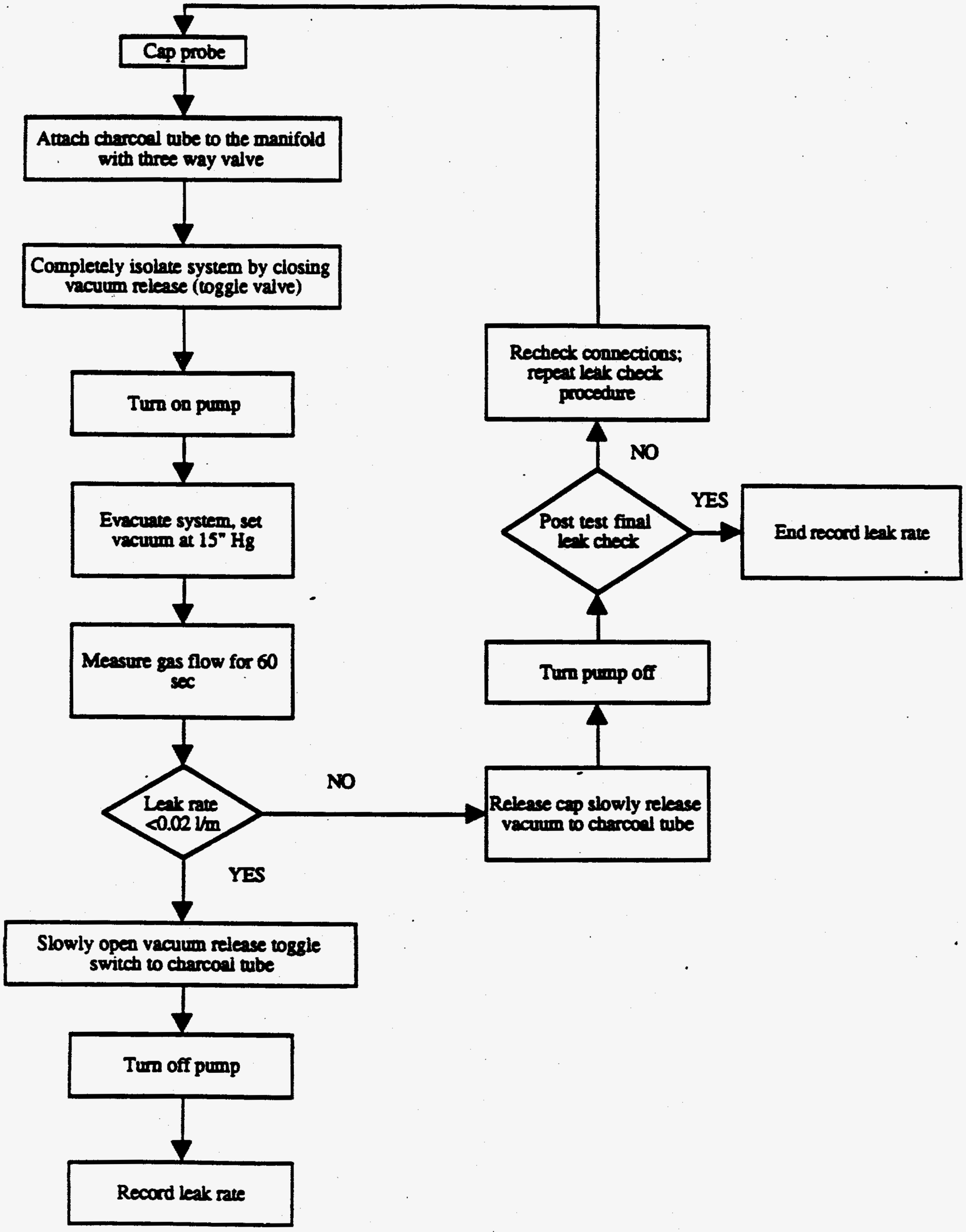


Figure C-6. M0030 leak check procedure.

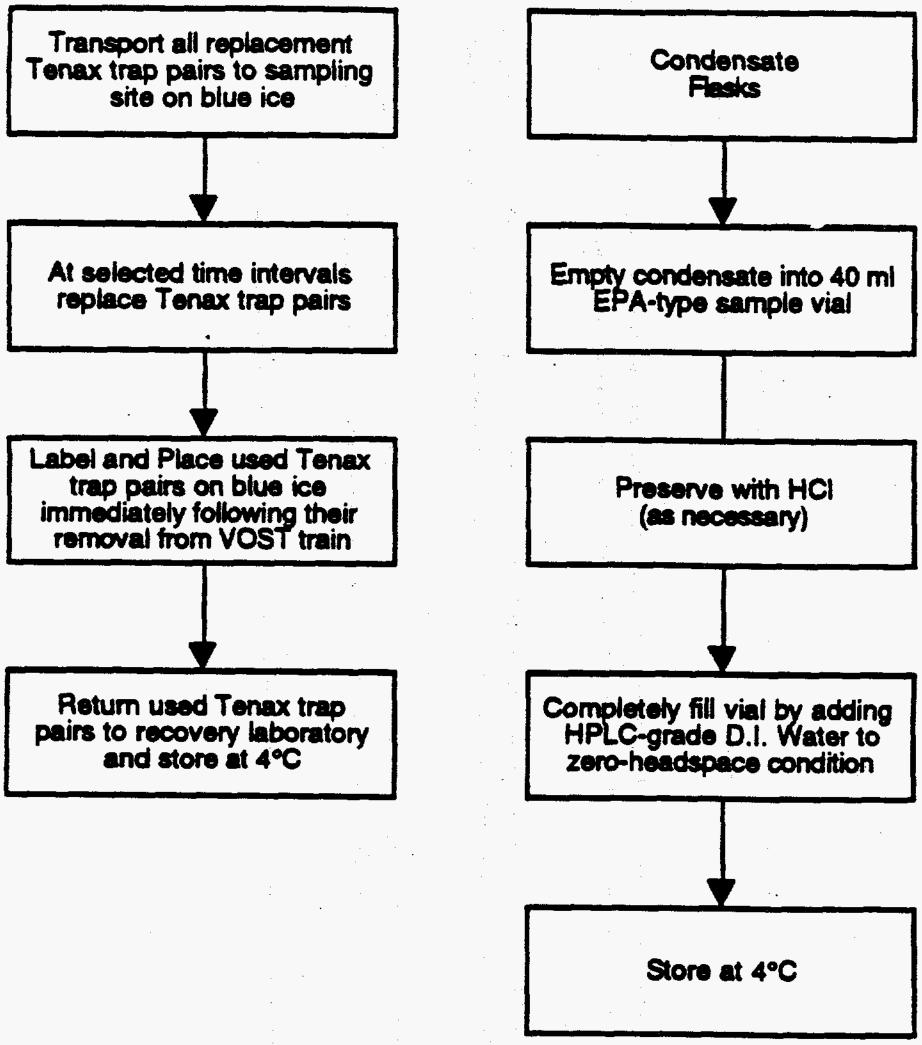


Figure C-7. M0030 field sample recovery.

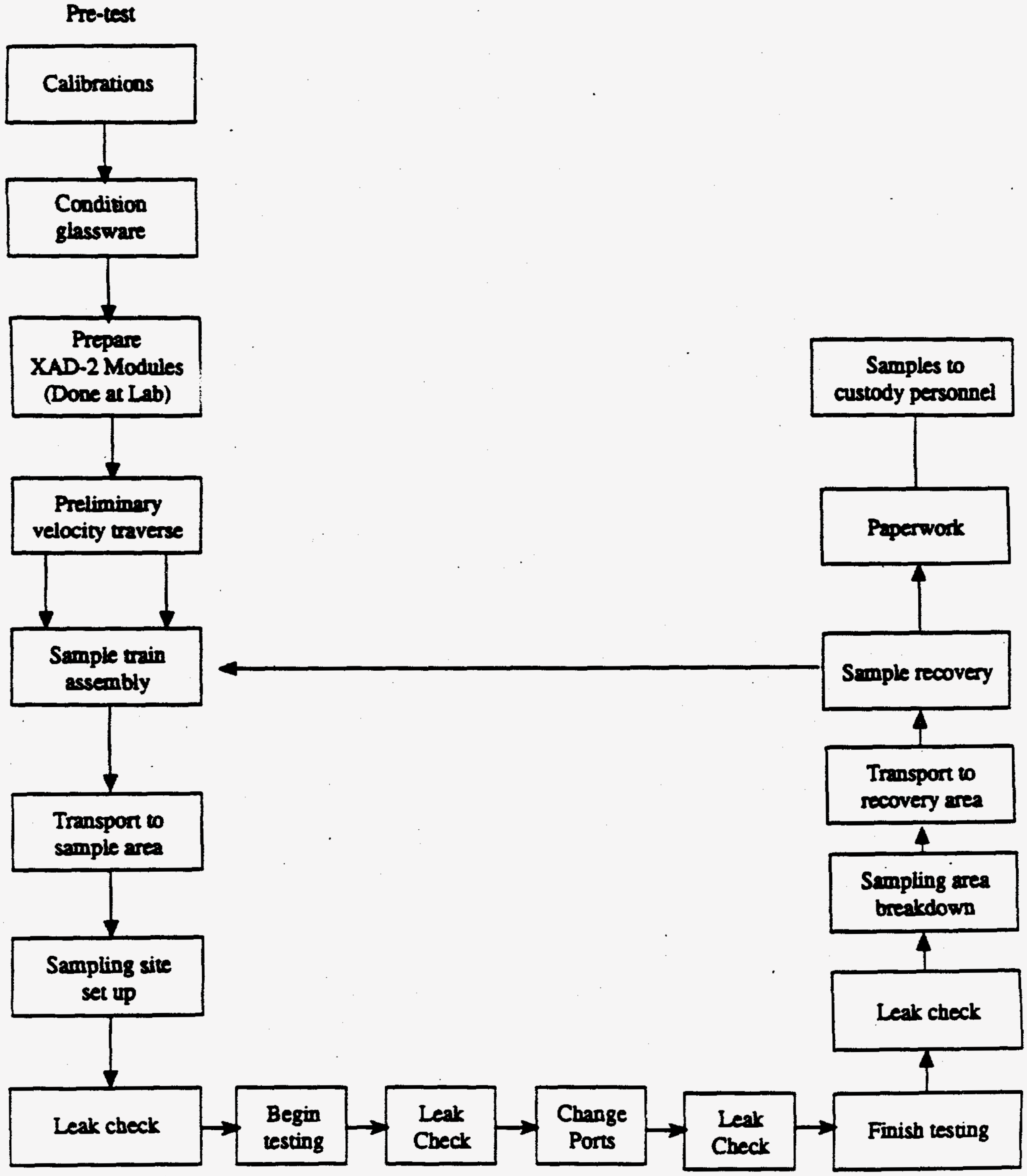


Figure C-8. Method 0010/23 sampling procedure overview.

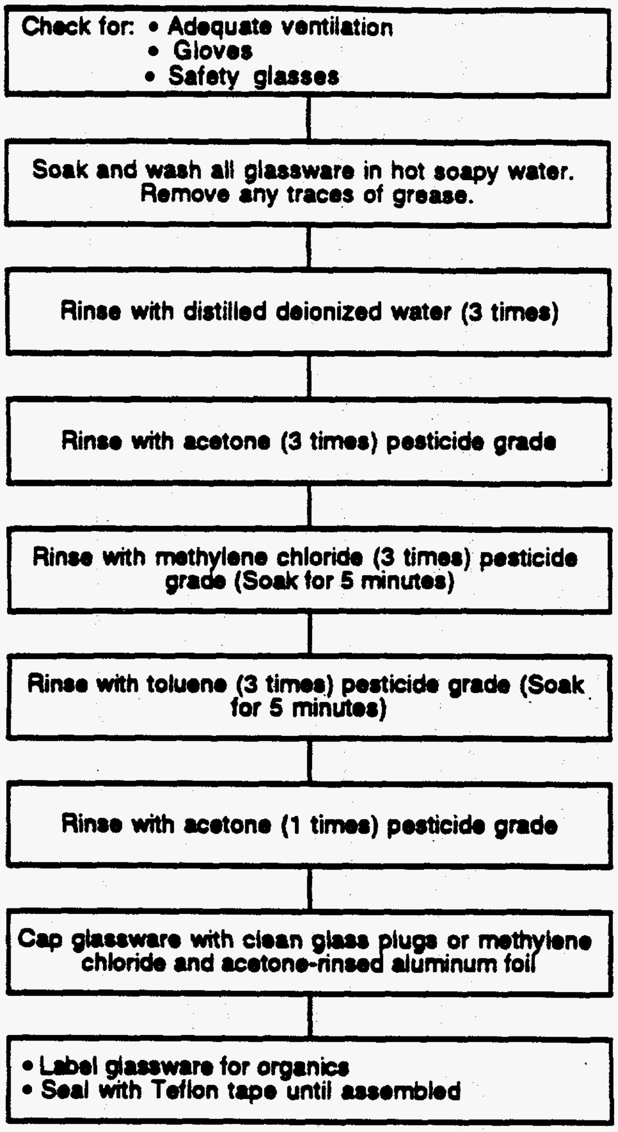


Figure C-9. Method 0010/23 glassware preparation procedure.

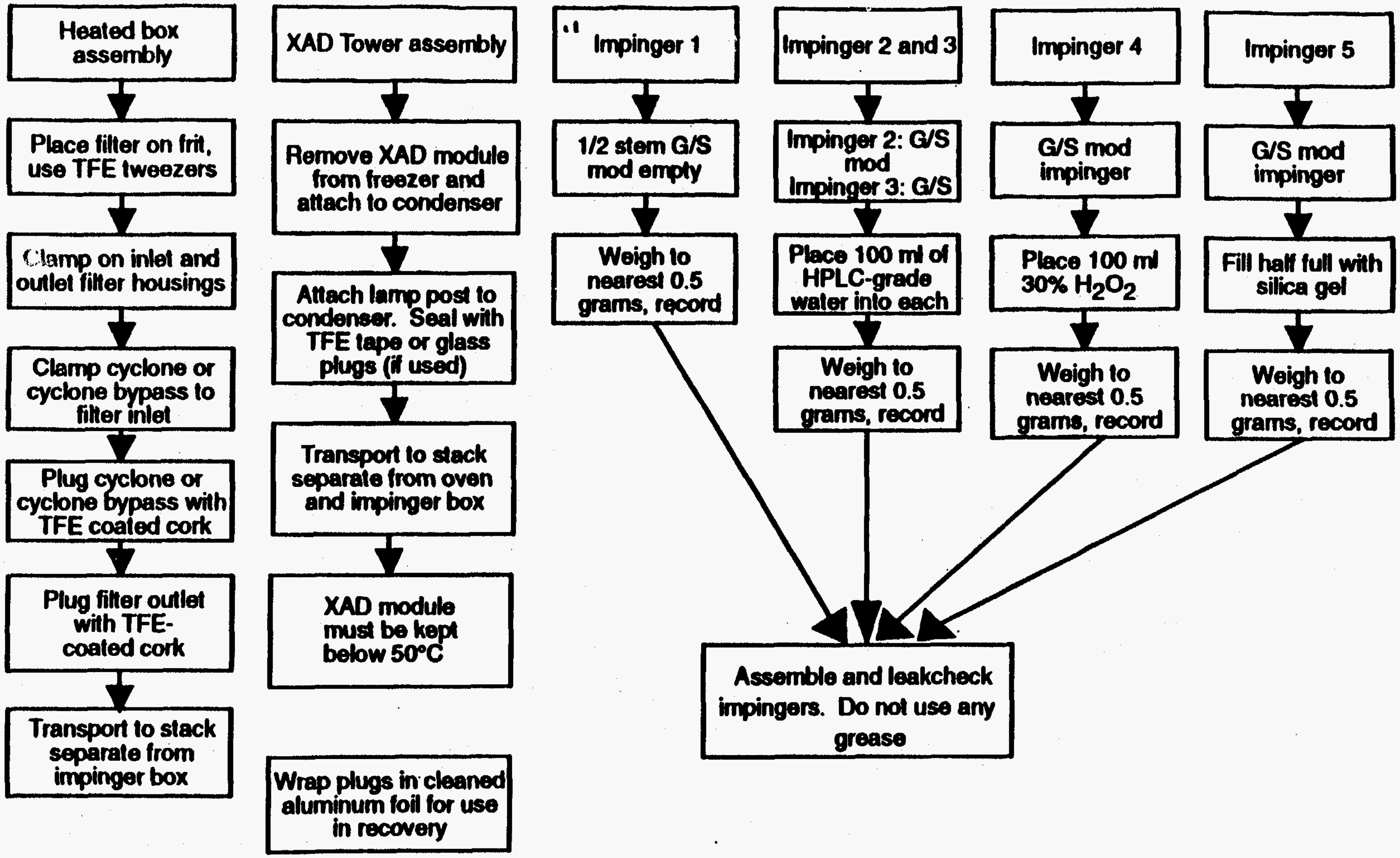
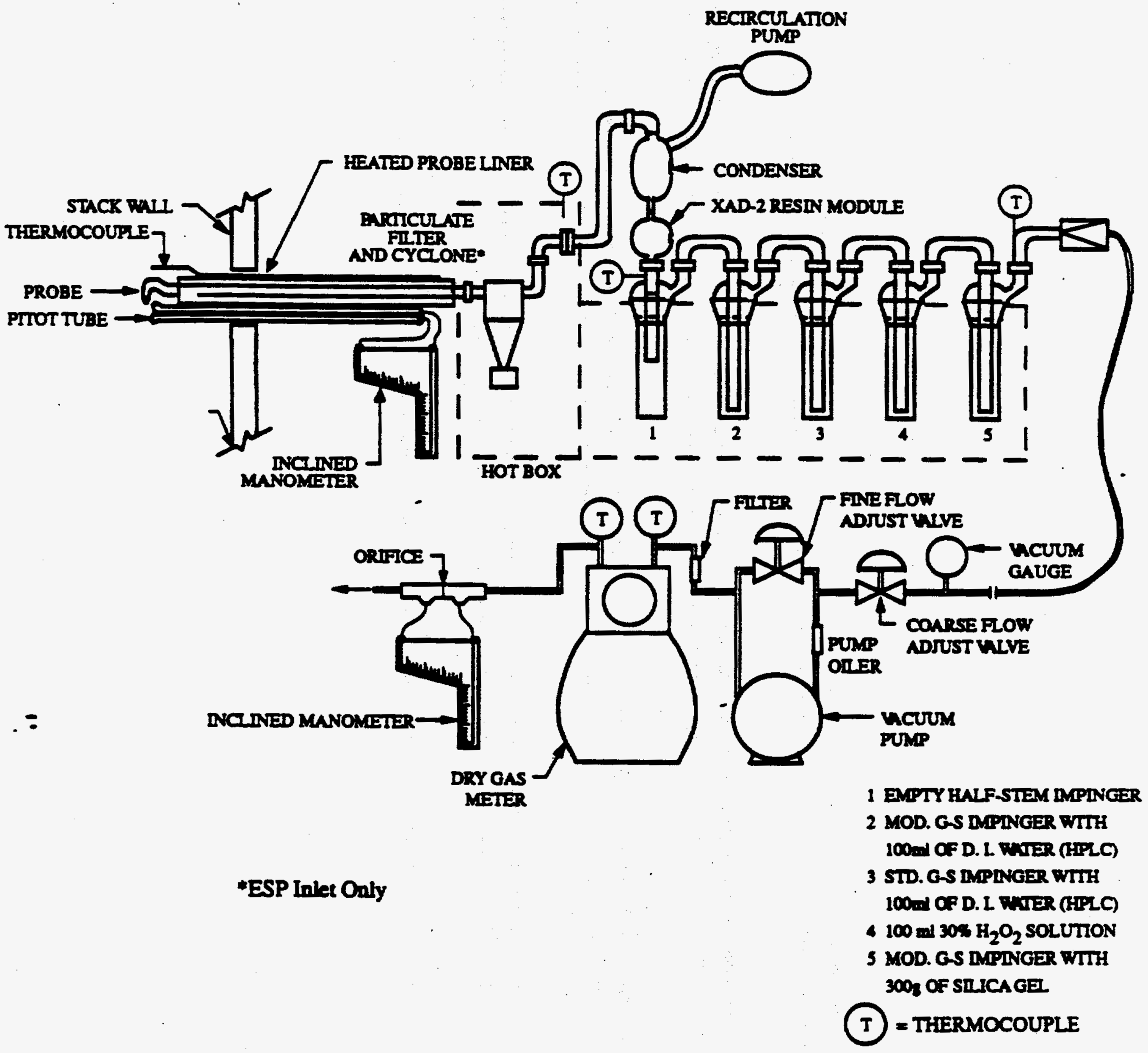


Figure C-10. Method 0010/23 sampling train assembly procedure.



*ESP Inlet Only

Figure C-11. M0010/M23 sampling system schematic marked for high SO_2 and particulate loading.

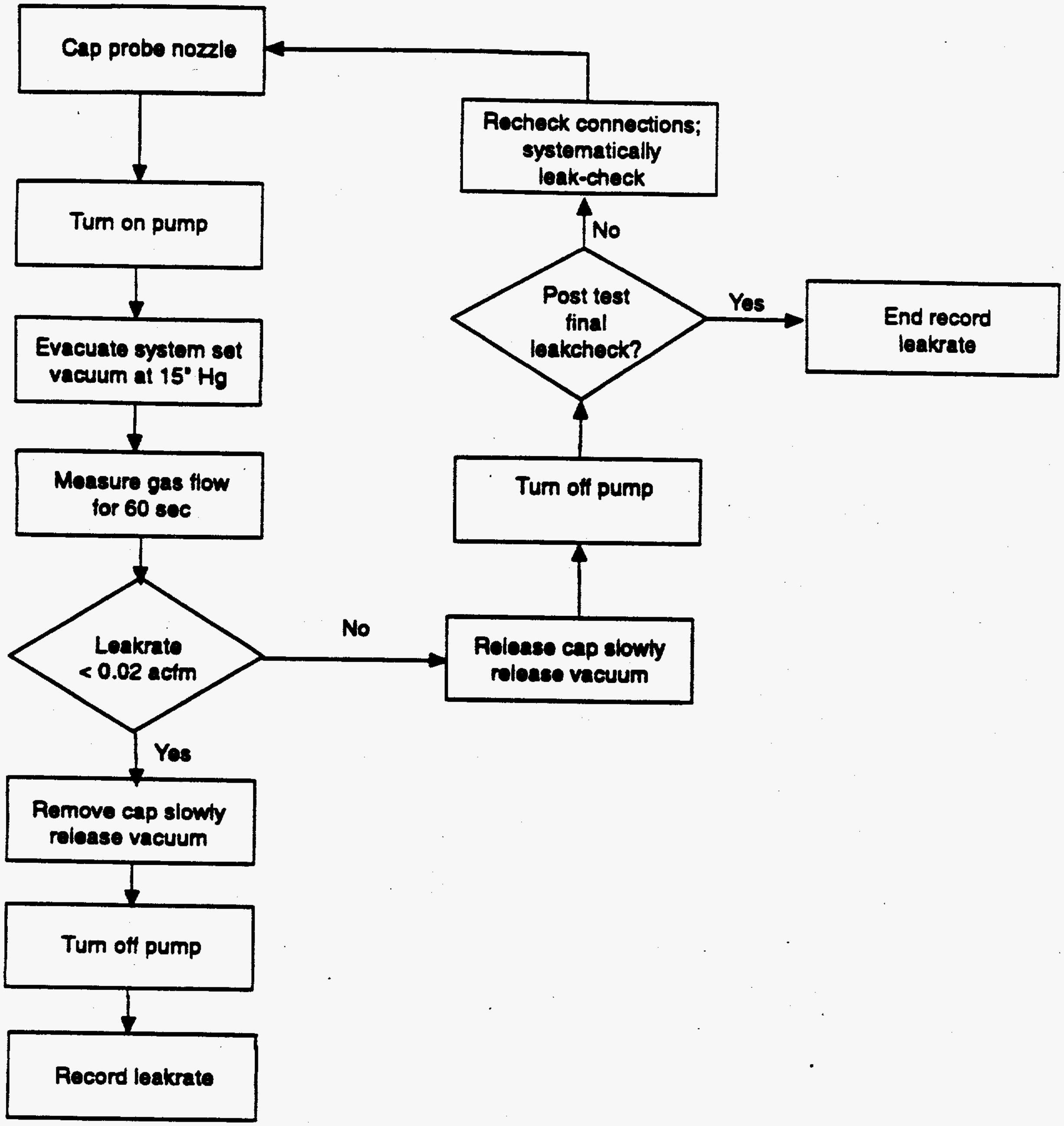


Figure C-12. M0010/M23 leakcheck procedure.

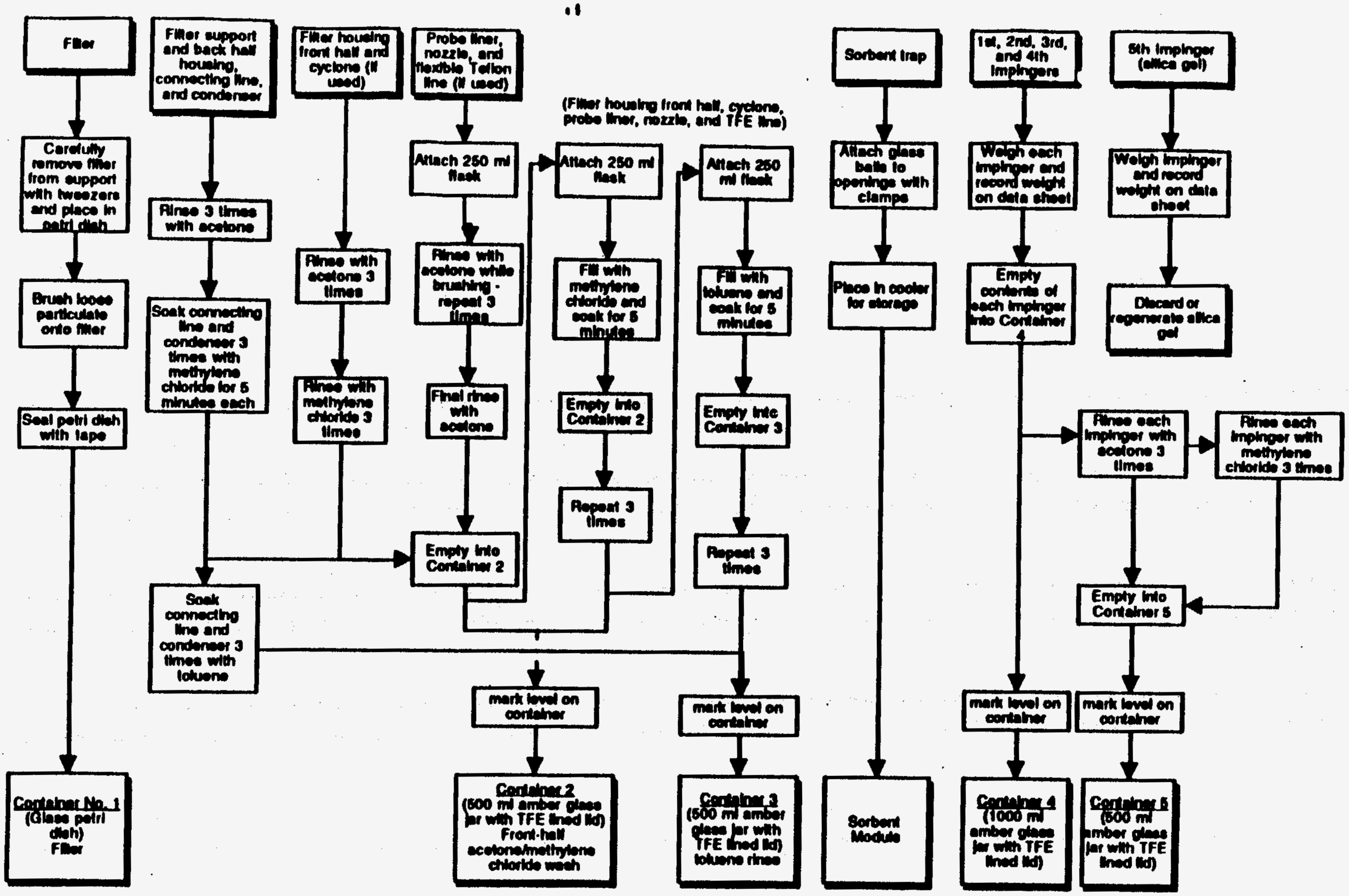


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Figure C-13. Combined EPA Method 0010/23 (modified for PAH determination and high SO2 concentration) sample recovery flowchart.

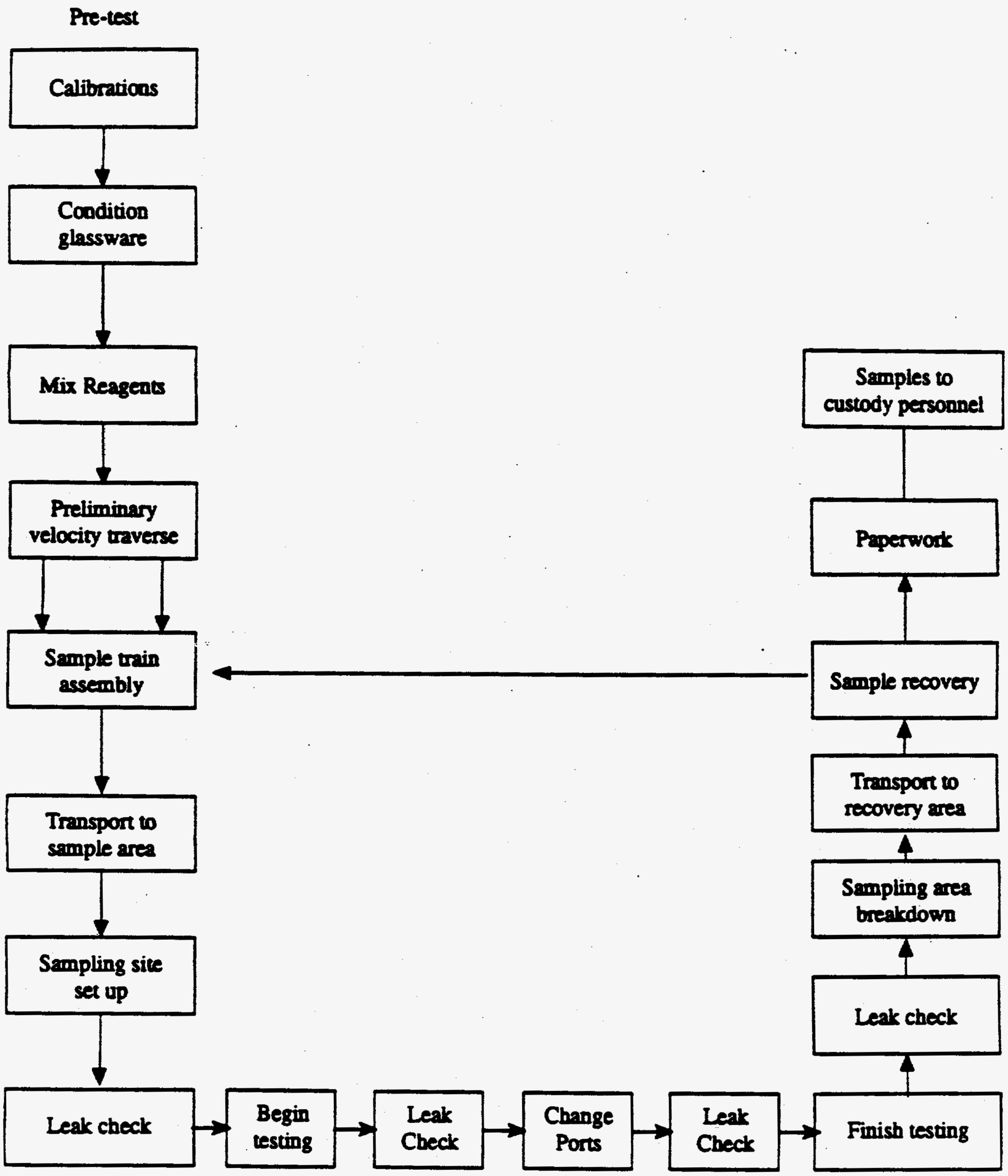


Figure C-14. M29 sampling procedure overview.

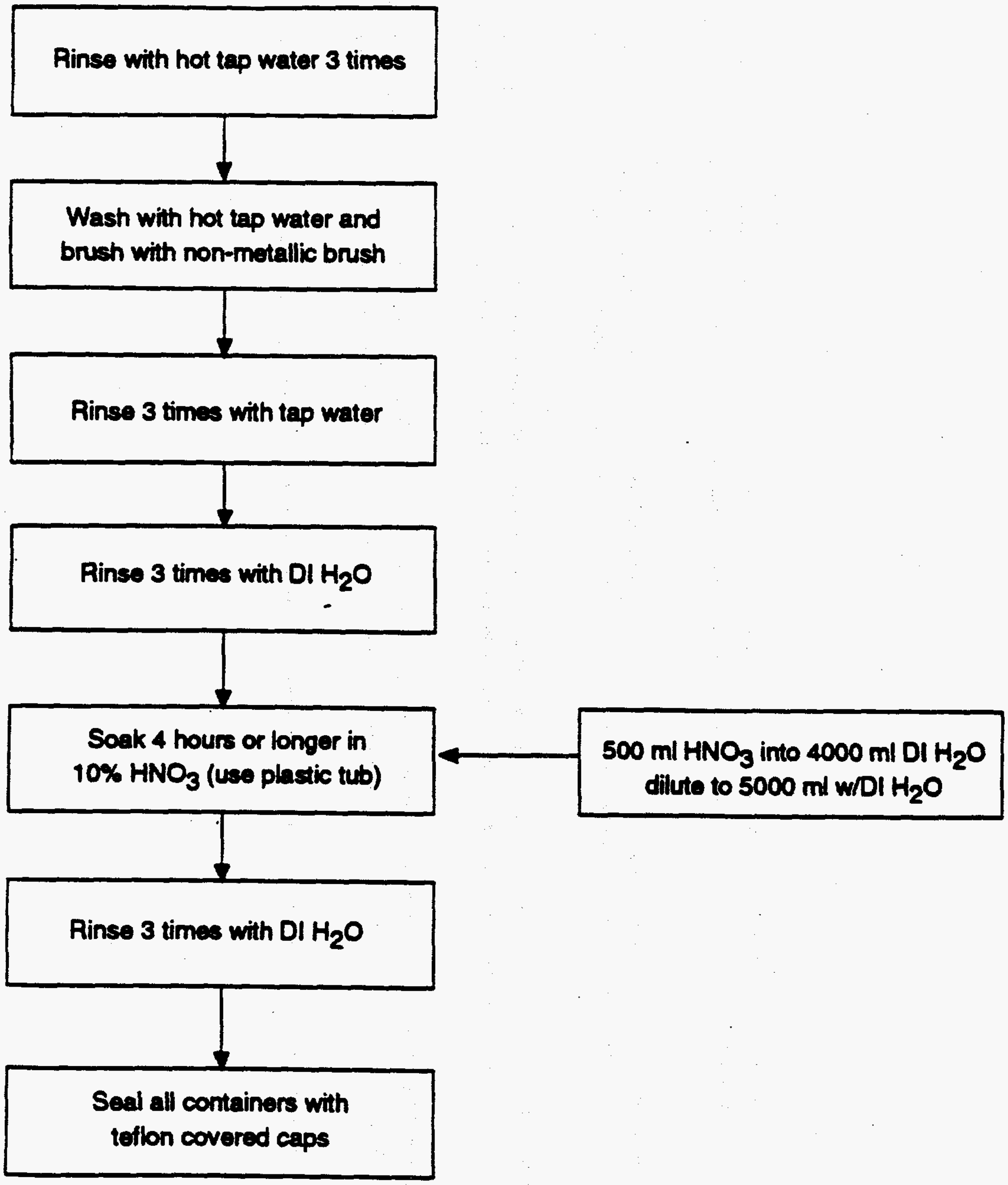


Figure C-15. M29 glassware preparation procedure.

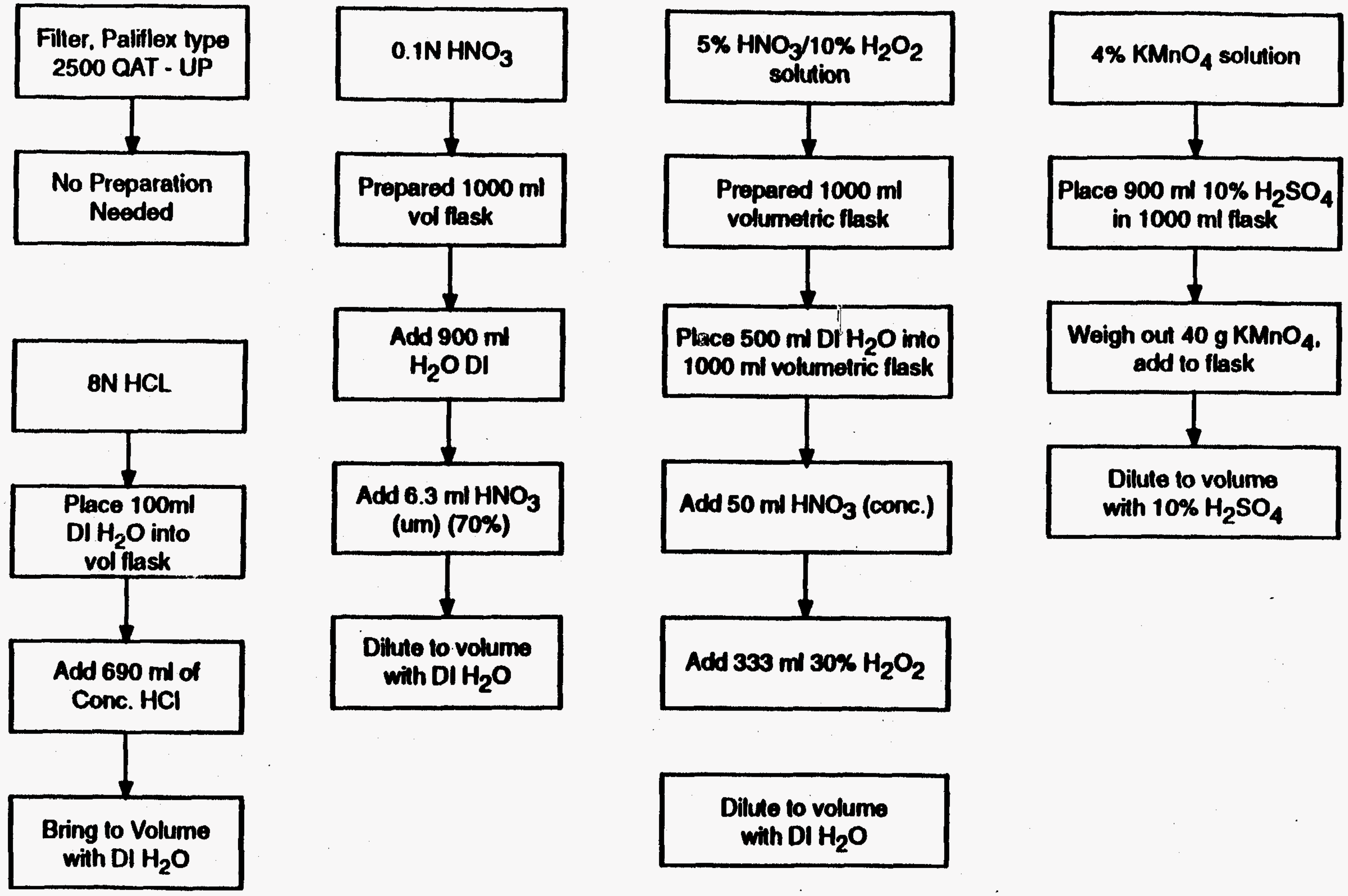


Figure C-16. M29 reagent preparation procedure.

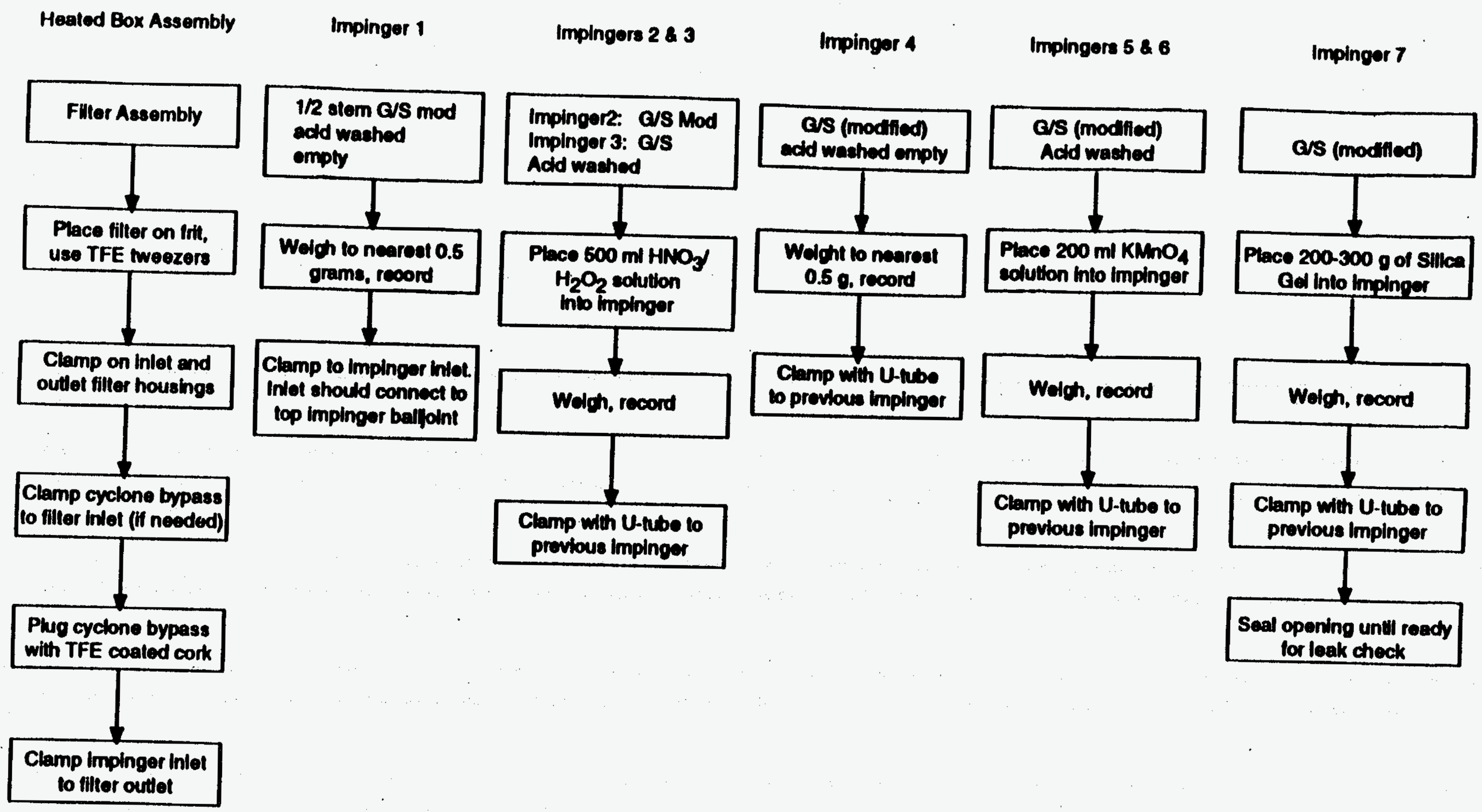
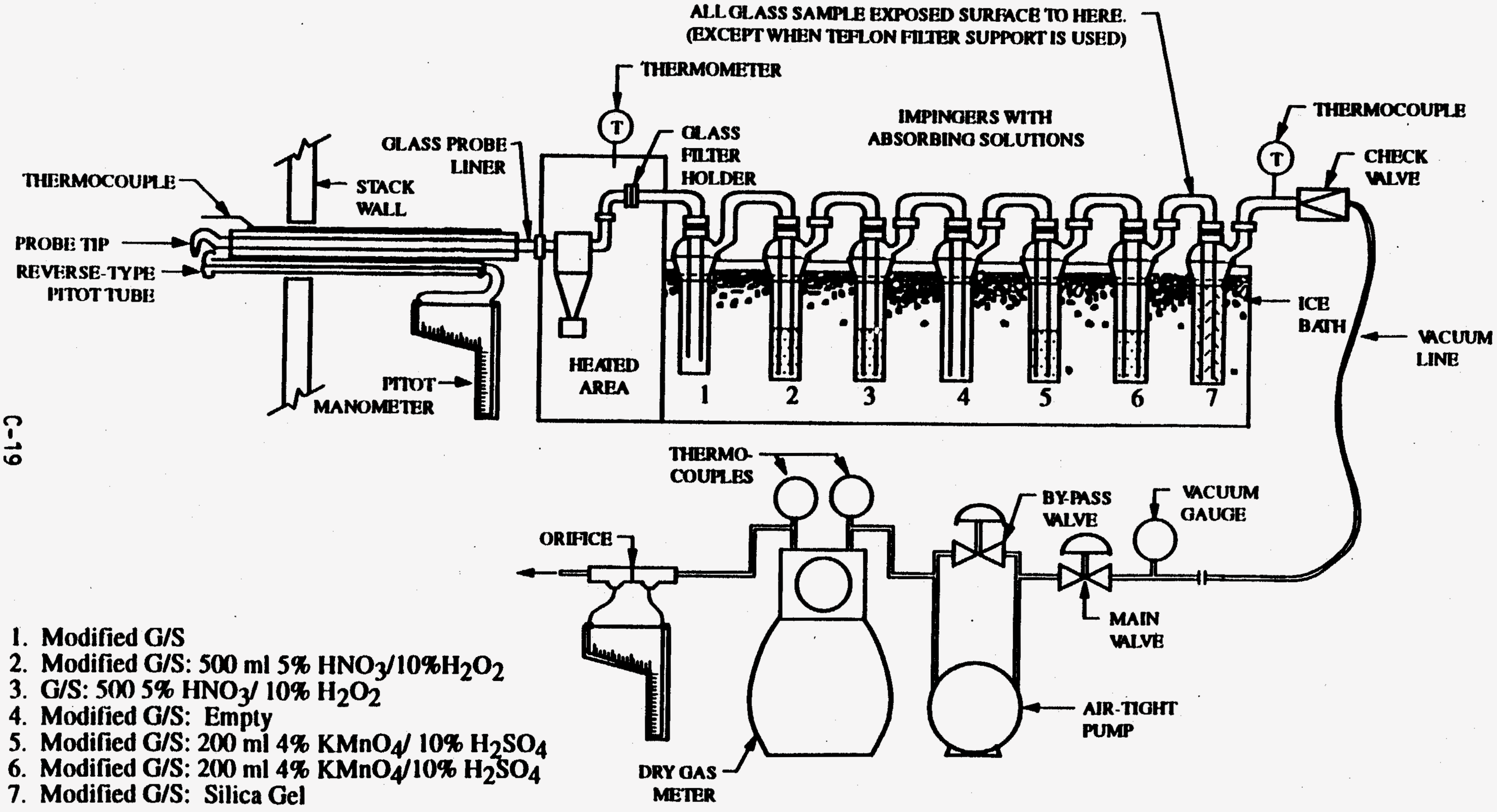


Figure C-17. M29 sampling train assembly procedure modified for high SO_2.



1. Modified G/S
2. Modified G/S: 500 ml 5% HNO_3/10%H_2O_2
3. G/S: 500 5% HNO_3/ 10% H_2O_2
4. Modified G/S: Empty
5. Modified G/S: 200 ml 4% $KMnO_4$/ 10% H_2SO_4
6. Modified G/S: 200 ml 4% $KMnO_4$/10% H_2SO_4
7. Modified G/S: Silica Gel

Figure C-18. M29 sampling system schematic.

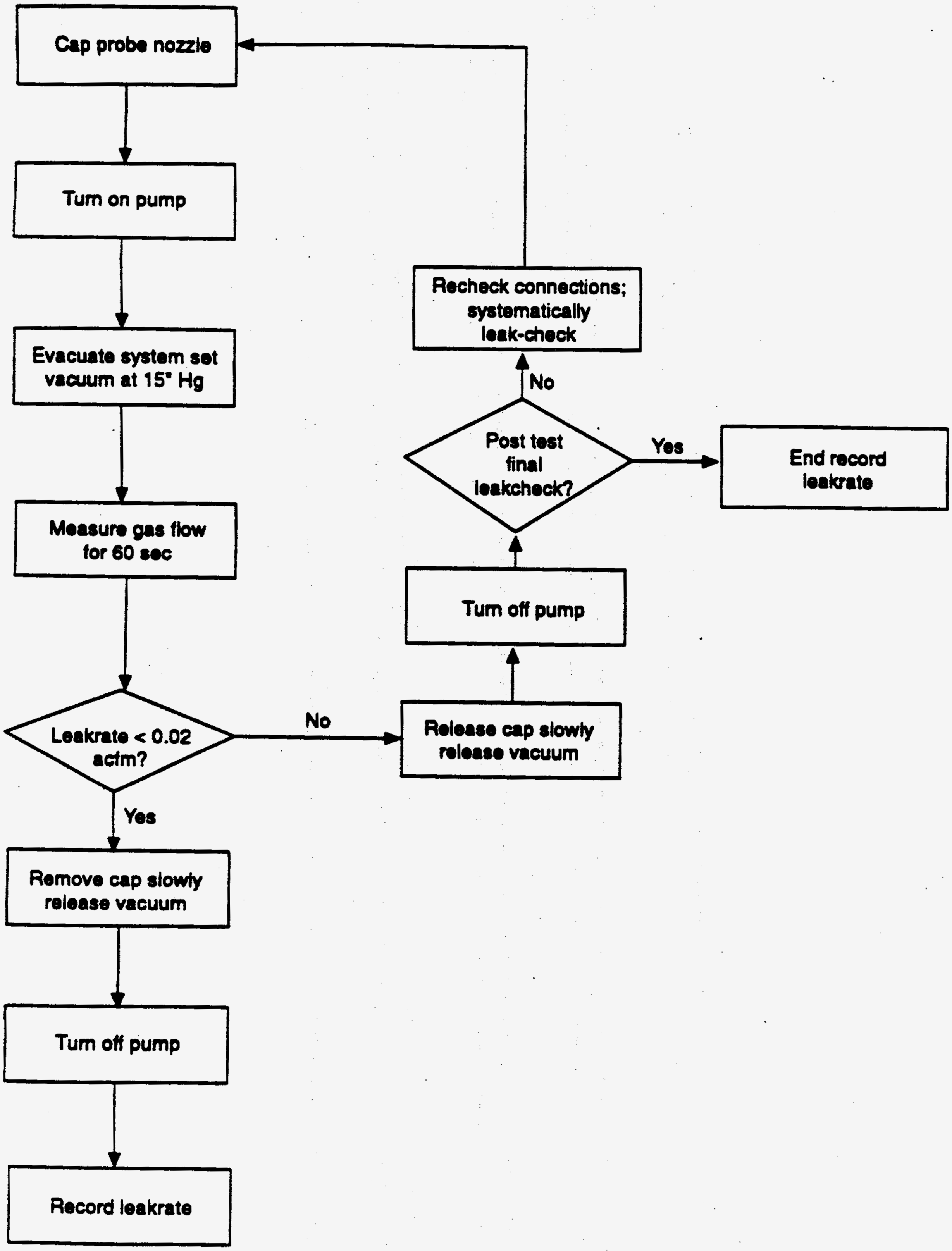


Figure C-19. M29 leakcheck procedure.

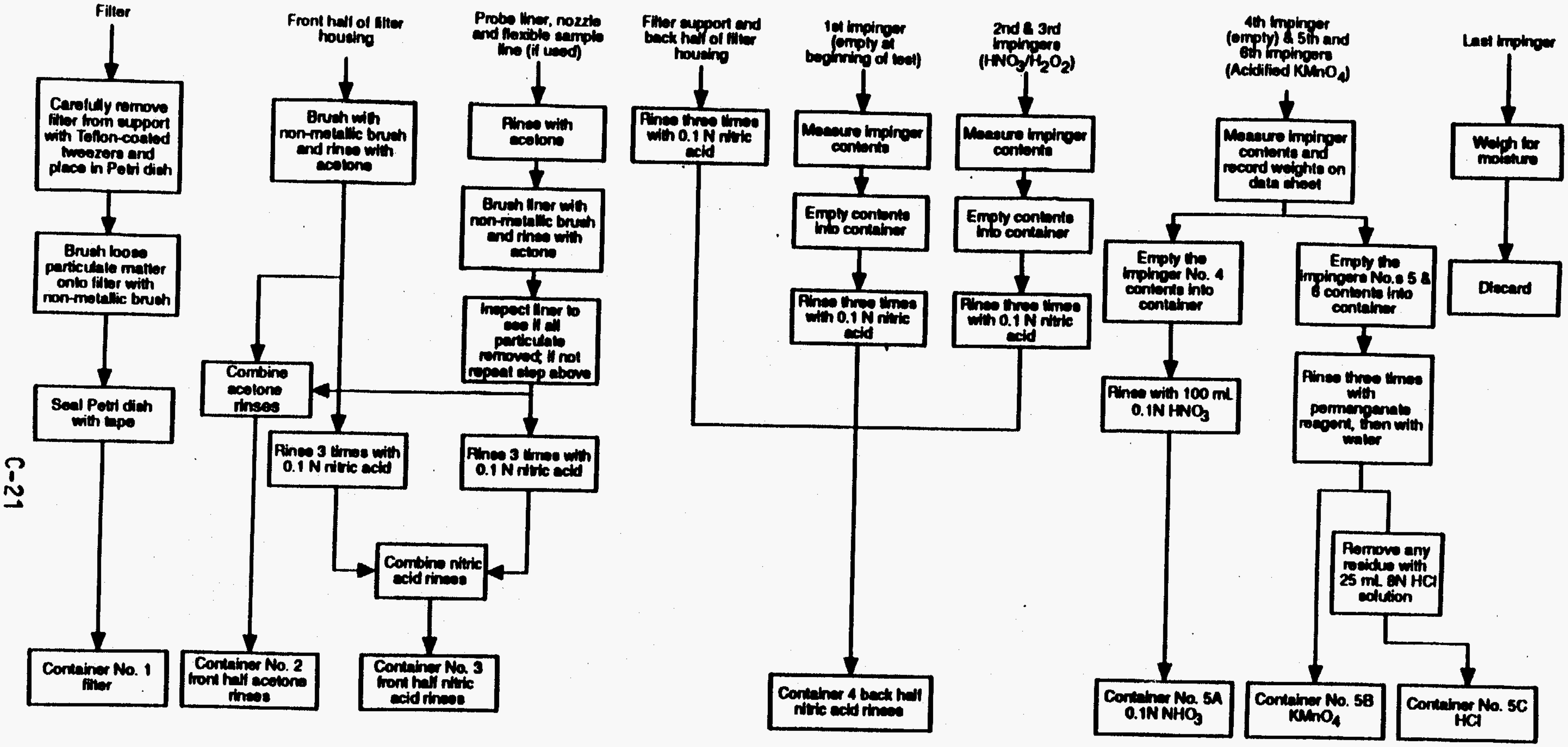


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Figure C-20. M29 sampling train field recovery procedure.

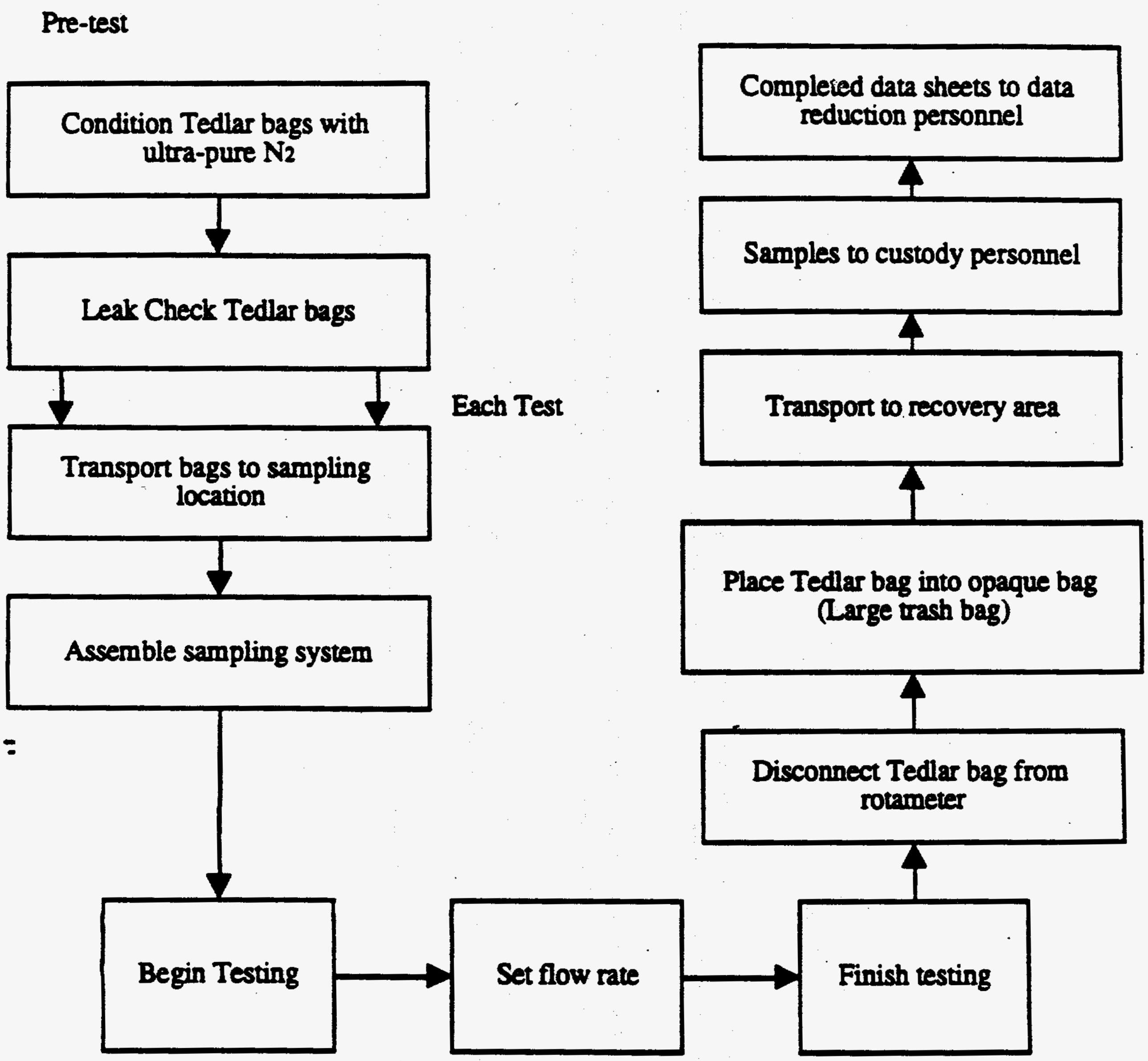


Figure C-21. Overview - Evacuated Tedlar bag sampling method.

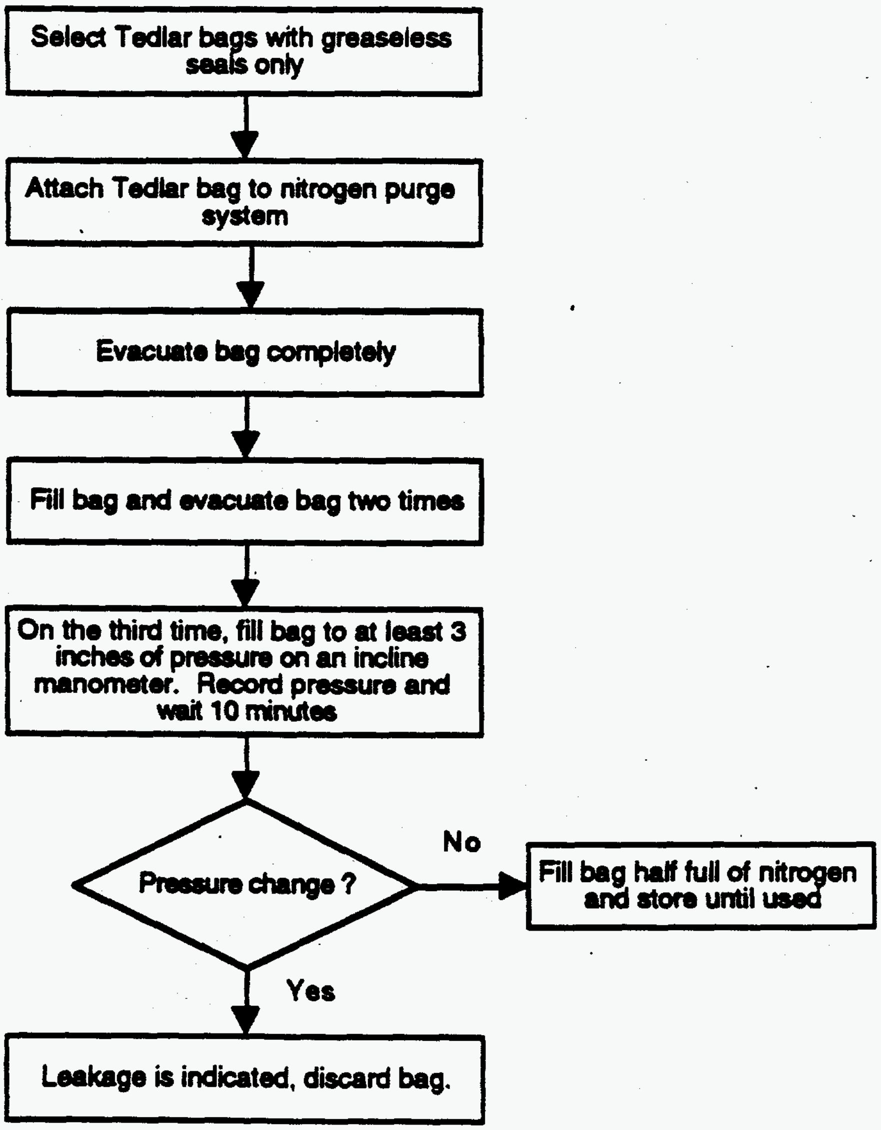


Figure C-22. Tedlar bag leakcheck and preparation.

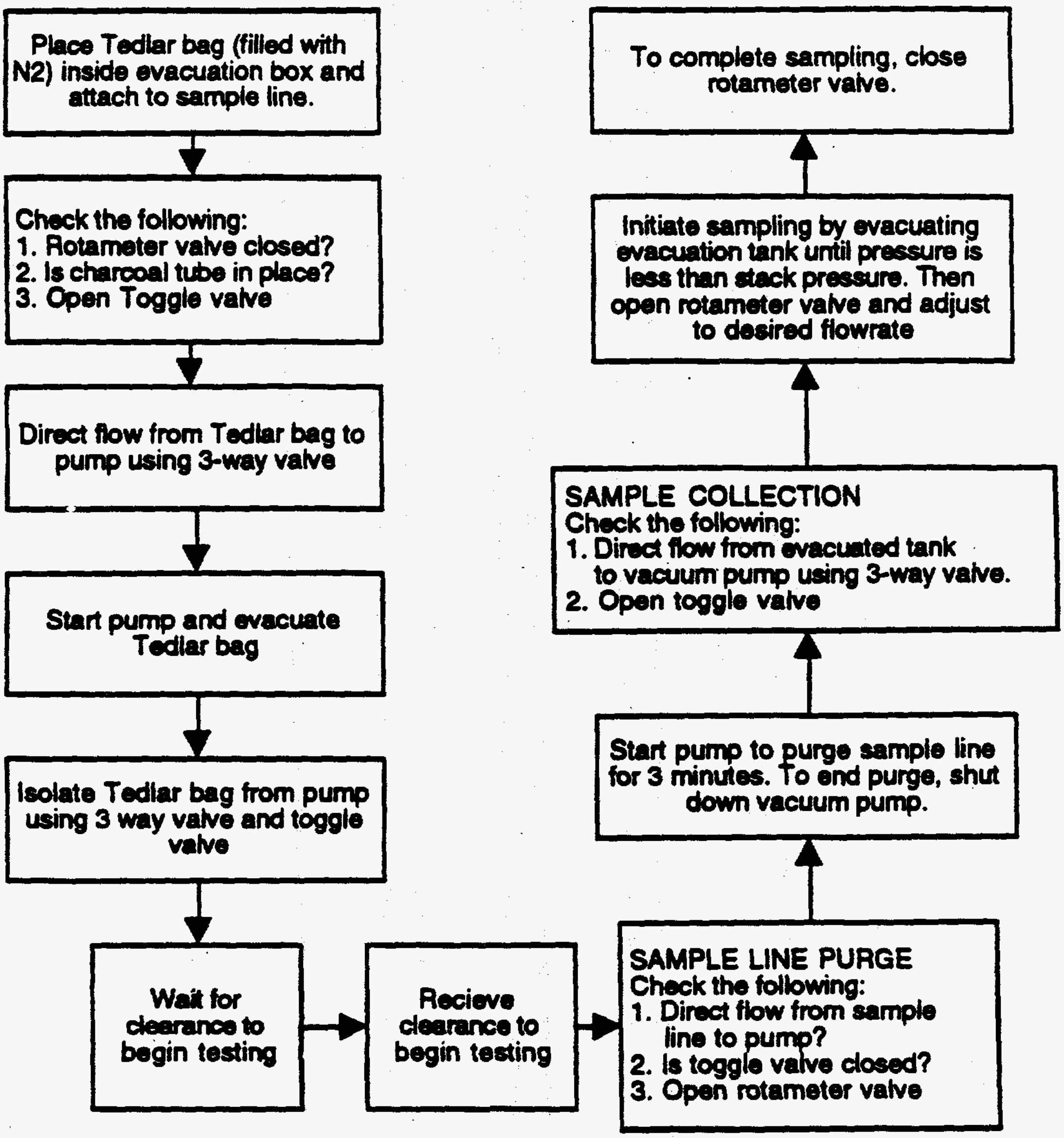
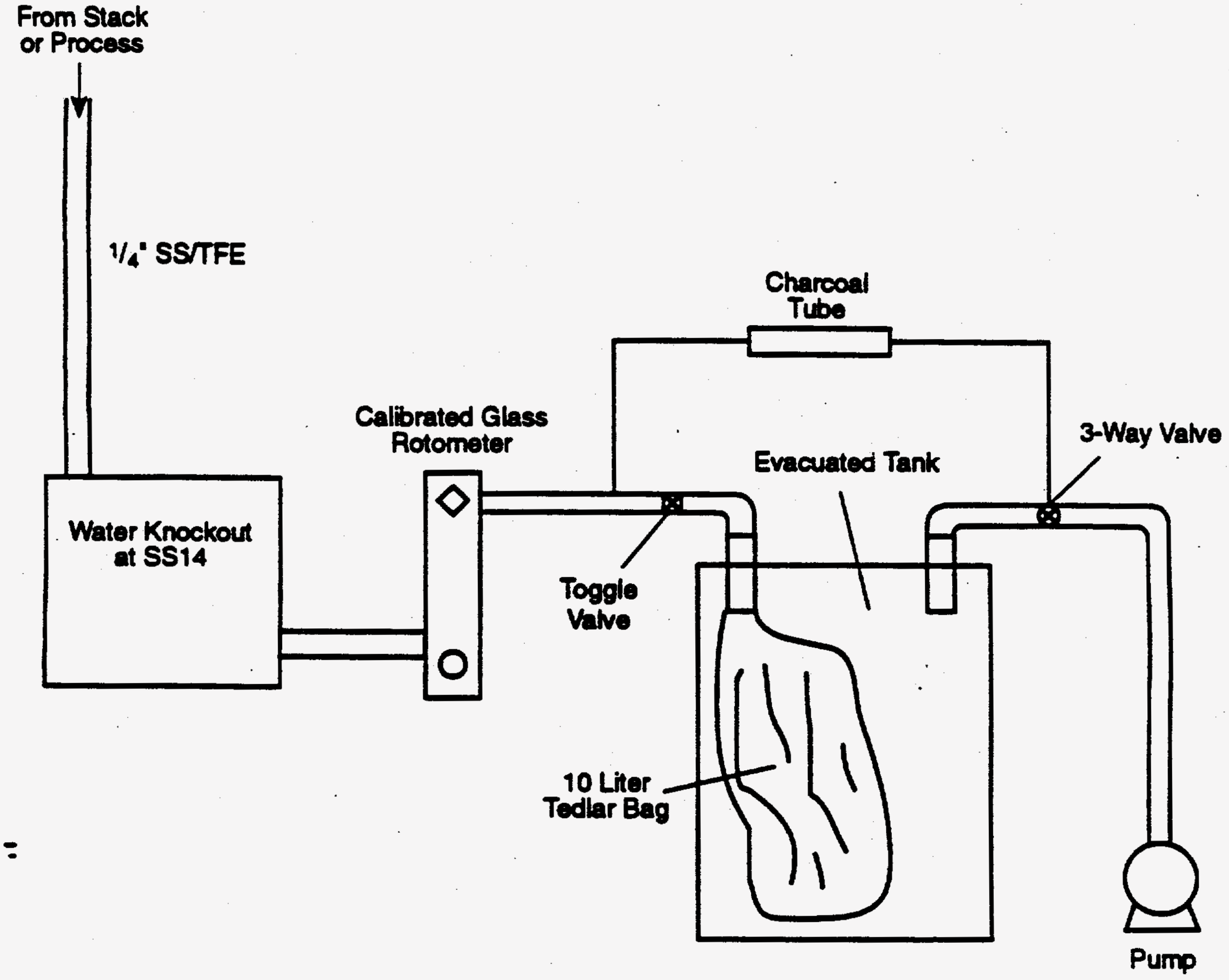


Figure C-23. Sampling system assembly and operation - Evacuated bag method.



This system will be used at:
SS14 - Reform Gas
SS17 - Thermal Desorber Flue Gas

Figure C-24. Evacuated Tedlar Bag sampling system.

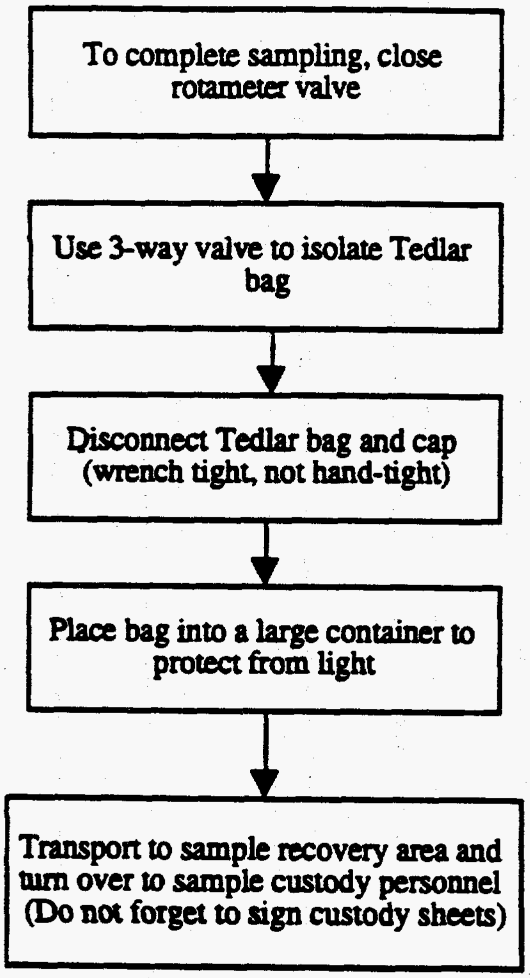


Figure C-25. Recovery procedure - Evacuated Tedlar bag sampling method.

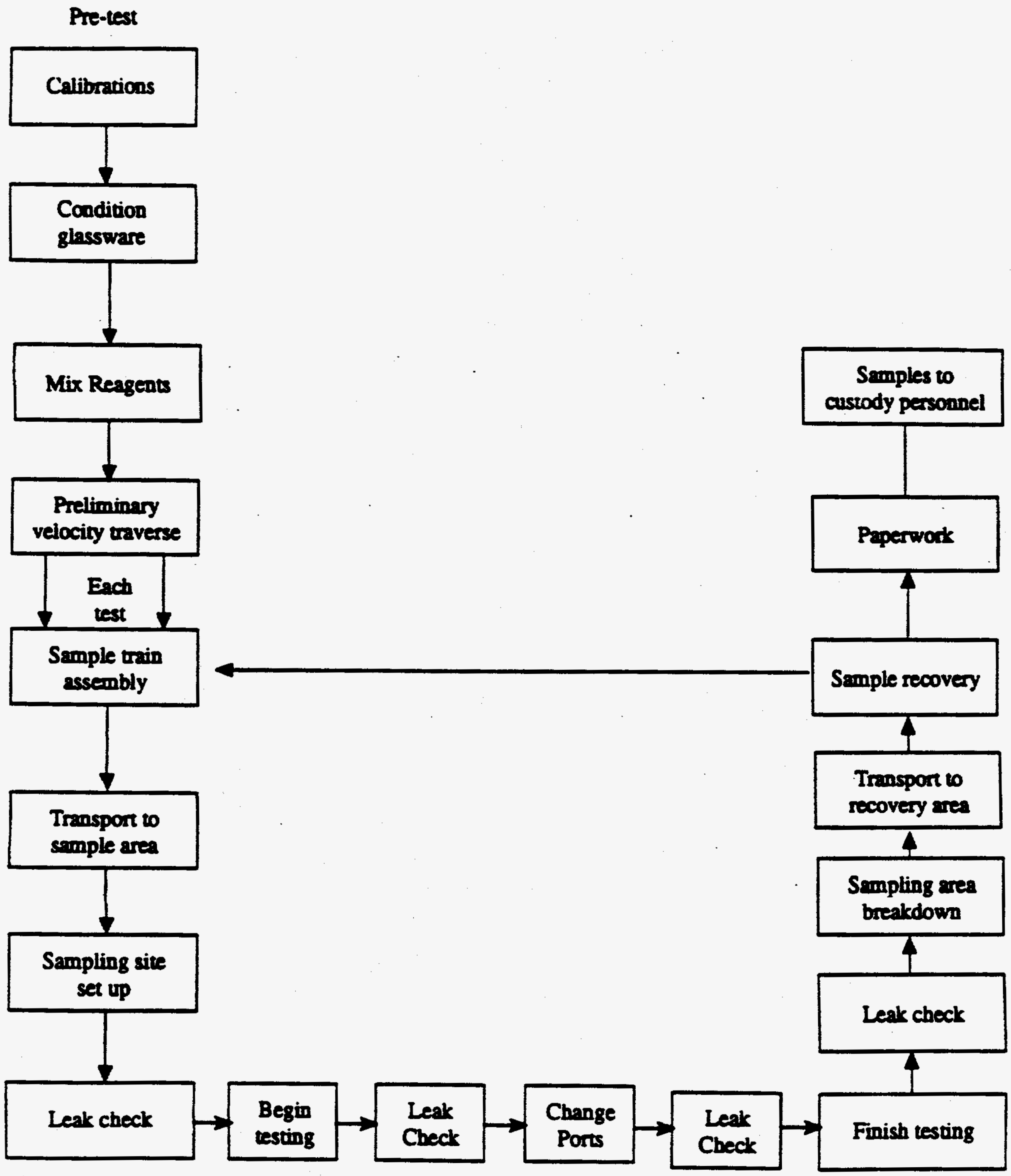


Figure C-26. M26 sampling procedure overview.

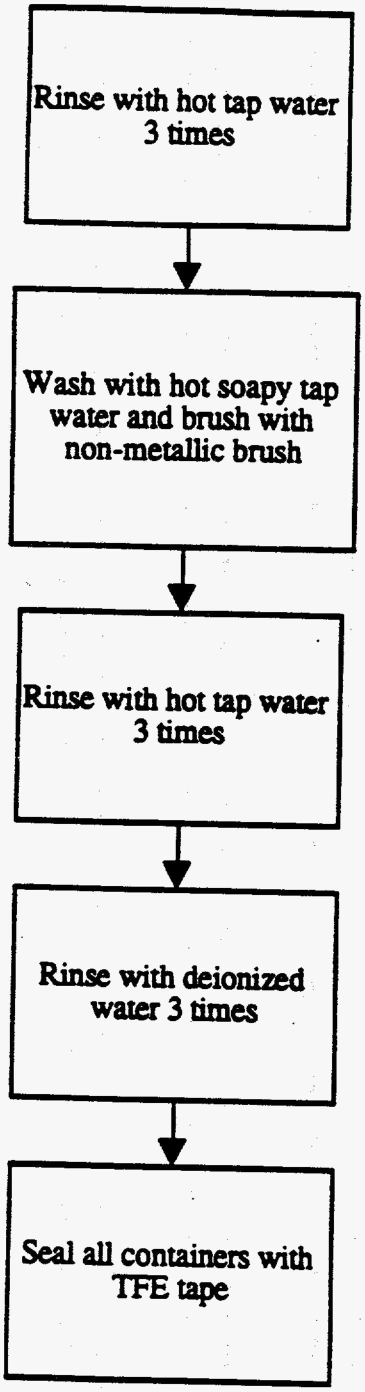


Figure C-27. M26 glassware preparation procedure.

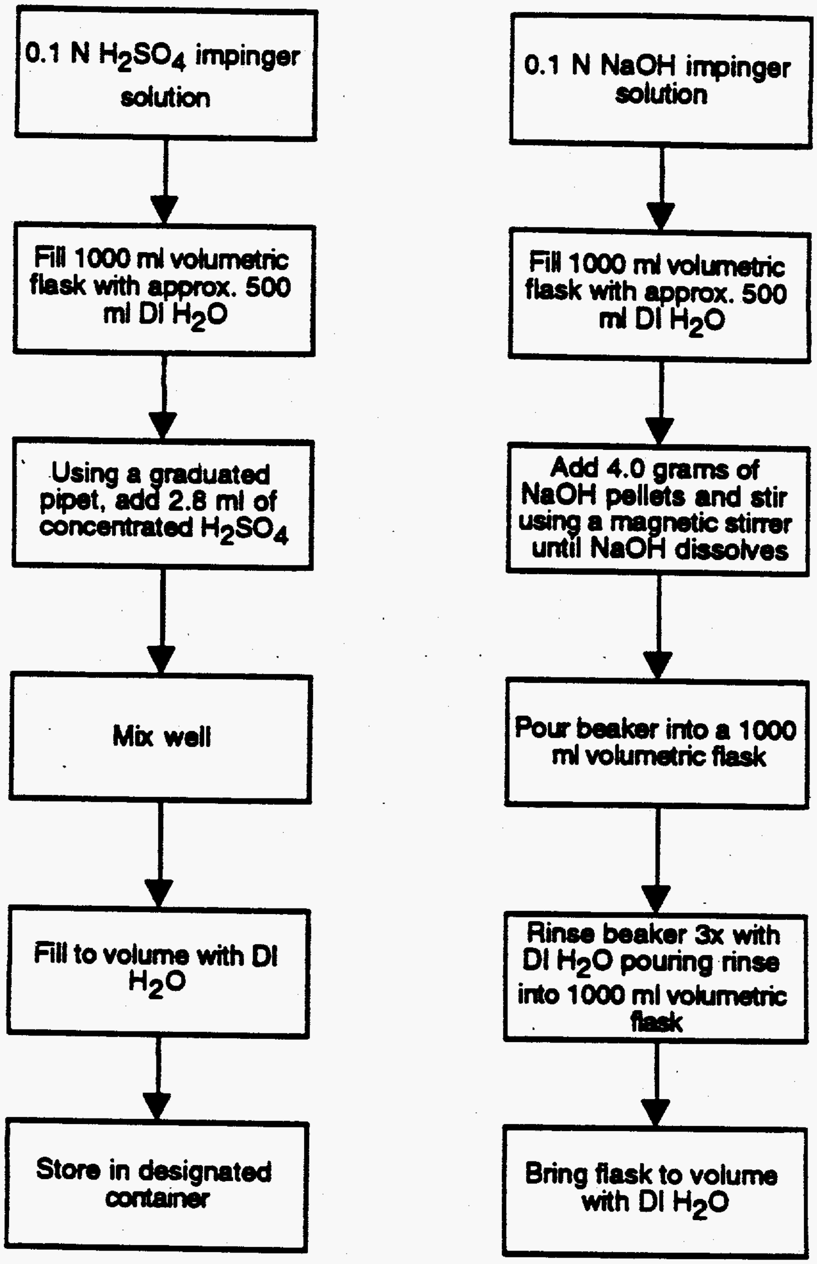


Figure C-28. M26 regent preparation procedure.

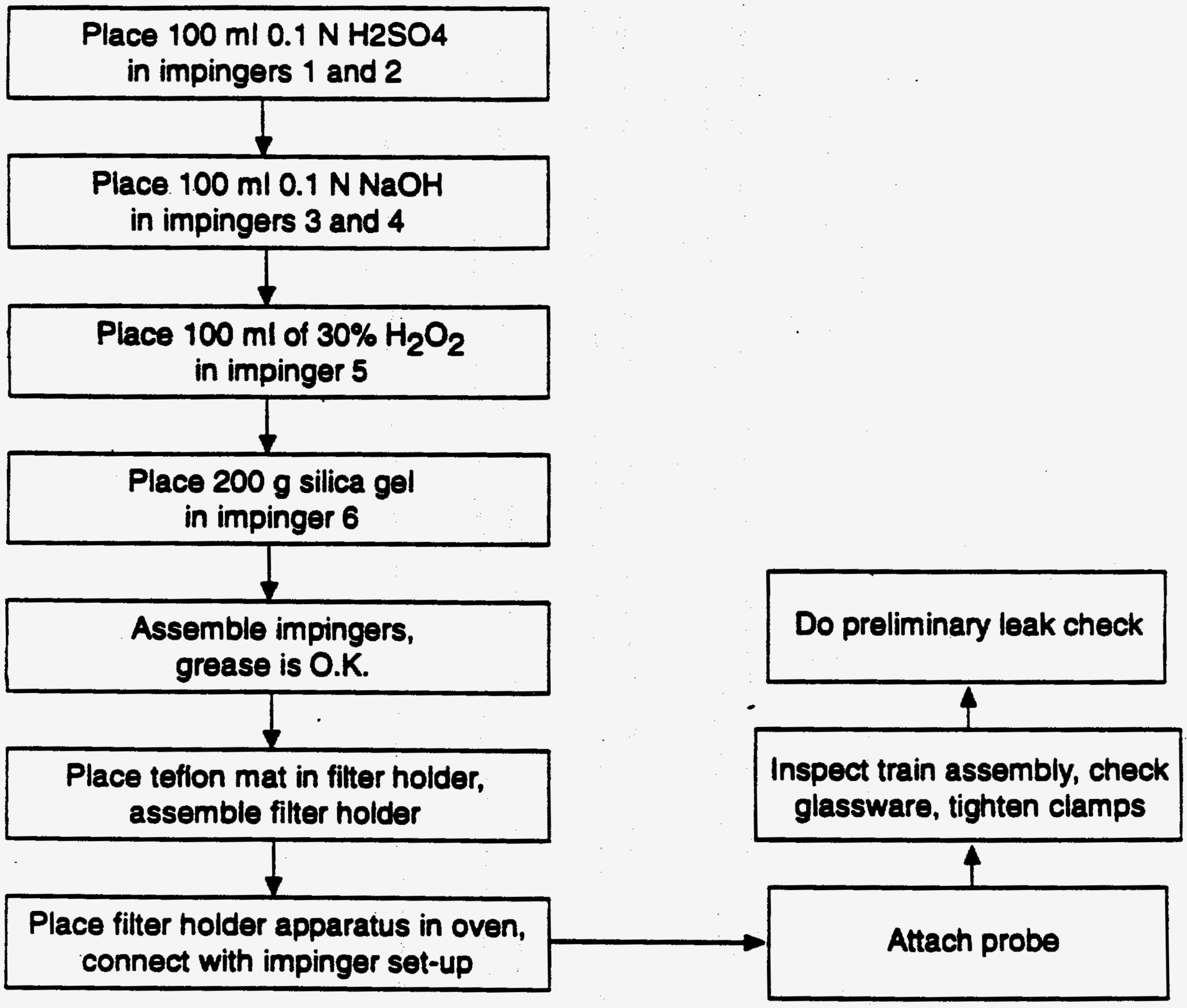
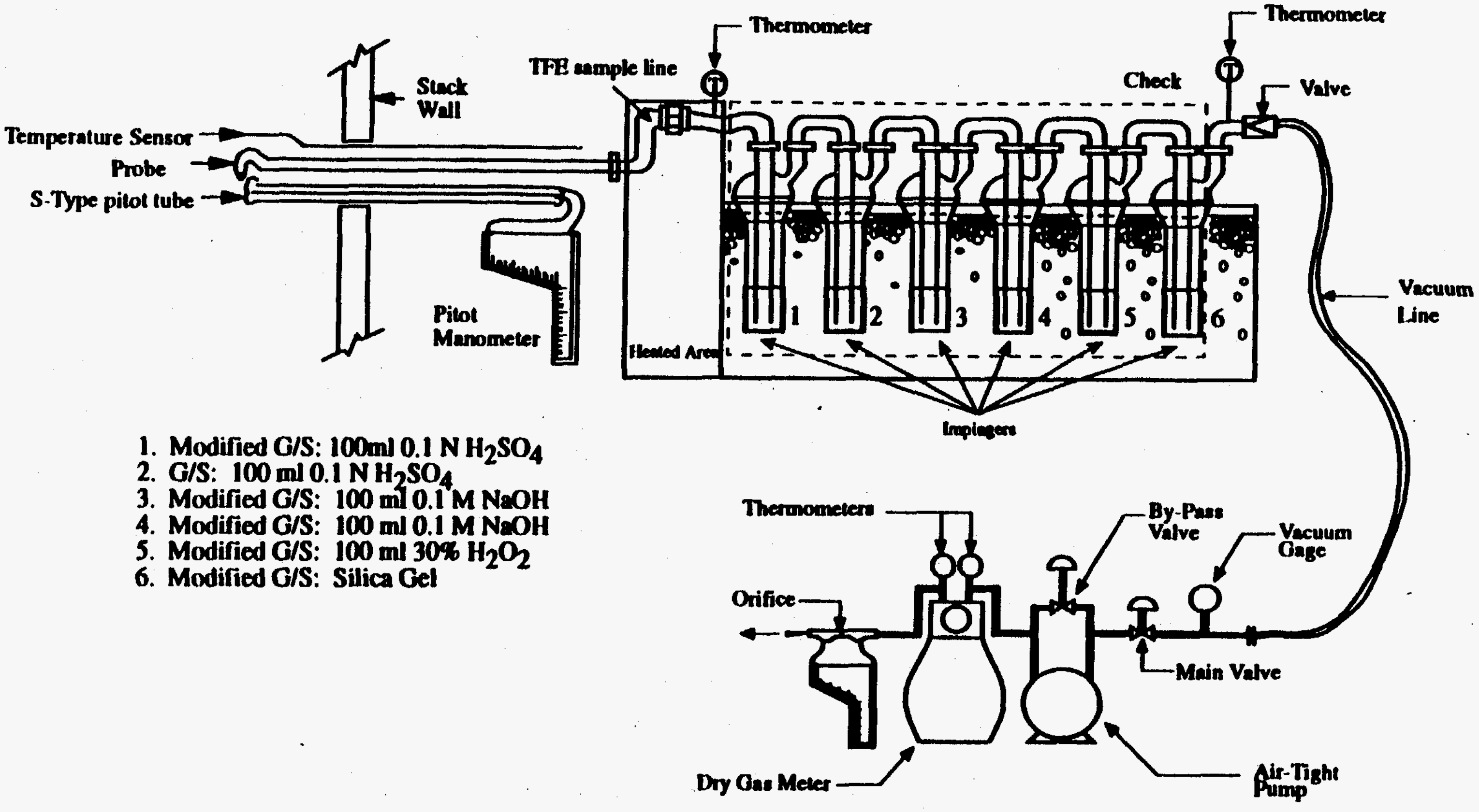


Figure C-29. M26 sample train assembly procedure.



1. Modified G/S: 100ml 0.1 N H_2SO_4
2. G/S: 100 ml 0.1 N H_2SO_4
3. Modified G/S: 100 ml 0.1 M NaOH
4. Modified G/S: 100 ml 0.1 M NaOH
5. Modified G/S: 100 ml 30% H_2O_2
6. Modified G/S: Silica Gel

Figure C-30. M26 sampling system schematic.

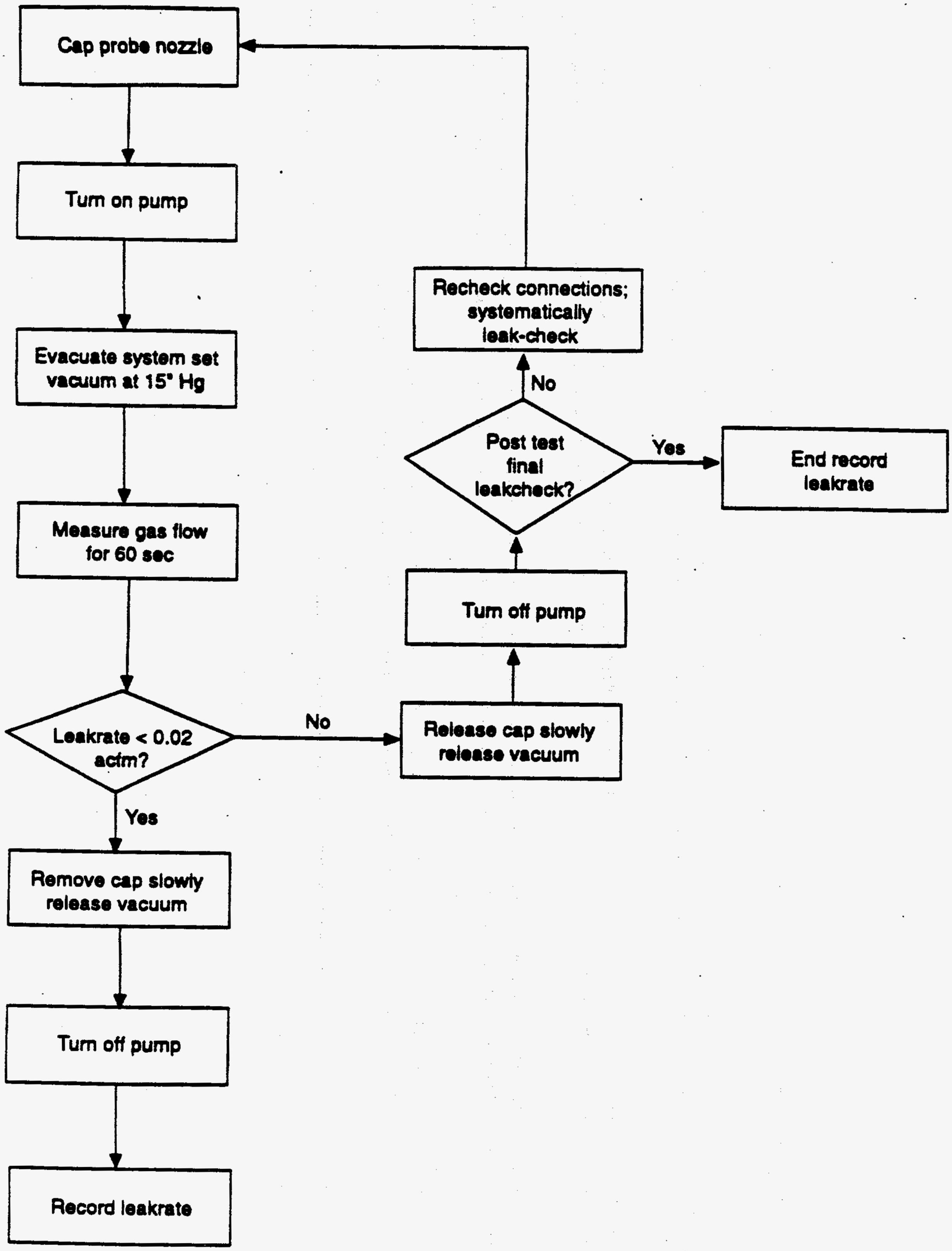


Figure C-31. M26 leakcheck procedure.

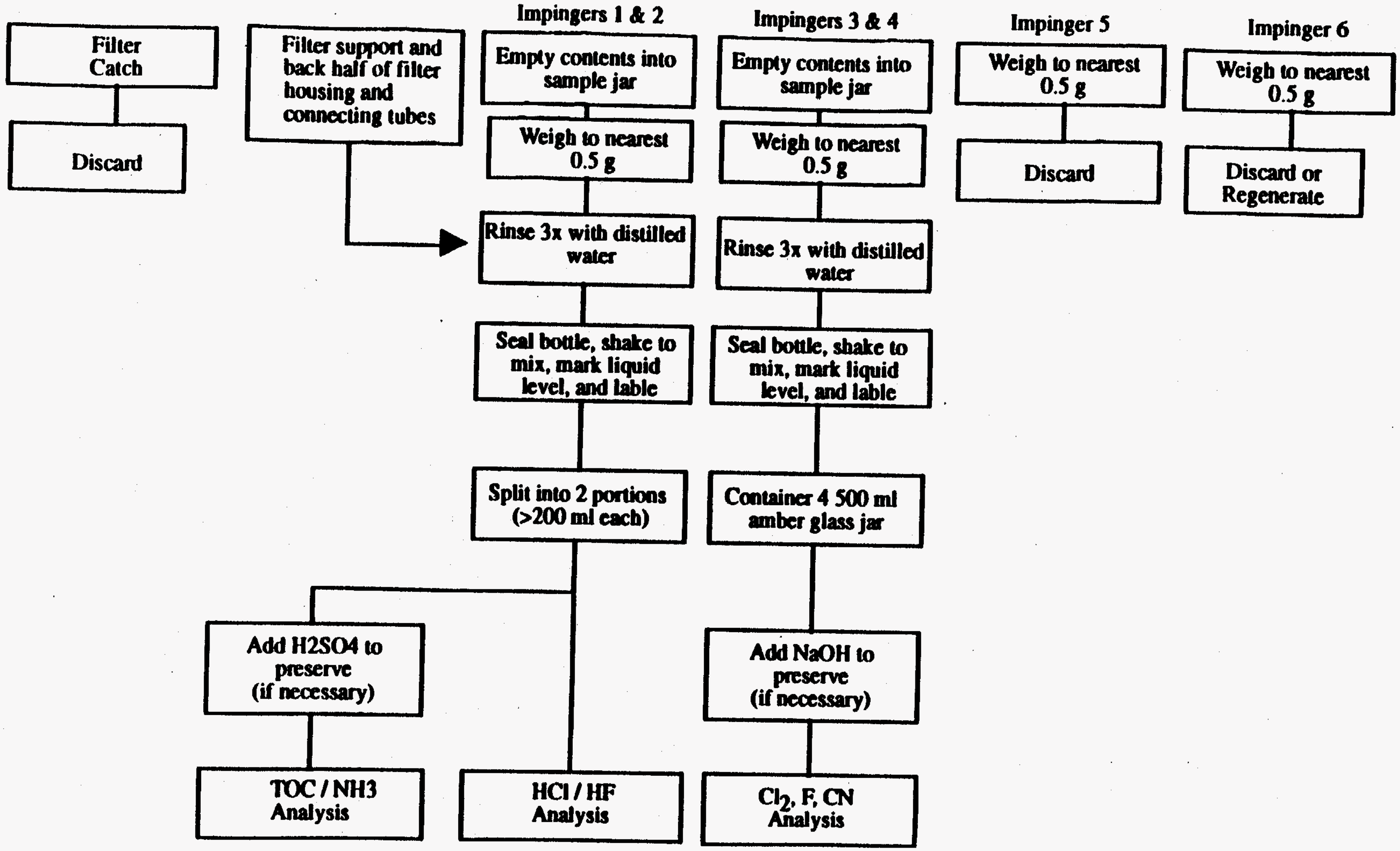


Figure C-32. M26 sampling train field recovery procedure.

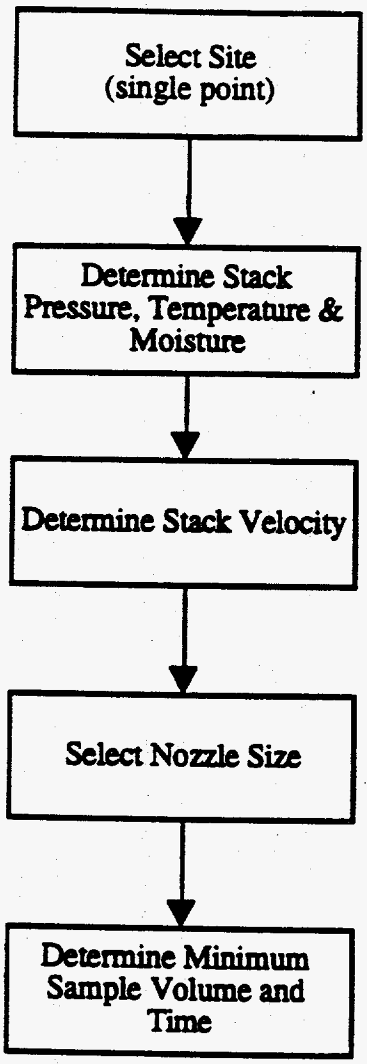


Figure C-33. Method 0011 pretest determinations.

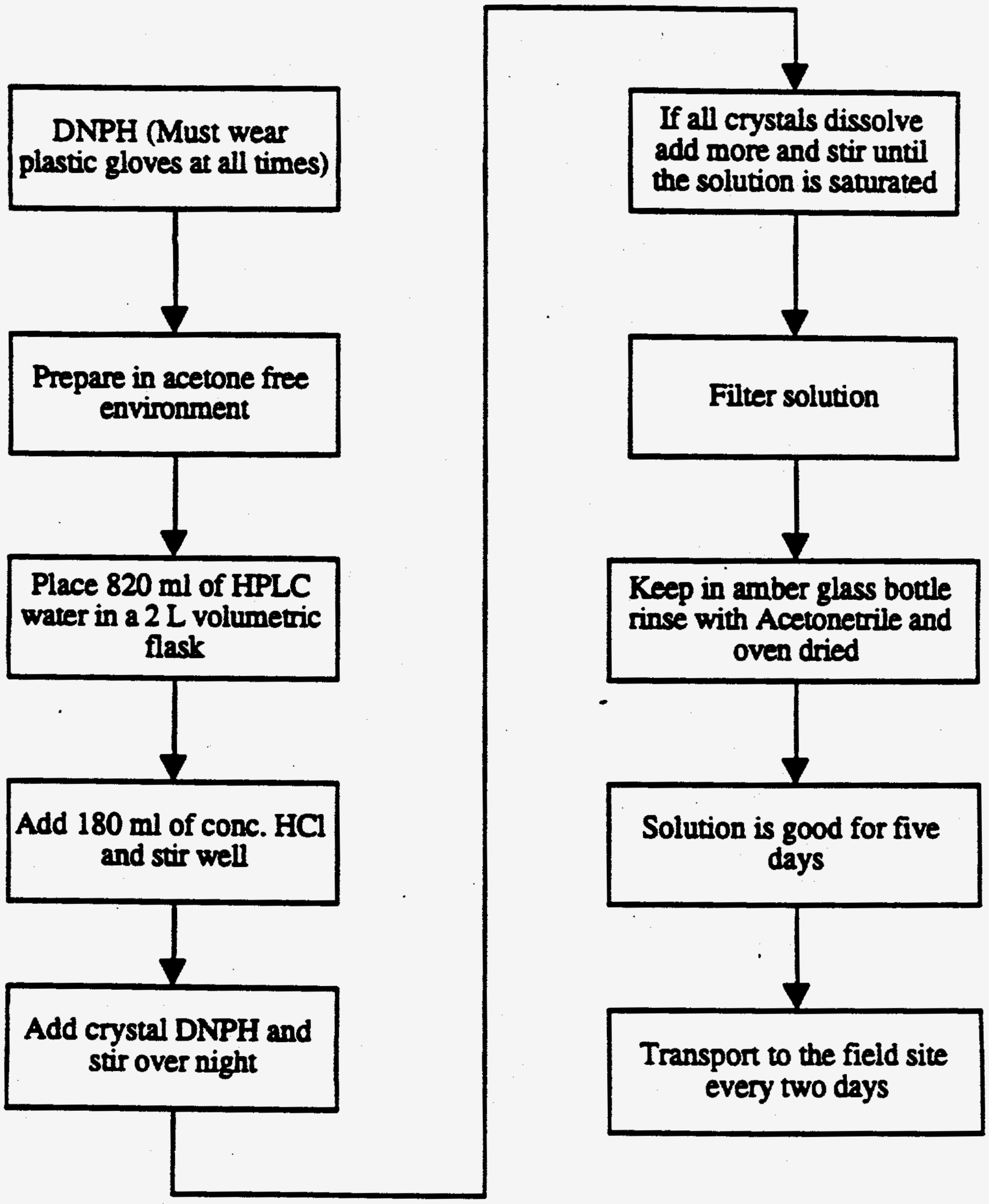
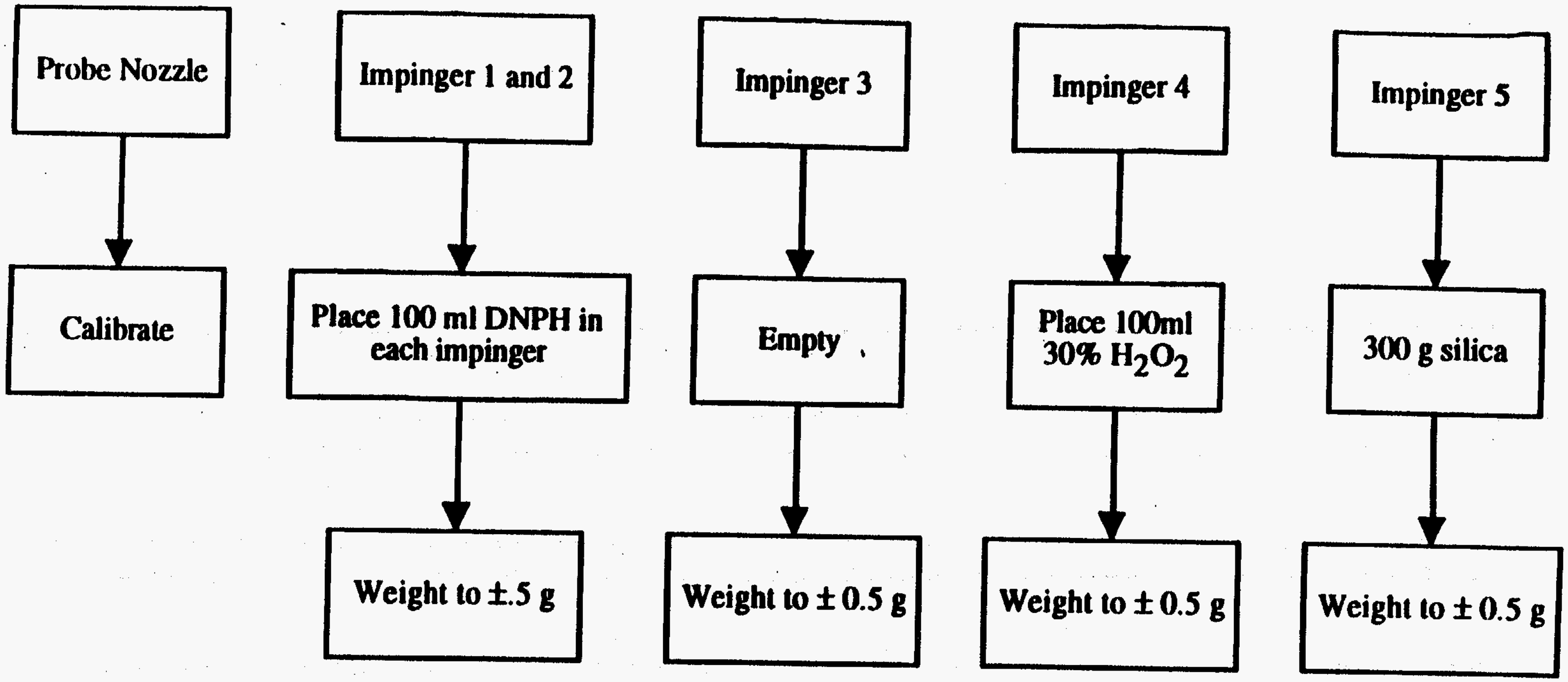


Figure C-34. DNPH reagent preparation procedure.



- Keep all openings covered with teflon tape or aluminum foil
- Do not use silicon grease upstream of impingers

Figure C-35. Method 0011 train assembly procedure.

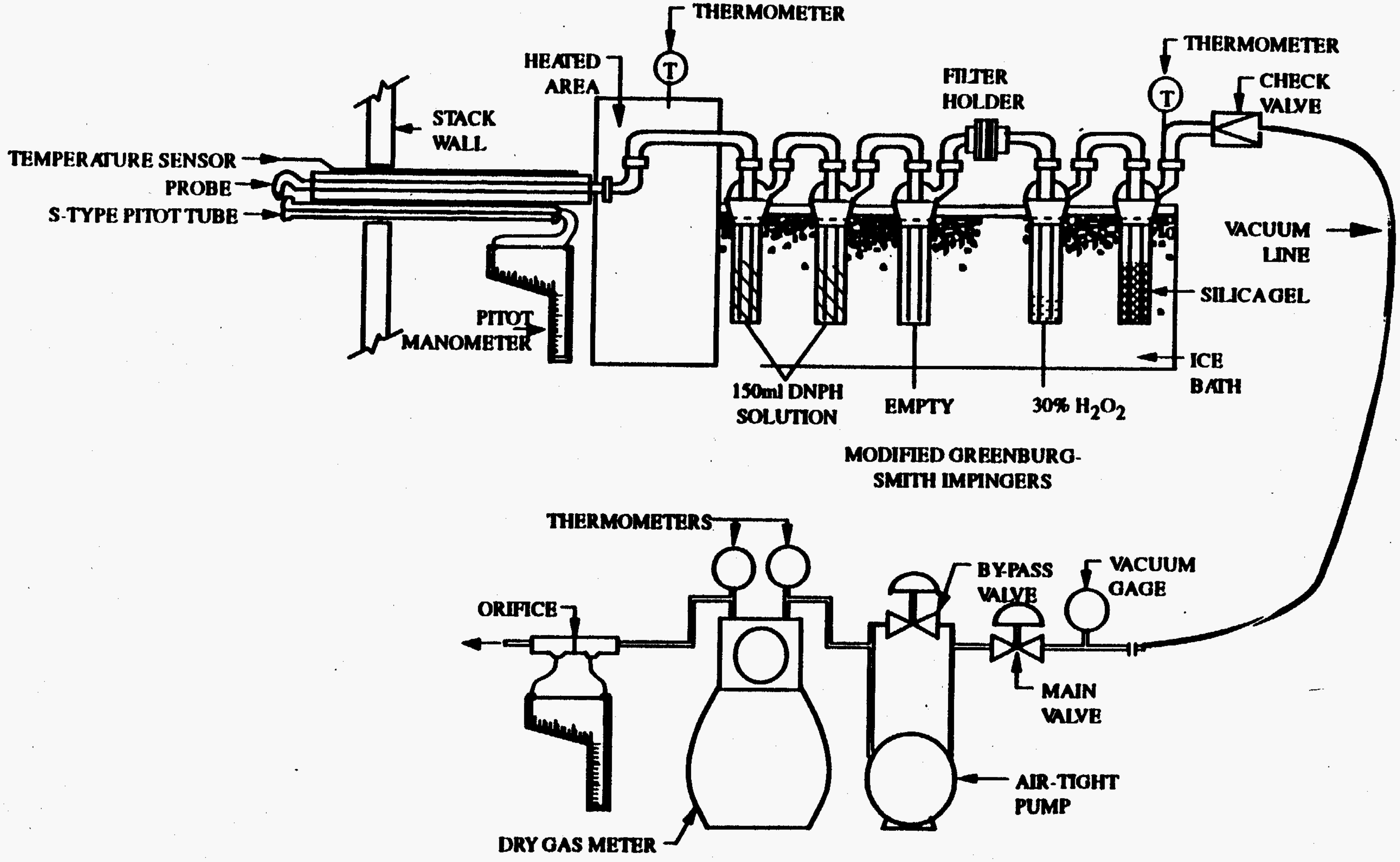


Figure C-36. M0011 sampling system schematic.

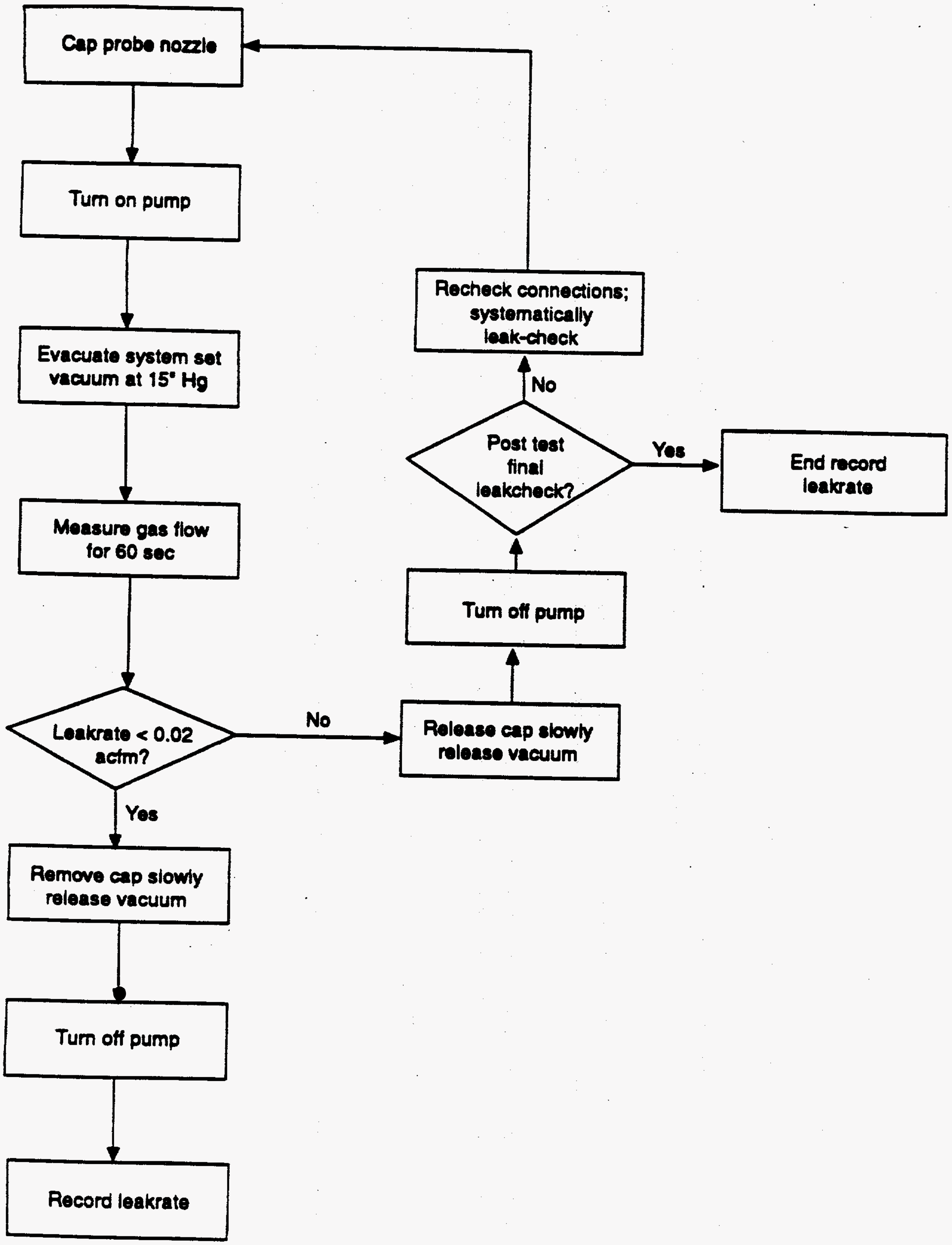


Figure C-37. Method 0011 leakcheck procedure.

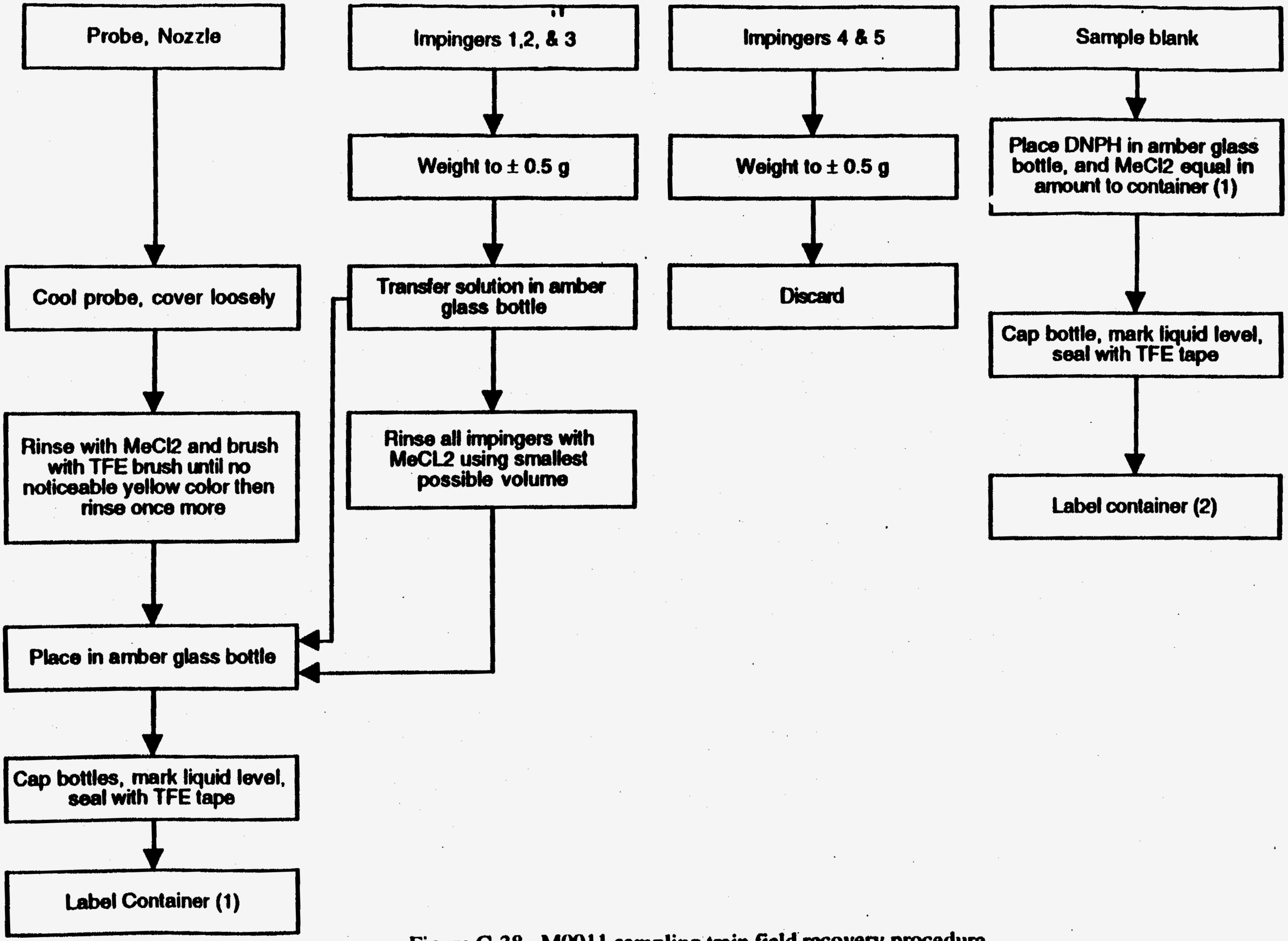


Figure C-38. M0011 sampling train field recovery procedure.

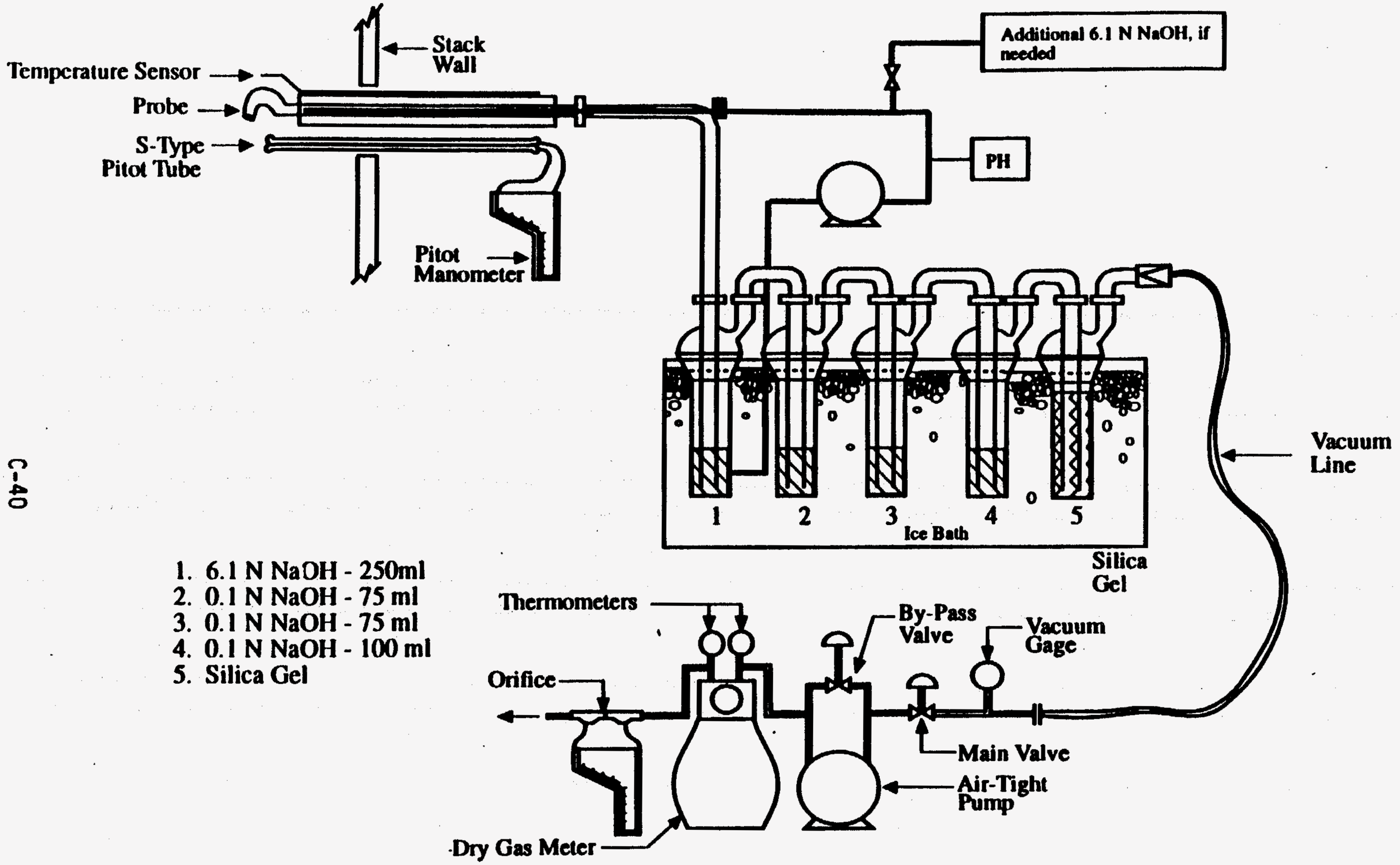
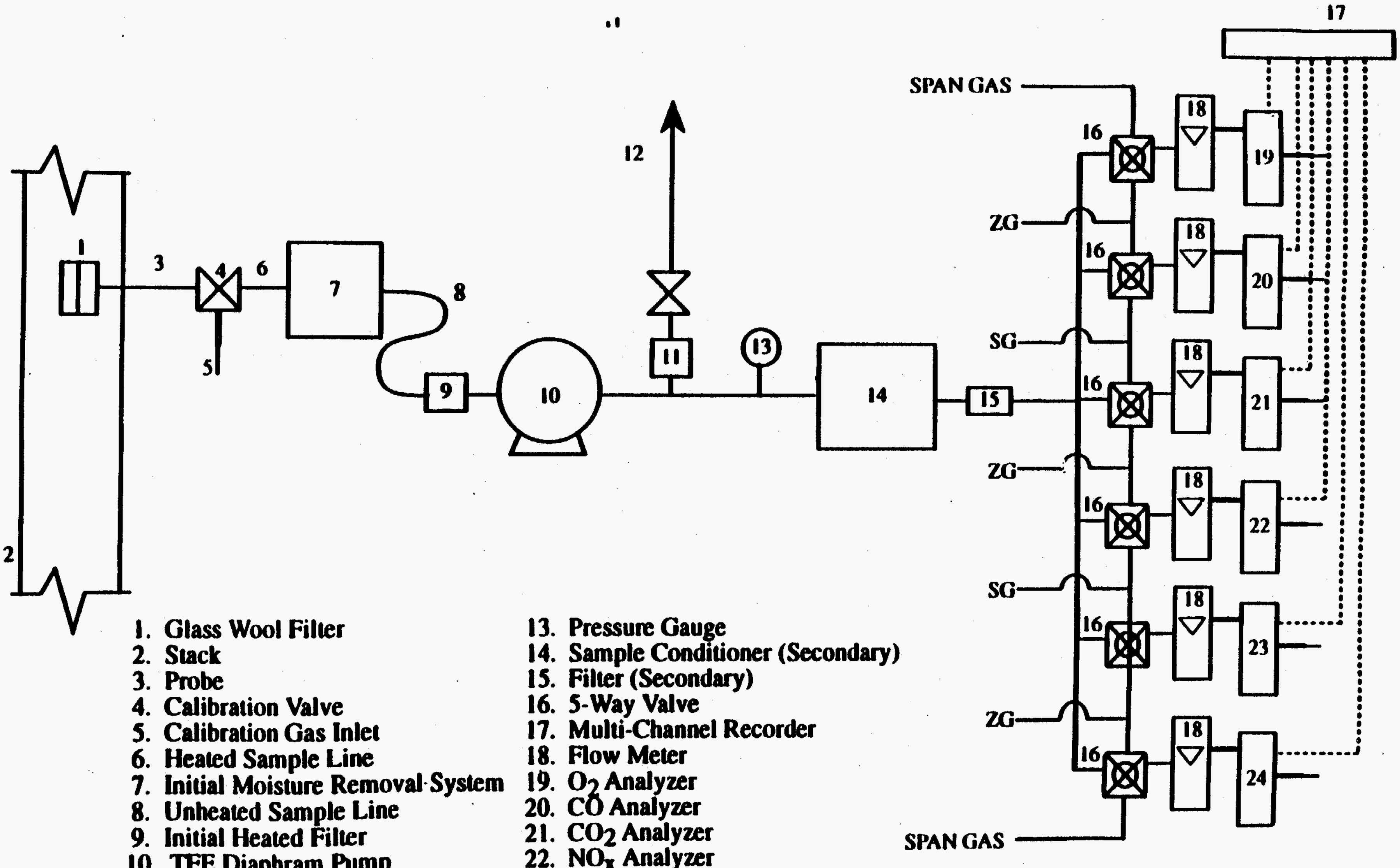


Figure C-39. Method 13 - Hexavalent chromium train modified for high SO_2.



1. Glass Wool Filter
2. Stack
3. Probe
4. Calibration Valve
5. Calibration Gas Inlet
6. Heated Sample Line
7. Initial Moisture Removal System
8. Unheated Sample Line
9. Initial Heated Filter
10. TFE Diaphram Pump
11. Heated Sample Bypass Regulator
12. Sample Bypass Discharge
13. Pressure Gauge
14. Sample Conditioner (Secondary)
15. Filter (Secondary)
16. 5-Way Valve
17. Multi-Channel Recorder
18. Flow Meter
19. O_2 Analyzer
20. CO Analyzer
21. CO_2 Analyzer
22. NO_x Analyzer
23. SO_2 Analyzer
24. THC Analyzer

Figure C-40. EER continuous emissions monitoring system.